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Interim Report

Transfit

Finite Element Analysis Data Fitting Software

Prepared in accordance with DR# 3

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Prepared for:
George C. Marshall Space Flight Center
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Submitted by:
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Finite Element Analysis Data Fitting Software

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TransFit

Finite Element Analysis Data Fitting Software

Background

The Advanced X–Ray Astrophysics Facility (AXAF) Mission Support team has made extensive use of geometric raytracing to analyze the performance of AXAF developmental and flight optics. One important aspect of this performance modeling is the incorporation of Finite Element Analysis (FEA) data into the surface deformations of the optical elements. *TransFit* is software designed for the fitting of FEA data of Wolter I optical suface distortions with a continuous surface description which can then be used by SAO's analytic raytracing software, currently OSAC (Optical Surface Analysis Code).

The improved capabilities of TransFit over previous methods include:

- Bicubic spline fitting of FEA data to accomodate higher spatial frequency distortions.
- Fitted data visualization for assessing the quality of the fit.
- The ability to accomodate input data from three FEA codes plus other standard formats.
- Options for alignment of the model coordinate system with the raytrace coordinate system.

TransFit uses the AnswerGarden Graphical User Interface (GUI) to edit input parameters and then access routines written in PV–WAVE, C, and FORTRAN to allow the user to interactively create, evaluate, and modify the fit. Upon achieving a satisfactory fit to the data, an output file may be created. This file (a coefficient set) is then used as input data for the surface reflection module of the raytrace analysis code. SAO is currently developing a suite of raytrace modules which communicate using the UNIX "pipe" and may be combined as needed to model the performance of an x–ray system.

Summary of Topics

- Introduction to TransFit – Requirements, design philosophy, and implementation
- Design Specifics – Modules, parameters, fitting algorithms, data displays

- Procedural Example
- Verification of Performance – comparison of fitting techniques with exact and "known" models
- Future Work
- Appendices – Online help (man pages), raytrace results of verification section

1. Introduction

TransFit is a software package designed to *trans*late an FEA model of a Wolter type–I optic into a uniform data structrure, and then *fit* the resulting dataset with a either of two types of surface descriptons: (1) Legendre–Fourier polynomials, or (2) bicubic splines. The fit may then be viewed using several types of data displays for the purpose of evaluating the quality of the fit and, as necessary, iterating through the fit and display tasks to achieve the best overall fit. The software package is divided into three major sections, or *tasks*:

1. Reading in FEA node data and conditioning it (if necessary) for fitting.
2. Fitting the model data with one of the two algorithms.
3. Displaying the data.

Each task has an associated set of parameters which control the execution of that task. These parameters may be edited using the associated AnswerGarden *paramedit window*. This window lists and allows editing of the control parameters for the task, and has a set of action buttons to perform various functions related to the task. Most important of these is *run*, which starts execution of the task using the current parameter set. A detailed list and description of each task's parameters is provided in Section 2.

The TransFit input task (*xf_in*) has been designed to read several FEA data formats currently used on the AXAF program. These are ANSYS, I–DEAS, and NASTRAN. Currently, all the input read routines are designed for a standard ASCII output file from the FEA code (eg. NASTRAN 'punch file'). Some flexibility has been sacrificed in doing so for the sake of cross–platform transportability of the data. The model data can be of a full optic or a symmetric section, and once read in, the orientation of the optic can be adjusted to agree with the raytrace coordinate system.

The fitting task (*xf_fit*) takes the normalised and expanded dataset from the input task and fits it using one of two external fitting routines. The first is a Legendre–Fourier polynomial fit, using the COGEN routine from the OSAC raytrace program. The second is a periodic bicubic spline fit implemented using routines from the Data Approximation Subroutine Library (DASL). The significant parameters for both routines are the two controlling the number of terms fit in the two directions (axial and azimuthal).

The last task is one in which the fit is displayed, in some cases with the original data, to help in determining whether or not it models the data with sufficient fidelity. This has been extremely useful in optimizing and/or finding problems with the fit of a particular dataset. Once an optimum fit has been found, this task also creates an output file of the coefficients of the fit for use in the raytrace of the model.

2. Design Specifics

Input Model (xf_in)

This is the first of three main functional blocks, or tasks. It is designed to read in, normalize, and expand, if necessary, the FEA model data of an X–ray optic (cylindrical shell). It removes rigid body displacements for display purposes, since they often obscure significant high–order distortions. However, the data are stored with full displacement in-

formation for the output section of the *xf_display* task.

As mentioned in Section 1, there are read modules for ASCII files generated by three of the FEA codes currently being used for analysis of the AXAF optics:

1. ANSYS
2. NASTRAN
3. SDRC I–DEAS

Each requires that a filename be entered as the first parameter, and a text string selecting the appropriate file format as the second. The load case must also be specified for NASTRAN files if more than one are present in the data file. If data are available which can be used to determine the weighting factor to be applied to each data point (proportional to the area of the mirror surface associated with each node), an appropriate entry may be made in parameter 4. Provisions for conversion of the model data from inches and degrees to the internal representation (mm amd radians) are provided, as well as the ability to limit the node number range used. The nodal position data must be in cylindrical coordinates (r, θ, z), with the coordinate system z–axis aligned with the axis of the mirror shell. In the OSAC coordinate system the positive z direction points from source to focal plane, and the usual convention aligns the positive y–axis with the anti–gravity direction ("up"). The mirror coordinate system has the $\theta = 0$ axis aligned with the +x axis that completes the right–handed system.

The input data are normalized to the raytrace representation, in which the axial coordinates range from +1 to –1 and azimuthal coordinates in are angles in radians. It should be noted that the node list from the FEA dataset maps to the limits of the *optical surface* (ie. the nomalized axial position limits correspond to the front and back of the active optical surface.)

Since the FEA model frequently makes use of symmetry and only includes an azimuthal segment of the full optic, the next several parameters are used to control the expansion of the FEA model data to a full optic (0 to 2π radians), and to align the optic to the raytrace coordinate system. This includes entries for the size of the angular segment and whether or not the segment must be reflected along its axial edge. Simple 90° rotations and/or an end–for–end flip may be specified.

The mirror expansion process is as follows (in this order):

1. A check is performed to determine if the azimuthal limits in the FEA dataset match the entered **seg_size** parameter. If not, a warning message is printed, and the nodes are shifted to cover the full specified segment.
2. If the parameter **mirror** is set, the nodal data are mirrored about the edge of maximum azimuthal angle.
3. If the model is still less than a full 2π radians, the segment is repeated to create a full optic. It is assumed that n times the current segment size equals 2π, where n is an integer.
4. The full optic is rotated by +π/2 times the **rot_ang** parameter.
5. The optic is rotated end for end about the vertical (+y) axis if the boolean parameter **flip** is 'yes'.

This task is run by first entering the model parameters in the 'TransFit xf_in task' parameter–editor window. These are given default values if the file has not been run through this task before. If it has, the parameters are saved in a file named after the input data file (eg. foo_in.dat –> foo_in.par). All parameters with arrows next to the 'value' field require a value (except weight_data). The parameters with no arrow are for information only, and will be filled in by calculation in the task software.

Once the parameters have been satisfactorily entered, click the 'Run' button.

'Reload' re–reads the values from the .par file. 'Update' writes the values to the .par file. 'Update' is performed automatically when 'Run' is activated. 'Help' brings up an information window.

PARAMETERS

filename (ASCII string) – the name of the FEA data file to be translated by TransFit.

code (ASCII string) – the name of the analysis code used to generate the the input data file. Currently supported are ANSYS, NASTRAN, MIR (LVS mirror format), and DFD (OSAC COGEN input format).

load_case (integer) – the load case in the FEA data file to use as input for the model. Currently this is only supported in the NASTRAN input file format.

weight_data (ASCII string) – filename of the nodal weighting information for the fitting algorithm (ANSYS) or the subcase ID of the weight data (NASTRAN).

units (ASCII string) – the linear measurement units of the input data file [in|mm].

ang_units (ASCII string) the angular measurement units of the input file [deg|rad].

n_min (integer) – the minimum node number to be included from the dataset. Note that the node numbers in the data need not be contiguous. Also note that the data will only include those nodes with a weighting factor greater than 0 if the 'weight_data' parameter is used.

n_max (integer) – the maximum node number to be included from the dataset. The data will include all nodes between n_min and n_max, except as noted above under 'n_min'.

seg_size (real) – the angular segment of the input model data in degrees.

mirror (boolean [yes|no]) mirror the data along the model edge of maximum theta.

rot_ang (integer) rotate the optic by an integer multiple of 90 degrees, for aligning the model with the raytrace software coordinate system. (OSAC nominally uses a right–handed system where +Z points in the direction from the source to the focal plane, and +Y is up {anti– gravity}). Model 0 degrees should be aligned with the +X axis. An entry of zero (0) performs no action.

flip (boolean [yes/no]) – flip the axial coordinates of the optic. This is done by 'rotating' the optic about the vertical (theta = 90 degrees). Used to align model coordinate system with that of the raytrace code. This step is performed after all other coordinate tranformations.

The following are informational parameters created by the input routine, and should not be entered by the user:
mir_length (real) – the length of the optic in mm.
x_decen (real) – Horiz. decenter (microns).
y_decen (real) – Vertical decenter (microns).
x_tilt (real) – Horizontal tilt (arcsec).
y_tilt (real) – Vertical tilt (arcsec).
oval (real) – Ovalization (microns 0 to peak).

Fit Model (xf_fit)

This is the second of three main functional blocks (tasks). It is the computational heart of TransFit, in that it fits a surface to the data points (Legendre–Fourier or bicubic splines) with user defined granularity.

'Fit Model' uses the OSAC routine 'cogen' to fit Legendre–Fourier polynomials to the dataset, or fitting routines from the Data Approximation Subroutine Library (DASL) to perform a periodic bicubic spline fit. The number of terms in each direction (axial and azimuthal) can be adjusted for the best fit by adjusting parameters **cnt_ax** and **cnt_az**. The third task, 'Display Model', allows the user to display the fit in several ways. The usual procedure is to fit the data, display it using the most use-

ful of the display modes, adjust the fit parameters, and continue cycling between the 'Fit' and 'Display' until you are satisfied with the fit quality. The RMS error is an indicator of the fit quality (but not always a reliable one, since it evaluates the fit only at the input data points, and does not show a poor result if the data are "overfit").

For fitting with Legendre–Fourier polynomials, the first two parameters correspond to the number of Legendre and Fourier polynomial terms, respectively. As mentioned above, the actual fit is performed by writng the data to a temporary file and issuing a shell command to run 'cogen'. The resulting coefficient dataset is then read back into TransFit to be used for the subsequent display task. For more detailed information on the operation of 'cogen' and fitting with Legendre–Fourier polynomials in general, consult the OSAC manual, esp. sections 4.7 and 5.9.

In spline fitting the first two parameters correspond to the number of "knots" in the two directions, thus defining a rectangular grid of panels for which the surface description in each is a single polynomial bicubic, and the "joints" between panels are continuous up thru the second derivative. These "knots" are placed using a simple algorithm in the DASL software based on the input dataset positions (see information on the routines *B1KE* and *B1KPE* in the DASL manual). If the number of azimuthal knots (**cnt_az**) is an even multiple of 12, the knots are placed in the same relative position for each 30 degree segment of the mirror, based on the twelvefold symmetry of the structure. Note that this does not necessarily create an identical *fit* for each segment. The actual fitting is done using the DASL routine *B2FPE*, which "provides a least squares fit to a given set of data points specified at arbitrary positions". Although the algorithm allows the choice of the degree of the polynomial spline surface, the implementation here fixes it to be bicubic (order = 4). Once the fit has been performed, coefficients for the the partial derivatives with respect to z and θ are determined using routines *B2DPZE* and *B2DPTE*. Evaluation of the surface at any position is performed using the module *B2VPRE*.

Communication between the TransFit software and these external modules is handled using the Remote Procedure Call (RPC) model, with a C interface program 'spline_server' handling requests from the TransFit PV–WAVE client and calling the appropriate FORTRAN subroutines. The server is started automatically when TransFit begins, and is killed upon exiting.

Parameters

cnt_ax (integer) – The axial order in the fitting equation, as well as the display density for the grid produced by the fit. If the Legendre–Fourier fitting technique is used, this is the order of the Legendre polynomial. If the bicubic spline fit is used, it is the number of 'knots' in the axial direction. The limit is 31 axial knots for the spline fit, and a total of 500 Legendre–Fourier coefficients for the COGEN fit.

cnt_az (integer) – The azimuthal order in the fitting equation, as well as the display density for the grid produced by the fit. If the Legendre–Fourier fitting technique is used, this is the maximum value of n in the SIN/COS(n*theta) If bicubic spline fitting is used, it is the number of 'knots' in a fully symmetric segment of the model (usually **after** mirroring, but **before** replication of a segment). In addition, if an even multiple of 12 is used, the knots are placed such that the relative placement in each 30° segment of the model is identical. The limit is 72 azimuthal knots per fitted segment for the spline fit.

gridder (ASCII string) – The fitting algorithm [splinelcogen] used to procuce a continuous description of the mirror surface from the FEA data. A choice of 'cogen' uses Legendre–Fourier polynomials of order 'cnt_ax' and 'cnt_az' respectively, as above. It uses the COGEN routine from the OSAC suite. For more details, see the OSAC Users manual. A choice of 'spline' produces a fit based on bicubic splines periodic in 2π radians, with the number of 'knots' in each direction specified by

'cnt_ax' and 'cnt_az'. The routines are based on FORTRAN subroutines from the Data Approximation Subroutine Library (DASL) and accessed via a server process called 'spline_server'. It is responsible for reading coefficients, fitting, and evaluating data, and is normally running as a background process in the 'WaveBaby' window.

refit (boolean[yes|no]) – The fitting process normally stores fit data in a coefficient file named foo#cnt_ax#cnt_az.[DFR|SPL] for an FEA data file named foo.dat, where cnt_ax and cnt_az are the integer values of the above parameters. Files ending in '.DFR' are produced by a 'cogen' fit, whereas '.SPL' indicates a spline fit. If there is already a coefficent file of the requested order and type, the program will normally read in the coefficients rather than performing a new fit. However, selecting 'yes' for this parameter will force a new fit of the data, and overwrite the previous coefficient file.

c_file (ASCII string) – The name of the coefficient file produced by the fitting routine. This file is named as described in the refit parameter above. The fitted surface is the model data *without rigid body distortions (ie. tilt and decenter),* since these tend to mask the higher order terms and make patterns in many of the display modes more difficult to interpret. A recommended technique is to use this file as the raytrace coefficient file (once a proper fit has been demonstrated), with rigid body terms taken as needed from the input .par file and added in as raytrace parameters.

rms_err (real) – A calculated parameter of the RMS error between displacement data and fit for all of the FEA nodes, in mm.

Display Model (xf_display task)

This is the third of the three main functional blocks. It is designed to be used in conjunction with the xf_fit task to obtain the best fit to the dataset. Its purpose is to provide the user with a variety of displays of data and fit to help the user iterate to the best fit. The usual procedure is to fit the data, display it using the most useful of the display modes, modify the fitting parameters, and then continue cycling between the 'Fit' and 'Display' tasks until satisfied with the fit quality.

To run this task, enter the model parameters in the 'TransFit xf_display task' parameter–editor window. When the window is initially opened these contain the values used during the last 'TransFit' session.

The display modes available within this task are PV–WAVE display routines customized for the display of distortions of the cylindrical optic. Most are primarily useful for a qualitative assessment of the fit. The 'slice' mode (see the **display** parameter description below) provides a more quantitative and detailed picture of the distortions. All displays are also available as hardcopy output by setting the **hardcopy** parameter.

Once a satisfactory fit has been achieved, the boolean **output** parameter is changed to 'yes', and after displaying the deformed surface in the specified manner, an output file of the specified type is created *with the rigid body distortions (ie. tilt and decenter) included.* This requires re–running the appropriate fitting software on the data, and consequently will take a noticeable interval to complete. If an output file without rigid body deformations is desired, the file produced by the xf_fit task may be used (see parameter **c_file** in the 'xf_fit' task..

Parameters

display (ASCII string [surface|slice|shade|polys]) – The type of data display for the fit. (1) 'surface' produces a 3D surface plot of the fit result, the grid having a mesh density based on the cnt_ax and cnt_az parameters of the xf_fit task. The plotted variable can be displacement, axial slope, or azimuthal slope, depending on the value of 'surf_type'. The individual data points are the normalized and expanded original data. (2) 'slice' creates three windows. The first shows the FEA mesh, and allows the user to select a location (using the left–mouse

button) to "slice" thru the optic to examine the fit in both the axial and azimuthal directions. The "row" and "column" of nodes related to the node nearest the cursor will be selected as the axial and azimuthal cuts for fit evaluation. The other two windows show these results. Clicking the middle–mouse button indexes thru the possible displayed variables (displacement, axial slope, or azimuthal slope). Right–mouse exits this display task. (3) 'shade' shows a 3D plot of the cylindrical optic, with an overlayed "fringe" plot of the displacements in the chosen colormap. (4) 'polys' shows a 3D plot of the cylindrical optic in polygon form, with each colored for its average displacement.

scale (real) – The plotting range for the distortion axes of 'surface' and 'slice' plots in mm. The range will be centered at the median displacement. If the value is zero (0.0), the display(s) autoscale.

a_scale (real) – The plotting range for the slope axes 'surface' and 'slice' plots in arcsec. The range will be centered at the median slope. If the value is zero (0.0), the display(s) autoscale.

surf_type (integer [1–3]) – Selector for the displayed data if 'surface' is chosen for 'display' (parameter 1).
1 –> Displacement (delta R)
2 –> Axial Slope
3 –> Azimuthal slope

hardcopy (boolean[yes|no]) – If selected, produces a PostScript file containing a plot of the selected display type. 'shade' and 'polys' produce color PostScript. The parameter is automatically reset to 'no' after one pass thru to avoid inadvertant overwriting of files.

output (boolean[yes|no]) – If 'yes' creates a coefficient file of the selected type of fit (see output_type). The data are refit with the rigid body effects included and the coefficients written to a file named in 'outfile'. An entry is also made to the database 'TransFit.rdb' detailing the parameters used in the creation of the fit, consisting of the current values used for both the xf_in and xf_fit tasks.

output_type (ASCII string [MIR|DFR|SPL]) – Selects the type of coefficient file to produce. Currently, only 'DFR' and 'SPL' are used and refer to Legendre–Fourier and Bicubic Spline fits respectively.

outfile (ASCII string) – The name of the coefficient file that is produced when 'output' is set to 'yes'. A default name of foo.[DFR|SPL] is set by the software for an input data file named foo.bar, but the user may enter any appropriate filename string.

x_win_size (integer) – The horizontal size of the main data display window, in pixels.

y_win_size (integer) – The vertical size of the main data display window, in pixels.

color_tab (integer[0–15]) – The PV–Wave color table to be used for the display window. 0 is a grayscale. Experiment with the others.

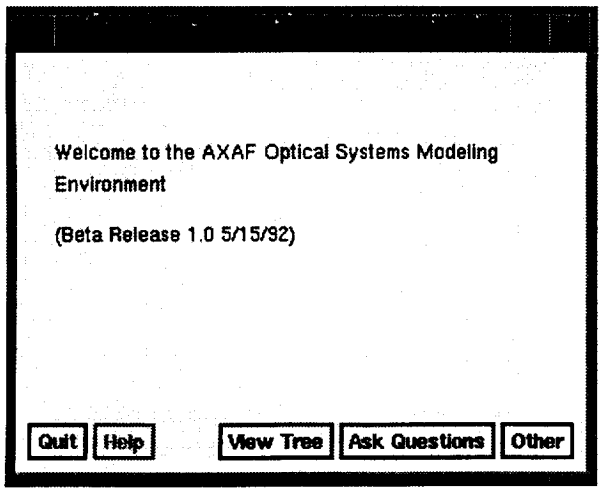
3. Procedural Example

TransFit utilizes an X–window based user interface called the AnswerGarden to handle the majority of the interaction between the user and the software. When TransFit (XF) is started, by typing

XF [FEA_filename]

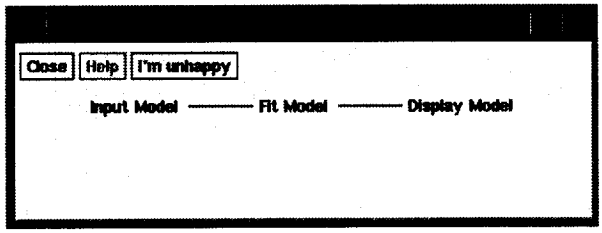
the following window, called the *Control* window will appear. This window contains two buttons that are important to the functioning of TransFit: (1) View Tree, which opens the next window containing a tree structure for the three main tasks, and (2) Quit, which performs an orderly shutdown of the software.

Two iconified windows will also appear during this startup. The first it called "Transfit", and is the window where the parameter set (pset) and other commands are executed by the parameter editor. The other window, "WaveBaby", is where the PV–



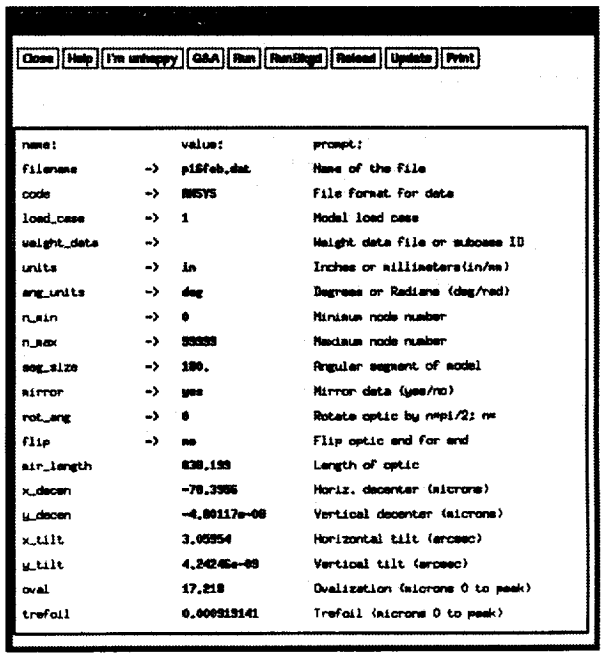
WAVE process and the spline fitting server program (spline_server) are run. These may be opened to provide more infomation on the status of TransFit during operation.

Pressing the 'View Tree' button (using left–mouse) brings up the next window, called the *Root Grapher.*



If the cursor is moved over the text describing the three tasks (graphed sequentially to indicate the normal order of processing), a box will appear around the task name. Clicking the left–mouse button will bring up the *parameter editor* window for that task.

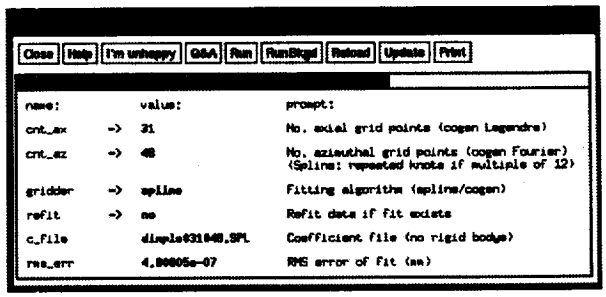
The parameter editor window for the first task (xf_fit) is shown here. Each of the parameters described in the preceding section can be entered or edited in this window. Simply move the cursor over the parameter to be edited, and use the normal command line editing functions to edit the value. If you are beginning with a new FEA data file, the filename you entered in the XF command will bw shown as the first parameter. The other values will be the defaults. Typically, the values for the node range, segment size, and whether or not to mirror the data must be edited. The last several parameters (without the arrows after the parameter name) are meant to be in-



formational, and will be filled in as the module executes.

Once all of the parameters have been entered satisfactorily, the 'Run' button will begin execution of the task. An information window will be placed on the display showing the status. If the module completes without errors, this will be stated in this widow for a few seconds before the window disappears, otherwise the TransFit error message will be posted to the window.

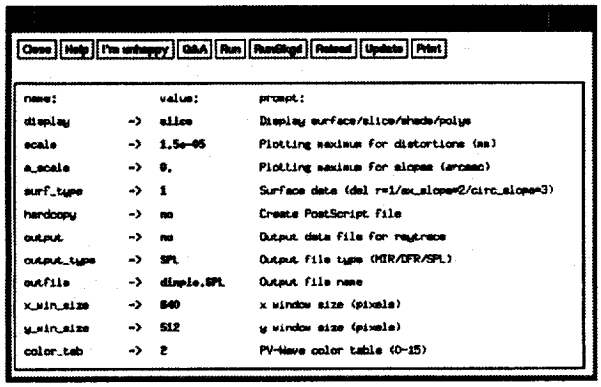
Once the data has been read in satisfactorily, click on the 'Fit Model' box of the grapher window. This will bring up the xf_fit task parameter editor. Enter



the parameters for the fit desired, usually the axial and azimuthal grid density and the type of fit. Clicking 'Run' will perform some setup within PV–WAVE and then call the appropriate external program to perform the fit.

RMS error is displayed as a calculated parameter at the end of the xf_fit task paramedit window. This value may be useful in judging the quality of the fit; however, it should be noted that the result is based on the fit quality at the input data positions, and will not reflect certain types of errors (eg. "ringing" due to overfitting). These effects may be assessed using the graphical tools in the xf_display task.

Clicking on 'Display Model' in the grapher window brings up the last of the three task parameter editor windows. As in the xf_fit task, the parameter values



are those that were entered the last time the task was executed, with the exception of the options for hardcopy and file output, which are always reset to "no" after use to avoid inadvertant overwriting of files. In general, first make a selection for the type of data **display**, set the **scale** and **a_scale** parameters to zero to allow the software to autoscale, and then click 'Run'. Parameters may then be modified to refine the display or look at the results in a different way. If the fit quality appears satisfactory (usually based on a final assessment using "slice"), change the output flag to "yes" and the output filename, if desired, and run it one last time to create the output coefficient file. Note that the file is written *last*, and so is not created until after the display execution completes.

If the fit is not satisfactory, click again on the 'Fit Model' task in the grapher window. If the xf_fit task window had been closed after fitting, it will be reopened. If still open, it is "popped" to the front by the window manager. Modify the fittng parameters appropriately, rerun, and re–assess using the xf_diplay task until the best fit is achieved, at which point a coefficient file may be output.

4. Validation and Comparison of Results

The use of Legendre–Fourier (L–F) coefficients for the fitting of low spatial frequency distortions of X–ray optics has long been the accepted technique. SAO has used them as the way of incorporating the Finite Element Analysis data of the optics and related structures since OSAC was first used here, using a module called COGEN. Eastman Kodak has similarly used CYLFIT for several generations of their raytrace software. There are several major features that make the use of L–F series attractive:

1. The Fourier series is inherently circularly periodic, ideal for fitting the cylindrical shape of the optics.
2. The individual coefficients have a readily understandable physical meaning (eg. $P_1(z)$ = "tilt")
3. The coefficients are orthonormal, facilitating the addition of coefficient sets of differing order.

Some drawbacks exist, however. The polynomial basis is not well suited to irregularly gridded data, as is typical with the AXAF optics, which are supported by relatively small areas of the mirror elements. The FE model is based on a surface description which is continuous only within the boundaries of an element (the element *shape function*), and meets certain conditions relative to the neighboring elements (slope continuity, for example). A direct approach based on element shape functions has been undertaken by V. Genberg of EKC (Ref.1) for their CYGNUS raytracing software. This technique provides the raytrace code with an exact description of the FEA modeled surface. However, it is limited at the current time to certain element shapes and a very regular FEA grid, since each element type has a different solution for the shape functions. It is also very slow in raytrace execution, due in part to the need to search for the

appropriate element at each surface intersection calculation.

Bicubic spline fitting of the FEA data closely approximates the underlying model, since it fits discrete regions with bicubic splines (*panels*, separated at *knots*). The knots can be more closely spaced in the regions of more data (and generally more rapid changes in displacement). This flexibility allows the fit more freedom in the needed areas, without creating instability in regions of sparse data. In contrast to the element shape function technique, there are no significant restrictions placed on the FEA modeler in terms of element types or gridding. The periodicity requirement can be dealt with by forcing matched boundary conditions at the edges.

A well known example has been chosen to illustrate some of the advantages that have been found for spline fitting of the surface deformations of X–ray optics vs. the traditional L–F technique. The Eastman Kodak NASTRAN model of the VETA–1 in the X–ray calibration facility (xrcfp1cell.pch, xrcfh1cell.pch) has been used extensively for both performance prediction and as a test case for the various features of TransFit, and to contrast the differences between Legendre–Fourier polynomials and the bicubic spline fit.

The raytrace simulations done during the VETA–1 test were done with L–F polynomials using 6 Legendre terms and 24 Fourier terms. An indication of the fit provided by these polynomials is shown in Figure 1. The FEA data are plotted as crosses, and the solid line is the COGEN fit. The data and fits shown here are azimuthal and axial locations that were particularly difficult to fit to best illustrate the fitting problems. It can be seen that although the fit is reasonably good, there are areas where it is not capable of following the higher frequency distortions. The effect of this error is a 'smearing' of the local distorions due to the mirror support pads over a greater portion of the surface.

It would appear from the fit to the above data that increasing the number of Legendre terms would improve the fidelity to the original data. Figure 2 shows the same data with the Legendre order increased to 10. Although the RMS fit to the data has improved and the azimuthal fit is better, note that the axial slope is becoming less representative of the mirror surface. The limited data are allowing the behaviour to become oscillatory in the area most strongly affecting the imaging performance (axial slope).

Figure 3 illustrates the bicubic spline fit to these data at the same axial and azimuthal positions, using 48 azimuthal and 11 axial knots. The fit is significantly better, especially in the areas immediately surrounding the pads, without producing the unwanted oscillations in the axial direction.

A better illustration of the differences in fit over the entire mirror is shown Figures 4 and 5. Fig. 4is an illustration of the COGEN fit of the VETA–1 1g model, as in Figure 1, exaggerated and gridded onto cylindrical shell. Fig. 5 is the bicubic spline fit of the same data, as in Fig. 3. Note the much larger 'dimples' of the L–F fit, and the loss of some of the finer detail that can be seen in the spline fit.

A comparison of raytrace results for these two representations of the VETA–1 1g model surfaces (see Appendix B) shows what might be expected by comparing Figs. 4 and 5. The 90% encircled energy diameters of the image spots are very similar, but there is significantly more fine detail in the spline–fit case, extending further from the image core.

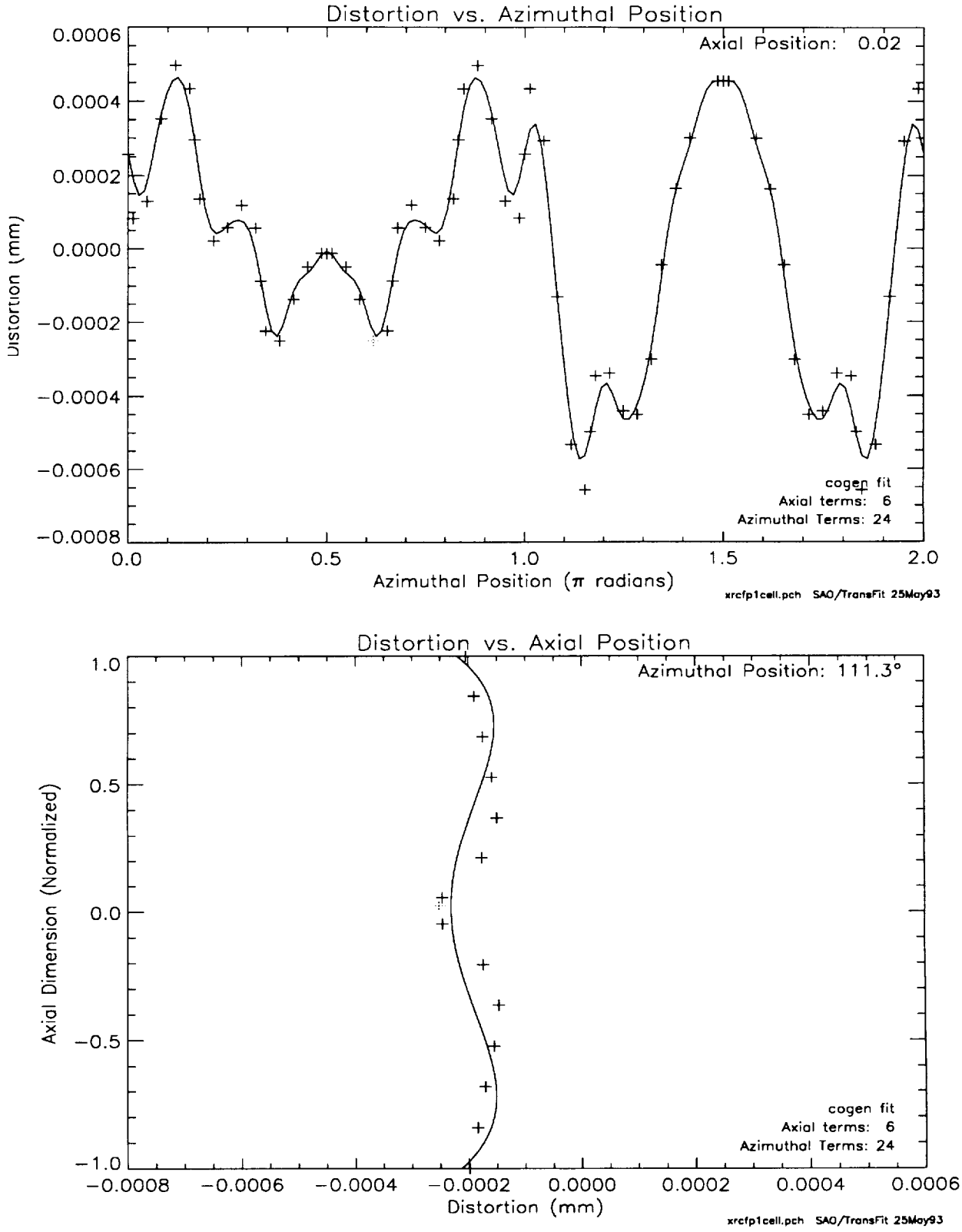


Figure 1 – Data (xrcfp1cell.pch) and COGEN fit

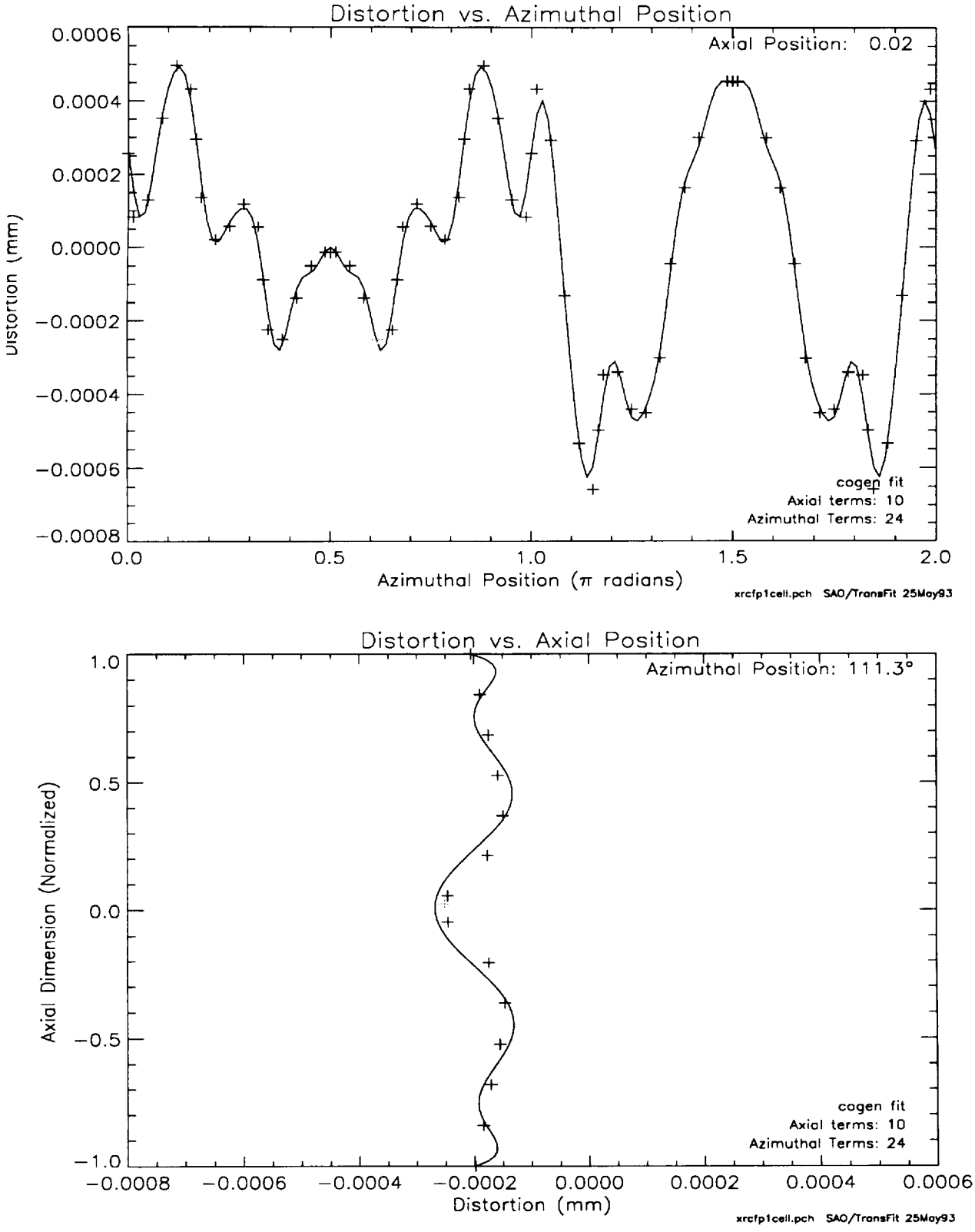


Figure 2. Data (xrcfp1cell.pch) and COGEN (10,24) fit

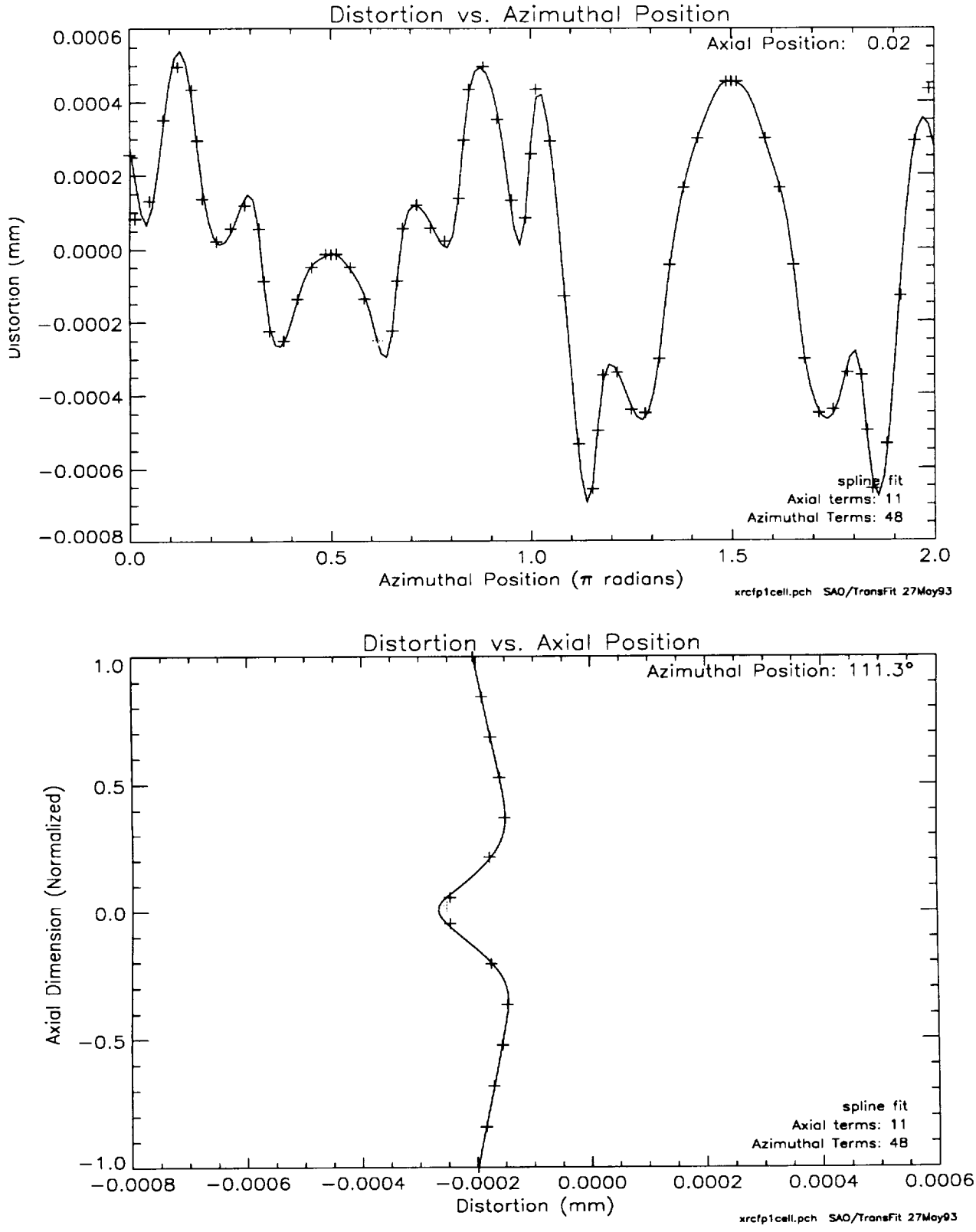


Figure 3 – Data (xrcfp1cell.pch) and spline fit

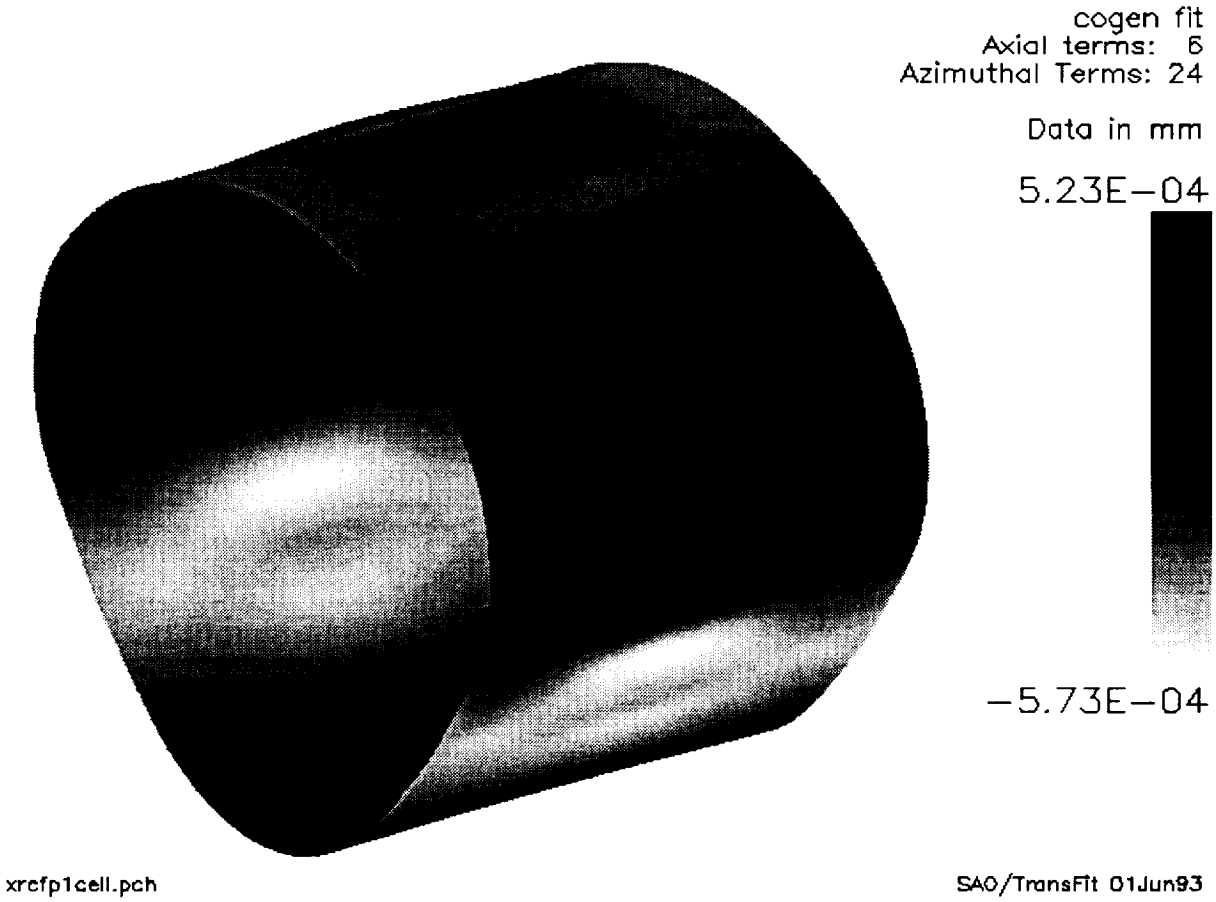


Figure 4. Shaded surface representation of the P1 optic in the VETA–1 1g environment – COGEN fit.

It should be emphasized that the fits shown here, and indeed fits of most new FEA models, are arrived at by trial and iteration; this is the strength of the TransFit software. It allows the user to easily try many different combinations of fitting techniques, axial and azimuthal orders to search for the "best" fit. Without a universal metric for the evaluation of the fitted data, human interaction has proven to be the most reliable means of acheiving the desired result.

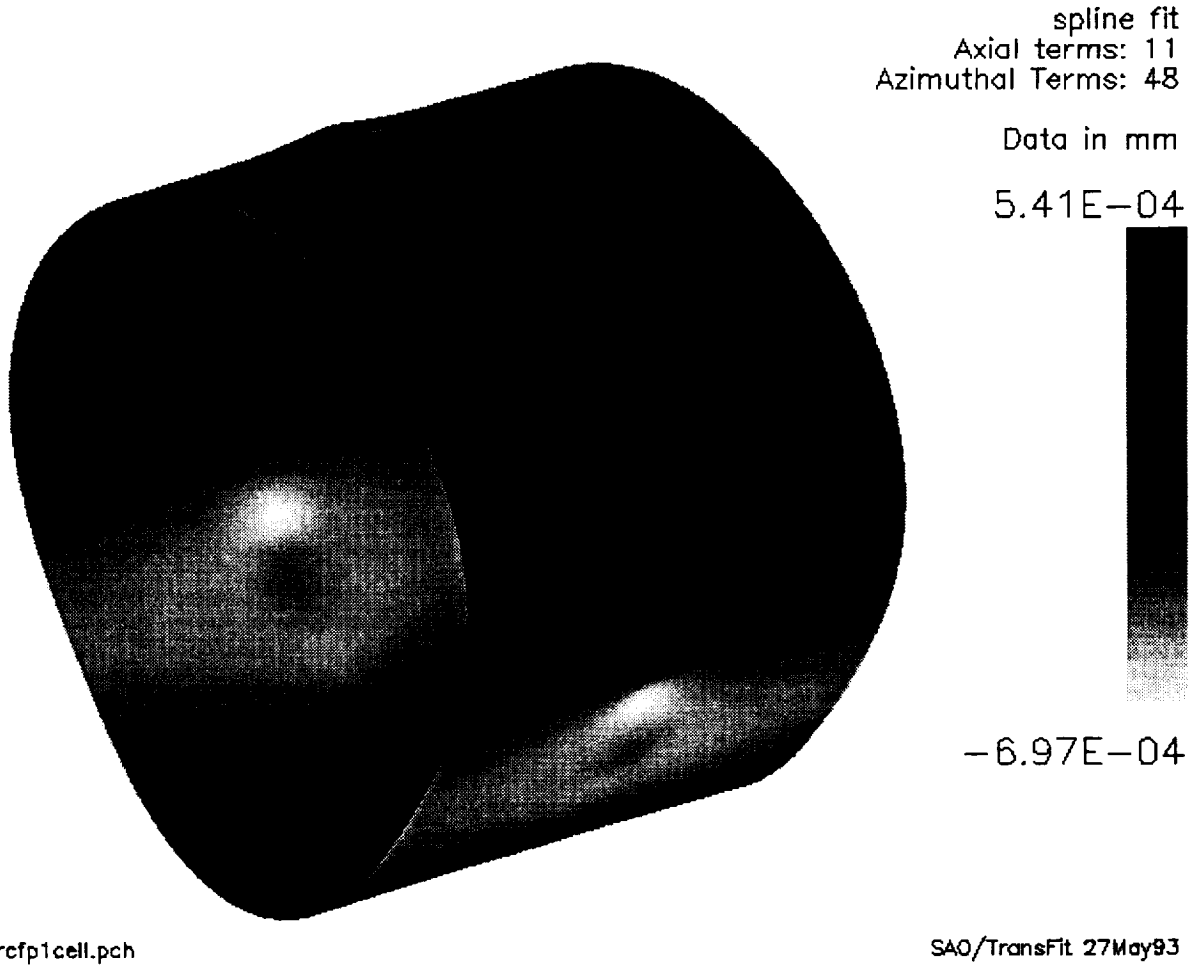


Figure 5. Shaded surface representation of the P1 optic in the VETA–1 1g environment – Spline fit.

5. Future Work

TransFit provides the needed tools for fitting all of the FEA data file types currently used on AXAF. However, these are ASCII files produced by the user, and subject to variability related to user options. In the case of the I–DEAS modeling software, there exists an ASCII "Universal file", which has a specific format that would provide a more stable input to the software. The I–DEAS input module will be rewritten to take advantage of this.

Eastman Kodak Co., in their CYGNUS software, uses a direct application of the FEM element shape functions to model the deformed surface. SAO intends to add a module to TransFit to allow the evaluation of this technique, as well as create a dense grid of data points, such that this grid could be fit with either of the standard techniques for raytracing, This would allow SAO to accurately compare raytrace models by minimizing the effects of data fitting,

Appendix A

UNIX Man pages for TransFit

NAME

xf_in - XF model input task using the AnswerGarden

DESCRIPTION

xf_in is the task that reads model input data into a structure array, then normalizes and expands it as necessary to a full mirror model for subsequent fitting (xf_fit). The underlying code uses PV-WAVE routines to perform its functions. The fitted data are ultimately used as input to a raytrace program (eg. OSAC). The operation of xf_in is controlled by a parameter file which is edited as necessary with the AnswerGarden parameter editor widget. The last seven parameters are intended as informational and are set by the program as the data are fit.

The parameters used by the xf_in task are as follows:

filename (ASCII string)
the name of the FEA data file to be translated and fit by TransFit.

code (ASCII string[ANSYS|NASTRAN|IDEAS|MIR|DFD])
the name of the analysis code file format of the input data file. Currently supported are ANSYS, NASTRAN, IDEAS, MIRROR, and DFD (OSAC COGEN input format). Note that the MIRROR and DFD input formats do not include some data about the original physical optic (ie. length, radius) that affects scaling of slope information in the display programs. The nominal length (842.2 mm) is inserted in the parameter file.

load_case (integer)
the load case in the FEA data file to use as input for the model. Currently this is only supported in the NASTRAN input file format.

weight_data (ASCII string)
filename of the nodal weighting information for the fitting algorithm (ANSYS) or the subcase ID of the weight data (NASTRAN).

units (ASCII string)
the linear measurement units of the input file (in/mm)...

ang_units (ASCII string)
the angular measurement units of the input file (deg/rad).

mir_length (real)
the length of the optic in mm. This is created by the input routine, and need not be entered by the user (see the 'code' entry above for special cases).

n_min (integer)
the minimum node number to be included from the dataset. Note that the node numbers need not be contiguous.

n_max(integer)
the maximum node number to be included from the dataset. The data will include all nodes between n_min and n_max.

seg_size (real)
the angular segment of the input model data in degrees.

mirror (boolean [yes|no])
mirror the data along the model edge of maximum theta.

rot_ang (integer)
rotate the optic by an integer multiple of 90 degrees, for aligning the model with the raytrace software coordinate system. (OSAC nominally uses a right- handed system where +Z points in the direction from the source to the focal plane, and +Y is up {anti- gravity}). Model 0 degrees should be aligned with the +X axis. An entry of zero (0) performs no action.

flip (boolean [yes|no])
flip the axial coordinates of the optic. This is done by 'rotating' the optic about the vertical (theta = 90 degrees). Used to align model C.S. with raytrace code C.S.

mir_length (real - read-only)
The length of the optic as determined by the nodal positions, in mm.

x_decen (real - read-only)
The x decenter of the optic in mm, as determined by COGEN.

y_decen (real - read-only)
The y decenter of the optic in mm, as determined by COGEN.

x_tilt (real - read-only)
The x tilt of the optic in arcsec, as determined by COGEN.

y_tilt (real - read-only)
The y tilt of the optic in arcsec, as determined by COGEN.

oval (real - read-only)
The average ovalization of the optic in mm, as determined by COGEN.

trefoil (real - read-only)
The average trefoil of the optic in mm, as determined by COGEN.

FILES

$AGBINDIR/xf_in
$UPARM/xf_in.par
$WAVE_USER/transfit.pro

SEE ALSO

xf_fit, xf_display, XF

BUGS

Probably many.

PROBLEMS or QUESTIONS: email mfreeman@cfa or call 5-7395.

NAME

xf_fit - XF model fitting task using the AnswerGarden parameter interface.

DESCRIPTION

xf_fit is the task that fits normalized model data with Legendre-Fourier polynomials (using OSAC **cogen**) or periodic bicubic splines (using NAG DASL). Prior reading, expanding, and normalising of the data must be performed using the **xf_in** task. The fitted data is ultimately used as input to a raytrace program (eg. OSAC). The operation of xf_fit is controlled by a parameter file which is edited as necessary with the AnswerGarden parameter editor widget.

The parameters used by the xf_fit task are as follows:

cnt_ax (integer)

The axial order in the fitting equation. If the Legendre-Fourier fitting technique is used, this is the order of the Legendre polynomial. If the bicubic spline fit is used, it is the number of 'knots' in the axial direction.

cnt_az (integer)

The azimuthal order in the fitting equation. If the Legendre-Fourier fitting technique is used, this is the maximum value of n in the SIN/COS(n*theta) If the bicubic spline fit is used, it is the number of 'knots' in the azimuthal direction **per fully symmetric segment**. If an even multiple of 12 is selected, the placement of the knots is uniform per 30 degree segment.

gridder (ASCII string [spline|cogen])

The fitting algorithm used to procuce a continuous description of the mirror surface from the FEA data. Selecting 'cogen' uses Legendre-Fourier polynomials of order routine from the OSAC suite. For more details, see the OSAC Users manual. The choice of 'spline' produces a fit based on bicubic splines periodic in azimuth, with the number of "knots" in each direction specified by 'cnt_ax' and 'cnt_az'. The routines are based on FORTRAN subroutines from the Data Approximation Subroutine Library (DASL) and accessed via a server process called 'spline_server'. It is responsible for reading coefficients, fitting, and evaluating data, and is normally running as a background process in the "WaveBaby" window.

refit (boolean [yes|no])

The fitting process normally stores fit data in a coefficient file named foo#cnt_ax#cnt_az.[DFR|SPL] for an FEA data file named foo.dat, where cnt_ax and cnt_az are the integer values of the above parameters. Files ending in '.DFR' are produced by a 'cogen' fit, whereas '.SPL' indicates a spline fit.

If there is already a coefficent file of the requested order and type, the program will normally read in the coefficients rather than performing a new fit. However, selecting 'yes' for this parameter will force a new fit of the data, and overwrite the previous coefficient file.

rms_err (real)

A read-only parameter of the calculated RMS error between displacement data and fit for all of the FEA nodes, in mm.

FILES

$AGBINDIR/xf_fit
$OSACDIR/spline_server
$UPARM/xf_fit.par
$WAVE_USER/xf_fit.pro

SEE ALSO

xf_in, xf_display, XF

BUGS

Probably many.

PROBLEMS or QUESTIONS: email mfreeman@cfa or call 5-7395.

NAME

xf_display - XF model display task using the AnswerGarden

DESCRIPTION

xf_display is the task that displays the model data vs. the fit to that dataset. It is necessary to have a full mirror model generated by **xf_in** and subsequent fitting by **xf_fit** before running the xf_display task. The underlying code uses PV-WAVE routines to perform its functions. The operation of xf_display is controlled by a parameter file which is edited as necessary with the AnswerGarden parameter editor widget.

There are four major types of data display available within this task. They are described in some detail in the description of the first parameter (*display*) below. The first four parameters control the actions of some or all of these basic display formats (eg. axis ranges, values displayed). The next four deal with the various types of output available using this task. The final three control window/display parameters to allow customization of the display. The parameters used by the xf_in task are as follows:

display (ASCII string [surface|slice|shade|polys])

Type of data display for the fit. **surface** produces a 3D surface plot of the fit result, the grid having a mesh density based on the cnt_ax and cnt_az parameters of the xf_fit task. The plotted variable can be displacement, axial slope, or azimuthal slope, depending on the value of 'surf_type'. The individual data points are the original data. **slice** creates three windows. The first shows the FEA mesh, and allows the user to select a location (using left mouse button) to "slice" thru the optic to examine the fit in both the axial and azimuthal directions. The other two windows show these results. The middle mouse button indexes thru the displayed variable (displacement, axial slope, or azimuthal slope). Right-mouse exits this display task. Note that if *output* (see below) is requested, the file will not be created until this display task is exited. **shade** shows a deformed 3D plot of the cylindrical optic, with an overlayed "fringe" plot of the displacements in the chosen colormap. **polys** shows a 3D plot of the cylindrical optic in polygon form, with each colored for its average displacement.

scale (real)

The plotting range for the distortion axes of 'surface' and 'slice' plots in mm. The range will be centered at the median displacement.

a_scale (real)

The plotting range for the slope axes 'surface' and 'slice' plots in arcsec. The range will be centered at the median slope.

surf_type (integer [1-3])

Selector for the displayed data if 'surface' is chosen for **display** (parameter 1).

1 -> Displacement (delta R)
2 -> Axial Slope
3 -> Azimuthal slope

hardcopy (boolean[yes|no])

If selected, produces a PostScript file containing a plot of the selected display type. 'shade' and 'polys' produce color PostScript. The parameter is automatically reset to 'no' after each pass thru to avoid inadvertant overwriting of files.

output (boolean[yes|no])

If 'yes' creates an fit coefficient file of the selected type (see output_type). The data are refit **with the rigid body effects included** and the coefficients written to a file named in 'outfile'. An entry is also made to the database 'TransFit.rdb' detailing the parameters used in the creation of the fit. The parameter is automatically reset to 'no' after each pass thru to avoid inadvertant overwriting of files. Note that the best way to incorporate rigid body effects in OSAC is to add them via the '.gi' file parameters, and to use the file automatically produced by xf_fit (no rigid body effects).

output_type (ASCII string [MIR|DFR|SPL])

Selects the type of coefficient file to produce. Currently, only 'DFR' and 'SPL' are used and refer

to Legendre-Fourier and Bicubic Spline fits respectively.

outfile (ASCII string)
The name of the coefficient file that is produced when 'output' is set to 'yes'. A default name of foo.[DFR|SPL] is set by the software for an input data file named foo.dat, but the user may enter any desired filename string.

x_win_size (integer)
The horizontal size of the main data display window, in pixels. The secondary windows of the 'slice' display type are sized to match.

y_win_size (integer)
The vertical size of the main data display window, in pixels. The secondary windows of the 'slice' display type are sized to match.

color_tab (integer[0-15])
The PV-Wave color table to be used for the display window. 0 is a grayscale. Experiment with the others (2 and 4 are nice).

FILES

$AGBINDIR/xf_display
$UPARM/xf_display.par
$WAVE_USER/xf_display.pro

SEE ALSO

xf_in, xf_fit, XF

BUGS

Probably many.

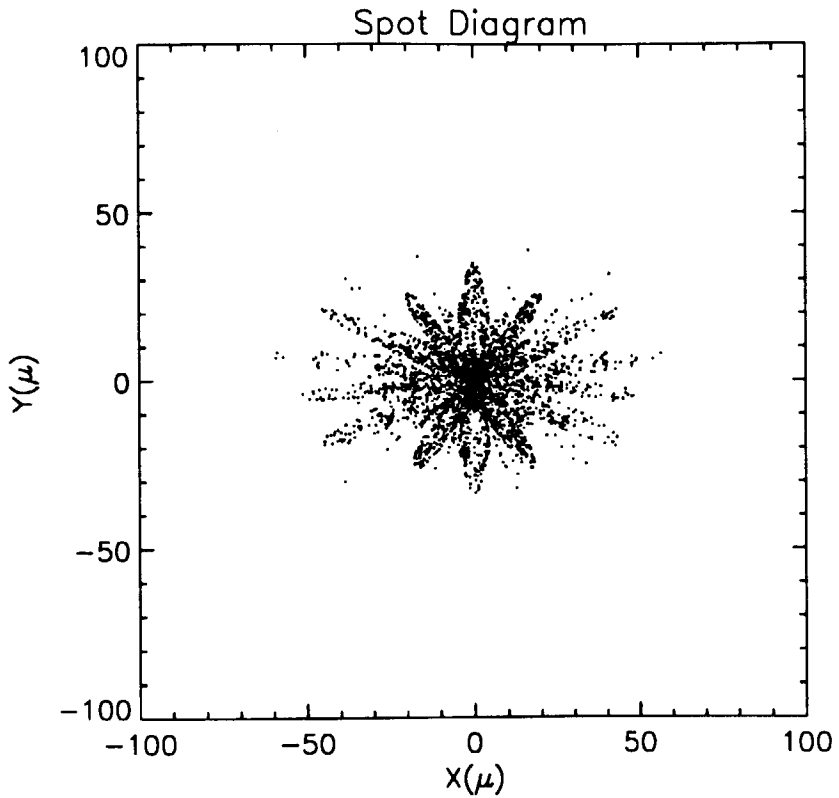
PROBLEMS or QUESTIONS: email mfreeman@cfa or call 5-7395.

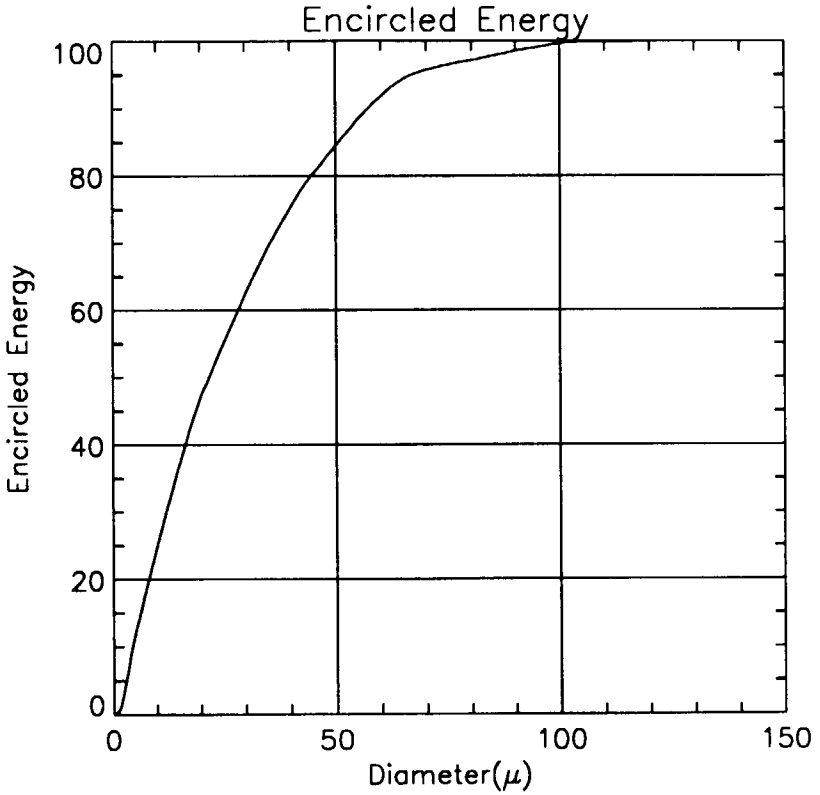
Appendix B

Raytrace results comparison of Legendre–Fourier and Bicubic Spline fits of the Eastman Kodak XRCF 1g model

Mon Jun 7 13:53:39 EDT 1993

Mark_cog.gi.rays





Total Rays: 9502

Plot center(X,Y): 0.00μ, 0.00μ, Image centroid(X,Y): −0.14μ, 0.01μ

90% Encircled Energy diameter: 57.11μ (about image centroid)

RMS Diameter: 33.46μ (about plot center)

RMS Diameter: 33.46μ (about image centroid)

SAO

Mark_cog.gi - VETA-I p1h1 with COGEN deformations

EOF WHILE READING GI FILE

SUMMARY OF DEFORMATION COEFFICIENTS

xrcfh1cell.pch SAO/TransFit 07Jun93

TOTAL NUMBER OF COEFFICIENTS	=	294
NUMBER OF LEGENDRE TERMS	=	6
AZIMUTHAL INDEX LIMIT	=	24
INDEX OF LARGEST CONTRIBUTION	=	25
LARGEST CONTRIBUTION	=	9.8792010E-05
ROOT SUM SQUARE	=	1.4350469E-04
SUM OF THE WEIGHTED SQUARES	=	2.0593595E-08

THE DEFORMATION COEFFICIENTS:

3.44896E-08	5.69271E-09	-8.28056E-08	-4.25919E-08	5.16602E-08
4.26932E-08	3.19064E-11	2.34974E-14	-5.21978E-12	1.90055E-13
3.20161E-12	3.58876E-14	1.35624E-05	3.83458E-07	-4.69473E-08
2.98745E-08	1.43135E-07	-3.42748E-08	1.63507E-12	6.97792E-14
5.16318E-13	-1.68939E-13	-5.24491E-13	1.14348E-13	1.39713E-04
1.30063E-05	-4.39053E-05	-6.29752E-07	8.42553E-06	1.83637E-08
6.27688E-12	7.00860E-13	-4.90715E-12	-2.92503E-14	2.90358E-12
-1.49519E-14	-9.74263E-07	-1.14503E-07	8.14004E-07	1.23152E-08
-2.62461E-07	1.39769E-08	1.67512E-12	3.95026E-13	-2.01400E-12
-4.65132E-13	1.80897E-12	3.33179E-13	1.01515E-05	3.97068E-07
-2.22487E-05	-4.34765E-07	1.51968E-05	1.63543E-07	-8.97743E-13
1.00555E-13	1.54355E-12	-5.52376E-13	-1.32715E-12	4.17024E-13
1.70896E-07	1.08793E-08	-3.95602E-07	-3.56466E-08	2.58797E-07
2.84866E-08	6.30053E-13	2.93583E-13	3.08570E-12	-1.93174E-13
-2.35097E-12	3.30511E-14	1.56425E-07	1.15827E-08	-4.22002E-07
-7.06266E-08	3.25887E-07	7.03169E-08	-5.71892E-12	-2.79213E-13
6.25347E-12	3.75743E-13	-3.72112E-12	-1.84154E-13	9.89846E-08
-5.46440E-09	-2.73598E-07	6.94400E-08	2.15778E-07	-7.75353E-08
-8.04429E-13	1.45915E-13	1.83704E-13	3.23006E-13	7.20386E-14
-8.74121E-13	-2.66923E-06	-3.47523E-08	8.08545E-06	6.73321E-08
-6.91270E-06	-3.81265E-08	-6.73695E-12	-8.05627E-13	2.32363E-12
3.69867E-13	-5.53728E-13	1.99592E-13	-2.20019E-07	-1.80941E-09
6.63527E-07	-7.23126E-09	-5.63572E-07	1.00131E-08	3.80544E-13
-5.62939E-14	2.81771E-12	4.40636E-13	-2.62791E-12	-5.92570E-13
1.13063E-06	-3.26888E-10	-3.46006E-06	9.74431E-08	2.99560E-06
-1.14772E-07	-2.05874E-12	-1.56375E-13	3.16503E-12	2.78823E-13
-2.43009E-12	-1.60537E-13	3.05078E-08	7.39915E-09	-9.59863E-08
-6.63973E-08	8.41375E-08	7.11445E-08	2.88738E-13	2.18389E-13
-2.60486E-12	4.40481E-13	2.40259E-12	-5.58758E-13	4.66845E-08
1.33144E-09	-1.45152E-07	-8.75620E-09	1.26752E-07	9.38410E-09
3.55072E-07	1.25158E-06	-7.85310E-05	-1.96705E-06	1.86998E-05
2.59988E-07	-1.22803E-12	-1.61555E-13	2.29672E-12	-8.30815E-14
-1.51056E-12	1.76552E-13	1.24309E-04	8.71441E-06	-5.36509E-06
4.38817E-09	2.54126E-06	-2.24908E-08	-3.74957E-12	-3.57370E-13

Mark_cog.gi - VETA-I p1h1 with COGEN deformations

RAY SUMMARY REPORT

CURRENT SURFACE (# 0)

STARTED		FAILED		SUCCEEDED	
NUM	WEIGHT	NUM	WEIGHT	NUM	WEIGHT
9502	6593.84109	0	0.00000	9502	6593.84109

PLANAR OPTIMAL FOCUS

SUM WEIGHTS	X LOCATION	Y LOCATION	Z PLANE	SPOT SIZE
6.59384D+03	-1.39146D-04	3.16961D-05	0.00000D+00	1.67007D-02

GLOBAL OPTIMAL FOCUS

SUM WEIGHTS	X LOCATION	Y LOCATION	Z PLANE	SPOT SIZE
6.59384D+03	-1.38799D-04	3.31412D-05	2.12906D-03	1.67002D-02

Mark_cog.gi - VETA-I p1h1 with COGEN deformations

EOF WHILE READING GI FILE

SURFACE NUMBER = 1

IN BODY CENTERED COORDINATE SYSTEM:

GEOMETRIC CENTER	= -1.00000000000000D+06
RADIUS OF CURVATURE	= -8.93331135301314D+00
LEFT VERTEX	= -1.00000000000000D+30
RIGHT VERTEX	= 2.05915856505122D+04
LEFT GEOM FOCUS	= -1.00000000000000D+30
RIGHT GEOM FOCUS	= 2.05871189948357D+04
ECCENTRICITY	= 1.00000000000000D+00

IN STANDARD COORDINATE SYSTEM:

GEOMETRIC CENTER	= -9.99580900000000D+05
LEFT VERTEX	= -1.00000000000000D+30
RIGHT VERTEX	= 2.10106856505122D+04
LEFT GEOM FOCUS	= -1.00000000000000D+30
RIGHT GEOM FOCUS	= 2.10062189948357D+04
CONFOCAL DELTA	= 0.00000000000000D+00

SURFACE NUMBER = 2

IN BODY CENTERED COORDINATE SYSTEM:

GEOMETRIC CENTER	= 1.46335094974179D+04
RADIUS OF CURVATURE	= -8.95249216741193D+00
LEFT VERTEX	= 9.60337425618012D+03
RIGHT VERTEX	= 1.96636447386556D+04
LEFT GEOM FOCUS	= 9.59890000000000D+03
RIGHT GEOM FOCUS	= 1.96681189948357D+04
ECCENTRICITY	= 1.00088949023546D+00

IN STANDARD COORDINATE SYSTEM:

GEOMETRIC CENTER	= 1.59716094974179D+04
LEFT VERTEX	= 1.09414742561801D+04
RIGHT VERTEX	= 2.10017447386556D+04
LEFT GEOM FOCUS	= 1.09370000000000D+04
RIGHT GEOM FOCUS	= 2.10062189948357D+04
CONFOCAL DELTA	= -3.63797880709171D-11

GENERAL SYSTEM FOCUS = 1.09370000000000D+04

```
   5.13078E-12   -1.21259E-13   -3.72335E-12    2.83571E-13    1.03865E-05
1*** OPTICAL SURFACE ANALYSIS PROGRAM (DRAT2   ) RELEASE (05.0) MVII     PAGE   2
                                                                07-Jun-9 08:25:16
  Mark_cog.gi - VETA-I p1h1 with COGEN deformations
 ------------------------------------------------------------------------------
   2.89426E-07   -6.89743E-06    4.84780E-09   -1.61558E-06   -1.10383E-07
  -7.80512E-12   -1.77021E-14    7.32805E-12   -6.98290E-14   -5.29103E-12
   3.09682E-13   -6.83305E-06   -1.37357E-07    1.24283E-05    2.25710E-07
  -8.04033E-06   -2.05739E-07   -2.42936E-12    2.93181E-14    6.72831E-12
   2.11309E-13   -6.38537E-12    7.65609E-14   -2.55700E-06   -2.56865E-08
   5.84980E-06    9.84375E-08   -4.01349E-06   -8.54285E-08   -2.87376E-12
  -1.59114E-13    6.77400E-12    2.32330E-13   -4.32027E-12   -2.96748E-13
  -3.22861E-05   -5.05619E-07    8.54850E-05    2.33871E-06   -6.55036E-05
  -2.20710E-06    1.31142E-11    6.59160E-13   -6.23019E-12    1.46255E-13
   3.52051E-12   -8.71767E-13   -2.35465E-05   -3.49810E-07    6.71866E-05
   2.06470E-06   -5.47701E-05   -2.07808E-06    2.17320E-12   -1.13020E-13
  -5.26619E-12    1.28068E-13    3.69749E-12   -2.62678E-13   -9.29237E-07
  -1.40025E-08    2.81618E-06    1.01475E-07   -2.33001E-06   -1.02276E-07
   7.66858E-12   -1.41660E-13   -3.58834E-12    7.37018E-14    2.56735E-12
   5.77299E-14   -1.16996E-06   -1.75946E-08    3.56378E-06    1.28863E-07
  -3.06454E-06   -1.36044E-07    1.14742E-11    2.79521E-13   -1.25488E-12
   3.95275E-13   -2.12680E-14   -3.80345E-13   -8.87759E-07   -1.24895E-08
   2.71992E-06    9.17133E-08   -2.34165E-06   -9.69244E-08   -6.92492E-12
  -3.82431E-13    3.48599E-12   -3.15996E-13   -1.64287E-12    4.10544E-13
  -3.34312E-07   -5.09784E-09    1.01122E-06    3.94610E-08   -8.59582E-07
1*** OPTICAL SURFACE ANALYSIS PROGRAM (DRAT2   ) RELEASE (05.0) MVII     PAGE   3
                                                                07-Jun-9 08:25:16
  Mark_cog.gi - VETA-I p1h1 with COGEN deformations
 ------------------------------------------------------------------------------
  -4.10247E-08    3.03642E-12    2.27589E-13   -2.45402E-12   -2.11998E-13
   1.04400E-12   -2.48111E-13   -4.72351E-06   -7.41002E-08    1.46792E-05
   5.70486E-07   -1.28162E-05   -6.09866E-07    5.14716E-12   -1.93988E-13
   4.19472E-12    4.37260E-13   -2.93882E-12    1.69679E-13
1*** OPTICAL SURFACE ANALYSIS PROGRAM (DRAT2   ) RELEASE (05.0) MVII     PAGE   4
                                                                07-Jun-9 08:25:16
  Mark_cog.gi - VETA-I p1h1 with COGEN deformations
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                              RAY SUMMARY REPORT
                              ------------------


                            CURRENT SURFACE (#     1)

          STARTED                    FAILED                  SUCCEEDED
      NUM          WEIGHT        NUM          WEIGHT      NUM          WEIGHT

    10000     10000.00000       498       498.00000     9502      7986.26470
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Mark_cog.gi - VETA-I p1h1 with COGEN deformations

EOF WHILE READING GI FILE

SUMMARY OF DEFORMATION COEFFICIENTS

xrcfp1cell.pch SAO/TransFit 18May93

TOTAL NUMBER OF COEFFICIENTS	=	294
NUMBER OF LEGENDRE TERMS	=	6
AZIMUTHAL INDEX LIMIT	=	24
INDEX OF LARGEST CONTRIBUTION	=	163
LARGEST CONTRIBUTION	=	2.3438610E-04
ROOT SUM SQUARE	=	2.7625998E-04
SUM OF THE WEIGHTED SQUARES	=	7.6319578E-08

THE DEFORMATION COEFFICIENTS:

4.23959E-08	2.75069E-10	-9.27306E-08	1.87871E-09	4.65966E-08
-3.69379E-09	-7.79616E-12	1.51708E-13	-7.00549E-12	-2.73572E-13
4.95052E-12	4.13385E-13	1.83380E-05	2.96977E-08	-3.97607E-08
-3.66943E-09	1.61266E-07	2.62834E-09	5.76504E-12	-1.03352E-13
-1.11643E-12	-4.43194E-13	7.94788E-13	2.59243E-13	1.87806E-04
5.38117E-06	-4.79571E-05	-2.78651E-08	9.57569E-06	-1.81911E-07
-6.36164E-12	-1.75996E-13	3.70309E-12	1.68714E-14	-2.38026E-12
-4.03048E-13	-9.18488E-07	-3.65711E-08	5.92428E-07	2.12549E-09
-1.58541E-07	4.04795E-09	-9.37400E-12	-3.19865E-13	-8.62883E-13
-5.01724E-13	4.57358E-13	2.65494E-13	1.21431E-05	1.89651E-07
-2.55967E-05	-4.97795E-07	1.71342E-05	4.32347E-07	-2.79866E-12
-7.72657E-14	4.20736E-12	3.12536E-14	-2.24433E-12	2.68933E-14
2.64843E-07	5.24620E-09	-5.97605E-07	-1.46573E-08	3.82277E-07
1.10293E-08	-6.98391E-12	6.23335E-15	1.20671E-12	-5.52147E-14
-6.89464E-13	2.38094E-13	2.29357E-07	3.77186E-09	-6.01546E-07
-1.63428E-08	4.51931E-07	1.46829E-08	3.12079E-12	-2.52278E-13
4.10739E-13	-6.71742E-14	2.11247E-13	4.69532E-13	1.54404E-07
2.28347E-09	-4.27416E-07	-1.08584E-08	3.37761E-07	1.01109E-08
-4.42301E-12	-2.40569E-13	-4.74359E-12	-2.54944E-13	3.50056E-12
2.82500E-13	-3.18669E-06	-4.65051E-08	9.61383E-06	3.32532E-07
-8.17264E-06	-3.43514E-07	-3.66304E-13	-3.46563E-13	-2.98052E-12
-1.65347E-13	2.80597E-12	6.11175E-13	-2.28215E-07	-3.87077E-09
6.84829E-07	2.68095E-08	-5.79490E-07	-2.82134E-08	1.28767E-11
2.12269E-13	-1.09487E-12	1.93588E-13	9.89137E-13	-1.98494E-13
1.39099E-06	2.08743E-08	-4.24130E-06	-1.57047E-07	3.66057E-06
1.65103E-07	1.05805E-12	-2.28382E-13	-1.08110E-11	-3.51219E-13
8.39328E-12	4.26902E-13	5.38240E-08	4.39238E-10	-1.66252E-07
-2.21804E-09	1.42829E-07	2.22321E-09	5.39426E-12	1.73737E-13
-5.82068E-12	-4.27441E-13	4.16874E-12	2.05254E-13	6.34807E-08
1.15184E-09	-1.96804E-07	-9.34255E-09	1.71008E-07	1.00655E-08
1.09199E-06	9.45248E-08	-7.61554E-05	-3.74473E-07	1.68801E-05
-1.82297E-07	-2.90236E-13	3.92089E-13	5.60485E-12	-2.15577E-14
-3.88741E-12	-2.20135E-13	3.31472E-04	6.75986E-06	-1.10053E-05
8.50944E-08	5.93834E-06	-9.75198E-08	-6.47288E-12	-1.53220E-13

4.24475E-07	-3.25821E-06	-2.48277E-07	-1.17730E-06	7.18440E-08
-3.14155E-12	-4.93682E-13	-1.42822E-12	-2.69053E-13	1.29445E-12
2.15388E-13	-3.97074E-06	-2.28345E-07	7.57418E-06	2.37876E-07
-4.89034E-06	-1.66947E-07	-4.35208E-12	-3.99748E-13	7.01708E-12
3.38852E-13	-5.69782E-12	2.56175E-13	-1.09882E-06	-2.33997E-08
2.58569E-06	7.40813E-09	-1.81022E-06	2.56414E-08	-3.99088E-12
-2.41618E-13	9.59957E-12	2.15072E-13	-6.81713E-12	-5.23436E-13
-2.88058E-05	-9.02284E-07	7.76653E-05	2.17600E-06	-6.04035E-05
-1.52073E-06	-2.83191E-12	-1.23024E-13	-3.31662E-12	4.89923E-14
2.94926E-12	1.62336E-13	-2.09716E-05	-4.76633E-07	6.05090E-05
1.28504E-06	-4.97746E-05	-1.01548E-06	-1.84073E-12	-4.44485E-15
1.08403E-13	-1.82108E-13	6.18256E-13	1.14163E-14	-3.50062E-07
2.27667E-09	1.06580E-06	-5.19376E-08	-8.86390E-07	6.38140E-08
-1.44521E-13	-3.86516E-13	-1.11381E-12	-7.89489E-13	2.27996E-13
8.40604E-13	-6.27906E-07	-8.21738E-09	1.92363E-06	1.92774E-08
-1.66190E-06	-1.67726E-08	6.45283E-12	3.40612E-13	-7.55993E-12
-3.42173E-13	6.25307E-12	4.90930E-13	-4.95533E-07	-1.19850E-08
1.52625E-06	6.81086E-08	-1.31835E-06	-7.03858E-08	1.80947E-12
-8.51956E-14	-8.60327E-12	-6.91707E-13	6.54882E-12	5.85189E-13
-1.58301E-07	7.74803E-09	4.80248E-07	-8.24260E-08	-4.08806E-07

9.09245E-08	9.94312E-13	-2.29874E-14	-3.97004E-12	-3.16025E-13
3.10409E-12	2.33248E-13	-4.23815E-06	-2.72741E-08	1.31936E-05
-8.53436E-08	-1.15326E-05	1.04232E-07	5.92074E-12	1.93028E-13
-6.28208E-12	-6.47160E-13	5.17968E-12	7.87662E-13	

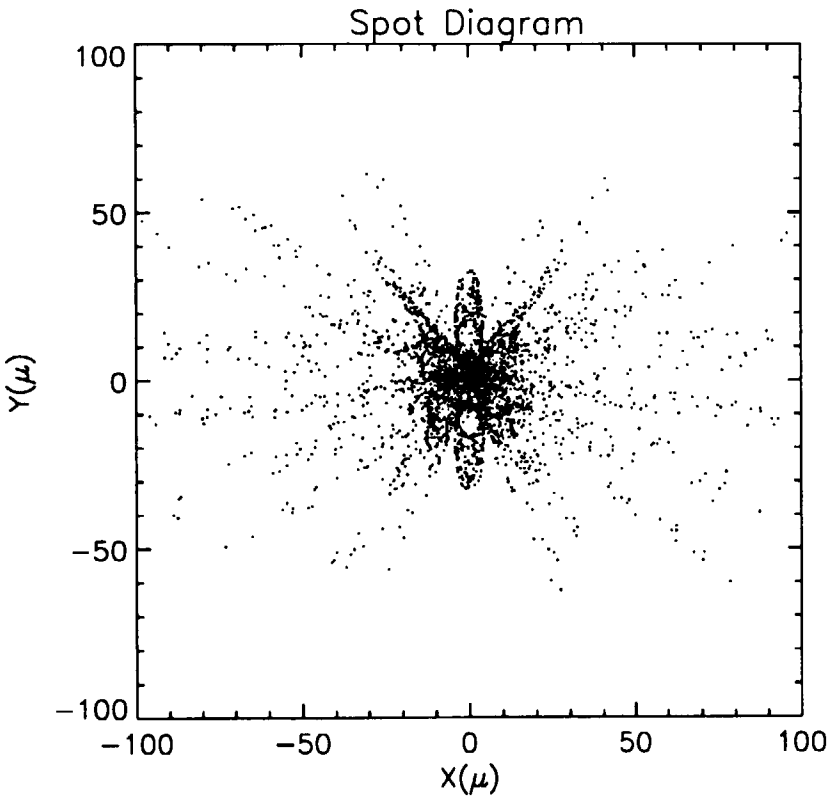
RAY SUMMARY REPORT

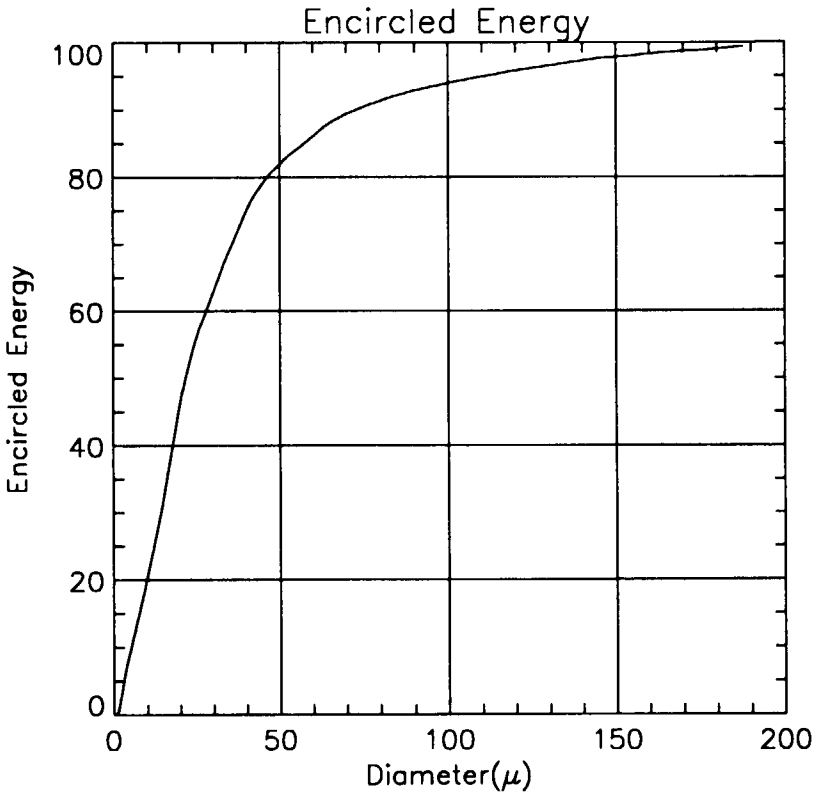
CURRENT SURFACE (# 2)

STARTED		FAILED		SUCCEEDED	
NUM	WEIGHT	NUM	WEIGHT	NUM	WEIGHT
9502	7986.26464	0	0.00000	9502	6593.84113

Mon Jun 7 13:56:09 EDT 1993

Mark_spl.gi.rays





Total Rays: 9487

Plot center(X,Y): 0.00μ, 0.00μ, Image centroid(X,Y): 0.07μ, −0.02μ

90% Encircled Energy diameter: 72.93μ (about image centroid)

RMS Diameter: 46.89μ (about plot center)

RMS Diameter: 46.89μ (about image centroid)

SAO

Mark_spl.gi - Perfect p1h1 with SPLINE deformations

EOF WHILE READING GI FILE

SUMMARY OF DEFORMATION COEFFICIENTS

TOTAL NUMBER OF COEFFICIENTS	=	611
NUMBER OF AXIAL KNOTS	=	9
NUMBER OF AZIMUTHAL KNOTS	=	47
MAXIMUM THETA OF FITTED SEGMENT	=	0.6283185E+01
LARGEST DISPLACEMENT COEFF.	=	0.9369930E-03
LARGEST AXIAL SLOPE COEFF.	=	0.3451063E-02
LARGEST AZIMUTHAL SLOPE COEFF.	=	0.7201053E-02

THE DEFORMATION COEFFICIENTS:

RAY SUMMARY REPORT

CURRENT SURFACE (# 1)

STARTED		FAILED		SUCCEEDED	
NUM	WEIGHT	NUM	WEIGHT	NUM	WEIGHT
10000	10000.00000	513	513.00000	9487	7973.65955

Mark_spl.gi - Perfect p1h1 with SPLINE deformations

EOF WHILE READING GI FILE

SUMMARY OF DEFORMATION COEFFICIENTS

TOTAL NUMBER OF COEFFICIENTS	=	611
NUMBER OF AXIAL KNOTS	=	9
NUMBER OF AZIMUTHAL KNOTS	=	47
MAXIMUM THETA OF FITTED SEGMENT	=	0.6283185E+01
LARGEST DISPLACEMENT COEFF.	=	0.6912550E-03
LARGEST AXIAL SLOPE COEFF.	=	0.3545293E-02
LARGEST AZIMUTHAL SLOPE COEFF.	=	0.6931599E-02

THE DEFORMATION COEFFICIENTS:

RAY SUMMARY REPORT

CURRENT SURFACE (# 2)

STARTED		FAILED		SUCCEEDED	
NUM	WEIGHT	NUM	WEIGHT	NUM	WEIGHT
9487	7973.65950	0	0.00000	9487	6583.45602

Mark_spl.gi - Perfect p1h1 with SPLINE deformations

EOF WHILE READING GI FILE

SURFACE NUMBER = 1

IN BODY CENTERED COORDINATE SYSTEM:

GEOMETRIC CENTER	= -1.00000000000000D+06
RADIUS OF CURVATURE	= -8.93331135301314D+00
LEFT VERTEX	= -1.00000000000000D+30
RIGHT VERTEX	= 2.05915856505122D+04
LEFT GEOM FOCUS	= -1.00000000000000D+30
RIGHT GEOM FOCUS	= 2.05871189948357D+04
ECCENTRICITY	= 1.00000000000000D+00

IN STANDARD COORDINATE SYSTEM:

GEOMETRIC CENTER	= -9.99580900000000D+05
LEFT VERTEX	= -1.00000000000000D+30
RIGHT VERTEX	= 2.10106856505122D+04
LEFT GEOM FOCUS	= -1.00000000000000D+30
RIGHT GEOM FOCUS	= 2.10062189948357D+04
CONFOCAL DELTA	= 0.00000000000000D+00

SURFACE NUMBER = 2

IN BODY CENTERED COORDINATE SYSTEM:

GEOMETRIC CENTER	= 1.46335094974179D+04
RADIUS OF CURVATURE	= -8.95249216741193D+00
LEFT VERTEX	= 9.60337425618012D+03
RIGHT VERTEX	= 1.96636447386556D+04
LEFT GEOM FOCUS	= 9.59890000000000D+03
RIGHT GEOM FOCUS	= 1.96681189948357D+04
ECCENTRICITY	= 1.00088949023546D+00

IN STANDARD COORDINATE SYSTEM:

GEOMETRIC CENTER	= 1.59716094974179D+04
LEFT VERTEX	= 1.09414742561801D+04
RIGHT VERTEX	= 2.10017447386556D+04
LEFT GEOM FOCUS	= 1.09370000000000D+04
RIGHT GEOM FOCUS	= 2.10062189948357D+04
CONFOCAL DELTA	= -3.63797880709171D-11

GENERAL SYSTEM FOCUS = 1.09370000000000D+04

Mark_spl.gi - Perfect p1h1 with SPLINE deformations

RAY SUMMARY REPORT

CURRENT SURFACE (# 0)

STARTED		FAILED		SUCCEEDED	
NUM	WEIGHT	NUM	WEIGHT	NUM	WEIGHT
9487	6583.45598	0	0.00000	9487	6583.45598

PLANAR OPTIMAL FOCUS

SUM WEIGHTS	X LOCATION	Y LOCATION	Z PLANE	SPOT SIZE
6.58346D+03	7.22617D-05	1.54299D-06	0.00000D+00	2.34057D-02

GLOBAL OPTIMAL FOCUS

SUM WEIGHTS	X LOCATION	Y LOCATION	Z PLANE	SPOT SIZE
6.58346D+03	7.20992D-05	1.15251D-06	-1.27916D-03	2.34056D-02