TOD-Distortion Tolerancing

The Distortion Tolerancing (TOD) option calculates changes in chief ray distortion due to changes in the constructional parameters of any lens system definable in CODE V. Compensating parameters may be used to simulate the manufacturing and assembly process.

When to Use the Distortion Tolerancing (TOD) Option

The Distortion Tolerancing (TOD) option is aimed at tolerancing of systems where the location and size (mapping) of images is more important than the image quality. Examples include:

- Distortion for visual systems, relative to some pre-defined positions
- Two-eye systems such as head up displays (HUDs) where you may care more about the differences between two sets of image positions, rather than their absolute values

In cases where both mapping and image quality are important, as may be the case in mapping lenses, for example, TOR is essential and distortion effects will be listed; boresight may be used to provide correction of one object point; TOD may provide helpful additional information to determine any distortion drivers (and ability to compensate), but no way is provided to provide a common solution. The performance criteria for TOR and TOD are different so, for the same set of tolerances, the values of compensators will be different.

Default Operation

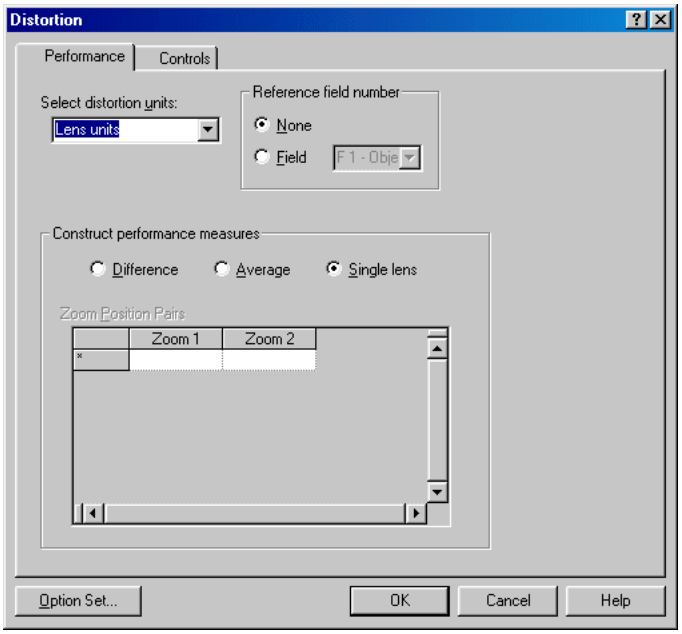
Distortion Tolerancing (TOD) calculates the changes in chief ray distortion produced by the set of tolerances defined with the lens. Distortion at each field is averaged over wavelength.

Command Mnemonics
(alphabetical)

BRF UNI WTF XSY ZPO

Defining Performance Measures

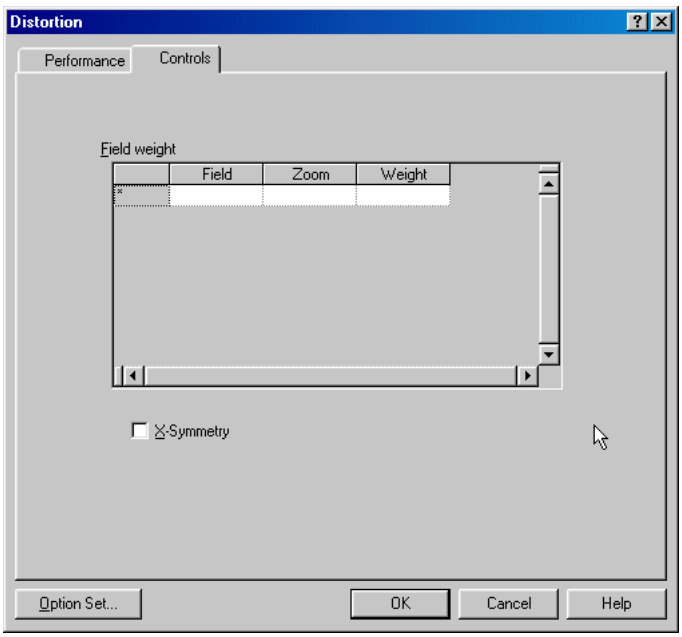
To define performance measures for the Distortion Tolerancing option, choose the **Analysis** > **Tolerancing** > **Distortion** menu. The **Distortion** dialog box displays, with the **Performance** tab automatically displayed. Define the controls on this tab as described in the table below.



Command Syntax		
Screen Control	**Explanation**	**Default**
UNI LNS | MIC | MIL | AMI | ASE | MLR | MCR		
Select distortion units	Selects units of distortion: On Image Surface — In Object Space LNS-lens units — AMI-arc minutes MIC-microns — ASE-arc seconds MIL-mils — MLR-milliradians MCR-microradians	LNS-Lens units.
BRF [Fk] Yes | No		
Reference field number	The chief ray values at the specified field are subtracted from the other fields. Fk default: F1.	No. No subtraction takes place.
ZPO SIN Zk or **ZPO** [DIF | AVE] Zk Zn		
Construct performance measures	For **Single lens** (SIN), specifies the zoom position at which the distortion is calculated. For **Difference** or **Average** (DIF | AVE), specifies the pairs of zoom positions that are differenced or averaged, respectively.	The single lens (SIN) calculation is done at each zoom position.

Defining Controls

To define controls for the Distortion Tolerancing option, choose the **Analysis** > **Tolerancing** > **Distortion** menu. The **Distortion** dialog box displays. Click the **Controls** tab, and define the controls on this tab as described in the table below.



Command Syntax		
Screen Control	**Explanation**	**Default**
WTF field-zoom_weight....f,z		
Field weight	Specifies relative weights for each field-zoom for compensation calculations.	Lens system weights from WTF in the LDM.
XSY Yes | No		
Symmetry override	Specifies that the system has x-symmetry regardless of whether it does. Used for compensation calculations.	No. Symmetry condition is defined by lens.

Discussion of Input and Computations

What to Include in the LDM Data

Distortion Tolerancing (TOD) uses the tolerance budget entered in the LDM or generated by TOR; if TOD is entered without them, the LDM default set (DEF TOL SA) plus one focus compensator (CMP DLZ SI) is generated.

No apodization (Gaussian or user defined) is applied because TOD only uses chief ray positions.

For details about defining tolerances in the LDM, see "Defining Tolerances" on page 8-3.

Specific tolerancing controls allow TOD to select the most effective set of compensators for your system. The **Singular Value Decomposition (SVD) Threshold** and **Used Compensators** controls in the **System Data** window (SVT and MCP commands, respectively) regulate the compensators used for individual tolerances. See "Defining Tolerance Controls" on page 3-60 for details about these commands. In addition, you can specify which compensators must be used, and which can be dropped from the system. This is done using the **Compensator Use Control** field in the **Surface Properties** window, on the **Tolerances** page. From the command line, use the CMP command. For details, see the CMP command description under "Other Tolerance Controls" on page 8-23.

Usage

Distortion is measured either on the image surface or in angular object space coordinates. **LNS**, **MIC** and **MIL** are on the image surface. **AMI**, **ASE**, **MLR** and **MCR** are in object space. The lens must have an infinite object if object space coordinates are used.

The default calculation gives changes in chief ray height at each zoom position. The **ZPO** command allows the user to select specific zoom positions and to difference or average two zoom positions. The differencing feature is useful for biocular systems.

The **BRF** command may be used to reference the output to the values for a specified field. In that case, the values at the specified field will be zero and all other fields will be deviations from the reference field.

Compensators and tolerances are defined with the lens. If compensators have been entered, the relative weighting of the fields and zoom positions effects the compensation. The default values are the LDM weights. These may be changed with the **WTF** command.

The standard output consists of an entry for each tolerance giving the change in distortion and the compensators, if any.

In a rotationally symmetric system, only one side of the field is normally entered. In the compensation calculations, the performance on the opposite side of the field is determined from the performance at the given fields. This is necessary for the correct determination of the compensators. When a system is not symmetric, all the fields which affect the calculation must be entered. However, there are cases where the system is optically symmetric but is considered asymmetric by CODE V. The most common case is a folded, rotationally symmetric system. To avoid having to enter additional fields (and increase computation time), the **XSY** command may be used.

Description of Output

The TOD output consists of sensitivity tables giving the change in chief ray distortion for each of the tolerances. The information for all the fields of view at a specific zoom position is included in the table, with each zoom position listed separately. Each of the tables has a header listing the wavelengths, wavelength weights, field weights, field angles and nominal values of the chief ray position.

Below the header are columns of data describing the tolerances and their effect on chief ray distortion. If compensator groups are used, there will be a separate list for each group. The first two columns, listed under TYPE and CHANGE, describe the tolerances. Both of these columns are under the label, MANUFACTURING ERROR. TYPE is the tolerance type, including the surface number(s), e.g., DLF S3. CHANGE is the value of the tolerance.

Next to the tolerance description are up to five columns listing the change in chief ray position for the value of the tolerance listed under CHANGE. Each column corresponds to a different field of view. There are two rows of data; the first row is the x component and the second row is the y component. The compensators, if any, are listed in the last column. Multiple compensators are listed one under the other. Since distortion is linear with respect to the tolerance, any of the distortion values may be simply scaled to get the affect of a different tolerance value. The compensators are, likewise, linearly related to the tolerance.

At the end of the distortion list, the probable change in distortion and the probable change in compensators are listed. The probable change is defined as the mean plus two sigma, using the same statistics as in TOR (see “TOR - Wavefront Differential Tolerancing” on page 20-5). Tolerance summary tables can be requested after TOD in the LDM by using the TTA command.

Examples

Example 1. TOD analysis on a biocular system with output in microradians

Start with the eyepiece and change it to a biocular system. Run TOD and request microradian output. Default tolerances and compensators will be used. The default compensator is the axial shift of the focal surface.

```
Command inputs:
   RES  CV_LENS:EYEPIECE          ! Restore eyepiece
   SCA  FAC  4                    ! Scale up by a factor of 4
   EPD  5                         ! Change the pupil diameter to 5 mm.
   TIT  "BIOCULAR EYEPIECE"
   XDE  S1 30                     ! Simulate the two eyes by zooming the
   DAR                            !   displacement of the entrance pupil,
   ZOO  2                         !   simulating an eye separation of 60 mm.
   ZOO  XDE  S1  30  -30

   TOD                            ! Run TOD
   ZPO  DIF  Z2  Z1               ! Difference the two eye positions
   UNI  MCR                       ! Request units of microradians
   GO
```

Table 1. Output: sensitivity table (not all tolerances shown)

```
 09-Mar-07                                C O D E   V                  POSITION  2 - POSITION  1

                                S E N S I T I V I T Y   A N A L Y S I S
                                  POLYCHROMATIC CHIEF RAY DISTORTION
        BIOCULAR EYEPIECE
-------------------------------------------------------------------------------------------------------------------
                                                                                                  Z 2      Z 1
                                                                                  WAVELENGTH    WEIGHT   WEIGHT
                                                                                    656.3 NM       1        1
                                                                                    587.6 NM       1        1
                                                                                    486.1 NM       1        1

                      FLD ANG X --      0.00        0.00        0.00
                      FLD ANG Y --      0.00       20.00       30.00
                       WEIGHT  ---      1.00        1.00        1.00

     NOMINAL CHIEF RAY ZOOM    X       518.9      1473.8      1344.0
        POSITION DIFFERENCE    Y         0.0         0.0         0.0
-------------------------------------------------------------------------------------------------------------------
                                                                                                 COMPENSATORS
                                                                                                   DLZ S10
 MANUFACTURING ERROR
                                      COMPONENTS OF CHANGE IN
TYPE                 CHANGE           CHIEF RAY POSITION

DLF S2              5.000000    X        -0.5        -0.2         0.7                            -0.015165
                                Y         0.0         0.0         0.0

CYD S5              1.000000    X         0.0         0.0         0.0                            -0.000501
                                Y         0.2         0.2         0.2

RLY S3..2           0.025000    X         0.0        -0.2         0.2                            -0.000027
                                Y         0.0         0.0         0.0

BTY S5..6           0.001000    X       -12.5         2.3         9.9                            -0.033135
                                Y         0.0         0.0         0.0

TRX S7              0.025000    X         0.0         0.0         0.0                             0.000000
                                Y         0.0        -0.7        -0.9

          PROBABLE CHANGE       X        62.6        23.2        81.1                             0.552970
                                Y         0.9        15.4        22.7
          TOLERANCE UNITS - Linear dimensions are in millimeters
                            Angles are in radians
                            Fringes are in wavelengths at  546.1 nm.
         DISTORTION UNITS - microradians
-------------------------------------------------------------------------------------------------------------------
```

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Technical Notes

The calculations are based on the same differential ray trace used in TOR. This gives the derivatives of the wave aberration with respect to the tolerance. The change in the chief ray position is determined from the derivative of the wave aberration with respect to pupil coordinate, which is obtained from a finite difference calculation. The distortion is approximately linear with respect to the tolerance.

The criterion for determining the compensation is the minimization of the sums of the squares of the x and y components of distortion over all the fields of view and zoom positions. Thus, modifying the field weights (**WTF**) affects the compensator values and resulting distortion residuals.