IMAGE EVALUATION

PARAXIAL and RAYTRACE (REFERENCE MANUAL SECTIONS) COMMAND PROMPTS

IMAGE EVALUATION - Most of the commands described here can be used in the immediate mode from the screen or they can be used inside macros to evaluate the optical performance of the current lens database.

ZEROTH, FIRST, THIRD, FIFTH AND SEVENTH ORDER ABERRATIONS - These are all based upon the paraxial ray trace plus selected shape coefficients.

WEIGHT (qualifier word) , i , j - The "WEIGHT" command calculates the weight of an element or group of elements based upon the assumptions that all surfaces are centered (no tilts or decenters) and that all surface profiles are either plano or spherical". The calculation uses the specific gravity entered in the lens database using the "SPGR" command. If the qualifier word "ACC" is used, no display occurs but the weight, in Kilograms, is placed in the accumulator (X-register). For mirror surfaces with a non-zero THM assigned, this mirror thickness is used in the calculation.

COST (qualifier word) , i , j - The "COST" command calculates the cost of an element or group of elements based upon weight and price per unit weight. The associated weight calculation is based upon the assumptions that all surfaces are centered (no tilts or decenters) and that all surface profiles are either plano or spherical". The calculation uses the specific gravity and price per Kg, entered in the lens database using the "SPGR" and "PRICE" commands. If the qualifier word "ACC" is used, no display occurs but the COST in "pricing units", is placed in the accumulator (X-register). For mirror surfaces with a non-zero THM assigned, this mirror thickness is used in the calculation.

DISPLAYING FIRST ORDER CONDITIONS

OCDY , i and **OCDX , i** - The "OCDY" and "OCDX" commands display the first order operating conditions of the current lens in either the YZ or the XZ-plane. Specific displayed data is determined by the paraxial raytrace and mode of the lens. "i" designates the wavelength number for which the values are to be calculated. If no "i" value is entered, the control wavelength is used. The default control wavelength number is 1.

LENS MODE and OBJECT POSITION	FIRST VALUE DISPLAYED	SECOND VALUE DISPLAYED	THIRD VALUE DISPLAYED	FOURTH VALUE DISPLAYED	FIFTH VALUE DISPLAYED	SIXTH VALUE DISPLAYED
Focal- Obj. at Inf.	EFL	BFD	F-NUM	LENGTH	GIH	(not used)
Afocal-Obj. at Inf.	EX P DIST	EX P RAD	A-MAG	LENGTH	(not used)	(not used
Focal- Near Obj.	EFL	BFD	IMG F-NUM	LENGTH	OAL	T-MAG
Afocal-Near Obj.	EX P DIST	EX P RAD	(not used)	LENGTH	(not used	(not used

Surface "i" is the final surface in the lens. EFL is the paraxial effective focal length. BFD is the axial distance from surface "i"-1 to surface "i", "i" being the last surface of the lens. LENGTH is the axial distance from surface 1 to "i:-1. OAL is the axial distance from the object surface to surface "i". T-MAG, the tangential magnification, is the ratio of the chief paraxial ray height at surface I to the chief paraxial ray height at the object surface. A-MAG, the afocal magnification, is the ratio of the slope of the paraxial chief ray after it leaves surface "i"-1 to the slope of the paraxial chief ray before it interacts with surface 1. EX P DIST is the axial distance from surface "i"-1 to the paraxial exit pupil. EX P RAD is the semi-diameter of the paraxial exit pupil. F-NUM is the paraxial f-number. IMG F-NUM is the image space paraxial f-number for a non-infinite distant object. GIH, the gaussian image height, is the height of the paraxial chief ray at surface I.

THE ALL COMMAND

ALL (ON or YES or OFF or NO) Any program command which can take surface number input or the qualifier word input "ALL" and has the characteristic behavior that when that command is entered with no input, data for the final lens surface is printed can be impacted by the "ALL" command. If "ALL" is set to "ON", the default behavior of that command will be to assume that the "ALL" qualifier word had been issued with that command. The default setting for "ALL" will be "OFF". If it is desired to have "ALL" always set to "ON", place the "ALL ON" command in the DEFAULTS.DAT file in the main program directory. It will be executed whenever the program is run.

SPECIFIC PARAXIAL RAY DATA

PXTY (ALL or OB or OBJ) or , i and **PXTX (ALL or OB or OBJ) or , i** - The "PXTY" and "PXTX" commands output the YZ or XZ-plane, paraxial marginal ray heights, paraxial marginal ray slopes (tangents), paraxial chief ray heights and paraxial chief ray slopes (tangents). This data may be output for "ALL" surfaces, for the object surface ("OB" or "OBJ") or for surface "i". Output is performed for the current control wavelength.

PITY (ALL or OB or OBJ) or , i and **PITX (ALL or OB or OBJ) or , i** - The "PITY" and "PITX" commands output the YZ or XZ-plane, paraxial marginal ray heights, paraxial marginal ray slope of incidence (tangent), paraxial chief ray heights and paraxial chief ray slope of incidence (tangent). This data may be output for "ALL" surfaces, for the object surface ("OB" or "OBJ") or for surface "i". Output is performed for the current control wavelength.

PRTY (ALL or OB or OBJ) or , i and **PRTX (ALL or OB or OBJ) or , i** - The "PRTY" and "PRTX" commands output the YZ or XZ-plane, paraxial marginal ray heights, paraxial marginal ray slope of reflection or refraction (tangent), paraxial chief ray heights and paraxial chief ray slope of reflection or refraction (tangent). This data may be output for "ALL" surfaces, for the object surface ("OB" or "OBJ") or for surface "i". Output is performed for the current control wavelength.

FIRST ORDER CHROMATIC ABERRATIONS

FCHY (ALL or OB or OBJ) or , i and **FCHX (ALL or OB or OBJ) or , i** - These commands display first order chromatic aberrations in the YZ and XZ-plane. Output consists of four values per surface. The primary aberrations are computed for the wavelength pair set by "PCW". The secondary aberrations are computed for the wavelength pair set by "SCW". The display will be converted to transverse or angular units or will be left unconverted (determined by the current lens MODE). Output may be produced at one or all surfaces. All values given for any surface are either

always converted or not converted. Issuing any of the following commands with no numeric surface input data "i" causes only the aberration totals to be displayed. Paraxial data in the YZ or XZ-plane is used for aberrations in the YZ and XZ-planes, respectively.

LENS MODE	**ABERRATION TOTALS CONVERSION**
UFOCAL	(none)
UAFOCAL	(none)
FOCAL	CONVERSION TO TRANSVERSE MEASURE
AFOCAL	CONVERSION TO ANGULAR MEASURE
ABERRATION TITLE	**ABERRATION DESCRIPTION**
PACY or PACX	Primary first order axial color
PLCY or PLCX	Primary first order lateral color
SACY or SACX	Secondary first order axial color
SLCY or SLCX	Secondary first order lateral color

CHROMATIC FOCUS SHIFTS

CHRSHIFT The "CHRSHIFT" command generates a table of paraxial focus shifts versus wavelength. For paraxial marginal rays, longitudinal focus shift in microns (FOCAL and UFOCAL systems) or marginal ray angle deviation in micro-radians (AFOCAL and UAFOCAL systems) is tabulated versus wavelength in microns. Shifts (deviations) are with respect to the paraxial marginal ray at the control wavelength. For paraxial chief rays, lateral ray shift in microns (FOCAL and UFOCAL systems) or chief ray angle deviation in micro-radians (AFOCAL and UAFOCAL systems) is tabulated versus wavelength in microns. Shifts (deviations) are with respect to the paraxial chief ray at the control wavelength. After it is generated, graphical display of this data is generated using the "PLCHRSHIFT" .

CHROMATIC FOCUS SHIFT PLOTS

PLTCHRSH (optional qualifier) -The "PLTCHRSH command causes a plot of the paraxial chromatic focus shift data. The default is to plot YZ-plane data. Using the optional qualifier word “X” causes the XZ-plane data to be plotted.

OTHER PARAXIAL DISPLAYS

FIRD (QUIET) , i , j , (λ)- The "FIRD" command displays the YZ-plane, paraxial effective focal length (EFL), back focal length (BFL), front focal length (FFL) and the principle plane positions PP1 and PP2 for the sub-set of the current lens beginning at surface "i" and ending with surface "j". If "λ" is not explicitly entered, then the values are calculated at the current control wavelength for the active lens configuration. If "λ" has been entered explicitly, then "λ" is interpreted as a "temporary" and "new" control wavelength in microns. After the calculation, the original control wavelength is restored. The yz-plane EFL, BFL, FFL, PP1 and PP2 values are placed general purpose storage registers 1 to 5. The xz-plane EFL, BFL, FFL, PP1 and PP2 values are placed general purpose storage registers 6 to 10. Make sure that solves are not in effect which could modify curvatures of thicknesses which would in themselves change the final answer. If the qualifier word "QUIET" is issued, the EFLY, BFLY, FFLY, PPY1. PPY2, EFLX, BFLX, FFLX, PPX1 and PPX2 will be stored in the first ten general purpose storage registers without any screen display..

INVAR - The "INVAR" command displays the YZ and XZ-plane, paraxial optical invarients for the current lens at the control wavelength for the active lens configuration.

DR/FR (qualifier word) , r , D , λ - The "DR/FR" command calculates the exact "delta radius per fringe" for a spherical optical surface whose radius of curvature is "r" lens units. The calculation is performed for a part diameter equal to "D" lens units. The wavelength of fringe interpretation is λ (in microns). In the absence of a qualifier word, the result is displayed at the current output device. If the qualifier word "ACC" is used, no display occurs but resultant delta radius per fringe (in the units of the current lens) is placed in the accumulator (X-register). "r" and "D" must be explicitly entered in lens units. The default value for λ is 0.5461 micron. Consider this a useful "side calculation" as it is not based on lens database values.

OUTFLAT (qualifier word) , m , D , λ The "OUTFLAT" command calculates the exact curvature for a circular optical surface which is "out of flat" by "m" fringes of power. The calculation is performed for a part diameter equal to "D" lens units. The wavelength of fringe interpretation is λ (in microns). In the absence of a qualifier word, the result is displayed at the current output device. If the qualifier word "ACC" is used, no display occurs but curvature (in the inverse units of the current lens) is placed in the accumulator (X-register). "m" and "D" must be explicitly entered. The default value for λ is 0.5461 micron. "m" need not be an integer. Consider this a useful "side calculation" as it is not based on lens database values.

THIRD, FIFTH, SEVENTH ORDER ABERRATIONS - The following commands display transverse or angular measures or unconverted aberration coefficients (determined by the current lens MODE) of the third and fifth order aberrations and seventh order spherical aberration. Output may be produced at one or all surfaces just as was done for the paraxial ray data. All values given for any surface are either always converted or not converted. Issuing any of the following commands with no numeric surface input data "i" causes only the aberration totals to be displayed. Paraxial data in the YZ or XZ-plane is used for aberrations in the YZ and XZ-planes, respectively. All aberrations are calculated at the current control wavelength.

MAB3 (ALL or OB or OBJ) or , i and **XMAB3 (ALL or OB or OBJ) or , i** - These commands display YZ or XZ-plane, third order monochromatic spherical aberration, coma, astigmatism, distortion and Petzval sum. Using the qualifier word "ALL" not only displays aberration contributions at each surface but also the aberration totals. If "i" is left blank and no qualifier word is used, only the aberration totals will be displayed. All aberrations are calculated at the current control wavelength.

MAB5 (ALL or OB or OBJ) or , i and **XMAB5 (ALL or OB or OBJ) or , i** - These commands display YZ or XZ-plane, fifth order monochromatic, intrinsic surface plus transferred spherical aberration, coma, astigmatism, distortion and Petzval sum. Using the qualifier word "ALL" not only displays aberration contributions at each surface but also the aberration totals. If "i" is left blank and no qualifier word is used, only the aberration totals will be displayed. All aberrations are calculated at the current control wavelength.

MABX5 (ALL or OB or OBJ) or , i and **XMAB5 (ALL or OB or OBJ) or , i** - These commands display YZ or XZ-plane, fifth order, extended, monochromatic, tangential oblique spherical aberration (TOBSA), sagittal oblique spherical aberration (SOBSA), elliptical coma (ELCMA), tangential astigmatism (TAS) and sagittal astigmatism (SAS). Using the qualifier word "ALL" not only displays aberration contributions at each

surface but also the aberration totals. If "i" is left blank and no qualifier word is used, only the aberration totals will be displayed. All aberrations are calculated at the current control wavelength.

SA357 (ALL or OB or OBJ) or , i and **XSA357 (ALL or OB or OBJ) or , i** - These commands display YZ or XZ-plane, third, fifth and seventh order, monochromatic, spherical aberrations SA3, SA5 and SA7. Using the qualifier word "ALL" not only displays aberration contributions at each surface but also the aberration totals. If "i" is left blank and no qualifier word is used, only the aberration totals will be displayed. All aberrations are calculated at the current control wavelength.

MAB5I (ALL or OB or OBJ) or , i and **XMAB5I (ALL or OB or OBJ) or , i** - These commands display YZ or XZ-plane, intrinsic surface component of fifth order monochromatic, spherical aberration, coma, astigmatism, distortion and Petzval sum. Using the qualifier word "ALL" not only displays aberration contributions at each surface but also the aberration totals of the intrinsic surface components. If "i" is left blank and no qualifier word is used, only the aberration totals will be displayed. All aberrations are calculated at the current control wavelength.

MABX5I (ALL or OB or OBJ) or , i and **XMABX5I (ALL or OB or OBJ) or , i** - These commands display YZ or XZ-plane, intrinsic surface component of fifth order, extended, monochromatic tangential oblique spherical aberration (TOBSA), sagittal oblique spherical aberration (SOBSA), elliptical coma (ELCMA), tangential astigmatism (TAS) and sagittal astigmatism (SAS). Using the qualifier word "ALL" not only displays aberration contributions at each surface but also the aberration totals. If "i" is left blank and no qualifier word is used, only the aberration totals will be displayed. All aberrations are calculated at the current control wavelength.

SA357I (ALL or OB or OBJ) or , i and **XSA357I (ALL or OB or OBJ) or , i** - These commands display YZ or XZ-plane, third order spherical aberration, SA3, and the intrinsic surface component of fifth and seventh order, monochromatic spherical aberration, SA5 and SA7. Using the qualifier word "ALL" not only displays aberration contributions at each surface but also the aberration totals. If "i" is left blank and no qualifier word is used, only the aberration totals will be displayed. All aberrations are calculated at the current control wavelength.

MABP3 (ALL or OB or OBJ) or , i and **XMABP3 (ALL or OB or OBJ) or , i** - These commands display the following YZ or XZ-plane, third order monochromatic, exit pupil aberrations: spherical aberration, coma, astigmatism, distortion and Petzval sum. Using the qualifier word "ALL" not only displays aberration contributions at each surface but also the aberration totals. If "i" is left blank and no qualifier word is used, only the aberration totals will be displayed. All aberrations are calculated at the current control wavelength.

THIRD, FIFTH, SEVENTH CHROMATIC VALUES

PCD3 (ALL or OB or OBJ) or , i and **XPCD3 (ALL or OB or OBJ) or , i** - These commands display YZ or XZ-plane, third order chromatic differences of spherical aberration, coma, astigmatism, distortion and Petzval sum. Using the qualifier word "ALL" not only displays aberration contributions at each surface but also the aberration totals. If "i" is left blank and no qualifier word is used, only the aberration totals will be displayed. All aberrations are calculated at the current control wavelength. The displayed aberration values are the aberration differences of the third order aberrations at the primary wavelength pair wavelengths. These two wavelengths are set by the "PCW" command. The following commands display primary chromatic differences of the aberrations generated by "MAB5", "XMAB5", "MABX5", XMABX5", "MABP3", "XMABP3", "SA357" AND "XSA357" :

PCD5 (ALL or OB or OBJ) or , i and **XPCD5 (ALL or OB or OBJ) or , i**
PCDX5 (ALL or OB or OBJ) or , i and **XPCDX5 (ALL or OB or OBJ) or , i**
PCDP3 (ALL or OB or OBJ) or , i and **XPCDP3 (ALL or OB or OBJ) or , i**
PCDSA (ALL or OB or OBJ) or , i and **XPCDSA (ALL or OB or OBJ) or , i**

The following commands display secondary chromatic differences of the third, fifth and seventh order aberrations. They use the secondary wavelength pair which can be set using the "SCW" command:

SCD3 (ALL or OB or OBJ) or , i and **XSCD3 (ALL or OB or OBJ) or , i**
SCD5 (ALL or OB or OBJ) or , i and **XSCD5 (ALL or OB or OBJ) or , i**
SCDX5 (ALL or OB or OBJ) or , i and **XSCDX5 (ALL or OB or OBJ) or , i**
SCDP3 (ALL or OB or OBJ) or , i and **XSCDP3 (ALL or OB or OBJ) or , i**
SCDSA (ALL or OB or OBJ) or , i and **XSCDSA (ALL or OB or OBJ) or , i**

REAL RAY ABERRATIONS

REAL RAY ABERRATIONS - These are all based upon the exact real trigonometric ray trace.

SURFACE COATINGS AND RAY TRACING

COATINGS (YES or ON or NO or OFF) - The "COATINGS" command is used to tell the program whether or not to calculate ray energy values based on currently assigned surface coating data and diffraction grating efficiency, in the case of diffraction gratings. When in the "OFF" setting, no ray energy calculations are possible. The default setting is "OFF". If "COATINGS ON" is set, then if there either bare substrate coatings or multiple layer coatings are defined on surfaces, polarization values for these surface will be computed. These polarization values can be explicitly output for single rays and are used appropriately in spot diagram and complex aperture function related calculations.

OBJECT POINT SPECIFICATION (FOB COMMAND)

FOB (qualifier word) , Y, X, Z, n, m - The "FOB command must be issued before any ray can be traced. This command defines the object point from which subsequent rays will be traced. "Y", "X" AND "Z" are the fractional y, x and z-coordinates of the object point measured on the current object surface if the reference object height is set via "SCY" and "SCX" commands. "Y", "X" are the fractional y and x-object space field angles if the reference object height is set via "SCY FANG" and "SCX FANG" commands. Z is represented as a fraction of the current object surface axial thickness. If "Z" is zero, the object point lies on the object surface. "Z" is a fractional measure.

It represents the fraction of the thickness assigned to the object surface and is an "off-set". If "Z" is +1.0, then the object point is a positive z-distance from the object surface equal to the axial thickness of the current object surface. If "Z" is -1.0, then the object point is a negative z-distance from the object surface equal to the axial thickness of the current object surface. Z is only used when the reference object height has been set by "SCY" and "SCX" commands. Issued with the iterrogator "?", the "FOB" command returns the last "FOB" input data if a chief ray exists. Normally, the reference ray is traced at the control wavelength if "n" is not explicitly input. If "n" is explicitly input, it can be 1 through 10, the reference ray is traced at wavelength number "n". The fifth numeric word entry, "m", is a composite number which defines a temporary reassignment for the object, reference and image surface numbers. If this entry is omitted, the object surface is surface 0, the reference surface is the surface defined as the reference surface in the lens input mode and the image surface is the last surface. Whenever telecentric ray aiming is in effect, reassignment of the object, reference and image surface with numeric word #5 of the "FOB" command is not allowed. "m" is a nine-digit integer of the form

"xxxyyyzzz". "xxx" is the new object surface number, "yyy" is the new reference surface number and "zzz" is the new image surface number. The choice of "qualifier word" selects the specific additional output to be displayed as shown in the following table:

Qualifier Word	OUTPUT
(none)	(none)
NULL	(none)
"P"	Yo, Xo, Zo
"PIC" or "PICNH"	Yo, Xo, Zo, Yi, X_i
"PFS" or "PFSNH"	Yo, Xo, Zo, Fy, Fx

The qualifier word "P" causes the reference ray coordinates at the object surface to be displayed. The qualifier words "PIC" and "PICNH" display the reference ray coordinates at the object surface, Yo, X0, Zo, and the Y and X-coordinates of the reference ray at the image surface, Yi, Xi. "PIC" produces header information; "PICNH" produces no header information. The qualifier words "PFS" and "PFSNH" display the reference ray coordinates at the object surface, Yo, Xo, Zo, and the YZ-plane and XZ-plane field sags at the image surface, Fy, Fx. "PFS" produces header information; "PFSNH" produces no header information. Calculation of Fy and Fx is performed by tracing differential rays about the reference ray corresponding to differential displacements in Y and X on the reference surface. Fy locates the intersection of the Y-differential ray with the reference ray. Fx locates the intersection of the X-differential ray with the reference ray. Fy and Fx are distances, measured in the Z direction, from the image surface to each focus. The options "P", "PIC" and "PFS" display information indicating the wavelength and the field angle. The field angle is defined to be the angle between the Z-axis and the reference ray in the object space. "PICNH" and "PFSNH" suppress these headings. The "FOB NULL" is used when it is necessary to trace rays in a situation in which the reference ray fails. In such a case, a non-chief ray may still pass through the lens system. Of course, since there will be no reference ray data, aberrations based upon reference ray calculations will not be possible. The "FOB NULL" command is identical to the usual "FOB" command, except that the tracing of the reference ray is suppressed.

FOBH (qualifier word) , YH, XH, ZH, n - The "FOBH" command is similar to the "FOB" command except that the "YH", "XH" and "ZH" input values are the Y, X and Z-positions of the current object point relative to the origin of the current object surface. They are always represented in current lens units. "n" is the wavelength number. "FOBH" does not take the fifth numeric word of the "FOB" command. All valid "FOB" qualifier words may be used with "FOBH".

FOBA (qualifier word) , Yang , Xang , n - The "FOBA" command is an alternate form of the "FOB" command. If has less power than "FOB" but allows the user to input field of view angles directly in degrees. The user may specify the "Yang", the "Xang" and the wavelength number "n". The defaults are 0.0, 0.0 and "cw", the control wavelength. The command will work whether the reference object height was specified using "SCX" and "SCY" or "SCX FANG" and "SCY FANG". For near objects and systems with internal stops/reference surfaces, the resultant field angles may not be exactly the angles requested due to the non-zero chief ray height on surface (newobj+1) and the less than large object distance. For object distances greater than 1.0×10^{10} lens units, the "FOBA" command should yield exact chief ray angles. All valid "FOB" qualifier words may be used with "FOBH".

THE SINGLE RAY TRACE

RAY , Y, X, n , I - "Y" and "X" are the fractional reference surface coordinates and "n" is the wavelength number. If no entry is made for "n", the ray is traced at the control wavelength number. "I" is the starting ray intensity which may be set to any non-zero value less than or equal to 1.0. The default value for "I" is 1.0. If the reference surface has no clear aperture assigned, the actual reference ray coordinates will be calculated based upon the reference aperture height set by the paraxial ray trace. If a clear aperture has been assigned to the reference surface, the actual reference ray coordinates will be calculated based upon the fractional reference aperture height relative to the center of the clear aperture.

RAY CAOB , Y, X, n , I - The "RAY CAOB" command works just like the standard "RAY" command, except that it causes checking for ray blockages due to clear apertures, obstructions and erases. If a ray falls outside a clear aperture or within an obscuration, a ray failure message will be generated, saved internally and displayed. In order for this message to be displayed, plotting MUST be turned "OFF". This is done by issuing a "PLOT END" message after plotting is completed. Clear aperture ray blocking is not checked on the current object surface or the current image surface by "RAY CAOB".

SINGLE RAY DATA DISPLAY - The following four commands allow the user to change the ray angle output mode for real rays to "degrees", "radians" or "tangents". Paraxial output angles are always expressed as tangents. These commands do not change any input units. The "ANGMODE" command displays the current angular mode. The default angular mode when the program starts is "degrees": **DEG** or **RAD** or **TANGENT** or **ANGMODE**

HEADINGS ON or **HEADINGS OFF** - Headings are always displayed when tabular output is requested via the qualifier "ALL". The "HEADINGS" command with the qualifier words "ON" and "OFF" controls whether or not headings will be displayed for single lines of displayed data. The default setting for "HEADINGS" is "OFF" when the program begins. New users may be more comfortable seeing headings for all data displays. Headings can be set to "ON" after program startup or the line "HEADINGS ON" can be added to the "DEFAULTS.DAT" file before starting the program. If requested program data does not exist, a message to that effect is displayed.

THE ALL COMMAND

ALL (ON or YES or OFF or NO) Any program command which can take surface number input or the qualifier word input "ALL" and has the characteristic behavior that when that command is entered with no input, data for the final lens surface is printed can be impacted by the "ALL" command. If "ALL" is set to "ON", the default behavior of that command will be to assume that the "ALL" qualifier word had been issued with that command. The default setting for "ALL" will be "OFF". If it is desired to have "ALL" always set to "ON", place the "ALL ON" command in the DEFAULTS.DAT file in the main program directory. It will be executed whenever the program is run.

SINGLE RAY DATA DISPLAY - The following commands all refer to data related to the last single ray traced:

PRX (ALL or OB or OBJ) or

PRX P , i or

PRX , i - The "PRX" command displays the X-coordinate of the ray at a surface and the ray angle to the Z-axis made by the projection of the ray on the XZ-plane in the space following the surface. For the image surface, angles are with respect to the previous surface. The qualifier "ALL" causes a

table of data for all surfaces to be displayed. If no qualifier is entered, single surface data is displayed. If no qualifier or numeric surface number "i" input is entered, the current image surface is assumed. The qualifier "P" causes the wavelength number and relative aperture coordinates in the reference surface to be displayed.
PRY (ALL or OB or OBJ) or
PRY P , i or
PRY , i - "PRY" acts just like "PRX" but displays Y-coordinate and YZ-plane angle projections.

PRXYZ (ALL or OB or OBJ) or
PRXYZ P , i or
PRXYZ , i - "PRXYZ" acts just like "PRX" but displays X, Y and Z-ray coordinates and XZ and YZ-plane angle projections.

PRXYI (ALL or OB or OBJ) or
PRXYI P , i or
PRXYI , i - "PRXYI" acts just like "PRXYZ" with Z replaced by the angle of incidence at the surface.

PRXYIP (ALL or OB or OBJ) or
PRXYIP P , i or
PRXYIP , i - "PRXYIP" acts just like "PRXYZ" with Z replaced by the angle of reflection, refraction or diffraction at the surface.

PRXYD (ALL or OB or OBJ) or
PRXYD P , i or
PRXYD , i - "PRXYD" acts just like "PRXYZ" with Z replaced by the optical path length along the ray in the space preceding the surface.

PRZ (ALL or OB or OBJ) or
PRZ P , i or
PRZ , i - "PRZ" acts like "PRX" but displays the Z-ray coordinate and the optical path length along the ray in the space preceding the surface.

PRR (ALL or OB or OBJ) or
PRR P , i or
PRR , i - "PRR" acts like "PRX" but displays the radial ray coordinate R and the angle from the ray to the Z-axis.

PRREF (ALL or OB or OBJ) or
PRREF P , i or
PRREF , i - "PRREF" acts like "PRXYZ" but displays the X, Y and Z-coordinates or the current reference ray and the tangents of the X and Y-angles which that ray makes with the Z-axis.

PRLMN (ALL or OB or OBJ) or
PRLMN P , i or
PRLMN , i - "PRLMN" acts like "PRXYZ" but displays the current ray X, Y and Z-coordinates and the L, M and N direction cosines.

PRFLUX (ALL or OB or OBJ) or
PRFLUX P , i or
PRFLUX , i - "PRFLUX" acts like "PRX" but displays the current relative ray energy or flux. If coatings are assigned to surfaces and if "COATINGS" are set to "ON", the surface coatings will be used to compute ray trasmission or reflection factors which will be used in the relative ray energy calculation.

PRPOL (ALL or OB or OBJ) or
PRPOL P , i or
PRPOL , i - "PRPOL" acts like "PRX" but displays the current ray polarization data.. Data includes the parallel and perpendicular reduction factors, phases and the angle between the plane of incidence and the y-vector dirrection of the current chief ray.

OPD - The "OPD" command calculates and displays the optical path difference for the last ray traced both in lens units and in waves (at the wavelength at which the reference ray was traced).

DIFFERENTIAL RAYS - If differential rays are being traced, differential ray data is displayed with the following four commands:
PRDIFFXR (ALL or OB or OBJ) or
PRDIFFXR P, i or
PRDIFFXR , i - "PRDIFFXR" acts like "PRX" but displays the X, Y and Z-coordinates and the L, M and N direction cosines of the current differential ray with respect to a differential shift in the starting ray X-coordinate at the object surface.
PRDIFFYR (ALL or OB or OBJ) or
PRDIFFYR P, i or
PRDIFFYR , i - "PRDIFFYR" acts like "PRX" but displays the X, Y and Z-coordinates and the L, M and N direction cosines of the current differential ray with respect to a differential shift in the starting ray Y-coordinate at the object surface.
PRDIFFXM (ALL or OB or OBJ) or
PRDIFFXM P, i or
PRDIFFXM , i - "PRDIFFXM" acts like "PRX" but displays the X, Y and Z-coordinates and the L, M and N direction cosines of the current differential ray with respect to a differential shift in the reference ray X-coordinate at the reference surface.

PRDIFFYM (ALL or OB or OBJ) or
PRDIFFYM P, i or
PRDIFFYM , i - "PRDIFFYM" acts like "PRX" but displays the X, Y and Z-coordinates and the L, M and N direction cosines of the current differential ray with respect to a differential shift in the reference ray Y-coordinate at the reference surface. Whenever an "FOB" command is issued, a "RAY , 0 , 0 , (wavelength number equal to that used in the "FOB" command)" command is automatically issued. As long as these two rays can be traced through the optical system and as long as "DIFFOB" and "DIFRAY" are set to "(ON or YES)", differential rays will be traced. This program behavior is used to generate a set of extremely useful data which we will call "GENERALIZED PARAXIAL RAY TRACE" data. This ray trace, unlike the true paraxial ray trace, takes into account surface tilts, decentrations and aspheric and other surface deformations. Whenever this generalized paraxial data is requested, appropriate rays will be traced automatically. For this trace, "DIFFOB" and "DIFRAY" will be temporarily turned "(ON or YES)" if they were "(OFF or NO)" and the associated differential ray trace will be used to generate the generalized paraxial ray data. The generalized paraxial ray trace data is generated and displayed using the following two commands:

GENERALIZED PARAXIAL RAY TRACE
GPXTY (ALL or OB or OBJ) or
GPXTY , i , y-fob , x-fob , z-obj. shift , wavelength #
and
GPXTX (ALL or OB or OBJ) or
GPXTX , i , y-fob , x-fob , z-obj. shift , wavelength # - The "GPXTY" and "GPXTX" commands generate and output the YZ or XZ-plane, generalized paraxial marginal ray heights, generalized paraxial marginal ray slopes, generalized paraxial chief ray heights and generalized paraxial chief ray slopes. Generalized paraxial ray data is always generated for the current configuration. Generalized paraxial ray data is never used in solves or for 3rd, 5th and 7th order aberration calculations. All the "GPXTX" and "GPXTY" commands may also take numeric words #2, #3, #4 and #5 input. Numeric words #2 and #3 are Y and X-FOB values which will override the default 0.0, 0.0. When explicit Y and X-FOB values are input, the output generated should no longer be considered a true "generalized paraxial ray trace" which can be compared to the regular paraxial ray trace. Numeric word #4 is used to specify a Z-obj. shift as is used in the "FOB" command. Numeric word #5 is used to specify a wavelength number other than the control wavelength number. Valid entries are 1 to 10. Generalized paraxial data is generated by tracing real chief and marginal rays close to a chief ray and then scaling the resultant data up by the appropriate and current "SCX", "SCY", "SAX" and "SAY" values.

GLOBAL COORDINATE RAY TRACING
GLOBAL , i - The "GLOBAL" command, when issued with integer numeric input, is used to define the surface number whose "local" coordinate system is to be used as the "global" coordinate system for all subsequent "global" ray trace data.
GLOBAL OFF - The "GLOBAL OFF" command shuts off global coordinate ray tracing.
OFFSET DEC , X , Y , Z - The "OFFSET DEC" command is used to define an offset from the vertex of the "global" surface vertex. This new "offset" location will be the origin for all "global" ray trace data. "X", "Y" and "Z" are the X, Y and Z-offsets measured in the local coordinate system of the "global" surface.
OFFSET TILT , ALPHA , BETA , GAMMA - The "OFFSET TILT" command is used to define an angular offset from the orientation of the "global" surface vertex coordinate system. This new "angular offset" will define the "global" coordinate system orientation for all "global" ray trace data. "ALPHA", "BETA" and "GAMMA" are defined in the local coordinate system of the "global" surface. They are input in degrees and are defined in the same sense as the "ALPHA", "BETA" and "GAMMA" tilts in the LENS section. The angular offsets in the "OFFSET TILT" command are considered to be either in the MIXED or in the RIGHT-HANDED directional sense depending upon the current angular setting in the current lens. See the LENS section for more details.
GLOBAL - The "GLOBAL" command, when issued with no additional input, is used to display the current status of "global" ray tracing. If "global" ray tracing has been previously set to "on", then the surface number of the surface whose coordinate system is used as the origin for "global" data, as well as any defined "offsets", will be displayed.
VERTEX (ALL or OB or OBJ) or
VERTEX , i - The "VERTEX" command displays "global" surface vertex coordinates X, Y and Z. It also displays "global" surface coordinate system L, M and N direction cosines for each local surface coordinate axis. If the qualifier "ALL" is used, a header is included which is similar to the display produced by the "GLOBAL" command.
PRGLOBAL (ALL or OB or OBJ) or
PRGLOBAL , i - The "PRGLOBAL" command displays "global" ray trace data. The "global" X, Y and Z ray coordinates and the "global" L, M and N ray direction cosines before (LOLD, MOLD and NOLD) and after (L, M and N) surface interaction (reflection, refraction or diffraction) are displayed. If the qualifier "ALL" is used, a header is included which is similar to the display produced by the "GLOBAL" command.

ADDITIONAL RAY COMMANDS
FOBDUMPThe "FOBDUMP" command displays all internal program reference ray data for all surfaces for the last single ray traced. It is intended as a debugging tool when attempting to trace a difficult or poorly understood case of ray trace failure.
RAYDUMPThe "RAYDUMP" command displays all internal program ray data for all surfaces for the last single ray traced. It is intended as a debugging tool when attempting to trace a difficult or poorly understood case of ray trace failure.
DIFFOB (ON or YES or OFF or NO) - The "DIFFOB (ON or YES)" and "DIFFOB (OFF or NO)" commands either activate or deactivate differential reference ray tracing in cases where differential reference ray tracing would normally apply such as in the single ray trace. It should only be used for diagnosing ray tracing problems. Issued with a "?", the "DIFFOB" command returns a message as to its current setting. It only applies to the action taken after a "FOB" command is issued. This command is "sticky" and remains as set until changed by the user or until the program ends.
DIFRAY (ON or YES or OFF or NO) - The "DIFRAY (ON or YES)" and "DIFRAY (OFF or NO)" commands either activate or deactivate differential ray tracing in cases where differential ray tracing would normally apply such as in the single ray trace. It should only be used for diagnosing ray tracing problems. Issued with a "?", the "DIFRAY" command returns a message as to its current setting. This command is "sticky" and remains as set until changed by the user or until the program ends.
AIMRAY (ON or YES or OFF or NO) - The "AIMRAY (ON or YES)" and "AIMRAY (OFF or NO)" commands either activate or deactivate real ray, ray aiming to a specific relative coordinate in the reference surface. When ray aiming is "(OFF or NO)", rays are aimed at next surface after the

object surface based only upon the existing paraxial ray trace. It should only be used for diagnosing ray tracing problems. Issued with a "?", the "AIMRAY" command returns a message as to the current setting. This command is "sticky" and remains as set for the current lens until changed by the user. The setting is remembered in the current lens database. This command is also described in the LENS section

AIMRAY OFFSET , x-offset , y-offset , z-offset - The "AIMRAY OFFSET" command is provided in order give the user maximum control over program ray tracing. It will rarely, if ever, be needed. When the program begins aiming a chief ray toward the center of the current reference surface, it uses, as its first guess, paraxial ray trace data at surface NEWOBJ+1, decentrations assigned to the surface NEWOBJ+1 and the numeric input issued with the "FOB" command. In all cases tested, either this "first guess" or the automatic search engine built into the program has been found to be good enough to allow chief ray aiming to proceed successfully. In the unlikely event that the first guess ray coordinate at surface NEWOBJ+1 is not good enough to allow the chief ray to be traced, the "AIMRAY OFFSET" command may be used to introduce a permanent "x-offset", "y-offset" and "z-offset" to the initial surface NEWOBJ+1 ray coordinate. The default "x-offset", "y-offset" and "z-offset" are always zero. The "x-offset", "y-offset" and "z-offset" will be stored with the lens database. These offsets are only used to give the program a different initial starting point when aiming the chief ray. They do not change the chief ray aim point at the reference surface. The command "AIMRAY", when issued with the special interrogator "?", will display the current status of ray aiming as well as the current "x-offset", "x-offset" and "z-offset" values.

GAUSSIAN BEAM PROPAGATION

BEAM (ALL or OB or OBJ) or BEAM , i , y-fob , x-fob , z-obj. shift , wavelength # - The "BEAM" command generates and outputs the YZ or XZ-plane gaussian beam propagation data. This data consists of:

ABERRATION RAY FANS - Ray fans are tabulations of ray aberration versus relative fractional ray position in the reference surface. Each of the following "ray fan" commands must be preceded by an "FOB" command.

XFAN (qualifier word) , Xmin , Xmax , n , m , δ and

YFAN (qualifier word) , Ymin , Ymax , n , m , δ and

PFAN (qualifier word) ,Pmin , Pmax , n , m , δ and

NFAN (qualifier word) , Nmin , Nmax , n , m , δ - The "XFAN", "YFAN", "PFAN" and "NFAN" commands are used to generate and display ray fan data for a set of rays intersecting the reference surface. These sets of rays are traced in fan lines and intersect the reference surface at fractional reference surface coordinates from "X_{min}" to "X_{max}" for "XFAN", "Y_{min}" to "Y_{max}", for "YFAN", "P_{min}" to "P_{max}" for "PFAN" and "N_{min}" to "N_{max}" for "NFAN". There will be "m" rays traced. These "m" rays are evenly spaced along the fan line between the minimum and maximum fan reference surface coordinate limits. If no entry is made for "m", four rays will be traced for an XFAN and nine rays for all other fans. All rays will be traced at wavelength number "n". "δ" is the fan offset shown in the next figure. "δ" allows a fan to be traced "offset" in the reference surface. "δ" is entered as a relative, fractional value of the reference aperture height rather than an offset in lens system units.

FAN TYPE	FAN QUALIFIER	MODE	DATA DISPLAYED
YFAN or XFAN	(none)	FOCAL or UFOCAL	DX, DY
PFAN and NFAN	(none)	FOCAL or UFOCAL	DN, DP
YFAN or XFAN	(none)	AFOCAL or UAFOCAL	DXA, DYA
PFAN or NFAN	(none)	AFOCAL or UAFOCAL	DNA, DPA
(all fan types)	OPD	(all modes)	OPD
(all fan types)	LA	FOCAL or UFOCAL	LAX, LAY, DTX, DTY or LAN, LAP, DTN, DTP
(all fan types)	LA	AFOCAL or UAFOCAL	(not functional)
(all fan types)	CD	FOCAL or UFOCAL	PCDX, PCDY, SCDX, SCDY or PCDXN PCDP, SCDN, SCDP
(all fan types)	CD	AFOCAL or UAFOCAL	PCDXA,PCDYA,SCDXA,SCDYA or PCDNA,PCDPA,SCDNA and SCDPA

EXPUP (qualifier word) - The "EXPUP" command controls how the radius of curvature of the reference sphere is calculated. It takes one of two qualifier words, "AUTO" or "NOAUTO", and only applies in modes FOCAL and UFOCAL. If the qualifier word "AUTO" is used (this is the default when the program starts and is ALWAYS used during spot diagram OPD calculations), then close real differential rays are traced along the chief ray to determine location of the real exit pupil. The reference sphere radius of curvature is then equal to the distance from this real exit pupil to the intersection of the chief ray with the image surface measured along the chief ray. If the qualifier word "NOAUTO" is used, then the radius of curvature of the reference sphere is computed as follows:

1. If the surface preceding the image surface has a non-zero thickness, then the radius of curvature of the reference sphere is set equal to that axial thickness.
2. If the surface preceding the image surface has a zero axial thickness, then the radius of curvature of the reference sphere is set equal to the axial distance from the image surface to the location of the paraxial exit pupil measured along the optical axis. The reference ray is always traced at the wavelength specified in the "FOB" command. The center of curvature and the radius of the reference sphere do **not** change as fans are traced at different wavelengths but only when the object point is redefined with a new "FOB" command.

For afocal systems, the reference "sphere" is not a sphere but is a plane located at the intersection of the reference ray with the image surface. It is perpendicular to the reference ray. In some cases, such as in visual systems, it may be a good idea to place this final surface at the location of the paraxial exit pupil by using an ASTOP EX setting, or at the location of the real ray exit pupil via an optimization based upon where the chief ray

crosses the optical axis. Since afocal systems vary so much in their intended use, designer judgement should be used in the selection of the location of the final surface in afocal systems when OPD wavefront performance must be evaluated. For focal systems which have their exit pupil at infinity (telecentric systems), the reference "sphere" is also not a sphere but is a plane perpendicular to the reference ray and located at infinity. Infinity in this case is a value whose magnitude is greater than or equal to $1.0X10^{10}$ lens units. If reference ray differential ray tracing has been shut off via the "DIFFOB (OFF or NO)" command, the paraxial exit pupil position will be used even if "EXPUP AUTO" was in effect.

ABERRATION FAN PLOTTING

DRAWFAN , (ssi) , dflag - During the design process it is often useful to issue a "FOB" command followed by one of the CMD level fan commands so as to examine the current aberration characteristic of the system being designed. If a "DRAWFAN" command is issued immediately after one of the fan commands, a graphical representation of this "last" fan will be displayed on the screen. This fan plot may be re-displayed on the screen with the "DRAW" command or may be sent to a printer or plotter with the "GRAOUT" command. The optional vertical scale length, "ssi", may be entered to specify the scale bar length used in the display. If it is ommitted, the scale bar length will be automatically picked by the program. The rest of the commands described in this section are independent of the last fan displayed using the CMD level fan commands. If "dflag" is explicitly input (any numeric value), the automatic "draw" command will not be issued.

PLT_FAN , (ssi) - This command is identical to "DRAWFAN" except that the fan is not drawn. A seperate "DRAW" command should be issued to draw the plotted fan.

AUTOMATED FAN PLOTS - These commands are provided so that the designer may custom tune the type of plot to be generated. They work best when issued from within a macro. They generate fan plots at three field-of-view positions. In the default mode, the field positions are at 1.0, 0.7 and 0.0 relative Y-field-of-view positions as defined by the "SCY" or "SCY FANG" setting in the current lens file.

FANFIELD (F1 or F2 or F3) , y-fob , x-fob

The CMD level command "FANFIELD" is used to reset the default values of the field positions for the automated fan plots to follow. The settings are "sticky" and stay set until reset or until the program terminates. The valid qualifiers are "F1", "F2" and "F3". The "y-fob" and "x-fob" are fractional object or field positions just like those used with the "FOB" command. The default "y-fob" and "x-fob" values for fields "F1", "F2" and "F3" are: (1.0,0.0), (0.7,0.0) and (0.0,0.0).

FANS (qualifier word) , ssi , dflag

The CMD level command "FANS" causes a one-page, three field-of-view fan plot to be generated. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. "ssi" is the amount of aberration represented by the vertical axis of the plots. If "ssi" is omitted, the plots will be auto-scaled by the maximum aberration value in the first field of view. Aberration fans will be generated and displayed based upon the current "SPTWT" and "SPTWT2" spectral weight settings in the lens database. The following table lists all of the valid qualifier words (the default qualifier word is "XYFAN") and the types of fans which will be generated by each:

QUALIFIER WORD	TYPE OF FAN GENERATED
XFAN or YFAN	X and Y-components of an X-fan or a Y-fan
XYFAN or YXFAN (XYFAN is the default)	Transverse tangential or sagittal aberrations of X and Y ray fans
NFAN or PFAN	N and P-components of an N-fan or a P-fan
XOPD or YOPD	OPD of an X-fan or a Y-fan
XYOPD	OPD of X and Y ray fans
NOPD or POPD	OPD of an N or a P-fan
XCD or YCD	X and Y-chromatic differences of X or Y-fans
XYCD of YXCD	Chromatic differences (tangential or sagittal components) of X and Y ray fans
NCD or PCD	N and P-chromatic differences of N or P-fans
XLA or YLA	X and Y-components of the longitudinal aberrations of an X or Y-fan
XYLA or YXLA	Longitudinal aberrations (tangential or sagittal) of X and Y ray fans
NLA or PLA	N and P-components of the longitudinal aberrations of an N or P-fan

It will be noticed that the X and Y-fans are not drawn on the same sides on the plots as in some other optical design programs. This is because X comes before Y in the English alphabet and we are using a left to right alphabetical layout for most of the fans in graphical output.

REGULAR RAY FAN COMMANDS

PLOTFANS SSI , i - The "PLOTFANS SSI" command sets the aberration plotting scale so that "i" units of the specified aberration are plotted in the vertical height of each fan plot drawn. This command also sets the magnitude of the aberration represented by the aberration scale bar. This bar is drawn in the caption area of the plot. If this command is omitted, the scale bar will be automatically set equal to the maximum aberration value at the first field of view position specified in the next two commands. If this default "ssi" determination yields a zero "ssi" value, "ssi" will be set to 0.001.

PLOTFANS YFOB , yfob1 , yfob2 , yfob3 - The "PLOTFANS YFOB" command sets Y-fractional object heights "yfob1", "yfob2" and "yfob3" for up to three fields of view.

PLOTFANS XFOB , xfob1 , xfob2 , xfob3 - The "PLOTFANS XFOB" command sets X-fractional object heights "xfob1", "xfob2" and "xfob3" for up to three fields of view. The program determines from these two commands whether one, two or three sets of fans will be drawn per fan plot. If these commands are omitted, one set of fans will be drawn using X and Y-fractional object heights both equal to 0.0.

PLOTFANS OFFSET , δ - The "PLOTFANS OFFSET" command sets the fan "offset" to be equal to δ. This "offset" is described in the discussion of ray fans in the CMD section.
PLOTFANS NEWOBJ , i - The "PLOTFANS NEWOBJ" command sets surface "i" to be the new temporary object surface for the next fan plot. The default object surface is surface 0.
PLOTFANS NEWREF , i - The "PLOTFANS NEWREF" command sets surface "i" to be the new temporary reference surface for the next fan plot. The default reference surface is the current reference surface defined in the lens database.
PLOTFANS NEWIMG , i - The "PLOTFANS NEWIMG" command sets surface "i" to be the new temporary image surface for the next fan plot. The default image surface is the last surface of the lens database.
PLOTFANS REFWV , n - The "PLOTFANS REFWV" command sets wavelength number "n" to be the new temporary reference wavelength for the next fan plot. The default reference wavelength is the control wavelength defined in the lens database.
PLOTFANS WV , i , j , k , l , m - The "PLOTFANS WV" command specifies the first five program wavelengths for which fans will be traced and plotted. Each of the "i" through "m" input values can be set to ±1 through ±10. A plus value indicates that a fan will be generated at that wavelength number. A minus indicates that a fan will not be generated at that wavelength number. If this command is omitted, the current state of the spectral weighting factors will be used to determine if a fan will be traced. Fans will be traced, in this default scenario, at each of the program wavelengths for which the spectral weighting factor is non-zero.
PLOTFANS WV2 , i , j , k , l , m - The "PLOTFANS WV2" command specifies the second five program wavelengths for which fans will be traced and plotted. Each of the "i" through "m" input values can be set to ±1 through ±10. A plus value indicates that a fan will be generated at that wavelength number. A minus indicates that a fan will not be generated at that wavelength number. If this command is omitted, the current state of the spectral weighting factors will be used to determine if a fan will be traced. Fans will be traced, in this default scenario, at each of the program wavelengths for which the spectral weighting factor is non-zero.
Primary Chromatic Difference (PCD) fan plots use line style #0 and the color assigned to wavelength #1 in the other types of fan plots. Secondary Chromatic Difference (SCD) fan plots use line style # 1 and the color assigned to wavelength #2 in the other types of fan plots.
PLT(X.or Y or XY or YX or N or P) FAN (qualifier) - The "PLTXFAN", "PLTYFAN", "PLTXYFAN", "PLTYXFAN", "PLTNFAN" and "PLTPFAN" commands specify the type of fan data that will be displayed. "PLTXFAN" will generate plot data for the X and Y-components of an X-fan . "PLTYFAN" will generate plot data for the X and Y-components of a Y-fan. "PLTXYFAN" will generate plot data for the X-component of an X-fan and the Y-component of a Y-fan. "PLTYXFAN" will generate plot data for the Y-component of an X-fan and the X-component of a Y-fan. "PLTNFAN" will generate plot data for the N and P-components of an N-fan. "PLTPFAN" will generate plot data for the N and P-components of a P-fan. If none of the above six commands is explicitly issued, then the default fan type will be that which would have been generated by a "PLTXYFAN" command. The "qualifier" may be (no qualifier) or "OPD" or "LA" or "CD". A more detailed description of aberration fans is contained in the CMD manual section. The qualifier "OPD" used with either the "PLTXYFAN" or the "PLTYXFAN" command, produces identical results.
PLOTFANS RESET - The "PLOTFANS RESET" command resets all fan plotting settings to their original state immediately after a "PLOT NEW" command.
PLOTFANS GO - The "PLOTFANS GO" command causes all plotfan settings, both implicit and explicit, to be used to generate a fanplot. This plot is sent to the NEUTRAL.DAT. Fan plot display is then performed via the "DRAW", or the "GRAOUT " command.

USER-DEFINED FAN PLOTS - The fan plotting commands which have been described so far attempt to give the user a way to generate aberration fan plots in a more or less automated way. The following user-defined fan plotting commands give the user complete control, and responsibility, for the generation of custom aberration fan plots. Before these five following user-defined fan plotting commands are issued, a "PLOT NEW" command should be issued. At anytime during the issuing of any of these user-defined aberration fan plotting commands, the user may issue "DRAW" commands to check on the progress of the user-defined aberration plotting.
PFANAXIS , (xpos) , (ypos) , (x-extent) , (y-extent) , (clipping) - The "PFANAXIS" command causes an aberration fan axis set to be generated. The axis set will be centered at "xpos" and "ypos". The default values are "xpos"= 5000 and "ypos" = 3500 device independent coordinates. The "x-extent" and "y-extent" set the x and y-extents of the respective axes in device independent units. Extent defaults are "x-extent" = 2500 and "y-extent" = 2000 device independent units. "clipping" set to 0 will cause the fan plots to be clipped outside of a box defined by the axes extents. "clipping" set to 1 will result is no fan plot clipping. The color of the axes will be the current RAY color set using "COLORSET" command and the line style will be the current line style set using the "PLOT LSTYLE" command. "PFANAXIS", issued with the interrogator "?", causes the current "xpos", "ypos", "x-extent", "y-extent" and "clipping" values to be displayed at the current output device.
PFANSSI ssi - The "PFANSSI" command allows the user to explicitly set the "ssi" scale bar for all user-defined fan plotting. If no explicit "ssi" is in effect, one will be computed based upon the first aberration fan plotted with the "PFANCOMP" command. "ssi" is the amount of vertically represented aberration which will be displayed in ("y-extent") device independent units. "PFANSSI" issued with the interrogator "?", causes the current "ssi" value to be displayed at the current output device.
PFANLBL (vertical axis label – up to 21 characters) - The "PFANLBL" command causes the current aberration fan axis set to be labeled. The left and right extremes of the x-axis will be labled –1.0 and 1.0 representing the limits of the reference aperture. The vertical axis will be labled with the optionally input label (up to 21 characters in length). The default label is blank.
PFANCAP (fan caption – up to 40 characters) - The "PFANCAP" command causes the current aberration fan axis set to be captioned with a caption up to 40 characters in length. The caption will be fit beneath the plot, as close to the plot as is practical. The default caption is blank.
PFANCOMP , component number , color number, line style number - The "PFANCOMP" command causes the specified component of the last aberration fan generated to be plotted on the current user-defined fan axis set. Components of the aberration fans are numbered as per the following table. Remember that "LA" fans are only available in the FOCAL and UFOCAL modes. Color numbers range from 1 to 10 and represent the 10 currently assigned colors associated with the WAV1 to WAV10 entries in the "COLORSET" command. Line stype numbers are the numbers associated with the line styles in the "LSTYLE" command. When tracing fans in a macro prior to plotting, the textual output at the screen can be supressed by issuing an "OUT NULL" before and after each "FAN" command.

	Component number	**Component number**	**Component number**	**Component number**
Fan Type (numeric word	1	2	3	4

#1 value)				
Fans (no qualifier)	DX, DXA,DN, DNA	DY, DYA, DP, DPA	(not used)	(not used)
OPD fans	OPD	(not used)	(not used)	(not used)
LA fans	LAX or LAX	LAY or LAP	DTX or DTN	DTY or DTN
CD fans	DCDX or DCDN or DCDXA or DCDNA	DCDY or DCDP or DCDYA or DCDPA	SCDX or SCDN or SCDXA or SCDNA	SCDY or SCDP or SCDYA or SCDPA

RAY FAILURE CODES

RAY FAILURE CODE 1 AT SURFACE (I) - Ray was not able to intersect surface I.
RAY FAILURE CODE 2 AT SURFACE (I) - Iterative intersection routine for an aspheric, toric or special surface failed to converge for surface (I).
RAY FAILURE CODE 3 - Ray trace failed to converge to the reference surface aim point.
RAY FAILURE CODE 4 AT SURFACE (I) - Total internal reflection occurred at surface (I).
RAY FAILURE CODE 5 AT SURFACE (I) - Angle of diffraction at the grating on surface (I) was physically unrealizable.
RAY FAILURE CODE 6 AT SURFACE (I) - Ray was blocked by a clear aperture on surface (I).
RAY FAILURE CODE 7 AT SURFACE (I) - Ray was blocked by an obscuration on surface (I).
RAY FAILURE CODE 8 - Chief ray from the current object point could not be traced.
RAY FAILURE CODE 9 AT SURFACE (I) - Angle of refraction for the HOE on surface (I) was physically unrealizable.
RAY FAILURE CODE 10 AT SURFACE (I) - (ray failur code 10 not currently in use)
RAY FAILURE CODE 11 AT SURFACE (I) - Reference ray cannot be traced because current trace wavelength is equal to 0.0 microns.
RAY FAILURE CODE 12 AT SURFACE (I) - Ray can not be traced because current trace wavelength is equal to 0.0 microns.
RAY FAILURE CODE 13 AT SURFACE (I) - Ray can not be traced because ray missed the grazing incidence surface section between the beginning and ending Z-coordinates defined in special surface coefficients C_1 and C_2.
RAY FAILURE CODE 14 AT SURFACE (I) - Illumination ray can not be traced because ray was blocked by a clear aperture.
RAY FAILURE CODE 15 AT SURFACE (I) - Ray can not be traced because GRID (apodization, sag or phase) file data was missing for this surface.
RAY FAILURE CODE 16 AT SURFACE (I) - Specified object point does not exist because sag on object surface at specified x and y points does not exist.
RAY FAILURE CODE 17 AT SURFACE (I) - No DEFORM file exists for the surface or the file has insufficient data.
RAY FAILURE CODE 18 AT SURFACE (I) - Ray coordinate lies beyond deformable surface bounds.
RAY FAILURE CODE 19 AT SURFACE (I) - Aimed chief ray could not hit defined target point in the image surface.
RAY FAILURE CODE 20 AT SURFACE (I) - Ray failed because it could not reflect in a TIR condition. This is related to the "REFLTIRO" command.
RAY FAILURE CODE 21 AT SURFACE (I) - Ray failed because it could not be traced in the CONSTRUCTION configuration for a HOE-R, Type 13 special surface.
RAY FAILURE CODE 22 AT SURFACE (I) - Ray failed because it could not be traced in the REFERENCE configuration for a HOE-R, Type 13 special surface.
RAY FAILURE CODE 23 AT SURFACE (I) - Reference ray could not intersect the NSS surface group.
RAY FAILURE CODE 24 AT SURFACE (I) - Ray could not intersect the NSS surface group.

SPOT DIAGRAM RAY TRACING Spot diagram ray tracing provides a means to trace one of several different types of ray distributions through the current lens system.

STATS (FULL or MIN) - The "STATS" command causes a sticky switch to be set which determines the amount of statistical data calculated and displayed by some of the "SPD" commands. The program default is "FULL

SPOT (RECT, RING, RAND) - The "SPOT" command, issued with one of the three qualifier words ("RECT", "RING" or "RAND"), is used to set the type of grid or ray distribution to be used in spot diagram ray tracing. "RING" is the default type

RINGS , n - The "RINGS" command is used to specify the number of rings to be used whenever the "SPOT RING" command is in effect. The maximum number of rings is set at 50. The program default for "n" is 4. These four default rings will have fractional aperture heights (relative fractional radius) of 0.5, 0.707, 0.866 and 1.0. Each default ring will have eight equally spaced rays on that ring. Issued with no numeric input or with the special interrogator "?", "RINGS" displays the current number of rings that will be used.

RING , i , r , m , θ - The "RING" command is used to specify the relative fractional radius "r" of ring "i", the number of rays "m" to be used in ring "i" and the angular offset "θ" of the first ray in ring "i". The program default value for "r", if "RING" is explicitly issued, is the reciprocal of the total number of rings times the number of the current ring. The maximum value for "r" is always 1.0. The maximum value for "n" is 2500 per ring. The program default is 8 rays per ring. "θ" is the first ray angular offset value measured counter-clockwise from the local X-axis of the reference surface coordinate system toward the local Y-axis of the reference surface coordinate system.

The default value for " θ" is 0.0. With this default value in effect, the first ray in the ring will always lie on the local Y-axis of the reference surface coordinate system. Issued with no numeric input or with the special interrogator "?", "RING" displays the current data for each ring. Issued with numeric word #1 input only, "RING" displays the current data for ring "i".

RECT , n - The "RECT" command is used to specify the dimensions of the "n" X "n" rectangular grid of rays to be traced when "SPOT RECT" is in effect. The default value for "n" is 10 and the maximum is 300. Issued with no numeric input or with the special interrogator "?", "RECT" displays the current number value of "n".

RANNUM , n - The "RANNUM" command is used to specify the total number of rays to be traced per wavelength when "SPOT RAND" is in effect. The default value for "n" is 100.

SPDRESET - The "SPDRESET" command is used to reset all non-optimization related spot diagram parameters to their program default values.

APOD (GAUSS or NONE) , dbloss - The "APOD" command is used to set the state of aperture apodization in spot diadram, complex aperture function and point spread function calculations. The default is "NONE" meaning a uniform apodization. If "GAUSS" is selected, a gaussian apodization will be used such that at the edge of the reference surface aperture, the ray intensity will be reduced by "dbloss" decibles. This

apodization will be applied program wide including in tolerance and optimization options. The default for "dbloss" is 0.0 meaning uniform apodization.

SPD , (λ#) , fflag , i - The "SPD" command causes a spot diagram to be traced from the field position defined by the last "FOB" command. Rays are traced in either a ring, rectangular or random distribution over the reference surface, depending upon the settings established by the foregoing spot definition commands. The default distribution is a 10x10 rectangular ray grid. Full statistics are printed unless STATS was set to MIN using the "STATS MIN" command. Rays will be traced at every wavelength for which there is a non-zero spectral weight if no explicit wavelength number , (λ#), is entered. If a specific wavelength number is entered, only that wavelength will be used and the spectral weight will be assumed to be 1.0. Ray energies are established in relation to the spectral weights set at each wavelength. RMS spot size and centroid location is computed and displayed along with ray failure statistics. When "STATS FULL" is in effect, distance to best geometrical focus is also displayed. After the spot has been generated, a number of data values may be "gotten" using the "GET" command described later in the RAYTRACE section of this manual. Spot statistics are reported in lens units for modes "FOCAL" and "UFOCAL" and in angular radian measure for modes "AFOCAL" and "UAFOCAL". If "flagg" is not explicitly input or is zero, clear aperture and obscuration checking checks for aperture and obscuration ray blocking from surface 0 to the final surface. If "fflag" has been explicitly issued or is set to "1", then clear aperture and obscuration ray blockages are checked from the final surface to surface 0. This provies support for simulated reverse ray tracing. If the third numeric word "i", is set to a surface number other than the surface number of the final surface, then all calculations performed inside the "MTRACEI GRID" command will use the X,Y and Z coordinates of the rays at surface "i" rather than at the final or NEWIMG surface. All other spot diagram calculations will remain un-affected.

SPD ACC, (λ#) fflag , i - The "SPD ACC" command works exactly as the "SPD" does, except that no display of output is performed. The RSM spot values are calculated by these commands. ". If "flagg" is not explicitly input or is zero, clear aperture and obscuration checking checks for aperture and obscuration ray blocking from surface 0 to the final surface. If "fflag" has been explicitly issued or is set to "1", then clear aperture and obscuration ray blockages are checked from the final surface to surface 0. This provies support for simulated reverse ray tracing.

FAIL , i , j and

FAIL ACC , i , j - The "FAIL" and "FAIL ACC" commands either display or store in the X-register (accumulator) the number of "failed" or "blocked" rays in the current spot diagram. A spot diagram must already exist for these commands to be used. If no numeric input is entered for "i" or "j", the total number of failed rays at all surfaces is returned. If only "i" is supplied, the number of failed rays at surface "i" will be returned. If "i" and "j" are both entered, the number of rays which failed at surface "i" through surface "j" will be returned.

SPD MOVE , δ and

SPD MOVEACC , δ - The "SPD MOVE" and "SPD MOVEACC" commands either display or store in the X-register (accumulator) the RMS spot size after a shift in focus of "δ" lens units. A spot diagram must already exist for these commands to be used. These commands are only applicable in MODE FOCAL and MODE UFOCAL systems. The RSM spot values are calculated by these commands.

SPD ISTAT , i , angle1, angle2 , δangle - The "SPD ISTAT" command generates a new spot diagram with surface "i" as the new current image surface. It then displays a table listing the number of rays, at surface "i", which have angles of incidence which range from "angle1" degrees to just less than "angle1" + "δangle" degrees. "angle1" is then incremented by "δangle". This table continues until "angle1" + "δangle" = "angle2". When this end condition occurs, rays with angles of incidence equal to "angle2" are included in the final value. The rays tabulated are non-zero energy, non-failed rays. The total number of non-zero energy, non-failed rays is also listed.

SPD IPSTAT , i , angle1, angle2 , δangle - The "SPD IPSTAT" command is identical to "SPD ISTAT" except that instead of performing statistics upon the angle of incidence of each ray in the spot diagram, statistics are performed upon the angle of refraction, reflection or diffraction.

SPDSAVE (filename) , wt - The "SPDSAVE" command causes the current spot diagram to be stored in the file "filename".DAT. Before the data is saved, the energy term for each ray will be multiplied by the "wt" factor. The default value for "wt" is 1.0. Any existing spot diagram stored in "filename".DAT is erased. RMS spot values are **not** calculated by this command. If no file name is explicitly entered, the file named "SPOTS.DAT" will be used.

SPDADD (filename) , wt - The "SPDADD" command causes the current spot diagram to be stored in the file "filename".DAT and appended to any spot diagram data already stored in that file. Before the data is saved, the energy term for each added ray will be multiplied by the "wt" factor. The default value for "wt" is 1.0. The RMS spot values are **not** calculated by this command. If no file name is explicitly entered, the file named "SPOTS.DAT" will be used.

SPOT DIAGRAM DEPENDENT CALCULATIONS

SPDSTATS (filename) - The "SPDSTATS" command causes the spot diagram data stored in the "saved and summed" spot diagram file "filename".DAT to be statistically analyzed and the results of the analysis to be displayed. This command is useful for creating averaged spot diagrams. The RMS spot values are calculated by this command. If the file name "filename" is not explicitly entered, the file SPOTS.DAT will be used. All "SPD" commands which calculate RMS (Root Mean Square) geometrical spot diameter and the X and Y-RMS spot dimensions cause these values to be automatically placed in the X, Y and Z-general purpose storage registers. A spot diagram must exist before radial energy distributions, expanding slit energy distributions, LSFs and MTFs calculations can be performed. At least 100 non-failing rays per non-zero weighted wavelength should be traced before any of the following commands are issued. The commands described below generate radial and expanding slit edge energy distributions, line spread functions and geometrical optical transfer functions, and these calculations are always based upon the most recent spot diagram.

WRITING A SPOT DIAGRAM

BWRTSPOT (filename) - The "BWRTSPOT" command causes the last current spot diagram to be written to the main program directory as the file named "filename" with the file extension .SPD. The "filename" is input as a qualifier word and may be up to 8 characters long. The data is written as a direct access binary file. The first record is an integer which specifies the number of records in the file not counting record 1 and the last record. This file may later be opened, read and post-processed by a user written program outside of this program. Each record, except the first and the last, consists of the 50 double precision data items kept for each ray in the spot diagram. The last record contains the x, y, z, l, m, n and wavelength number of the chief ray at the object surface. The file may be opened using the following FORTRAN open statement: OPEN (UNIT = {unit number}, ACCESS = DIRECT, FILE = {file name}, FORM = 'UNFORMATTED', RECL = 240, STATUS = 'UNKNOWN'). If there are 100 rays in the spot diagram, there will be 101 records in the file.

AWRTSPOT (filename) - The "AWRTSPOT" command causes the last current spot diagram to be written to the main program directory as the file named "filename" with the file extension .ASC. The "filename" is input as a qualifier word and may be up to 8 characters long. The data is written in

ASCII format. The first line contains an integer which specifies the number of rays in the spot diagram. Every following group of 25 lines contain the 50 items stored in a spot diagram for each ray. This file may later be printed or opened, read and post-processed by a user written program outside of this program. If there are 100 rays in a spot diagram, there will be 1301 lines in the file plus the ending seven entries. The last seven entries are the x, y, z, l, m, n and wavelength number of the chief ray at the object surface. The first line holds items 1 and two, the second line items 3 and 4 etc. The twenty-six data items written for each ray in the spot diagram are:

Item Number	Data Description
1	Ray X-coordinate at image surface
2	Ray Y-coordinate at image surface
3	Ray Z-coordinate at image surface
4	(reserved for CAPFN calculations)
5	Ray X-coordinate at reference surface
6	Ray Y-coordinate at reference surface
7	Ray failure code 1
8	Ray failure code 2
9	Ray XZ-slope angle in radians at image surface
10	Ray YZ-slope angle in radians at image surface
11	Ray aperture apodization term
12	Ray Energy term
13	OPL from object to image surface
14	Ray X-coordinate at current Object+1 surface
15	Ray Y-coordinate at current Object+1 surface
16	Ray Wavelength Number (1 to 10)
17	Ray Spectral Weighting Factor
18	Ray Z-coordinate at Object+1 surface
19	L-dir cosine of ray at Object+1 surface in coordinate system of surface Object
20	M-dir cosine of ray at Object+1 surface in coordinate system of surface Object
21	N-dir cosine of ray at Object+1 surface in coordinate system of surface Object
22	L-dir cosine of ray at Image surface in coordinate system of surface Image-1
23	M-dir cosine of ray at Image surface in coordinate system of surface Image-1
24	N-dir cosine of ray at Image surface in coordinate system of surface Image-1
25	Ray angle of incidence at the image surface
26	Ray angle of exitance at image surface
27	X - ray coordinate at Image-1
28	Y - ray coordinate at Image-1
29	Z - ray coordinate at Image-1
30	L - dir cosine before surface interaction at Image-1
31	M - dir cosine before surface interaction at Image-1
32	N - dir cosine before surface interaction at Image-1
33	User for Polychromatic RMSOPD only
34	Ray Energy ingnoring adjustment due to pupil distortion
35	Spectral weight for rays wavelength
36	0 is aimed ray is inside reference surface clap, 1 if outside it.
37-50	(reserved for future use)

WRITING A SUMMED SPOT DIAGRAM

BWRTSUM (tofilename) (fromfilename) - The "BWRTSUM" command causes the summed spot diagram in the file named "fromfilename" in the LIBSPO directory to be written to the main program directory as the file named "tofilename" with the file extension .SPD. The "tofilename" is input as a qualifier word and the "fromfilename" is input as a string. Each may be up to 8 characters long. The data is written as a direct access binary file. The first record is an integer which specifies the number of records in the file not counting record 1. This file may later be opened, read and post-processed by a user written program outside of this program. Each record after record #1 consists of the 50 double precision data items kept for each ray in the spot diagram. The file may be opened using the following FORTRAN open statement: OPEN (UNIT = {unit number}, ACCESS = DIRECT, FILE = {file name}, FORM = 'UNFORMATTED', RECL = 280, STATUS = 'UNKNOWN'). If there are 100 rays in the spot diagram, there will be 101 records in the file. The "tofilename" must be explicitly entered. If the "fromfilename" is not explicitly entered, the file SPOTS.DAT will be used.

AWRTSUM (filename) (fromfilename) - The "AWRTSUM" command causes the summed spot diagram in the file named "fromfilename" in the LIBSPO directory to be written to the main program directory as the file named "tofilename" with the file extension .ASC. The "tofilename" is input as a qualifier word and the "fromfilename" is input as a string. Each may be up to 8 characters long. The data is written in ASCII format. The first line contains an integer which specifies the number of rays in the spot diagram. Every following group of 25 lines contain the 50 data items stored in a spot diagram for each ray. This file may later be printed or opened, read and post-processed by a user written program outside of this program. If there are 100 rays in a spot diagram, there will be 1301 lines in the file. The "tofilename" must be explicitly entered. If the "fromfilename" is not explicitly entered, the file SPOTS.DAT will be used. The twenty-six data items written for each ray in the spot diagram were listed in the preceding table.

SPOT DIAGRAM PLOTS - The following commands are used to plot the current spot diagram.

SPDSSI , ssi - The CMD level command "SPDSSI" is used to set the number lens system units (in the FOCAL and UFOCAL mode) or number of RADIANS (in the AFOCAL or UAFOCAL mode) for the little scale bar at the bottom of the spot diagram plot. The bar is 1.0 inch (25.4 mm) long

in the printed version of spot diagram plots. The "ssi" value remains set until a new spot diagram is generated. If no "SPDSSI" command is issued, the "ssi" value will be automatically set so that the maximum extent of the spot diagram spans 3.6 inches (91.44 mm) on the display. The entire "square" in which the spot diagram plots measures 4.0 inches (101.6 mm). If "SPDSSI" is issued with the interrogator "?", the current "ssi" value will be displayed.

DET (ON or OFF) - The CMD level command "DET" issued with the qualifier words "ON" or "OFF" is used to specify whether or not a detector is to be included in the spot diagram plot. The default is "OFF".

DET CIRC , diam , Δx , Δy

The CMD level command "DET" issued with the qualifier word "CIRC" is used to specify that the detector is to be circular with diameter "diam". It is to be offset from its nominal center position by "Δx" and "Δy" in the X and Y-directions, respectively. The defaults for "Δx" and "Δy" are 0.0. "diam" must be explicitly input.

DET RECT ,x , y , Δx , Δy , θ - The CMD level command "DET" issued with the qualifier word "RECT" is used to specify that the detector is to be rectangular with X and Y-dimensions "x" and "y". It is to be offset from its nominal center position by "Δx" and "Δy" in the X and Y-directions, respectively. If is to be rotated "θ" degrees counterclockwise as seen looking from the current object surface toward the detector. The defaults for "Δx", "Δy" and "θ" are 0.0. "x" and "y" must be explicitly. If "DET" is issued followed by the interrogator "?", the full current status of "DET" will be displayed. If the detector shape is not explicitly input, the detector will not be drawn, even if "DET ON" has been issued.

PLTSPD (CHIEF or CENT or SUM or ZERO) , dflag - The CMD level command "PLTSPD" causes a plot of the current spot diagram to be generated. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. Solid horizontal and vertical lines intersect at the spot center. The qualifier "CHIEF" causes the chief ray location to be the center of the plot. The qualifier "CENT" causes the spot centroid to be the center of the plot. If the qualifier "CHIEF" is entered, a pair of intersecting dashed lines will mark the spot centroid location. If the qualifier "CENT" is entered, a pair of intersecting dashed lines will mark the chief ray location. The qualifier "ZERO" causes the center of the spot plot to be located at x=0, y=0 on the image surface. Normally the current spot diagram in file SPD.DAT is plotted. The qualifier "SUM" causes the "saved and summed" spot diagram in file SPOTS.DAT to be plotted. This plot is centered the X=0.0, Y=0.0 position in the spot.. Spot diagrams are "saved and summed" with the "SPD SAVE" and SPD SAVEADD" commands described in the CMD section of this manual. If the "saved and summed" spot diagram is stored in a file whose name is not SPOTS.DAT, the file will first need to be renamed or copied to the file SPOTS.DAT.

A framed window 4.0 inches on a side defines the extent of plotted spot diagram data. Any rays which would be plotted outside this window are not plotted. If the detector would be drawn outside this window, it, too, will be omitted. The spot diagram plot is annotated with the lens identifier, field-of-view position and spot diagram specification data. Spot diagrams are always displayed with the positve y-axis of the final surface local coordinate system pointing up, the positive x-axis of the final surface local coordinate system pointing to the right and the positive z-axis of the final surface local coordinate system pointing toward the observer.

GEOMETRICAL ENERGY DISTRIBUTIONS - In the case of "perfect" geometrical systems, 100.0 percent of the energy will always lie within a spot of radius = 1.0X10-20 units or a slit of semi-width = 1.0X10-20 units (units will either be linear system units or angular radian units).

RED (N) , ΔE , ΔX , ΔY , ΔZ and

RED (N)CENT , ΔE , ΔZ - The "RED" and "RED CENT" commands produce radial energy distributions using the current spot diagram data. "CENT" specifies that the distribution center or reference point will be the spot centroid location. In the absence of "CENT", the chief ray location at the current image surface is used as the distribution center. "ΔE" specifies the percent energy increments to be displayed. The default for "ΔE" is 10.0 (percent). Maximum and minimum allowed values for "ΔE" are 100.0 (percent) and 1.0 (percent), respectively. "ΔX" and "ΔY" are interpreted as linear offsets (in lens units) in modes "FOCAL" and "AFOCAL" and angular offsets (in radians) in modes "AFOCAL" and "UAFOCAL". "ΔZ" is a defocus term which is only applicable in the "FOCAL" and "UFOCAL" modes. If the qualifier words "N" or "NCENT" are used, no output is generated.

RED ACC , E , ΔX , ΔY , ΔZ and

RED CACC , E , ΔZ - The "RED ACC" and "RED CACC" commands produce no display. "RED ACC" returns to the X-register (accumulator), the radius of the circle which encloses "E" percent energy. All the above comments concerning "ΔX" , "ΔY", and "ΔZ" apply in the same way as for the "RED" and "RED CENT" commands. "RED ACC" centers the distribution at the chief ray; "RED CACC" centers it at the spot centroid location.

ESEDX (N) , ΔE , ΔX , ΔY , ΔZ and

ESEDX (N)CENT , ΔE , ΔZ and

ESEDX ACC , E , ΔX , ΔY , ΔZ and

ESEDX CACC , E , ΔZ and

ESEDY , ΔE , ΔX , ΔY , ΔZ and

ESEDY CENT , ΔE , ΔZ and

ESEDY ACC , E , ΔX , ΔY , ΔZ

ESEDY CACC , E , ΔZ - The preceding eight commands act in exactly the same manner as the four "RED" commands, except that they produce one dimensional, expanding slit edge energy distributions in either the X or the Y-directions at the current image surface. Instead of spot semi-diameters, slit semi-width dimensions are displayed or returned to the X-register (accumulator) when using the "ESED", "ESEDX" and "ESEDY" commands. If the qualifier words "N" or "NCENT" are used, no output is generated.

ESED (N) , ΔE , ΔX , ΔY , ΔZ , θ and

ESED (N)CENT , ΔE , ΔZ , θ and

ESED ACC , E , ΔX , ΔY , ΔZ, θ and

ESED CACC , E , ΔZ , θ - The preceding four commands act in exactly the same manner as the eight "ESEDX" and "ESEDY" commands, except that instead of limiting themselves to the X and Y directions, they can produce expanding slit edge energy distributions at any orientation specified by "θ" (in degrees). "θ" = 0 degrees corresponds to "ESEDX" and "θ" = 90.0 degrees corresponds to "ESEDY". Instead of spot semi-diameters, slit semi-width dimensions are displayed or returned to the X-register (accumulator) when using the "ESED", "ESEDX" and "ESEDY" commands. All offset dimensions for radial and expanding slit energy distributions are represented in the coordinate system of the image surface. If the qualifier

words "N" or "NCENT" are used, no output is generated. After tabular data is generated with the "RED" or the "ESED" commands, it may be graphically displayed using the "PLTRED" and "PLTESED" commands.

SUMMED ENERGY DISTRIBUTIONS-I - In the case of "perfect" geometrical systems, 100.0 percent of the energy from each spot diagram in the summation will always lie within a spot of radius = 1.0X10-20 units or a slit of semi-width = 1.0X10-20 units (units will either be linear system units or angular radian units).

SRED (N) , ΔE , ΔX , ΔY , ΔZ and

SRED (N)CENT , ΔE , ΔZ - The "SRED" and "SRED CENT" commands produce radial energy distributions using the current summed spot diagram data stored in the default summed spot diagram file, SPOTS.DAT. "CENT" specifies that the distribution center or reference point will be the spot centroid location. In the absence of "CENT", the vertex of the current image surface is used as the distribution center. "ΔE" specifies the percent energy increments to be displayed. The default for "ΔE" is 10.0 (percent). Maximum and minimum allowed values for "ΔE" are 100.0 (percent) and 1.0 (percent), respectively. "ΔX" and "ΔY" are interpreted as linear offsets (in lens units) in modes "FOCAL" and "AFOCAL" and angular offsets (in radians) in modes "AFOCAL" and "UAFOCAL". "ΔZ" is a defocus term which is only applicable in the "FOCAL" and "UFOCAL" modes. If the qualifier words "N" or "NCENT" are used, no output is generated.

SRED ACC , E , ΔX , ΔY , ΔZ and

SRED CACC , E , ΔZ - he "SRED ACC" and "SRED CACC" commands produce no display. "SRED ACC" returns to the X-register (accumulator), the radius of the circle which encloses "E" percent energy. All the above comments concerning "ΔX" , "ΔY", and "ΔZ" apply in the same way as for the "SRED" and "SRED CENT" commands. "SRED ACC" centers the distribution at the image surface vertex; "SRED CACC" centers it at the spot centroid location.

SESEDX (N) , ΔE , ΔX , ΔY , ΔZ and

SESEDX (N)CENT , ΔE , ΔZ and

SESEDX ACC , E , ΔX , ΔY , ΔZ and

SESEDX CACC , E , ΔZ and

SESEDY (N) , ΔE , ΔX , ΔY , ΔZ and

SESEDY (N)CENT , ΔE , ΔZ and

SESEDY ACC , E , ΔX , ΔY , ΔZ and

SESEDY CACC , E , ΔZ - The preceding eight commands act in exactly the same manner as the four "SRED" commands, except that they produce one dimensional, expanding slit edge energy distributions in either the X or the Y-directions at the current image surface. Instead of spot semi-diameters, slit semi-width dimensions are displayed or returned to the X-register (accumulator) when using the "SESED", "SESEDX" and "SESEDY" commands. If the qualifier words "N" or "NCENT" are used, no output is generated.

SESED (N), ΔE , ΔX , ΔY , ΔZ , θ and

SESED (N)CENT , ΔE , ΔZ , θ and

SESED ACC , E , ΔX , ΔY , ΔZ, θ and

SESED CACC , E , ΔZ , θ - The preceding four commands act in exactly the same manner as the eight "SESEDX" and "SESEDY" commands, except that instead of limiting themselves to the X and Y directions, they can produce expanding slit edge energy distributions at any orientation specified by "θ" (in degrees). "θ" = 0 degrees corresponds to "ESEDX" and "θ" = 90.0 degrees corresponds to "SESEDY". Instead of spot semi-diameters, slit semi-width dimensions are displayed or returned to the X-register (accumulator) when using the "SESED", "SESEDX" and "SESEDY" commands. All offset dimensions for radial and expanding slit energy distributions are represented in the coordinate system of the image surface. If the qualifier words "N" or "NCENT" are used, no output is generated. After tabular data is generated with the "SRED" or the "SESED" commands, it may be graphically displayed using the "PLTRED" and "PLTESED" commands.

RED AND ESED PLOTS

PLTRED , dflag , (x-extent) - The "PLTRED" command causes a plot of the current Radial Energy Distribution data to be generated. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. "PLTRED" applies to the most recently generated RED data. If no RED data exists, a message to that effect is issued and no plot is generated. (x-extent) optionally allows the user to specify the number of lens units at the final surface which are represented by the horizontal axis of the energy distribution plot. RED data may be generated using one of the radial energy distribution commands described in the CMD section (geometrical based calculations) or the FOE section (diffraction based calculations) of this manual.

PLTESED , dflag , (x-extent) - The "PLTESED" command causes a plot of the current Expanding Slit Energy Distribution data to be generated. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. "PLTESED" applies to the most recently generated ESED data. If no ESED data exists, a message to that effect is issued and no plot is generated. (x-extent) optionally allows the user to specify the number of lens units at the final surface which are represented by the horizontal axis of the energy distribution plot. ESED data may be generated using one of the expanding slit energy distribution commands.

SUMMED ENERGY DISTRIBUTIONS-II - This command is only of use from inside macros. Unlike the "SRED", "SESED", "SESEDX" and "SESEDY" commands, it can analyze "summed and saved" spot diagrams which are stored in files which have been given user specified names. The "REDSUM" command uses "summed and saved" spot diagram data which was created by the "SPDSAVE" and "SPDADD" commands. The file read is "filename.DAT. If the file name is not explicitly entered, the file "SPOTS.DAT" will be used.

REDSUM (filename) , E - The "REDSUM" command produces no display but returns to the X-register (accumulator), the radius of the circle which encloses "E" percent energy in the current "summed and saved" spot diagram. No "ΔX" , "ΔY", or "ΔZ" apply in this command. "REDSUM" centers the distribution at the spot centroid.

ENSQUARED ENERGY DISTRIBUTIONS

REDSQ (N), ΔE , ΔX , ΔY , ΔZ and

REDSQ (N)CENT , ΔE , ΔZ - The "REDSQ" and "REDSQ CENT" commands produce ensquared rather than encircled energy distributions using the current spot diagram data. "CENT" specifies that the distribution center or reference point will be the spot centroid location. In the absence of "CENT", the chief ray location at the current image surface is used as the distribution center. "ΔE" specifies the percent energy increments to be displayed. The default for "ΔE" is 10.0 (percent). Maximum and minimum allowed values for "ΔE" are 100.0 (percent) and 1.0 (percent), respectively. "ΔX" and "ΔY" are interpreted as linear offsets (in lens units) in modes "FOCAL" and "AFOCAL" and angular offsets (in radians) in modes "AFOCAL" and "UAFOCAL". "ΔZ" is a defocus term which is only applicable in the "FOCAL" and "UFOCAL" modes. If the qualifier words "N" or "NCENT" are used, no output is generated.

REDSQ ACC , E , ΔX , ΔY , ΔZ and

REDSQ CACC , E , ΔZ - The "REDSQ ACC" and "REDSQ CACC" commands produce no display. "REDSQ ACC" returns to the X-register (accumulator), the length of the side of a square which encloses "E" percent energy. All the above comments concerning "ΔX" , "ΔY", and "ΔZ" apply in the same way as for the "REDSQ" and "REDSQ CENT" commands. "REDSQ ACC" centers the distribution at the chief ray; "SQRED CACC" centers it at the spot centroid location. After tabular data is generated with the "REDSQ" command, it may be graphically displayed using the "PLTRED" command described above.

SUMMED ENERGY DISTRIBUTIONS-III

SREDSQ (N), ΔE , ΔX , ΔY , ΔZ and

SREDSQ (N)CENT , ΔE , ΔZ - The "SREDSQ" and "SREDSQ CENT" commands produce ensquared distributions using the current summed spot diagram data stored in the default summed spot diagram file, SPOTS.DAT. "CENT" specifies that the distribution center or reference point will be the spot centroid location. In the absence of "CENT", the vertex of the current image surface is used as the distribution center. "ΔE" specifies the percent energy increments to be displayed. The default for "ΔE" is 10.0 (percent). Maximum and minimum allowed values for "ΔE" are 100.0 (percent) and 1.0 (percent), respectively. "ΔX" and "ΔY" are interpreted as linear offsets (in lens units) in modes "FOCAL" and "AFOCAL" and angular offsets (in radians) in modes "AFOCAL" and "UAFOCAL". "ΔZ" is a defocus term which is only applicable in the "FOCAL" and "UFOCAL" modes. If the qualifier words "N" or "NCENT" are used, no output is generated.

SREDSQ ACC , E , ΔX , ΔY , ΔZ and

SREDSQ CACC , E , ΔZ - The "SREDSQ ACC" and "SREDSQ CACC" commands produce no display. "SREDSQ ACC" returns to the X-register (accumulator), the length of the side of the square which encloses "E" percent energy. All the above comments concerning "ΔX" , "ΔY", and "ΔZ" apply in the same way as for the "SREDSQ" and "SREDSQ CENT" commands. "SREDSQ ACC" centers the distribution at the image surface vertex; "SREDSQ CACC" centers it at the spot centroid location. After tabular data is generated with the "SREDSQ" command, it may be graphically displayed using the "PLTRED" command described above.

SUMMED ENERGY DISTRIBUTIONS-IV - This command is only of use from inside macros. Unlike the "SREDSQ" command, it can analyze "summed and saved" spot diagrams which are stored in files which have been given user specified names. The "REDSUMSQ" command uses "summed and saved" spot diagram data which was created by the "SPDSAVE" and "SPDADD" commands. The file read is "filename.DAT. If the file name is not explicitly entered, the file "SPOTS.DAT" will be used.

REDSUMSQ (filename) , E - The "REDSUMSQ" command produces no display but returns to the X-register (accumulator), the ensquaring side length which encloses "E" percent energy in the current "summed and saved" spot diagram. No "ΔX" , "ΔY", or "ΔZ" apply in this command. "REDSUMSQ" centers the distribution at the spot centroid.

I

NVERSE ENERGY DISTRIBUTIONS - In all of the above energy distribution commands, the qualifier words "ACC" and "CACC" were used to return to the X-register, the size of the circle or square which encircled or ensquared the percent energy specified in numeric word #1. If, instead, the qualifier words "ACCX" and "CACCX" are used, then, commands return to the X-register either the percent energy encircled by the circle whose radius is specified in numeric word #1 or the percent energy ensquared by the square whose side length was specified in numeric word #1.

GEOMETRICAL LINE SPREAD FUNCTIONS

LSF , N , ΔX , ΔY , ΔZ , θ and

LSF CENT , N , ΔZ , θ and

LSF ACC , pos , ΔX , ΔY , ΔZ, θ and

LSF CACC , pos , ΔZ , θ - These four "LSF" commands act in a similar manner to the four preceding "ESED" commands, except that they produce geometrical line spread functions based upon the current geometrical spot diagram. They calculate image intensity versus position across a line spread function. Peak intensity is always normalized to 1.0. The line spread function orientation is specified by "θ" (in degrees). "ΔX" , "ΔY" and "ΔZ" have the same meaning as in the above "RED" and "ESED" commands. "N" specifies the number of positions across the line spread function for which intensity values will be displayed. The default value for "N" is 21. "pos" specifies the position in the line spread function for which an intensity value will be calculated. The maximum allowable value for "N" is 100. The preceding figure illustrates line spread function orientation as a function of θ. Positions in the line spread function are specified in current lens system units in the "FOCAL" and "UFOCAL" modes and in radians in modes "AFOCAL" and "UAFOCAL". "ΔX" and "ΔY" are interpreted as linear offsets (in lens units) in modes "FOCAL" and "AFOCAL" and angular offsets (in radians) in modes "AFOCAL" and "UAFOCAL". "ΔZ" is a defocus term which is only applicable in the "FOCAL" and "UFOCAL" modes. For geometrically "perfect" systems, the spread function is always a delta function with height always equal to 1.0.

OLSF , N and

OLSF CENT , N and

OLSF ACC , pos and

OLSF CACC , pos - These four "OLSF" commands (meaning Old LSF) produce displays based upon a pre-existing geometrical line spread function calculated from spot diagram data via the preceding four "LSF" commands. They interpolate and display image intensity versus position across the existing line spread function. "N" specifies the number of positions across the line spread function for which intensity values will be displayed. The default value for "N" is 21. "pos" specifies the position in the line spread function for which an intensity value will be displayed. If no line spread function exists, a message to that effect is issued and no values are displayed. The default value for "N" is always 21. The maximum allowable value for "N" is 100. All offset dimensions for geometrical line spread functions are represented in the coordinate system of the image surface. The "RSPH" command, described later in this section, is used to specify the center of the geometrical line spread function. By default, the

center of a geometrical line spread function is at the intersection of the chief ray with the image surface. After Line Spread Functions are generated, they may be graphically displayed using the "PLTLSF" command.

LSF PLOTS

PLTLSF , (x-range) , dflag - The "PLTLSF" command causes a plot of the current geometrical Line Spread Function (LSF) data to be generated. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. "PLTLSF" applies to the most recently generated LSF data, whether that data is generated using the "LSF" command or the "OLSF" command. The optional input value "x-range" sets the semi-extent of the X-axis scale. By default, the X or function extent scale will be sized so as to include the entire spread function. If no LSF data exists, a message to that effect is issued and no plot is generated. LSF data may be generated using the "LSF" command or the "OLSF" command which are described in the CMD section of this manual.

GEOMETRICAL OPTICAL TRANSFER FUNCTION - The commands described below generate various tabular outputs of the Geometrical Optical Transfer Function (GOTF). This transfer function is based only upon the residual geometrical aberrations of the current lens system and does not consider any of the effects of diffraction. It is best used for optical systems whose peak-to-valley optical path differences exceed one or two wavelengths at the reference wavelength. All "GOTF" commands use the existing spot diagram. If no spot diagram exists, one must first be calculated using the "SPD" command.

GOTF , Fmax , ΔF , θ , ΔZ - This version of the "GOTF" command generates an output of the GOTF from spatial frequency 0.0 to spatial frequency "Fmax" in frequency steps of "ΔF". The default for "Fmax" is the diffraction limit "cutoff" frequency,discussed in the FOE section of this manual. The smallest allowable value of "ΔF" is a value which produces 101 data points. "θ" = 0.0 degrees represents a vertical bar target (sinusoidal intensity variation in the X-direction). "θ" = 90.0 degrees represents a horizontal bar target (sinusoidal intensity variation in the Y-direction). "θ" is measured in a positive sense from the positive X-axis toward the positive Y-axis in the local coordinate system of the image surface. "ΔZ" represents a focus shift (in lens units) to be applied before the calculation is performed and is applicable only for modes "FOCAL" and "UFOCAL". "θ" = 0.0 degrees represents vertical bar targets (sinusoidal intensity variation in the X-direction). "θ" = 90.0 degrees represents horizontal bar targets (sinusoidal intensity variation in the Y-direction). In the absence of an explicit entry for "θ", GOTF values will be calculated for both "θ" = 0.0 and "θ" = 90.0 degrees. The default value for "ΔF" is "F_{max} "/ 10.0. The default value for "ΔZ" is 0.0. After GOTF data has been generated with this command, the data may be plotted using the "PLTGOTF" command.

GOTF IN OBJECT SPACE - All GOTF calculations are performed in the frequency domain of "image space". In the AFOCAL or UAFOCAL mode, the frequency units are "lp/mrad". In FOCAL or UFOCAL modes the frequency units are "lp/mm". Many times it proves convernient to express the MTF in the frequency domain of "object space" The following two commands provide the user with a way of telling the program that the tabular MTF listings and the graphical MTF plots of MTF versus frequency are to be displayed in the frequency domain of "object space".

SPACE (O or I) - The "SPACE" command instructs the program as to the spatial domain in which the tabular and graphical GOTF is to be represented. The default is "I" for image space. This command does not change the way the GOTF values are computed but it does change the spatial frequency units used in the tabular and graphical displays. ". Issuing this command with the "?" returns the current setting

NEAR or FAR - The "NEAR" and "FAR" commands are used to specify the units for optical transfer function display when space is set to "O". "NEAR" sets units to "lp/mm" whereas "FAR" specifies "lp/mrad". Issuing this command with the "?" returns the current setting. The program default setting is "FAR"

THRU-FOCUS/FREQ GOTF

GOTF TFOCUS , F , Zmin , Zmax , ΔZ , θ - The "GOTF TFOCUS" command generates an output of the through-focus GOTF at spatial frequency "F" in steps of "ΔZ" about the current image position. "θ" = 0.0 degrees represents a vertical bar target (sinusoidal intensity variation in the X-direction). "θ" = 90.0 degrees represents a horizontal bar target (sinusoidal intensity variation in the Y-direction). "θ" is measured in a positive sense from the positive X-axis toward the positive Y-axis in the local coordinate system of the image surface. "ΔZ" is the focus shift step size (in lens units). "GOTF TFOCUS" is applicable only for modes "FOCAL" and "UFOCAL". The default value for "θ" is 0.0 degrees representing vertical bar targets (sinusoidal intensity variation in the X-direction). The default value for "ΔZ" is ("Zmax" - "Zmin") / 10.0.

GOTF TFREQ , ΔZ , Fmin , Fmax , ΔF , θ - The "GOTF TFREQ" command generates an output of the through-frequency GOTF from frequency "Fmin" to frequency "Fmax" in frequency steps "ΔF" and at focus offset "ΔZ" about the current image position. "θ" = 0.0 degrees represents a vertical bar target (sinusoidal intensity variation in the X-direction). "θ" = 90.0 degrees represents a horizontal bar target (sinusoidal intensity variation in the Y-direction). "θ" is measured in a positive sense from the positive X-axis toward the positive Y-axis in the local coordinate system of the image surface. "ΔZ" is only used for modes "FOCAL" and "UFOCAL". The default value for "θ" is 0.0 degrees representing vertical bar targets (sinusoidal intensity variation in the X-direction). The default value for "ΔF" is ("Fmax" - "Fmin") / 10.0. The default value for "ΔZ" is 0.0.

GOTF ACC , F , θ , ΔZ - The "GOTF ACC" command causes the GOTF modulus, calculated at frequency "F", orientation θ and focus offset "ΔZ", to be placed into the accumulator or X-register. The GOTF phase is calculated and placed into the Y-register. The original content of the X-register is placed in the LASTX-register. The command produces no output. "ΔZ" is only used for modes "FOCAL" and "UFOCAL". Among other uses, this command makes the modulus and phase of the GOTF available as an optimization operand. The default value for "θ" is 0.0 degrees representing vertical bar targets (sinusoidal intensity variation in the X-direction).

The default value for "ΔZ" is 0.0. Spatial frequency is always in units of line pairs per millimeter (lp/mm) for modes "FOCAL" and "UFOCAL" and in units of line pairs per milli-radian (lp/mr) for modes "AFOCAL" and "UAFOCAL". All offsets and image orientations for geometrical optical transfer functions are represented in the coordinate system of the image surface.

MULTIPLE FOV GOTF - If multiple field of view definitions are included in the lens database (using the "FLDS" command) and if the command which immediately precedes the "GOTF" command is not an "FOB" command and if "GOTF" is issued without qualifier or numeric input, then GOTF values will be computed for each of the defined multiple field of view positions. These values will be stored so that they may be plotted with the next "PLTGOTF" commands.

GOTF PLOTS

PLTGOTF (LEICA) , dflag

CASE: No qualifier word

In this case the "PLTGOTF" command causes a plot of the modulus of the existing Geometrical Optical Transfer Fuction data versus spatial frequency to be generated from 0 If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. "PLTGOTF" applies to the most recently generated GOTF. If no GOTF data exists, a message to that effect is issued and no plot is generated. There is no "max freq" input for PLTGOTF as the maximum frequency in under the control of the "GOTF" command itself. If GOTF data exists for both vertical and horizontal target orientations, they both will be included on one plot. If multiple field of view "GOTF" data exists, it will be plotted on a multiple field of view type of GOTF display. Each curve will be labeled as to field of view position and target orientation.

CASE: Qualifier word = "LEICA" (There must exist GOTF data for at least 5 multiple field of view positions)

In this case the "PLTGOTF" command causes a plot of the modulus of the existing Geometrical Optical Transfer Fuction data versus field of view to be generated. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. "PLTGOTF" applies to the most recently generated GOTF. If no GOTF data exists, a message to that effect is issued and no plot is generated. This command plots both target bar orientations of the first 10, non-zero frequency MTFs generated using the previous "GOTF" command. GOTF data is generated using the "GOTF" command described in the CMD section of this manual.

GEOLEICA (ON or YES or OFF or NO) , freq# - The GEOLEICA command is used to shut off any of the GOTF vs FOV plots in a "PLTGOTF LEICA" type of plot. The "freq#" can be 1 through 10. Once frequency numbers are turned "off" they stay "off" until they are "tuned on" of until the program ends. Entered with a "?", the status for all 10 frequencies will be displayed.

SURFACE SAG COMMANDS - The commands described below generate a printout of surface sag and surface normal direction cosine data. Sag data consists of Z-coordinates of points on a surface for specified X and Y-coordinates as well as the surface normal L, M and N direction cosines. N is positive if it points in the local coordinate system +Z direction.

SAG X , i , Xmin , Xmax , Δx , δy - The "SAG X" command generates surface sag and surface normal data for a line extending in the X direction of surface number "i". Sags are computed in intervals of Δx. The Y-coordinate is defined by "Y" = $\delta_{y.}$ "X" ranges from Xmin to Xmax

SAG Y , i , Ymin , Ymax , Δy, δx - The "SAG Y" command generates surface sag and surface normal data for a line extending in the Y direction of surface number "i". Sags are computed in intervals of Δy. The X-coordinate is defined by "X" = $\delta_{x.}$ "Y" ranges from Ymin to Ymax.

SAG (PT or PTACC) , i , X , Y - The "SAG PT" command generates sag and surface normal data for the point "X" and "Y" on surface "i". The resultant sag value is stored in the accumulator ("X"-register). The X and Y input values are placed in the "IX" and "IY" registers. The L, M and N direction cosines of the surface normal are placed in the "Y", "Z" and "T" registers. If "PT" is issued, the values will be displayed. If "PTACC" is issued, no values are displayed.

SAG FILE , i , N , code - The "SAG FILE" command generates sag data over an "N" by "N" square grid on surface "i" and then saves that data to the ASCII file SAG.DAT. The data saved consists of the "x" and "y" coordinates of each grid point and the associated surface sag value at that grid point. The grid is processed from left to right and bottom to top starting at the most negative "x" and "y" point on the grid. The default value for "N" is 25. The grid is spread over the greatest extent of the clear aperture on surface "i". If no explicit clear aperture is assigned, then the grid is spread over a temporarily assigned clear aperture equal to the sum of the absolute values of PY and PCY or PX and PCX paraxial ray values at that surface (which ever is the larger sum). "SAG FILE" does not output the surface L, M and N surface normal direction cosines. The "code" value is interpreted via the following table. The SAG.DAT file may be plotted using the "PLOT SAGFILE" command. If "prflag" is omitted, statistics are displayed, else they are suppressed.

code	action
0 (default)	SAG due to all surface parameters.
1	SAG leaving out special surface definitions.
2	SAG leaving out all radius, toric radius, conics and aspheric definitions but using any existing special surface definitions.

In all "SAG" commands, X and Y coordinates are expressed in lens units. The "SAG" commands properly recognize all contributions to surface shape, including all special surface types.

SAGFILE PLOTTING

PLOT SAGFILE , drflag - The "PLOT SAGFILE" command causes a 3-D plot of the current SAG.DAT file, if one exists, to be displayed.The SAG.DAT file is generated by the "SAG FILE" command as described in the CMD section of this manual The horizontal axes represent the surface clear aperture. If "drflag" is left blank, the plot will be displayed to the screen. Otherwise it will not be displayed.

SAGFLROT ("YES" or "ON" or "NO" or "OFF") - The "SAGFLROT" command is used to specify whether or not the current SAG.DAT file is to be plotted with a 90 degree rotation or not. This helps see "hidden" features. Issued with the interrogator "?", "SAGFLROT" causes the current SAG.DAT file rotation status to be displayed. If the status is "YES" or "ON", then each time a SAG.DAT file is generated, it will be plotted with a 90 degree rotation

BEST FIT SPHERE - Best fit sphere calculations are useful when it is desired to determine the closest sphere to some non-spherical surface such that the sphere can first generated. This sphere will such that a minimum amount of material will need to be removed from it to form the desired non-spherical shape. The "best fit sphere" calculation is not supported by dedicated commands but instead a procedure using existing program commands is used to compute this value. This procedure is outlined in the following example. In this example, a rotationally symmetric concave, aspheric mirror will be the surface for which the best fit sphere is determined. Since this non-spherical surface is rotationally symmetric, only rays in the YZ-plane are needed. If the aspheric was not rotationally symmetric, more rays in the YZ and XZ-planes would be needed. Since the aspheric is a concave mirror, the GTE command is used in setting up the optimization. The use of GTE or LTE will need to be determined by the user depending on whether the best fit sphere will need to have a radius of curvature greater than or less than the non-spherical surface.

EXAMPLE:

It is desired to determine the best fit sphere to a concave, aspheric mirror. The mirror will be 10 cm in diameter. It will have a base radius of curvature of 35 cm, a conic constant of -0.085 and a 6th order aspheric coefficient of $+0.123348 \times 10^{-9}$.

STEP 1 Set up a new lens file by issuing the following commands:

```
LENS
UNITS CM
SAY , 5
TH 1E20
AIR
AIR
AIR
RD , -35
CC , -0.85
AE , 0.123348E-9
AIR
AIR
AIR
EOS
MODE AFOCAL
```

STEP 2. Make sure that field #1 and rays #1 to #11 are defined to represent sampling the aperture at 0.1 fractional aperture heights from an on-axis object position by issuing the following commands:

```
F1 , 0 0 0
R1 , 0
R2 , .1
R3 , .2
R4 , .3
R5 , .4
R6 , .5
R7 , .6
R8 , .7
R9 , .8
R10 , .9
R11 , 1.0
```

STEP 3. Set up the optimization definitions using as operands, the optical path length along each ray from surface 2 to 3. Set the variable to be the curvature of surface #2.

```
MERIT
GTE
OPL 0 1 3 1 1
OPL 0 1 3 1 2
OPL 0 1 3 1 3
OPL 0 1 3 1 4
OPL 0 1 3 1 5
OPL 0 1 3 1 6
OPL 0 1 3 1 7
OPL 0 1 3 1 8
OPL 0 1 3 1 9
OPL 0 1 3 1 10
OPL 0 1 3 1 11
CV 0 .0000001 2
EOS
```

The CV operand on surface 2 with the very small weight keeps the sphere from taking on too much power. Make the weight small enough that none of the other operands go negative.

```
EOS
VARI
CV 2
EOS
```

STEP 4. Optimize surface 2 curvature using the following commands:

```
IT
PFIND 20
IT 5
ROBB

PFIND 20
IT 5
ROBB
```

STEP 5. Get the radius of curvature of surface 2 using the following command:

```
SHO RD 2
```

(the value will be [to three decimal places] -35.119)

Using the OPRD command, the OPLs differences between the best fit sphere and the non-spherical surface may be listed. The maximum of these values will be the maximum departure from the best fit sphere in lens units. If a more accurate computation is requires, the number of operands and rays may be increased and the optimization re-run.

LIMIT RAY CALCULATIONS

The "LIMRAYS" command generates a tabular printout of limit ray data for the current lens at the current control wavelength and current active configuration..

LIMRAYS (PARAX or REAL or VREAL) , (n) - For optical systems for which real rays cannot yet be traced, the qualifier word "PARAX" is provided. Using the "PARAX" qualifier word causes the limiting ray heights at each surface to be calculated as the sum of the absolute values of the marginal and chief paraxial ray heights at each surface. All clear apertures, surface tilts and surface decentrations are ignored. This version of the "LIMRAYS" command is useful during very early stages of design.. Issuing the "LIMRAYS" command with no qualifier word or with the qualifier word "REAL" causes limit ray heights to be calculated using a set of unvignetted real rays. This set of rays consists of eight marginal rays traced around the periphery of the current reference surface from each of nine field of view positions traced from around the periphery of the current object surface. If there are no clear apertures assigned to the object and reference surfaces, then circular or elliptical clear apertures are assumed and they are sized by the current values of the SCY, SCX, SAY and SAX values respectively. If the clear apertures assigned to these surfaces are rectangular or racetrack in shape, then four of the marginal rays are positioned at the top, bottom, left and right sides of the clear apertures while the other four rays are positioned at the extremes of the "corners" of these clear apertures. If any of these 72 rays cannot be traced due to ray failures, excluding clear aperture of obscuration blocking, then a warning message is issued as part of the output. All clear aperture decentrations and tilts are considered during these calculations. Issuing the "LIMRAYS" command with the "VREAL" qualifier word causes limit ray heights to be calculated using a set of eight vignetted real marginal rays traced from the same nine field of view positions as described in the preceding paragraph. The vignetting factors for these rays are calculated automatically at each of the nine field of view positions. The "finesse" of the vignetting calculations is set with the "n" value. By default, "n" = 25 meaning that 50 rays are traced across both the X and Y-directions at the reference surface in order to determine the vignetting factors. "n" may be set as low as 10 or as high as 100. All clear aperture decentrations and tilts are also considered during these calculations. Tabular output when using the "PARAX" qualifier word consists of a table listing surface #, and maximum X and Y -coordinates of the limiting rays. Tabular output when using the "REAL" or "VREAL" qualifier words or when no qualifier is used consists of two tables. The first table lists surface #, and the minimum and maximum X and Y -coordinates of the limiting rays in the local coordinate system of each surface. The second table lists surface #, maximum radial dimension and suggested center position of the limit ray pattern in the local coordinate system of each surface. Vignetting factors are **ONLY** computed in the local XZ and YZ-planes of the reference surface. The "LIMRAYS" command is useful in setting the minimum part sizes for most optical systems being designed. In systems where there are many complex folds, it would be wise to verify the limit ray calculations by plotting beam footprints. Multi-configuration systems should always have their part sizes determined using the beam footprint plotting option.

AUTOMATIC CLEAR APERTURES - The "SETCLAP" command works exactly the same as the "LIMRAYS" command except that instead of generating tabular output, it uses limit ray data to assign clear aperture data to surfaces. If a clear aperture is already assigned to a surface, the dimensions of the clear aperture and the clear aperture offsets are adjusted. If no clear aperture is assigned to a surface, a circular aperture will be assigned if the surface is not a "dummy" surface. This exclusion of "dummy" surfaces does not occur; however, if both starting and ending surfaces, "i" and "j", are explicitly input by the user. "SETCLAP" does not modify alternate configuration data. It only operates upon the current configuration. In order to set clear apertures for multi-configuration systems, run "SETCLAP" for each configuration, note the assigned clear aperture values and then issue the appropriate CONFIGS or UPDATE CONFIGS commands.

SETCLAP (PARAX or REAL or VREAL) , i , j , (n) - "i" and "j" specify the starting and ending surface numbers to which "SETCLAP" will apply. Defaults for "i" and "j" are surfaces 0 and the image surface. For optical systems for which real rays cannot yet be traced, the qualifier word "PARAX" is provided. Using the "PARAX" qualifier word causes the clear aperture values at each surface to be calculated as the sum of the absolute values of the marginal and chief paraxial ray heights at each surface. All clear apertures, surface tilts and surface decentrations are ignored when "PARAX" is used. This version of the "SETCLAP" command is useful during very early stages of design.. Issuing the "SETCLAP" command with no qualifier word or with the qualifier word "REAL" clear aperture values to be calculated using a set of unvignetted real rays. This set of rays consists of eight marginal rays traced around the periphery of the current reference surface from each of nine field of view positions traced from around the periphery of the current object surface. If there are no clear apertures assigned to the object and reference surfaces, then circular or elliptical clear apertures are assumed and they are sized by the current values of the SCY, SCX, SAY and SAX values respectively. If the clear apertures assigned to these surfaces are rectangular or racetrack in shape, then four of the marginal rays are positioned at the top, bottom, left and right sides of the clear apertures while the other four rays are positioned at the extremes of the "corners" of these clear apertures. If any of these 72 rays cannot be traced due to ray failures, excluding clear aperture of obscuration blocking, then a warning message is issued and no clear apertures are assigned. All existing clear aperture decentrations and tilts are considered during these calculations. Issuing the "SETCLAP" command with the "VREAL" qualifier word causes clear aperture values to be calculated using a set of eight vignetted real marginal rays traced from the same nine field of view positions as described in the preceding paragraph.. The vignetting factors for these rays are calculated automatically at each of the nine field of view positions. The "finesse" of the vignetting calculations is set with the "n" value. By default, "n" = 25 meaning that 50 rays are traced across both the X and Y-directions at the reference surface in order to determine the vignetting factors. "n" may be set as low as 10 or as high as 100. All existing clear aperture decentrations and tilts are also considered during these calculations. Vignetting factors are **ONLY** computed in the local XZ and YZ-planes of the reference surface. If the program determines that clear aperture decentrations should be assigned, they will be assigned if they are greater than or equal to 1.0×10^{-6} lens units. The "SETCLAP" command is useful in setting clear aperture values for most optical systems being designed. In systems where there are many complex folds, it would be wise to verify the clear aperture values by plotting beam footprints with commands. Multi-configuration systems should always have their clear aperture values determined using the beam footprint plotting option.

DISTORTION - Distortion is defined to be "FtanΘ distortion. For modes "FOCAL" and "UFOCAL", distortion is therefore defined by the following equation:

$$\%Dist = \frac{HT_{real\_chief\_ray} - HT_{gen\_parax\_chief\_ray}}{HT_{gen\_parax\_chief\_ray}} \times 100\%$$

The "HT"s are ray heights at the final surface. For modes "AFOCAL" and "UAFOCAL", distortion is defined by the following equation:

$$\%Dist = \frac{Tan\left(U_{real\_chief\_ray}\right) - Tan\left(u_{gen\_parax\_chief\_ray}\right)}{Tan\left(u_{gen\_parax\_chief\_ray}\right)} \times 100\%$$

"U" and "u" are ray slope angles in radian measure. All ray heights and ray slopes are evaluated in the space of the final surface of the current lens system. Distortion calculations are based upon real chief rays and upon the "GENERALIZED PARAXIAL RAY TRACE". Since the "GENERALIZED PARAXIAL RAY TRACE" is based upon real differential rays, distortion calculations are valid for optical systems containing tilted and decentered surfaces.

DIST θ, factor , n - The "DIST" command generates tabular percent distortion data for the current lens. Distortion values are generated at "n" field of view positions along a line defined in object space. The starting point of this line is defined by the ray "RAY 0 0" traced from the central field point defined by "FOB 0 0". The default values for "θ" and "factor" are 0.0 and 1.0, respectively. "n" may range from 1 to 50. Its default value is 10. The ending point of this line is defined by the ray "RAY 0 0" traced from the field point "FOB Y_f , X_f", where "Y_f" and "X_f" are given by the following equations:

$$Y_f = factor \times \cos(\theta)$$

$$X_f = factor \times \sin(\theta)$$

In the default case, with "θ" = 0.0 and "factor" = 1.0, Y_f = 1.0 and X_f = 0.0. All calculations are performed at the current control wavelength. If the distortion is not calculable, a message to that effect is displayed and no data is displayed.

After distortion calculations are performed, the data may be displayed in graphical form using the "PLTDIST" command.

NOTE: In systems with tilts and decenters in which the central, gut chief ray does not strike the final surface at zero height, a TILT AUTO may be required on the final surface in order to compute meaningful distortion values.

DISTORTION PLOTS

PLTDIST , (x-range) , dflag - The "PLTDIST" command causes a plot of the existing distortion data to be generated. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. This is another automated plot routine. "PLTDIST" applies to the most recently generated distortion data. The optional input value "x-range", entered in aberration units, sets the semi-extent of the X or aberration axis scale. By default, the X or aberration scale semi-extent will be sized so as to include all current aberration data. If no distortion data exists, a message to that effect is issued and no plot is generated. Distortion data is generated using the "DIST" command described in the CMD section of this manual.

FISHEYE-DISTORTION - Fisheye-distortion is defined to be "FΘ distortion. For modes "FOCAL" and "UFOCAL", distortion is therefore defined by the following equation:

$$\%Dist = \frac{\left(\left(HT_{real\_chief\_ray} \times \left(\frac{U_{real\_chief\_ray}}{Tan\left(U_{real\_chief\_ray}\right)}\right)\right) - \left(HT_{gen\_parax\_chief\_ray} \times \left(\frac{u_{gen\_parax\_chief\_ray}}{Tan\left(u_{gen\_parax\_chief\_ray}\right)}\right)\right)\right)}{\left(HT_{gen\_parax\_chief\_ray} \times \left(\frac{u_{gen\_parax\_chief\_ray}}{Tan\left(u_{gen\_parax\_chief\_ray}\right)}\right)\right)} \times 100\%$$

The "HT"s are ray heights at the final surface. This distortion is a representation of the perpendicular distance from the generalized paraxial chief ray's intersection with the final surface to an extension of the real chief ray. "U" and "u" are ray slope angles in radian measure. For modes "AFOCAL" and "UAFOCAL", distortion is defined by the following equation:

$$\%Dist = \frac{\left(U_{real\_chief\_ray}\right) - \left(u_{gen\_parax\_chief\_ray}\right)}{\left(u_{gen\_parax\_chief\_ray}\right)} \times 100\%$$

All ray heights and ray slopes at computed in the space of the final surface of the current lens system. Distortion calculations are based upon real chief rays and upon the "GENERALIZED PARAXIAL RAY TRACE". Since the "GENERALIZED PARAXIAL RAY TRACE" is based upon real differential rays, distortion calculations are valid for optical systems containing tilted and decentered surfaces.

NOTE: In systems with tilts and decenters in which the central, gut chief ray does not strike the final surface at zero height, a TILT AUTO may be required on the final surface in order to compute meaningful distortion values.

FISHDIST θ, factor , n - The "DIST" command generates tabular percent distortion data for the current lens. Distortion values are generated at "n" field of view positions along a line defined in object space. The starting point of this line is defined by the ray "RAY 0 0" traced from the central field point defined by "FOB 0 0". The default values for "θ" and "factor" are 0.0 and 1.0, respectively. "n" may range from 1 to 50. Its default value is 10. The ending point of this line is defined by the ray "RAY 0 0" traced from the field point "FOB Y_f , X_f", where "Y_f" and "X_f" are given by the following equations:

$$Y_f = factor \times \cos(\theta)$$

$$X_f = factor \times \sin(\theta)$$

In the default case, with "θ" = 0.0 and "factor" = 1.0, Y_f = 1.0 and X_f = 0.0. All calculations are performed at the current control wavelength. If the distortion is not calculable, a message to that effect is displayed and no data is displayed. After fisheye distortion calculations are performed, the data may be displayed in graphical form using the "PLTFDIST" command.

FISHEYE DISTORTION PLOTS

PLTFDIST , (x-range) , dflag - The "PLTFDIST" command causes a plot of the existing distortion data to be generated. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. This is another automated plot routine. "PLTDIST" applies to the most recently generated distortion data. The optional input value "x-range", entered in aberration units, sets the semi-extent of the X or aberration axis scale. By default, the X or aberration scale semi-extent will be sized so as to include all current aberration data. If no distortion data exists, a message to that effect is issued and no plot is generated. Distortion data is generated using the "DIST" command described in the CMD section of this manual.

FIELD CURVATURE AND ASTIGMATISM - The field curvature and astigmatism calculations are based upon real chief rays and upon the "GENERALIZED PARAXIAL RAY TRACE". Since the "GENERALIZED PARAXIAL RAY TRACE" is based upon real differential rays, the field curvature and astigmatism calculations are valid for optical systems containing tilted and decentered surfaces.

FLDCV θ, factor , n and

AST θ, factor , n The "FLDCV" and "ASTIG" commands, respectively, generate tabular field curvature and astigmatism data for the current lens. Data values are generated at "n" field of view positions along a line defined in object space. The starting point of this line is defined by the ray "RAY 0 0" traced from the central field point "FOB 0 0". The default values for "θ" and "factor" are 0.0 and 1.0 respectively. "n" may range from 1 to 50. Its default value is 10. The ending point of this line is defined by the ray "RAY 0 0" traced from the field point defined by "FOB Y_f , X_f", where "Y_f" and "X_f" are given by the following equations:

$$Y_f = \text{factor} \times \cos(\theta)$$

$$X_f = \text{factor} \times \sin(\theta)$$

In the default case, with "θ" = 0.0 and "factor" = 1.0, Y_f = 1.0 and X_f = 0.0. All calculations are performed at the current control wavelength. If field curvature or astigmatism is not calculable, a message to that effect is displayed and no data is displayed. After a field curvature or astigmatism calculations are performed, the data may be displayed in graphical form using the "PLTFLDCV" and "PLTAST" commands.

FIELD CURVATURE PLOTS

PLTFLDCV , (x-range) , dflag - The "PLTFLDCV" command causes a plot of the existing field curvature data to be generated. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. "PLTFLDCV" applies to the most recently generated field curvature data. The optional input value "x-range" sets the semi-extent of the X or aberration axis scale. By default, the X or aberration scale semi-extent will be sized so as to include all current aberration data. If no field curvature data exists, a message to that effect is issued and no plot is generated. Field curvature data is generated using the "FLDCV" command described in the CMD section of this manual.

ASTIGMATISM PLOTS

PLTAST , (x-range) , dflag - The "PLTAST" command causes a plot of the existing astigmatism data to generated. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. "PLTAST" applies to the most recently generated astigmatism data. The optional input value "x-range" sets the semi-extent of the X or aberration axis scale. By default, the X or aberration scale semi-extent will be sized so as to include all current aberration data. If no astigmatism data exists, a message to that effect is issued and no plot is generated. Astigmatism data is generated using the "AST" command described in the CMD section of this manual.

BEAM FOOTPRINTS

FOOT GRID , n - The "FOOT GRID" command is used to change the grid size for footprint ray tracing. "n" may be set to a value greater than 4, indicating a 2n+1 x 2n+1 ray grid. The larger the grid size, the longer the ray grid ray trace will take and the larger the "FOOT1.DAT" file will become. The default for "n" is 4 yielding a 17 x 17 grid.

FOOT (APE) , i - The "FOOT" command generates ray beam footprint data at surface "i". The rays are traced from the last field point established with the last "FOB" command. The program traces a rectangular grid of rays from this object point through the current lens. The rays are aimed at coordinates in the NEWREF surface (current reference surface). The rectangular grid always fully fills the NEWREF reference surface with rays. The X, Y and Z coordinates of each ray at surface "i" and a fail/no fail code are remembered in the file "FOOT1.DAT". This saved "footprint" data is used by the next "PLOT FOOT" command issued. If the optional qualifier word "APE" is NOT used, then the fail/no fail code is set only by clear apertures and obscurations assigned to the NEWREF reference surface and by non-aperture/obscuration related ray failures. If the optional qualifier word "APE" is used, then the fail/no fail code setting considers clear aperture and obscuration assignments on all surfaces as well as non-aperture/obscuration ray failures. If no clear aperture is assigned to the NEWREF reference surface, then a temporary circular clear aperture will be assigned. Its semi-diameter will be equal to the larger of the XZ and YZ-paraxial marginal ray heights at the reference surface.

FOOTAREA (ACC) - The "FOOTAREA" command is used to calculate the area, in current lens units, of the last current beam footprint generated at the surface designated by the "i" input of the "FOOT" command. This calculation becomes more accurate as the number of rays in the footprint ray grid increases. The value is stored in the accumulator. The screen display is suppressed if the optional qualifier word "ACC" is included.

FOOTSANG (ACC) , x , y , z - The "FOOTSANG" command is used to calculate the solid angle, in steradians, subtended by the last beam footprint generated at the surface designated by the "i" input of the "FOOT" command. The calculation is performed from a point "x", "y" and "z"

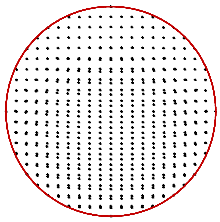
with respect to the vertex of the surface at which the beam footprint was computed. The value is stored in the accumulator. The screen display is suppressed if the optional qualifier word "ACC" is included.

AREA EQUIVALENT F-NUMBER - Using the "FOOT" and the "FOOTAREA" commands, the area of a beam from any object point may be calculated at the entrance pupil of an optical system. This is done by placing surface #1 at that entrance pupil using the "ASTOP EN" command. From this, an effective aperture diameter for an equivalent area circular aperture may be computed. If the real ray effective focal length is also computed and retrieved using the appropriate "GET" option, then an effective area F/# may be easily computed. This is an excellent metric for evaluating the variation in collection efficiency as a function of field position in optical systems with large amounts of pupil distortion. The "PLOT FOOT" command is used to plot the current beam foot print.

BEAM FOOTPRINT PLOTS

PLOT FOOT - The "PLOT FOOT" command causes a plot of the current beam footprint, generated by the last "FOOT" command, to be plotted. In general, the "PLOT FOOT" command is used as shown in the following example. The example used the COOK TRIPLET delivered with the program.

LIB GET 1
FOOT GRID 10 (sets a 21x21 grid of rays)
FOB (specifies the rays will come from the on axis object point)
FOOT APE 2 (generates a 21x21 ray grid footprint at surface 2)
PLOT NEW (starts a fresh plot)
ORIENT 2 (sets the look vector so that the plot will be facing and normal to surface 2)
PLOT SCALE 2 2 (sets the scale factor to 2 - meaning the plot is twice life size)
PLOT CLAP 2 2 (plots the clear aperture of surface 2)
PLOT FOOT (plots the foot print)
FOB .5 (sets another object point)
FOOT APE 2 (traced another foot print from the FOB .5 position for surface 2)
PLOT FOOT (plots the new foot print)
DRAW (draws the plot on the screen)
The foot print appears as shown below with the on axis foot print filling surface 2 and the off axis foot print partiall filling surface 2:



Example Beam Foot Print Plot

IMAGE ORIENTATION

IMAGEDIR (ALL or OB or OBJ) or
IMAGEDIR , i - The "IMAGEDIR" command displays the orientation of two vectors. These two vectors, named the "X-VECTOR" and the "Y-VECTOR" are originally oriented parallel to the local x and y-axes on the object surface. Whenever a chief ray is traced using the "FOB" command, and when chief ray differential ray tracing is "on", the results of the chief differential ray trace are used to determine the orientations of the "X-VECTOR" and the "Y-VECTOR" at each surface of the current lens database, in the loacal coordinate system of each surface. Since these vectors are determined for each chief ray traced, the resultant vectors may reflect coordinate system distortion in the lens database and may not always be exactly 90 degree from eachother.

RAY TRACE CONTROL PARAMETERS - Ray trace control parameter commands are used to set or to display parameters which effect the operation of ray tracing. With almost no exceptions, these control parameter values will not need to be altered by the use. The commands should be used with extreme care. Futhermore, if any of the ray tracing operating condition qualifier words is issued as a command word rather than a qualifier word, then if they are issued without numeric input, then they are treated as if they had been preceeded by the "PMP" command. If they are entered with numeric input, then they are treated as if they had been preceded by the "PM" command.
PMP (qualifier) - The "PMP" command displays the current value of the parameter identified by "qualifier".
PM (qualifier) , i - The "PM" command is used to set a control parameter, identified by "qualifier", to the numeric value specified by "i". The table below lists the various control parameters:

QUALIFIER	DESCRIPTION
SURTOL	This is the tolerance used for the iterative search for the ray intersection with an aspheric or other surface which cannot be analytically intersected. **Default value = 1.0D-8 lens units**
AIMTOL	This is the tolerance used for iterative ray aiming toward specific coordinates in the reference surface. **Default value = 1.0D-8 lens units**
CAIMTOL	This is the tolerance used for iterative ray aiming toward specific coordinates in the image plane when RXIM and RYIM are set. Make large enough to avoid ray aiming failures. **Default value = 1.0D-3 lens units**
NRAITR	This is the maximum number of iterations used in ray aiming and ray-surface intersecting. **Default value = 100**
DIFTOL	This is the fractional increment used in the calculation of the ray intercept derivatives like DY/DX or DYA/DY, etc. If, in some strange systems, differential ray failures occur, adjust this value up or down until they no longer occur. **Default value = $1.0D^{-3}$ x Relative Aperture Ht. on the Reference Surface.**
DELSUR	This is the starting derivative increment used in the calculation of the surface normals for non-flat, non-spherical or non-conic surfaces. **Default value = 0.0025**
SAGDEL	This is the starting surface position increment used in the calculation of the surface normals in SAG calculations. **Default value = 0.001**
MAXREG	This sets the maximum number of general purpose numeric and alpha numeric storage registers. Maximum allowed value is 100,000. **Default (also minimum) value = 4000**
MRAYS	This sets the maximum number of multiple surface intersections in an NSS surface group or the maximum number of steps when ray tracing in a gradient index material. **Default (also minimum) value = 200**
DELSUR	This is the starting derivative increment used in the calculation of the surface normals for non-flat, non-spherical or non-conic surfaces. **Default value = 0.25**
SERINC	This is the starting search increment used in chief ray aiming if the initial guess, based upon the paraxial ray trace, fails. It should never exceed 1/20 of the value assigned to SERLIM. **Default value = 0.01 lens units**
SERLIM	This is the limit of the search range used in chief ray aiming if the initial guess, based upon the paraxial ray trace, fails. It always be greater than 20 times the SERINC value. **Default value = 10.0 lens units**

SHORTCUT: If any of the above operating condition qualifier words is issued as a command word rather than a qualifier word, then if they are issued without numeric input, then they are treated as if they had been preceeded by the "PMP" command. If they are entered with appropriate numeric input, then they are treated as if they had been preceded by the "PM" command.

SAVING RAY DATA

SAVERAY - The "SAVERAY" command is used to save, for later use, all of the ray data associated with the current chief and regular ray. This saves all ray data including differential ray data if it exists.

RESTORING RAY DATA

RESTRAY - If ray data has been previously saved, it may be restored using the "RESTRAY" command. "RESTRAY" completely overwrites all internal memonry areas occupied by the existing "current" ray data.

CLEARING SAVED RAY DATA

CLEARRAY - If ray data has been previously saved, the "CLEARRAY" erases the internal data and deallocates any allocated memory which was allocated with the last "SAVERAY" command.

REFERENCE RAY SAVE - The current reference ray may be saved and reused in complex aperture function optical path difference calculations using the following commands.

SAVEREF - The "SAVEREF" command causes the the last reference ray and all associated values such as differential rays and differential ray pupil data to be saved for later use in complex aperture function calculations.

USEOLREF (YES or NO or ON or OFF) The "USEOLREF" tells all complex aperture function calculations ("CAPFN" in the FOE section of this manual) whether or not to use saved reference ray data (ON or YES) if it exists rather than using the most recent reference ray data. If saved reference ray data does not exits, current reference ray data will be used. The default is "NO" or "OFF".

DIFFRACTION CALCULATIONS

COMPLEX APERTURE

CAPFN , n or

CAPFN PERFECT , n or **CAPFN SILENT , n** - The "CAPFN" command causes a uniformly spaced, "n" x "n" rectangular grid of rays to be traced over the reference surface of the current system. "n" may be any even integer greater than or equal to 16. The default value for "n" is 16. A

COMPLEX APERTURE FUNCTION is computed and held in memory for use in future diffraction based calculations. The qualifier "PERFECT" creates a perfect COMPLEX APERTURE FUNCTION with zero OPD. This "perfect" CAPFN considers all system obscurations and clear apertures. The "APOD" command settings, described earlier in the spot diagram section, are also used in weighting or apodizing the rays traced during "CAPFN" ray trace. If the program detects OPD differences across adjacent grid points of greater than λ/4, or if the entire wave front has more than one wave of OPD error, a message will be issued warning the user of that fact. "CAPFN SILENT" is exactly like "CAPFN" except that no warning messages or other output is generated. When "n" is explicitly input, it is also used to reset the value of the "capfnnrd" value. This new "capfnnrd" value will remain set to this value until explicitly reset by the user or until the program terminates execution.

CAPFNNRD , capfnnrd - The "CAPFNNRD" command is used to reset the default CAPFN grid dimension from the program default of 16 to an even integer greater value than or equal to 16. This saves time when issuing a large number of CAPFN commands which use the same ray grid size.

CAPFNOUT (file name) - The "CAPFNOUT" command causes the current COMPLEX APERTURE FUNCTION to be output to the ASCII file named (file name) .dat. The default file is CAPFNOUT.DAT if no file name is supplied. It is stored in the working program directory. The filename may be from 1 to 8 characters. The CAPFN is output a row at a time starting in the lower left (-x, -y) corner of the pupil grid. The first line of output is a header line and contains the number of rows/columns (N) in the CAPFN and the spacing between rows/columns (lens units for FOCAL systems or radians for AFOCAL systems). The next (NxN) lines consist of four values. They are the modulus (intensity), phase (2π. times the OPD in waves at the reference wavelength), the ray failure code and the surface at which the ray stopped. The format is D23.15,1X,D23.15,1X,I3,1X,I3.

CAPFNIN (file name) - The "CAPFNIN" command causes the COMPLEX APERTURE FUNCTION stored in the ASCII file named (file name) . DAT to be read into an internal program array. The default file is CAPFNOUT.DAT if no file name is supplied. After the file is read, the peak-to-valley and rms opd values for the CAPFN are computed and may be retrieved using the GET or SHOW PTOVOPD and RMSOPD commands.

CAPFNADD (file name) - The "CAPFNADD" command causes the COMPLEX APERTURE FUNCTION stored in the ASCII file named (file name) . DAT to be read and added into the internal program CAPFN array. The default file is CAPFNOUT.DAT if no file name is supplied. After the file is added, the peak-to-valley and rms opd values for the resultant CAPFN are computed and may be retrieved using the GET or SHOW PTOVOPD and RMSOPD commands. This command is useful in constructing composite CAPFNS generated from different lens files or different alternate configurations of the same lens file.

CAPFNCLR - The "CAPFNCLR" command causes the internal memory used by the "CAPFNIN" and "CAPFNADD" commands to be released.

CAPGRID λ# - The "CAPGRID" command causes the COMPLEX APERTURE FUNCTION for wavelength λ# to be output both as a grid apodization file, GRIDAPD.DAT, and a grid phase file GRIDOPD.DAT. The units of the phase file are current lens units. The grid spacing at the currrent reference surface, in lens units, will be placed into the accumulator and displayed on the current output device.

WAVEFRONT AND APERTURE MAPS - The commands described below are used to display, in a textual sense, both the wavefront and the aperture apodization functions relative to fractional reference surface position as they are represented in the current CAPFN.

WAMAP , i or

AMAP , i - The "WAMAP" command displays a coded representation of the current wavefront map. The X-direction at the system reference surface is displayed horizontally and the Y-direction is displayed vertically. Following the "map" is a decoding system which relates the alphanumeric symbols used in the map to specific wavefront values. These wavefront values are in waves of the current wavelength used in the CAPFN generation. "i" specifies the wavelength number in the CAPFN to be mapped. The default for "i" is the control wavelength number. If no CAPFN data exists at wavelength number "i", a message to that effect will be displayed and no other action will be taken. The "AMAP" command displays a coded representation of the current aperture apodization map. The X-direction at the system reference surface is displayed horizontally and the Y-direction is displayed vertically. Following the "map" is a decoding system which relates the alphanumeric symbols used in the map to specific aperture transmission values. These aperture transmission values are relative to the average transmission through the aperture. "i" specifies the wavelength number in the CAPFN to be mapped. The default for "i" is the control wavelength number. If no CAPFN data exists at wavelength number "i", a message to that effect will be displayed and no other action will be taken.

WAVE FRONT MAP FITTING

FITZERN , λ# - The "FITZERN" command causes the current wave front represented in the current CAPFN to be fitted to the standard 37-term "Fringe" Zernike polynomial. The "Fringe" Zernike polynomial is discussed in some detail in the SPFIT and SPSRF manual sections. The fitting is performed using CAPFN generated OPD data generated at the wavelength number specified in numeric word #1. If this numeric input is left blank, then the current control wavelength is assumed. Since this Zernike polynomial is orthonormal only for unit circular apertures, the fitting will work best if a circular clear aperture is assigned to the reference surface. All ray obscurations are ignored during this fit. All rays not blocked by clear apertures are assumed to have unit intensity. The fit is performed in unit normalized reference surface coordinates and then scaled to the actual reference surface coordinates. The current reference surface aperture height at the control wavelength is used to normalize the reference surface coordinates. The coefficient values may be used in macros via the "GET ZERN37" command discussed in the CMD section of this manual. Complex Aperture Functions generated in systems with highly non-circular reference surface apertures, particularly those with high X-to-Y aspect ratios, should not be fit using Zernike polynomials. If this is done, even though the fit may seem "good" when checked with the "LISTOPD" command, the coefficients may not properly represent the true aberrations present in the system. Always use caution in these cases and check your results using X and Y OPD fans.

LISTOPD - The "LISTOPD" command causes a report of the last Fringe Zernike polynomial OPD map fit to be displayed. The actual reference surface coordinates, the raw OPDs, the fit OPDs and the fitting error are displayed for all rays not blocked by clear apertures.

LISTZERN - The "LISTZERN" command causes a report of the coefficient values of last Fringe Zernike polynomial OPD map fit to be displayed.

LISTREPT - The "LISTREPT" produces a 37-tern Fringe Zernike report based upon the last wavefront map fit.. The report displays RMS wavefront values, based upon the coefficient values. The calculation is based on the equations in Appendix 2 of "Optical Shop Testing" by Daniel Malacara.

WAVE FRONT MAP FITTING TO A DM

FITDM , λ# Δd , n - The "FITDM" command causes inverse of one-half or the current wave front represented in the current CAPFN to be fitted to a deformable mirror. The influence function for the deformable mirror is the same influence function described in the deformable mirror section in the lens database portion of the manual. The fitting is performed using CAPFN generated OPD data generated at the wavelength number specified in numeric word #1. "Δd" is the spacing in x and y of the deformable mirror actuators

and "n" is the number of actuators in the x and y-dimensions of the mirror. The fitting is performed assuming that the deformation at the DM is equal to the inverse of one-half the OPD in the CAPFN and, in this sense, the DM is treated as a "phase" type of surface. The "stroke" of the "n"x"n" actuators are stored in the first "n²" general purpose storage registers and a deformable surface data file is created which may then be used to define the actuator strokes in a deformable mirror in the lens database. The file name is FITDM.DAT. The strokes of the actuators are stored a row at a time starting with the actuator in the most negative x and y location on the DM and proceeding to the actuator in the most positive x and y location. Make certain that the MAXREG setting is large enough to accomodate the fitting or the fitting will not be performed. The assumption is that the DM is normal to the incoming wave front.

DMFIT - The "DMFIT" command causes a report of the last DM-OPD map fit to be displayed. The actual exit pupil ray coordinates, the raw OPDs, the fit OPDs and the fitting error are displayed for all rays not blocked by clear apertures or obscurations.

LISTDM - The "LISTDM" command causes a report of the actuator stroke values of last DM- OPD map fit.

CAPFN PLOTTING

PLOT CAPFNOPD , λ# , drflag , zmin , zmax - The "PLOT CAPFNOPD" command causes a 3-D plot of the wavefront part of the current Complex APerture FuNction (CAPFN), if one exists, to be displayed. Numeric word #1 specifies the wavelength number for which the wavefront data will be displayed. The default value is the control wavelength number. The horizontal axes are the relative exit pupil coordinates. If "drflag" is left blank, the plot will be displayed to the screen. Otherwise it will not be displayed. If "zmin" and "zmax" are not entered, the z-axis (opd) will be auto-scaled to a reasonable value. If auto-scaling is not desired, then both "zmin" and "zmax" must be explicitly entered. Units for "zmin" and "zmax" are waves are the current wavelength.

PLOT CAPFNAPD, λ# , drflag - The "PLOT CAPFNAPD" command causes a 3-D plot of the apodization part of the current Complex APerture FuNction (CAPFN), if one exists, to be displayed. Numeric word #1 specifies the wavelength number for which the wavefront data will be displayed. The default value is the control wavelength number. The horizontal axes are the relative exit pupil coordinates. If "drflag" is left blank, the plot will be displayed to the screen. Otherwise it will not be displayed.

CAPFNROT ("YES" or "ON" or "NO" or "OFF") - The "CAPFNROT" command is used to specify whether or not the current CAPFN is to be plotted with a 90 degree rotation or not. This helps see "hidden" features. Issued with the interrogator "?", "CAPFNROT" causes the current CAPFN rotation status to be displayed. If the status is "YES" or "ON", then each time a CAPFN is generated, it will be plotted with a 90 degree rotation.

PLOTCON CAPFNOPD , λ# , drflag , zstep - The "PLOTCON CAPFNOPD" command causes a 2-D contour plot of the wave front part of the current Complex APerture FuNction (CAPFN), if one exists, to be displayed. Numeric word #1 specifies the wavelength number for which the wave front data will be displayed. The default value is the control wavelength number. The horizontal axes are the relative exit pupil coordinates. If "drflag" is left blank, the plot will be displayed to the screen. Otherwise it will not be displayed. If "zstep" is not entered, then the steps between contours will be automatically set so that there are 10 contours. The units of "zstep" are fractions of the wavelength for which the CAPFN is being plotted. The maximum number of contours is 20. If "zstep" is set such that more than 20 contours would be drawn, then "zstep" is automatically re-adjusted so that 20 contours are drawn.

PLOTCON CAPFNAPD, λ# , drflag - The "PLOT CAPFNAPD" command causes a 2-D contour plot of the apodization part of the current Complex APerture FuNction (CAPFN), if one exists, to be displayed. Numeric word #1 specifies the wavelength number for which the wave front data will be displayed. The default value is the control wavelength number. The horizontal axes are the relative exit pupil coordinates. If "drflag" is left blank, the plot will be displayed to the screen. Otherwise it will not be displayed. 10 contours will be drawn from 0.0 to 100.0 % (maximum relative intensity).

OPD FIELD MAPS

RMSMAP , λ# , nrd , nflds , drflag - The "RMSMAP" command causes a contour plot of the RMS OPD to be generated and plotted over the field of view defined by the current SCY/SCX or SCY FANG/SCX FANG values stored in the lens database. The wavelength number is set by "λ#, numeric word #1. Its default is the control wavelength. The density of the ray grid traced over the system aperture is set by "nrd", numeric word #2. Its default is 16. "nrd" must be an even integer between 16 and 512. The number of field of view points across the full x and y-field of view is set by "nflds", numeric word #3. Its default is 3. It "drflag" is not explicitly entered, the results will be displayed to the screen, else automatic display will be suppressed.

PTVMAP , λ# , nrd , nflds , drflag - The "PTVMAP" works exactly as "RMSMAP" except "peak to valley" OPD will be plotted.

STRLMAP , λ# , nflds , drflag - The "STRLMAP" works exactly as "RMSMAP" except psf based Strehl Ratio will be plotted.

DIFFRACTION OPTICAL TRANSFER FUNCTION - The DOTF command described below generates the Diffraction Optical Transfer Function (DOTF). This transfer function is based upon residual optical path differences in the current lens system and considers the effects of diffraction due to apertures and obscurations. "DOTF" uses the existing CAPFN if one exists. If no CAPFN exists, then a "CAPFN" command is automatically issued using a default "capfnnrd" value of 16. The user may always change the default “capfnnrd” value with the “CAPFNNRD” command listed earlier. DOTF is always a response to a set of sinusoidally varying target bars.

DOTF (Y or X or YACC or XACC) , (f) , n The "DOTF" command either generates a range of DOTF data from spatial frequency 0.0 to the "cutoff" frequency or it generates DOTF data at a single spatial frequency value "f". The qualifier word may be "Y", "YACC", "X" or "XACC". The "cutoff" frequency used in the DOTF calculation is based either on a true aberrated f/number or an aberrated entrance/exit pupil calculation, depending upon the current lens MODE and the SPACE in which the calculation is performed. The cutoff frequency calculation, used in DOTF, does not consider vignetting due to apertures or ray failures. This vignetting is included in the DOTF calculation by its inclusion in the complex aperture function (CAPFN). If the (optional) single frequency "f" is explicitly input, then the Modulation Transfer Function (MTF) and the Phase Transfer Function (PTF) values corresponding to that frequency will be generated and placed in the "X" and "Y" registers. These two values will be displayed if the qualifier words "Y" or "X" are used. If the qualifier "YACC" or "XACC" is used in the single frequency context, then all display will be suppressed. When a range of DOTF values are generated, the qualifier words "YACC" and "XACC" act exactly as do the qualifiers words "Y" and "X". Qualifier word "Y" or "YACC" causes DOTF data to be generated in response to horizontal target bars. This is known as YZ-plane response The qualifier word "X" or "XACC" causes DOTF data to be generated in response to vertical target bars. This is known as XZ-plane response. Horizontal target bars are target bars which are parallel to the local X-axis of the current reference surface. Vertical target bars are target bars which are parallel to the local Y-axis of the current reference surface. If no qualifier word is entered, DOTF data will be calculated and

displayed for both vertical and horizontal target bar orientations. "n" specifies the number of data points to display during tabular output. The minimum for "n" is 3, the maximum is 100 and the default is 10. After DOTF data has been generated with this command, the data may be plotted using the "PLTDOTF" command. The definitions of "horizontal" and "vertical" are referenced to the local coordinate system of the current reference surface. Only when the local X and Y-axes of the object and image surfaces are parallel to the local X and Y-axes of the reference surface will the target orientation definitions apply at the object and image surfaces. All DOTF calculations are polychromatic calculations weighted by the current spectral weight values as set with the "SPTWT" and "SPTWT2" commands. Monochromatic calculations are performed by setting all but one wavelength's spectral weight to zero.

CUTOFF (O, OACC, I or IACC) - The "CUTOFF" command generates and displays the current value of the "cutoff" frequency. This "cutoff" frequency calculation is based either upon a real ray f/number calculation or a real ray entrance/exit pupil calculation depending upon the current lens MODE and the space in which the "cutoff" frequency is requested. The qualifier "O" or "I" causes the "cutoff" spatial frequency to be calculated either in "object" space or "image" space. The default qualifier is "I". The value of the "cutoff" frequency is always placed into the "X"-register. The qualifiers "OACC" and "IACC" work just as do "O" and "I" except that they suppress all display.

DOTF IN OBJECT SPACE - All DOTF calculations are performed in the frequency domain of "image space". In the AFOCAL or UAFOCAL mode, the frequency units are "lp/mrad". In FOCAL or UFOCAL modes the frequency units are "lp/mm". Many times it proves convernient to express the MTF in the frequency domain of "object space" The following two commands provide the user with a way of telling the program that the tabular MTF listings and the graphical MTF plots of MTF versus frequency are to be displayed in the frequency domain of "object space".

SPACE (O or I) - The "SPACE" command instructs the program as to the spatial domain in which the tabular and graphical DOTF is to be represented. The default is "I" for image space. This command does not change the way the DOTF values are computed but it does change the spatial frequency units used in the tabular and graphical displays. ". Issuing this command with the "?" returns the current setting

NEAR or **FAR** - The "NEAR" and "FAR" commands are used to specify the units for optical transfer function display when space is set to "O". "NEAR" sets units to "lp/mm" whereas "FAR" specifies "lp/mrad". Issuing this command with the "?" returns the current setting. The program default setting is "FAR"

REFERENCE SPHERE ADJUSTMENTS

RSPH CHIEF or

RSPH NOTILT or

RSPH BEST - The "RSPH CHIEF" command causes the center of the reference sphere to be located where the current chief ray crosses the current image surface. "RSPH NOTILT" attempts to remove wavefront tilt by fitting the wavefront to a sloped plane in a least squares sense. It uses this sloped plane to remove wavefront tilt and then estimates the resultant reference sphere center of curvature position such that the center of curvature still lies in the original image plane. "RSPH BEST" attempts to remove wavefront tilt and focus by fitting the wavefront to a tilted sphere in a least squares sense. It uses this tilted sphere to remove wavefront tilt and focus and then estimates the resultant reference sphere center of curvature position. The reference sphere center may no longer be located on the original image surface.

If the "RSPH" command is issued followed by the "?", then the current mode for locating the center of the reference sphere will be displayed. These commands impact the behavior of RMS OPD calculations during CAPFN ray tracing. They, in turn, impact the calculation of the diffraction based optical transfer function and PFSs. In the case of polychromatic calculations, the reference sphere center position picked, is the best position considering all wavelength's opds. The "RSPH" command is also used during geometrical spot diagram ray tracing to specify the center of the geometrical line spread function before any additional offsets are applied.

NOTILT or

BEST - The "NOTILT" command acts to remove wavefront tilt from the current complex aperture function (FOCAL and UFOCAL MODES only). This is done by fitting the wavefront to a sloped plane in a least squares sense. It uses this sloped plane to remove wavefront tilt and then estimates the resultant reference sphere center of curvature position such that the center of curvature still lies in the original image plane. The "BEST" command acts to remove wavefront focus and tilt from the current complex aperture function (FOCAL and UFOCAL MODES only). This is done by fitting the wavefront to a sloped plane in a least squares sense. It uses this sloped plane to remove wavefront focus and tilt and then estimates the resultant reference sphere center of curvature position such that the center of curvature still lies in the original image plane. In both cases the new resultant complex aperture function replaces the CAPFN which existed before the command was issued. The associated reference sphere motion may be retrieved using the "GET RSPHX", "GET RSPHY" and "GET RSPHZ" commands. New RMS and Peak to Valley wavefront errors are also automatically computed and are available via the "GET PTOVOPD" and "GET RMSOPD" commands.

MULTIPLE FOV DOTF - If multiple field of view definitions are included in the lens database (using the "FLDS" command) and if the command which immediately precedes the "DOTF" command is not an "FOB" command and if "DOTF" is issued without qualifier or numeric input, then DOTF values will be computed for the diffraction limit and for each of the defined multiple field of view positions. These values will be stored so that they may be plotted with the next "PLTDOTF" command. For multiple field of view DOTF calculations, if the reference sphere center location had been previously set to "BEST", it will be temporarily be reset to "NOTILT" for the duration of the calculations.

THRU-FOCUS DOTF - Many other optical design programs provide a thru-focus diffraction MTF calculation based upon the axial motion of the final surface of the lens database. This is usually performed via some motion of the final reference sphere center. Even though this method is fast, it is totally inadequate for most real optical designs for the following reasons:

1. The method ignores all AFOCAL systems
2. Many times in REAL optical systems "focus" is achieved through the motion of some element other than the image surface.

To support a useful thru-focus MTF capability the following commands are provided:

TFMOTION (X , Y or Z) , i , Δt , tmin , tmax - The "TFMOTION" command defines the motion of surface "i" which will be used to change system "focus". The qualifier word indicates whether the motion will be in the local X, Y or Z-direction with respect to the local surface coordinate system at surface "i". "Δt" is the increment of motion and "tmin" and "tmax" are the limits of the motion. The default direction is "Z". The default surface "i" is the final surface, which for AFOCAL and UAFOCAL modes won't really work and so should be changed by the user to a more effective surface in afocal systems. The default for "Δt" is 0.001 lens unit. The defaults for "tmin" and "tmax" are -5 and +5 times the current "Δt".

TFDOTF , freq , n - The "TFDOTF" command generates a range of DOTF data at spatial frequency "freq" over the thru-focus range specified by the last "TFMOTION" command. Both XZ (vertical target bars) and YZ (horizontal target bars)-plane modulus and phase values are displayed. "n" is the grid size for the complex aperture function. The default value is 16. The definitions of "horizontal" and "vertical" are referenced to the local coordinate system of the current reference surface. Only when the local X and Y-axes of the object and image surfaces are parallel to the local X and Y-axes of the reference surface will the target orientation definitions apply at the object and image surfaces. All DOTF calculations are polychromatic calculations weighted by the current spectral weight values as set with the "SPTWT" and "SPTWT2" commands. Monochromatic calculations are performed by setting all but one wavelength's spectral weight to zero.

DOTF PLOTS

PLTDOTF (LEICA) , (max-freq.) , dflag

CASE: No qualifier word

In this case the "PLTDOTF" command causes a plot of the modulus of the existing Diffraction Optical Transfer Fuction data versus spatial frequency to be generated. If "(max-freq) is entered (this input is not used in LEICA type plots), the plot will only go out to this frequency. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. "PLTDOTF" applies to the most recently generated DOTF. If no DOTF data exists, a message to that effect is issued and no plot is generated. If DOTF data exists for both vertical and horizontal target orientations, they both will be included on one plot. If multiple field of view "DOTF" data exists, it will be plotted on a multiple field of view type of DOTF display. Each curve will be labeled as to field of view position and target orientation.

CASE: Qualifier word = "LEICA" (There must exist DOTF data for at least 5 multiple field of view positions)

In this case the "PLTDOTF" command causes a plot of the modulus of the existing Diffraction Optical Transfer Fuction data versus field of view to be generated. "max-freq" input is ignored in this case. If "dflag" is zero (the default), the plot is automatically displayed on the screen. Afterward, the plot may be printed using the "GRAOUT" command. If "dflag" is set to any non-zero value, the automatic display is suppressed. The plot may still be displayed with the "DRAW" command and printed with the "GRAOUT" command. "PLTDOTF" applies to the most recently generated DOTF. If no DOTF data exists, a message to that effect is issued and no plot is generated. This command plots both target bar orientations of the first 10, non-zero frequency MTFs generated using the previous "DOTF" command. GOTF and DOTF data is generated using the "GOTF" and "DOTF" commands described in the CMD section of this manual.

DIFLEICA (ON or YES or OFF or NO) , freq# - The DIFLEICA command is used to shut off any of the DOTF vs FOV plots in a "PLTDOTF LEICA" type of plot. The "freq#" can be 1 through 10. Once frequency numbers are turned "off" they stay "off" until they are "tuned on" of until the program ends. Entered with a "?", the status for all 10 frequencies will be displayed.

DIFFRACTION PSF - Diffraction PSF's are calculable for both focal and afocal systems. Focal systems represent the PSF in lens units. Afocal systems represent the PSF in radian measure in the far field. The commands described below are used to generate a true diffraction Point Spread Function (PSF). They use the same routines which generate the CAPFN and which are described in the first part of this manual section.

PSF FROM THE CURRENT CAPFN - If a CAPFN already exists, it will be used to generate the next PSF. If a CAPFN does not exist, one will be generated. The ray grid size for that PSF will be set equal to the current "capfnnrd" value. "tgr" will be set to be a power of 2 and will initially be greater than or equal to four times the "capfnnrd". The "pgr" will be set to "tgr"-1. The user may reset the "tgr" and "pgr" values after the CAPFN is generated and before the PSF is generated. All "nrd", "pgr" and "tgr" values which are reset, will remain reset until explicitly reset again by the user or until the program terminates execution.

PSF SETUP - The commands described below are used to set up the program parameters which will be used when generating the PSF. The PSF is polychromatic and includes information from any non-zero wavelength for which the spectral weight is non-zero.

PSF or **PSF PERFECT** or **PSF PERFNOOB , dflag , λ# , I** - The "PSF" command is used to generate a diffraction based Point Spread Function via a Fast Fourier Transform of the Complex Aperture Function. "PERFECT" causes all OPD errors to be set to ZERO. "PERFNOOB" causes all OPD to be set to ZERO and causes all obscurations to be ignored. If “dflag” is zero and PSF plotting is on, the plot will be drawn to the screen. If “dflag” is non-zero and PSF plotting is on, the plot will be generated but not drawn to the screen. If "λ#" is explicitly input, the PSF will be only computed using a complex aperture function at that wavelength #, else a polychromatic PSF will be generated. If "I" is a starting point object intensity. The default is 1.0 and it may be set to any value between 0.0 and 1.0.

NRD , nrd - The "NRD" command is used to specify the number of rays which will span the exit pupil of the current system at the shortest wavelength. The default value is 16. Any even integer greater than or equal to 16 and less than TGR may be used. Issued with the interrogator "?", "NRD" causes the current "nrd" value to be displayed.

PGR , pgr - The "PGR" command is used to specify the FFT transform plotting grid extent during PSF and Streaked PSF plotting. It also specifies the extent of the integration grid for the line spread function output tables in the PSF.DAT and SPSF.DAT files and the region considered during Pixel Linearity Analysis when the qualifier words "LSF" and "SLSF" are used. It may be set to any odd integer less than TGR. The default value is 127 which is the default "tgr" value minus 1. If the "tgr" value is decreased below that of the current "pgr" value, then the "pgr" value will be automatically reset to "tgr"-1. Issued with the interrogator "?", "PGR" causes the current "pgr" value to be displayed.

TGR , tgr - The "TGR" command is used to specify the FFT transform grid size. It may be any even integer power of 2 greater than or equal to 64. The default value is 128 which is four times the default value of "nrd" Issued with the interrogator "?", "TGR" causes the current "tgr" value to be displayed.

GRI , gri - The "GRI" command is used to specify the FFT transform grid spacing. By default, the "gri" value is determined from the current "tgr" and "nrd" values and by the shortest wavelength and the f-number at the shortest wavelength. If a "gri" value is explicitly input by the user, then the program adjusts the "nrd" value and applies special ray scaling so as to yield the requested "gri" If the "NRD" command is issued after the "GRI" command is issued, then the existing "gri" specification will be cancelled and the "gri" will again be determined from the "tgr" and "nrd" values. In modes FOCAL and UFOCAL, "gri" is entered in lens units. In modes AFOCAL and UAFOCAL, gri is entered in "radians".

EXTENT , extent - The "EXTENT" command is used to specify the FFT transform displayed extent by using the existing PGR value to calculate a new internal "gri" value such that "gri"x"pgr" = "extent". This is just an alternate way for the user to specify the "gri" value.

PSFLIN - The "PSFLIN" command is used to switch the PSF presentation from the PSFLOG mode to the original default "linear" presentation. Issued with the interrogator "?", the current PSF presentation mode is displayed.
PSFLOG , d - The "PSFLOG" command is used to specify the PSF is to be replaced everywhere by its LOG_{10} spread over "d" decades. The default for "d" is "2". Issued with the interrogator "?", the current PSF presentation mode is displayed.
PSFPLOT ("YES" or "ON" or "NO" or "OFF" or "HCONLY") - The "PSFPLOT" command is used to specify whether or not the current PSF is to be plotted to the screen. Issued with the interrogator "?", "PLOTPSF" causes the current PSF plot status to be displayed. If the status is "YES" or "ON", then each time a PSF is generated, it will be plotted to the screen and will be available for re-draw using the "DRAW" command or for hard copy display using the "GRAOUT" command. If the qualified word "HCONLY" is used, "PSFPLOT YES" is assumed but no automatic "DRAW" command is issued and the PSF plot is not automatically displayed on the screen.
PSFROT ("YES" or "ON" or "NO" or "OFF") - The "PSFROT" command is used to specify whether or not the current PSF is to be plotted with a 90 degree rotation or not. This helps see "hidden" features. Issued with the interrogator "?", "PSFROT" causes the current PSF rotation status to be displayed. If the status is "YES" or "ON", then each time a PSF is generated, it will be plotted with a 90 degree rotation.

PSF FILE OUTPUT - The following commands control the output of the current PSF to the ASCII file PSF.DAT.
PSFTAG , psftag - The "PSFTAG" command is used to specify the character value of "psftag". "psftag" will be written as the first line of the ASCII PSF data file. The default value is " PSF.DAT". The tag may be up to 12 characters long. Issued with the interrogator "?", "PSFTAG" causes the current "psftag" to be displayed
PSFLI , psfli - The "PSFLI" command is used to specify the character value of "psfli". "psfli" will be written as the second line of the ASCII PSF data file. The default value is "THIS IS AN ASCII REPRESENTATION OF A POINT SPREAD FUNCTION". The "psfli" may be up to 78 characters long. Issued with the interrogator "?", "PSFLI" causes the current "psfli" to be displayed
PSFWRITE , ("YES" or "ON" or "NO" or "OFF") - The "PSFWRITE" command is used to specify whether or not the current PSF is to be output to the ASCII file PSF.DAT. Issued with the interrogator "?", "PSFWRITE" causes the current PSF write status to be displayed. If the status is "YES" or "ON", then each time a PSF is generated, it will be output to the ASCII file PSF.DAT. If more than one PSF file needs to be saved, use the "SYSTEM" command to issue "RENAME" or "COPY" commands from the operating system. The PSF.DAT file has the formats described below. The magnitude of the PSF is written out a row at a time starting at the -x,-y corner. The first "tgr-1" elements of the PSF will be the "bottom" row. The last row written out will be the top row starting at -x,+y and ending at +x,+y. The coordinates are in the coordinate system of the reference surface. The magnitude of the PSF is scaled to a peak value of 32767. A PSF.DAT file must exist before a Pixel Linearity analysis can be performed.
PSF.DAT FORMAT - See the description in the reference manual.
PSFBIN , ("YES" or "ON" or "NO" or "OFF") - The "PSFBIN" command is used to specify whether or not the current PSF is to be output to the binary file PSFBIN.DAT. Issued with the interrogator "?", "PSFBIN" causes the current PSFBIN write status to be displayed. If the status is "YES" or "ON", then each time a PSF is generated, it will be output to the binary file PSFBIN.DAT. If more than one PSF needs to be saved, use the "SYSTEM" command to issue "RENAME" or "COPY" commands from the operating system. The PSFBIN.DAT file has the formats described below. The magnitude of the PSF is written out a row at a time starting at the -x,-y corner. The first "tgr-1" elements of the PSF will be the "bottom" row. The last row written out will be the top row starting at -x, +y and ending at +x, +y. The coordinates are in the coordinate system of the image surface. There will always be ("tgr-1) x ("tgr-1") + 4 records in a PSFBIN.DAT file.
PSFBIN.DAT FORMAT - See the description in the reference manual.
PSF STREAKING - There may be times when it is desired to create a "streaked" diffraction PSF from original PSF which was stored in the PSF.DAT file. The following commands provide this capability.
STREAK PLOT ("YES" or "ON" or "NO" or "OFF") - The "STREAK PLOT" command is used to specify whether or not the streaked PSF is to be plotted to the screen. Issued with the interrogator "?", "STREAK PLOT" causes the current streaked PSF plot status to be displayed. If the status is "YES" or "ON", then each time a streaked PSF is generated, it will be plotted to the screen and will be available for re-draw using the "DRAW" command or for hard copy display using the "GRAOUT" command. The program default is "ON". "pgr"x"pgr" elements of the streaked PSF are displayed even though the entire streaked PSF is written to the SPSF.DAT file.
STREAK WRITE , ("YES" or "ON" or "NO" or "OFF") - The "STREAK WRITE" command is used to specify whether or not the streaked PSF is to be output to the ASCII file SPSF.DAT. Issued with the interrogator "?", "STREAK WRITE" causes the current streaked PSF write status to be displayed. If the status is "YES" or "ON", then each time a streaked PSF is generated, it will be output to the ASCII file SPSF.DAT. If more than one streaked PSF file needs to be saved, use the "SYSTEM" command to issue "RENAME" or "COPY" commands from the operating system. The SPSF.DAT file has exact same file format as used for the PSF.DAT file previously described except that no optional PSFLI or PSFTAG may be set by the user. The magnitude of the streaked PSF is written out a row at a time starting at the -x,-y corner.
The first "m+tgr-1" elements of the PSF will be the "bottom" row. The last row written out will be the top row starting at -x,+y and ending at +x,+y. The coordinates are in the coordinate system of the reference surface. The magnitude of the streaked PSF is scaled to a peak value of 32767. "m" is the number of PSF grid spaces that the PSF is "streaked".
STREAK (X or Y or XY) , m - The "STREAK" command causes the current PSF stored in the PSF.DAT file to be streaked (shift-added) either in the X or Y or XY-direction by "m" "gri" units. A new streaked PSF is created in memory. The new streaked PSF has dimension "tgr-1+m"x"tgr-1+m". If "STREAK WRITE" has been set to "ON", the streaked psf will be written to the file SPSF.DAT. If "STREAK PLOT" has been set to "ON", the streaked psf will be plotted on the screen and may be re-drawn using the "DRAW" command or printed using the "GRAOUT" command.

PIXEL LINEARITY (CENTRIOD) ANALYSIS - See the description in the reference manual.
PIXEL , m , n - The "PIXEL" command is used to set up or specify "m" the number of sub-pixels per pixel and "n" the number of pixels in the CCD window. "n" specifies the "n"x"n" grid of pixels mentioned above. If the "PIXEL" command is not issued, then the default values for "m" and "n" will be 3 and 3 respectively. "m" must always be an odd integer. "n" may be even or odd.
CENTROID (LSF or SLFS or PSF or SPSF) - The "CENTROID" command causes a Pixel Linearity Analysis to be performed and the results sent to the screen or other current output device. If no optional qualifier word is issued (the same as using qualifier word "LSF"), the analysis is performed using the LSF data stored in the PSF.DAT file. If the qualifier "SLSF" is issued, the analysis is performed using the "streaked" LSF data stored in the SPSF.DAT file. If the qualifier word "PSF" is issued, the PSF data in file PSF.DAT is used and if the qualifier word "SPFS" is used, the streaked PSF data in the file SPSF.DAT is used. Existing Point Spread Functions stored in the files PSF.DAT or SPSF.DAT may be interpolated

from their odd grids to even grids with the "PSFINT" and "PSFINTS" commands. The grid extents of these interpolated PSF's will be set to "pgr"+1. If this leads to PSF extrapolation rather than interpolation, then the extrapolated values will be set to zero.

PSFINT and

PSFINTS - "PSFINT" causes interpolation of the file PSF.DAT to an even grid. PSFINTS causes interpolation of the file SPSF.DAT (a streaked PSF) to an even grid. The new interpolatied PSF is output to the file IPSF.DAT.

STREHL RATIO - There are two ways in which the STREHL ratio of the current lens database may be computed. The exact method and the approximate method. The exact method is described first. In this method, the STREHL ratio of an optical system is exactly defined to be the ratio of the peak value of the diffraction point spread function of the aberrated optical system to the peak value of the diffracting point spread function of the same system in the absence of aberrations.

STREHL (ACC or ACCNOOB or NOOB) - After a field of view position is defined using an "FOB" command, the "STREHL" command calculates, displays, and places into the X-register, the true value of the current optical system STREHL ratio. The PSFs which are used in this calculation are based upon PSF parameter values which would have been used if the "PSF" command had been issued. If "STREHL" is issued with the qualifier words "ACC" or "ACCNOOB", the STREHL ratio value will not be displayed. Issued with the qualifier words "NOOB" or "ACCNOOB" causes the strehl ratio calculation to ignore all system obscurations. The second method is an approximate method based upon the RMS wavefront error computed when a CAPFN (Complex Aperture Function) is produced. After appropriate "FOB" and "CAPFN" commands have been issued, the approximate STREHL ratio (see, Born and Wolf, Principles of Optics, Programing Press) may be calculated using the "APSTREHL" command. This approximation is generally valid for systems for which the RMS wavefront error does not exceed 0.1 wave. For monochromatic systems, there is an approximate relationship between the RMS wavefront error and STREHL ratio. This approximate relationship listed in the reference manual.

APSTREHL (ACC) - The "APSTREHL" command computes, displays and stores in the X-register, the approximate STREHL ratio based upon the RMS wave front error computed by the last issuance of the "CAPFN" command. If "APSTREHL" is issued with the qualifier word "ACC", the approximate STREHL ratio value will not be displayed.

DIFFRACTION ENERGY DISTRIBUTIONS

ENCIRCLED ENERGY

DRED (N) , ΔE , ΔX , ΔY - The "DRED" command produces a radial energy distribution (energy versus radial distance from the center of the PSF) using the current diffraction PSF data. "ΔE" specifies the percent energy increments to be displayed. The default for "ΔE" is 10.0 (percent). Maximum and minimum allowed values for "ΔE" are 100.0 (percent) and 1.0 (percent), respectively. "ΔX" and "ΔY" are interpreted as linear offsets (in lens units for focal systems and radians for a focal systems) from the center of the PSF If the qualifier word "N" is used, no output is generated. After tabular data is generated with the "DRED" command, it may be graphically displayed using the "PLTRED" command.

DRED ACC , E , ΔX , ΔY - The "DRED ACC" command produces no display. "DRED ACC" returns to the X-register (accumulator), the radius of the circle which encloses "E" percent energy. All the above comments concerning "ΔX" and "ΔY" apply in the same way as for the "DRED" command.

ENSQUARED ENERGY

DREDSQ (N) , ΔE , ΔX , ΔY - The "DREDSQ" command produces an ensquared energy distribution (ensquaring square side length, centered at the PSF center, versus energy) using the current PSF data. "ΔE" specifies the percent energy increments to be displayed. The default for "ΔE" is 10.0 (percent). Maximum and minimum allowed values for "ΔE" are 100.0 (percent) and 1.0 (percent), respectively. "ΔX" and "ΔY" are interpreted as linear offsets (in lens units for focal systems and radians for afocal systems) from the center of the PSF. If the qualifier word "N is used, no output is generated.

DREDSQ ACC , E , ΔX , ΔY - The "DREDSQ ACC" command produces no display. "DREDSQ ACC" returns to the X-register (accumulator), the side length of the square which encloses "E" percent energy. All the above comments concerning "ΔX" and "ΔY" apply in the same way as for the "DREDSQ" command. After tabular data is generated with the "DREDSQ" command, it may be graphically displayed using the "PLTRED" command.

INVERSE DISTRIBUTIONS ENSQUARED ENERGY - In all of the above energy distribution commands, the qualifier words "ACC" and "CACC" were used to return to the X-register, the size of the circle or square which encircled or ensquared the percent energy specified in numeric word #1. If, instead, the qualifier words "ACCX" and "CACCX" are used, then, commands return to the X-register either the percent energy encircled by the circle whose radius is specified in numeric word #1 or the percent energy ensquared by the square whose side length was specified in numeric word #1.

ILLUMINATION RAY TRACING

IFOB (qualifier word) , Y, X , Z , n - The "IFOB command must be issued before any illumination rays or illumination spot diagrams can be traced. This command defines the object point from which subsequent illumination rays will be traced. It stays in effect until another "IFOB" command is issued or until it is canceled by some other program option such as "UPDATE LENS". "Y", "X" AND "Z" are the fractional y, x and z-coordinates of the object point measured in the coordinate system of the object surface if the reference object height is set via "SCY" and "SCX" commands. "Y", "X" are the fractional y and x-object space field angles if the reference object height is set via "SCY FANG" and "SCX FANG" commands. Z is represented as a fraction of the object surface axial thickness. If "Z" is zero, the object point lies in the plane of the object surface. If "Z" is +1.0, then the object point is a positive z-distance from the object surface equal to the axial thickness of the current object surface. If "Z" is -1.0, then the object point is a negative z-distance from the object surface equal to the axial thickness of the current object surface. Z is only used when the reference object height has been set by "SCY" and "SCX" commands. Issued with the interrogator "?", the "IFOB" command returns the last "IFOB" input data if a chief illumination ray exists. The fifth numeric word entry, "m" is used to specify the relative intensity of the reference ray. The default value is 1.0. It may be set to any non-zero value less than or equal to 1.0. Unlike the "FOB" command, no automatic ray is traced when the "IFOB" command executes. The choice of "qualifier word" selects the specific output to be displayed as shown in the reference manual.

IRAYA , el , az , n , I - The "IRAYA" command is used to specify illumination ray tracing in a particular direction with respect to the chief ray direction. "el" and "az" are the angular elevation and azimuth angles (in degrees) measured from the illumination chief ray direction as defined by the last "IFOB" command. "n" is the wavelength number. If no entry is made for "n", the ray is traced at the control wavelength number. "I" is the relative ray intensity which can be set to any non-zero value less than or equal to 1.0. The "az" angle is measured positive from 0 through 360

degrees (counter-clockwise) in a plane perpendicular to the direction of the chief ray. This definition is shown in the following figure. The positive Z-axis is coming out of the figure.

IRAYA CAOB , el , az , n , I - The "IRAYA CAOB" command works just like the standard "IRAYA" command, except that it causes checking for ray blockages due to clear apertures and obstructions. If a ray falls outside a clear aperture or within an obscuration, a ray failure message will be generated, saved internally and displayed. Clear apertures are not checked on the current object surface or the current image surface by "IRAYA CAOB".

IRAY , Y, X, n , I - The IRAY" command is very similar to the "RAY" command described in the CMD section. "Y" and "X" are the relative fractional surface #1 coordinates with respect to the vertex of surface #1. "n" is the wavelength number. If no entry is made for "n", the ray is traced at the control wavelength number. All decenters and tilts and decentered clear apertures are ignored by the "IRAY" command. "I" is the starting intensity of the ray. It is assumed to be 1.0 by default. It may be set to any value from 0.0 to 1.0.

ISPD , n - The "ISPD" command causes a random distribution spot diagram to be traced from the field position defined by the last "IFOB" command. The maximum number of rays to be traced may be issued as numeric word #1. The random grid of rays is spread over a square which covers surface #1 so as to "fill" surface #1. If no clear aperture is defined on surface #1, a temporary clear aperture will be assigned just as is done with the "SPD" commands of the CMD section. The default value for numeric word #1 is 1000. "ISPD" is most useful when the object surface is far removed from surface #1 and surface #1 subtends less than 180 degrees when seen from the object surface. This command uses "IRAY CAOB" ray tracing.

ISPDA , n , ang - The "ISPDA" command causes a random distribution spot diagram to be traced from the field position defined by the last "IFOB" command. The maximum number of rays to be traced may be issued as numeric word #1. The maximum cone half-angle may be issued as numeric word #2. The default value for numeric word #1 is 1000. The cone half-angle must be explicitly input by the user. "ISPDA" is most useful when the object surface is near or "inside" surface #1 and when surface #1 subtends more than 180 degrees as seen from the object surface. This command uses "IRAYA CAOB" ray tracing.

IMAGING - The following commands perform visualization of optical system imaging performance

COLOR (MONO or RGB) - The "COLOR" command specifies that the imagery will either be 8 bit monochrome (MONO) or 24 bit color (RGB). The wavelength used when MONO is set is the control wavelength. The wavelengths used in RGB mode are the control wavelength for Green, the first wavelength number in the secondary wavelength pair for Blue and the second wavelength in the secondary wavelength pair for Red. 8 bit data is written as 24 bit data with the R, G abd B values identical. The default color mode is MONO.

IOBJECT , X , Y , Δx , Δy - The "OBJECT" command defines a pixelated reference "Object Field of View". "X" and "Y" are the full extent dimensions of the "Object Field of View", assumed symmetric about the optical axis defined by the central chief ray traced at the control wavelength and intersecting the object surface. "Δx" and "Δy" are the "x" and "y" dimension of each pixel. All pixels are "rectangular". All values must be explicitly input. There is no dead space between pixels. If "x" and "y" are not integer divisors of "X" and "Y", "X" and "Y" will be adjusted so that they are. All "Object Plane" dimensions" are in lens units. The extents are measured from center of pixel positions.

IOBJECTN , X , Y , Nx , Ny - The "OBJECTN" command defines a pixelated reference "Object Field of View". "X" and "Y" are the full extent dimensions of the "Object Field of View", assumed symmetric about the optical axis defined by the central chief ray traced at the control wavelength. "Nx" and "Ny" are the number of pixels in the x and y-directions. All pixels are "rectangular". All values must be explicitly input. There is no dead space between pixels. All "Object Plane" dimensions" are in lens units. The extents are measured from center of pixel positions.

IOBJECTD Δx , Δy, Nx , Ny - The "IOBJECTD" command defines a pixilated reference “Object Field of View”. "Δx" and "Δy" are the "x" and "y" lengths of a single pixel". The "Object Plane" is assumed symmetric about the optical axis defined by the central chief ray traced at the control wavelength. "Nx" and "Ny" are the number of pixels in the x and y-directions. All pixels are "rectangular" All values must be explicitly input. There is no dead space beteween pixels. All "Object Plane" dimensions" are in lens units.

OBJVAL (M, R, G or B) , i , j , value - The "OBJVAL" command sets the intensity value of the "i"th row and "j"th column object space to "value" where "value" ranges from 0 (zero intensity) to 255 (maximum intensity). M specifies MONO, R specifies Red, G specifies Green and B specifies Blue.

IIMAGE , X , Y , Δx , Δy - The "IMAGE" command defines a pixelated "Image Plane", "X" and "Y" are the full extent dimensions of the "Image Plane", assumed symmetric about the optical axis defined by the central chief ray traced at the control wavelength. "Δx" and "Δy" are the "x" and "y" lengths of each image plane pixel. All pixels are "rectangular". All values must be explicitly input. If "x" and "y" are not integer divisors of "X" and "Y", "X" and "Y" will be adjusted so that they are. All "Image Plane" dimensions" are in lens units. The extents are measured from center of pixel positions.

IIMAGEN , X , Y , Nx , Ny - The "IMAGEN" command defines a pixelated "Image Plane", "X" and "Y" are the full extent dimensions of the "Image Plane", assumed symmetric about the optical axis defined by the central chief ray traced at the control wavelength. "Nx" and "Ny" are the number of pixels in the x and y-directions. All pixels are "rectangular" All values must be explicitly imput. There is no dead space beteween pixels. All "Image Plane" dimensions" are in lens units. The extents are measured from center of pixel positions.

IIMAGED Δx , Δy, Nx , Ny - The "IMAGED" command defines a pixelated "Δx" and "Δy" are the "x" and "y" lengths of a single pixel". The "Image Plane" is assumed symmetric about the optical axis defined by the central chief ray traced at the control wavelength. "Nx" and "Ny" are the number of pixels in the x and y-directions. All pixels are "rectangular" All values must be explicitly imput. There is no dead space beteween pixels. All "Image Plane" dimensions" are in lens units.

IMTRACE1 - The "IMTRACE1" command causes one chief ray to be traced, at each wavelength set by the COLOR command, from each object plane pixel, through the current system, and terminating at the image plane. The image is then automatically built using the resulting "Image Plane" array. Since only chief rays are traced, only lateral chromatic aberration and distortion can be represented with this image tracing command.

IMTRACE2 - The "IMTRACE2" command is exactly like "IMTRACE1 , 1" except that an on-axis Point Spread Functions is generated (one for MONO and three for RGB mode) and are then used in the image plane, image reconstruction. The assumption is that the PSF is uniform over the field of view.

IMTRACE3 - The "IMTRACE3" command is exactly like "IMTRACE2 , 1" except that after each chief ray is traced, a diffraction based Point Spread Function is generated from the object point (one for MONO and three for RGB mode) and are then used in the image plane, image reconstruction. This is slow and should only be used when the PSF varies significantly across the field of view.

PSFTOIMG , n - The "PSFTOIMG" command causes the last Point Spread Function generated with a "PSF" command to be added to one of four storage levels in the Image Array designated by "n". "n" may be 1, 2, 3 or 4.

INTTOIMG , n - The "INTTOIMG" command causes the data saved in the INTEN.DAT file generated by an "INTEN" command to be added to one of four storage levels in the Image Array designated by "n". "n" may be 1, 2, 3 or 4.

IMSLICE (X or Y or DIAG) , offset , color # , k - The "IMSLICE" command a slice through the current Image Array to be plotted. The slice may be in the "X" or "Y" or "DIAG" direction. The offset is measurd from the bottom (X) or the left (Y) edge of the array. The offset defaults place the slice through the center of the Image Array. "DIAG" takes no user supplied offset. The offset is in pixels. Color # is the1, 2 or 3 for R, G or B. The default color # is 2. If "k" is not explicitly input, the resulting plot will be linear. I "k" is explicitly input, the plot will be log10 intensity.

LMINUSR , threshold , color # - The "LMINUSR" command plots the results of a left minus right analysis. The LEFT values are the 1 and 2 positions in the Image Array, the RIGHT values are the 3 and 4 positions. The "theshold" value (default 0.001) allows the user to elliminate small stored values. The color # is as in the IMSLICE command.

OTOBMP (filename with no extension) - The "OTOBMP" command causes the current object field of view array to be written as a bitmapped .BMP file. If the color mode is MONO, a monochromatic, 24 bit file will be created with identical R, G and B values. If the color mode is RGB, an RGB 24 bit, bitmapped file will be created. The file name will be "filename" with a BMP file extension.

ITOBMP (filename with no extension) - The "ITOBMP" command causes the current image plane array to be written as a bitmapped .BMP file. If the color mode is MONO, a monochromatic, 24 bit file will be created with identical R, G and B values. If the color mode is RGB, an RGB 24 bit, bitmapped file will be created. The file name will be "filename" with a BMP file extension.

OFROMBMP (filename with no extention) , X-extent - The "OFROMBMP" command causes the file named "filename".BMP to be read into the current object field of view array where it can be used as a source object field for image simulations. The full X-extent of the object field of view array, in current lens units in the object surface plane, is specified by "X". There is no default for "X". The dimensions of the .BMP file are used to automatically specify the Δx, Δy and full Y-extent of the object field of view array. The full extents are assumed to be measured from center of pixel positions.

IFROMBMP (filename with no extension) , X-extent - The "IFROMBMP" command causes the file named "filename".BMP to be read into the current image array. The full X-extent of the image array, in current lens units in the image surface plane, is specified by "X". There is no default for "X". The dimensions of the .BMP file are used to automatically specify the Δx, Δy and full Y-extent of the image array. The full extents are assumed to be measured from center of pixel positions.

PLTOBJ - The "PLTOBJ" command causes the object array to be plotted.

PLTIMG , trim pixels - The "PLTIMG" command causes the image array to be plotted. A non-zero value for "trim pixels" causes that many pixels to be trimmed from each edge of the image. This is used to trim off the dark edge caused by the fact that the object plane was not false padded.

BMPREADR (name of .BMP reader) - The "BMPREADER" command is used to set the name of the program bit map reader application. The current application is BMP.EXE and is provided with this program.

IMAGING DEMO - The included file "IMDEMO.DAT" contains a working demonstration of PSF imaging using the 24 bit .BMP file "PORT.BMP". "PORT.BMP" is a 320x240 RGB bitmapped image of the L. A. Airport area. Loading the demo by typing "**IN FILE IMDEMO.DAT**" causes a simple perfect (no aberrations, just diffraction effects) lens file to be loaded and stored in lens library file number 999. It then loads three macros named IMTEST1, IMTEST2 and IMTEST3 into the macro library. IMTEST1 performs perfect IMTRACE1 chief ray imaging. IMTEST2 assumes that the PSF is essentially uniform over the object field of view (as it really is) and performs IMTRACE2 imagery. IMTEST3 performs a new PSF for every 10th pixel row and column and performs IMTEST3 imagery. This is the slowest type of image reconstruction and is appropriate when aberrations are present which vary significantly over the field of view. The demo is run by typing "**IMTEST1 or IMTEST2 or IMTEST3**". The object image is first displayed to the screen. After you close this object file view, PSFs are created at each wavelength and then are convolved with the bit mapped file. This takes seconds to min on a P4 running at 2 GHz. The PSF is significantly larger than a pixel and so the resultant image is degraded, as expected. The TGR is set to 512. NRD is set to 64 and pgr is set to 91. PGR was set to 91 empirically to minimize aliasing during image reconstruction. The resultant image is then displayed to the screen. Setting the SAY value to greater than 1.0, speeds up the optical system and thus reduced the PSF size and the image degradation.

THE MULTI RAY TRACE - Multiple rays may be traced following an "FOB" command. Furthermore they may be traced from multiple FOV positions. The multiple ray trace commands generate no display. The "MFOBS" command is used to set up multiple FOV positions. The MRAYS command is used to set up multiple ray definitions. These commands populate a ray history file. They have no other purpose.

MFOBS , Y, X , n , m - If the number of FOBs to be traced ("m") is 1, then "Y" and "X" are the FOB values from which the chief ray will be traced. If the number of FOBs to be traced ("m") is greater than 1, then "Y" and "X" are the absolute values of fractional reference object heights. "n" is the wavelength number. If no entry is made for "n", the rays are traced at the control wavelength number. "m" is the dimension of an "m" x "m" array of rays extending from FOBs -X to +X and from -Y to +Y.

MRAYS (CAOB) , Y, X, n , I , m - If the number of RAYs to be traced ("m") is 1, then "Y" and "X" are the fractional reference aperture heights through which the ray will be aimed. If the number of rays to be traced ("m") is greater than 1, then "Y" and "X" are the absolute values of fractional reference surface coordinates. "n" is the wavelength number. If no entry is made for "n", the rays are traced at the control wavelength number. "I" is the starting ray intensity which may be set to any non-zero value less than or equal to 1.0. The default value for "I" is 1.0. If the reference surface has no clear aperture assigned, the actual reference ray coordinates will be calculated based upon the reference aperture height set by the paraxial ray trace. If a clear aperture has been assigned to the reference surface, the actual reference ray coordinates will be calculated based upon the fractional reference aperture height relative to the center of the clear aperture. "m" is the dimension of an "m" x "m" array of rays extending from -X to +X and from -Y to +Y. If the qualifier word "CAOB" is used, clear aperture checking is performed. Rays which fail are not added to the ray history.

MTRACE - The "MTRACE" command is used to execute a multi-ray trace.

MTRACEI , n , D , i - The "MTRACEI" command is used to execute a multi-ray trace and perform an intensity calculation at the current spot diagram surface specified by "i". By default, "i" is the final surface of the system (see the SPD command) for each FOB specified in the "MFOBS" command. "n" is the dimensionality of the 2-D intensity array centered at the spot diagram surface. "D" is the side length of the intensity map in lens units at the spot diagram surface. The intensity map is always square. Ray intensities are summed into this array. The angle of incidence (or the average when more than one ray impacts an intensity grid square, is also stored, along with its X and Y-components.

A report is also sent to the default output device. The report comprises:

FOB#, total summed intensity at surface i from that FOB, p-v intensity variation across surface, number of rays stricking surface and average intensity at surface "i"
The final line reports for all FOBs:
Total summed intensity at surface "i", p-v intensity variation across surface, number of rays stricking surface and average intensity at surface "i"
During the execution of the "MTRACEI" command, all ray aiming and differential ray tracing is temporarily turned "off".

THE SCREEN SURFACE

SCREEN (YES or ON or NO or OFF) , i , d , h , s , ang - A screen surface comprises a surface property which diminished the intensity of the radiation passing through that surface. It acts in a manner similar to an opaque plate with many small circular holes drilled in it on a uniform rectangular grid. "i" specifies which surface the screen will be attached to. "d" is the hole diameter. "h" is the screen's plate thickness. "s" is the x and y-hole spacing on an assumed rectangular grid. The default qualifier word is "ON". "SCREEN" issued with a "?" will return the "SCREEN" setting for the current lens prescription. The screen surface is not zoomable.

Rays are not blocked by the screen surface but the ray intensity of a group of rays representing a beam of light will be reduced by the following factor:

$$\text{Intensity}-\text{Reduction}=\frac{\pi\left(\frac{d}{2}-h\sin(AOI)\right)\left(\frac{d}{2}\cos(AOI)-h\sin(AOI)\right)}{s^2\cos(AOI)}$$

AOI is the angle of incidence of each ray striking the screen. If AOI is 90 degrees, the Intensity-Reduction factor is 0.0. If the reduction factor goes negative. it is automatically set to 0.0. Near field diffraction is ignored. This is a slightly approximate representation of the true Intensity-Reduction factor but it avoids the necessity of performing a slow elliptical integral! "ang" is the angle of incidence beyond which nothing gets through the screen and relates to other screen geometry.

RAY HISTORIES

RHIST (YES or ON or NO or OFF or WRITE or SWRITE) - The "RHIST" command is used to turn ray history saving "on" ("YES" or "ON") or "off" ("NO" or "OFF") The default is "off". All ray data and differential ray data for all individual rays traced using the "MRAYS" command is saved for all surfaces. The qualifier word "WRITE" causes all this saved ray data to be written to a file named RAYHIST.DAT". One header line with the total number of rays in I10 format followed by the total number of surfaces in I4 format followed by the total number of field of view positions in I10 format. The header line is then followed (number of rays)x(number of the final surface+1) number of lines, each holding the following 93 data items:
Surface #
Sequential Ray #
1. Local X-coordinate
2. Local Y-coordinate
3. Local Z-coordinate
4. Local L-Direction Cosine after interaction
5. Local M-Direction Cosine after interaction
6. Local N-Direction Cosine after interaction
7. Optical Path Length from surface I-1 to surface I
8. Physical length from surface I-1 to surface I
9. Cosine of angle of incidence
10. Cosine of Angle of reflection, refraction or diffraction
11. Marginal XZ-slope angle (radians)
12. Marginal YZ-slope angle (radians)
13. Surface normal L-dircos
14. Surface normal M-dircos
15. Surface normal N-dircos
16. Local X-coordinate before interaction
17. Local Y-coordinate before interaction
18. Local Z-coordinate before interaction
19. Local L-Direction Cosine before interaction
20. Local M-Direction Cosine before interaction
21. Local N-Direction Cosine before interaction
22. Optical Path Length fron NEWOBJ surface to surface I
23. 1 for non-RV ray, -1 for RV ray (direction of ray)
24. 1 for POSRAY, -1 for not POSRAY (object distance negative)
25. Ray energy term
26. Local XL-Direction Cosine after interaction
27. Local XM-Direction Cosine after interaction
28. Local XN-Direction Cosine after interaction
29. Local YL-Direction Cosine after interaction
30. Local YM-Direction Cosine after interaction
31. Local YN-Direction Cosine after interaction

32. (NOT USED ALL ZERO)
33. (NOT USED ALL ZERO)
34. Polarization Parallel Modulus
35. Polarization Perpendicular Modulus
36. Polarization Parallel Phase
37. Polarization Perpendicular Phase
38. Polarization angle in degrees between Y-ray vector and the parallel plane
39. - 50. (NOT USED ALL ZERO)
51. XZ-plane X-coordinate chief differential trace
52. XZ-plane Y-coordinate chief differential trace
53. XZ-plane Z-coordinate chief differential trace
54. XZ-plane L-dircos chief differential trace (after interaction)
55. XZ-plane M-dircos chief differential trace (after interaction)
56. XZ-plane N-dircos chief differential trace (after interaction)
57. YZ-plane X-coordinate chief differential trace
58. YZ-plane Y-coordinate chief differential trace
59. YZ-plane Z-coordinate chief differential trace
60. YZ-plane L-dircos chief differential trace (after interaction)
61. YZ-plane M-dircos chief differential trace (after interaction)
62. YZ-plane N-dircos chief differential trace (after interaction)
63. XZ-plane L-dircos chief differential trace (before interaction)
64. XZ-plane M-dircos chief differential trace (before interaction)
65. XZ-plane N-dircos chief differential trace (before interaction)
66. YZ-plane L-dircos chief differential trace (before interaction)
67. YZ-plane M-dircos chief differential trace (before interaction)
68. YZ-plane N-dircos chief differential trace (before interaction)
69. XZ-plane X-coordinate marginal differential trace
70. XZ-plane Y-coordinate marginal differential trace
71. XZ-plane Z-coordinate marginal differential trace
72. XZ-plane L-dircos marginal differential trace (after interaction)
73. XZ-plane M-dircos marginal differential trace (after interaction)
74. XZ-plane N-dircos marginal differential trace (after interaction)
75. YZ-plane X-coordinate marginal differential trace
76. YZ-plane Y-coordinate marginal differential trace
77. YZ-plane Z-coordinate marginal differential trace
78. YZ-plane L-dircos marginal differential trace (after interaction)
79. YZ-plane M-dircos marginal differential trace (after interaction)
80. YZ-plane N-dircos marginal differential trace (after interaction)
81. YZ-plane L-dircos marginal differential trace (before interaction)
82. YZ-plane M-dircos marginal differential trace (before interaction)
83. YZ-plane N-dircos marginal differential trace (before interaction)
84. XZ-plane L-dircos marginal differential trace (before interaction)
85. XZ-plane M-dircos marginal differential trace (before interaction)
86. XZ-plane N-dircos marginal differential trace (before interaction)
87. X-coordinate of cheif ray at object surface
88. Y-coordinate of cheif ray at object surface
89. XZ-slope angle, in radians, of the chief ray at the object surface
90. YZ-slope angle, in radians, of the chief ray at the object surface
91. Sequential number of the chief ray (from 1 to the maximum number of chief rays)
92. RAYCOD(1) (Ray failure code, 0 = no fail)
93. RAYCOD(2) (Surface where ray stopped)

The qualifier word "SWRITE" causes a subset this saved ray data to be written to a file named RAYHIST.DAT. One header line with the total number of rays in I10 format followed by the total number of surfaces in I4 format followed by the total number of field of view positions in I10 format. The header line is then followed (number of rays)x(number of the final surface+1) number of lines, each holding the following 14 data items:

Surface #
Sequential Ray #
1. Local X-coordinate
2. Local Y-coordinate
3. Local Z-coordinate
4. Angle of Incidence
5. Ray Energy Term
6. X-component of the Angle of Incidence
7. Y-component of the Angle of Incidence

8. X-coordinate of cheif ray at object surface
9. Y-coordinate of cheif ray at object surface
10. XZ-slope angle, in radians, of the chief ray at the object surface
11. YZ-slope angle, in radians, of the chief ray at the object surface
12. Sequential number of the chief ray (from 1 to the maximum number of chief rays)
13. RAYCOD(1) (Ray failure code, 0 = no fail)
14. RAYCOD(2) (Surface where ray stopped)

INTENSITY - The following command provides a way to generate a surface intensity file INTEN.DAT from the RAYHIST.DAT file

INTEN , i , n , D - The "INTEN" command is used to generate a program internal intensity map for surface "i" from the current RAYHIST.DAT file when it is written as a "short" ray history file using the "SWRITE" qualifier of the "RHIST" command and a SCENE.DAT scene file if one exists. The scene file is an ascii file which is used to assign a ray intensity multiplicative factor to each ray intensity value, based upon the FOB position of the starting multi-ray ray trace on the object surface. The format of the scene file is:

# of FOB positions (must match the number of FOB positions stored in the short RAYHIST.DAT file)
multiplicative factor for FOB #1
multiplicative factor for FOB #2
multiplicative factor for the last FOB

FOB #1 is the FOB with the most negative X and Y-FOB values. **Be carefull to remember whether "FANG" was set in the "SCY" and "SCX" reference object specification commands.**

FOB #2 is the FOB with the most negative Y-FOB value but with a lesser X-FOB value than FOB #1

The next to last FOB has the most positive Y-FOB value but a less positive X-FOB value than the last FOB value

The last FOB has the most positive X-FOB and Y-FOB values. The SCENE.DAT file is read as free format. If no SCENE.DAT file exists, a uniform scene with all multiplicative factors = 1.0 is assumed. "n" is the dimension of the 2-D intensity array. "D" is the side length of the intensity map in lens units. The intensity map is always square. The map is assumed to be centered at the local coordinate origin of the specified surface. Ray intensities, multipled by the cosine of the angle of incidence are then summed into this array. If a SCENE.DAT file exists, then the appropriate scene multiplicative factor, based upon the FOB of the current ray, will be multiplied into the intensity. The angle of incidence (or the average when more than one ray impacts an intensity grid square, is also stored, along with its X and Y-components. After the short RAYHIST.DAT file is processed, the following data is written to the ASCII file INTEN.DAT. The lower left hand corner (X=-D/2,Y=-D/2) of the array is designated by the indecies 1,1, the upper right corner (X=D/2), Y=(D/2) of the array is designated by the indecies n,n. The INTEN.DAT file comprises a header line followed by nxn entries of the form x-index , y-index , summed intensity, angle of incidence (or average of angles of incidence), X-component angle of incidence (or average of X-components of the angles of incidence), Y-component angle of incidence (or average of Y-components of the angles of incidence).

INTEN.DAT file sample follows:

i , n , D
1 , 1 , summed intensities, raw summed AOIs, raw summed X-AOIs, averaged intensity, averaged AOI, averaged X-AOI, averaged Y-AOI
1 , 2 , summed intensities, raw summed AOIs, raw summed X-AOIs averaged intensity, averaged AOI, averaged X-AOI, averaged Y-AOI
.
.
n , n , summed intensities, raw summed AOIs, raw summed X-AOIs, averaged intensity, averaged AOI, averaged X-AOI, averaged Y-AOI

The "INTEN" command also writes a file named RHFOOT.DAT to enable "footprint" type plots to be generated for the INTEN surface "i".

A report is also sent to the default output device. the report comprises:

FOB#, total summed intensity at surface i from that FOB, p-v intensity variation across surface, rms intensity variation across surface, number of rays stricking surface

The final line reports for all FOBs:

total summed intensity at surface i , p-v intensity variation across surface, rms intensity variation across surface, number of rays stricking surface

PLOT RHFOOT - The "PLOT RHFOOT" command causes a ray footprint plot to be generated from the current RHFOOT.DAT command. It assumes the surface is being viewed along its surface normal, so if the clear aperture is to be drawn, the "ORIENT , i , 1" command should be issued.