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1. Introduction

OOFELIE for Advanced Optics is linked to the optical software ZEMAX®. Structural and optical models are coupled by OOFELIE for high precision opto-thermo-mechanical analyses based on the combination of finite element simulation and ray tracing. ZEMAX is a very popular, easy-to-use and powerful optical design tool. Dedicated to engineers and scientists who use ZEMAX, or intend to use it, our solution offers a unique automated in-memory communication with this software, providing fast and reliable modeling of complete opto-mechanical systems. Based on the DDE protocol on Windows (Dynamic Data Exchange), OOFELIE for Advanced Optics is compatible with EE and IE ZEMAX versions (up to ZEMAX 12) or Professional and Premium versions (ZEMAX 13), in 32 or 64 bits.

Advanced designs of optical systems often need to take into account environmental conditions. OOFELIE for Advanced Optics provides all thermo-mechanical modeling capabilities of the OOFELIE::Multiphysics platform. With OOFELIE for Advanced Optics, one can model a whole system composed by optical and mechanical components and analyze stresses, deformations and temperature fields. OOFELIE for Advanced Optics updates automatically an optical model defined in ZEMAX by accounting for deformations of optical surfaces and for thermally induced change of refractive index.

OOFELIE for Advanced Optics also includes electrical effects and related couplings (piezoelectric, pyro-piezoelectric). According to the license keys the user has, modeling capabilities can be further extended to e.g. electrostatic effects. Complex devices such as MOEMS and active/adaptive optics can so be modeled.

Typical applications are telescopes, space optics, projection systems, lasers and laser optics, active/adaptive optics and MOEMS. For further view on the key features of OOFELIE for Advanced Optics and application examples, please visit our website (www.open-engineering.com).

The ZEMAX connection can be activated as shown in Figure 1. Optical surface deviation and GRIN computation and exportation to ZEMAX (cf. sections 5 and 7), and further advanced features (cf. section 8) are then allowed.

![Figure 1: The ZEMAX connection is activated in the Multiphysic Problem Configuration dialog box](image-url)
Since updating a ZEMAX model is not always required, the ZEMAX link can be activated or deactivated in the Simulation Settings dialog box, as shown in Figure 2.

Figure 2: Activation/deactivation of the ZEMAX link
2. The design process

Starting with an optical model defined in ZEMAX, the corresponding opto-mechanical model with appropriate geometries and material parameters can be built in OOFELIE (see next section). Thermal and mechanical loads, and other boundary conditions can then be applied. OOFELIE performs finite element analyses, giving information such as deformation, temperature and stress fields.

Before and after the thermo-mechanical computation, OOFELIE communicates with ZEMAX. Before the computation, the initial sag parameters of each optical surface are automatically retrieved from ZEMAX and are used by OOFELIE for managing local coordinates of each surface and for processing the sag correction (cf. next section). After the computation, the surface deviation of each optical surface is computed and fitted (see sections 5 and 6). Optionally OOFELIE computes the refractive index distributions (GRIN) in bulk optical elements due to the thermo-optic effect (see section 7). GRIN can be exported to ZEMAX simultaneously with surface deformations via a customized surface type (a dynamic link library provided by Open Engineering combines Zernike Standard polynomials and GRIN). The optical post-treatment (computation of surface deviations and GRIN, and fit processes) uses information previously retrieved from ZEMAX. The optical model is then automatically updated and optical indicators such as wavefront errors are retrieved by OOFELIE and displayed in its graphical interface.

The optical performances of the system under loads are then analyzed in the ZEMAX updated model. The whole system behavior impacts each optical component, which in turn impacts the global optical response. According to finite element results (such as stresses) and optical simulations, the design of the whole opto-mechanical system can be improved by optimizing both structural and optical models, until satisfactory performances are obtained. The design and optimization process using OOFELIE for Advanced Optics is described schematically in Figure 3.

![Figure 3: Design process principle using OOFELIE for Advanced Optics](image-url)
3. Combining structural and optical models

3.1 Required options in ZEMAX

As already mentioned in section 1, OOFELIE for Advanced Optics is compatible with Professional and Premium versions of ZEMAX (formerly EE and IE versions) and both 32 and 64 bits versions are supported.

If the ZEMAX link is activated, OOFELIE connects to ZEMAX by means of the DDE Windows mechanism. If ZEMAX is not started, OOFELIE will try to launch it by seeking in several repertories. If this operation failed, an error message is displayed. In that case, start ZEMAX and try again.

As OOFELIE will request ZEMAX to update an optical model, the "Allow Extensions To Push Lenses" option of ZEMAX must be activated. This option is set in the preferences of ZEMAX (see Figure 4). Note that with recent versions of ZEMAX, this option is set by default.

With recent versions of ZEMAX, the text output from analysis features is either in ANSI (ASCII) or Unicode format, with Unicode as default. For retrieving in OOFELIE optical indicators from ZEMAX after the model updating, the ANSI format is required. This option is set in the preferences of ZEMAX (in the TXT File Encoding field, select ANSI, as shown in Figure 5). Note that this setting has to be done only one time.
3.2 Avoid “solve” in the Lens Data Editor of ZEMAX

Using solve (e.g. F/# solve) in the Lens Data Editor is often useful for designing an optical model. However, all solves should be removed before updating a ZEMAX model with OOFELIE. Indeed, when updating a model with some parameters controlled by solves, the values of these parameters may be changed by ZEMAX with unpredictable (and sometimes strong) modifications in the design.

3.3 Using CAD from ZEMAX

The recommended way to build the geometry is to import in OOFELIE the optical component CAD exported from ZEMAX. This process insures the good definition of each optical surface and the compatibility between the two model frames. When exporting from ZEMAX the CAD of each optical element, the option “Surfaces as solids” has to be activated. The STEP format is advised. For mirrors, the substrate shape and thickness can be defined in the "Draw" surface property tab (available for sequential surfaces). The geometry of the surrounding mechanical parts is then added in the structural model.

Once the CAD (coming from ZEMAX) of the optical elements have been imported in OOFELIE, it is very often necessary to perform a Shape Repair Mode → Shape Healing (in the Modeler module of the OOFELIE’s graphical interface), selecting the operation Split Continuity, as shown in Figure 6. If this operation is omitted, an error message may appear when attempting to update the ZEMAX model (in this case the updating process fails).
The local coordinates of each optical surface are managed by OOFELIE thanks to the information retrieved from ZEMAX. Mind that the frame in the structural model in OOFELIE has to be the same as in ZEMAX. Once the structural model has been built, never change the global coordinate reference surface in ZEMAX (sequential mode). For updating a non-sequential object (cf. section 3.5.2), the reference object ("Ref Object") has to be 0, and, again, the ZEMAX global frame must be identical to the frame in OOFELIE.

### 3.4 Sag correction

For each optical surface (surface for which an optical behavior is defined), the sag correction feature compares the positions of the nodes belonging to the surface with the corresponding sag defined in ZEMAX, then corrects the node positions before starting the finite element computation. The sag correction can be visualized via the result type Sag Correction (cf. Figure 7). The sag correction is always considered and applied along the optical axis of the surface. So, if the criterion Scalar Projection is used for visualizing the sag correction, it considers local coordinates of the surface (the sag correction values are not zero only in the Z local direction).
If the sag correction is closed to one wave, even locally, it is recommended to improve the shape definition of the optical surface. If this improvement is not possible, the sag correction process repairs the shape in the finite element model. With quadratic meshes, half of the nodes (the ones which are not the vertices of elements) on an optical surface are not well positioned (the errors could be as much as several µm). The sag correction repairs the positions of these nodes along the optical axis. To see the influence of the sag correction on the results, the sag correction can be deactivated by use of the command

```
pilot_##.setSagCorrectionHypo(false);
```

which has to be placed in the epilogue in section

```
#SECTION_PARAM_SOLVER#.
```

Strong values of the sag corrections (e.g. several millimeters or more) mean that the optical surface is not compatible with the corresponding one in ZEMAX. Check first that the surface number of the ZEMAX model is correctly set in the optical behavior (cf. section 6) and that both frames are compatible. If it does not solve the problem, the geometry must be corrected.

### 3.5 ZEMAX surface types which can be updated by OOFELIE

#### 3.5.1 Sequential surfaces

In sequential ZEMAX models, Standard, Even Asphere and Biconic surfaces can be updated by OOFELIE.

The initial sag base (of Standard, Even Asphere or Biconic form) is kept and the surface is updated by adding Zernike polynomials or a grid of values for representing the deformation (cf. section 6).

#### 3.5.2 Non-sequential surfaces

OOFELIE for Advanced Optics is principally dedicated to sequential optical models, i.e. imaging systems. Future extensions could include an improvement of the capabilities of OOFELIE for Advanced Optics for updating non-sequential models. Note that another kind of coupling with non-sequential analyses is presented in section 8.4.

Presently, the non-sequential object of type Standard Surface can be converted by OOFELIE to a Zernike Surface. These non-sequential surfaces (Standard Surface and Zernike Surface) may reflect or absorb rays. The updating process is currently available in the pure non-sequential mode of ZEMAX and does not account for refractive index change. The separation of Rigid Body motion is not supported (see section 5).

The parameter ”Maximum Aper” in the Non-Sequential Component Editor of ZEMAX defines at the same time the aperture of the surface and the normalization radius for Zernike polynomials. When updating a non-sequential model, OOFELIE may change the value of this parameter by using the maximum radial coordinate (in local coordinates) of mesh nodes belonging to the optical surface. Hence, the surfaces defined in OOFELIE and in ZEMAX must have exactly the same aperture. Another condition is that the ”Ref Object” parameter must be set to zero for each non-sequential surface to be updated by OOFELIE (this is required for the management of local coordinates). See the ZEMAX User’s Manual for further information.

### 3.6 Using mechanical and thermal numerical gluings

An opto-mechanical system is in general modeled in OOFELIE through several separated geometric entities. A first manner to construct the assembly is to use geometric gluings as allowed in the OOFELIE’s user interface (cf. Gluing and Dominant Fuse operations in the Modeler module). A more flexible and powerful way is to use numerical gluings provided by OOFELIE (Analysis Data module, Used Data: Assembly). Numerical gluings allow non compatible meshes to be glued together. Mechanical and thermal gluings are defined separately. The definition of non perfect gluings is possible to simulate some sliding effects or the
presence of an air gap between two surfaces. Wire-to-face numerical gluings are also available in OOFELIE (presently wire-to-face perfect gluings only) and are very useful to model lens assemblies. For further information about numerical gluings, please contact us (info@open-engineering.com or support@open-engineering.com) or see the tutorials.
4. Available analyses & simulation settings

The ZEMAX updating process by OOFELIE is available for static and transient analyses (linear or non linear analyses). In the case of transient simulations (or if multi load cases are defined), an updated ZEMAX file is created for each step. As shown in Figure 8, the user can set the path and name of the ZEMAX file to be updated (Zemax Input File field) and the directory where the updated file(s) will be saved (Zemax Output Directory field).

Figure 8: Files & Memory tab of the Simulation Settings dialog box

As shown in Figure 9, in the Static Data (or Transient Data) tab of the Simulation Settings dialog box, the ZEMAX Link can be activated or deactivated. If the link is activated, the user can use the option “Create file with Zernike Coefficients for Zernike surfaces” for generating in the Working Directory text files containing Zernike coefficients corresponding to surface deformations (one file for each surface which is updated by use of Zernike polynomials). In these files, the user can retrieve the number of Zernike terms, the normalization radius and the coefficients which are numbered according to the ZEMAX definition (either for Zernike Standard or Zernike Fringe polynomials, the ZEMAX convention is applied). In the same tab, the user can choose between several exportation hypotheses, as explained in the next section.

In the Oofelie Data tab of the Simulation Settings dialog box, one can set the number of significative digits used for computation (cf. Figure 10). The default value is 6. It is recommended to increase this parameter since optical problems generally require a very high accuracy.
Figure 9: Static Data tab of the Simulation Settings dialog box

Figure 10: Oofelie Data tab of the Simulation Settings dialog box
5. Surface deviation & exportation hypotheses

In the sequential mode of ZEMAX, an optical surface can be deformed by modifying its sag (local Z value as a function of local X and Y coordinates). The same process can be done with the Standard Surface non-sequential object which is basically defined as sequential surfaces. From finite element results, OOFELIE computes the sag modification (called surface deviation), which is then represented by Zernike polynomials or by an array of values (Grid Sag) for exportation to ZEMAX (cf. section 6). The surface deviation is always considered along the local Z axis of the surface (i.e. its optical axis). For an off-axis mirror, the optical axis of the parent surface is taken. The same remark as for the sag correction (cf. section 3.4) can be done about the visualization of the surface deviation (result type: Surface Deviation).

Depending on the application, the user can choose between several exportation hypotheses which command the way the surface deviation is computed (cf. Figure 11). These exportation hypotheses are described here below.

5.1 Sag deviation

This exportation hypothesis is set by default and is adequate in most cases. Transverse nodal displacements (i.e. nodal displacements in the plane perpendicular to the optical axis) are taken into account. Neglecting them could lead to significant errors, especially when thermal effects are involved.

OOFELIE considers the local coordinates of each optical surface when computing the surface deviation from nodal displacements. Starting from the Z component of nodal displacements, a correction is made for accounting for the two other components, as schematically described in Figure 12. This correction is computed by use of the transverse nodal displacements and the initial sag.

Note that the hypothesis "Sag deviation and Rigid Body motion" also accounts for transverse nodal displacements (see section 5.3).
5.2 Only Z component

With this exportation hypothesis, only the Z component (in local coordinates) of nodal displacements is considered. For plane surfaces, it gives exactly the same surface deviation as with the previous exportation hypothesis. Of course, it is also the case if transverse nodal displacements are null everywhere on the optical surface. In all other cases, the exportation hypotheses "Sag deviation" and "Sag deviation and Rigid Body motion" give a more precise representation of surface deformations and are especially recommended when thermal loads are present (since thermal effects generally lead to strong transverse nodal displacements). However, the hypothesis "Only Z component" may be useful in certain applications (e.g. control devices for active/adaptive mirrors).

5.3 Sag deviation and Rigid Body motion

If translation and rotation errors are critical in the optical design, as it is typically the case for telescopes and for guiding optics, this exportation hypothesis should be taken. Rigid body translations and rotations are displayed in the Solver Monitoring for each optical surface and each step. If significant values are shown, it is always recommended to use this exportation hypothesis which gives a better precision than the "Sag deviation" hypothesis for both elastic deformation and rigid body components exported to ZEMAX. With the "Sag deviation and Rigid Body motion" exportation hypothesis, the surface deviation is based on the elastic deformation only, while rigid body components are exported separately to ZEMAX. The surface deviation is fitted into Zernike polynomials or into a grid (cf. section 6). More precise fits can be obtained by removing decenters and tilts from the surface deformation. Rigid body components are represented in ZEMAX as tilts and decenters (Tilt/Decenter surface property) and additional changes of thicknesses, with again a better accuracy.

This exportation hypothesis also offers the ability of watching individually the effect of each rigid body component in the updated ZEMAX model (by removing the other ones) and the effect of the elastic deformation.

As it is the case for the surface deviation, tilts, decenters and thickness changes are computed in local coordinates of the optical surface. Coordinate breaks are allowed in the ZEMAX model when using this exportation hypothesis but the use of tilts and decenters (Tilt/Decenter surface property) on a surface to be updated is not allowed since their values would be replaced by rigid body errors.
5.4 Only Z component and Rigid Body motion

With this exportation hypothesis as with the previous one, the surface deviation is computed from the elastic deformation and the rigid body errors are exported to ZEMAX separately. If the application requires a representation of the surface deviation taking only Z nodal displacements and if significant rigid body errors are observed, this exportation hypothesis should be used instead of “Only Z component”. Indeed, as transverse nodal displacements are not taken into account, the surface deviation with the “Only Z component” hypothesis cannot represent decenters and tilts.

Note that these two last exportation hypotheses are based on tilts and decenters to be introduced in ZEMAX as surface properties of a sequential surface. Presently no separation of rigid body motion is available in the non-sequential updating process (only the elastic deformation is exported to a non-sequential ZEMAX model when one of these hypotheses is used).
6. Optical behaviors & surface deviation representation

An optical behavior has to be defined in the OOFELIE’s graphical interface for each optical surface to be updated. Optical behaviors can be applied on geometric entities (faces) or on mesh entities (cf. section 8.3). The support of an optical behavior defines in OOFELIE an optical surface (which corresponds to a surface of the ZEMAX model). An optical behavior commands the way the surface deviation is exported to ZEMAX, i.e. the type of fit: Zernike polynomials or a regular grid. Indeed, the user can choose between Zernike Standard polynomials, Zernike Fringe polynomials or Grid Sag. The user can set the number of polynomials or the number of points in the local X and Y directions.

6.1 Behavior types

6.1.1 Sequential optical behaviors

Two optical behaviors are available for updating sequential models: Sequential Lens and Sequential Mirror. As shown in Figure 13, the user can set the type of fit (as explained above) in the Sequential Lens Type field, the aperture type (circular, rectangular or elliptical) in the Aperture field, the ZEMAX surface number in the Lens Order field and the number of Zernike polynomials or the number of grid points (cf. sections 6.2 and 6.3).

In the current version of OOFELIE, the only distinction between the two sequential optical behaviors is that only Sequential Lens supports the GRIN feature (cf. section 7). An optical behavior always links to a specified surface in ZEMAX. Currently, an optical behavior can only be applied one time on the same support. Hence, a given optical behavior (Sequential Lens or Sequential Mirror) cannot point to two different ZEMAX surfaces. When a double pass optical model has to be updated by OOFELIE, this limitation is overcome by combining the two sequential optical behaviors since both Sequential Lens and Sequential Mirror can be used for refractive surfaces and mirrors. Sequential Lens must be used for ZEMAX surfaces which have to include the GRIN effect. Sequential Mirror can be used for any sequential ZEMAX surfaces to be updated by OOFELIE without GRIN.

Figure 13: Example of sequential optical behavior definition
6.1.2 Non-sequential optical behavior

As explained in section 3.5.2, the non-sequential object of type Standard Surface can be converted by OOFELIE to a Zernike Surface (using up to 231 Zernike Standard polynomials). To do so, the non-sequential optical behavior named Non-Sequential Lens is used, as shown in Figure 14.

![Figure 14: Example of non-sequential optical behavior definition](image)

6.2 Zernike polynomials

In the sequential mode of ZEMAX, Zernike polynomials can be added to surfaces of types Standard, Even Asphere or Biconic. When OOFELIE updates a ZEMAX model, the sag base is always kept unchanged. OOFELIE takes care of the sag base parameters which are previously retrieved from ZEMAX. Zernike polynomials describing the surface deviation are added to the initial sag. Initial surfaces of types Standard or Even Asphere are so converted to surfaces of types Zernike Standard or Zernike Fringe. For Biconic surfaces, only Zernike Standard polynomials are available with maximum 210 terms since the Biconic surface is converted to a Biconic Zernike surface (see ZEMAX User’s Manual for more information).

6.2.1 Zernike Standard

Except for Biconic surfaces (with maximum 210 Zernike terms), up to 231 Zernike Standard polynomials can be used (the default number of terms in OOFELIE is 28). The definition of these polynomials can be found in the ZEMAX User’s Manual. Recurrence equations are used in OOFELIE for generating up to 231 Zernike Standard polynomials. Generally speaking, the fit precision increase with the number of Zernike terms, even though it depends on the deformation (see section 6.2.4).
6.2.2 Zernike Fringe

The maximum number of Zernike Fringe polynomials is 37 (this value is also the default number in OOFELIE). Again, the definition of these polynomials can be found in the ZEMAX User’s Manual. Due to the limited number of terms, Zernike Standard polynomials should be preferred in most cases.

6.2.3 Normalization radius and apertures

Zernike polynomials are expressed in polar coordinates in the local frame of the optical surface. The radial coordinate is normalized so that it varies in the range [0,1]. The normalization radius depends on the aperture of the surface and is computed by OOFELIE from the mesh node coordinates. OOFELIE defines the normalization radius as the maximum radial coordinate of mesh nodes belonging to the optical surface (in the surface local frame). For a rectangular aperture, the radius of the circumscribed circle is so considered, so that all locations in the surface aperture are well inside the unit circle (i.e. radial coordinates in Zernike polynomials are well in the range [0,1]). However, if the aspect ratio of the rectangular aperture is about 2 or higher, the Zernike fit could fail in representing precisely the deformation. A grid fit is so advised for that kind of aperture.

If a decentered sub-aperture is considered (off-axis mirror), a Zernike decomposition of the surface deviation is possible if the surface defined in OOFELIE corresponds well to the shape of the parent sag and to the sub-aperture defined in ZEMAX. Again, the normalization radius is defined by the maximum radial coordinate of the nodes belonging to the optical surface but in this case the local frame is related to the parent sag. Even though the Zernike fit is of good quality in the sub-aperture, extrapolation of Zernike polynomials beyond the sub-aperture area may lead to strong errors, even for rays that hit the surface inside the normalization circle.

It is possible to restrict the surface deviation computation and the Zernike fit to a sub-area of a surface (by adapting the geometry, e.g. by use of the footprint technique). In this case, it is strongly recommended to set the extrapolate flag to 0 in the updated ZEMAX model. This flag is used for Zernike surfaces and is set to 1 by default. By setting it to 0, the Zernike terms are ignored for incoming rays outside the normalization circle. The reason of this precaution is that, as explained in the ZEMAX User’s Manual, Zernike polynomials tend to diverge quite rapidly beyond the normalization radius.

Zernike Standard polynomials can be used for annular apertures. A high number of terms is recommended to obtain a sufficient precision.

6.2.4 Fit process and fit errors

The Gram-Schmidt orthogonalization method is used to generate a set of orthogonal polynomials evaluated on the mesh nodes belonging to the optical surface. Zernike coefficients are then obtained from the coefficients of the Gram-Schmidt polynomial decomposition. All Zernike terms up to the number of terms chosen by the user are involved in the fit process. Hence it is not possible to realize a Zernike fit of the surface deviation by removing one or several Zernike term(s). However, thanks to the Gram-Schmidt orthogonalization, each Zernike term does not depend on the other terms so that some of the Zernike coefficients can be removed by setting them to zero in the ZEMAX updated model (the values of the other coefficients are still right). Some of the Zernike modes of the surface deviation can so be isolated (for example for the modeling of a modal deformable mirror) but the representation of the surface deviation is only correct with all Zernike terms involved in the fit process.

The fit accuracy is strongly dependent on the deformation and depends also on the mesh size and order, and on the aperture (circular and square apertures are preferred for Zernike fits). As already mentioned, the fit precision increases with the number of polynomials. The number of nodes on an optical surface must be closed to the number of Zernike terms or higher. RMS and maximum fit errors are displayed in the Solver Monitoring for all optical surfaces using Zernike polynomials and all simulation steps. If the precision is not
sufficient, the number of Zernike terms may be increased and the mesh may be improved. If the errors are still too elevated, Grid Sag should be used instead of Zernike polynomials.

### 6.3 Grid Sag

It is sometimes useful to represent the surface deviation through a regular grid (Grid Sag surface type) instead of Zernike polynomials. This is possible for Standard and Even Asphere surfaces which are converted into a Grid Sag. Grid Sag is available with the optical behaviors Sequential Lens and Sequential Mirror. As shown in Figure 15, when defining an optical behavior with Grid Sag, an advanced box may be used to set the numbers of points in X and Y local directions (click on the "more" button). Only odd values higher or equal to 7 are allowed. The default value is 23 in both directions.

![Figure 15: Setting the numbers of grid points](image)

One advantage of Grid Sag is that it can suit any kind of apertures. The node locations on the optical surface (in local frame) are used by OOFELIE to define a bounding box. The grid dimensions and location are set by this rectangular area. The surface deviation is null in all grid points located outside the optical surface aperture. For an off-axis mirror, the bounding box is limited to the sub-aperture and appropriate decenters are applied (since the local frame is defined by the parent surface). Data about the bounding box, grid decenters, pixel numbers and pixel sizes are displayed in the Solver Monitoring for all optical surfaces using Grid Sag.

The principal disadvantage of Grid Sag is that fine grids (typically several hundreds of points in each direction) are required to obtain a precise fit. As the node density on the optical surface has to be closed to the grid point one, the finite element computation time can be much more important than when using a Zernike fit.

The Grid Sag precision is also related to the interpolation made in ZEMAX. Note that by default, ZEMAX performs a bicubic spline interpolation (Interpolate flag in the Lens Data Editor equal to 0). The user can set the Interpolate flag to 1 for a linear interpolation, which is to be preferred when discontinuities are present in the surface deviation (see the ZEMAX User’s Manual for further information).
6.4 Choosing Zernike polynomials or Grid Sag

Choosing between Zernike polynomials or Grid Sag is really problem dependent. One has to consider the aperture of the optical surface and the surface deviation. Zernike polynomials are constructed over a unit circle and are more suited for circular or square apertures, while Grid Sag can be used for any kinds of aperture. Grid Sag can represent local deformations and discontinuities, for which a Zernike decomposition could fail. But the precision of Grid Sag strongly depends on the sampling resolution. Grids with several hundreds of points in each direction are recommended, with the obligation of very fine meshes on optical surfaces. Zernike polynomials are convenient in most cases and do not require fine meshes. Zernike Standard polynomials are in general to be preferred instead of Zernike Fringe polynomials since a higher number of terms can be used. Furthermore, Zernike coefficients are easy to interpret by the user since they are related to optical aberrations.

In general, Zernike (Standard) polynomials should be chosen first. Zernike fit errors are displayed in the Solver Monitoring. If these errors are too elevated (even with the maximum number of terms), Grid Sag can be used instead of Zernike polynomials.

A convenient way to check the fit quality is to perform in a ZEMAX updated model (sequential mode) the Surface Sag analysis, by setting the radius of curvature of the surface to infinity. This shows the surface deformation. The surface deviation can so be visualized in OOFELIE and compared to the one exported to ZEMAX (the surface deviation has to be visualized in OOFELIE with the criterion Scalar Projection on Z). An example of such a comparison is shown in Figure 16 and Figure 17. If rigid body translations and rotations are exported separately to ZEMAX (cf. section 5), the surface deviation corresponds to the elastic deformation, while the Surface Sag analysis shows the total deformation. In this case, it is possible to visualize the surface deviation in ZEMAX by removing all tilts and decenters, and setting thicknesses to their initial values. Note that in the non-sequential mode of ZEMAX, the Universal Plot 2D analysis may be used to visualize the sag if a source is defined just before the non-sequential object in the Non-Sequential Component Editor. However, ray tracing errors sometimes occur so that the display is not always possible and the precision is quite poor.
Figure 16: Example of surface deviation visualized in OOFELIE

Figure 17: Example of surface deviation exported to ZEMAX (Zernike Standard fit with 231 terms)
7. GRIN (Gradient of Refractive INdex)

Thermally induced change of refractive index in optical elements is often to be taken into account. Depending on the optical system and on the thermo-mechanical problem, its effects on the optical performances are more or less important in comparison with deformation effects. OOFELIE models the refractive index change due to a change of temperature (thermo-optic effect) and the spatial distribution of refractive index if a temperature gradient occurs.

7.1 Thermo-optic effect

A change of temperature in an optical element leads to a change of its refractive index. This effect is called the thermo-optic effect. It is modeled in OOFELIE as expressed in the following equation:

\[ n(x, y, z) = n_0 + \frac{dn}{dT} \Delta T(x, y, z) \]

\( n(x,y,z) \) is the refractive index field, \( \Delta T(x,y,z) \) is the relative temperature field, \( n_0 \) is the refractive index at the reference temperature and \( \frac{dn}{dT} \) is the thermo-optic coefficient at the reference temperature. This expression is based on the assumptions that the change of temperature is not very high (since only one thermo-optic coefficient is used) and that the wavelength range considered in ZEMAX is not too wide. If a large range of wavelength must be covered, several simulations may be required (by adapting the values of \( n_0 \) and \( \frac{dn}{dT} \) in several sub-ranges of wavelength).

An example of temperature gradient is shown in Figure 18. The corresponding refractive index distribution in the optical element is shown in Figure 19.

![Figure 18: Example of temperature field in a lens and its mount](image)
7.2 GRIN settings

The GRIN data is available in the Solver module of the OOFELIE’s graphical interface (Output button). The GRIN "archive" is defined as shown in Figure 20. The values of the refractive index (n₀) and of the thermo-optic coefficient (dn/dT) are set by the user (as explained in section 7.3, these values are relative to air). The GRIN, i.e. the refractive index distribution can be computed and visualized in OOFELIE without exportation to ZEMAX. If the exportation to ZEMAX is wanted, the "Export GRIN to Zemax" option has to be activated and the "Entrance Optical Surface" field has to link to the optical behavior of the entrance face of the optical element. The support of the GRIN data is defined in the "Placed on" field. This support is in general a solid corresponding to an optical element. As it is the case for optical behaviors, the GRIN data can also be applied on mesh entities (cf. section 8.3).
7.3 Convention: refractive index relative to air

Even though the thermo-optic coefficients in the ZEMAX glass catalogue are defined as absolute, the refractive index is always defined in ZEMAX models as relative to air. In other words, the refractive index of air is always equal to 1, at any conditions of temperature and pressure, and for all wavelengths. That is the reason why OOFELIE exports to ZEMAX the relative refractive index and why relative values of \( n_0 \) and \( dn/dT \) have to be set by the user.

7.4 Exportation of GRIN and deformation to ZEMAX

The GRIN exportation to ZEMAX is available for sequential optical models and for surfaces on which an optical behavior of type Sequential Lens is defined (cf. section 6.1.1). The surface deviation is exported simultaneously with the GRIN and represented by Zernike Standard polynomials. A customized surface type which combines up to 231 Zernike Standard polynomials with the refractive index distribution (GRIN) has to be used. This user-defined surface is controlled by a Dynamic Link Library (DLL), named OÖZernikeGRIN.dll and provided by Open Engineering. The DLL file can be found in the solver directory of OOFELIE, in 32 or 64 bits version depending on the OOFELIE version. Since the DLL has to be compatible with the ZEMAX version (32 or 64 bits), Open Engineering can provide you with both versions of the DLL. Please contact us if needed (info@open-engineering.com or support@open-engineering.com).

All ZEMAX built-in surface types which can be used for GRIN media are based on Standard sag. These surface types are not convenient for modeling thermally induced deformations and refractive index distributions. The initial sag of type Standard, Even Asphere or Biconic is kept unchanged and the fitted Zernike Standard terms are added to represent the surface deviation. Up to 231 Zernike Standard polynomials can be used, even for Biconic surfaces. The GRIN is interpolated and represented in ZEMAX by the following polynomial (considered in local coordinates of the surface):

\[
n = n_0 + n_{x1}x + n_{x2}x^2 + n_{y1}y + n_{y2}y^2 + n_{z1}z + n_{z2}z^2 + n_{xy}xy + n_{yz}yz + n_{xz}xz
\]

The first seven terms of the right side of the above equation are the same as in the Gradient 4 surface type of ZEMAX. The last three terms are additional cross-terms, allowing complex GRIN descriptions.

Note that for observing the effects of GRIN alone (without deformation of the optical element), Zernike coefficients can be set to zero in the ZEMAX updated model.

Figure 21 shows a ZEMAX updated model combining deformation and GRIN in a lens. The customized surface of type "OOZerGrin" is used for the entrance face of the lens. A dummy surface, with the same shape as the back face of the lens and a null thickness, has to be defined in ZEMAX before updating a model with GRIN (see surface number 4 in Figure 21). The same glass as for the front face of the lens is set for the dummy surface. The reason of this dummy surface is that ZEMAX does not allow a refractive index gradient to be followed by any surface types. In particular, Biconic, Biconic Zernike, Zernike Standard, Zernike Fringe and Grid Sag surfaces are not allowed. Hence, the back face of the optical element has to be initially of Standard or Even Asphere type. The dummy surface is then defined with the same type. The back face can be converted into Zernike Standard, Zernike Fringe or Grid Sag since it does not involved a GRIN.

As shown in Figure 21, the Extrapolate flag is not available for a DLL surface, meaning that for the "OOZerGrin" surface, Zernike polynomials may be extrapolated beyond the normalization circle (cf. section 6.2.3).
Figure 21: Example of ZEMAX updated model with the "OOZerGrin" surface type

As shown in Figure 22, the interpolated values of the polynomial coefficients describing the GRIN are introduced by OOFELIE in the Lens Data Editor of ZEMAX. An additional parameter, named Delta T is also set. This parameter is the maximum step size (see the ZEMAX User’s Manual). OOFELIE sets the value of Delta T to one tenth of the lens thickness. Negative thicknesses and negative values of Delta T are allowed. To increase the ray tracing accuracy, one can decrease manually the maximum step size but this will slow down the ray tracing.

The GRIN polynomial coefficients and the RMS and maximum fit errors are displayed in the Solver Monitoring of OOFELIE for all optical surfaces with GRIN exported to ZEMAX and all simulation steps. Zernike fit errors are also displayed.

ZEMAX can perform some simple thermal analyses, considering homogeneous temperature changes. The GRIN feature should not be mixed with thermal analyses in ZEMAX. If a thermal analysis is performed via the Multi-Configuration Editor of ZEMAX (cf. section 8.2.4), remove all operands relative to the optical elements whose deformations and GRIN are already modeled by OOFELIE.

Note that the GRIN exportation to ZEMAX capability of OOFELIE is also used for the modeling of refractive index distributions in plastic optics (cf. section 8.3).
8. Advanced features

Advanced features are presently not completely interfaced in the graphical interface, meaning that they require the use of the epilogue and sometimes the use of the OOFELIE’s Command Line Interpreter (CLI). For some advanced features, manual operations in ZEMAX are also required.

8.1 Deferred ZEMAX updating

It is sometimes useful to run thermo-mechanical simulations on a computer (or a cluster) and update the ZEMAX model later on another computer on which ZEMAX is installed. When thermo-mechanical results are obtained, the ZEMAX model updating can be done on a less powerful computer (the updating process is fast and does not require much RAM). The deferred ZEMAX updating process is also interesting when mechanical and optical engineers have to share the design work.

8.1.1 Stage one

Some very simple commands have to be used in the epilogue. For the first stage, i.e. finite element analyses without ZEMAX link, write the following command in section #SECTION_PARAM_EXPORT#:

```c
writeCurrentAnalysisOnFiles(dom_##,"Name");
```

The symbol ## is automatically replaced by the Problem Name. Files containing simulation results will be created in the Working Directory with names starting by Name and ending by the step number followed by the extension .ooStep. The name given by the user (Name) can include the Problem Name (e.g. results_##).

8.1.2 Stage two

For the second stage, i.e. the ZEMAX model updating, using the same sfield file as in the first stage is more convenient (all data will be ignored, except optical behaviors and optionally the GRIN output which have to be added). If another sfield file is used, geometries and meshes of all optical elements have to be exactly the same as in the model of stage one. Mind to place in the current Working Directory the file(s) generated in the first stage.

In section #SECTION_AFTER_MODEL#, write the following command:

```c
fillAnalysisFromFiles(dom_##,AnalysisID,"Name");
```

The second argument (AnalysisID) has to be adapted to the type of simulation performed in the first stage: LINEARSTATIC_PO, NONLINEARSTATIC_PO or DYNAMIC_PO.

In section #SECTION_PARAM_SOLVER#, use always the same command (no argument to be defined):

```c
solver_##.setInactive();
```

Note that in the deferred updating process, the sag correction is not active (it can be visualized but no correction is applied since the finite element computation is separated from the OOFELIE – ZEMAX data exchange).
8.2 Modeling of deformed DOEs

8.2.1 Introduction

DOEs (Diffractive Optical Elements) can be included in optical models to be updated by OOFELIE. Starting with surfaces of types Binary Optic (Binary Optic 1 to Binary Optic 4 can be used), the surface describing the DOE is manually replaced by a Grid Phase surface in the updated ZEMAX model. OOFELIE computes the deformed phase of the DOE and writes a phase grid file to be imported in ZEMAX. The diffractive structure has to lie on a plane surface since the process is based on the replacement of the initial Binary Optic surface by a Grid Phase surface. Pure DOEs or hybrid lenses can be modeled (see Figure 23, (b) and (c)).

As it is the case in ZEMAX, OOFELIE does not model the (sub-) microscopic details of the diffractive structure. Indeed such a modeling by finite element methods would be impossible in most cases. Based on the hypothesis that diffractive details do not influence the substrate deformation, only the substrate (or the lens in the case of a hybrid element) is modeled in OOFELIE. The deformation of the substrate is used to evaluate the modified phase of the DOE, which is then modeled in ZEMAX via a Grid Phase. DOEs with etched details on a surface are considered here, not bulk holograms. The process is especially dedicated to diffractive Fresnel lenses (cf. Figure 24) but more complex diffractive structures whose phase can be retrieved in OOFELIE via a phase grid can also be modeled. Since the diffractive details are not modeled, the deformation of these details along the optical axis is not considered. In general, this on-axis deformation leads to a change of diffraction efficiency. The diffraction efficiency is not modeled in ZEMAX.

Figure 23: (a) refractive lens ; (b) DOE on a plane substrate ; (c) hybrid lens with DOE placed on a plane surface
8.2.2 How to proceed

The first step is to launch a computation with a link to ZEMAX, a command being added in the epilogue. During the OOFELIE – ZEMAX updating process, the substrate of the DOE is deformed and the GRIN is optionally considered, as for any refractive optical element. A file is created in which initial and deformed nodal coordinates are stored for subsequent computation of the deformed phase. In the section #SECTION_PARAM_SOLVER#, use the following command:

\[ \text{pilot}_##.createFileWithPosInitFinal(SurfId, "NodeCoordFileName.txt"); \]

where the first argument (SurfId) is an integer setting the number of the ZEMAX surface which is in contact with the DOE, i.e. the surface of a substrate or of a lens holding the DOE, not the surface of the DOE itself. An optical behavior has to be defined on the corresponding face of the OOFELIE model. This is not only needed for updating the ZEMAX model but also for the management of local coordinates in the deformed phase computation.

The second argument specifies the name (with extension .txt) of the file to be created. If this file has to be saved in a directory different from the Working Directory, the complete path can be specified.

Once finite element simulation and ZEMAX updating have been done, a Grid Phase surface can be introduced in the updated ZEMAX model to describe the deformed phase of the DOE. For doing this, first generate a grid file with appropriate sampling via the Surface Phase analysis in ZEMAX (selecting the surface number corresponding to the Binary Optic surface). Then replace the Binary Optic surface by a Grid Phase surface and mind of the diffraction order (by default the diffraction order is set to zero, meaning that no diffraction occurs; hence the user has to set the right value, the same as before with the Binary Optic surface). Then the deformed phase grid has to be computed and imported in ZEMAX through the Extra Data Editor (Tools \(\rightarrow\) Import). The file to be imported in ZEMAX is created by use of the Command Line Interpreter (CLI), writing:

\[ \text{DoePhaseComputation doe("NodeCoordFileName.txt","GridFileName.txt",WeightMethodFlag);} \]

The two first arguments specify the name (with extension .txt) of the mesh coordinate file generated during the simulation and the name (again with extension .txt) of the phase grid file exported from ZEMAX. The third argument is an integer flag which can be omitted in most cases (see next section).
A reminder of the argument definition can be found in the CLI by use of the `help` command:

```plaintext
>>Help("DoePhaseComputation");
```

DoePhaseComputation generates three output files with compatible format and extension (.dat) for further use in ZEMAX. Starting with the initial phase grid file with name `GridFileName` and of a given resolution, the three files are generated in the Working Directory with the same sampling resolution. As usual, the Working Directory can be set in the CLI via the command: `chdir("DirectoryPath")`; to be called before DoePhaseComputation, if the Working Directory is not the predefined one (see documentation of the OOFELIE’s Command Line Interpreter).

The file `GridFileName_Updated.dat` contains the deformed phase and has to be used in the updated ZEMAX model.

The file `GridFileName_Rewrited.dat` contains the initial phase in the right format for importation in ZEMAX. With this file, one can check in the initial ZEMAX model that the replacement of the Binary Optic surface by the Grid Phase surface does not lead to a change of optical indicators (especially wavefront errors). A sampling of 513x513 pixels usually offers a sufficient precision but the resolution of the grid could be increased if necessary (cf. next section).

The third file is named `GridFileName_UpdatedMinusRewrited.dat` and gives the difference between the updated phase and the initial one. This file may be used either in the updated or in the initial ZEMAX model to display the phase change due to applied loads (by use of the Surface Phase analysis).

### 8.2.3 Remark about sampling resolution and computation time

As already mentioned, the reliability of the process depends on the resolution of the phase grids. By setting the sampling of the initial phase grid, the user also set the one of the deformed phase grid. The sampling resolution has to be set according to the DOE macroscopic and microscopic dimensions, i.e. the size of the substrate and the size of the diffractive details (the pixel size has to be quite close to the smallest size of the diffractive details). The mesh of the substrate (or lens in the case of a hybrid optical element) can be irregular and the average size of elements on the surface of interest (the one in contact with the DOE) can be bigger than the pixel size. Nevertheless, a very fine mesh on this surface is requested (the average distance between nodes must not be much higher than the pixel size). Progressive meshes, which can be easily generated in the OOFELIE’s graphical interface by applying appropriate mesh constraints, moderate the total number of degrees of freedom in the finite element simulation. An example of such a mesh is shown in Figure 26. In this example, the diameter of the substrate is 10 millimeters and the average size of (linear) elements on the surface holding the DOE is 20 micrometers (225000 nodes on this surface). Phase grids of 513x513 pixels, with a pixel size of 19.5 micrometers, were used in this model, which is presented in the next section.
The generation of the phase grids within the CLI is quite fast but the finite element simulation can be quite long, depending on the computer power. The Mumps-Out-Of-Core process can be used in case of not enough RAM but this process is quite low. Hence, it is advised to start with a mesh of reasonable size and then increase the number of nodes on the surface in contact with the DOE if necessary. Increasing progressively the phase grid resolution could also be needed (but mind that the use of very fine grids can considerably slow down optical analyses performed in ZEMAX).

The computation of the deformed phase is based on interpolation methods. To check that this process does not lead to unacceptable errors, one can use the file `GridFileName_Rewritten.dat` as explained in the previous section or the file `GridFileName_UpdatedMinusRewritten.dat` generated without any load applied on the model. Indeed, for testing purpose, in the absence of deformation on the substrate of the DOE, this file contains the difference between the regenerated phase and the initial one, showing interpolation errors. The regenerated phase grid is the one constructed by interpolation of the phase values between the positions of the pixels of the grid and the positions of the mesh nodes belonging to the surface in contact with the DOE. Interpolation is performed by triangulation and use a weighting function to weight the influence of surrounding points in the evaluated phase values. By default, the Lorentzian function is used but one can choose the Inverse Distance weighting instead (cf. Figure 27). When calling the class `DoePhaseComputation` in the CLI, omit the third argument (or set this argument to 0) for keeping the default weighting function, or set the third argument to 1 if the Inverse Distance function is wanted. This second optional weighting function will give more weight to distant points, which could be useful when the density of nodes is quite different from the one of grid pixels.
8.2.4 Example

A very simple model is considered here to illustrate and validate the method. A diffractive Fresnel lens modeled by a Binary Optic 2 surface is deformed due to a homogeneous heating. Such a simple thermal effect can be modeled in ZEMAX, so that it is possible to check the reliability of the process. Of course more complex thermo-mechanical simulations are possible using OOFELIE for Advanced Optics.

Figure 28 shows the ZEMAX model (ZEMAX 12 Release 2 was used for the simulations presented here). The plane substrate of the DOE has a diameter of 10 mm, a thickness of 1 mm and is made of BK7. The Binary Optic 2 coefficients are set in the Extra Data Editor (the phase function is defined here by means of 3 coefficients). The diffraction order is set to 1. The phase of the modeled DOE is visible in Figure 28 (from 0 in the center of the lens to -318 cycles of 2π radians on the edge). The Macro named "PHASES" gives the radial coordinates of the 2π phase shifts. The minimum radial change is about 6 µm and is located on the edge of the lens. The entrance pupil diameter is 8 mm.

A thermal analysis is performed in ZEMAX by use of the Multi-Configuration Editor and the tool "Make Thermal" (cf. Figure 29). The temperature of the system is elevated from 20°C (Configurations 1 and 2) to 200°C (Configuration 3). The last operand in the Multi-Configuration Editor is the normalization radius of the phase function. ZEMAX simulates the change of phase by modifying this parameter.

![Figure 28: Diffractive Fresnel lens modeled in ZEMAX](image-url)
The mesh model in OOFELIE and the sampling parameters have been presented in the previous section (cf. Figure 26). A static analysis is performed in OOFELIE with a reference temperature of 20°C and a prescribed temperature of 200°C. No clamp is defined and the advanced parameter "Relative Precision For Factorization" is adjusted so that OOFELIE filters the 6 null pivots. The updated ZEMAX model, shown in Figure 30, includes the deformation of both surfaces of the substrate (Zernike fits), the change of refractive index inside the substrate (via the GRIN feature) and the deformed phase. The option "Adjust Index Data To Environment" is not activated and no thermal analysis is done in ZEMAX since thermal effects are here accounted for by OOFELIE.
Figure 30: ZEMAX model updated by OOFELIE

Figure 31 presents wavefront errors in the initial model with the Binary Optic 2 surface and with the Grid Phase surface (by use of the file “GridFileName_Rewrited.dat”). No difference is observed. PTV is the Peak To Valley wavefront error, RMS is the Root Mean Square error, Z4 is the focus Zernike coefficient and Z11 the spherical aberration one (these two aberrations are the principal ones). Figure 32 shows the comparison of wavefront errors between the two models which account for thermal effects. Both models gives the same results, even if a slight difference is observed in the PTV wavefront error values. In the very simple model presented here, since a collimated beam is crossing a plane substrate on which a DOE is placed, a homogeneous heating does not modify the wavefront errors if the DOE phase change is not modeled (this has been observed in both models as well). Accounting for modifications of phase distributions of diffractive optics is so essential in certain applications.

Figure 31: Wavefront errors in wave unit at 0.5876 μm (initial models)
Figure 32: Wavefront errors in wave unit at 0.5876 µm (models with thermal effects)

| Wavefront errors | Thermal analysis in ZEMAX | Model updated by OOFELE |  |
|------------------|----------------------------|-------------------------|  |
| PTV              | 1.602                      | 1.627                   |  |
| RMS              | 0.428                      | 0.428                   |  |
| Z 4              | -0.148                     | -0.147                  |  |
| Z 11             | -0.091                     | -0.090                  |  |
8.3 MOLDEX 3D – ZEMAX chaining by OOFELIE

8.3.1 Introduction

Taking benefit of the automated data exchange between OOFELIE and ZEMAX®, the MOLDEX 3D® – ZEMAX® chaining operated by OOFELIE enables the analyses of the optical performances of injection molded plastic optics.

Figure 33 shows the operating way of the tool, which is described in details in section 8.3.3.

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8.3.2 Retrieving MOLDEX 3D results in OOFELIE

It is possible to import in the OOFELIE’s graphical interface the mesh and some results from MOLDEX 3D. This is for visualization purpose only. It is not requested for the MOLDEX 3D – ZEMAX chaining.

8.3.2.1 Data files from MOLDEX 3D

Four types of text files in ASCII (ANSI) format can be retrieved from MOLDEX 3D and used in OOFELIE either for result visualization or for the modeling of a "warped" plastic lens (cf. section 8.3.3).
The .inp file contains the mesh data, plus optionally the packing temperature. Presently, two types of elements can be present in the mesh: linear tetrahedron and linear pentahedron. The length unit has to be millimeter.

The .m3w file contains data about the shrinkage and the warp of the molded piece. The final displacements of MOLDEX 3D are used by OOFELIE to simulate the warped lens. These nodal displacements include the different steps of the injection molding process simulated by MOLDEX 3D (including the lens ejection from the mold). The length unit has to be millimeter.

The .optic file is generated by the optic module of MOLDEX 3D and contains the birefringence and refractive index data. The chaining tool uses the refractive index map which can be exported to ZEMAX simultaneously with the lens deformation.

In addition, the .sts files with thermal and flow stresses can also be used for visualization purpose or for further post-treatments, such as the simulation of stress relaxation when cutting off the injection channel, which could be performed on demand by Open Engineering.

### 8.3.2.2 Importation of MOLDEX 3D data in OOFELIE

In the Command Line Interpreter of OOFELIE (CLI), the following commands are used to read the data from MOLDEX 3D and rewrite them in the right format for visualization in OOFELIE.

1. `chdir("WorkingDirectory");`
2. `FromMoldex moldex;`
3. `moldex.readINP("FileName.inp");`
4. `moldex.readM3W("FileName.m3w",1);`
5. `moldex.readOPTIC("FileName.optic");`
6. `moldex.readSTS("FileName.sts",1e6);` //1e6 is a conversion factor
7. `ToSamcefField sf(moldex.getDomain());`
8. `sf.exportMesh("FileName.dat");` //Initial mesh
9. `sf.exportCode(TX|TY|TZ|GD|I1);` //final displacements
10. `sf.exportCode(TS);` //stresses
11. `sf.exportCode(TO|AB);` //packing temperature
12. `sf.exportCode(TM|GD|I4);` //birefringence
13. `sf.exportCode(TM|GD|I5);` //refractive index
14. `sf.exportCode(TM|GD|I6);` //retardation
15. `sf.writeResults("ResultName");`

The command No. 1 sets the Working Directory where the files from MOLDEX 3D are placed. After the instantiation of the class FromMoldex (command No. 2), the user can ask for the reading of several files which have been described in section 8.3.2.1 (commands No. 3 to 6). Then the class ToSamcefField is instantiated (command No. 7). A .dat file with the mesh data is created by use of command No. 8. The name of the file is set by the user. This mesh will be imported in OOFELIE (see section 8.3.2.3). The following commands (No. 9 to 14) are defining the results to be visualized. The result of command No. 14 is in fact the optical path difference due to birefringence. With the command No. 15, a _fieldresults folder is created in the Working Directory. It contains the wanted results for visualization in OOFELIE.

### 8.3.2.3 Visualization in OOFELIE

The mesh file and the result folder previously generated can be imported in the OOFELIE’s graphical interface. The different result types are given in the data tree, as shown in Figure 34. For example, one can visualize the final nodal displacements computed by MOLDEX 3D (Figure 35).
8.3.3 Example of simulation of an injection molded lens (description of the chaining tool)

Currently, the process can involve a unique lens with a circular aperture. The global Z axis in the ZEMAX model has to be the optical axis of the lens and the lens may not be decentered. As usual, the frame in OOFELIE has to be the same as the global frame in ZEMAX. The frame in MOLDEX 3D has to be defined in the same way.

The MOLDEX 3D – ZEMAX chaining is based on the computation of the optical surface deviation by use of a deformed mesh. The deformed mesh is created from the initial mesh and from the final nodal displacements given by MOLDEX 3D. Rigid body translations and rotations are computed and removed from the deformed mesh, so that a free molded lens is modeled (free meaning here that the lens has been ejected from the mold and is ready to use).
8.3.3.1 Generation of the deformed mesh

The generation of the deformed mesh is the preliminary step realized in the CLI before the chaining. The following commands are used.

1. `chdir("WorkingDirectory");`
2. `FromMoldex moldex;`
3. `moldex.readINP("FileName.inp");`
4. `moldex.readM3W("FileName.m3w");`
5. `moldex.addFinalDisplacementsWithoutRBMInDB(rLens);`
6. `moldex.restrictDeformedMeshToCylinder(rPupil);`
7. `moldex.readOPTIC("FileName.optic", 1);`
8. `ToSamcefField sf(moldex.getDomain());`
9. `sf.exportMesh("FileName.dat");`

The role of some of these commands has been explained in section 8.3.2.2. Note that the command No. 4 is used without the second argument which was a flag. Here the final displacements of MOLDEX 3D are used for the creation of the deformed mesh, not for visualization.

The command No. 5 is used for the deformed mesh generation. The argument rLens is the lens semi-diameter, given in millimeter by the user. It corresponds to the initial mesh, whose size is in general a little bit more elevated than the deformed mesh one (due to shrinkage effect). Setting the same value of the semi-diameter as the one defined in the ZEMAX model gives a sufficient precision for the calculation by OOFELIE of the rigid body components.

The command No. 6 is then called for keeping in the deformed mesh only the lens or a sub-aperture of the lens (which has to be also considered in the ZEMAX model). This means that rPupil is inferior or equal to rLens. As for the parameter rLens, rPupil is set in millimeter for more convenience (since it is very often the lens unit applied in ZEMAX).

In this process, the order of the commands has to be respected. The command No. 7 is so called once the mesh has been deformed and restricted to the lens. Note the presence of a second argument which is set to 1. It means that the refractive index distribution will be exported to ZEMAX. If only the lens deformation has to be exported, the command may be used without the second argument for visualizing the refractive index distribution.

An example of use of the commands given above is shown in Figure 36. Information are given about the element types present in the mesh from MOLDEX 3D and about the rigid body motion (RBM) corresponding to the deformed configuration of the lens. The RBM translation is given in meter, which is the usual length unit in OOFELIE. The warning message displayed in the CLI is useless in this process.

![Figure 36: Generation of the deformed mesh via the CLI of OOFELIE](image-url)
8.3.3.2 Chaining parameters in OOFELIE

8.3.3.2.1 Selection of mesh entities

Once the deformed mesh has been imported in OOFELIE, the user can isolate the skin elements belonging to the optical surfaces by use of the mesh selection feature, as shown in Figure 37. This operation has to be done for each optical surface of the lens (front face and rear face).

![Figure 37: Creation of a mesh selection corresponding to one of the optical surfaces](image)

8.3.3.2.2 Optical behaviors

Optical behaviors can then be defined, for each optical surface, as shown in Figure 38. Each optical behavior links to the corresponding surface in ZEMAX (in this example the surface No. 2). It sets the way the deformation will be exported to ZEMAX. Here Zernike Standard polynomials are used with a number of terms set to 100. For the exportation of the refractive index simultaneously with the deformation of the entrance face of the lens, Zernike Standard polynomials must be used. If the refractive index inhomogeneities are not taken into account, the user can also use Zernike Fringe polynomials or Grid Sag to export the surface deformation. The optical behaviors are "fetched" on the mesh selections created before.
Before the optical behavior definition, the user has checked the "Zemax Connection" option in the Multiphysic Problem Configuration dialog box, as shown in Figure 39.

Figure 39: Activation of the connection with ZEMAX

8.3.3.2.3 Refractive index (GRIN)

The GRIN feature is used for exporting to ZEMAX the refractive index distribution computed by MOLDEX 3D, as shown in Figure 40. Here the GRIN (Gradient of Refractive INdex) is not due to the thermo-optic effect, so the refractive index and the thermo-optic coefficient keep their default values (cf. Figure 40). These two parameters are not used. The GRIN is linked to the optical behavior of the entrance surface of the lens and is applied on the mesh model corresponding to the whole lens.
8.3.3.4 Epilogue

Figure 41 shows the commands to be written in the section #SECTION_PARAM_SOLVER# of the epilogue. They are used to deactivate the solver of OOFELIE, deactivate the sag correction process and use the sag correction for defining the surface deviations.

8.3.3.5 Simulation settings

As shown in Figure 42, in the Files & Memory tab of the Simulation Settings dialog box, the user sets the Working Directory (the same as the one used in the CLI if the GRIN option is used, cf. section 8.3.3.1), the directory and name of the ZEMAX file to be updated and the directory in which the updated ZEMAX file will be created.
8.3.3.3 Updating the ZEMAX optical model

When starting the chaining by clicking on the Convert and Launch button, a warning message appears. It informs that the optical behaviors have been applied on mesh entities, so they do not contain geometric parameters. This message can be ignored by clicking on Yes.

During the chaining, some information is displayed in the output window of the Solver Monitoring box, as for any ZEMAX model updating. The displayed data concern the refractive index polynomial fit, the Zernike fit and the rigid body motion (i.e. the rigid body components of the deformation of each optical surface). Optical indicators retrieved from ZEMAX and corresponding to both initial and updated optical models are also displayed in the Solver Monitoring.

As usual, the surface deviation exported to ZEMAX can be visualized in OOFELIE, as shown in Figure 43. The refractive index distribution can also be displayed (cf. Figure 44).
Figure 43: Surface deviation computed by OOFELIE

Figure 44: Refractive index distribution retrieved from MOLDEX 3D
An example of an optical model updated by OOFELIE is shown in Figure 45. Both deformation and refractive index can be simultaneously exported to ZEMAX by use of the customized surface type named "OOZerGrin" (cf. section 7.4).

![Figure 45: Optical model of the lens in ZEMAX, updated by OOFELIE](image)

### 8.3.4 Optional features

#### 8.3.4.1 Correction of the lens position

The shrinkage of the lens fabricated by injection molding can lead to an inaccurate positioning of the lens along the optical axis (Z axis). Indeed, an over-size initial mesh in often considered in MOLDEX 3D to take into account the shrinkage effect. The deformed mesh constructed by OOFELIE has dimensions close to the nominal ones but the lens location can be wrong. The translation to be done (if the optical model does not allow a piston error) is visible in the surface deviation for an optical surface whose center should be in \( z = 0 \) (cf. Figure 43). Once a first chaining has been done, one can use a specific command in the epilogue to correct the lens position according to the optical model in ZEMAX. The mesh is not really modified but the requested translation is taken into account in the deformation computed by OOFELIE and exported to ZEMAX. The command added in the epilogue is shown in Figure 46. The argument of this command is the applied translation along Z axis with meter as length unit.
8.3.4.2 Optical behaviors applied on element groups

If the process of mesh selection explained in section 8.3.3.2.1 fails because of a complex shape, it is possible to create groups of skin elements before the mesh importation in OOFELIE.

The following commands are used in the CLI for the generation of the deformed meshed, as explained in section 8.3.3.1. Again the order of the commands is important. In this case a deformed meshed is created for the whole model but groups of skin elements separate the different parts of the model (injection channel, molded piece, …), as shown in Figure 47. Two of these groups are used for the definition of the optical behaviors (cf. Figure 48). A sub-aperture of the lens can be considered whose size is set by the parameter rPupil. Note that with this special process, the GRIN exportation to ZEMAX is not allowed.

1. chdir("WorkingDirectory");
2. FromMoldex moldex;
3. moldex.createSkinElementGroups(1,rPupil);
4. moldex.readINP("FileName.inp");
5. moldex.readM3W("FileName.m3w");
6. moldex.addFinalDisplacementsWithoutRBMInTheDB(rLens);
7. ToSamcefField sf(moldex.getDomain());
8. sf.exportMesh("FileName.dat");
8.3.4.3 Lens warp visualization

Without updating the optical model, the user can visualize the lens warp in OOFELIE. If the warp is not admissible, simulation parameters in MOLDEX 3D may be modified. The lens warp corresponds to the nodal displacements computed by MOLDEX 3D (called final displacements), corrected for rigid body translations and rotations (which have to be removed from the deformed mesh). An example of such a warp is presented in Figure 49.
In the same way as the procedure explained in section 8.3.2, the initial mesh is used to visualize the warp. The following commands are used in the CLI to generate the mesh file and the result folder. These data are then imported in the OOFELIE’s graphical interface. The parameter rLens has the same definition as before.

1. chdir("WorkingDirectory");
2. FromMoldex moldex;
3. moldex.readINP("FileName.inp");
4. moldex.readM3W("FileName.m3w");
5. moldex.createFinalDispSetWithoutRBM(rLens);
6. ToSamcefField sf(moldex.getDomain());
7. sf.exportMesh("FileName.dat");
8. sf.exportCode(TX|TY|TZ|GD|I1);
9. sf.writeResults("ResultName");
8.4 Automated thermal load definition by use of irradiance and absorption maps from ZEMAX

Absorption of light and further heating and deformation of irradiated pieces or of optical elements is an important matter in certain applications (especially in laser applications). OOFELIE offers the possibility to define complex thermal loads related to inhomogeneous irradiance distributions (power per surface) or to bulk distributions of absorbed flux per volume (called absorption maps for simplicity). The proposed approach is to perform non-sequential simulations in ZEMAX, export text files from ZEMAX and use them in OOFELIE. Some simple commands have to be introduced in the epilogue, then thermal load definition is performed automatically (automated interpolation processes). All information about how to proceed is given in the power point presentation enclosed at the end of this document. A pdf version of this presentation with one slide per page is available on request. For further explanation or for requesting the pdf documentation, please contact us (info@open-engineering.com or support@open-engineering.com).

Two kinds of thermal loads are concerned: Surface Heat Flux (for the modeling of light absorption on a surface) and Volume Heat Source (for the modeling of absorbed light inside optical elements).

An example of Surface Heat Flux definition via an irradiance map is given in Figure 50. In this example, a non-transparent medium (e.g. a metallic plate) is irradiated. The light is absorbed on a surface only (no bulk absorption). The user sets the absorbance of the material in the epilogue. In this case, a 2D irradiance map is exported from ZEMAX for defining in OOFELIE a Surface Heat Flux. With recent OOFELIE releases (2014), 3D irradiance maps can also be used. This is very important for the modeling of light absorption inside coatings placed on lens faces.

The case of bulk absorption is illustrated in Figure 51. A fraction of the incoming light is absorbed in an optical element (e.g. a lens). Transmission data as a function of wavelength is defined in the glass catalog of ZEMAX. The 3D map of absorbed flux per volume computed in ZEMAX is then used in OOFELIE for defining the Volume Heat Source.

After the thermo-mechanical analysis done in OOFELIE, updating a ZEMAX model is as usual possible.
Heating due to light

Automated thermal load definition in
OOFELIE by use of irradiance and absorption maps from Zemax®

Overview

- Aim: modeling of the heating due to light (sun light, laser, projector, ...) by accounting for the light source definition and material/coating properties

- A Non-Sequential (N-S) Zemax model can give grids (text files) of irradiance (flux per surface) and of absorbed flux per volume, which can then be retrieved in OOFELIE for the thermal load definition [ some simple commands have to be written in the epilogue (i.e. the OOFELIE Command Line Interpreter inside the OOFELIE User Interface) → see next slides ]

- Irradiance and bulk absorption maps can be combined on a same optical element (irradiance maps have to be used in case of light absorption in coatings)

- A set of time-varying grids obtained via several N-S analyses in Zemax can be used for a transient simulation in OOFELIE, with or without updating a Zemax model

- Optics Link license key required
Multiphysic & Simulation Settings

The Zemax Connection must be activated (available with the Optics Link license key)

The Zemax Link may be activated for updating a Zemax model

Which detectors have to be used in Zemax®

Irradiance map for defining a Surface Heat Flux in OOFELIE

- For planar surfaces (2D):
  - Detector Rectangle

- For planar or non-planar surfaces (3D):
  - Detector Surface
  - N-S objects which can be defined as detectors

Absorption map (i.e. a map of absorbed flux per volume) for defining a Volume Heat Source

- Detector Volume
Which classes have to be used in OOFELIE

Irradiance map for defining a Surface Heat Flux in OOFELIE

- **For planar surfaces (2D):**
  - `Zemax2DIrradianceMappedProperty` (old name still supported: `ZemaxMappedProperty`)

- **For planar or non-planar surfaces (3D):**
  - `Zemax3DIrradianceMappedProperty`

Absorption map (i.e. a map of absorbed flux per volume) for defining a Volume Heat Source

- `Zemax3DAbsorptionMappedProperty` (old name still supported: `Zemax3DMappedProperty`)

```
help("ClassName"); in the OOFELIE Command Line Interpreter will give you a complete list of available methods and the description of their arguments
```

Specifications for irradiance grid files

- Use **at least two pixels** in each direction
- Use the default length unit, i.e. **Lens Unit = Millimeter**
- Use **Watts/cm^2** (as defined by default in System → General → Units)
- Use **Incoherent Irradiance** as “Show Data” in the Detector Viewer settings:
Specificities of Zemax3DIrradianceMappedProperty

- A more complex and full 3D algorithm is used in Zemax3DIrradianceMappedProperty, which leads to **two additional (and optional) methods**:
  
  1. `objectName.scaleSearchRadius(radiusFactor)`; with:
     - `radiusFactor`: a positive real value for re-sizing the radius of the search sphere (for each node, grid points inside a sphere centered at the node are used to compute the irradiance value)
  
  2. `objectName.scaleWeightFunction(weightFactor)`; with:
     - `weightFactor`: a positive real value for re-sizing the weight function (less than 1 for giving less weight to distant grid points; more than 1 for giving more weight to distant grid points)

- **The smoothing in irradiance grids is not allowed with an "object as detector"**

- **A smoothing can be applied within the Detector Surface but only for visualization in Zemax:** the smoothing is actually not included in text file data used by OOFELIE (this Zemax issue could be corrected in the future)

Specifications for absorption grid files

- **Use at least two pixels** in each direction
- **Use the default length unit**, i.e. **Lens Unit = Millimeter**
- **Use Absorbed Flux/Volume** as "Show Data" in the Detector Viewer settings (the unit will be **Watts/mm^3**):

  ![Detector Viewer](image)

  - **Mind to select Z-Plane: Center** in order to get all Z planes in the file exported from Zemax
  - No smoothing is advised in Zemax versions previous to Zemax OpticStudio (2014): the smoothing will not be included in the file
Special care when using a Detector Volume

- Mind to define the Detector Volume before the optical element in the Non-Sequential Component Editor → the material of the optical element is so well defined
- If several optical elements, using one detector for each element is advised
- The local Z axis of the detector should preferentially be parallel to the optical axis

N.B.: The above last two points are related to the special treatment made at the front face and rear face (or front vertex and rear vertex) of the optical element, using only one Z plane of the grid in the interpolation process. That is also the reason why the Domain and a Connectivity Set are defined in the constructor of Zemax3DAbsorptionMappedProperty.

---

#SECTION_AFTER_MODEL#

// In this section, the object(s) of the class is (are) defined:

Zemax..IrradianceMappedProperty map("FilePath",absorptionRate);

with:

- **map**: Arbitrary name given to the object of the class Zemax..IrradianceMappedProperty
- **FilePath**: FileName.txt if the file is in the Working Directory, or else Directory\FileName.txt
- **absorptionRate**: absorption coefficient (ratio) of the irradiated material (non transparent medium, meaning that the light is absorbed close to the surface on which the Surface Heat Flux is defined)

// To activate the Free Frame Mode (see after), add 1 as a third argument:

Zemax..IrradianceMappedProperty map("FilePath",absorptionRate,1);
Definition of the overloaded Surface Heat Flux

The name begins with the symbol #

Keep default value and unit (they will not be taken into account)

Apply the Surface Heat Flux on the right face(s)

#SECTION_AFTER_MODEL#

//In this section of the epilogue, first create the object of Zemax..IrradianceMappedProperty
//Then overload the Surface Heat Flux:

Zemax..IrradianceMappedProperty map("FilePath",absorptionRate);

lightHeating_Quad4.put(SURFACE_HEAT_FLOW,map);

(Name without #)

⚠️ Quad4, Quad8, Tri3 or Tri6
(if combination of Quad and Tri, “duplicate” the command)

Creation of the object(s) of Zemax3DAbsorptionMappedProperty

#SECTION_AFTER_MODEL#

//In this section, the object(s) of the class is (are) defined:

Zemax3DAbsorptionMappedProperty map("FilePath",dom_##,ConnectivitySetName);

with:
map: Arbitrary name given to the object of the class Zemax3DAbsorptionMappedProperty
FilePath: FileName.txt if the file is in the Working Directory, or else Directory\FileName.txt
dom ##: To set the domain, ## is automatically replaced by the Problem Name in .e files
ConnectivitySetName: The name of the connectivity set associated with the optical element (placed on a solid)

//To activate the Free Frame Mode (see after), add 1 as a fourth argument:
Zemax3DAbsorptionMappedProperty map("FilePath",dom_##,ConnectivitySetName,1);
Definition of the overloaded Volume Heat Source

The name begins with the symbol #

Keep default value and unit (they will not be taken into account)

Apply the Volume Heat Source on the right solid(s)

#SECTION_AFTER_MODEL#

// In this section of the epilogue, first create the object of Zemax3DAbsorptionMappedProperty
// Then overload the Volume Heat Source:

Zemax3DAbsorptionMappedProperty
map("FilePath", dom_##, ConnectivitySetName);

lightHeating_Hexa8.put(VOLUME_HEAT_SOURCE, map);

( Name without #)

Hexa8, Hexa20, Tetra4, Tetra10, Penta6, Penta15, Pyra5 or Pyra13
(if combination of several element types, the command can be used several times)

Default Mode

- The grid has to be rightly localized with respect to the irradiated surface or solid

- In the Default Mode (Free Frame Mode not actived), the global frame in Zemax = OOFELIE’s frame and the detector location has to be defined in the global frame: Ref Object = 0 for the detector

- X Position, Y Position, Z Position, Tilt About X, Tilt About Y and Tilt About Z of the detector are retrieved by OOFELIE (these data are given in the “grid.txt” file used by OOFELIE)
Free Frame Mode

The grid location and orientation are set by the user (Positions and Tilts defined in the Non-Sequential Component Editor are not used), so no need for frame compatibility between OOFELIE and Zemax

```csharp
#SECTION_AFTER_MODEL#
//Creation of the object with Free Frame flag set to 1:
Zemax..IrradianceMappedProperty map("FilePath", absorptionRate, 1);
//Or:
Zemax3DAbsorptionMappedProperty map("FilePath", dom_#, ConnectivitySetName, 1);

//Then definition of the location and orientation of the grid:
map.setDetectorCenter(x, y, z);
with:
x, y, z: Coordinates of the detector center in the OOFELIE’s frame (in meter)

map.setDetectorXandYaxes(X1, X2, X3, Y1, Y2, Y3);
with:
X1, X2, X3: Direction cosines of the detector X axis in the OOFELIE’s frame (automatically normalized)
Y1, Y2, Y3: Direction cosines of the detector Y axis in the OOFELIE’s frame (automatically normalized)

//Example (detector tilted of 30° about the OOFELIE X axis):
map.setDetectorXandYaxes(1, 0, 0, 0, cos(30*3.1415926/180), sin(30*3.1415926/180));
```

⚠️ In the Free Frame Mode, it may be quite difficult to manage several tilts simultaneously!

Connectivity Set for visualization (irradiance)

Define (as shown below) a Predefined Connectivity Set for visualizing the irradiance distribution (optional)
Irradiance visualization

It is often interesting to check that the irradiance map is well retrieved in OOFELIE. To do so, the following commands are used:

```bash
#SECTION_AFTER_SOLVER#

map.fillIrradianceSet(dom_##,ConnectivitySetName);

with:
map: The name which was given to the object of the class Zemax::IrradianceMappedProperty
dom_##: To set the domain, ## is automatically replaced by the Problem Name in .e files
ConnectivitySetName: Name of the connectivity set

#SECTION_PARAM_EXPORT#

toSF_##.exportCode(TO|GF|I3);

Or, with recent OOFELIE versions:

toSF_##.exportRecord(IRRADIANCE_FROM_ZEMAX_DBE);

Incoming irradiance distribution (nodal interpolated values)

Nodal Heat Source visualization (irradiance)

```bash
#SECTION_PARAM_EXPORT#

```bash
toSF_##.exportCode(TO|GF);

Imposed power visualized at nodes (computed from interpolated irradiance values, accounting for the absorption rate)
Connectivity Set (absorbed flux/volume)

- Define (as shown below) a Predefined Connectivity Set
- This definition is mandatory since the Connectivity Set is used in the constructor of Zemax3DAbsorptionMappedProperty
- The Connectivity Set is also used by OOFELIE for visualizing the absorbed flux/volume distribution (optional)

Absorbed flux/volume visualization

To check that the absorption map is well retrieved in OOFELIE, use the following commands:

```
#SECTION_AFTER_SOLVER#

map.fillAbsorptionSet(); //No argument needed, except for multi load cases (see after)

with:
map: The name which was given to the object of the class Zemax3DAbsorptionMappedProperty

#SECTION_PARAM_EXPORT#

toSF##.exportCode(TO|GF|I4);

Or, with recent OOFELIE versions:

toSF##.exportRecord(
    ABSORBED_FLUX_FROM_ZEMAX_DBE);
```

Absorbed flux/volume distribution (nodal interpolated values)
Nodal Heat Source visualization (absorbed flux/volume)

As shown here, with irregular or quadratic meshes, the distributions can be very different when compared to the input from Zemax.

Summary

Zemax. IrradianceMappedProperty map("FilePath",absorptionRate,1);
//Or:
Zemax3DAbsorptionMappedProperty map("FilePath",dom_##,ConnectivitySetName,1);
map.setDetectorCenter(x,y,z);
map.setDetectorXandYaxes(X1,X2,X3,Y1,Y2,Y3);

lightHeatingElementType.put(SURFACE_HEAT_FLOW,map);
//Or:
lightHeatingElementType.put(VOLUME_HEAT_SOURCE,map);

Can be repeated several times if several maps (e.g. several optical elements)

Optional Free Frame Mode

#SECTION_PARAM_EXPORT#

toSF##.exportCode(TO|GF);

toSF##.exportCode(TO|GF|I3);
//Or:
openengineering

toSF##.exportCode(TO|GF|I4);

Imposed power visualized at nodes (computed from interpolated values of absorbed flux/volume)
Multi-maps definition in multi load cases

It is possible to create several load cases by use of a set of maps. To do so, simply repeat the commands below as much times as the number of load cases (here we omit the Free Frame Mode to simplify):

```plaintext
#SECTION_AFTER_MODEL#
Zemax..IrradianceMappedProperty mapi("FilePath",absorptionRate);
//Or:
Zemax3DAbsorptionMappedProperty mapi("FilePath",dom_##,ConnectivitySetName);

lightHeatingi_ElElementType.put(SURFACE_HEAT_FLOW,mapi);
//Or:
lightheatingi_ElElementType.put(VOLUME_HEAT_SOURCE,mapi);

#SECTION_AFTER_SOLVER#
mapi.fillIrradianceSet(dom_##,ConnectivitySetName,i);
//Or:
mapi.fillAbsorptionSet(i);
```

Overloaded Surface Heat Fluxes and/or Volume Heat Sources have to be defined according to the defined load cases.

Time varying maps in transient analyses

- It is possible to run transient simulations (with or without updating a Zemax model) while using irradiance and/or absorption maps as thermal loads placed on surface(s) and/or solid(s)

- **In case of transient analyses, it is possible to define time varying maps at times which can be directly related to step times or not**

- Two methods are proposed:
  - The maps are defined at given *times* (method 1)
  - The maps are defined at given *time intervals* (method 2)
**Time varying maps: method 1**

```csharp
//SECTION_AFTER_MODEL#
Zemax..IrradianceMappedProperty map(absorptionRate);
//Or:
Zemax3DAbsorptionMappedProperty map(dom_##,ConnectivitySetName);

//map is the parent object, sub-objects are then created:

map.setMapAndTime("FilePath1",Time1);
map.setMapAndTime("FilePath2",Time2);
...
map.setMapAndTime("FilePathN",TimeN);

with:
Time1 < Time2 < ... < TimeN  (in second)

//Then, as usual:
lightHeating_ElementType.put(SURFACE_HEAT_FLOW,map);
//Or:
lightHeating_ElementType.put(VOLUME_HEAT_SOURCE,map);

//No change in #SECTION_AFTER_SOLVER# and #SECTION_PARAM_EXPORT#
```

**Time varying maps: method 2**

```csharp
//SECTION_AFTER_MODEL#
Zemax..IrradianceMappedProperty map(absorptionRate);
//Or:
Zemax3DAbsorptionMappedProperty map(dom_##,ConnectivitySetName);

//map is the parent object, sub-objects are then created:

map.setMapAndTime("FilePath1",Time1_1,Time1_2);
map.setMapAndTime("FilePath2",Time2_1,Time2_2);
...
map.setMapAndTime("FilePathN",TimeN_1,TimeN_2);

with:
Time1_1 < Time1_2 < ... < Time2_1 < Time2_2 < ... < TimeN_1 < TimeN_2  (in second)

//Then, as usual:
lightHeating_ElementType.put(SURFACE_HEAT_FLOW,map);
//Or:
lightHeating_ElementType.put(VOLUME_HEAT_SOURCE,map);

//No change in #SECTION_AFTER_SOLVER# and #SECTION_PARAM_EXPORT#
```
Time varying maps with Free Frame Mode

```c
#SECTION_AFTER_MODEL#
Zemax..IrradianceMappedProperty map(absorptionRate,1);
//Or:
Zemax3DAbsorptionMappedProperty map(dom_##,ConnectivitySetName,1);

map.setDetectorCenter(x,y,z);
map.setDetectorXandYaxes(X1,X2,X3,Y1,Y2,Y3);

//When the parent object map has defined the location and orientation of the detector, sub-objects
//can be created (in Free Frame Mode, the same detector must be used for all time varying maps):

map.setMapAndTime("FilePath1",Time1_1,Time1_2);
map.setMapAndTime("FilePath2",Time2_1,Time2_2);
...  map.setMapAndTime("FilePathN",TimeN_1,TimeN_2);
```

Method 2 in this example

Difference between method 1 and method 2

- **Method 1 and method 2 cannot be used simultaneously in a same simulation**

- In method 1, a linear interpolation between two maps is made for each step whose time is between two map times (if a step time is equal to a map time, only this map is used for this step)

- In method 2, for which no overlap is allowed between time intervals, a step whose time is inside a map time interval (closed time interval) considers this map; while a step whose time corresponds to none of time intervals gets null irradiance or null absorbed flux

- **Method 2 is more flexible than method 1. For example, it is possible to define a periodic pulsed light source by using only one map and writing a “for loop” in the epilogue**