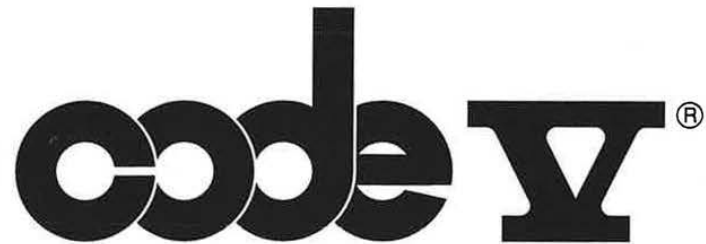


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550 North Rosemead Boulevard
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Fax: (818) 795-9102

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Reference Manual

Editor:

Richard C. Juergens

Contributing Authors:

Barry Broome

Thomas I. Harris

Bruce R. Irving

Peter Maccini

Stephen F. Sagan

Tom Bruegge

David M. Hasenauer

John Isenberg

Daren V. Reid

Kevin Thompson

Eric Ford

Michael Hayford

Don Koch

Matthew P. Rimmer

William B. Wetherell

Darryl E. Gustafson

Robert S. Hilbert

Thomas Kuper

Michael Rodgers

Program Development Staff:

Tom Bruegge

Darryl E. Gustafson

Peter Maccini

Rhonda L. Shook

C. Tom Walker

Sanguan Chow

Thomas I. Harris

Robert Mortensen

Michael D. Strawn

Kenny Yang

Jimmy Chu

Michael Hayford

Daren V. Reid

Phillip Suematsu

Tri Dang

Thomas Kuper

Matthew P. Rimmer

Samuel Sun

Production Staff:

Deborah A. Afarian

Kathleen Clark

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PREFACE

READ FIRST
THINGS YOU SHOULD KNOW WHEN FIRST USING CODE V

1. Read:
 - CODE V Documentation (page vii) - it describes the role of each document in the set.
 - HOW TO USE THIS MANUAL, immediately following this material - it describes the special features of this Reference Manual.
2. How you use this material is up to you, depending on your learning style and how quickly you have to come up to speed. Eventually you will acquire a mental "model" in your mind of CODE V's structure and how things work; once you have this "user model" in mind, everything will seem more natural to you. We have designed the structure with great care to give you all of the power of CODE V and its interface to the computer's operating system, and yet retain simplicity. The first appearance will be one of complexity, but as you use it you will see the simplicity.
3. Some people learn best by plunging in and trying things. If you are one, try the following "quick study" course:
 - Browse through Section 1A. Operating CODE V, picking up enough to sign on and know what other material is in there for future reference.
 - Get the concept of Immediate Commands p. 1A- 10 (and Chapter 10) so that when you want to change your working environment, you will know where to look. You can also put them into a file (DEFAULTS.SEQ) that will set up your own chosen environment each time you sign on to CODE V.
 - Get the concept that you feed in lens data and get it into shape for other calculations through the Lens Data Manager (the LDM - see later in this section and, for details, Chapter 2). The lens data is available to you and to the rest of the program at all times, until you start another lens or exit (hopefully having saved your priceless creation in the lens library - Section 2E).
 - The "other calculations" are called "options" and comprise Chapters 3 through 9. In between options you are automatically back in the LDM (shown by the CODE V> prompt in command mode), ready to change lens data or run other options.
 - When you are in the LDM, it can accept LDM commands and Immediate commands. When you are in an option (shown by XXX> prompt in command mode where XXX is the option mnemonic), it can accept its own commands and Immediate commands. (Immediate commands are valid anytime).
 - A few options can alter the lens (AUTOMATIC DESIGN to optimize, TOR to generate tolerances, etc.), but most analyze different aspects of the lens, or generate information for mechanical design and fabrication.

That's it. You have the structure of CODE V and the skeleton to hang your knowledge on; the rest is detail.

Continued....

PREFACE

THINGS YOU SHOULD KNOW WHEN FIRST USING CODE V (Continued)

Now try CODE V, using the following additional information:

- If you want to use screens for input and control, browse through Section 1D. Using Screens, and then try the Test Drive or Introductory User's Guide (each of which includes a subset of Section 1D material and goes on into sample CODE V operations).
 - If you want to use commands for input and control, browse through and even duplicate the operations of Section 1B. A User's Session. (But skip over the illustrative detours you do not want to explore). In the back of the Introductory User's Guide there are command equivalents for all of the screen examples, and the more complex examples are given in commands. To use commands on your own, you need to understand the rules given in Section 1C. Syntax/Entry Rules - how to read the commands as written in the Reference Manual and Prompting Guide, and how to type them in. But don't worry, the syntax checker will let you know what, if anything is wrong.
 - **BE AWARE THERE IS AN INDEX JUST FOR THE LDM, at the end of Section 2A.** It is good because there are over 300 commands to set up all of the kinds of optical systems that CODE V can represent; usually only about 10 of these are enough for an ordinary centered lens system.
4. If you want a more leisurely pace before you try CODE V, there isn't any - except to read a little more in this section and do a quick scan of the other parts of this manual and the other manuals so you will know where to find things.
 5. If all else fails, call us - we offer telephone support every working day. Plus seminars several times a year.

Note:

Once you are familiar with commands, look at the Macro Command Language in Chapter 11. You do not have to use the language, but you may find that it offers easier alternatives for control and input, great flexibility for handling special problems, and letting you extend the functionality of CODE V.

HOW TO USE THIS MANUAL

First, get familiar with its content and organization. Look at the main Table of Contents; then flip each tab and look at the table of contents following it; find the LDM index at the end of Section 2A and the indices at the back. Then read sections that interest you or for which you have immediate need; do not try to read and absorb the whole manual - it is a reference manual, not the world's greatest novel.

Second, get familiar with the overall structure of CODE V and its relation to the manual:

The LDM (Lens Data Manager):

- Section 2A - Entering and changing lens data items singly or in groups
- Section 2B, 2C, 2D, 2E - Operating on, displaying, testing and saving/restoring lens data as a whole

The Options:

- Chapter 3 - Automatic Design
- Chapter 4 - Diagnostic Analysis/Graphics
- Chapter 5 - Image Evaluation
- Chapter 6 - Tolerancing
- Chapter 7 - Fabrication Support
- Chapter 8 - Environmental Analysis
- Chapter 9 - Systems Analysis and Multilayer Design

Immediate Commands/Defaults (see Chapter 10)

Utility Functions/Options (see Chapter 10)

Macro-PLUS (see Chapter 11)

Third, get familiar with the reference features and styles that are used in various sections:

Reference features:

- Tabs select major sections
- Table of contents (and for options, an option index) immediately after each tab, and contiguous page numbering within each tabbed section help in quickly finding topics of interest.
- Contents page following each tab gives a description of the purpose of the section and purpose of each option or topic to aid selection.
- Section 2A, for Entering/Changing Data has an extra level of sectioning:
 - A master Table of Contents listing each section
 - A local Table of Contents for each section highlighting the detailed contents
 - Edge bars to act as tabs in finding each section
 - At the end, the LDM Index, which lists all commands and major topics for the LDM (Sections 2A through 2E).

These separate the more than 300 possible commands defining the lens.

- Indices for the whole Reference Manual; these currently include an option index, a command index covering all commands, and a subject index.

Continued....

PREFACE

HOW TO USE THIS MANUAL (Continued)

- Commands are in easy-to-select, boxed format. For example, the operation specifying the glass map in the AUTOMATIC DESIGN option within which variable glasses are to be constrained, is given by:

Command Syntax		
Screen Prompt	Explanation	Default
GLA [Sk Si.j] map_corner1 map_corner2 map_corner3....5		
Glass map boundary points... (AUT1-2)	Constrain variable, fictitious glasses on specified surfaces to lie within a <u>convex</u> polygon in the n_d vs. $n_f - n_c$ glass map shown on the next page. This polygon is defined by specifying, in <u>clockwise order</u> , 3 to 5 glasses at the corner points, using fictitious glass codes. Multiple GLA commands may be given; the commands and surface ranges are cumulative. If no surface range is given map applies to all variable glasses.	GLA SA 487.704 620.603 744.447 755.276

In general,

Syntax statement -

Follows rules for reading and entry defined in Section 1C. Commands in Section 2A which represent variables and their control codes for AUTOMATIC DESIGN have a reference to their partner added to the syntax box (see, for example, the CUY command).

Screen Prompt -

Enough of the words on the screen to identify the particular entry for the screens user.

Explanation -

In general, a concise but complete description of what the command will do by itself and its limitations; examples of correct syntax are included if needed to clear up ambiguities, but not to illustrate optical points; use of multiple commands to accomplish a particular task are placed in nearby sections on usage or discussion of input and output.

Default -

What happens when the command is omitted; if no Default is given, there is no default action; if the command, when issued, has values which are supplied by default, they are provided in the Explanation.

Continued....

HOW TO USE THIS MANUAL (Continued)

Style features:

The LDM (Lens Data Manager):

Section 2A -

Explanatory notes, when needed, precede the command descriptions to tie them into the overall concept of constructing data for your optical system. (The screen prompt is currently omitted, pending development of an appropriate format.)

Section 2B, 2C, 2D, 2E -

More like the options, these have their explanatory notes in a Usage section following the commands.

The Options (for each):

Purpose -

A quick overview of what the option does, so you can tell whether it is the one you need. Also it is in the chapter Table of Contents, for the same purpose.

Default Operation -

Tells what will happen when the option is run with no additional option commands - the base on which you can build and modify the option's action. This usually is the simplest, most frequently used, and/or most optically logical use of the option.

Screen Flow Diagram -

Shows the relationship between the screens (which comes first, etc.) used just in the option, with a unique screen identifier code (AUT 1, AUT 1-1, etc.) that matches the code found in the upper left hand corner of the screen itself.

Screens -

Shows the way they look. Multiple screens for an option are organized by topics which appear centered just below the option name in the top line; within each screen entries are organized by topic also, with those most frequently needed and/or most important at the top.

Command Mnemonics (Alphabetical) -

Summary list of the command mnemonics so that you can verify by quick scan that the one you are looking for is there.

Commands -

See above for example and content. These are organized in parallel to their order of appearance in the screens and under similar topics.

Discussion of Input and Computations -

Discusses the default computations, nuances of commands (HOW, WHEN and WHY to use), how commands affect the computation and are used to solve particular optical problems, and examples of input.

Description of Output -

Covers interpretation of output, how commands can alter the form of output and examples of commands needed to generate specific listings or plots. Included are examples of runs you can make to duplicate the output shown.

Continued....

PREFACE

HOW TO USE THIS MANUAL (Continued)

Technical Notes -

If present, provide information and references which may contribute to the understanding of the behavior of the CODE V option.

For each option, the portion of text that is likely to be needed most frequently (default operation, screens, and commands) are first, to aid in quick reference; the remaining sections need to be read once or referenced infrequently and are last. Within each chapter options are arranged in the same order as the screen menu used to select them, which generally places them with the most important, or frequently used, options at the beginning of the chapter.

Immediate Commands/Defaults:

Explanatory notes are in a Usage section following the commands.

Utility Functions/Options:

Like other options, explanatory notes are covered in discussions of input and output.

Fourth, try using CODE V, using this and the other documentation to augment your knowledge.

P.S. A word about version numbers and manual updates

This manual corresponds to program release 7.60; the next major release will be 8.0, for which a new Prompting Guide and update for the Reference Manual will be provided. After each major release, minor releases will be issued periodically to fix critical bugs reported by customers and Optical Research Associates (ORA®) staff. These intermediate releases, if needed, will be numbered 7.61, 7.62, etc.

Only by regular insertion of each update as it is received will this manual be up to date and accurate; the version number and date on the cover page (which will be updated, too) will identify the level of your manual. To be sure that you continue to receive updates, please send any change of address to ORA, referring to CODE V documentation.

Pages which have been updated carry identifying marks according to the following plan:

- Identified with the release (i.e., 7.60) at the bottom of each page that was part of the corresponding update; if the update page is not identified with the release, the change must be on the other side. Reasons for the change are indicated by thin change bars on the outer edge or by horizontal change bars at the top, inner edge:
 - **No change bar** - Typo correction, a page supplied as part of re-paging, or a change of style, not content.
 - **Change bar on outer edge of page** - SIGNIFICANT CHANGE - Content of lines it matches have been changed in the documentation and/or represent a program change, or enhancement.
 - **Horizontal change bar at top of page** - ALL NEW PAGE - This usually represents a documentation addition. If a new option or major new section and capability for the LDM is added, it will also carry this top change bar.

CODE V DOCUMENTATION

What is included in the documentation set?

The full CODE V documentation set consists of:

1. Introductory User's Guide
2. Test Drive - An Introduction to the Screens Interface
3. Prompting Guide
4. Reference Manual - This manual, in three volumes

The first three have been given to you previously or with this manual. Other materials available from ORA are:

1. Training Materials
 - for attendees of CODE V seminars
2. ORA Network Access Guide
 - for users of the ORA VAX Computing Facility, either through TYMNET, direct phone line or at ORA

What is the best way to use these materials?

- Test Drive:

Best for a short (~ 1 hour) self-guided demonstration of simple screen operations in CODE V.

- Introductory User's Guide:

The best place to start for understanding CODE V and its use:

- A comprehensive introduction to CODE V using the screens mode of data entry and sampling most frequently used features
- Examples of how to use CODE V to design and evaluate lenses, with examples using both screens and commands

- Prompting Guide:

Best for the command mode user; familiar commands will have enough material that no further information is needed; unfamiliar commands will trigger use of the Reference Manual for more detail. Contains:

- The complete command syntax definition for every command
- An identifying phrase with critical information
- An abbreviated representation of the default effect of omitting the command (it sometimes serves as an example, also).

- Reference Manual:

The most complete definition of CODE V.

Why is the Reference Manual in multiple volumes?

Our goals are to provide:

- The most comprehensive program:
 - Over 1000 commands are available to model almost any conceivable lens system and to apply a broad range of calculations to it. More than 350 commands are available just to describe the attributes of the lens itself (in the LDM).
 - A number of planned-for extensions, including:
 - User-defined error function
 - MTF optimization
 - First-order optical system layout aids
 - Programs to aid diagnosis of problems in optical system structure
 - More examples and operational tips
- The easiest-to-use program:
 - EASE (Easy Access Screen Entry) allows the user to run completely without using commands or to intermix the two
 - Only about 10 LDM commands are needed to describe centered lens systems
 - Useful, optically valid defaults are provided for missing data
 - In almost all options, defaults produce standard results that are useful in their entirety or as a building block for further runs
 - A full HELP facility of several levels is available at all times on-line
 - Comprehensible messages that give information about what is happening, warnings of possible problems, and errors on unallowable inputs
- A designer-oriented tool:
 - Planned and developed by active optical engineers, for optical engineers, for efficiency of use

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TABLE OF CONTENTS

VOLUME I

Preface.....	i
READ FIRST - Things You Should Know When First Using CODE V	
How to Use This Manual	
CODE V Documentation	
Table of Contents.....	x
1. OVERVIEW / INTRODUCTION.....	1-1
Table of Contents (for this section)	
Introduction to CODE V	
The Architecture and Structure of CODE V	
A. Operating CODE V	1A-1
Table of Contents (for this section)	
Important Commands	
VMS Help on CODE V (VAX only)	
Choosing a Version of CODE V	
Starting CODE V on a VAX	
Starting CODE V on a Sun	
Starting CODE V on a PC	
Starting CODE V from a CODE V Icon	
Starting CODE V from a DOS Window	
Control of System Messages - Batch Jobs (VAX/VMS only)	
Exit from CODE V	
Immediate Commands	
Prompts	
Correcting/Reusing Commands	
Option Processing	
Files Used by CODE V	
File Naming Conventions in CODE V	
File Types used in CODE V	
Editing Files	
File Input/Output, Printing, and Plotting	
Input	
Text Output	
SEQ File Output (for lenses only)	
Graphics Output	
Graphics Devices	
Sending Data to Printers, Plotters, and Raster Graphics Devices	
Plotting and Printing after Exit	
Recovery	
Starting Other Processes from within CODE V	
Defaults Setup	
User-defined Functions and User Versions of CODE V	
User-defined Graphics Drivers	
CODE V Accounting (Sun and VAX only)	
The Accounting File	
Required Monthly Accounting Report (Variable Fee Licenses)	
Optional Accounting Reports	
Dynamic Memory	
Appendix 1A-A – Implementing a User-defined Gradient	
Appendix 1A-B – Implementing a User-defined Surface	
Appendix 1A-C – Implementing a User-defined Macro-PLUS Subroutine	
Appendix 1A-D – Calculating Dynamic Memory Requirements	

Appendix 1A-E – Lenses Supplied with CODE V	
Sample Lenses	
Optical Suppliers' Lens Catalogs	
Lens Catalogs	
Catalog Lens Data Format	
Using the Catalog Lenses	
Catalog Lens Design Example	
Searching the Catalog Lenses	
SEARCH Example	
Database Lenses	
Appendix 1A-F – CODE V on the VAXstation	
Getting Started	
CODE V Commands for the VAXstation Environment	
General Information and Restrictions	
Appendix 1A-G – CODE V on a Sun SPARCstation	
Getting Started	
CODE V Commands for the SPARCstation Environment	
Appendix 1A-H – Running from an X Window Device	
Running CODE V from an X Window Device	
Controlling Graphics Windows on X Window Devices	
Appendix 1A-I – Printing and Plotting Outside of CODE V	
Plotting Outside of CODE V (CVPLOT Command)	
Printing Outside of CODE V (CVPRINT Command)	
Plotting Raster Files Outside of CODE V (CVRAST Command)	
B. A User's Session.....	1B-1
Table of Contents (for this section)	
The Optical Problem	
A Note on Typography	
Logging In and Running CODE V	
Setting Up Your Session	
Defining a New Lens	
Getting Help	
Entering Surface Data	
Saving and Displaying Data	
Adding Zoom Data	
Running CODE V Options	
Changing Your Lens	
Using Sequence Files	
Accessing the VMS Operating System from CODE V	
Wrapping Up	
C. Syntax/Entry Rules.....	1C-1
Table of Contents (for this section)	
Syntax Description	
Command Line Format and Elements	
Command	
Qualifiers	
Data	
Comment	
Additional Syntax Elements for AUT (Automatic Design)	
The Syntax Definition	
Command Entry Rules	
Rules for Interpreting Command Notation	
Additional Rules for the LDM	
Rules for Command Entry	
CODE V File Usage	
CODE V Glass Names	

Table of Contents (continued)

D. Using Screens.....	1D-1
Table of Contents (for this section)	
Purpose of Screens	
Screens Requirements	
Hardware	
Communication Speed	
Screens Terminology	
Keyboard Terminology	
Screen "Command" Keys (GOLD Commands)	
"Global" GOLD Commands	
Lens Data Manager (LDM) GOLD Commands	
Screen "Shortcuts"	
GOLD/Q "Quick" Command	
GOLD/O	
Screen Files	
What Are "Screen Files"?	
Automatic Saving of Screens	
GOLD/F (Files Command)	
GOLD/F Menu Items	
Relationship between Screen and Command Mode	
Screen Errors and Error Recovery	
Typical Screen Session	
VAX CODE V Keyboard	
Sun CODE V Keyboard	
Appendix 1D-A – Gold Key Reference Card	
2. LENS DATA	2-1
Table of Contents (for this section)	
THE LDM - Introduction	
A.) Entering/Changing Data	2A-1
Table of Contents (for this section)	
THE TASK	
Re-starting for New Lens	
Title	
Specification Data	
Wavelength	
Pupil	
Field	
Vignetting	
Depth of Focus	
Miscellaneous	
THE LENS SYSTEM	
Materials	
Designating Glasses on Surfaces	
Using Pre-stored Glass Catalogs	
Using Fictitious Glasses	
Using Reflecting Surfaces	
Using Private Glass Catalog	
Other Properties	
Surface Shape & Position	
Representing Optical Systems in CODE V/Surface Order	
Entering Surface Data	
Shorthand Surface Entry	
Inserting/Deleting/Copying Surfaces	
Thickness/Separation	

- Glass Change
- Sphere/Cylinder Surfaces
- Solves
- Tilts/Decenters
 - Introduction to Decentered Systems
 - Global Reference System
 - Other Decentered Capabilities
 - Global References
 - Surface Tilts/Decenters

BUILDING THE LENS SYSTEM

- Element Structure
 - Apertures/Obscurations/Edges/Holes
 - First Surface Mirror Substrates
 - Coating/Cement Data
- Tolerances
 - Usage in CODE V
 - Interpreting Command Descriptions
 - Centered Tolerances
 - Irregularity Tolerances
 - Single Surface Decenter and Displacement Tolerances
 - Group Decentering Tolerances
 - Other Controls
 - Description of Tolerances

OTHER

- Introduction
- Zoom/Dezoom Facility
- Variable Designation/Control Codes
- Delete

A. Entering/Changing Data - SPECIAL TOPICS..... 2A-201
 Table of Contents (for this section)

SPECIAL SURFACES

- Introduction
- CON/ASP - Conic/Asphere
- XTO - X-Toroid of Base Asphere
- YTO - Y-Toroid of Base Asphere
- THG - Thermal Gradient on Base Asphere
- SPL - Radial Spline Asphere
- AAS - Anamorphic Asphere
- GRT - Diffractive Surfaces - Diffraction Grating on Base Asphere
- HOE - Diffractive Surfaces - Holographic Surface
- MOD - Lens Module ("Black Box" Lens)
- UDS - User-defined Surface

ARRAY ELEMENT

- Usage
- Regular Grid, Parallel Array
- Individual General Channels
- Polynomial Decenter and Tilt Channels

NON-SEQUENTIAL SURFACES

- Introduction - When to Use Non-Sequential Surfaces
- Implementation of NS Ray Tracing
- Cautions
- High Level Modules
- Constructing Non-Sequential Surface Ranges - NS Primitives
- Getting Started with Non-Sequential Ray Tracing
- References

Table of Contents (continued)

GRADIENT INDEX MATERIALS (GRIN)

Definitions & Examples
General Commands
Forms

PUPIL APODIZATION

General Apodization
Gaussian Apodization

POLARIZATION

Introduction/Polarization Ray Tracing
Defining the Input Polarization
Its Effect on Imagery/Modeling Effects that Alter the Polarization State of a Beam
Use of Polarization Ray Trace Information by CODE V
Activating Polarization Ray Tracing/Geometrical Representation
Jones Vector Representation
Stokes Parameters/Specifying Linear Polarizers and Retarders
Examples of Output

INTERFEROMETRIC DEFORMATIONS AND INTENSITY APODIZATION

Introduction
Interferograms
Intensity Apodization
INT Files
Coordinate Systems and Sign Conventions
Zernike Polynomials
INT File Format
Interface to Commercial Interferometers
Sample Output
Technical Notes
Attaching INT Data to the Surface
Orientation of INT Data

NASTRAN-GENERATED DEFORMATIONS

Introduction/Running MSC/NASTRAN/Running CVNAS
Output/Units/Dynamic Analyses
Examples
Sample Files

LDM INDEX

B. Operations on Lens Data 2B-1
Table of Contents (for this section)

End-for-End Flips
Scale Lens System
Ray-based Setting of Data
Usage

C. Displaying Data 2C-1
Table of Contents (for this section)

Queries
Listing of Data
Drawing of Lens
Usage

D. Quick Analyses 2D-1
 Table of Contents (for this section)
 Evaluate Optical Values
 First-order Calculations
 Third-order Calculations
 Single Ray Traces
 Single Ray Trace Output Format
 Usage

E. Saving/Restoring Data 2E-1
 Table of Contents (for this section)
 Save and Restore Data
 Copying Stored Lens into Current Lens
 Converting Lens to Sequence Data
 Usage

INDICES Indices-1
 Table of Contents (for this section)
 Option Index
 Command Index
 Subject Index

END OF VOLUME I

VOLUME II

Table of Contents ii

3. AUTOMATIC DESIGN 3-1
 Table of Contents (for this section)

AUT- Automatic Design
 Specific Constraints
 Variables
 Optical Definitions
 Manufacturing and Packaging
 Paraxial Ray Trace Data
 First- and Third-order Aberrations
 Real Ray Trace Data
 Holographic Optical Elements
 User-defined
 General Constraints
 Optimization Controls
 Global Synthesis
 Exit Conditions
 Listing/Drawing
 Convergence
 Error Function Construction
 Aberrations
 Weights
 Through-Focus Optimization
 Ray Grid
 MTF Optimization
 User-defined Error Function
 Outputs to Macro-PLUS

Table of Contents (continued)

4. DIAGNOSTIC ANALYSIS/GRAPHICS	4-1
Table of Contents (for this section)	
ANA - Analysis	
FIE - Field Aberrations - Astigmatism and Distortion Analysis	
RIM - Rimray Aberration Plot	
PMA - Pupil Map	
CAT - Catseye Diagram	
FMA - Field Map	
FOV - Biocular Field of View Plot	
BEA - Beam Propagation	
5. IMAGE EVALUATION	5-1
Table of Contents (for this section)	
Point and Line Spread Functions	
PSF - Point Spread Function*	
SPO - Spot Diagram	
QUA - Quadrant Detector Analysis	
RAD - Encircled Energy	
GDE - Detector Energy	
LSF - Line Spread Function/Edge Trace, Pixel Analysis*	
GLS - LSF/Edge Trace - Geometrical	
Other Image Evaluation	
WAV - Wavefront Analysis*	
MTF - Modulation Transfer Function*	
PAR - Partial Coherence*	
BIO - Biocular Display Analysis	
*Diffraction Based	
6. TOLERANCING	6-1
Table of Contents (for this section)	
TOR - Ray Based Tolerancing	
TOD - Distortion Tolerancing	
TOL - Primary Aberration Based Tolerancing	
7. FABRICATION SUPPORT	7-1
Table of Contents (for this section)	
FAB - Fabrication Data	
VIE - Lens View and Plot	
LAY - Lens Drawing	
ELE - Element Drawing	
FOO - Footprint Analysis	
COS - Cost Analysis	
WEI - Weight Calculation	
TES - Test Plate Fitting	
CAM - Cam Calculations for Zoom Systems	
SLD - Solids Modeling	
ALI - Alignment Optimization	
IGE - IGES Interface	
INDICES	Indices-1
Table of Contents (for this section)	
Option Index	
Command Index	
Subject Index	

END OF VOLUME II

VOLUME III

Table of Contents	ii
8. ENVIRONMENTAL ANALYSIS	8-1
Table of Contents (for this section)	
ENV - Environmental Analysis	
9. SYSTEMS ANALYSIS AND MULTILAYER DESIGN	9-1
Table of Contents (for this section)	
SPE - Spectral Analysis	
TRA - Transmission Analysis	
GHO - Ghost Image Analysis	
NAR - Narcissus Analysis	
MUL - Multilayer Coating Design	
SSS - Solar Simulator System Option (SSS)	
IMS - 1-D Image Simulation	
10. DEFAULTS AND UTILITIES	10-1
Table of Contents (for this section)	
Command Processing	
Option Processing and EXIT	
Immediate Commands/Defaults	
LIB - Library Maintenance	
GLD - Glass Catalog Data	
UGR - User Graphics	
11. Macro-PLUS OVERVIEW/INTRODUCTION	11-1
Table of Contents (for this section)	
A. Language Reference	11A-1
B. Database Reference	11B-1
C. Examples	11C-1
D. CODE V Supplied Macros	11D-1
E. Worksheet Buffer	11E-1
APPENDICES	
A. Error Messages and HELP	A-1
B. Glossary	B-1
INDICES	Indices-1
Table of Contents (for this section)	
Option Index	
Command Index	
Subject Index	

Chapter 1C

Syntax/Entry Rules

TABLE OF CONTENTS

SYNTAX DESCRIPTION	1C-3
COMMAND LINE FORMAT AND ELEMENTS	1C-3
Command	1C-3
Qualifiers	1C-3
Data	1C-4
Comment	1C-4
Additional Syntax Elements for AUT (Automatic Design)	1C-6
THE SYNTAX DEFINITION.....	1C-6
COMMAND ENTRY RULES.....	1C-7
Rules For Interpreting Command Notation.....	1C-7
Additional Rules for the LDM.....	1C-9
Rules For Command Entry.....	1C-10
CODE V File Usage.....	1C-11
CODE V Glass Names	1C-12

SYNTAX/ENTRY RULES

1C-2

SYNTAX DESCRIPTION

COMMAND LINE FORMAT AND ELEMENTS¹

CODE V command lines have the following general form:

COMMAND QUALIFIERS DATA

This is the principal order dependence: the command must be first and the data (if any) must be last; the qualifiers (if any), except labels, may be in any order; the label qualifier (if any) must be the last of the qualifiers.

Blanks are delimiters; they are not allowed to be embedded in commands, qualifiers, or data. Leading blanks and extra spaces are acceptable.

Command lines are normally ended by a carriage return.

Command lines may be:

- Stacked on one line by putting a semi-colon(;) between command lines
- Continued onto the next line by ending the prior line with an ampersand(&) just before the carriage return
- Commented by using an exclamation mark(!); all characters following the ! on that line will be ignored by CODE V. Thus the form becomes:

COMMAND QUALIFIERS DATA !COMMENT

Command

- A 1 to 3 character alphanumeric string recognized by CODE V.
- The first character is always a letter.
- Additional characters may be added to 3 character commands as desired for readability (e.g., GLA -> GLASS); these additional characters are ignored by CODE V.
- 1 or 2 character commands may NOT be extended (e.g., Y, WL, SF, etc.).
- No spaces are permitted within commands.
- Special cases - A few multi-word commands start with a prefix command:

PREFIX COMMAND QUALIFIERS DATA !COMMENT

Examples of prefixes are:

ZOO (zoom), DEZ (dezoom), DEF (default), DEL (delete), CMP (compensator) in the LDM
 DSP (display) in AUTO
 LIM (limits) in TOR

Qualifiers

Qualifier word:

- 1 to 3 character alphanumeric code that are valid with certain commands to restrict or refine their operation (e.g., OAL or ET in solves).
- Qualifier words may be extended in length under the same restrictions as those applying to commands; they also must not contain spaces.

¹The Macro-PLUS language is compatible with the standard command language, but has its own extensions and differences. See Chapter 11.

SYNTAX/ENTRY RULES

Index qualifier:

- For specifying a surface number, wavelength number, field number, zoom position number, etc.
- Consists of a letter that identifies the type of index (S for surface, Z for zoom, W for wavelength, etc.), followed by an integer or a valid index expression (O, I-1, S+2, etc.). No spaces are permitted in index qualifiers.
- O, S, and I (for Object, Stop, and Image) are valid surface numbers.
- L can be used for Last surface, wavelength, field or zoom number, or last column or row of a worksheet.
- C can be used to indicate current row or column in the worksheet buffer (IC, JC+3, etc).
- Examples: W3, F2, ZL, S17, SI-1, JL+1.

Index qualifier range:

- When a range of index qualifiers is required or permitted, the range is specified by separating its beginning and ending values by two periods (..) without intervening spaces, such as S67..129, Z1..L, IC-1..C+1.
- "A" can be used to mean All, as in SA instead of SO..I and ZA instead of Z1..L .

Label qualifier:

- Up to 3 characters as a string (enclosed between single or double quotes) to identify a particular aperture.

Data

Numeric data:

- Integers or floating point values, with or without leading signs (+, -) or leading zeros (.5, 0.5), or power of ten exponents (1E10, -2.0E-7, etc.).
- No spaces are permitted within numerics.
- Calculator mode: two numerics can be connected by an arithmetic operator (+, -, *, /) to give a single result. Examples: 34.5/2, 0.707*12.5, etc.

Alphanumeric data:

- Any permitted number of alphanumeric characters, plus underscore.
- For glasses, a catalog name is appended using an underscore, e.g. ADF1_HOYA, KZFS8_OHARA

String data:

- Any number of alphanumeric and/or printing special characters enclosed between single (') or double (") quotes.
- Normally single quotes are used; double quotes should be used if a single quote is a part of the string.
- Examples: 'This is a title', 'My BK7', "Joe's Lens; Keep Out"

Comment

- Any string of characters beginning with an exclamation point (!).
- ALL information on the line beyond the ! is ignored by CODE V, *including semicolons (;)*.
- Provides a way to annotate CODE V input - easier to read and understand.
- A comment may be an entire line starting with !

Examples of the Syntax

CUY S3 .125
YAN F2 10
YAN 0 7 10
YOB 0 .707*20 20
CIR S2 25.4/2

THI S2 5.0; THI S3 1.3

GLA S7 BK7
GLASS S7 BK7
GLA S7 BK7_OHARA

BTI S3..5

LIM DLT .005 .025 .001
DEL DLR S5..10

TITLE 'New Melts Added'

! This is a Comment
THI S7 1.0 ! Trailing comment

RAY NO YES NO
RAY Z1 NO; RAY Z3 NO
RAY BLU RED GRE

THI S5 OAL S3..8 6.0

TIT Z1 'Zoom 1 title'

SYNTAX/ENTRY RULES

Examples of the Syntax for AUT

EFL = 100

CT S12 > 2.5

OAL S4..10 Z4 > 3.9

DSP DSY F2

@EXP == (THI SI-1) - (EXP F1)

Additional Syntax Elements for AUT (Automatic Design)

Constraint relational operators:

- Used to separate the constraint name (and any necessary index qualifiers) from the target value or bound(s). One or both bounds can be entered at a time.
- Relational operators are =,<,>. Adjoining spaces are required.

User-Defined Constraints:

UDC name:

- Any 1 to 31 character alphanumeric preceded by an @.
- All references to UDC names (both in definitions and constraint entry) must include the @ with the name.

UDC definition:

- Are entered using the assignment operator (==). Adjoining spaces are not required. The form is:

@xyz == arithmetic expression

THE SYNTAX DEFINITION

The complete definition of the new syntax, command by command, is contained in both the Prompting Guide and this Reference Manual.

- Each command is represented in a notation that is based on the command syntax itself; read the Rules For Interpreting Command Notation to understand the meaning.
- Read the Rules for Command Entry to understand how to enter commands.

Examples given throughout the documentation set also use the same syntax notation.

COMMAND ENTRY RULES

To enter commands means that you need to:

- understand how to interpret the commands as written here
- supply user-defined items
- type in the completed command

Rules For Interpreting Command Notation:

CODE V can accept both upper and lower case inputs; however, we use both in the command descriptions to distinguish between what you must type (CAPS) and what you make substitutions for (lowercase).

CAPITAL LETTERS are to be typed, as in: WFR, S, F, W, Z, R, G, C, L

The single letter prefix means the following:

A - user-defined aberration number	L - label (1 to 3 character alphanumeric string)
B - buffer number	P - plotting window number
C - HOE, UDS, array polynomial and UDG coefficient number	Q - Macro-PLUS format string
E - entrance pupil position number	R - ray number
F - field number	S - surface number
G - global reference surface number	T - through-focus position number
H - NSS hit number	U - Macro-PLUS I/O unit number
I - row number in buffer	W - wavelength number
J - column number in buffer	Z - zoom position number

Qualifiers using these may be in any order.

lowercase letters are to have contents supplied by you, as in:

k, i, j, max, min, increment

THUS: Sk means you should type: S7 or S56 (where 7 or 56 is the desired surface number)

lowercase_ words_ joined_by_ underscore mean a single quantity to be supplied by you, as in:

lines_per_mm, decrease_in_performance
If the first word is num_, then enter it as an integer, as in:
NRD num_rays_across_diameter

UNITS: Usually clear from the context or in lens units; otherwise included in the lowercase words.

Abbreviations used:	degr	= degrees
	nm	= nanometers
	per_scale_bar	= uses plotted scale bars (on pen plotters, 25mm long for millimeter or centimeter lens units, 1 inch long for inch lens units)

blanks are used in what you type as delimiters, as shown in each command; you may use more than one for readability.

commas are never entered except as you wish to include them in titles.

.. means a range of values; it IS to be typed, as in:

Si..j, Zi..j

THUS: Si..j means you should type: S7..12 to indicate that an OAL, for example, extends from surface 7 to 12

'abcdefg' means a string of characters that YOU choose, typed with the quote marks (''); you can also use double quote marks (") as long as they are used at both ends of the string. This is done when you wish to include a quote within the string; choose the opposite one as the string delimiter. Characters can be upper and/or lower case, numbers and any punctuation except the string delimiter (' or ") you have chosen. Each allowable type of character string has a maximum number of characters (between the quotes) denoted as follows:

'system_title'(80) - up to 80 characters are allowed

'temporary_title'(20+20) - the total of 40 characters are split into two lines of 20 each

THUS: 'temporary_title'(20+20) means you can type 'This is my lens in the 5th zoom position' - exactly 40 characters, which splits between t and h of 'the'. The numbers and parentheses (20+20) are NOT typed.

Continued....

SYNTAX/ENTRY RULES

....6	is NOT typed; it means that up to that number (6, in this case) of entries may be made. There is no qualifier to alter specific elements or a sub-range.
....z	is NOT typed;z means that multiple entries may be made up to the total number of zoom positions allowed or active. This also means that a specific zoom position or range of positions can be used by including the qualifier Zk Zi..j prior to the value. Similarly for wavelength (....w) and field (....f).
....f	
....w	
THUS:	IFR incr_lines_per_mm....z means you can enter all zoom position values in one record, if they are the same, with: IFR 10 or IFR 10 10 10 10 10 10 (for 6 positions) If the values are different, use, for example: IFR 10 10 20 20 20 20 (for 6 positions) But, you also can modify the 3rd zoom position with IFR Z3 30 or the 4th through the 6th can be modified with IFR Z4..6 50
....f,z	is NOT typed; it shows that a 2-dimensional table is enterable. Using WTF (....f,z) as an example, acceptable formats are: If the system is not zoomed: WTF Fk field_weight - fills Fk WTF field_weight....f - fills each field If the system is zoomed: WTF Fk Zk field-zoom_weight - fills Fk,Zk field WTF Fk field-zoom_weight - fills Fk, all pos the same WTF Fk field-zoom_weight....z - fills Fk in each pos WTF Zk field-zoom_weight....f - fills each field of Zk WTF Zk field-zoom_weight - fills all fields the same
....w,z	Similarly forw,z. Use of ranges (Zi..j,Fi..j,Wi..j) allows the filling of any submatrix of the 2-D table with a single value. Example: WTF Z3..5 F2..3 1.0 would fill fields 2 and 3 in zoom positions 3 - 5 with 1.0.
	is NOT typed; it means 'or' as in: Yes No, Yes No color, degrees RAD TAN
Yes	can be typed Y or YES; if all entries are YES, they need not be typed.
No	can be typed N or NO
color	can be typed BLA, RED, GRE, YEL, BLU, MAG, CYA, WHI, COM
[]	are NOT typed; they indicate <u>optional</u> qualifiers that change the action of the command as in: [SUP] - suppresses the labeling of contours for CON command in PSF [Sk] - applies the action of the command only to surface k or optional values
Indented command	indicates that this command is only valid when the preceding non-indented command is used; the indenting does not need to be typed.

SYNTAX/ENTRY RULES

Additional rules that only apply locally to one option or small area of the program will be given there.

Additional Rules for the LDM:

- [...z] is NOT typed; it is shown in the LDM to mean that the parameter is zoomable; only after it has been zoomed by use of the ZOO command can changes be made in the zoomed formats implied by ...z
-w[,z]
....f[,z] is NOT typed; it is shown in the LDM to mean that the parameter is zoomable; only after it has been zoomed by use of the ZOO command can changes be made in the zoomed formats implied byw,z orf,z
- Selective changes after zooming After a parameter has been zoomed with, for example,
ZOO CUY S3 value1 value2 value3
it may be changed at any time with
CUY S3 new_value1 new_value2 new_value3
Using No for any of these values will leave it unchanged:
CUY S3 N new_value2 new_value3
would leave the first position value unchanged.
NOTE: To avoid undue complexity, the use of No is not shown in the LDM command statements.
To dezoom to the first position value,
DEZ CUY S3
If you are dealing with parameters that allow an array in zoom and field or wavelength, e.g., YAN, you can also dezoom all of the fields/wavelengths at once. For example:
DEZ YAN F1.4
dezooms all 4 field angles;
DEZ YAN F2.3
would dezoom only field angles 2 and 3.
- Sk or Sk|Si..j are required; either you provide them or the pointer to the current surface will be used. You can always include the surface designator if you wish; if the command is intended to alter data, it will move the pointer at the same time to the single designated surface Sk or to the first surface Si of the range. If the command is only for display or testing, the pointer will NOT be moved.
- Exception: On INS (insert) and DEL (delete) you must supply the surface number(Sk) or range(Si..j) to prevent accidental loss of data from too simple a command.
- [Si..j] or [Sk|Si..j] are optional; in the LDM, these only occur in Operations on Lens Data, Displaying Data, and in Testing Data. Omission means either SO..I or S1..I-1, as appropriate.

SYNTAX/ENTRY RULES

Rules For Command Entry:

1. Always separate parts of a CODE V instruction with one or more spaces.
2. Never put spaces inside command words, qualifier words, index qualifiers or ranges, or numbers. Leading blanks and extra spaces between items are acceptable.
3. Always precede a surface number, wavelength number, field number, zoom number, etc. with its proper index qualifier prefix (S for surface, W for wavelength, Z for zoom, etc.), without spaces. O, S, and I (for object, stop and image) are valid surface numbers. L can be used for the last surface, wavelength, field or zoom number. Examples: W3, F2, S17, Z4, FL. Addition and subtraction can be used (S1-1, SS+2, FL-1, etc.)
4. Never add additional characters to a one or two character command or qualifier word. You may add additional characters to any three character command or qualifier as desired for readability.
5. When a range of surface numbers or other qualifiers is called for, enter the lower and upper value separated by two periods and no spaces, such as S67..129 or F1..L, L can be used for last. A (for all) can be used in place of 1..L, as in FA.
6. Numeric data, alphanumeric data, strings, or (when permitted) expressions are defined as follows:
 - a. Numerics: Integers or floating point values, with or without leading signs (+,-) or leading zeros (.5,0.5), or power of ten exponents (1E10, -2.0E-7, etc.). No spaces are permitted within numerics.
 - b. Alphanumerics: Any permitted number of alphanumeric and/or printing special characters. For glasses, a catalog name is appended using an underscore, e.g. ADF1_HOYA, BPH8_OHARA.
 - c. Strings: Any permitted number of alphanumeric and/or printing special characters. If spaces or semi-colons(;) are included (e.g., in titles), the entire string must be enclosed in single or double quotes (e.g., "This is a title", "As is this").
 - d. Expressions: User data that include mathematical operations and/or references to operands - CODE V data items (THI, CUY, etc.) that appear in the LDM or specific constraints in AUTOMATIC DESIGN. If an expression contains any operands they must be enclosed in parentheses. For example, (CUI S5 Z3), (EFX S2..8 Z2), etc. See Chapter 11 - Macro-PLUS for details.
7. Upper and lower case letters can be used as desired; CODE V ignores case (ThIs = THIS = this).
8. Continue a command onto the next line by ending the previous line with an ampersand (&). Combine commands onto one line by separating them with a semi-colon (;). Comments are any string of characters beginning with an exclamation point (!), and including semicolons (;). They can be a separate line or at the end of any CODE V instruction.
9. When defining something (user defined constraint in AUTO, etc.), use the ASSIGNMENT OPERATOR (=).
10. When entering an AUTO constraint, use the = sign alone or < and > signs to specify the desired relationship between the constraint and its target.

SYNTAX/ENTRY RULES

CODE V File Usage

File names - used on VAX, Sun, and PC:

Definitions:

filespec = up to 63 total characters (letters, underscores, and numbers, but NOT \$) in the format:
[pathname:] [directory spec] filename.filetype (version)
or filename (version) OR 'extfilespec'

where:

pathname = (optional) corresponds to a VMS logical or a UNIX or DOS environment variable

directory spec = (optional) directory specification for filename. Subdirectories are separated by period (rather than slashes as used in UNIX, or back slashes as used in DOS)

filename = * or name up to 14 characters long (8 on PC), the first of which must be a letter

filetype = * or SEQ, LEN, MUL, LIS, PLT, REC, etc.

version = *, -(dash), or number up to 3 digits (1 on PC). Note: the enclosing parentheses () separates it from the filetype or filename

* = "wild card" which means "all files", "all types", or "all versions"

- = (dash) means "all versions below the highest version"

extfilespec = filespec defined only in the terminology of the operating system definitions - enclosed in single or double quotes and passed to the operating system without alteration

Examples:

- filename.filetype(version):

OPTSEQNC.SEQ(2)
or rscanner:OPTSEQNC.SEQ(2)
or [rick.scanner]OPTSEQNC.SEQ(2)

- filename(version):

MYLENS(3)
or rscanner:MYLENS(3)
or [rick.scanner]MYLENS(3)

Uses default filetype:

.LEN for SAV, RES, CSA
.SEQ for IN
.LIS for OUT, PRT
.PLT for GRA, PLT
.BUF for BUF SAV, BUF RES

- wild card character:

DIR *.SEQ list directory of all .SEQ files
DEL OPTSEQNC.SEQ(*) delete all versions of OPTSEQNC.SEQ

- use of - (dash):

DEL *.LEN(-) delete all but the highest version of
all .LEN files - equivalent to PURGE

- external filespecs:

IN '[MIKE.CMGOBJ01]DBGAUSS.SEQ;6' (VAX)
IN '/home/mike/cmgoobj01/dbgauss.seq.6' (Sun)
IN '\MIKE\CMGOBJ01\DBGAUSS.SE6' (PC)

Continued...

SYNTAX/ENTRY RULES

Note: The major differences between the CODE V filespec and VMS are:

- parentheses () are used as a separator for the version, instead of semi-colon (;)
- the wild card, *, applies to the whole name only rather than the whole or partial names of VMS
- the dash (-) is not an element in VMS

CODE V Glass Names

Glass names - see page 2A-23 for details

Definitions:

glass_name = predefined_glass or nnnnnn or xxx.yyy or 'glass_label'

where:

predefined_glass is a 1 to 13 character alphanumeric code from one of the manufacturer's catalogs. If the catalog is to be designated, it is appended using an underscore, e.g. BK7_SCHOTT

= AIR (or blank) (Index = 1.0 at all wavelengths)

nnnnnn = a six digit glass code (e.g. 517642) corresponding to one of the glass catalog glasses - alternate to designating by the predefined_glass name

xxx.yyy = a fictitious code. .xxx = $n_d - 1$, .yyy = $V_d / 10$

'glass_label'(8) = a user-defined or gradient index material entered via Private Catalog

Note: For convenience, 'predefined_glass' can also be two of the reflective/refractive modes:

REFL - Reflecting surface - all rays are reflected, like a metallic mirror

TIRO - Total internal reflection only - rays that meet TIR conditions are reflected (others are ray failures), like a glass prism face

In the lens data, for either of these types of reflecting surfaces, material following the surface is identical to that preceding it. All thicknesses following the REFL/TIRO surface must also be reversed to track the direction of light. See RMD command for changing modes.

Chapter

2

Lens Data

This chapter describes the Lens Data Manager (The LDM) which provides for entry, display, testing, correction and storing of the lens database, with fast response and immediate checking of entries, in preparing the data for use by the options described in Chapters 3 through 9.

TABLE OF CONTENTS

The LDM - Introduction	2-3
Describes the role of the LDM as a database manager and lens editor; defines coordinate systems and sign conventions; discusses the interrelationship in CODE V of vignetting, reference rays and apertures.	
The LDM - Entering/Changing Data	2A-1
Allows entry or change of any lens data items:	
- Restart for new lens	
- Entry of surface data in shorthand form	
- Adding/deleting/copying surfaces	
- Entering/changing of any individual data item:	
Title	
Lens specifications	
Material properties	
Surface data, including solves and tilts/decenters	
Clear apertures, obscurations, edge shapes and first-surface mirror substrates	
Coating/cement	
Tolerances	
- Zooming/dezooming of any individual data items to form multi-configuration systems	
- Setting up variables for AUTOMATIC DESIGN	
The LDM - Entering/Changing Data - SPECIAL TOPICS	2A-201
Allows entry/change for special surfaces, array elements, non-sequential surfaces, GRIN materials, polarization, apodization, interferometric deformations, and NASTRAN-generated deformations	
The LDM - Operations on Lens Data	2B-1
Allows direct generation or change of selected parts of the lens data:	
- End-for-end flip (about X or Y axis) of all or a part of the system	
- Generate circular surface apertures based on current lens aperture specification and vignetting	
- Generate lens aperture specification based on current surface apertures	
- Generate vignetting based on current lens aperture specification and surface apertures	
- Scale all or part of the lens system according to various criteria	
The LDM - Displaying Data	2C-1
Allows text and graphical display of lens data:	
- Queries of individual LDM database items	
- Listing of all or selected parts of the LDM database	
- Quick lens drawing	
The LDM - Quick Analyses	2D-1
Allows quick analysis of lens data:	
- Evaluation of any Macro-PLUS expression	
- Listing of first order system parameters	
- First-order ray tracing	
- Third-order surface-by-surface contributions and sums	
- Tracing of single rays in designated wavelengths, with user-defined formatting	
The LDM - Saving/Restoring Data	2E-1
Allows:	
- Saving of current lens	
- Restoring of previously saved lens	
- Conditional saving of an improved lens	
- Conversion of lens data to equivalent LDM commands	

LENS DATA

CHAPTER 2 - THE LDM - INTRODUCTION

THE CODE V LENS DATA MANAGER (LDM)	2-3
- The Lens Database	
CODE V is Built Around a Primary Lens Database	
Additional Databases Are Also Used by CODE V	
- The LDM as a "Data Editor"	
The LDM Is Used to Create, Modify, and Display Lens Data	
Some CODE V Options Also Modify the Lens Database	
The LDM Has Two "Edit Modes"	
- The LDM as "Home Base"	
- Lens Data Post-processing	
- Sources of Lens Data	
Creating a New Lens Interactively	
Restoring a Previously Saved Lens	
Reading Lens Data from a Sequence File	
Using Standard Library Lenses	
Using Standard Library Lens Components	
OPTICAL DATA DEFINITIONS	2-6
- What Constitutes "a Lens" in CODE V?	
CODE V Minimizes Required Data	
Minimum Requirements for a Ray Traceable Lens	
Additional Data that Is Nearly Always Specified	
Additional Data that Is Specialized or Optional	
CATEGORIES OF DATA DESCRIBING AN OPTICAL SYSTEM	2-7
- The Task	
What Do We Mean by "the Task?"	
Specifications (What the Lens Is to Do)	
Wavelengths (Required)	
Aperture (Required)	
Field or Format Definition	
The Aperture Stop Surface	
Depth of Focus for Analysis	
Vignetting Factors	
Afocal Systems	
- The Lens System	
Surfaces	
Dummy Surfaces	
Elements	
Operations on Surfaces	
Materials	
Surface Shape & Position	
Special Surfaces	
Non-Sequential Surfaces (NSS)	
- Building the Lens System	
Apertures and Edges	
Mirror Substrates, Cements, Coatings	
Tolerances	
- Other Lens Information	
COORDINATES	2-13
- Local Coordinate Systems	
- Global Coordinates	
- CODE V Output Coordinates	
- Coordinate Systems and Interferometry	
SIGN CONVENTIONS	2-15
- Thickness Sign Convention	
- Curvature Sign Convention (CUX, CUY)	
- Signs of First-order Quantities	
- Ray Trace Sign Conventions	
- Other Sign Conventions	
REFERENCE RAYS, VIGNETTING, AND APERTURES	2-17
- Basic Definitions for CODE V	
Vignetting	
Reference Rays	
Apertures	
Default Apertures	
Relationships Between Reference Rays, Vignetting Factors, & Apertures	

CHAPTER 2 - THE LDM - INTRODUCTION**THE CODE V LENS DATA MANAGER (LDM)****The Lens Database****CODE V is Built Around a Primary Lens Database**

The lens database is retained in CODE V's "active memory" and includes all the optically relevant information describing the one optical system you are currently working on. For a large or complex lens, the lens database can contain hundreds of pieces of data to describe features as diverse as surface curvatures, multilayer coatings, field angles, interferogram data, and fabrication tolerances. Note that in general, instructions on how the lens should be analyzed or optimized are not considered to be part of the description of the lens itself and will not be included in the lens database.

Additional Databases Are Also Used by CODE V

In addition to information entered by you to define an optical system, CODE V may need additional data to complete its definition. Glass data is the most common example of this. When you request an optical material by name (BK7, SILICA, etc), CODE V uses its extensive databases of optical materials to get detailed information on index of refraction and other optical properties. See Chapter 2A, "THE LENS SYSTEM - Materials" for details on using optical materials and Chapter 10, "GLD - Glass Catalog Data" for additional information on the glass databases.

The LDM as a "Data Editor"**The LDM Is Used to Create, Modify, and Display Lens Data**

If you think of your lens data as a database, you can see the need for a database management program to create, modify, or display this data. This is the function of CODE V's Lens Data Manager (or LDM for short). The LDM is an interactive program that lets you quickly create lens data, modify it, delete it, display it in various ways, and save it in files. As an aid in setting up lens systems, the LDM can also make simple lens drawings and perform basic analysis (single rays, third order aberration, etc.). Another way to think of this is as a specialized lens "data editor," different from a general purpose text editor in that it "understands" the structure of the lens data. This entire chapter is devoted to the LDM and to the details of creating, modifying, and displaying all of the many types of data that CODE V can handle.

Some CODE V Options Also Modify the Lens Database

Although most changes to the lens database are made by the LDM, a few of CODE V's special-purpose options can also make changes. When you optimize a lens with the AUT option (Chapter 3), AUT changes the lens database as it alters variables to improve the image quality of the lens. ENV (environmental analysis, Chapter 8) changes the lens database to simulate the effects of temperature and pressure changes. Tolerancing options (TOR, TOD, TOL - Chapter 6) calculate fabrication tolerances and add these to the lens database (you can also enter or modify tolerances directly in the LDM). The other options of CODE V generally perform calculations based on the lens database but do not modify the lens data.

LENS DATA

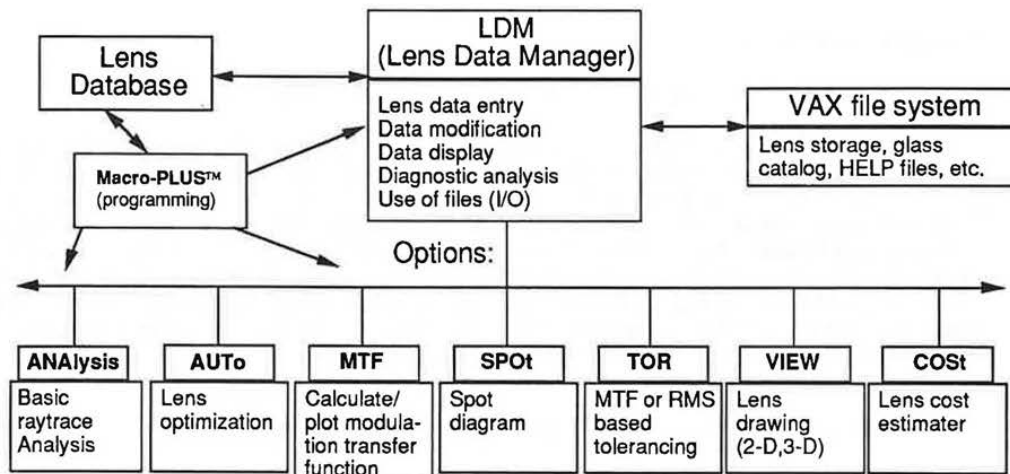
The LDM Has Two "Edit Modes"

Like all of CODE V, the LDM can operate in two basic "modes," command mode and screen/menu mode (CODE V with EASE). In command mode, the prompt "CODE V>" indicates that the LDM is ready to accept commands to modify or display parts of the lens database (e.g., the command THI s6 5.3 will change the thickness following surface 6 to 5.3, while the command SUR s1..5 will display surface related data for surfaces 1 to 5). This chapter has details of all the LDM commands and many examples of their use. For an extended example of using the LDM in this mode, see Chapter 1B, "A USER'S SESSION."

In screen/menu mode, tables showing the various parts of lens data are displayed on screen, and you can modify lens data by simply typing new values in the appropriate tables. This "full screen" mode makes it possible to change data and see the effects of changes without the use of commands. Extensive examples of LDM use in screens mode can be found in the *CODE V Test Drive* and *CODE V Introductory User's Guide* manuals.

The LDM as "Home Base"

In addition to its role as a data editor or database manager, the LDM also serves as the top level or "home base" for running CODE V. As shown in the diagram below, CODE V has two basic levels, the LDM and the Options. When you enter CODE V, you start out in the LDM, and from here you can create a lens, restore one from a file, modify it, etc. After a lens is defined, you can run any of the Options, launching the option from the LDM (by typing the name of the option in command mode, or by choosing the option from a menu in screens).



Note: This is just a "typical set" of options selected from the 42 total options.

Each option has its own set of commands and screen operations. Once you have entered an option, only commands or screen operations defined by that option will be valid - LDM operations are not allowed. After entering commands or screen operations for an option, you can either execute the option (i.e., tell it to perform the requested calculations) or cancel it. To execute the option, you type the command GO (or GOLD/G in screens). To cancel the option, type CAN (GOLD/M or GOLD/L in screens). In either case, the option is completed and control is returned to the LDM.

For details on these and other issues for operating CODE V, please see Chapter 1A, "Operating CODE V" and Chapter 1D, "Using Screens."

Lens Data Post-processing

Lens data post-processing refers to additional checks and calculations that are done by the LDM after you enter or change data. Such steps are needed to insure that lens data is complete and valid before extensive calculations are attempted. Some post-processing is done whenever any change is made, while other, more extensive post-processing is done on an as-needed basis. Examples of simple post-processing include calculating first order solves and retrieving index of refraction data from a glass catalog. More extensive post-processing is done before entering an option. This includes tracing reference rays and calculating values for default apertures.

Sources of Lens Data

There are several potential sources of lens data. Although you can have any number of lenses stored in disk files for rapid retrieval by CODE V, the lens database (CODE V's "memory") can hold data for only one lens at a time. Creating or restoring a new lens will destroy any data in memory (i.e., a previous lens), so be sure to save this data to a file if it has value. There is a partial exception to this "one lens" rule in the form of the LDM COPY command that allows you to extract part or all of a lens stored in a file and insert that data in the current lens database (see Chapter 2A, "THE LENS SYSTEM - Surface Shape and Position - Inserting/Deleting/Copying Surfaces").

Creating a New Lens Interactively

You can interactively create a new lens at any time in a CODE V session. The LEN command initializes the lens database to prepare for new lens entry, removing any previous lens database from active memory (in screens, choose RESTART from the GOLD/1 menu).

Restoring a Previously Saved Lens

Lenses that have been saved in .LEN files can be restored at any time. This includes lenses in your own local directory, lenses in other directories or subdirectories (provided you have privileges needed to access these directories), and CODE V standard lenses. Restoring a lens immediately updates the CODE V lens database, replacing any lens previously in memory. Lens files (filename.LEN) are binary files that are specific to your operating system (VMS or Sun/Unix). Because they are binary files, .LEN files can be read into CODE V very quickly. They cannot, however, be edited with a text editor, nor can they easily be transferred to other types of computers. For information on saving and restoring lens data, see Chapter 2E, "THE LDM - SAVING AND RESTORING LENS DATA."

Reading Lens Data from a Sequence File

You can define a lens by reading LDM commands from a sequence or macro (.SEQ) file. You can create such a file directly by using a text editor, by transferring it from another computer (e.g., with a terminal emulator), or with the CODE V WRL (write lens) command. Because a .SEQ file is a standard text file, it is also very easy to transfer lens data in this form to other computers. Sequence files are read into CODE V with the immediate command IN (this command works only in command mode). See Chapter 10, "Defaults and Utilities," for information on IN and other immediate commands.

Using Standard Library Lenses

ORA supplies a starting library of various lens types to use as examples and starting points. Their use is discussed in Chapter 1, Appendix 1A-E, "Lenses Supplied with CODE V."

Using Standard Library Lens Components

ORA also supplies lens prescriptions for a large number of standard lens components (singlets, doublets, and others) from several suppliers of optical parts. These can be used on a standalone basis, or more often as "building blocks" to construct more complex lens systems. Their use is discussed in Chapter 1, Appendix 1A-E, "Lenses Supplied with CODE V."

LENS DATA

OPTICAL DATA DEFINITIONS

What Constitutes "a Lens" in CODE V?

CODE V Minimizes Required Data

CODE V is designed to minimize the amount of data required to define a lens. CODE V provides default values for most user omitted data items (some specialized data is simply optional and requires no default value). In the early stages of a design, a simple lens model may suffice, for which many CODE V defaults may be quite adequate (e.g., detailed aperture and edge information can always be entered, but default circular apertures are often accurate enough for early design and analysis). Tolerances, coatings, and polarization specifications are other examples of data that can be omitted until needed for detailed analysis or fabrication support.

In later stages of design, CODE V provides great flexibility in defining detailed and specialized features. By providing such additional details, you can refine the lens model into a closer simulation of the behavior and physical properties of the real lens that may be built from the design data. This allows you to make better predictions of diffraction performance, packaging limitations, lens performance in production, etc.

Minimum Requirements for a Ray Traceable Lens

The following requirements must be met if CODE V is to consider a lens to be complete and ray traceable:

- Minimum of one wavelength defined
- System aperture defined (entrance pupil diameter, f/number, or numerical aperture)
- Minimum of one surface defined (in addition to the pre-defined object and image surfaces)

Additional Data that Is Nearly Always Specified

Although not required to establish a minimally acceptable lens, practical applications almost always require additional lens data.

- Field or format definition (up to 25 field points)
- Multiple wavelengths and spectral weights (unless system is monochromatic)
- The aperture stop surface (placed at surface 1 by default)
- Vignetting information for each field (user-defined or calculated by SET command)
- Apertures on one or more critical surfaces

Additional Data that Is Specialized or Optional

When specialized features of CODE V are used, additional requirements may apply. For example, use of holographic optical elements (HOE surface) requires definition of construction wavelength and geometry information for each HOE surface. Such requirements are defined in detail in this chapter for each special feature.

CATEGORIES OF DATA DESCRIBING AN OPTICAL SYSTEM

The Task

What Do We Mean by "the Task?"

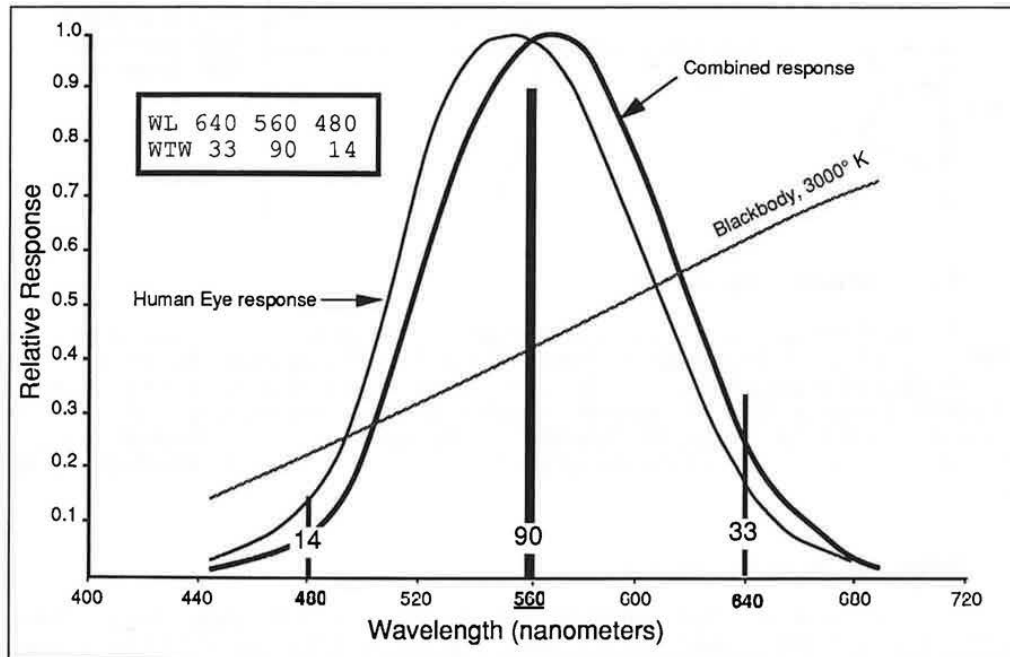
"The task" is that part of the optical system description that specifies how the lens must operate, including its spectral range, aperture size, and field coverage. Such parameters are specified as requirements and are generally not changed by CODE V except by specific user request. Whenever you start to define a new lens, you must specify these task parameters before CODE V can perform any meaningful analysis of the lens.

Specifications (What the Lens Is to Do)

The most fundamental specifications of any lens are its spectral range (wavelengths) and its system aperture (f/number, entrance pupil diameter, or numerical aperture). These must always be provided by the user – there are no defaults provided. Other specifications are optional, though some are virtually always supplied by the user. Specific commands for various specification data items are described in detail in Chapter 2A under "THE TASK - Specification Data." You may find the following background information useful in interpreting several of the more common specification data commands.

Wavelengths (Required)

You may specify up to 7 discrete wavelengths at which the optical system will be analyzed and optimized, although 3 wavelengths will be sufficient for many tasks, and monochromatic systems naturally require only one. Because these discrete wavelengths are used in most options to simulate a continuous polychromatic distribution, spectral weights can be very important. The CODE V SPE option (Spectral Analysis - Chapter 9) is a very useful tool in determining suitable wavelengths and weights when the spectral responses of source, filter, and detector are known (or can be estimated). The following figure is based on data from the SPE option and shows source and detector spectral curves, the combined spectral curve, three discrete wavelengths chosen by the user (WL 640 560 480), and the spectral weights calculated by SPE to best fit the combined curve for these wavelengths (WTW 33 90 14).



LENS DATA

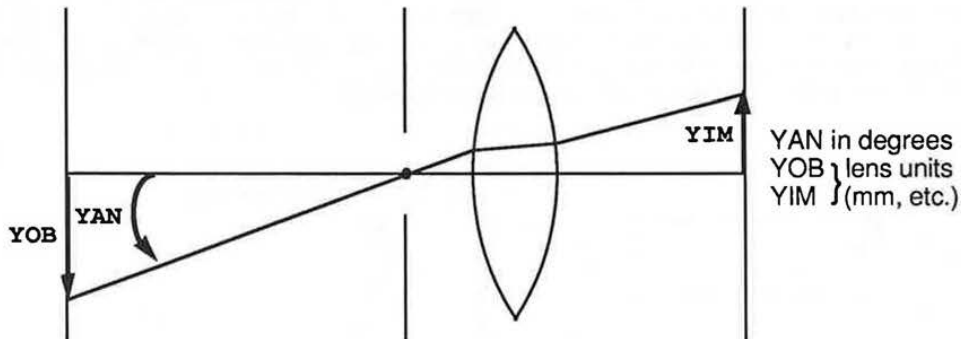
You must also specify which wavelength the program is to use for such monochromatic calculations as first order ray tracing (including derived quantities such as focal length), Seidel aberrations, and reference ray tracing. This is called the reference wavelength (the reference wavelength of 560 nm is highlighted in the above figure).

Aperture (Required)

"Aperture" in this context refers to the paraxial system aperture, not to apertures on individual surfaces. Whether specified as f/number (FNO), entrance pupil diameter (EPD), or numerical aperture (NAO on object side, NA on image side), system aperture determines the unvignetted size of the light bundles from each field point. For complete definitions and recommendations, see Chapter 2A, "THE TASK - Specification Data - Aperture Specification." System aperture must be considered along with vignetting factors and surface apertures to understand the nature of light bundles that are used in various parts of CODE V. These relationships are discussed later in this introduction.

Field or Format Definition

Although CODE V works only with individual point objects (not extended objects), you can define multiple field or object points as part of your lens data. Analysis options will provide output for each defined field; optimization is carried out simultaneously over all fields. Fields can be defined in three ways (the figure shows Y components only - X components are similarly defined). For usage recommendations, definitions, and command details, see Chapter 2A, "THE TASK - Specification Data - Field Specification."

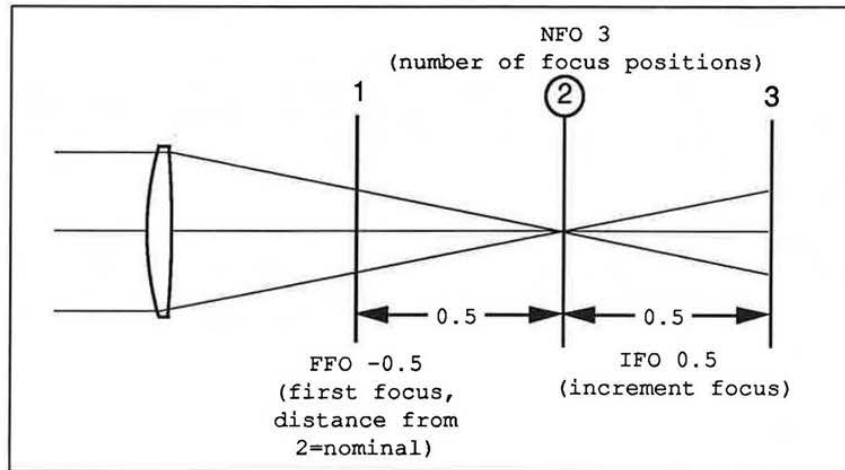


The Aperture Stop Surface

The aperture stop surface is the surface whose aperture limits the axial bundle of light. By definition, chief rays from all fields go through the center of the aperture stop surface. The aperture stop can be placed on any surface, real or dummy, other than object or image. If you do not specify otherwise, CODE V assumes surface 1 to be the aperture stop. Aperture stop positioning varies depending on your application and can have major effects on aberrations and element sizes. CODE V cannot automatically determine the optimum surface on which to place the stop.

Depth of Focus for Analysis

Some optical systems have performance specifications over a designated range of focus. As shown in the following example figure, CODE V provides commands for defining an initial focus position (FFO), step size (IFO), and up to 18 steps in the desired range (NFO).



When it is defined, through-focus data is used by most image evaluation options (GLS, LSF, MTF, PAR, PMA, PSF, QUA, RAD, SPO, and WAV). Note that the computation time and volume of output from these options can increase substantially when depth of focus is specified. Refer to Chapter 2A, "THE TASK - Specification Data - Depth of Focus" for details on these commands. AUT (automatic design) has separate commands for through focus optimization (see Chapter 3).

Vignetting Factors

Vignetting factors are used when you want to specify a specific degree of vignetting. Vignetting factors must be considered along with system aperture and surface apertures to understand the nature of light bundles that are used in various parts of CODE V. These relationships are discussed later in this introduction.

Afocal Systems

Afocal systems have exiting beams that are nominally collimated (parallel), i.e., they do not form an image at a finite distance. CODE V handles such system through the mechanism of an "afocal perfect lens" that is defined by the user for the purpose of bringing the nominally collimated beams to a focus without introducing additional aberration. See Chapter 2A, "THE TASK - Specification Data - Miscellaneous" for details on the AFI and AFO commands that are used to define the afocal perfect lens.

The Lens System

Surfaces

The surface is the basic organizing unit in a CODE V lens description. A CODE V lens is made up of an object surface (where rays originate), an image surface (where rays terminate), and one or more user defined surfaces, one of which is the aperture stop surface. Each surface represents a location of interest in the optical system, and various optically relevant data can be attached to this location, allowing it to represent (for example) an air/glass interface with a particular shape (curvature) and extent (aperture) in space. When rays are traced, they normally proceed from one surface to the next in sequential fashion, following the order in which the surfaces have been defined (non-sequential surfaces are a useful exception to this norm). CODE V allows you to define a large number of surfaces in a lens model (currently 250).

This chapter contains complete information on surface modeling. See in particular Chapter 2A, "THE LENS SYSTEM - Surface Shape & Position" for a detailed overview.

LENS DATA

Dummy Surfaces

Dummy surfaces are those with the same material on both sides (air/air or glass/glass). Such a surface has no refractive effect and can thus be placed anywhere in an optical system setup. Dummy surfaces can represent mechanical stops, apertures, obscurations, mounts, baffles, etc.– in such cases, user-defined apertures are placed on dummy surfaces to enable them to block rays in image evaluation options. Dummies with default apertures will NOT block rays in image evaluation options.

It is always possible to ray trace to a dummy surface and determine ray coordinates there, regardless of its location – virtual ray tracing (essentially geometric extension of ray segments) is used when necessary to accomplish this (virtual ray tracing is not allowed in non-sequential surface ranges). Note, however, that such virtual ray segments extending to dummy surfaces are not generally shown on lens drawings.

Elements

Although we often talk about optical elements, CODE V does not explicitly define elements or other groups of surfaces in its lens database. Options that make use of elements and groups of surfaces may break surface data down into elements for reporting purposes. Elements and groups are most important in tolerancing, where the mounting structure of the lens must be approximated, and the LDM provides commands to define element and group tolerances in addition to surface tolerances (see "BUILDING THE LENS SYSTEM - Tolerances" in Chapter 2A, and also Chapter 6, "TOLERANCING," for detailed information).

Operations on Surfaces

Surfaces can be inserted, deleted, and copied (both within the current lens and from other lenses stored in files). In all such operations, the affected surfaces are automatically renumbered and all associated data is updated to reflect this. The data associated with a surface (curvature, apertures, aspheric data, solves, etc.) can be queried, modified, or deleted (in most cases). Many operations can be performed on a specified range of surfaces, such as flipping a group of surfaces front to back, displaying the focal length of a specified group, or scaling a group of surfaces in various ways. These operations are discussed in Chapters 2B, 2C, and 2D.

Materials

Glass and air are the two most common optical materials, although other materials are often used as well (water, plastics, crystals, etc). The associated material for each surface is the one following the surface. Although index of refraction is the most important material property for optical systems, some options of CODE V can make use of other data as well (transmission, specific gravity, price, etc). The LDM allows you to define optical materials in several ways, described early in Chapter 2A (see "THE LENS SYSTEM - Materials"). Gradient index (GRIN) materials are described in the second half of Chapter 2A, "ENTERING/CHANGING DATA - SPECIAL TOPICS."

Surface Shape & Position

Surface shape refers to the refracting profile of the surface (flat, spherical, cylinder, aspheric, etc.). There are various ways to specify curvature, including solves. Position refers to the location and orientation of a surface with respect to other surfaces. This includes thickness/separation as well as thickness solves and various forms of tilts and decenters (including both local and global coordinate systems). These issues are all described in Chapter 2A, "THE LENS SYSTEM - Surface Shape & Position."

Special Surfaces

In addition to the basic parameters of surface shape, CODE V supports a wide range of special surface types. These extend beyond common aspheric surfaces to include holographic elements and even interferometric data. These are described in the second half of Chapter 2A, "ENTERING/CHANGING DATA - SPECIAL TOPICS."

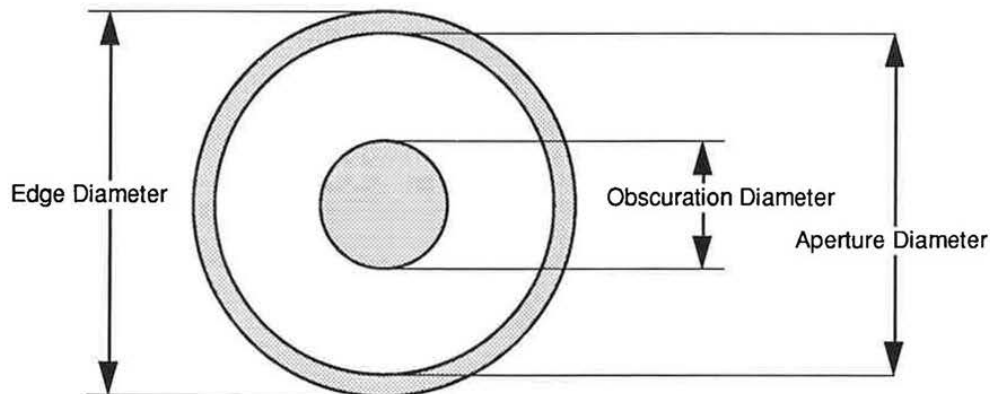
Non-Sequential Surfaces (NSS)

Some optical systems cannot be represented by a set of surfaces that are ray traced in invariant, sequential order. Corner cubes and certain other prisms are one class of such systems, while segmented windows and optical fibers are others. Many such systems can be modeled with CODE V's non-sequential surface (NSS) feature. Some of the rules for setting up and ray tracing must be modified for NSS systems. A complete section on this special subject is included in the second half of Chapter 2A, "ENTERING/CHANGING DATA - SPECIAL TOPICS."

Building the Lens System

Apertures and Edges

Apertures define the used or optically relevant portions of a surface. Although the general term "aperture" can be used to refer to apertures of all types, it usually refers to the outer extent of this portion (the term "clear aperture" is also used). Obscurations (optional) define the inner extent of the used portion. Edges refer to the physical extent of the surface rather than its optical extent. As shown in the figure below, rays are blocked if they fall outside of the aperture or inside the obscuration (shaded areas). Surfaces can have multiple apertures, edges, and obscurations when necessary. Circular, elliptical, and rectangular shapes are supported. Additional comments relating to apertures are included later in this introduction (see "Reference Rays, Vignetting, and Apertures"). For complete details, see Chapter 2A, "BUILDING THE LENS SYSTEM - Element Structural Data Apertures/Obscurations/Edges/Holes."



Non-sequential surfaces (NSS) are used to model optical systems with unusual geometries or other special properties. In NSS systems, edges are much more important than for normal systems, and a special aperture type (hole) is defined which applies only to NSS systems. Please see the second half of Chapter 2A, "ENTERING/CHANGING DATA - SPECIAL TOPICS."

LENS DATA

Mirror Substrates, Cements, Coatings

Some types of information are applicable only in a subset of options. First surface mirror substrate information (backing material and shape) does not affect raytracing but can be important for lens drawing, thermal modeling (ENV option), and for weight and cost calculations. Cements (between cemented components) and coatings (single layer or multilayer) can be important in calculating transmission and whenever polarization is considered in diffraction based options. These specialized lens data items are described in Chapter 2A, "BUILDING THE LENS SYSTEM - Element Structural Data ."

Tolerances

When optical elements are fabricated, their design parameters must be held within certain limits if the lens system is to perform as intended. These limits are called tolerances, and they are defined for most of the parameters that define a lens in CODE V (thickness, decentration, index of refraction, etc). Although tolerances are calculated and used primarily within the tolerancing options (see Chapter 6), they are considered to be part of the lens database and can be defined, viewed and modified within the LDM. These capabilities are covered in Chapter 2A, "BUILDING THE LENS SYSTEM - Tolerances."

Other Lens Information

Certain special purpose data is considered to be part of lens data by CODE V. Additional information must be added to the lens database to simulate zoom or multiconfiguration lenses (scanners, attachments, etc). Special considerations and commands apply to such systems. Before optimization can be done (AUT option, Chapter 3), free variables and any coupled groups of variables must be defined. This task is done in the LDM and the control codes are stored as part of the lens database. Zoom features and control codes are discussed in Chapter 2A under "ENTERING/CHANGING DATA - Other." This section also contains a combined list of commands to delete various attributes of the lens database (gathered for reference from various sections of Chapter 2).

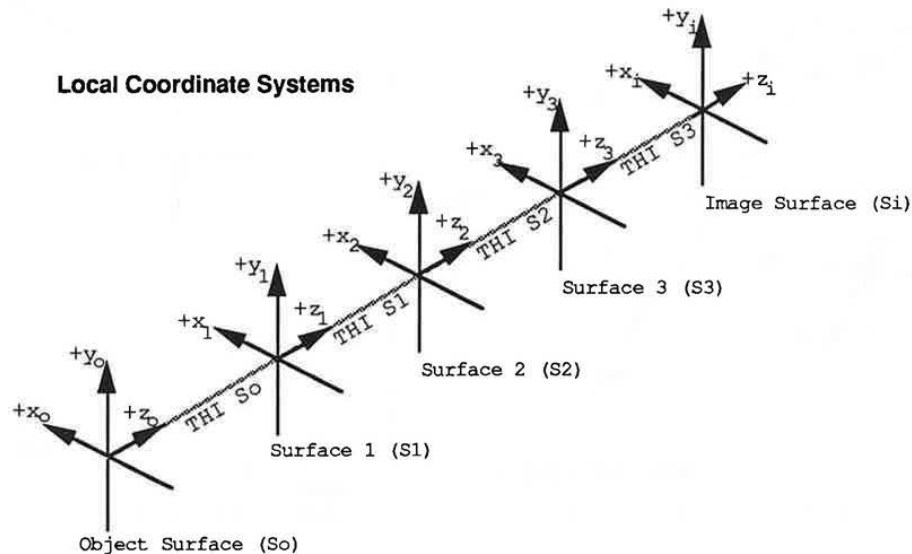
COORDINATES

Local Coordinate Systems

CODE V uses right-handed coordinates. In a centered optical system, the nominal optical axis is the z-axis. As you look from object space toward image space (+z direction)

- The +y axis is "up"
- The +x axis is toward the left.

Each surface in a CODE V lens has its own local, right-handed coordinate system. In a centered, sequential system, these local coordinate systems are related by a simple translation along the z-axis (THI, or thickness to next surface - see figure).



In a decentered system, coordinate breaks are used to model tilts and/or decenters. See Chapter 2A, "THE LENS SYSTEM - TILTS/DECENTERS" for a detailed discussion of the many issues involved in describing non-centered systems.

Global Coordinates

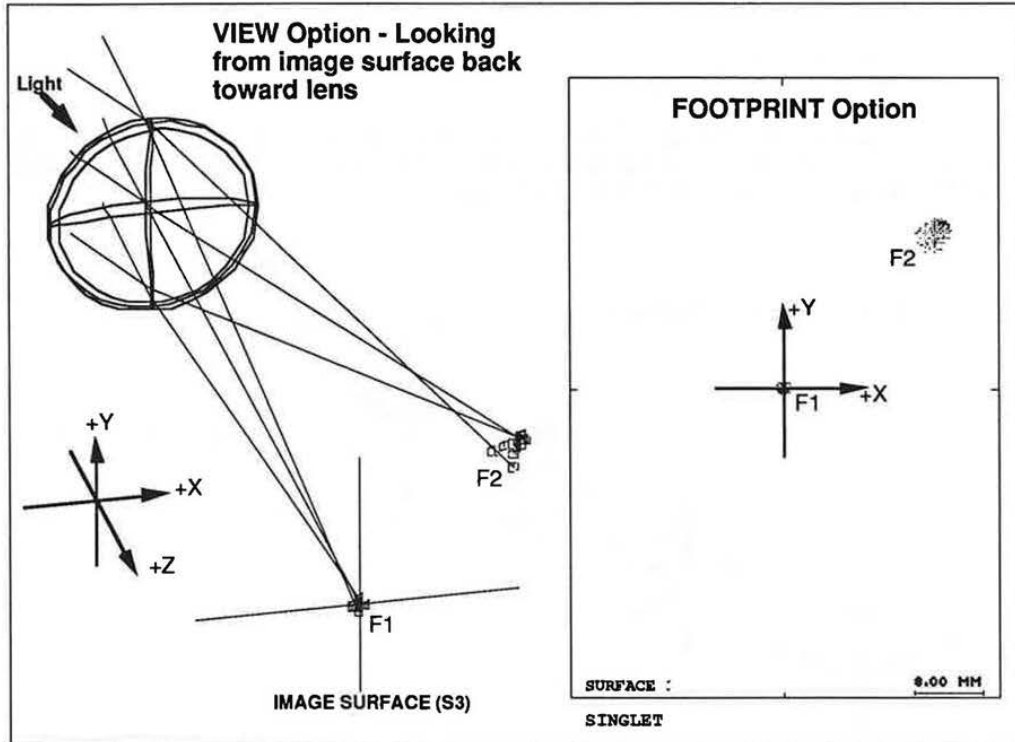
When data for one surface is defined or viewed in the coordinate system of another surface (rather than in the surface's own local coordinate system), we refer to these as global coordinates. Global coordinates are particularly useful when setting up, analyzing, and optimizing tilted and decentered systems, and they are discussed in this context in Chapter 2A under "THE LENS SYSTEM - Tilts/Decenters." One of the requirements for setting up non-sequential surfaces is that they be positioned with global coordinates. NSS systems are explained in the second half of Chapter 2A, "SPECIAL TOPICS - Non-Sequential Surfaces."

CODE V Output Coordinates

When you look at output from CODE V, you need to understand the coordinate system in which the data is expressed and how this relates to the lens model you are using. Some output represents data on the image surface (spot diagram, PSF). The FOO (footprint) option displays ray distributions on any specified surface. Other options represent wavefront or other data in the

LENS DATA

exit pupil (PMA). Most of these options display the data as seen from the image surface, looking in the -Z direction. The figure below demonstrates this for a footprint on the image surface (essentially a spot diagram showing both fields that are defined for this lens).



The two exceptions to this interpretation of CODE V output are the CAT (catseye diagram) and FOV (field of view) options. These portray the data from object space, looking in the +Z direction (see Chapter 4).

Coordinate Systems and Interferometry

CODE V can import interferometric data (interferograms) from various sources, attach the data to specified surfaces, and calculate the effect of these perturbations on ray trace and wavefront data. Although the interferogram interface is quite easy to use, coordinate systems are often a problem. This is because the conventions of interferometry differ somewhat from those of lens design. Coordinates and sign conventions are explained completely in the second half of Chapter 2A, "SPECIAL TOPICS - Interferometric Deformations and Intensity Apodization."

SIGN CONVENTIONS

Thickness Sign Convention

Thickness is the distance along the Z-axis from the current surface vertex to the next surface vertex. If the next surface lies to the RIGHT of the current surface (+Z), thickness is POSITIVE. If the next surface lies to the LEFT of the current surface (-Z), thickness is NEGATIVE. Note that when modeling reflecting systems, the you must alternate the signs of thicknesses after each reflection:

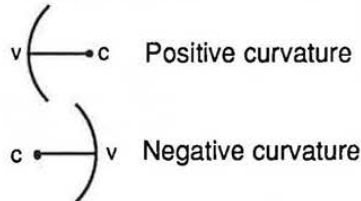
- Thickness is POSITIVE after an EVEN number of reflections (including none)
- Thickness is NEGATIVE after an ODD number of reflections.

Curvature Sign Convention (CUX, CUY)

Curvature (CUX, CUY) is the reciprocal of radius of curvature (RDX, RDY), and the same sign conventions apply for both (note that curvature is the primary definition of surface shape for CODE V). A curvature of zero indicates a plane surface (for convenience, a zero value entered for radius of curvature is also interpreted as plano). The sign convention for curvature is as follows:

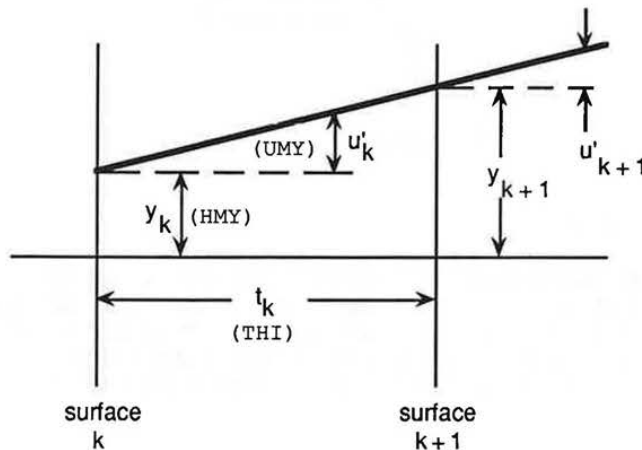
- POSITIVE if $Z(\text{Center of Curvature}) > Z(\text{Surface Vertex})$
- NEGATIVE if $Z(\text{Center of Curvature}) < Z(\text{Surface Vertex})$.

This is demonstrated in the following diagram, where c represents the center of curvature and v indicates the surface vertex.



Signs of First Order Quantities

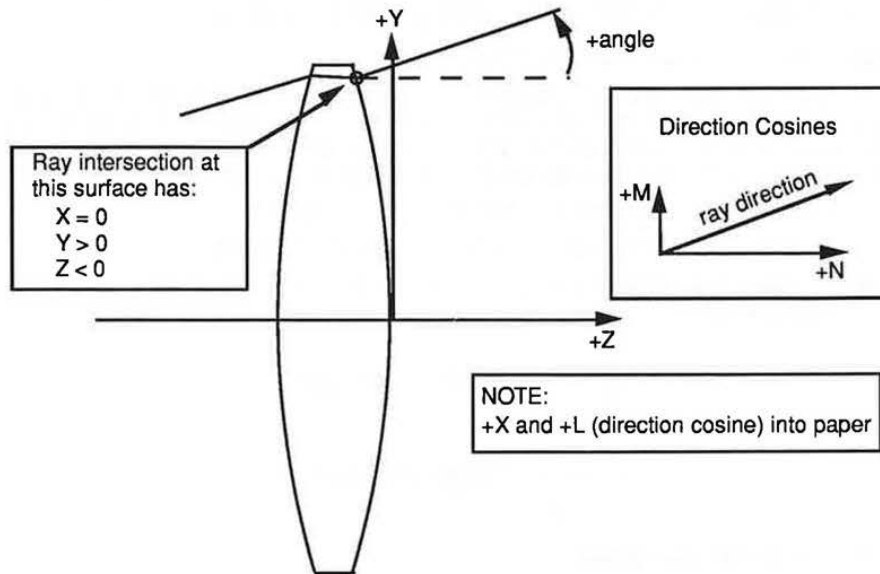
The first order or paraxial ray trace quantities are ray heights (measured on the surface tangent plane), ray slopes (tangent of the ray angle), and paraxial angle of incidence. These quantities are used to calculate effective focal length (EFL) and other paraxial constants. Data is calculated for two paraxial rays, the marginal ray (sometimes called axial ray or a-ray – passes from center of object through edge of paraxial entrance pupil) and the chief ray (sometimes called the principal ray or b-ray – passes from edge of object surface through center of paraxial entrance pupil). In the figure below, y and u' are POSITIVE. Commands used to display first order properties are discussed in Chapter 2D, "THE LDM - QUICK ANALYSIS."



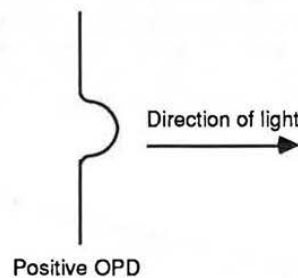
LENS DATA

Ray Trace Sign Conventions

Ray trace sign conventions are important in interpreting the output from single ray tracing (RSI, SIN) and in using reference ray data, either in Macro-PLUS expressions or as constraints in optimization. By default, ray information is expressed in the local coordinates of each surface, following the definitions discussed above ("Local Coordinate Systems"). Ray data can also be displayed and used in global coordinates, relative to the coordinate system of any specified surface. The following figure illustrates the sign conventions for ray coordinates, ray angles, and direction cosines.



The sign convention for optical path difference (OPD) is that a leading wavefront produces a positive OPD. The small deviation in the wavefront below illustrates a positive OPD.



Other Sign Conventions

There are a number of other parameters in CODE V for which sign conventions apply. Vignetting is discussed later in this introduction. Signs for tilts and decenters are defined in a special section (Chapter 2A, "THE LENS SYSTEM - Tilts/Decenters"). When dealing with interferometric data, signs are very important and potentially complex. See Chapter 2A, "SPECIAL TOPICS - Interferometric Deformations and Intensity Apodization."

REFERENCE RAYS, VIGNETTING, AND APERTURES

Basic Definitions for CODE V

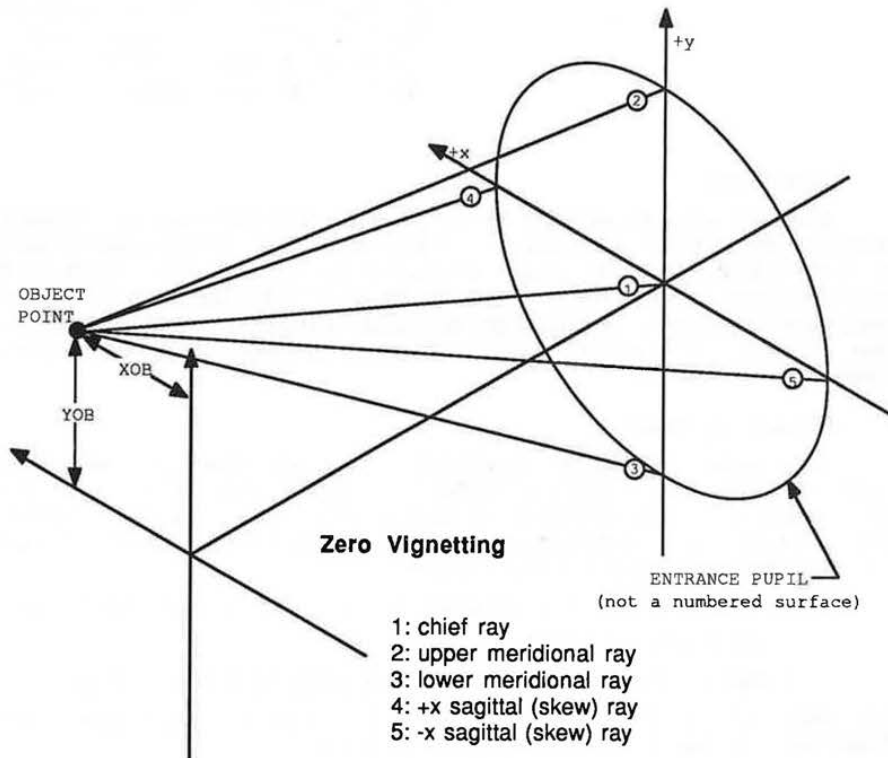
Vignetting

Vignetting refers to the clipping of portions of a ray bundle by apertures on surfaces other than the aperture stop surface. Vignetting is considered to be positive if the ray bundle is reduced in size, negative if the bundle expands ("pupil expansion"). For a more complete discussion of vignetting, refer to "THE TASK - Specification Data - Vignetting" (Chapter 2A) and "THE LDM - OPERATIONS ON LENS DATA" (Chapter 2B).

Reference Rays

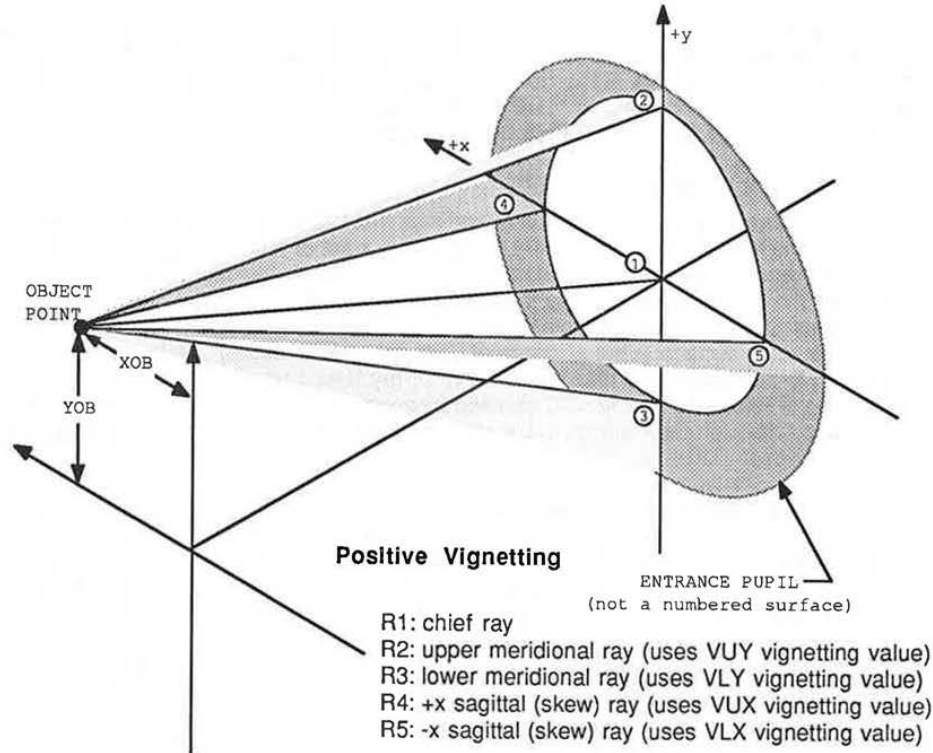
Reference rays are a special set of real rays that CODE V traces and maintains automatically whenever the lens is changed. CODE V maintains a set of reference rays for every user-defined field point and for every zoom position, and for some calculations, these rays are used to represent the entire bundle of rays from a particular field point. CODE V uses the reference ray coordinates at each surface to determine default apertures (i.e., apertures the program assumes to apply at each surface in the absence of user-defined apertures). Reference ray information is also used to calculate edge thicknesses and for ray based constraints in optimization. Note that the tracing of reference rays is NOT affected by apertures. This means that reference rays cannot be blocked (although they can fail in several ways, such as missing a surface or encountering total internal reflection [TIR]).

For a general field point (asymmetric, i.e., containing both X and Y components), five reference rays are defined (see figure). For symmetric field points, CODE V saves time by not tracing equivalent rays from the same field point (it still "knows" the coordinates of these rays, however). The chief ray (R1) is considered to be most representative ray of the ray bundle from a particular field point, while the marginal rays (R2 - R5) define the "envelope" of the bundle.



LENS DATA

As shown in the figure below, reference rays are based on pupil definition and vignetting factors. The relationships between reference rays, vignetting factors, and apertures are explained in the following section.



Apertures

Apertures define the optically relevant extent of each optical surface. In image evaluation options (such as MTF), apertures directly limit the bundles of light used in the calculation. Apertures in CODE V can be circular, elliptical, or rectangular. More complex shapes can be constructed with combinations of these basic forms, including decentered or rotated apertures and central obscurations. Apertures and their applications are discussed in detail in Chapter 2A (see "BUILDING THE LENS SYSTEM - Element Structure Apertures/Obscurations/Edges/Holes").

Default Apertures

Every surface has at least one aperture. For any surface without a user-defined aperture, CODE V defines a default aperture. A default aperture is always a centered, circular aperture whose size is determined from the reference rays. When one or more user-defined apertures are placed on a surface, these are used instead of the default aperture. The CA command allows you to control which apertures are used by CODE V:

- Use user-defined apertures where entered, otherwise Defaults (CA YES)
- Use only default apertures (CA NO)
- Use only user-defined apertures, ignoring defaults (CA APE YES).

See Chapter 2A, "BUILDING THE LENS SYSTEM - Element Structure - Apertures/Obscurations/Edges/Holes" for more information on the CA command.

Relationships Between Reference Rays, Vignetting Factors, & Apertures

The relationships between reference rays, vignetting factors, and apertures are very important. Vignetting factors and system aperture (EPD, FNO, NAO, or NA) are used in some diagnostic analysis options and in AUT (optimization) to determine the extents of rays bundles from each defined field point. Surface apertures are ignored by these options. Image evaluation options such as MTF and SPO trace grids of rays to determine the size and shape of each field bundle more precisely. Every such ray is checked against apertures at every surface to determine whether it is passed or not. Vignetting factors are not directly used by these options.

By using these two approaches to ray bundle modeling, CODE V can achieve speed and accuracy while giving the user great flexibility in defining a lens model. There is a risk of inconsistency in this dual approach, however, since the user is free to specify surface apertures and vignetting factors independently. It is possible to specify completely inconsistent ray bundles for the same lens.

To help with this problem, CODE V includes a special command (SET) that can be used in several forms to assure that system aperture, vignetting factors, and surface apertures are all internally consistent. This is very easy to do, but does require your attention – the SET command is not used automatically. You must remember to use it whenever the lens is changed in a way that can affect ray apertures or vignetting. The SET command and its application to apertures and vignetting are discussed in detail in Chapter 2B, "THE LDM - OPERATIONS ON LENS DATA."

LENS DATA

THE LDM - ENTERING/CHANGING DATA - SPECIAL TOPICS

TABLE OF CONTENTS

SPECIAL SURFACES	2A-205
Introduction	2A-207
CON/ASP - Conic/Asphere	2A-208
XTO - X-Toroid of Base Asphere	2A-210.2
YTO - Y-Toroid of Base Asphere	2A-211
THG - Thermal Gradient on Base Asphere	2A-212
SPL - Radial Spline Asphere	2A-214
AAS - Anamorphic Asphere	2A-218
GRT - Diffractive Surfaces - Diffraction Grating on Base Asphere	2A-220
HOE - Diffractive Surfaces - Holographic Surface	2A-222
MOD - Lens Module ("Black Box" Lens)	2A-230
UDS - User-defined Surface	2A-238
ARRAY ELEMENT	2A-241
Usage	2A-244
Regular Grid, Parallel Array	2A-248
Individual General Channels	2A-250
Polynomial Decenter and Tilt Channels	2A-251
NON-SEQUENTIAL SURFACES	2A-253
Introduction - When to Use Non-Sequential Surfaces	2A-255
Implementation of NS Ray Tracing	2A-256
Cautions	2A-258
High Level Modules	2A-260
Constructing Non-Sequential Surface Ranges - NS Primitives	2A-262
Getting Started with Non-Sequential Ray Tracing	2A-268
References	2A-281
GRADIENT INDEX MATERIALS (GRIN)	2A-285
Definitions & Examples	2A-287
General Commands	2A-290
Forms	2A-292
PUPIL APODIZATION	2A-301
General Apodization	2A-303
Gaussian Apodization	2A-303
POLARIZATION	2A-307
Introduction/Polarization Ray Tracing	2A-309
Defining the Input Polarization	2A-310
Its Effect on Imagery/Modeling Effects that Alter the Polarization State of a Beam	2A-313
Use of Polarization Ray Trace Information by CODE V	2A-315
Activating Polarization Ray Tracing/Geometrical Representation	2A-317
Jones Vector Representation	2A-318
Stokes Parameters/Specifying Linear Polarizers and Retarders	2A-319
Examples of Output	2A-321
INTERFEROMETRIC DEFORMATIONS AND INTENSITY APODIZATION	2A-325
Introduction	2A-327
Interferograms	2A-328
Intensity Apodization	2A-330
INT Files	2A-331
Coordinate Systems and Sign Conventions	2A-332
Zernike Polynomials	2A-334
INT File Format	2A-336
Interface to Commercial Interferometers	2A-339
Sample Output	2A-341
Technical Notes	2A-344
Attaching INT Data to the Surface	2A-346
Orientation of INT Data	2A-348
NASTRAN-GENERATED DEFORMATIONS	2A-351
Introduction/Running MSC/NASTRAN/Running CVNAS	2A-353
Output/Units/Dynamic Analyses	2A-354
Examples	2A-355
Sample Files	2A-356
LDM INDEX	2A-359

ENTERING/CHANGING DATA

**SPECIAL TOPICS
EXTENDED TABLE OF CONTENTS**

SPECIAL SURFACES	2A-205
Introduction	2A-207
CON/ASP - Conic/Asphere	2A-208
XTO - X-Toroid of Base Asphere	2A-210.2
YTO - Y-Toroid of Base Asphere	2A-211
THG - Thermal Gradient on Base Asphere.....	2A-212
SPL - Radial Spline Asphere.....	2A-214
AAS - Anamorphic Asphere	2A-218
GRT - Diffractive Surfaces - Diffraction Grating on Base Asphere	2A-220
HOE - Diffractive Surfaces - Holographic Surface	2A-222
Introduction	2A-222
HOE Commands.....	2A-223
Cautions.....	2A-224
References.....	2A-224
MOD - Lens Module ("Black Box" Lens)	2A-230
Introduction	2A-230
Module Representation in CODE V	2A-230
Cautions.....	2A-231
Technical Notes	2A-232
Example	2A-233
UDS - User-defined Surface	2A-238
ARRAY ELEMENT	2A-241
Usage.....	2A-244
Arrays of Lens Elements/Channels.....	2A-244
Method.....	2A-244
Array Input	2A-244
Start of Array.....	2A-244
End of Array.....	2A-246
Example	2A-246
Restrictions	2A-247
Order of Operation.....	2A-247
Tips on Usage.....	2A-248
Regular Grid, Parallel Array	2A-248
Individual General Channels	2A-250
Polynomial Decenter and Tilt Channels	2A-251
NON-SEQUENTIAL SURFACES	2A-253
Introduction - When to Use Non-Sequential Surfaces	2A-255
Implementation of NS Ray Tracing	2A-256
NS Coordinate System	2A-256
Glass Specification for NS Surfaces	2A-256
Edges/Apertures in NS Ray Tracing.....	2A-256
Refractive/Reflective Mode Specification.....	2A-257
Transfer Criteria	2A-257
Exit Port Definition	2A-257
Cautions	2A-258
High Level Modules.....	2A-260
Constructing Non-Sequential Surface Ranges - NS Primitives.....	2A-262
NSS Command	2A-262
RMC Command	2A-262
NSL Command	2A-262
Getting Started with Non-Sequential Ray Tracing	2A-268
References.....	2A-281
GRADIENT INDEX MATERIALS (GRIN)	2A-285
Definitions & Examples	2A-287
CODE V Facilities for Gradient Index Calculations.....	2A-287
Definitions	2A-288
Examples	2A-289
General Commands	2A-290
Forms.....	2A-292
SEL - SELFOC™ Gradient	2A-292
AXG - Linear Axial Gradient.....	2A-293
URN	2A-294
LUN - Luneberg Lens.....	2A-295
SPG - Spherical Gradient	2A-296

ENTERING/CHANGING DATA

MAX - Maxwell's Fisheye.....	2A-297
UDG - User-defined Gradient	2A-298
PUPIL APODIZATION	2A-301
General Apodization	2A-303
Gaussian Apodization	2A-303
Usage	2A-304
POLARIZATION	2A-307
Introduction	2A-309
Polarization Ray Tracing.....	2A-309
Defining the Input Polarization	2A-310
Polarization State.....	2A-310
Geometrical Representation (Polarization Ellipse).....	2A-310
Jones Vector Representation	2A-311
Stokes Parameter Representation	2A-311
Polarization Coordinate System	2A-312
Its Effect on Imagery	2A-313
Modeling Effects that Alter the Polarization State of a Beam	2A-313
Polarization Effects Modeled by CODE V	2A-313
Modeling of Dielectric or Metallic Interfaces	2A-313
Modeling of Linear Polarizers and Retarders	2A-314
Use of Polarization Ray Trace Information by CODE V.....	2A-315
Activating Polarization Ray Tracing	2A-317
Geometrical Representation	2A-317
Jones Vector Representation.....	2A-318
Stokes Parameters	2A-319
Specifying Linear Polarizers and Retarders.....	2A-319
Examples of Output	2A-321
INTERFEROMETRIC DEFORMATIONS AND INTENSITY APODIZATION	2A-325
Introduction	2A-327
Interferograms.....	2A-328
The Use of Interferograms in CODE V	2A-328
Interferograms for Surfaces.....	2A-328
Interferograms for the Entrance/Pupil and ALIgnment Option.....	2A-329
Null Test Conversions in the ALIgnment Option.....	2A-329
Intensity Apodization.....	2A-330
INT Files.....	2A-331
Coordinate Systems and Sign Conventions	2A-332
CODE V	2A-332
Interferograms - Axes	2A-332
Wavefront Interferograms - Deformations	2A-333
Surface Interferograms - Deformations	2A-333
Zernike Polynomials.....	2A-334
INT File Format.....	2A-336
Interface to Commercial Interferometers	2A-339
Transferring Zygo Interferometric Data to CODE V.....	2A-339
Kermit Program.....	2A-339
Converter Programs/Cabling/VAX Procedure/Mark IV, Model 8100 Procedure.....	2A-340
Sample Output	2A-341
LDM Output	2A-341
FAB Output	2A-342
PMA Output	2A-342
Technical Notes	2A-344
Ray Tracing	2A-344
Behavior of Rays in Regions of "NO DATA"	2A-344
Preparation For Running The ALIgnment Option	2A-344
Attaching INT Data to the Surface	2A-346
Orientation of INT Data	2A-348
NASTRAN-GENERATED DEFORMATIONS	2A-351
Introduction	2A-353
Running MSC/NASTRAN/Running CVNAS.....	2A-353
Output	2A-354
Units.....	2A-354
Dynamic Analyses	2A-354
Examples	2A-355
Sample Files	2A-356
LDM INDEX.....	2A-359

ENTERING/CHANGING DATA

2A-204

SPECIAL TOPICS - Special Surfaces

SPECIAL SURFACES	2A-205
Introduction	2A-207
CON/ASP - Conic/Asphere	2A-208
XTO - X-Toroid of Base Asphere	2A-210.2
YTO - Y-Toroid of Base Asphere	2A-211
THG - Thermal Gradient on Base Asphere	2A-212
SPL - Radial Spline Asphere	2A-214
AAS - Anamorphic Asphere	2A-218
GRT - Diffractive Surfaces - Diffraction Grating on Base Asphere	2A-220
HOE - Diffractive Surfaces - Holographic Surface	2A-222
Introduction	2A-222
HOE Commands	2A-223
Cautions	2A-224
References	2A-224
MOD - Lens Module ("Black Box" Lens)	2A-230
Introduction	2A-230
Module Representation in CODE V	2A-230
Cautions	2A-231
Technical Notes	2A-232
Example	2A-233
UDS - User-defined Surface	2A-238
ARRAY ELEMENT	
Usage	
Regular Grid, Parallel Array	
Individual General Channels	
Polynomial Decenter and Tilt Channels	
NON-SEQUENTIAL SURFACES	
Introduction - When to Use Non-Sequential Surfaces	
Implementation of NS Ray Tracing	
Cautions	
High Level Modules	
Constructing Non-Sequential Surface Ranges - NS Primitives	
Getting Started with Non-Sequential Ray Tracing	
References	
GRADIENT INDEX MATERIALS (GRIN)	
Definitions & Examples	
General Commands	
Forms	
SEL - SELFOC™ Gradient	
AXG - Linear Axial Gradient	
URN - University of Rochester Gradient	
LUN - Luneberg Lens	
SPG - Spherical Gradient	
MAX - Maxwell's Fisheye	
UDG - User-defined Gradient	
PUPIL APODIZATION	
General Apodization	
Gaussian Apodization	
Usage	
POLARIZATION	
Introduction	
Defining the Input Polarization	
Its Effect on Imagery	
Modeling Effects that Alter the Polarization State of a Beam	
Use of Polarization Ray Trace Information by CODE V	
Specifying the Polarization State and Activating Polarization Ray Tracing	
Specifying Linear Polarizers and Retarders	
Examples of Output	
INTERFEROMETRIC DEFORMATIONS AND INTENSITY APODIZATION	
Introduction	
Interferograms	
Intensity Apodization	
INT Files	
Coordinate Systems and Sign Conventions	
Zernike Polynomials	
INT File Format	
Interface to Commercial Interferometers	
Sample Output	
Technical Notes	
Attaching INT Data to the Surface	
Orientation of INT Data	
NASTRAN-GENERATED DEFORMATIONS	
Introduction	
Examples	

ENTERING/CHANGING DATA
Special Surfaces

SPECIAL TOPICS - **Special Surfaces**

2A-206

SPECIAL TOPICS - Special Surfaces

INTRODUCTION TO SPECIAL SURFACES

Besides the default surface type - spherical/plano - a number of special surface types are provided. These are invoked by using a type designator command specifying the surface number; for example, for an aspheric on surface 5:

ASP S5

Usually the surface form is further defined by coefficients of various types, entered with additional commands; default data is supplied for these, usually 0. Some of these surface types also use CUX/RDX and/or CUY/RDY commands described as part of the Sphere/Cylinder text.

The surface types provided are:

- CON - Conic
- ASP - General (rotationally symmetric) asphere, including Fresnel surface on a base sphere
- XTO - X-toroid with aspheric base curve
- YTO - Y-toroid with aspheric base curve
- THG - Thermal gradient surface (rotationally symmetric), with ASP type asphere and radial index gradient
- SPL - Radial spline aspheric
- AAS - Anamorphic asphere, with symmetry about X and Y axes only
- GRT - Diffraction grating on ASP type asphere
- HOE - Holographic surface
- MOD - "Black box" lens module, simulating another lens
- UDS - User-defined surface (linked FORTRAN or C subroutine)

In addition, the type designator SPH is provided to switch any of these back to spherical/plano.

In the descriptions that follow, the equation is given with the commands that apply to that type.

COMMAND MNEMONICS (alphabetical)

A	AAS	AP	AR	ASP	B
BP	BR	C	CON	CP	CR
CUF	D	DP	DR	E	F
G	GRO	GRS	GRT	GRX	GRY
GRZ	H	HCO	HDI	HDN	HIN
Hn	HNO	HOE	HOR	HSW	HTH
HTO	HVn	HWL	HXn	HYn	HZn
IC	J	K	KX	KY	MBF
MCO	MED	MEN	MFD	MFF	MFL
MOD	MRD	MWL	SPL	SPn	TAn
TBn	THG	UCO	UDS	XTO	YTO

ENTERING/CHANGING DATA
Special Surfaces

SPECIAL TOPICS - Special Surfaces - **Conic/Asphere**

CON - **Conic**
ASP - **Asphere**

$$Z = \frac{ch^2}{1 + \text{SQRT} \{1 - (1+k)c^2h^2\}} + Ah^4 + Bh^6 + Ch^8 + Dh^{10} + Eh^{12} + Fh^{14} + Gh^{16} + Hh^{18} + Jh^{20}$$

where Z is the sag of the surface parallel to the Z axis
c is the curvature at the pole of the surface (CUY)
k is the conic coefficient (K) and

k = 0	- sphere
-1 < k < 0	- ellipsoid with major axis on the optical axis (prolate spheroid)
k = -1	- paraboloid
k < -1	- hyperboloid

Also, k = - e², where e is eccentricity.
For k > 0 - oblate spheroid (not a conic section)
the surface is generated by rotating an ellipse about its minor axis and

$$k = e^2 / (1 - e^2)$$

where e is the eccentricity of the generating ellipse.

A, B, C, D, E, F, G, H, J are the 4th, 6th, 8th, 10th, 12th, 14th, 16th, 18th, 20th order deformation coefficients respectively;
A = B = C = D = E = F = G = H = J = 0 for a pure conic surface

$$h^2 = X^2 + Y^2$$

Special values of k:

An even ordered polynomial is represented by setting

$$k = -1$$

and using c/2, A, B,... as the even order coefficients.

A cone can be approximated by a hyperboloid with large curvature and

$$k = - (1 + \tan^2 a)$$

where a is the angle between the cone generatrix and the local surface axis (cone half angle). The large curvature (small radius) will generate first-order traces and properties that are probably useless; avoid solves and other operations dependent on them.

A ray at a high angle to the local axis can intersect a surface twice; a means must be provided to choose which intersection is needed. This is determined by selecting the intersection code (IC) as follows:

1. Sketch the surface and incoming ray in the desired configuration. By definition, the surface normal points so that the angle between the incoming ray and surface normal (as vectors) is less than 90°. (Note: Draw the vectors with the tails at the intersection point, with the incoming ray extended to form its vector in the direction of light travel, and the surface normal vector direction chosen so the angle between vectors is less than 90°.)
2. If the surface normal so defined points in the positive Z direction for a positive index in the space of the incoming ray, the default IC code

IC Sk Yes

is correct. Use the same if both "positives" in the preceding sentence are negative.

Continued....

SPECIAL TOPICS - Special Surfaces - **Conic/Asphere** (Continued)

3. To select the opposite combination,

IC Sk No

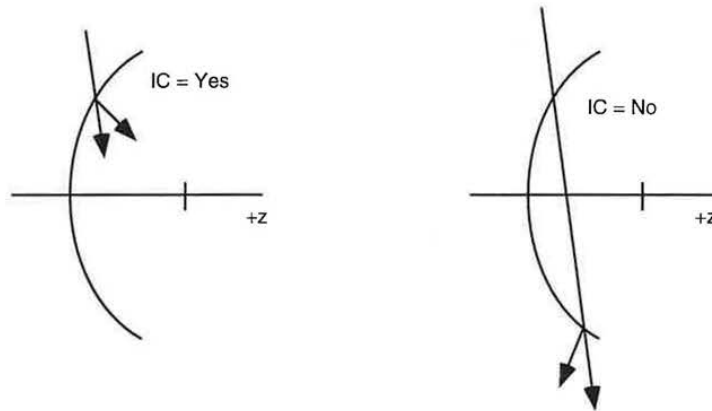


Figure 1. Physical meaning of IC code.

At first it might appear that a shallow angle ray could intersect a sphere or ellipse on its "back" side; this is not allowed since this is the surface which would be represented by having its pole at a different position along the axis. Note also that only the ASP, XTO, YTO, THG, UDS and GRT surfaces have the IC code; this may require conversion of spheres or conics into this form in order to specify the "unusual" intersection point.

Fresnel surfaces ("lighthouse lenses") are surfaces that are finely stepped with small prismatic sections of a lens superimposed on a base shape, usually plano. These are simulated by specifying the base curve (CUF) and using the aspheric terms to define the refracting power as a function of h. It is assumed that the steps are infinitely small; the base curve (CUF) thus defines the physical shape and CUY, K, A, ..., J represent the added refractive power. Use the FAB option to generate a table of slopes.

Note that in surface listings the ASP surface will only list data for A, B, C, and D, unless one of E, F, G, H, J is nonzero or if one of EC, FC, GC, HC or JC is not 100.

Command Syntax	
Screen Prompt	Explanation
CON Sk	
	Change surface type to conic (rotationally symmetric) on surface Sk. CON surface defined by CUY/RDY and K. Preserves current CUY/RDY and K, if any; otherwise sets K = 0.
ASP Sk	
	Change surface type to asphere (rotationally symmetric) on surface Sk. ASP surface defined by CUY/RDY, K, A, B, C, D, E, F, G, H, J, IC and/or CUF. Preserves current CUY/RDY, K, A, B, C, D; otherwise, sets K = A = B = C = D = E = F = G = H = J = CUF = 0, IC = Yes.

Continued....

ENTERING/CHANGING DATA
Special Surfaces

SPECIAL TOPICS - Special Surfaces - **Conic/Asphere** (Continued)

Command Syntax		Control Code
Screen Prompt	Explanation	
K Sk conic [...z]	See KC	
	<p>Conic coefficient for surface Sk, where the value of conic (k) is</p> <p>k > 0 - oblate spheroid (not a conic section)</p> <p>k = 0 - sphere</p> <p>-1 < k < 0 - ellipsoid with major axis on the optical axis (prolate spheroid)</p> <p>k = -1 - paraboloid</p> <p>k < -1 - hyperboloid</p> <p>Used on CON, ASP, GRT, XTO, YTO, THG type surfaces.</p>	
A Sk 4th_order_coef [...z] B Sk 6th_order_coef [...z] C Sk 8th_order_coef [...z] D Sk 10th_order_coef [...z] E Sk 12th_order_coef [...z] F Sk 14th_order_coef [...z] G Sk 16th_order_coef [...z] H Sk 18th_order_coef [...z] J Sk 20th_order_coef [...z]	See AC BC CC DC EC FC GC HC JC	
	4th, 6th, 8th, and 10th order coefficients for ASP, GRT, XTO, YTO, THG type surface Sk. 12th, 14th, 16th, 18th, and 20th order coefficients for ASP type surface Sk.	
IC Sk Yes No [...z]		
	<p>Selects which of two possible intersections of rays with surface Sk will be used. Used with ASP, GRT, XTO, YTO, THG, UDS type surfaces. Seldom needed except when rays are at a high angle to the local axis.</p> <p>Yes - Surface normal points in the positive Z direction for a positive index in the space of the incoming ray, or in the negative Z direction for a negative index in the space of the incoming ray. DEFAULT.</p> <p>No - Reverse condition; surface normal points in the Z direction of sign opposite to index of refraction in the space of the incoming ray.</p>	
CUF Sk fresnel_base_curvature [...z]	See CCF	
	Converts surface Sk into a Fresnel surface with a base curve (shape) of fresnel_base_curvature. For ASP type surfaces, only. Uses CUY, K, A, ...J to represent the added refractive power of the infinitely small steps. Use the FAB option to generate a table of slopes. Fresnel surface is identified by CUF≠0; for plano substrates use small value, e.g., 0.000001.	

SPECIAL TOPICS - Special Surfaces - **Conic/Asphere** (Continued)



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2A-210.1

Chapter 2C

Displaying Data

TABLE OF CONTENTS

THE LDM - DISPLAYING DATA.....	2C-3
SCREEN FLOW DIAGRAM.....	2C-3
COMMAND MNEMONICS (alphabetical).....	2C-4
DATA INPUT DESCRIPTION.....	2C-4
Queries.....	2C-4
Listing of Data.....	2C-5
Drawing of Lens.....	2C-7
USAGE.....	2C-8
LIS Command.....	2C-8
SUR Command.....	2C-8
SPC Command.....	2C-9
APE Command.....	2C-9
NSL Command.....	2C-10
PVC Command.....	2C-10
IND Command.....	2C-10
SOL Command.....	2C-10
ZLI Command.....	2C-10
TLI Command.....	2C-11
TTA Command.....	2C-11
CLI Command.....	2C-11
GSC Command.....	2C-12
DRA Command.....	2C-12

DISPLAYING DATA

2C-2

DISPLAYING DATA

THE LDM - DISPLAYING DATA

Allows text and graphical display of lens data:

- Queries of individual LDM database items
- Listing of all or selected parts of the LDM database
- Quick lens drawing

Along with the optical operations in "Quick Analyses," these permit verification of lens data and diagnosis of data mistakes before invoking the more comprehensive option calculations. None of these operations move the surface pointer.

SCREEN FLOW DIAGRAM

GOLD/2 Subscreen from LEN1:

Draw Lens System	
Select section: 1	1. Y-Z 2. X-Z
Starting surface number 1	Automatic draw (Y/N)? N
Ending surface number 12	
RET - Enter data	B - Bypass entry

DISPLAYING DATA

COMMAND MNEMONICS (alphabetical)

APE	CLI	DRA	GSC	IND	LIS
NSL	PVC	SOL	SPC	SUR	TLI
TTA	ZLI	?			

DATA INPUT DESCRIPTION

Queries

Adding a question mark (?):

Before or after any data entry command descriptor displays the value (first zoom position) currently in memory. Examples:

?CUY or CUY?	-	Displays curvature of pointer surface (assume = 1): CUY S1 = .0703
?CUY S3	-	Displays curvature of surface 3 (without moving pointer): CUY S3 = -.0234
EPD?	-	Displays entrance pupil diameter: EPD = 1.25

Ranges (Si..j) are allowed on SPC, PRC, CEM, CIN, CTH, and tolerances to display all quantities within the range; apertures are not displayable with queries - use APE (Display).

Before or after Sk|Si..j displays the surface number, CUY or RDY, THI, and GLA for each designated surface. Examples:

?S or S?	-	Displays values for the pointer surface (assume = 1): 1: .0703 .1 BK7_SCHOTT
?S3 or S3?	-	Displays values for surface 3: 3: -.0234 .05 F2_SCHOTT
?S1..5	-	Displays values for surfaces 1 through 5
?SA	-	Displays values for all surfaces

This query feature applies to the LDM (as shown above), to immediate commands (see Chapter 10), and for any option commands with defined defaults.

Listing of Data

Command Syntax	
Screen Prompt	Explanation
LIS	
8. List lens data (GOLD/8 Subscreen)	List all lens data including the lens title and data provided by SUR, SPC, APE, NSL, PVC, IND, SOL, ZLI; FIR from "Quick Analyses" is also included. TLI, TTA, CLI, and GSC are not included.
SUR Sk Si..j [F]	
	List surface data (first zoom position) for designated surface(s); if Sk Si..j is omitted, surface pointer supplies Sk. Full print flag: omit F - all data types for that surface(s), except GCH, SPC, PRC, CUM, THM and control variable/coupling codes F - include all data types and control codes Headings use the command mnemonics to identify each item. Listing includes the surface number, but replaced with OBJ, STO, IMG to designate object, stop and image, respectively; the pointer surface is denoted by a > preceding the surface number, if it is in the range Si..j.
SPC [WL APE FLD VIG OTH]	
	List all specification data (for first zoom position). Optional qualifiers limit the list: WL - Wavelength: WL, REF, WTW, CWL APE - Aperture: EPD/FNO/NA/NAO, PUI, PUX, PUY FLD - Field: YIM/YAN/YOB, XIM/XAN/XOB VIG - Vignetting: VUY, VLY, VUX, VLX OTH - Other: FFO, IFO, NFO, AFO/AFI, TEL, XFO, IRS, TEM, PRE, DIM, INI, FOC Each item is identified by its command mnemonic.
APE Sk Si..j [EDG OBS HOL]	
	List surface aperture data (first zoom position), user-entered or generated by SET APE, for the designated surface(s); if Sk Si..j is omitted, surface pointer supplies Sk. Optional qualifiers: EDG - List edges only OBS - List obscurations only HOL - List holes only omitted-List apertures, edges, obscurations, and holes Each aperture type is identified by its command mnemonic.
NSL	
	List all non-sequential data (for first zoom position): Surfaces - Range, exit port surface and thickness, outside material and Z axis direction Elements - For ROO, CCR, apex length, material, mode and dihedral angle errors

Continued....

DISPLAYING DATA

Listing of Data (Continued)

Command Syntax	
Screen Prompt	Explanation
PVC	
	List private catalog data, for all user-defined materials, at entered wavelengths.
IND	
	List index of refraction table, for all lens system glasses at used wavelengths.
SOL Sk Si..j	
	Lists solve data (first zoom position) for the designated surface(s); if Sk Si..j is omitted, surface pointer supplies Sk. System solves RED, PIM appear for SO, SI-1, respectively. Each solve type is identified by its command mnemonic.
ZLI Sk Si..j [SPC zoomed_command]	
	Lists zoomed data for the designated surface(s); if Sk Si..j is omitted, surface pointer supplies Sk. Optional qualifiers: SPC - Lists zoomed specification data and system solves only zoomed_command - Lists this zoomed data type only; zoomed_command is the mnemonic for the data type, e.g., THI neither - Lists all zoomed data System solves are included when SPC or surfaces they affect are requested. Each zoomed parameter is identified by its command mnemonic.
TLI Sk Si..j [Zk] [CMP] [to_code C V F] [L'label'(3) ALL]	
	Lists tolerance data for the designated surface(s); if Sk Si..j is omitted, surface pointer supplies Sk. Optional qualifiers: Zk - Lists zoom positions only CMP - Lists compensator(s) only to_code - Lists this tolerance type only; to_code is the command mnemonic for the tolerance type, e.g., DLT C - Lists coupled group(s) only V - Lists varied tolerance(s) only F - Lists frozen tolerance(s) only L'label'(3) - Lists the specified subset; if omitted, lists a subset having a blank label. ALL - Lists all subsets Each tolerance type is displayed with its command mnemonic.
TTA	
	Lists table of optical data and tolerances, centered and decentered.

Continued....

Listing of Data (Continued)

Command Syntax	
Screen Prompt	Explanation
CLI [Sk Si..j]	
	<p>List apertures for each surface: (1) aperture just large enough to pass all zoom positions, (2) LDM surface apertures, (3) for each zoom position, aperture just large enough to pass that position. Apertures that exceed LDM surface apertures and/or do the vignetting are flagged.</p> <p>For rotationally symmetric lenses:</p> <ul style="list-style-type: none"> - Table based on Y reference rays (R1,R2,R3) <p>For non-rotationally symmetric lenses:</p> <ul style="list-style-type: none"> - Table based on Y reference rays (R1,R2,R3) - Table based on X reference rays (R1,R4,R5) - Summary table: largest aperture of either X or Y table, for all zoom positions <p>If Sk Si..j is included, listing only spans those surfaces.</p>
GSC [Sk Si..j] [COS] Yes No....z	
	<p>List position of each surface relative to the single coordinate system established by GLO command; if GLO command is not active or no GLO command has been given, the coordinate system of surface 1 is used. Listing includes X, Y, Z displacement of each surface's local coordinate system, and:</p> <ul style="list-style-type: none"> COS - Local Z axis expressed in direction cosines no COS - Local Z axis expressed in rotation angles (α, β, γ) <p>with respect to the global coordinate system. If Sk Si..j is included, listing only spans those surfaces.</p>

Drawing of Lens

Command Syntax	
Screen Prompt	Explanation
DRA [XZ] [Si..j]	
Draw Lens System (GOLD/2 Subscreen)	<p>Draw YZ section of entire lens, scaled to fit screen. Optional qualifiers:</p> <ul style="list-style-type: none"> XZ - Draw XZ section (default: YZ) Si..j - Limit drawing to designated surfaces (default: S1..I) <p>If zoomed, the first active position (POS command) is drawn. This provides a "quick look"; use the VIEW or LAYOUT option (Chapter 7) for more control selection, border and labeling. Destination of drawings (terminal and/or file) is subject to control of the GRA command; if you are using a terminal and GRA directs drawings to it, the normal pause requiring response will occur after each drawing; for a workstation, the drawing will appear in a separate window and a query will only occur if you are also directing plots to a file.</p>

DISPLAYING DATA

USAGE

During the course of a CODE V session, you will find it useful to review the current lens, or parts of it, to help to decide what to do next or to remind you of what has already been input. For example, you may wish to review the surface-by-surface data, or the specification data, or the user-defined apertures that have been specified, etc.

Several commands in CODE V are available to display specific parts of the total data comprising the optical system under study. The output of each of these commands is a listing, except the **DRA** command, which draws a layout of the lens. Most of these commands generate output for the first zoom position only; use the **ZLI** (zoom list) command to get data for zoomed parameters.

LIS Command

The **LIS** command gives an output which lists all the data necessary to input the lens from scratch, including special surface data, aperture data, all material data, tilt and decenter data, etc. This is the command to use when you wish to make a complete lens description for someone else or for your files. In addition to listing all the necessary data, it also includes a **FIR** command from the "Quick Analysis" set of commands (see Section 2D) to display the first order properties of the lens.

The only lens data not included with the **LIS** output are tolerance data, which are not necessary to define the lens optically, and default aperture sizes. There are commands, however, to list each of these.

The data output with the **LIS** command are formatted to a fixed number of significant digits. If this is insufficient for a given item of data, increased precision can be obtained with the **EVA** command (see pages 2D-4 and 2D-12).

The **LIS** command is essentially equivalent to a series of several different data display commands as follows:

```
TIT?  
SUR SA F  
SPC  
APE SA  
NSL  
PVC  
IND  
SOL SA  
ZLI SA  
FIR
```

To use the **LIS** command, just type **LIS**. There are no qualifiers or data associated with the command. (You may first wish to direct output to a file with the **OUT** command.)

SUR Command

The **SUR** (surface) command is used to display surface specific data for a given surface or for a range of surfaces. If no **S** qualifier is used, only data for the current surface is listed (the one the **LDM** pointer points to); use **SUR SA** to see data for all the surfaces. The command displays all the data associated with the requested surfaces except for data listed with other **LDM** data display commands described in this section (apertures, tolerances, solves, refractive indices, etc.). If the **F** qualifier (meaning "full") is given, the variable control codes for the surfaces are listed also along with any special glass data (**GCH**, **SPC**, **PRC**, **CUM**, and **THM**) and any coating data. If a curvature or thickness is generated by a solve, it cannot be an independent variable in **AUT** and the type of solve (**UMY**, **PIM**, **ET**, **OAL**, etc.) is shown where the control code would normally appear. Data are given for the first zoom position only; use **ZLI** to see values for other zoom positions.

The **SUR** command with the **F** qualifier is one of only three ways (outside of **AUTO**) to see which parameters are variables and which are not for **AUTOMATIC DESIGN**, and is the only way in command mode (the other two ways are in the screens mode, one by seeing the "v" in the appropriate screen, the other is number 6 under **GOLD/8**, Other Operations).

DISPLAYING DATA

The form of the output of the **SUR** command is slightly different for sequential surfaces and non-sequential surfaces, due to the differences in data associated with each. Non-sequential surfaces are identified in **SUR** output with a ! NSS.

In **SUR** output listings, if the surface or surface range includes the current pointer surface, a > is printed before the surface number. The **SUR** command (like all the other commands in this section) does not move the surface pointer.

Examples:

```
SUR SA      ! List all surface data for the lens
SUR S3..6   ! List surface data for surfaces 3 through 6
SUR         ! List surface data for the current (pointer) surface
SUR SA F    ! List all surface data plus variable control codes
              and special glass data
```

Occasionally the user may wish to see just the radius (or curvature), thickness, and glass data per surface, and not see the other data. This would make the listing shorter, especially if there are many special surfaces or many tilted/decentered surfaces. The data query **S?** can be used for this, instead of using the **SUR** command. (Note that the ? can come before or after the S.)

```
S?          ! List just the curvature, thickness and glass for the
              current surface
S3..5?      ! List just the basic data for surfaces 3 through 5
SA?         ! List just the basic data for all surfaces
?SA         ! List just the basic data for all surfaces
```

SPC Command

The **SPC** (specification data) command is used to list the specification data of the lens. The specification data are the data which apply to the lens as a whole, mainly defining the light bundles (wavelengths, fields, vignetting, etc.). Data are listed for the first zoom position only; to see the specification data for other zoom positions, use the **ZLI SPC** command.

The **SPC** command by itself lists all the specification data. Qualifiers may be used to limit the list to items of interest. Allowable qualifiers are WL, APE, FLD, VIG, and OTH (for other).

Examples:

```
SPC          ! List all the specification data for the lens
SPC FLD      ! List only the field specifications
SPC VIG      ! List the vignetting data for the lens
```

APE Command

The **APE** (aperture) command lists the user-defined aperture data for a surface or range of surfaces. If no **S** qualifier is used, only data for the current surface is listed. The command will list all types of user-defined apertures-standard, obscuration, edge, and hole apertures. The **APE** command does not list default aperture sizes determined automatically by CODE V (use **CLI**). It will list all aperture data, or can be limited by qualifiers to list only certain types of apertures (EDG, OBS, and HOL qualifiers). Note that there is no qualifier to list only standard apertures when there are also other types of apertures on a surface. (For example, if there is a standard aperture and an obscuration on a surface, you can list just the obscuration or both, but you cannot list just the standard aperture.)

In the output, each user-defined aperture is identified by its shape (CIR, REX, REY, ELX, ELY), by its type (EDG, OBS, HOL, if applicable), by its location and orientation (ADX, ADY, ARO), and by any labels (L'xxx').

Aperture data are only listed for the first zoom position. Use **ZLI** to see data for other zoom positions.

DISPLAYING DATA

Examples:

```
APE          ! List all aperture data for the current (pointer)
             surface
APE SA       ! List all apertures in the lens
APE S3..6    ! List all aperture data for surfaces 3 through 6
APE S2 EDG   ! List the EDG apertures on surface 2
```

NSL Command

The **NSL** (non-sequential list) command is used to list the non-sequential surface ranges and exit port data for all non-sequential surface groups in the lens. If either of the special non-sequential surface high level modules (corner cube or roof prism) have been used, they are also listed with the **NSL** command. There are no qualifiers or data associated with this command.

PVC Command

The **PVC** (private catalog) command is used to list the Private Catalog data for the lens. This includes all the user-defined materials and all gradient-index materials in the lens. The entire Private Catalog is listed, even though all the materials included may not be used in the lens. There are no qualifiers or data associated with this command.

IND Command

The **IND** (index) command lists the refractive indices of all materials used in the lens at the wavelengths given with the **WL** command. Note that these indices are always listed as positive, regardless of the direction of light in the materials as used in the lens. There are no qualifiers or data associated with this command.

SOL Command

The **SOL** (solve) command lists all the solves for a surface or a range of surfaces. If no **S** qualifier is used, only data for the current surface is listed. Data are given only for the first zoom position. Use **ZLI** to see the data for other zoom positions. (Note that only **RED** and **PIM** solves can be explicitly zoomed. Some solves, however, such as **THI OAL** or **THI ET**, are done for each zoom position and may create an implicitly zoomed parameter which will not show up in the **ZLI** output.) There are no qualifiers to limit output to only one type of solve.

Examples:

```
SOL          ! List all solves for the current (pointer) surface
SOL SA       ! List all solves in the lens
SOL S2       ! Only list solves on surface 2
```

ZLI Command

The **ZLI** (zoom list) command is used to list the zoomed data for a surface or range of surfaces. If no **S** qualifier is used, only zoomed parameters for the current surface are listed. Qualifiers may limit the listing to only specification data or only to a specific zoomed data type.

Note that the output from **ZLI** may be wider than 80 columns, depending on the number of zoom positions, and may not fit on a standard screen (it will either truncate or wrap, depending on the terminal settings). Setting the terminal to wide mode (132 column output) will display the output properly.

Examples:

```
ZLI          ! List all zoomed data for the current (pointer)
             surface
ZLI SA       ! List all zoom data in the lens
ZLI SPC      ! List only the zoomed specification data
ZLI SA THI   ! List all the zoomed thicknesses in the lens
ZLI S3..5    ! List all zoom data for surfaces 3 through 5 and
             any zoomed specification data
```

.....

DISPLAYING DATA

The previous commands were the commands which make up the **LIS** command. The following commands list additional data of interest.

TLI Command

The **TLI** (tolerance list) command lists the tolerances in the lens, if any have been defined, for a surface or range of surfaces. It also gives a count of the total number of tolerances listed. If no **S** qualifier is used, only tolerances applicable to the current surface are listed. Compensators are not listed with the tolerances; use **TLI CMP** to list the compensators. Qualifiers may be used to limit the output to a specific type of tolerance, to only frozen, variable, or coupled tolerances, or to specific labels only. Data for all zoom positions are included in the same listing.

Examples:

```
TLI           ! List all unlabeled tolerances for the current (pointer) surface
TLI SA       ! List all unlabeled tolerances in the lens
TLI SA ALL   ! List all tolerances in the lens (regardless of label)
TLI S1..3 DLT ! List the unlabeled thickness tolerances (DLTs) for
              surfaces 1 through 3
TLI SA L'cen' ! List all tolerances in the lens with the label 'cen'
TLI CMP SA   ! List all unlabeled compensators in the lens
TLI SA CMP ALL ! List all compensators in the lens (regardless of label)
TLI S2 F ALL ! List all frozen tolerances for surface 2
TLI SA C     ! List all unlabeled coupled tolerances
```

TTA Command

The **TTA** (tolerance table) command lists the tolerances of the lens, but in a different format than the output of the **TLI** command. The output is the same as the output at the end of a **TOR** option run. The tolerances are listed in two tables, one for centered tolerances (**DLR**, **DLF**, **IRR**, **DLT**, **DLN**, **DLV**, and **HOM**) and one for decentered tolerances (**TIR**, **DEC**, **BTI**, etc.). Tolerances which do not fit in the two tables (such as coupled tolerances) are listed in a third table labeled Additional Tolerances. A separate set of tolerance tables is automatically generated for each zoom position if there are any zoomed tolerances.

Note that the output from **TTA** requires 110 columns, and thus may not fit on a standard screen (it will either truncate or wrap, depending on the terminal settings). Setting the terminal to wide mode (132 column output) will display the tables properly.

There are no qualifiers or data associated with the **TTA** command.

CLI Command

The **CLI** (clipping) command lists both the user-defined apertures and the default circular apertures for a surface or range of surfaces. If no **S** qualifier is used, only clipping data for the current surface is listed. Data are listed for default apertures (**CA OFF**) and for user defined apertures (**CA ON**). If the lens is bilaterally symmetric (no **X** fields, **X** tilts or decenters, or non-rotationally symmetric surface types) then the clipping table is based on **Y** reference rays (**R1**, **R2**, and **R3**). If the lens is not bilaterally symmetric, then data are output in three tables, one for the **Y** reference rays, one for the **X** reference rays (**R1**, **R4**, and **R5**), and one combined table, which lists the larger of **X** or **Y** output. If required apertures in **X** or **Y** exceed user-defined apertures, those surfaces are indicated, as are the surfaces which limit the vignetting. The tables take into account all zoom positions automatically.

Note that the output of this command may not be sufficient to describe needed apertures if the lens is asymmetric. Refer to **SET APE** in Section 2B for a discussion of the limitations of this output.

Examples:

```
CLI           ! List clipping apertures for the current (pointer) surface
CLI SA       ! List all clipping apertures in the lens
CLI S3..5    ! List the clipping apertures for surfaces 3 through 5
```

DISPLAYING DATA

GSC Command

The **GSC** (global surface coordinates) command is used to locate the vertices of a surface or range of surfaces relative to the absolute coordinates and orientation of a given reference surface. The reference surface used is selected with the GLO command. If no GLO command is given, surface 1 is used. The GLO command cannot specify the object surface as the reference. The default is to list data for all surfaces; a surface (S) qualifier may be used to select a surface or range of surfaces for output.

The output of the command lists the X, Y, and Z locations of the surface vertex relative to the vertex of the reference surface, and the orientation of the surface's local coordinate system with respect to that of the reference surface. The orientation is listed as the X, Y, and Z angles (ASC, BSC, CSC) of the local coordinate system in degrees, or the X, Y, and Z direction cosines (LSC, MSC, NSC) of the local z axis if the COS qualifier is used.

This command is extremely useful in verifying the setup of tilted or decentered systems, especially globally defined systems such as non-sequential surface systems.

Examples:

```
GSC          ! List all surface vertex locations and local
              coordinate system orientations relative to the
              GLO surface
GSC COS      ! List all surface vertex locations and local
              z axis direction cosines relative to the
              GLO surface z axis
GSC SS       ! List the surface location and coordinate system
              orientation of the stop surface
```

DRA Command

The **DRA** (draw) command provides a quick-look draw of the lens. The default is to draw the lens from surface 1 to the image; a surface range may be given to change this default. The YZ cross-section is the default; if the XZ qualifier is used then an XZ drawing is made. Drawings are made for the first zoom position only. To obtain drawings for other zoom positions, use the LAY or VIE options.

The **DRA** command will automatically scale the drawing to fit the screen, and draws only the reference rays. If any of the reference rays other than a chief ray fails to trace, that ray is drawn up to the point of failure. If one of the chief rays fails to trace, none of the reference rays for that field are drawn. The **DRA** command is equivalent to a VIE; SUR Si..j; LAB NO; GO series of commands (or VIE; SUR Si..j; PLC XZ; LAB NO; GO) with list output suppressed.

Examples:

```
DRA          ! Draw the lens from surface 1 to the image
DRA S3..6 XZ ! Draw the lens in the XZ plane from surfaces 3
              through 6
```

Whether the DRA output appears on the screen or a .PLT file, or both, is controlled by the GRA command. Note that the AUT option also has a DRA command of the same form, that will draw the lens at each cycle of optimization.

Chapter 2D

Quick Analyses

TABLE OF CONTENTS

THE LDM – QUICK ANALYSES.....	2D-3
SCREEN FLOW DIAGRAM.....	2D-3
COMMAND MNEMONICS (alphabetical).....	2D-4
DATA INPUT DESCRIPTION.....	2D-4
Evaluate Optical Values.....	2D-4
First-order Calculations.....	2D-5
Third-order Calculations.....	2D-6
Single Ray Traces.....	2D-8
Single Ray Trace Output Format.....	2D-11
USAGE.....	2D-12
Data Evaluation – The EVA Command.....	2D-12
First- and Third-order Analyses.....	2D-13
FIR Command.....	2D-13
FIO Command.....	2D-13
THO Command.....	2D-13
Ray Tracing.....	2D-13
RSI Command – With Relative Pupil Coordinates.....	2D-14
RSI Command – Targeted to a Spot on a Surface.....	2D-15
SIN Command.....	2D-16
ROF Command.....	2D-16
Ray Trace Output.....	2D-17
Examples of Ray Tracing.....	2D-18

QUICK ANALYSES

2D-2

THE LDM - QUICK ANALYSES

Allows quick analysis of lens data:

- Evaluation of single system quantities or any expression, using Macro-PLUS
- Listing of first order system parameters
- First order ray tracing
- Third order surface-by-surface contributions and sums
- Tracing of single rays in designated wavelengths, with user-defined formatting

These simple calculations, along with the text and graphical display operations in the section "Displaying Data," permit verification of lens data and diagnosis of data mistakes before invoking the more comprehensive option calculations. None of these operations move the surface pointer.

SCREEN FLOW DIAGRAM

GOLD/8 Subscreen from LEN1:

OTHER OPERATIONS	
<ol style="list-style-type: none"> 1. Flip 2. Scale lens system 3. Set data (VIG/APE/Others) 4. Title/Input/Output Mode 5. Freeze/Vary/Default Variables 6. Control code/coupling/pickup 	<div style="text-align: right; border: 1px solid black; padding: 2px; width: fit-content; margin: 0 auto;">Enter 1-10: 7</div> <ol style="list-style-type: none"> 7. Evaluate parameters 8. List lens data 9. List apertures and clipping effects 10. List Non-sequential data
<div style="display: flex; justify-content: space-between;"> RET - Enter selection B - Bypass entry </div>	

Selection 7 from GOLD/8 Subscreen:

Evaluate System Parameters
<p style="text-align: center;">Enter parameter (macro_expression) █</p>
<div style="display: flex; justify-content: space-between;"> RET - Enter data B - Bypass entry </div>

GOLD/6 Subscreen from LEN1:

RAYTRACING	
<ol style="list-style-type: none"> 1. Paraxial Ray Trace 2. Third Order Aberration 3. Single Ray - Specify field and pupil coordinates 4. Single Ray - Specify field and coordinates on user-selected surface 5. Single Ray - Specify position and direction at tangent plane of surf 1 6. Select the data to display for Single Ray output 7. Set Global Coordinates 	<div style="text-align: right; border: 1px solid black; padding: 2px; width: fit-content; margin: 0 auto;">Enter 1-7: █</div>
<div style="display: flex; justify-content: space-between;"> RET - Enter selection B - Bypass entry </div>	

QUICK ANALYSES

COMMAND MNEMONICS (alphabetical)

EVA FIO FIR ROF RSI SIN
THO

DATA INPUT DESCRIPTION

Evaluate Optical Values

Command Syntax	
Screen Prompt	Explanation
EVA macro_expression	
7. Evaluate parameters (GOLD/8 Subscreen)	Evaluate and list the value of the Macro-PLUS expression. See Chapter 11 in the Reference Manual for expression formation. Remember to enclose database items in parentheses. Examples: EVA (EFY S1..5) - Calculates EFL for part of the system (surfaces 1 thru 5) EVA 2*(NA)/(WL WL) - Calculates diffraction cutoff frequency for shortest (last) wavelength (default MFR in MTF option)

First Order Calculations

Command Syntax	
Screen Prompt	Explanation
FIR	
<i>Bottom half of LEN1 screen, use GOLD/J for other zoom positions</i>	<p>List table of first order system parameters (e.g., EFL, OAL, etc.) for all zoom positions. Listing includes:</p> <p>At any conjugate, finite or infinite:</p> <ul style="list-style-type: none"> EFL - Effective focal length BFL - Back focal length FFL - Front focal length FNO - f/number IMG DIS - Actual image distance (SI-1 to SI) OAL - Overall length (S1 to SI-1) <p>PARAXIAL IMAGE</p> <ul style="list-style-type: none"> HT - Height on image surface YAN - Last field angle (in degrees) <p>ENTRANCE PUPIL</p> <ul style="list-style-type: none"> DIA - Diameter THI - Distance from S1 to pupil <p>EXIT PUPIL</p> <ul style="list-style-type: none"> DIA - Diameter THI - Distance from SI-1 to pupil <p>Add at finite conjugates (if applicable):</p> <ul style="list-style-type: none"> RED - Reduction ratio FNO - f/number at actual conjugate OBJ DIS - Object distance (SO) TT - Total track distance (SO to SI) <p>PARAXIAL IMAGE</p> <ul style="list-style-type: none"> THI - Paraxial image distance (from SI-1) <p>Add, for zoomed systems:</p> <ul style="list-style-type: none"> STO DIA - Ray traced diameter of axial bundle on stop surface (SS)
FIO [Sk Si.j] [Zk]	
1. Paraxial Ray Trace (GOLD/6 Subscreen)	<p>List paraxial data for marginal and chief rays for designated surface(s) and zoom position. If Sk Si.j is omitted, lists all surfaces; if Zk is omitted, lists all zoom positions. For each ray listing includes:</p> <ul style="list-style-type: none"> HMY, HCY - Height on surface (y) UMY, UCY - Ray angle after surface (u) N*IMY, N*ICY - Incidence angle/refraction angle times corresponding index (ni) <p>If XZF flag is set, data are for XZ plane instead of YZ plane.</p>

QUICK ANALYSES

Third Order Calculations

Command Syntax	
Screen Prompt	Explanation
THO [Sk Si..j] [Zk]	
2. Third Order Aberration (GOLD/6 Subscreen)	<p>List all third order (Seidel) aberration contributions for designated surface(s) and zoom positions. If Sk Si..j is omitted, lists all surfaces; if Zk is omitted, lists all zoom positions. Listing includes:</p> <ul style="list-style-type: none"> SA - Spherical aberration TCO - Tangential coma TAS - Tangential astigmatism SAS - Sagittal astigmatism PTB - Petzval blur DST - Distortion, tangential AX - Axial color LAT - Lateral color <p>All are expressed in lens units of maximum shift/blur on the image surface, for full aperture and last field. See Chapter 4. ANA option for equations and definitions. If the XZF flag is set, the aberrations are for the X-Z plane.</p>

QUICK ANALYSES



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2D-7

QUICK ANALYSES

Single Ray Traces

Command Syntax	
Screen Prompt	Explanation
<p>RSI [Sk Si..j] [Zk] [Wn] x_fract_pupil y_fract_pupil x_fract_max_x_field y_fract_max_y_field or RSI [Sk Si..j] [Zk] [Wn] Fm x_fract_pupil y_fract_pupil or RSI [Sk Si..j] [Zk] [Wn] Fm Rs or RSI [Sk Si..j]</p>	
<p>3. Single Ray - Specify field and pupil coordinates (GOLD/6 Subscreen)</p>	<p>Trace a single ray, for the designated zoom position and wavelength. The various forms of the command allow several different methods of specifying field and entrance pupil coordinates. The first form uses fractional field and pupil coordinates defined by:</p> <p>x_fract_pupil - X pupil coordinate, as a fraction of unvignetted pupil radius y_fract_pupil - Y pupil coordinate, as a fraction of unvignetted pupil radius x_fract_max_x_field - X field coordinate, as a fraction of maximum X field coordinate, retaining the sign y_fract_max_y_field - Y field coordinate, as a fraction of maximum Y field coordinate, retaining the sign</p> <p>Output will be for surface(s) Sk Si..j (SA is the default), and for zoom position Zk. If Zk is omitted, the ray is traced for all zoom positions. The second form of the RSI command uses a numbered field designated by Fm to specify the field coordinates while retaining the fractional pupil coordinate method for specifying the entrance pupil coordinates. The third form allows the user to specify one of the five reference rays, designated by Rs, from a particular field. The final form will trace the ray that was traced by the last RSI command. Listing includes up to 10 components as selected by the ROF command. If global coordinates are active, as specified by the GLO command, these components for all surfaces are relative to the single coordinate system of the GLO command; otherwise, components for each surface are relative to each surface's local coordinate system.</p> <p>Note: RSI also traces a chief ray from the same object point; both rays must be traceable. If chief-ray aim points have been entered (CRA), then they will be used ONLY IF the field is specified by entering a field number (i.e. the second and third forms of the command).</p>

Continued....

Single Ray Traces (Continued)

Command Syntax	
Screen Prompt	Explanation
or RSI [Sk Si..j] [Zk] [Wn] x_ref_surf y_ref_surf_ x_fract_max_x_field y_fract_max_y_field num_of_ref_surf or RSI [Sk Si..j] [Zk] [Wn] Fm x_ref_surf y_ref_surf num_of_ref_surf or RSI [Sk Si..j]	
4. Single Ray - Specify... on user-selected surface (GOLD/6 Subscreen)	<p>Trace a single ray for the designated zoom position and wavelength. The field can be specified either as a numbered field (the second form of the command) or as fractional field coordinates given by:</p> <p>x_fract_max_x_field - X field coordinate, as a fraction of maximum X field coordinate, retaining the sign</p> <p>y_fract_max_y_field - Y field coordinate, as a fraction of maximum Y field coordinate, retaining the sign</p> <p>The final information needed to select a ray are the X and Y coordinates on a user selected reference surface:</p> <p>x_ref_surf - actual X coordinate on reference surface</p> <p>y_ref_surf - actual Y coordinate on reference surface</p> <p>num_of_ref_surf - number of the target surface on which the X and Y coordinates are designated.</p> <p>Output will be for surface(s) Sk Si..j (SA is the default), and for zoom position Zk. If Zk is omitted, the ray is traced for all zoom positions. The third form of the RSI command will trace the ray defined by the last RSI command. Listing includes up to 10 components as selected by the ROF command. If global coordinates are active, as specified by the GLO command, these components for all surfaces are relative to the single coordinate system of the GLO command; otherwise, components for each surface are relative to each surface's local coordinate system.</p> <p>Note: RSI also traces a chief ray from the same object point; both rays must be traceable. If chief-ray aim points have been entered (CRA), then they will be used ONLY IF the field is specified by entering a field number (i.e. the second form of the command).</p>

Continued....

QUICK ANALYSES

Single Ray Traces (Continued)

Command Syntax	
Screen Prompt	Explanation
SIN [Sk Si..j] [Zk] [Wn] x_1st_surf_tan_plane y_1st_surf_tan_plane x_dir_tan y_dir_tan or SIN [Sk Si..j]	
5. Single Ray - Specify tangent plane of surface 1 (GOLD/6 Subscreen)	Trace single ray, for designated zoom position and wavelength, defined by: x_1st_surf_tan_plane - X coordinate on tangent plane of first surface y_1st_surf_tan_plane - Y coordinate on tangent plane of first surface x_dir_tan - X field coordinate, expressed as a direction tangent in object space (L/N) y_dir_tan - Y field coordinate, expressed as a direction tangent in object space (M/N) Output will be for surface(s) Sk Si..j (SA is the default), and for zoom position Zk. If Zk is omitted, the ray is traced for all zoom positions. Second form of SIN will trace ray defined by last SIN command. Listing includes up to 10 components as selected by ROF command. If global coordinates are active, as specified by the GLO command, these components for all surface are relative to the single coordinate system of the GLO command; otherwise, the components for each surface are relative to each surface's local coordinate system. Note: Only the one ray is traced; no corresponding chief ray needs to be traceable, as with RSI.

QUICK ANALYSES

Single Ray Trace Output Format

Command Syntax		
Screen Prompt	Explanation	Default
<p>ROF 'Format' X Y Z L M N TNX TNY AOI AOR LEN SRL SRM SRN POL PXI PYI PFR PTP POR PRO JR1 JR2 JR3 JR4 JI1 JI2 JI3 JI4 MGS MGP PHS PHP JNS... 10]</p>		
6. Select the data to display for Single Ray output (GOLD/6 Subscreen)	<p>Ray output format for RSI and SIN commands; select for listing, up to 10 of the following parameters:</p> <ul style="list-style-type: none"> X,Y,Z - Coordinates of ray on surface L,M,N - Optical direction cosines of ray after surface TNX,TNY - X, Y direction tangents (L/N, M/N) AOI - Angle of incidence (deg.) AOR - Angle of refraction (deg.) LEN - Ray length from prior surface SRL, SRM, SRN - Direction cosines of surface normal POL - Equiv: ROF PXI PYI PFR PTP POR PRO PXI, PYI - Intensity through linear polarizer with transmission axis parallel to X, Y axis PFR - Fraction of light polarized PTP - Intensity ratio: minor axis to major POR - Orientation of major axis PRO - Right, left or linear JR1, JR2, JR3, JR4 - Real components of Jones matrix JI1, JI2, JI3, JI4 - Imaginary components of Jones matrix MGS, MGP - Magnitude of s and p components of polarization PHS, PHP - Phase (in degrees) of s and p components of polarization JNS - Equiv: all 4 Jones matrix real and imaginary components plus MGS MGP PHS PHP, output in two rows per surface <p>(Polarization output only available if POL command is activated.)</p> <p>These are listed in the order specified. (Note that more than six items may require greater than 80 columns of output.)</p> <p>'format' is FORTRAN format for output ('F D E Gn.d')</p> <ul style="list-style-type: none"> F - Fixed format E - Exponential format (E+xx) D - Exponential format (D+xx) G - General format n - Field width (range: 7 to 20) d - Digits after decimal (range: 0 to n-2) <p>Default format: 'F11.5' Maximum printed width is 120 characters</p>	X Y Z TNX TNY LEN

QUICK ANALYSES

USAGE

These commands provide short, easy to perform, analyses on the lens prior to performing a more involved and comprehensive option analysis. These Quick Analyses can be grouped under three headings: Data Evaluation, First- and Third-order Analyses, and Ray Tracing.

Data Evaluation – The EVA Command

The **EVA** (evaluate) command is one of the most useful and versatile commands in CODE V. It is intimately linked with Macro-PLUS, and can be considered as a Macro-PLUS command. Simply, it gives a way to see the result of the specified Macro-PLUS expression.

The **EVA** command allows display of virtually any part of the lens database, and allows calculations to be made with these database items or with user-defined variables. Refer to the Database Reference section (11B-3) for a description of the database items that can be accessed by **EVA**. Refer to the Expressions section (11A-16) for syntax rules on expressions that can be evaluated by **EVA** and for a description of the pre-defined functions that can be used in expressions.

The general form of the **EVA** command is **EVA** followed by a Macro-PLUS expression. There are no limits to what can be in a macro expression, as long as it follows the standard rules. If the expression to be evaluated is longer than a single line, an ampersand (&) can be placed at the end of a line to indicate continuation on the next line (multiple lines are allowed).

The output of an **EVA** command is a repeat of the requested expression followed by the result. This result may be a number or a text string. If the results are logical values, they are given as 1 for TRUE and 0 for FALSE (for example, **EVA** (NUM F)>3 will result in 1 if there are four or five fields specified, or 0 if there are three fields or less specified).

Note that all CODE V database items must be enclosed in parentheses (even if they are used inside other parentheses, such as a function argument) and note that all trigonometric calculations assume that angles are in radians. As in the rest of CODE V, expressions ignore case (upper or lower), except in text strings.

Examples:

```
EVA (EFL)          ! Evaluate the effective focal length of the lens
EVA (EFL Z2)       ! Evaluate the focal length for the second zoom
                  ! position
EVA SIN((ADE S2)/57.295) ! Angle must be in radians
EVA (HMY S4)*(CUY S7)/LOGF((FNO)) ! Arbitrary calculation
```

The **EVA** command can be used as a general purpose calculator (the expression does not have to include database items):

```
EVA SQRTF(28.345)
EVA 10*4/((16*4+3)-SINF(.27))
```

The **EVA** command can access ray trace data and perform calculations on them. If the R and F qualifiers are used, then the corresponding reference ray datum is used. If the R and F qualifiers are not used, then the datum is for the last ray traced. The reference wavelength is assumed unless specified by the W qualifier, and the first zoom position is assumed unless specified by the Z qualifier.

```
EVA (Y F1 R2 SI)   ! Evaluate the Y value at the image surface (SI) of
                  ! the upper marginal ray (R2) for field 1 (F1)
EVA (Y R1 FL SI W3 Z3)-(Y R1 FL SI W2 Z3)
                  ! Evaluate real lateral color (Y difference
                  ! for chief ray, R1) between the 2nd and 3rd
                  ! wavelength, at the last field (FL)
                  ! for the third zoom position (Z3)
EVA (M S3)/(N S3) ! Evaluate the ray Y direction tangent (M/N) after
                  ! surface 3 for the last ray traced
```


QUICK ANALYSES

The output of the **EVA** command is given to 12 significant digits (if needed). This can provide extra precision for database items which are listed to less precision in standard CODE V output.

```
SUR S2      ! Lists the radius to 5 digits (after the decimal point)
EVA (RDY S2) ! Lists the radius to 12 digits (if needed)
```

If any user-defined variables have been declared by you, they can be used in **EVA** expressions. Refer to User-defined Variables, page 11A-3, for a description of Macro-PLUS variables and their use.

```
^RAD == 45/ATANF(1) ! Define variable ^rad to be 1 radian (57.295...)
EVA SIN(30/^RAD)   ! Converts degrees to radians for trigonometric
                   ! calculation
```

First- and Third-order Analyses

FIR Command

The **FIR** (first-order data) command prints a list of various first-order properties. For finite conjugate lenses ($THI \ SO < 1E10$) first-order properties at both infinite conjugates and at the used conjugates are listed. Listings are automatically made for each zoom position. There are no qualifiers or data associated with the **FIR** command.

FIO Command

The **FIO** (first-order ray trace) command performs a paraxial ray trace of the marginal and chief ray. The default is to list output for all surfaces from the object to the image; a surface range qualifier may be used to limit the output to the requested surfaces.

The output of the **FIO** command is six columns of data. These are the ray height, ray angle (in radians), and refractive index times angle of incidence, all given for both paraxial rays. Separate tables are generated for each zoom position; a zoom qualifier may be used to limit the output to only one zoom position. Refer to Description of Output for the Analysis option, Chapter 4, for a more complete description of the output of the **FIO** command.

THO Command

The **THO** (third-order) command lists the Seidel aberrations for each surface, plus a summary of the totals. The default is to print the listing for all surfaces; a surface range qualifier may be used to limit the output to the requested surfaces. A separate table is generated for each zoom position; a zoom qualifier may be used to limit the output to only one zoom position.

This output is identical to the third-order output from the Analysis option. Refer to the Description of Output section of ANA, Chapter 4, for a complete description of the output of the **THO** command.

The output from **THO** requires 110 columns, and may be truncated or wrapped (depending on terminal settings) on the screen. If this is the case, setting the terminal to wide mode (132 column mode) will display the output correctly.

Ray Tracing

CODE V has two forms of a single ray trace. These are **SIN** (single ray trace), which traces any arbitrary ray, and **RSI** (relative single ray trace), which first traces a chief ray for the requested relative field and then traces the requested ray.

SIN and **RSI** are complementary to each other and have different uses. **RSI** is the more commonly used command; it is easy to use since its arguments are relative entrance pupil coordinates and relative field locations, and, because it is a relative ray, it also outputs the OPD between the ray and its chief ray. However, **RSI** does require that the chief ray for the requested relative field traces to the image plane. The **SIN** command has no such restriction. It will trace any arbitrary ray, although you have to be specific in defining the ray's entrance coordinates to the optical system and its direction tangents. The **SIN** command is especially useful when the chief ray for a given field angle will not trace.

QUICK ANALYSES

RSI Command – With Relative Pupil Coordinates

The arguments for the **RSI** command are generally the X and Y relative pupil coordinates, and the X and Y relative field angles, but short forms can be used for pupil and field. If the desired field is one of the five fields (F2, F2, F3, F4, F5) in the specification data, the field can be specified by a F qualifier. An R qualifier can be used for the pupil coordinates to select one of the five reference rays (R1, R2, R3, R4, R5) but only if an F qualifier has also been used.

Other qualifiers for the **RSI** command are W, Z, and S. Rays are traced in the reference wavelength unless specified with the W qualifier. The chief ray in the reference wavelength for that field is traced first; in addition, if the requested wavelength is a wavelength other than the reference wavelength, a chief ray is also traced at the requested wavelength; for **RSI**, these chief rays must be traceable. The requested ray is traced for all zoom positions; a Z qualifier will limit the output to only one zoom position. The default is to list ray trace output for all surfaces from object to image, unless limited with a S qualifier.

An **RSI** command with no qualifiers or data will retrace the last ray traced. If only the S qualifier is given, the last ray is traced again, with data output for the new surface range. This is helpful when you are making changes to the lens data and testing with a ray.

If the short forms are not used, pupil and/or field coordinates are given in relative values. The X and Y pupil coordinates are relative to the circular pupil for the requested relative field angle. The pupil used is the paraxial entrance pupil diameter located at the real entrance pupil location for that field. A value of 1 for relative X or relative Y means trace the ray at the edge of the pupil in that direction. Vignetting values are ignored by **RSI**. Since the vignetting values change for different fields, **RSI** can not know what the vignetting value would be for an arbitrary field, hence **RSI** does not use any vignetting values. You must manually take them into account. This is true even when using the F qualifier, even though the specified fields do have defined vignetting values. Note also that **RSI** ignores any CRA specification unless the field is specified with an F qualifier, in which case the CRA specification is used.

```
YAN 0 10
VUY 0 .3
RSI 0 1 0 1          ! Traces the ray at the upper rim of the pupil at
                    ! the maximum field (vignetting value is ignored)
RSI 0 .7 0 1        ! Traces a ray at a relative pupil position
                    ! of 0.7 in Y (the same as the vignettted
                    ! marginal ray) at the full field
RSI 0 1-(VUY F2) 0 1 ! Traces the upper Y vignettted ray (same as R2)
                    ! for full field
RSI F2 0 1          ! Traces the ray at the upper rim of the pupil
                    ! (vignetting is ignored) for field 2
RSI F2 0 1-(VUY F2) ! Traces the upper Y vignettted ray for field 2
                    ! (same as R2)
```

If the R qualifier is used, then the reference rays are traced, and these reference rays do take into account any vignetting.

```
YAN 0 10
VUY 0 .3
RSI F2 R2          ! Traces the upper vignettted marginal ray for field 2
                    ! (reference ray R2)
```

The field angle inputs to the **RSI** command are relative to the maximum X and Y values for any of the five field angles specified in the LDM (regardless of whether the largest value is the fifth field or not); the X and Y maximums are selected separately and may thus come from different field points. The sign of the maximum value is retained as the definition of the "largest" field. Thus, if the maximum field angle specified in the LDM is negative, then a relative field of +1 in **RSI** corresponds to the negative angle. If there are both a positive and a negative field angle with the same absolute maximum value, the positive value is retained for the maximum. X and Y relative angles are calculated separately for the X and Y field specifications. If there are no X field specifications, then any relative X field in a **RSI** command will trace a 0 field, since the maximum value is 0; if you want to trace a ray from an X field, you must first have a non-zero X field specification entered in the LDM.

QUICK ANALYSES

```
YAN 0 10 20
RSI 0 0 0 1 ! Traces a ray at +20 degrees

YAN 0 -10 -20
RSI 0 0 0 1 ! Traces a ray at -20 degrees
RSI 0 0 0 -1 ! Traces a ray at +20 degrees

YAN 0 -10 10
RSI 0 0 0 1 ! Traces a ray at +10 degrees

YAN 0 10
XAN 0 0
RSI 0 0 1 0 ! Traces an on-axis ray (no X field specified)

YAN 0 10
XAN 0 5
RSI 0 0 1 0 ! Traces a ray at +5 degrees in X
RSI 0 0 1 1 ! Traces a ray at 5 degrees in X and 10 degrees in Y
```

Since object heights are stored in CODE V, relative angles do not multiply the angle value, but multiply the tangent of the maximum angle.

```
YAN 0 10
RSI 0 0 0 1 ! Traces a ray at 10 degrees
RSI 0 0 0 .5 ! Traces a ray at 5.038369 degrees (the angle
! whose tangent is half the tangent of 10 degrees)
```

What is used by **RSI** is the maximum value of the field specifications. It does not matter what the other values are or how many there are.

```
YAN 10
RSI 0 0 0 .5 ! Trace a ray at 5.038369 degrees
YAN 1 2 10 3 4
RSI 0 0 0 .5 ! Trace a ray at 5.038369 degrees
```

If the F qualifier is used, then both the X and Y field specifications are used for that field number. For example, set up three fields on-axis and along the diagonal of a square format:

```
YAN 0 5 10
XAN 0 5 10
```

There is no F qualifier for these fields which will represent a ray at 10° in Y only. To trace such a ray, relative fields must be used, as in:

```
RSI 0 0 0 1 ! Trace a ray at 10 degrees in Y and 0 degrees in X
```

RSI Command – Targeted to a Spot on a Surface

The **RSI** command also allows targeting of a ray to a specific spot on a specific surface. This is accomplished by adding a fifth entry to the **RSI** data arguments. This fifth entry is the surface number of the targeted surface. If this is used, then the first two entries are not relative pupil coordinates, but are actual X and Y positions on the targeted surface. CODE V will then iterate to find the ray from the specified field which hits the targeted surface at the targeted spot. The field may be specified with a F qualifier. If the F qualifier is used, then the surface number is the third entry.

```
RSI .3 .5 0 1 7 ! Trace a ray at full field in Y which hits
! surface 7 at an X value of .3 and a Y value of .5
RSI F1 1 2 5 ! Trace a ray at the first specified field to
! hit surface 5 at a point of 1 in X and 2 in Y
```

If the F qualifier is used, then any CRA specifications are used, otherwise they are ignored. The CRA will only affect the chief ray traced, and will have no effect on the targeted ray. Note that since **RSI** requires

QUICK ANALYSES

the chief ray to trace, the CRA and F qualifier can be used to trace a ray that would normally not be traced due to chief ray failure.

In a non-sequential system, if a ray is requested to hit a surface at a specific point, and the ray can hit the surface two or more times, the target is applied to the first hit at the surface. (Note that in AUTO, ray data for the last hit on the surface is the data retained and used for any constraints.)

SIN Command

The **SIN** command is used to trace an arbitrary ray into the optical system. It does not trace a chief ray, and does not depend on any other ray being able to trace. Because it does not trace a chief ray first, no OPD output is made for **SIN**. Also, because there is no object point specified (only a ray direction), optical path (OP) is only calculated from the tangent plane of the first surface, rather than from a sphere centered on the object.

The data inputs for the **SIN** command are actual X and Y coordinates on the tangent plane to the first surface (not on the first surface, unless it is plano), and actual X and Y direction tangents in object space. The **SIN** command also accepts W, Z, and S qualifiers in the same way as **RSI** to specify a wavelength, zoom position, or surface output range.

```
SIN 0 0 .3 .4      ! Trace a ray with direction tangents of .3 in X and .4
                   !   in Y which hits the vertex of the first surface
SIN .6 .7 0 0      ! Trace an on axis ray which hits the first
                   !   surface at .6 in X and .7 in Y
SIN .3 .4 0 .2     ! Trace a ray with a Y direction tangent of .2 which
                   !   hits the tangent plane of the first surface at .3
                   !   in X and .4 in Y
SIN 0 0 0 TANF(20/^RAD ! Trace a ray at 20 degrees in Y which hits the
                   !   vertex of the first surface (assumes variable
                   !   ^rad is defined as the ratio of degrees to
                   !   radians)
```

Note that the X and Y direction tangents are the ratios of the X and Z direction cosines (L/N) and ratios of the Y and Z direction cosines (M/N), respectively.

ROF Command

The **ROF** (ray trace output format) command lets you select which ray trace output is displayed and the format of the output. You have a choice of 20 different output data items, although 6 of the data items relate only to polarization properties. Up to ten may be selected for output with a single **ROF** command. More than 6 may result in output wider than 80 columns, which may truncate or wrap (depending on display settings) on a standard display. By setting the display to display wider output, more output may be viewed on a single line.

The default **ROF** is the X, Y, and Z coordinates at the surface plus the X and Y directions tangents after refractions and the ray length from the previous surface (note that the ray length is geometric only - it is not an optical path length). The default format is 'F11.5'. An **ROF** command with ray trace outputs listed but no format specified will use the previous format. An **ROF** command with only a format specification will not change the list of ray trace outputs. An **ROF** command with no qualifiers (format or ray outputs) will reset both the format and list of ray trace outputs to the defaults.

Format types F (fixed format), E (exponential, form E±xx), D (exponential, form D±xx), and G (general format) may be used. The first number in the format (integer before the decimal) specifies the field width (total characters, including sign, decimal, and any exponent); the field width can range from 7 to 20 (limited to a maximum of 11 in screens). The second number in the format (integer after the decimal) specifies the number of digits after the decimal, and can range from zero to two less than the field width. The specified format is used for all outputs on the line; the total number of characters output is restricted to 120 columns (including the surface numbers and one intervening blank between fields).

Note that if direction cosines are chosen for output (L, M, or N) that they are for the ray after refraction/reflection/diffraction. Also note that the direction cosines are optical direction cosines, i.e., they are multiplied by the refractive index of the medium.

Polarization data items are only available if polarization ray tracing has been enabled with the POL command. A POL qualifier will select all 6 polarization related outputs for display.

QUICK ANALYSES

```
ROF X Y Z TNX TNY LEN      ! Default
ROF Y Z M N                ! Select reduced output for meridional rays
ROF                        ! Restores default ROF setting
ROF POL                    ! Selects all 6 polarization outputs
ROF PXI PYI PFR PTP POR PRO ! Same as ROF POL
ROF X Y POL                ! Selects X and Y output plus the 6 polarization
                          ! outputs (eight outputs in all)
ROF 'E15.6'                ! Change format, do not change output list
ROF 'F9.3' Y Z             ! Change format and output list
```

Note: The LEN output is simply the geometrical length of the ray from the previous surface intersection to the current surface intersection. It is not an optical path, as index is not included. Optical path from surface-to-surface is not a displayable ray trace item with ROF, but it is available through the Macro-PLUS database item OP. This OP also includes the optical path contribution of diffractive optics (such as HOEs), lens modules, and interferogram effect (.INT files).

Ray Trace Output

The output of an **RSI** or **SIN** command is a line for each requested surface with the surface number followed by the output data selected with the **ROF** command. If the ray was traced with **RSI**, the output is followed by the OPD of the ray with respect to its chief ray. If the ray has a HOE with a diffraction efficiency less than 100%, then the **RSI** output is followed by the ray transmittance. If polarization ray tracing has been enabled, the output is followed by polarization phases and ray intensity. Refer to the Polarization section (2A-307) for a description of these outputs.

The OPD is calculated as the difference of the ray's optical path and its chief ray's optical path. These optical path calculations are made from a reference sphere at the first surface tangent plane centered on the object point to a reference sphere at the exit pupil centered on the image point.

If the requested ray fails to trace, a diagnostic is given. There are three possibilities for ray failure: (1) the ray encountered a total internal reflection (or refracted when TIRO mode was specified), (2) the ray missed a surface, and (3) the iteration to a special surface failed to converge. For non-sequential surfaces there are also other ray failure modes. In any of these cases, the ray is traced up to the failure point. In the case of an **RSI**, if the chief ray for the requested relative field fails to trace, then a message to that effect is given, and there is no ray trace output. If a ray fails to trace for any reason, a Macro-PLUS database item RER (ray error) is set to the surface number of the ray failure; the sign tells whether it was the requested (+) or chief ray (-) that failed. If the ray traces correctly, RER is set to zero.

Three other diagnostics are supplied with the ray trace output. The first one relates to negative edge thicknesses. If at any surface in the lens, the ray length from the last surface is negative, indicating virtual ray tracing (tracing backwards along the ray), then an E (for edge error) is listed next to the surface number in the ray trace output. The usual reason for this is negative edge thickness on a lens, but it also can occur in decentered systems, especially on dummy surfaces used to reorient the coordinate system (in which case the E flag can be ignored).

The other two diagnostics relate to the ray encountering an aperture or an obscuration. The output of these diagnostics depends on the status of the CA command (CA NO, CA YES, or CA APE). In CODE V a ray traced with either **RSI** or **SIN** is traced to the image plane without regard to apertures or obscurations. In the ray trace output, however, if a ray hits a surface outside the apertures (user-defined or default) and the CA status is YES (the default for CA), an A (for aperture) is listed next to the surface number. If the ray encounters an obscuration, an O (for obscuration) is listed next to the surface number. Note that the E diagnostic will override the A or O diagnostics in the output. If the CA status is APE (for user-defined apertures only), then the check is only made on user-defined apertures, i.e., default apertures are ignored. If the CA status is NO, then no check is made at all.

If the ray encounters an aperture or obscuration and sets the A or O diagnostic, a Macro-PLUS database item called BLS (blocking surface) is set to the surface number. If the ray passes outside the aperture on more than one surface, BLS is set to the number of the first such surface. In the case of the ray hitting a surface inside an obscuration, BLS is set to the negative of the surface number. If the ray encounters neither (i.e., passes inside all apertures and outside all obscurations), BLS is set to zero. Thus, macros can interrogate RER and BLS to determine the status of traced rays.

QUICK ANALYSES

Examples of Ray Tracing

We will work with the doublet which is supplied with CODE V. This lens is stored in the directory CV7_LENS.

```
CODE V> RES CV7_LENS:DOUBLET
```

```
WARNING - Glass SSK4 is no longer available from SCHOTT
          A replacement glass is SSK4A
File CV7_LENS:DOUBLET.LEN(1) has been restored
Lens title: " Doublet"
```

First we will trace an on-axis upper marginal ray. The relative height is 1 for rays at the edge of the pupil.

```
CODE V> RSI 0 1 0 0
```

```
Doublet
Position 1, Wavelength = 587.6 NM
      X      Y      Z      TANX      TANY      LENGTH
OBJ  0.00000  0.00000  0.00000  0.00000  0.00000
STO  0.00000  16.66667  2.31817  0.00000  -0.10730  2.31817
  2  0.00000  16.15024  -3.21473  0.00000  -0.07560  4.84036
  3  0.00000  15.75919  -0.39303  0.00000  -0.16803  5.18773
IMG  0.00000  0.15898  0.00000  0.00000  -0.16803  94.14463
OPD = -8.153 Waves
```

If we try to trace a ray at twice the pupil height, the ray will strike the first surface outside its default aperture, as indicated by the A in the output. Note that the ray also is beyond where the first and second surfaces cross, and thus there is also an edge thickness error, indicated by the E.

```
CODE V> RSI 0 2 0 0
```

```
Doublet
Position 1, Wavelength = 587.6 NM
      X      Y      Z      TANX      TANY      LENGTH
OBJ  0.00000  0.00000  0.00000  0.00000  0.00000
STO A 0.00000  33.33333  9.89894  0.00000  -0.23751  9.89894
  2 E 0.00000  40.25901 -29.60644  0.00000  0.04655 -29.97092
  3 A 0.00000  41.61842  -2.75143  0.00000  -0.01519  29.23792
IMG  0.00000  40.17249  0.00000  0.00000  -0.01519  95.21249
OPD = ***** Waves
```

Now, we will change the Ray Trace Output Format (ROF) to display just Y-oriented data for marginal rays, and then trace the on-axis marginal ray.

```
CODE V> ROF Y Z M N TNY LEN
CODE V> RSI 0 1 0 0
```

```
Doublet
Position 1, Wavelength = 587.6 NM
      X      Y      Z      TANX      TANY      LENGTH
OBJ  0.00000  0.00000  0.00000  1.00000  0.00000
STO  16.66667  2.31817  -0.17259  1.60841  -0.10730  2.31817
  2  16.15024  -3.21473  -0.12945  1.71247  -0.07560  4.84036
  3  15.75919  -0.39303  -0.16570  0.98618  -0.16803  5.18773
IMG  0.15898  0.00000  -0.16570  0.98618  -0.16803  94.14463
OPD = -8.153 Waves
```

QUICK ANALYSES

Now, reset the **ROF** to the default, and trace an off axis chief ray for the second field.

```
CODE V> ROF
CODE V> RSI F2 R1
```

```

Doublet
Position 1, Wavelength = 587.6 NM
      X           Y           Z           TANX           TANY           LENGTH
OBJ   0.00000    -0.33E+11    0.00000    0.00000    0.03492
STO   0.00000    0.00000    0.00000    0.00000    0.02158    0.00000
  2   0.00000    0.22324    -0.00059    0.00000    0.02063    10.34745
  3   0.00000    0.27176    -0.00012    0.00000    0.03483    2.35225
IMG   0.00000    3.49195    0.00000    0.00000    0.03483    92.50626
      OPD = 0.000 Waves

```

Next, trace a ray from the second field point which hits surface 3 at an X value of 0 and a Y value of 10.

```
CODE V> RSI F2 0 10 3
```

```

Doublet
Position 1, Wavelength = 587.6 NM
      X           Y           Z           TANX           TANY           LENGTH
OBJ   0.00000    -0.33E+11    0.00000    0.00000    0.03492
STO   0.00000    10.46235    0.90283    0.00000    -0.04475    0.90338
  2   0.00000    10.09461    -1.22588    0.00000    -0.02767    8.22515
  3   0.00000    10.00000    -0.15820    0.00000    -0.07044    3.42027
IMG   0.00000    3.47659    0.00000    0.00000    -0.07044    92.83775

```

The previous examples have all been **RSI** commands. Now we will trace a ray which strikes the first surface tangent plane at an X value of 0 and a Y value of 5 with a Y direction tangent of 0.1.

```
CODE V> SIN 0 5 0 .1
```

```

Doublet
Position 1, Wavelength = 587.6 NM
      X           Y           Z           TANX           TANY           LENGTH
OBJ   0.00000    -0.94E+11    0.00000    0.00000    0.10000
STO   0.00000    5.02067    0.20672    0.00000    0.02981    0.20775
  2   0.00000    5.31292    -0.33598    0.00000    0.03544    9.80729
  3   0.00000    5.40652    -0.04623    0.00000    0.04861    2.64268
IMG   0.00000    9.90244    0.00000    0.00000    0.04861    92.60552

```

Note that the Y value at surface 1 is not exactly equal to 5. 5 is the value of the ray at the tangent plane to surface 1, and since surface 1 is curved, the Y value will be different. The **SIN** command does not accept a R or F qualifier, as these are used with relative rays only.

QUICK ANALYSES

2D-20

Chapter
2E

Saving/Restoring Data

TABLE OF CONTENTS

THE LDM – SAVING/RESTORING DATA.....2E-3
SCREEN FLOW DIAGRAM.....2E-3
COMMAND MNEMONICS (alphabetical)2E-4
DATA INPUT DESCRIPTION2E-4
 Save and Restore Data 2E-4
 Copying Stored Lens into Current Lens 2E-5
 Converting Lens to Sequence Data..... 2E-5
USAGE2E-6

SAVING/RESTORING DATA

2E-2

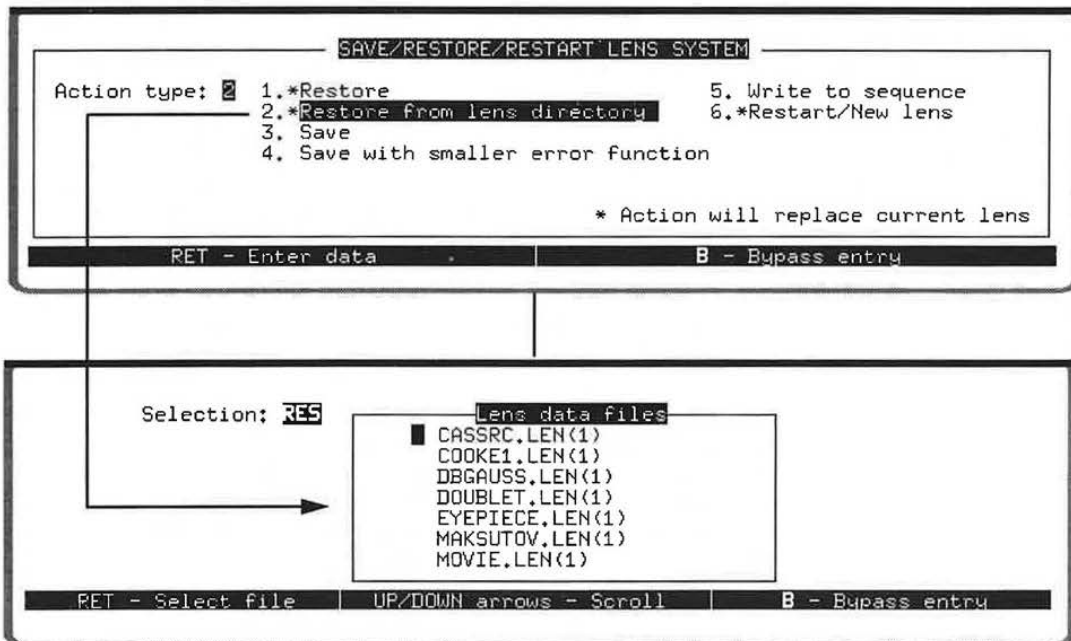
SAVING/RESTORING DATA

THE LDM – SAVING/RESTORING DATA

Allows saving of the current lens data (in a .LEN file) for later use, or restoring of a previously saved lens; also allows unattended conditional saving of lenses if they are better than the previous version or a pre-defined level of performance. Alternatively, lens data can be converted into a .SEQ file of the equivalent LDM commands, for editing or merging with other such files. None of these operations move the surface pointer.

SCREEN FLOW DIAGRAM

GOLD/1 Subscreen from LEN1:



2E-3

SAVING/RESTORING DATA

COMMAND MNEMONICS (alphabetical)

COP CSA RES SAV WRL

DATA INPUT DESCRIPTION

Save and Restore Data

Command Syntax																											
Screen Prompt	Explanation																										
SAV [filespec]																											
3. Save (GOLD/1 Subscreen)	Save lens in new version of filespec (.LEN default filetype). If filename is omitted the last used filename will be used; if there is none, LENS will be used.																										
RES [filespec]																											
1. Restore 2. Restore from... (GOLD/1 Subscreen)	<p>Restore lens from highest version of filespec (.LEN default filetype). Displays filespec, lens title, and if AUT has been used, the error function value. If filespec is omitted, the last used filespec will be used; if there is none, LENS.LEN will be used. Note: Replaces current lens in memory. A pre-defined set of lenses is provided with CODE V (in both .LEN and .SEQ format) that can be transferred into your directory, using</p> <table border="0"> <tr> <td>RES CV7_LENS:CASSRC</td> <td>- Ritchey-Chretien Cassegrain system</td> </tr> <tr> <td>RES CV7_LENS:COOKE1</td> <td>- f/4.5 Cooke triplet</td> </tr> <tr> <td>RES CV7_LENS:DBGAUSS</td> <td>- Double Gauss type objective</td> </tr> <tr> <td>RES CV7_LENS:DOUBLET</td> <td>- f/3 Doublet</td> </tr> <tr> <td>RES CV7_LENS:EYEPIECE</td> <td>- Erfle eyepiece</td> </tr> <tr> <td>RES CV7_LENS:MAKSUTOV</td> <td>- Catadioptric telephoto</td> </tr> <tr> <td>RES CV7_LENS:MOVIE</td> <td>- 9 mm - 36 mm f/2 zoom</td> </tr> <tr> <td>RES CV7_LENS:PETZVAL</td> <td>- Petzval lens with field flattener</td> </tr> <tr> <td>RES CV7_LENS:SCHMIDT</td> <td>- Flat-field Schmidt camera</td> </tr> <tr> <td>RES CV7_LENS:SINGLET</td> <td>- f/5 Singlet</td> </tr> <tr> <td>RES CV7_LENS:TELEPHOT</td> <td>- Refracting telephoto</td> </tr> <tr> <td>RES CV7_LENS:TRIPLET</td> <td>- Another triplet</td> </tr> <tr> <td>RES CV7_LENS:WIDEANG</td> <td>- Wide angle photo-objective</td> </tr> </table> <p>Follow each with a SAV command. See Chapter 1A, Appendix E for many more lenses. RES is allowed in the DEFAULTS.SEQ file (see Immediate Commands/Defaults in Chapter 10). The PTH LENS command defines a search path for .LEN files.</p>	RES CV7_LENS:CASSRC	- Ritchey-Chretien Cassegrain system	RES CV7_LENS:COOKE1	- f/4.5 Cooke triplet	RES CV7_LENS:DBGAUSS	- Double Gauss type objective	RES CV7_LENS:DOUBLET	- f/3 Doublet	RES CV7_LENS:EYEPIECE	- Erfle eyepiece	RES CV7_LENS:MAKSUTOV	- Catadioptric telephoto	RES CV7_LENS:MOVIE	- 9 mm - 36 mm f/2 zoom	RES CV7_LENS:PETZVAL	- Petzval lens with field flattener	RES CV7_LENS:SCHMIDT	- Flat-field Schmidt camera	RES CV7_LENS:SINGLET	- f/5 Singlet	RES CV7_LENS:TELEPHOT	- Refracting telephoto	RES CV7_LENS:TRIPLET	- Another triplet	RES CV7_LENS:WIDEANG	- Wide angle photo-objective
RES CV7_LENS:CASSRC	- Ritchey-Chretien Cassegrain system																										
RES CV7_LENS:COOKE1	- f/4.5 Cooke triplet																										
RES CV7_LENS:DBGAUSS	- Double Gauss type objective																										
RES CV7_LENS:DOUBLET	- f/3 Doublet																										
RES CV7_LENS:EYEPIECE	- Erfle eyepiece																										
RES CV7_LENS:MAKSUTOV	- Catadioptric telephoto																										
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RES CV7_LENS:TELEPHOT	- Refracting telephoto																										
RES CV7_LENS:TRIPLET	- Another triplet																										
RES CV7_LENS:WIDEANG	- Wide angle photo-objective																										
CSA [filespec] [err_fun]																											
4. Save with smaller error function (GOLD/1 Subscreen)	<p>Save lens in new version of filespec (.LEN default filetype) if current err_fun is less than err_fun for previous version of filename.LEN lens; if [err_fun] is included, the test is made against it instead of err_fun for the previous version. If filename is omitted, the last used filename will be used; if there is none, LENS will be used. Ex:</p> <table border="0"> <tr> <td>CSA BEST</td> <td>- Save lens in BEST.LEN if it is better than prior version</td> </tr> <tr> <td>CSA GOOD 0.0001</td> <td>- Save lens in GOOD.LEN if its error function is less than 0.0001</td> </tr> </table>	CSA BEST	- Save lens in BEST.LEN if it is better than prior version	CSA GOOD 0.0001	- Save lens in GOOD.LEN if its error function is less than 0.0001																						
CSA BEST	- Save lens in BEST.LEN if it is better than prior version																										
CSA GOOD 0.0001	- Save lens in GOOD.LEN if its error function is less than 0.0001																										

SAVING/RESTORING DATA

Copying Stored Lens into Current Lens
(Same command as described in Section 2A)

Command Syntax	
Screen Prompt	Explanation
COP Sk Si..j Sn [* filespec [FLX FLY NEG FNX FNY] [final_thickness]]	
	Copy surfaces Sk Si..j in source lens, inserting ahead of Sn in current lens (Sk Si..j, Sn required): * - Source lens is current lens (default) filespec - Source lens is library lens (.LEN default file type) FLX, FLY - Flip source lens surfaces about X or Y axis NEG - Negate (scale by -1) – for matching to current lens light direction FNX, FNY - Flip about X or Y axis and negate final_thickness - Override last copied thickness

Converting Lens to Sequence Data

Command Syntax	
Screen Prompt	Explanation
WRL [filename]	
5. Write to sequence (GOLD/1 Subscreen)	Write lens - Convert lens into LDM command equivalents so it can be edited, and save command file in filename.SEQ. If filename is omitted, the last used filename will be used; if there is none, LENS.SEQ will be used.

SAVING/RESTORING DATA

USAGE

You can change lens data directly at any time and in any way through the LDM; or you can modify the lens indirectly by using such options as AUTomatic design to optimize the lens, TESTplate fitting, or generation of tolerances through TOR. These modified systems can be saved in the lens library for later retrieval, rather than having to enter them all over again. The binary file form for these files is one that can be read in quickly, without testing for syntax or optical completeness, since this has already been done before saving it. It is a good idea:

- to save the lens whenever you think you might want to go back to that version.
- to do the save at the earliest point after the change, in the unlikely event that you inadvertently destroy the system or lose communication with the computer.

Two forms are available: an absolute save (**SAV**) and a conditional save (**CSA**). **SAV** will always execute; **CSA** will only execute if the error function of the current lens is less than the previously stored version or an input value. You will most often use **SAV** interactively because you are in control, or in **.SEQ** files because you want to be sure the lens is saved somewhere; you will most often use **CSA** in **.SEQ** files following AUTomatic design, where you don't know whether the end result will be better than prior forms.

Examples:

- | | |
|------------------------|---|
| SAV | - Save lens in last used filename.LEN file with the next higher version number (or LENS.LEN if no prior filename was used in this session) |
| SAV PROJECT | - Save lens in PROJECT.LEN file with the next higher version number |
| SAV PROJECT(3) | - Save lens in PROJECT.LEN file with version number 3; allows over-writing of a prior file |
| SAV PROJECT.XYZ(3) | - Save lens in PROJECT.XYZ file with version number 3; allows over-writing of a prior file |
| SAV '[JOE]PROJECT.LEN' | - Save lens on Joe's directory as the highest version of PROJECT.LEN (VAX only) |
| CSA | - Save lens in last used filename.LEN file with the next higher version number (or LENS.LEN if no prior filename was used in this session) if it is better than prior version |
| CSA BEST | - Save lens in BEST.LEN if it is better than prior version |
| CSA BEST(1) | - Over-writes BEST.LEN;1 file if it is better; allows a known file to hold the best lens to date |
| CSA GOOD .0001 | - Save lens in GOOD.LEN if its error function is less than .0001 |

Other examples can be derived by using various combinations allowed by the syntax.

Once a lens has been **SAV**ed it, of course, can be retrieved by the restore (**RES**), using the same format as **SAV**.

Examples:

- | | |
|------------------------|---|
| RES | - Restore lens in last used filename.LEN file with the highest version number (or LENS.LEN if no prior filename was used in this session) |
| RES PROJECT | - Restore lens in PROJECT.LEN file with the highest version number |
| RES PROJECT(3) | - Restore lens in PROJECT.LEN file with version number 3, if it exists |
| RES PROJECT.XYZ(3) | - Restore lens in PROJECT.XYZ file with version number 3, if it exists |
| RES '[JOE]PROJECT.LEN' | - Restore lens in highest version of PROJECT.LEN file on Joe's directory (VAX only) |

SAVING/RESTORING DATA

A "conditional update" can be achieved by using both **CSA** and **RES** in combination to keep working on the best lens to date. An example of the total .SEQ file to do this would be:

```
! Case 1
RES BEST(1)           ! Get best lens so far
  Make changes, if needed
AUT
  Automatic design inputs
GO                   ! Optimize to completion
SAV TEMP             ! Save as next higher version of TEMP.LEN, in case
                   !   recovery is needed
CSA BEST(1)         ! Save if best to date in known file
Do any required brief analyses or outputs for the record, then repeat the pattern:
! Case 2
RES BEST(1)           ! Get best lens so far
  Make changes, if needed
AUT
  Automatic design inputs
GO                   ! Optimize to completion
SAV TEMP             ! Save as next higher version of TEMP.LEN, in
                   !   case recovery is needed
CSA BEST(1)         ! Save if best to date in known file
Continue with as many cases as desired, and then finish with:
! Best case
RES BEST(1)           ! Restore best lens
  Do complete analysis on final lens
```

The binary file form for .LEN files does not allow it to be edited, merged with another file, or displayed as a string of input commands for the equivalent lens. These can all be done with the **WRL** command which takes the lens in memory and "de-compile" it into the LDM commands that will generate the same lens in memory and places these in a .SEQ file, ready for editing, merging, display, and/or reading in through the **IN** command (see Chapter 10 - Immediate Commands/Defaults). Example:

```
RES BEST(1)           ! Restore BEST.LEN;1
WRL BEST              ! Write BEST.SEQ, the LDM command equivalents
EDI BEST              ! Enter Editor, operating on BEST.SEQ
  Make necessary changes, then exit, writing a new version of BEST.SEQ
IN BEST               ! Reads in new BEST.SEQ
```

In the editor, any changes can be made, including merging of files or bringing in surfaces from another file to merge optical systems into one.

Note that the **COP** command (Section 2A) does allow the copying of part or all of the surfaces for a .LEN lens into the current active lens, ahead of a designated surface.

The **RES** command reads in files from the current directory. The path command **PTH** can be used to define a search path of up to five additional directories to be searched for the requested .LEN file. See Chapter 10, "Immediate Commands/Defaults" for details on **PTH**. Note that .LEN files in the search path but not in the current directory will not be shown in the list in the restore lens screen.