A Technical Overview of CODE V Version 7

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ABSTRACT

The technical features of the CODE V™ program for computer-aided optical design and analysis are described. Examples of typical applications are presented which illustrate various special features of the program. The recently introduced interferogram interface is presented in more detail as an example of CODE V's technical depth and approach to new technological requirements.

I. INTRODUCTION

CODE V Version 7 is the latest version of Optical Research Associates' software package for optical design, analysis, and manufacturing support. Although it is a large, comprehensive program capable of solving a wide range of optical problems, CODE V includes extensive features that make it easy for persons with varying levels of optical experience to learn and use it. Such "friendliness" features as screens and menus, interactive text, and on-line help have been discussed elsewhere [1,2]. This paper will present a brief overview of CODE V's technical features aimed primarily at the optical engineer or designer. Several specific features will be treated in more detail as examples of the program's approach and technical depth. Because of the brevity of this review and its emphasis on describing CODE V's features, very little information on the actual use of the program will be included. Please consult the CODE V documentation set for detailed usage information.

History: CODE V had its beginnings in the early 1960's, when Tom Harris (ORA's founder and current president) began developing a program to use in his own lens design consulting business. Building on ideas he had first explored at Bell & Howell in the 1950's,

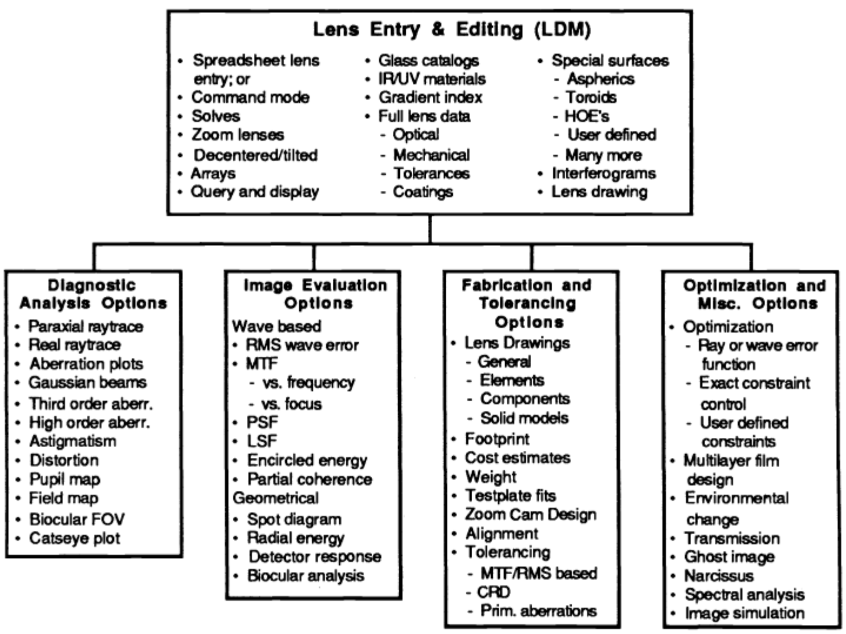

Figure 1. CODE V major features summary (not all features included)

Tom developed the basic structure, optimization capability, and analysis options of CODE V's predecessor ("CODE V" stands for "computerized optical design and evaluation, version 5"). Limited outside use began in the late 1960's, and in the 1970's, ORA began to actively support CODE V as a "commercial" program. Its features, size, and user base continued to grow as it was expanded, improved, made more interactive, and placed in other computing environments, including networks. Today it is one of the most widely used programs of its type, available on any of Digital Equipment Corporation's popular line of VAX, MicroVAX, and VAXstation computers and workstations, as well as via TYMNET, an internationally accessible time-sharing network. In addition to a staff of optical specialists and programmers who develop, maintain, document, and support the program, Optical Research Associates also operates a major optical design consulting business. These in-house lens designers and optical engineers are an important source of guidance, testing, and feedback in the development of CODE V.

Philosophy: Because it was developed by practicing lens designers, CODE V has always had a strong "designer orientation." Long before "expert system" became a popular concept, CODE V was incorporating lens designers' "expert knowledge" in its algorithms, input methods, and default provisions ("defaults" are commands and values that the program assumes in the absence of user instructions). ORA has also tried to make CODE V as comprehensive as possible, giving the optical specialist all the design and analysis tools he is likely to need in one convenient and consistent package. Ease of learning and use have always been addressed by minimizing needed inputs and by using terminology and input structures that are "natural" to optical engineers. The extensive use of graphics has also been an important goal in CODE V's development (Figure 2).

II. APPLICATION EXAMPLES

An important question in evaluating a software package might be, "What is it good for?" In other words, what sorts of problems are people solving with CODE V now? A few examples selected from the many types of systems that have been designed with CODE V will serve to illustrate a number of the program's special features.

Optical disc lenses: Optical disc lenses are used in consumer applications (audio and video disc) as well as in optical data storage systems [3]. Because it is typically a bi-aspheric singlet, the optical disc lens might seem to be a rather simple system to design and analyze. To

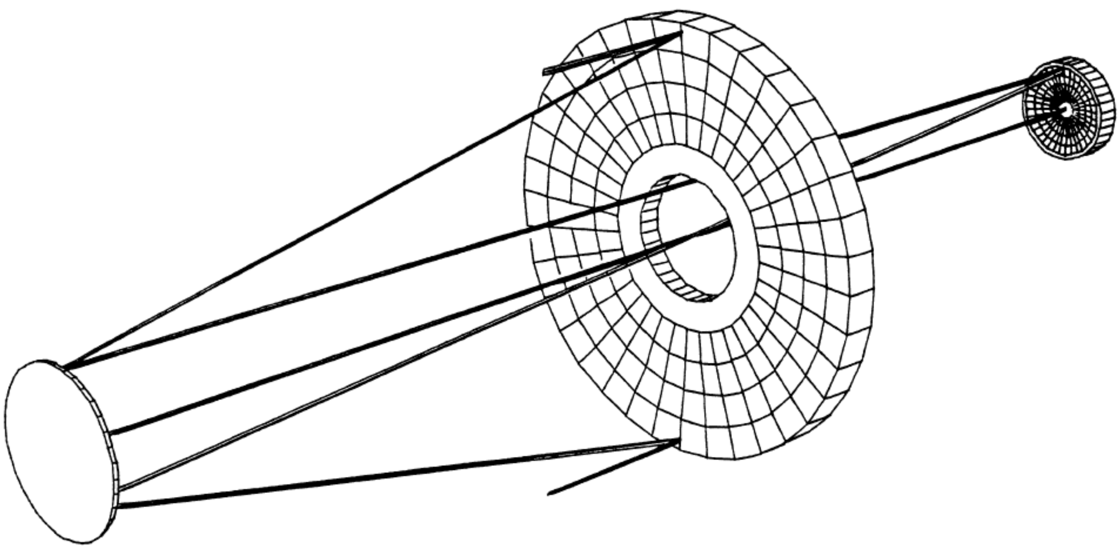

Figure 2. Graphics example - wire-frame solids model of a Cassegrain system with a field flattener

analyze the end-application, however, requires calculation of the diffraction point-spread function (**PSF** option) with asymmetric Gaussian apodization to simulate the semiconductor laser source. Multi-configuration features (**ZOOm**) can be used to design a lens with reduced sensitivity to molding and mounting errors. Severe thermal environments (such as car dashboards in the summer) can be simulated with the **ENV** (environmental change) option.

Zoom lenses: CODE V considers any system with parameters that change during use to be a "zoom" (i.e., multi-configuration) lens, but "true zoom lenses" (where only the lens separations are zoomed) are the classic application [4]. Photographic, broadcast, and military zoom lenses are frequently designed with CODE V. Zoom lens designers make use of CODE V's ability to simultaneously optimize up to seven zoom positions and to define and use constraints that interlink various zoom positions (**AUT** option). When it is time to consider building a zoom lens, the **TOR** option can be used to simultaneously tolerance the multiple zoom positions, while the **CAM** option can assist in specifying cams that will move the zoomed elements.

Scanner lenses: As far as CODE V is concerned, a scanner lens is simply a "zoom lens" in which tilts or decenters are "zoomed" rather than air spaces. But scanners often do have special requirements. You can easily specify f-theta linearity as a set of image-height constraints in optimization (**AUT** option), and you can analyze the linearity with a special field aberration request (**FIE** option). Many scanners (product code readers and laser printers, among others) use very "slow" laser beams (perhaps f/50 to f/300). In these cases, Gaussian beam optics (**BEAm** option) must be used to determine spot size and orientation (this option works on any type of system, including asymmetric scanner geometries and those containing holographic optical elements).

Holographic head-up display optics: The design of visual systems has been a strength of CODE V for many years. While visual displays in general present challenging design problems, the holographic head-up display (HHUD) can be especially difficult, requiring both special program features and special design techniques [5,6]. CODE V provides a general HOE model that includes aspheric phase terms and volume hologram diffraction efficiency parameters (HOE thickness, delta index, etc.). The diffraction efficiency of a volume HOE system must be considered at all stages of the design, so CODE V allows it to be constrained during optimization and analyzed in several different ways. Aberration differences between the light bundles received by the viewer's eyes are critical in biocular display systems, so specialized biocular analysis (**BIO** option) is needed. Packaging constraints can be important in airborne systems; global ray constraints in optimization (**AUT**) allow packaging constraints to be entered conveniently. The footprint (**FOO**) option provides an easy way to determine the shape of "used portion" of any surface in an optical system.

FLIR Systems: Forward-looking infrared (FLIR) systems are typically scanning systems that provide ther-

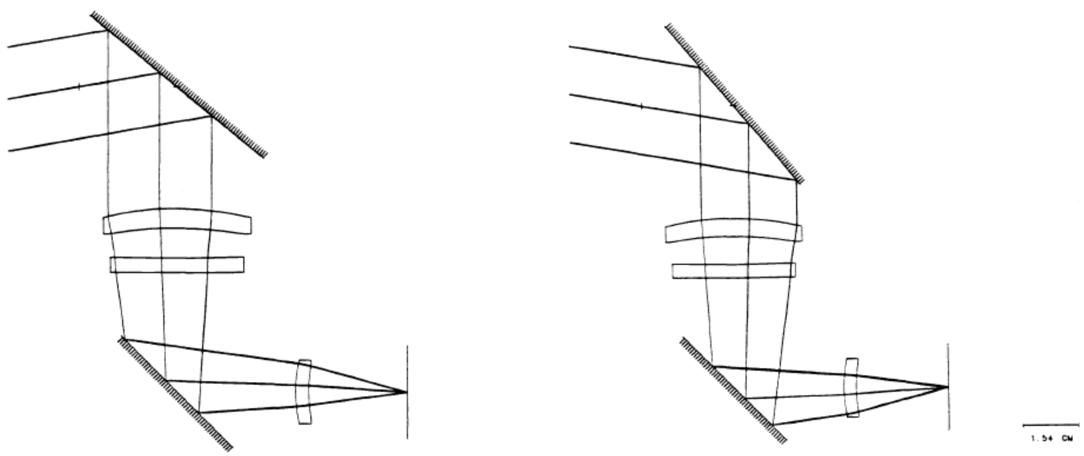

Figure 3. FLIR system modeled in CODE V as a "zoom" scanner

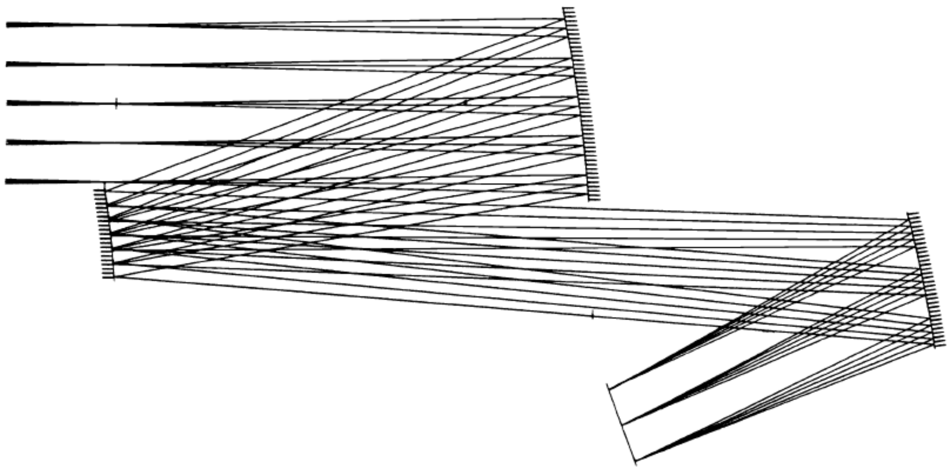

Figure 4. Unobscured all-reflecting system

mal IR "TV" imagery in aircraft and other applications (Figure 3). FLIR's have features in common with all scanners and multi-configuration systems (they often have flip-in/flip-out attachments as well as scan mirrors), but of course also make use of special infrared materials (a catalog of these is built into CODE V). In addition, thermal IR systems have special analysis problems of their own. "Narcissus" is one such problem, in which a thermal detector can "see" a scanned image of itself as a spurious signal. Narcissus parameters can be controlled as constraints during optimization (**AUT**o option), and the narcissus (**NAR**) option is available to analyze narcissus conditions.

Unobscured All-Reflecting Objectives: This type of system (Figure 4) offers potential advantages in compactness and lack of the large central obscuration found in classical all-reflecting designs. Because of the inherent asymmetry of such designs, however, they also can present special design, analysis, and fabrication problems. CODE V offers a variety of tilt and decenter types (as well as decentered apertures) that simplify the set-up of such asymmetric systems. When special surface types are needed, users can select conventional aspheres, aspheric toroids, anamorphic aspheres ("potato chip" surface), or user-defined surface equations. In optimization (**AUT** option), global ray constraints allow packaging geometry to be easily controlled [7]. All of CODE V's image evaluation options (**MTF**, **PSF**, **PAR**, etc.) are fully functional regardless of the degree of asymmetry of the lens system. The recently introduced interferometry interface and alignment option (**ALI**) will certainly be useful in the fabrication, testing, and alignment of these often difficult systems (see section V).

III. PROGRAM STRUCTURE

CODE V's central metaphor is the "lens database" (Figure 5). The program's active memory contains all the available information on the lens currently under consideration (any number of additional lenses may be stored in disk files). This database naturally includes optical definitions (curvature, thickness, glass data, aspheric data, decenters, wavelength, f/number, etc.), but also includes mechanical data (outside diameters, mirror thicknesses, weight, etc.), tolerance data (tolerances and compensators), and miscellaneous data (multilayer coatings, glass cost, temperature and pressure, etc.). Interferometrically measured data can also be part of the lens database.

Managing Data: To manipulate this database, CODE V provides a highly interactive "lens data manager" (LDM). This central program section allows users to create, modify, and display database items, singly or in groups (data can also be saved in or retrieved from disk files). Limited features for quick analysis (paraxial raytrace, single real rays, third order data, etc.) and display (tabular data and simple lens pictures) are also available to guide the data creation/modification process. In its full-screen mode, the LDM has a spread-sheet like display and data-entry screen that allows the effects of data changes to be seen immediately. Over 350 commands are available to change or examine any aspect of a lens system (although for most systems, only a tiny fraction of these are actually needed).

Option Structure: Once LDM features have been used to establish and verify a lens database (i.e., to create a lens model), CODE V "options" can be used to generate (in database parlance) "reports" based on various analyses of the lens data. Each option represents a logical segment of the designer's task, such as calculating diffraction MTF, plotting raytrace curves, or producing element drawings. Some options actually modify the lens database directly (e.g., optimization changes lens data to improve performance, tolerancing adds tolerances to the database, etc.). CODE V has some 43 of these specialized options (see Figure 1).

IV. CODE V OPTIONS

The following are brief descriptions of most of the program's major options, broken down into functional categories. Many CODE V options can provide graphical output in addition to the standard tabular data.

Diagnostic Analysis Options: These options assist the designer in understanding a lens' performance at a relatively low level. Fans of rays (tabular or graphic); surface-by-surface real raytrace, paraxial, and third-order aberrations; and tables or plots of field aberrations (distortion and astigmatism) are included here. Pupil maps of OPD (printed or plotted) and other quantities give additional diagnostic data. There are also several special-purpose diagnostic options. These include Gaussian beam propagation for "slow beam" systems, biocular field of view plots for visual systems, and "field maps" of diffraction efficiency versus field-of-view for holographic systems. A recently added feature is the astigmatism full field display, used to locate astigmatism nodes in asymmetric systems.

Image Evaluation Options (Geometrical): When a lens is not diffraction-limited, geometrical optics-based image evaluation is appropriate. These options include effects of apertures and obscurations (but not diffraction effects) on such analyses as spot diagrams, radial energy distribution, geometrical MTF, quadrant detector response, detector energy calculation, line spread and edge response functions. A specialized option performs several zoom-position differencing functions that are especially useful for biocular visual systems.

Image Evaluation Options (Wave Based): Proper analysis of well-corrected lens systems must take diffraction into account. CODE V offers RMS wavefront error

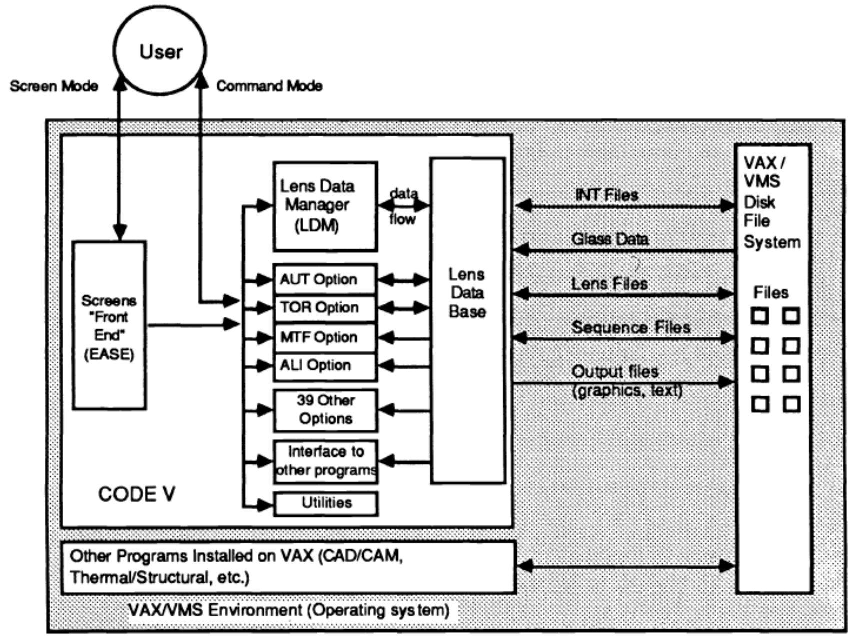

Figure 5. CODE V operations schematic

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