zygo®

Zernike

OMP-0383B

MetroPro Application

This booklet is a quick reference; it assumes that you are familiar with MetroPro software and the instrument. Information on MetroPro is provided in *Getting Started With MetroPro,* OMP-0398, and the *MetroPro Reference Guide*, OMP-0347. For information on the instrument, please refer to the Zygo manual included with your instrument.

The Zernike Application

The Zernike Application is designed for the advanced user who is evaluating wavefronts in terms of Zernike polynomials. It also provides controls for generating polynomials and wavefronts without the actual test optics. Wavefronts can be subtracted or added to current data sets.

> **Note:** Zernike analysis is for advanced users who are already familiar with Zernike polynomials and their interpretation.

The Zernike Application supports the Zygo GPI XP and the Mark IV*xp* interferometers. The application is licensed with standard MetroPro. For information on licensing, see the *Getting Started With MetroPro* manual.

The Zernike Application:

- Expresses optical aberrations in mathematical form.
- Provides the controls to generate theoretical wavefronts.
- Can be used to subtract Zernikes from another wavefront.

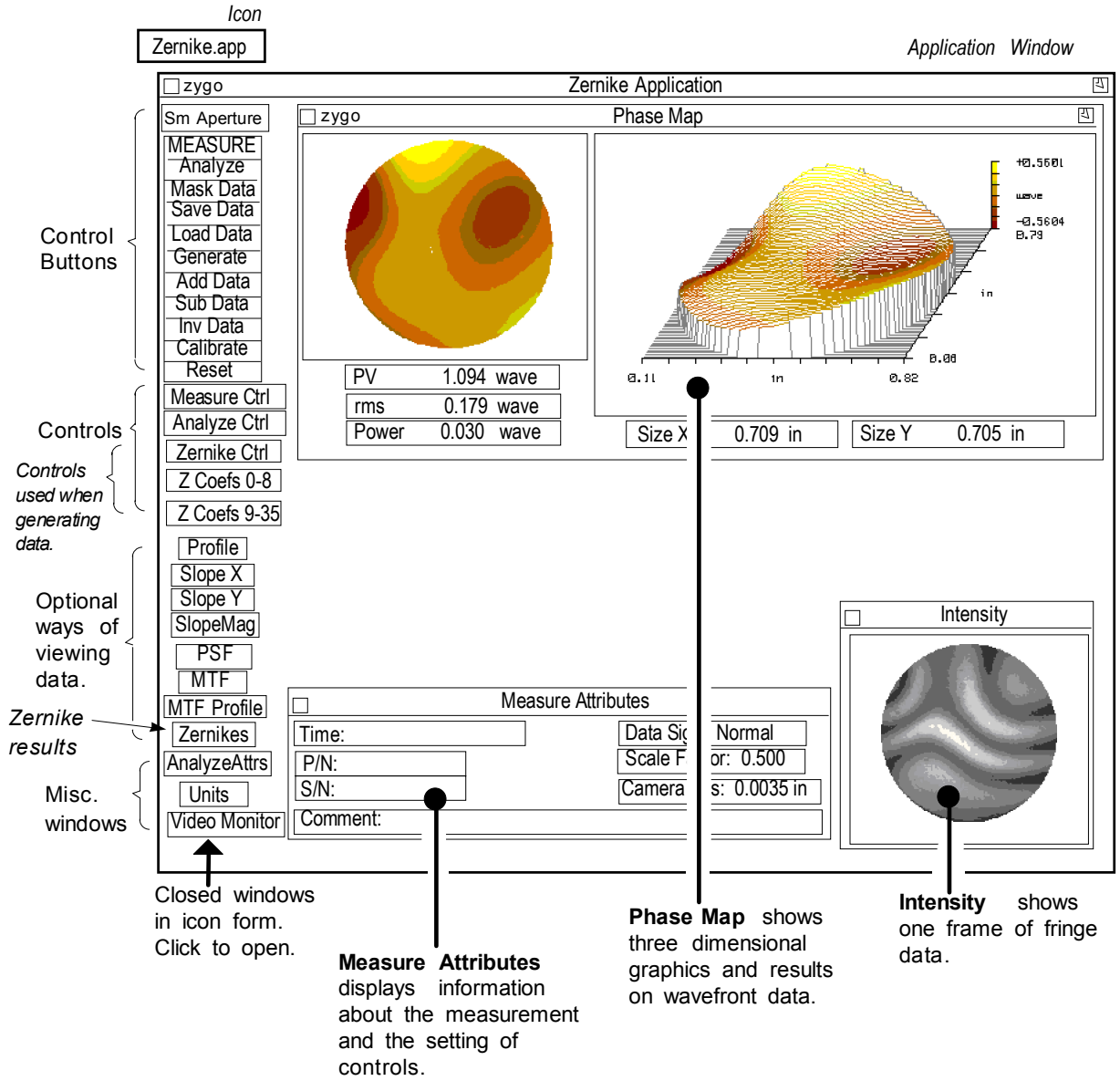
Purpose of Zernikes

It is often necessary to represent aberrations in an optical system in an organized manner, so that the nature of the aberrations is understood and to determine the effect upon an image. Zernike decomposition of optical system aberrations provides a technique for expressing aberrations in a useful mathematical form. Zernike polynomials are used for this purpose, since they are made up of terms that are a similar form as the types of aberrations often observed in optical tests.

The wavefront errors are fit by a least-squares method to the desired subset of all the possible Zernike polynomials. These polynomials are derived as a set of orthogonal polynomials within a unit circle. When the aperture is not circular, the polynomials are no longer orthogonal and the results may be erroneous.

The Application Screen

To start MetroPro, refer to the *Getting Started With MetroPro* manual. To open the application, click on the icon. If the icon is not on the MetroPro base window, then use the Load Application command from the MetroPro Window menu to first load the application icon.

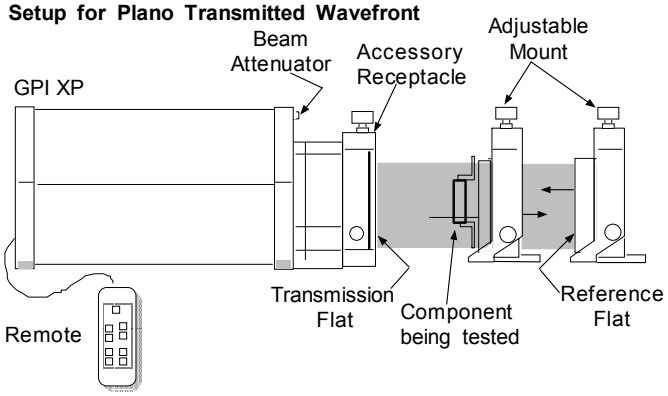


Making Measurements

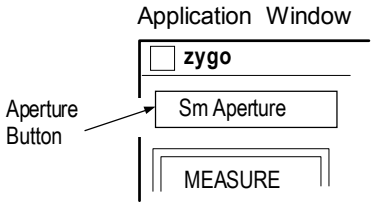
The information below is a quick overview of a sample measurement of transmitted wavefront. More complete information on making measurements is located in the instrument manual.

For transmitted wavefront quality evaluation, the measurement wavefront passes through the part and is reflected back by a reference mirror of known quality. The wavefront passes through the part a second time before entering the interferometer.

Typical Setup for Plano Transmitted Wavefront



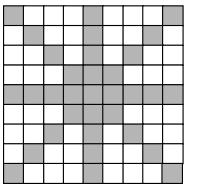
1. Push the interferometer beam attenuator knob in.
2. Install and align the transmission element.
3. Place the reference optic in an adjustable mount. Position and align the reference optic.
4. Place the test optic in another adjustable mount. Position the test optic between the transmission and reference optics. Align the test part.
5. Press the ALIGN/VIEW button on the remote. You should be able to see a fringe pattern on the video monitor. Fill the image area on the video monitor by pressing the ZOOM buttons on the remote.
6. Press the FOCUS buttons on the remote to adjust for the sharpest focus. Fine-tune the tip and tilt of the test optic to minimize the number of fringes.
7. Click on the Aperture button until it displays the aperture in use.
8. Click the Calibrate software button and calibrate the test setup.
9. Press F1 to measure. Zernike Polynomials are then calculated.



Software Controls and Results

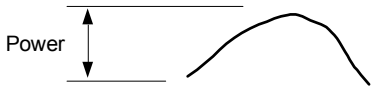
For items not listed, or for greater detail, refer to the *MetroPro Reference Guide*.

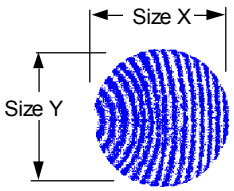
Control	*Function*
Zernike Terms	Specifies how many Zernike terms are analyzed and displayed in the Zernikes window. The choices are 3, 4, 9, 16, 25, or 36. The more terms, the longer the analysis.
Zernike Sample	Specifies the number of data points used in the Zernike calculation; it also reduces the processing time. The choices are 1, 2, 3, and 4. A setting of 1 includes all data points. A sample of 2, 3, and 4 are subsets, the shaded points are always included. Sample 2 is about 1/4 of the points. Sample 3 is about 1/9 of the points. Sample 4 is about 1/16 of the points.
Intf Scale Factor	Specifies the number of waves per fringe. The default setting of 0.5 corresponds to a double-pass interferometer setup, in which the measurement beam travels through the test item and then is reflected back through the item a second time.
Remove	Specifies the overall shape(s) to subtract from the data during analysis. It contains 6 buttons: PST (piston), TLT (tilt), PWR (power), AST (astigmatism), CMA (coma) and SA3 (spherical aberration). More than one button can be depressed. Remove uses a least-squares technique.
Trim	Specifies a number of pixel layers to remove from data edges and obscurations. The default setting is 0.



Result	*Description*
PV	PV is the height between the lowest and the highest point on the test part surface.
rms	Rms is the root-mean-square deviation of all points from a plane fit to the test part surface.
Power	A measure of the curvature of the surface or wavefront. Positive for a concave surface, negative for a convex.
Size X	Size X is the lateral dimension of the data set in X-axis.
Size Y	Size Y is the lateral dimension of the data set in Y-axis.

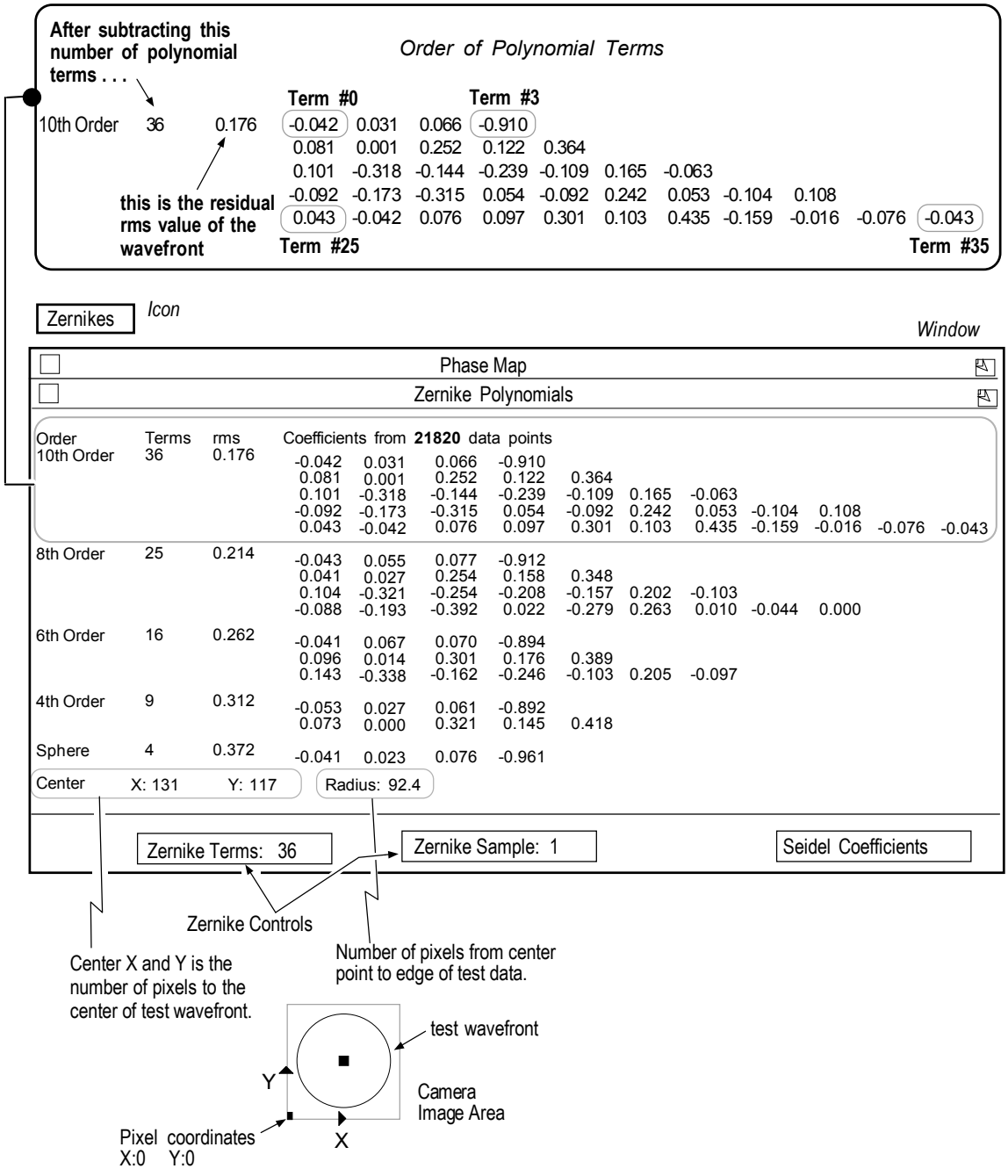






The Zernike Polynomials Window

Zernike polynomial terms are displayed in a Zernike result window. The layout of a sample window is illustrated below.



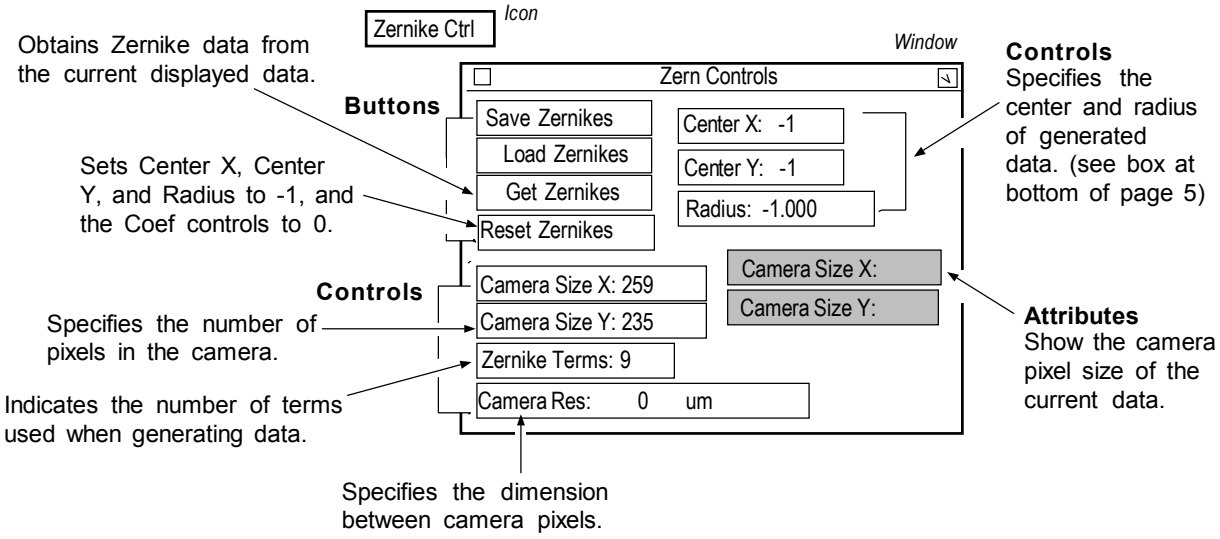
Zernike Polynomials

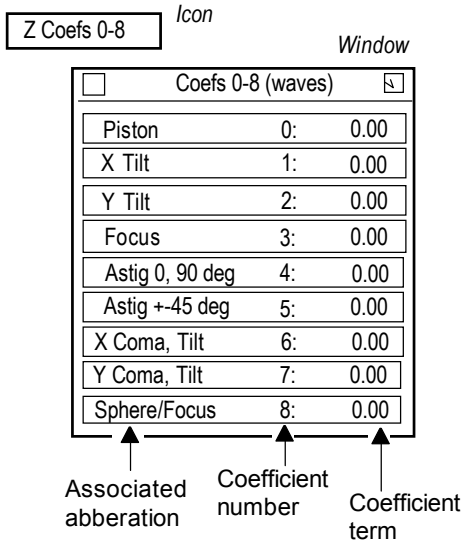
The polynomials themselves are listed below. In the table, f = polar coordinate angle, and r = radius (normalized to 1 at the edge of the aperture). The numbers in columns **m** and **n** are the indices for Zernike polynomials.

n	m	Term #	Polynomial	Meaning
0	0	0	1	Piston
1	+1	1	$\rho \cos \phi$	X Tilt
	-1	2	$\rho \sin \phi$	Y Tilt
	0	3	$2\rho^2-1$	Focus
2	+2	4	$\rho^2 \cos 2 \phi$	Astigmatism 0° or 90°
	-2	5	$\rho^2 \sin 2 \phi$	Astigmatism ±45°
	+1	6	$(3\rho^2-2)\rho \cos \phi$	X Coma and Tilt
	-1	7	$(3\rho^2-2)\rho \sin \phi$	Y Coma and Tilt
	0	8	$6\rho^4-6\rho^2+ 1$	Spherical and Focus
3	+3	9	$\rho^3 \cos 3 \phi$	
	-3	10	$\rho^3 \sin 3 \phi$	
	+2	11	$(4\rho^2-3)\rho^2 \cos 2 \phi$	
	-2	12	$(4\rho^2-3)\rho^2 \sin 2 \phi$	
	+1	13	$(10\rho^4-12\rho^2+3)\rho \cos \phi$	
	-1	14	$(10\rho^4-12\rho^2+3)\rho \sin \phi$	
	0	15	$20\rho^6-30\rho^4+12\rho^2-1$	
4	+4	16	$\rho^4 \cos 4 \phi$	
	-4	17	$\rho^4 \sin 4 \phi$	
	+3	18	$(5\rho^2-4)\rho^3 \cos 3 \phi$	
	-3	19	$(5\rho^2-4)\rho^3 \sin 3 \phi$	
	+2	20	$(15\rho^4-20\rho^2+6)\rho^2 \cos 2 \phi$	
	-2	21	$(15\rho^4–20\rho^2+6)\rho^2 \sin 2 \phi$	
	+1	22	$(35\rho^6-60\rho^4+30\rho^2-4)\rho \cos \phi$	
	-1	23	$(35\rho^6-60\rho^4+30\rho^2-4)\rho \sin \phi$	
	0	24	$70\rho^8-140\rho^6+90\rho^4-20\rho^2+1$	
5	+5	25	$\rho^5 \cos 5 \phi$	
	-5	26	$\rho^5 \sin 5 \phi$	
	+4	27	$(6\rho^2-5)\rho^4 \cos 4 \phi$	
	-4	28	$(6\rho^2-5)\rho^4 \sin 4 \phi$	
	+3	29	$(21\rho^4-30\rho^2+10)\rho^3 \cos 3 \phi$	
	-3	30	$(21\rho^4-30\rho^2+10)\rho^3 \sin 3 \phi$	
	+2	31	$(56\rho^6-105\rho^4+60\rho^2-10)\rho^2 \cos 2 \phi$	
	-2	32	$(56\rho^6-105\rho^4+60\rho^2-10)\rho^2 \sin 2 \phi$	
	+1	33	$(126\rho^8-280\rho^6+210\rho^4-60\rho^2+5)\rho \cos \phi$	
	-1	34	$(126\rho^8-280\rho^6+210\rho^4-60\rho^2+5)\rho \sin \phi$	
	0	35	$252\rho^{10}-630\rho^8+560\rho^6-210\rho^4+30\rho^2-1$	

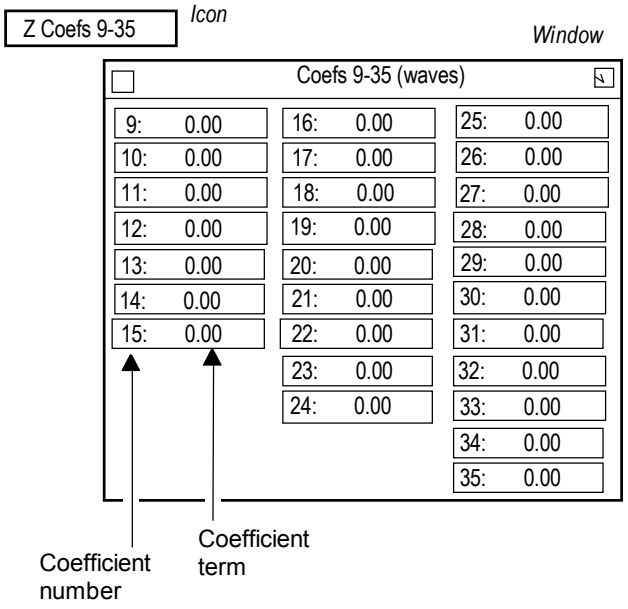
Generating Zernikes

Zernike polynomials can be generated from existing data which may be data from a measurement just made, or from phase data previously acquired; for example, from a two sphere test. Zernikes can also be generated from Zernike parameters and coefficients that you enter and then use to create the data. The buttons and controls used when generating Zernikes are shown below. Sample uses of these controls are described on the following pages.





Coefficient controls specify the Coefficient term when generating Zernikes or indicate the terms of the current data set if the Get Zernikes button was clicked.



For some Zernike measurement situations, it may be necessary to display results with more than the number of decimal places shown. To change the number of decimal places, select the Value Format command from the Control's Menu.

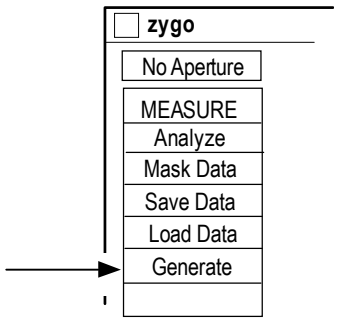
Generating Zernikes (continued)

To Generate Zernikes From a Current *Loaded Data Set*

1. Click on the Zernike Ctrl icon to open the Zernike Controls window.
2. Click the Get Zernikes button to create Zernike data from a current displayed measurement.
3. In the Zernike Controls window, set the Center X and Center Y values to -1.
4. Click on the Z Coefs 0-8 icon to open the coefficients window.
5. Set the Piston, X Tilt, and Y Tilt values to 0.
6. Click the Generate button to generate Zernike data.
7. In the Analyze Control window, click the Save Zernikes button. In the File Handler, click the Current Selection box, enter a name for the file, ending with ".zfr", and press [Return]. Click the Done button to close the File Handler. This saves the generated Zernike data.

To Generate Zernikes From a Phase Data File (for example Data From a Two Sphere Test)

1. Open the following windows: Analyze Ctrl, Z Coifs 0-8, Z Coefs 9-35, and Zernike Ctrl.
2. In the Analyze Controls window, set Subtract to Off and Auto Aperture to Off.
3. Click on the Load Data button to open the File Handler. To load a file, click on its name. Click Done to close the File Handler.
4. Click on the Mask Data button. If there is a mask applied be sure that includes all of the data from the loaded file. If it does not, either resize the mask or delete it.
5. In the Zernike Controls window, click Get Zernikes.
6. In the Zernike Controls window, enter a value of -1 for Center X, Center Y, and Radius. This will ensure that the data is on center.
7. In the Zernike Controls window, set the number for Zernike terms. If this setting reads 9, and you want 36 terms, only 9 will be generated.
8. In the Coefs 0-8 window, enter a zero for the following terms: Piston, X Tilt, Y Tilt, and Focus.
9. Click the Generate button.
10. Toggle Subtract (in Analyze Controls) to GenZern. This will ensure that all subsequent measurements will have the two sphere zernikes subtracted automatically.
11. To save this file for future use, click on Save Zernikes in the Analyze Control Window. In the File Handler, click the Current Selection box, enter a name for the file, ending with ".zfr", and press [Return]. Click the Done button to close the File Handler.



Generating Zernikes (continued)

To Generate Zernikes From Input Parameters

1. Click on the Zernike Ctrl, Z Coefs 0-8, and Z Coefs 9-35 icons to gain access to the Zernike controls.
2. Enter values in Center X, Center Y and Radius; enter -1 to center the data set and fill the camera.
3. Enter values in Camera Size X, Camera Size Y, Zernike Terms, and Camera Res controls.
4. Enter values for the polynomials in the coefficient controls that correspond to the number of terms used.
5. Click the Generate button.
6. To save the file, click on Save Zernikes in the Analyze Control Window. In the File Handler, click the Current Selection box, enter a name for the file, ending with ".zfr", and press [Return]. Click the Done button to close the File Handler.

Subtracting a Data File

A generated Zernike file or an existing data file can be subtracted from current data. Two techniques of subtracting generated Zernikes are provided.

To Subtract a Particular Aberration at Each Measurement

1. Measure the test part as usual.
2. Click on the Zernike Ctrl, Z Coefs 0-8, and Z Coefs 9-35 icons to gain access to the Zernike controls.
3. Click the Get Zernikes button to capture the Zernikes from the data.
4. Zero out the Coef controls that are insignificant by clicking on the control and entering all zeroes and press [Return].
5. Click the Generate button to create a generated Zernike data set.
6. Click on the Analyze Ctrl icon to gain access to the Subtract control. Click on the Subtract control until it says "Gen Zern".
7. Click the Analyze button; the generated data is subtracted from the current data. When the Subtract control is set to Gen Zern, all subsequent measurements will also have the generated Zernikes subtracted.
8. To save the generated data, click the Save Zernikes button, enter a name for the file and press [Return].

Subtracting a Data File (continued)

To Subtract a Selected Data File

1. Generate a set of Zernikes that contains the information you want to subtract. Use of the generate controls is explained in the previous section.
2. Click the Save Data button. In the File Handler, click the Current Selection box, enter a name for the file and press [Return]. Click Done to close the File Handler. Be sure to save the generated data to the current directory.
3. Make a measurement of the test part.
4. Click the Sub Data button. Enter the name of file you want to subtract and press [Return]. The current displayed data is updated.

Other Operations

Operation	*How to*
Save data	Click the Save Data button. In the File Handler, click the Current Selection box, enter a name for the file, ending with ".dat", and press [Return]. Then click the Done button.
Print	Click the word zygo in the window you want to print or select the Print command from the window's menu.
Saving changes made to controls, plots, results, and windows.	You must save the application under a new name. Select the Save Application command from the Application Window menu. In the File Handler, click the Current Selection box, enter a name for the file, ending with ".app", and press [Return]. Then click the Done button.
Calibration	Click the Calibrate button. Press the left mouse button and move the mouse to draw a line across the image area. The line should match up to some portion of the image for which your know the lateral dimension. Release the mouse button and enter the dimension of the line in millimeters. Press [Return] and close the Calibrator window. For more information, refer to "Calibrator" in the *MetroPro Reference Guide*.
Turn off the system	**Warning!** Improper shutdown may damage the instrument. Select the Quit command from the MetroPro menu; turn off power after you have shut down from within Windows.

Troubleshooting

Symptom	*Possible Cause and Fix*
Application is not functional.	MetroPro is not licensed. The application is licensed as part of standard MetroPro; contact Zygo for licensing information.
	The hardware key or ID Module is not installed. Install the hardware key and restart the computer.

References for Zernikes

Max Born and Emil Wolf, *Principles of Optics* (New York: Pergamon Press, 1980).

Daniel Malacara, *Optical Shop Testing,* 2nd edition (New York: John Wiley and Sons, 1992) Chapter 13.

C-J Kim and Robert Shannon, *Catalog of Zernike Polynomials*, Applied Optics and Optical Engineering, Vol. X (New York: Academic Press Inc., 1987).

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