

Optomechanical design software for segmented mirrors

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ABSTRACT

The software package presented in this paper, still under development, was born to help analyzing the influence of the many parameters involved in the design of a large segmented mirror telescope. In summary, it is a set of tools which were added to a common framework as they were needed. Great emphasis has been made on the graphical presentation, as scientific visualization nowadays cannot be conceived without the use of a helpful 3d environment, showing the analyzed system as close to reality as possible. Use of third party software packages is limited to ANSYS, which should be available in the system only if the FEM results are needed. Among the various functionalities of the software, the next ones are worth mentioning here: automatic 3d model construction of a segmented mirror from a set of parameters, geometric ray tracing, automatic 3d model construction of a telescope structure around the defined mirrors from a set of parameters, segmented mirror human access assessment, analysis of integration tolerances, assessment of segments collision, structural deformation under gravity and thermal variation, mirror support system analysis including warping harness mechanisms, etc.

Keywords: software, segmented mirror, telescope, 3d, simulation, mirror support system

1. INTRODUCTION

The design of an optomechanical system, in particular a large telescope, involves the consideration of hundreds of interlinked parameters. These parameters cannot normally be considered together in the same software package, being usual the need of several tools like a CAD software, ANSYS, Zemax and Matlab. The software package presented hereafter allows performing some of the requested analysis within a single working environment, increasing speed and avoiding data transfer mistakes.

Interpretation of results is better accomplished when a proper graphical representation is available so this package puts great emphasis in the use of 3d or 2d objects whenever it makes more sense. The author has developed a custom 3d engine based on OpenGL to achieve a decent graphical output.

Main features of the software will be introduced in the next paragraphs.

2. USER INTERFACE

The user interface has the following sections:

- Main panels. These are splittable panels, they can be as many as needed and configured with the required information, e.i. the 3d model representation of the system, a 2d colorful optical surface, etc.
- System tree. All elements within the analyzed system are shown here hierarchically.
- Creation buttons. Quick addition of new elements.
- Element definition. All design parameters of the selected element are shown here, and available for change. As information can be large, foldable menus are available which can be opened or closed to access the required parameters without overpopulating the scroll panel.
- Menus and toolbars. Typically where all functions available are accessed.

User interface components are shown in figure 1.

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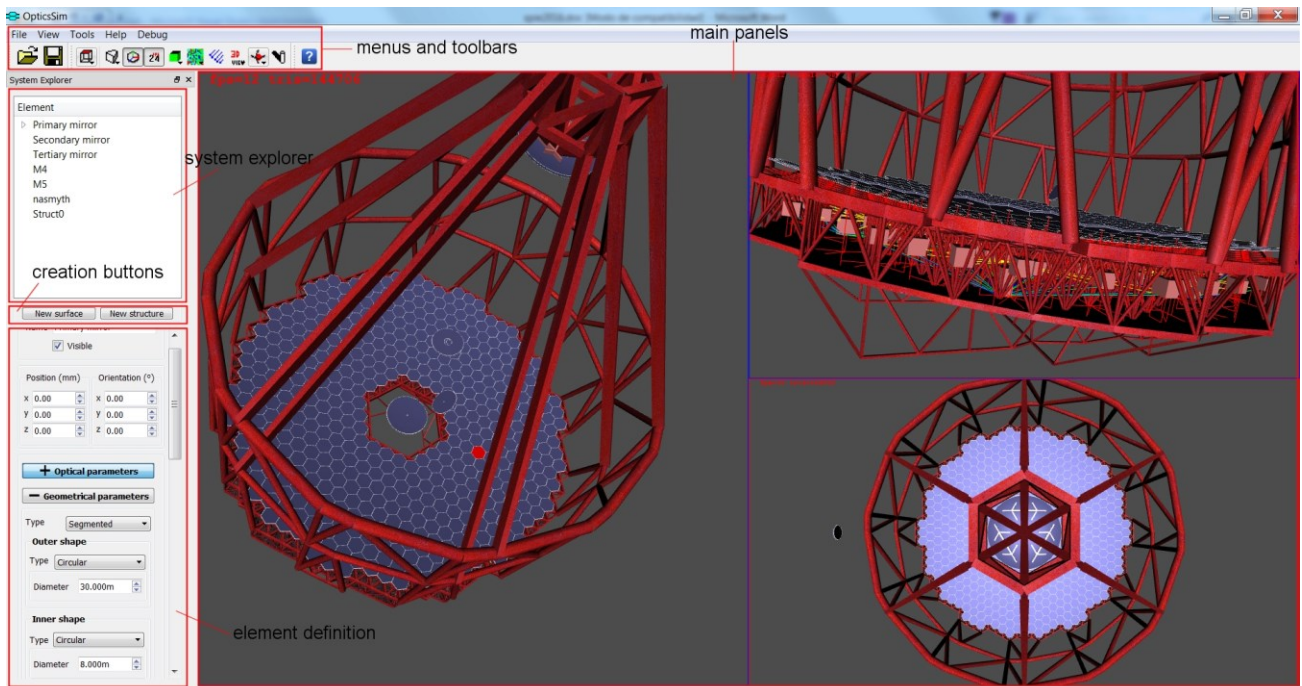


Figure 1. User interface

3. SIMPLE SYSTEM

The software is not limited to segmented mirror systems and can help on the analysis of many lenses systems. In figure 2, a 6 elements system is represented together with the ray tracing. Reflective and refractive elements are allowed, with optical properties defined for both sides of the element. The support system is also defined.

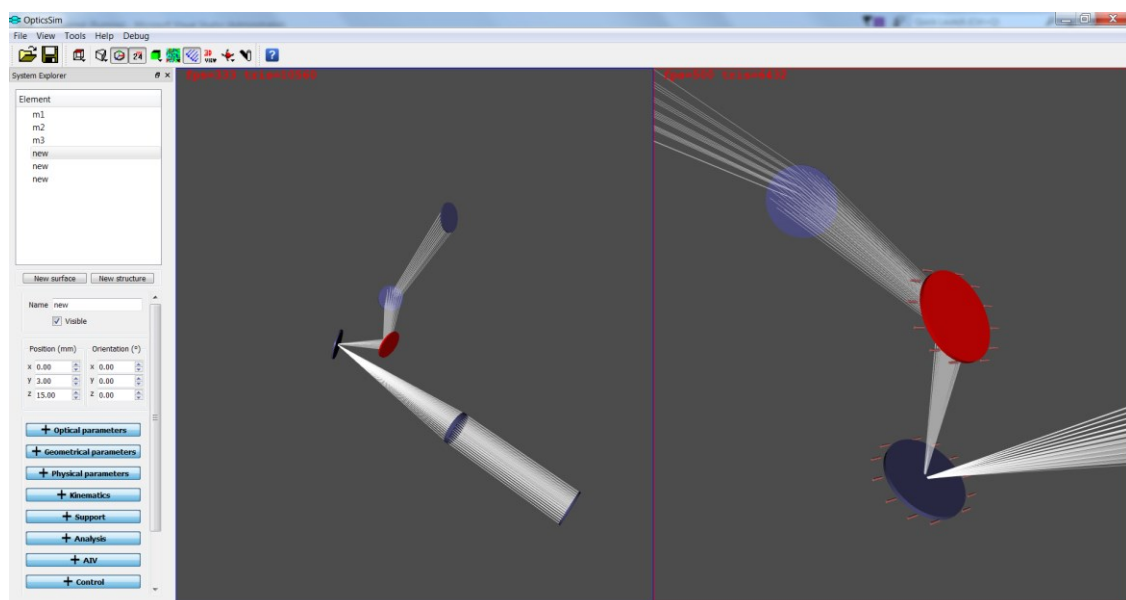


Figure 2. Optical system with raytracing

4. SEGMENTED MIRROR

Major functionality is oriented towards the analysis of a segmented mirror. At the moment every segment for a segmented mirror is defined as an irregular hexagon which area can be optimized for low dispersion among segments. Any mirror size with any set of parameters can be simulated within the boundaries of the system capabilities in terms of memory and processing power. Figure 3 shows some examples of segmented mirrors created by the software by inputting the adequate parameters in the element definition panel.

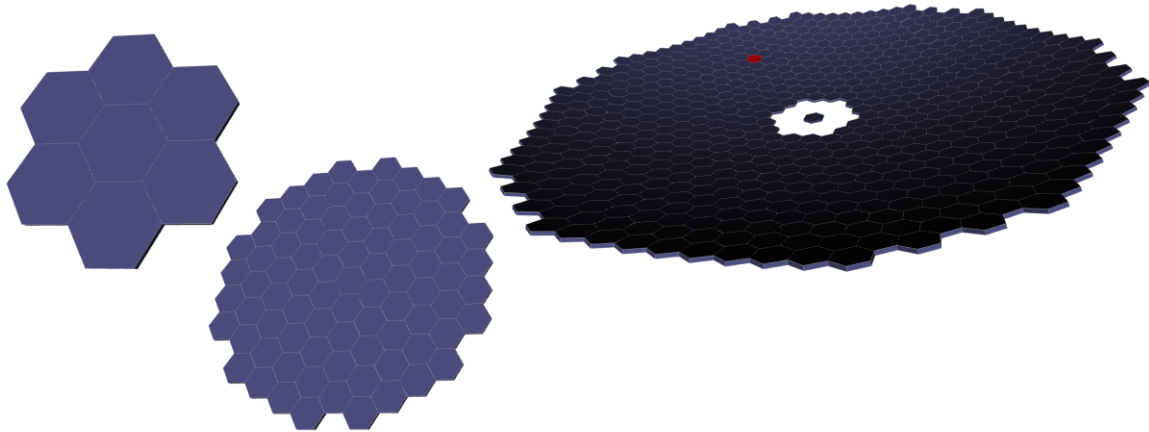


Figure 3. Several segmented mirror definitions

A segmented mirror is considered reflective, as the support system behind would hardly allow refractive optics. Each segment is assumed axially mounted on a multipoint support system based on whiffletrees^[1], which rests on 3 position actuators responsible for moving the segment on piston and tip/tilt. The lateral constraining is assumed to be carried out by a central membrane. The position actuators are mounted on an interfacing structure to reference the segment to the telescope.

The software can generate on demand a supporting structure for the mirror, together with the telescope tube. Tuning of every parameter for this structure is possible, helping to analyze accessibility, stiffness, etc. Two possible structures are shown in figure 4, which main distinctive feature is the cell floor. Figure on the left shows a cell floor following the curvature of the mirror while figure on the right shows a flat floor.

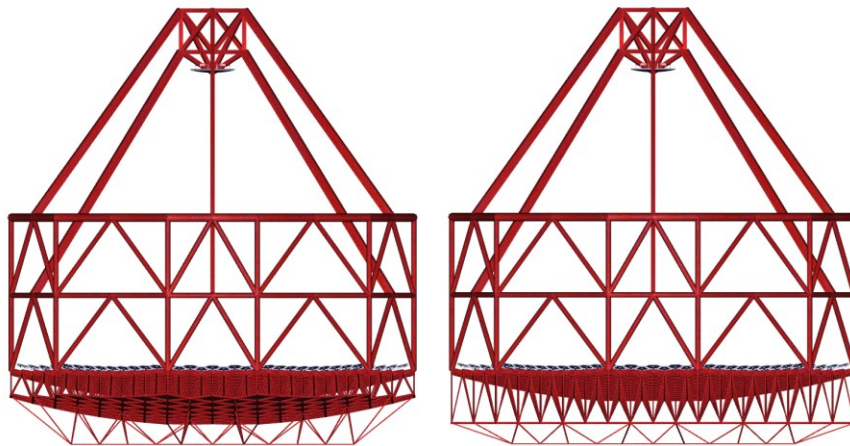


Figure 4. Telescope tube examples

Accessibility can be assessed making use of a 1st or 3rd person view mode on a mirror cell walkthrough. In figure 5, making use of the 3rd mode view, natural corridors are easily noticed, and enough height to allow comfortable movement under the segments is apparent.

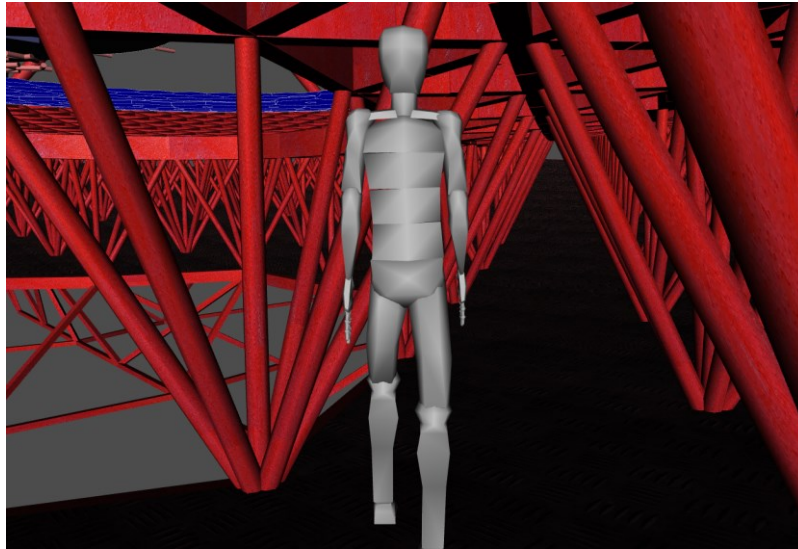


Figure 5. 3rd person view mode

Once the structure has been generated, deflections due to gravity and thermal change can be studied. This functionality is achieved by sending automatically generated scripts to ANSYS in the background and capturing the results once they are ready, without the need to halt the rest of the tasks. Deflection results are applied to each segment, showing all 6 degrees of freedom movement of each individual element. As an example, figure 6 shows x and y segments displacements due to the telescope tube elevation set to 78°.

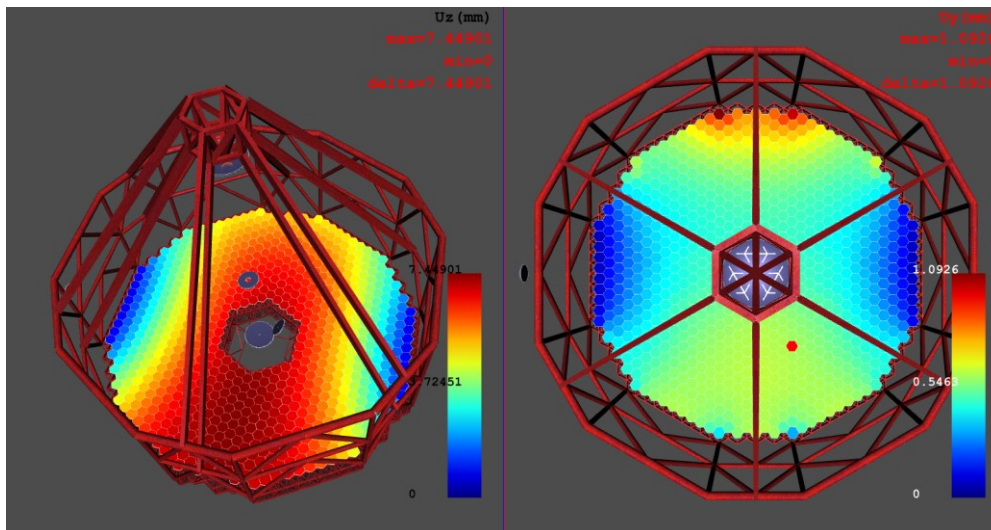


Figure 6. Segments x and y displacements due to gravity, elevation 78°

Another function worth mentioning is the analysis of the effect of tolerances on the final position of segments, away from nominal. A particular part of the element definition panel is dedicated to the input of expected tolerances. Characteristic tolerances are: Laser tracker errors, segment vertex to segment support interface, segment support to structure interface, edge sensors to segment, etc. Final position of segments can be visualized after tolerances are applied, as shown in figure 7.

As tolerances have a statistical nature, combination is made in 3 possible ways: normal zero centered distribution, uniform distribution and maximum values.

Position and number of laser tracker units can be changed to study the best alignment strategy.

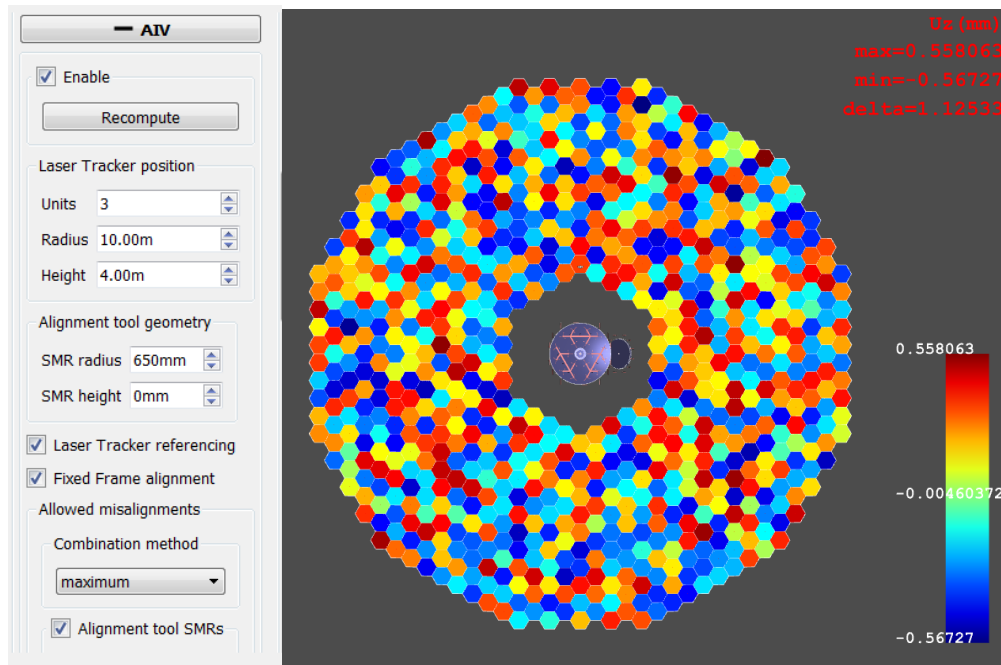


Figure 7. Segments departure from nominal position due to tolerances

A number of parameters can increase the probability of segment to segment collision, including gap value, tolerances, structure deformation, segments shape dimension tolerances, etc. The software allows for collision detection by checking border planes contact. It also checks for collision between neighboring edge sensors. Segments collision can be analyzed as a probabilistic event, letting the user select which contributors are to be considered.

Figure 8 shows the dialog box where the user can select the contributors to be considered for the collision analysis. As seen in the figure, for that particular example 761 segment to segment collisions occur. Main contributor happens to be the position actuator stroke, which can force a strong and unfavorable tip of neighboring segments. The study can be run multiple times, in order to capture the statistical nature of the event, obtaining in such a way the average, variance, etc.

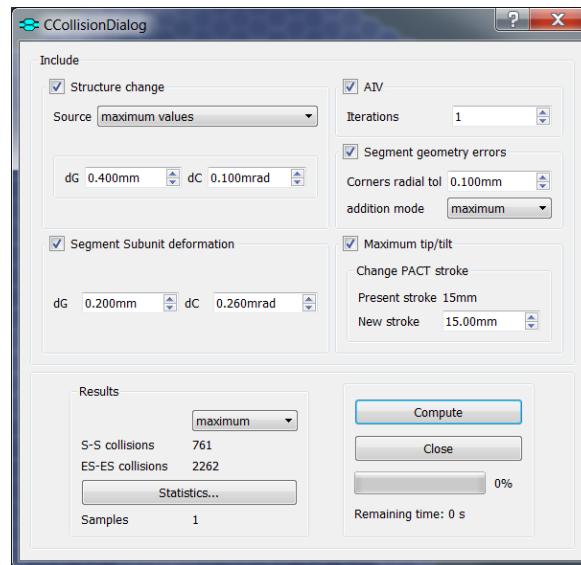


Figure 8. Collision analysis dialog box

The edge sensors are the sensing elements placed under the segment at each border which feeds the control system with the relative position of neighboring segments, in order for the system to react to misalignments and allow for proper corrective measures.

Another function available is the analysis of the maximum misalignment between paired sensors. Due to tolerances, structure deformation, etc., the neighboring sensors will undergo a departure from their nominal position and it is important to find out how much is to be expected, as the sensors need to be designed with the capacity to receive the signal up to that expected distance.

An example is shown in figure 9, where also the capacity to chart the values is demonstrated. Results, as usual, can be obtained as maximum, average and 3 sigma.

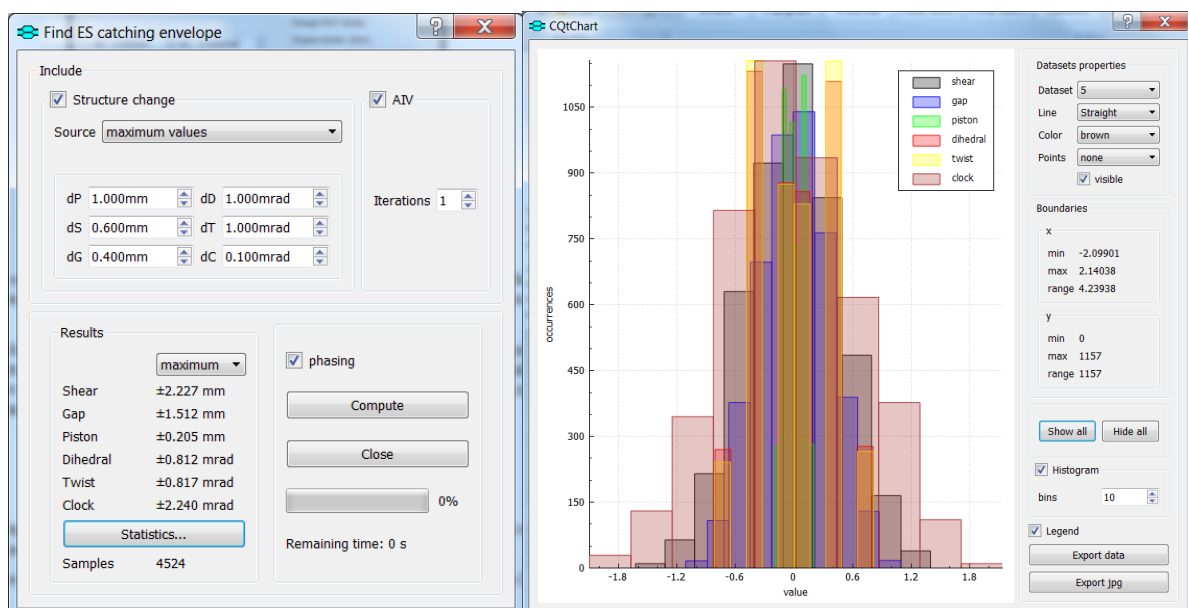


Figure 9. Edge Sensors catching range analysis dialog box

The optimization of the position actuator needed stroke is another functionality of the software. Given maximum structure deformation, radius of curvature uncertainty and several other parameters, the software will compute the maximum needed stroke to keep the mirror operative.

One last feature to mention is the possibility of automatically generate an approximate lay out for the necessary cabling and piping of the control system, with the positioning of the control cabinets according to certain rules. That is shown in figure 10. Once the cabling is generated, several results can be checked like length, mass, etc.

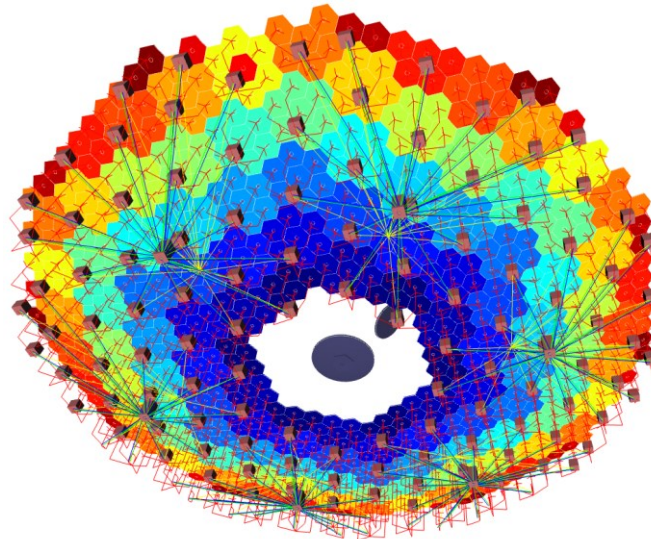


Figure 10. Cabling lay out

5. MIRROR SUPPORT SYSTEMS

The analysis of the surface error due to supporting conditions is an important feature of the software. It allows for easy selection of different support configurations and quickly assessment of the performance. Figure 11 shows 3 different configurations for an hexagonal segment, where not only the number of support points is selected but also the type and dimensions of the whiffletree elements. In figure 12, an 18 points axial support with load spreaders and border pads is shown.

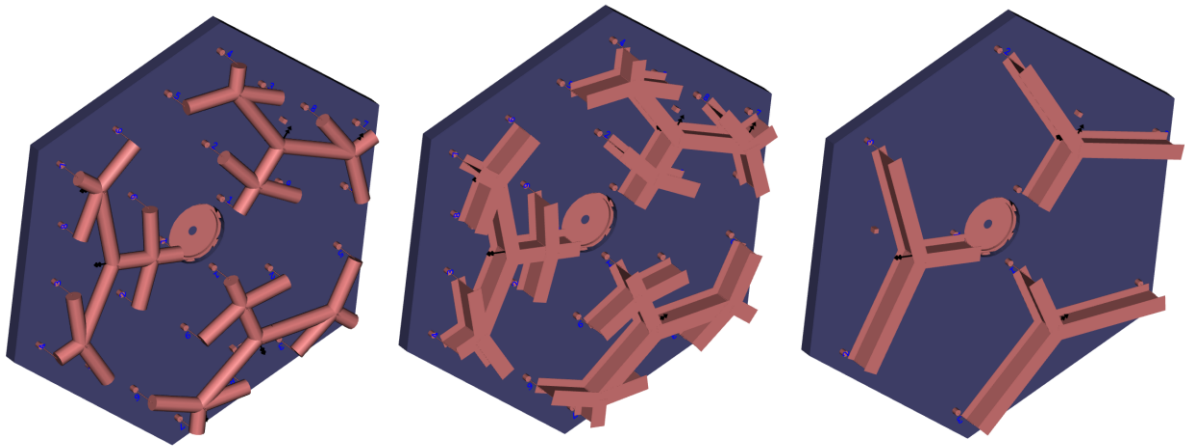


Figure 11. Segment support systems

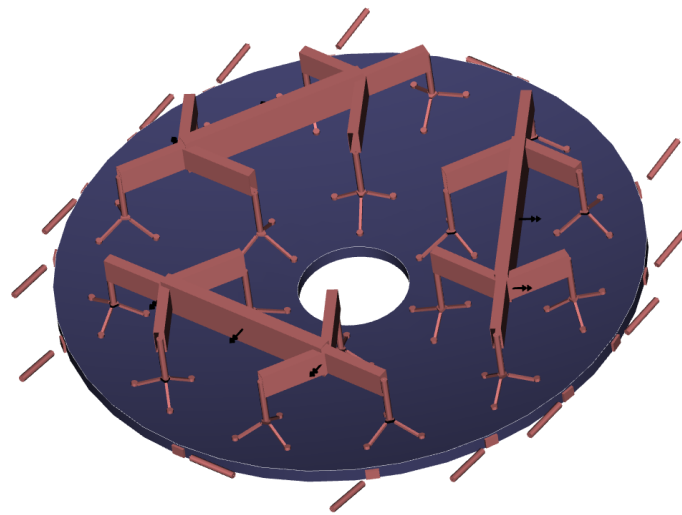


Figure 12. Load spreaders demonstration

Once the parameters have been selected, analysis of surface deformation can be performed through ANSYS, which will be called in the background and results will be retrieved when ready for postprocessing. Load cases to be analyzed are: gravity x, gravity y, gravity z and influence functions for the warping harness.

Several tools are available for the postprocessing, including Zernike decomposition, warping harness torques computation, etc. Figure 13 shows the wavefront of a 27 support points system after correction with warping harness torques.

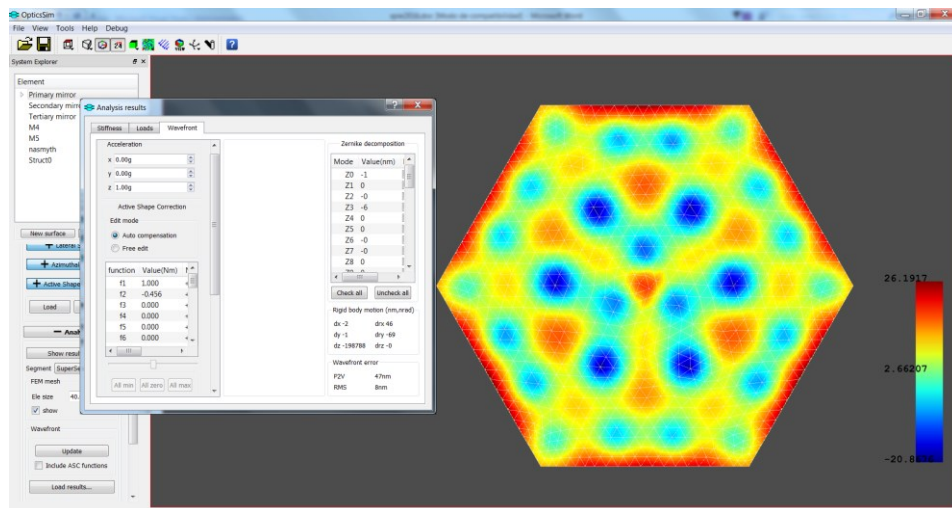


Figure 13. Wavefront analysis tools

6. INPUT/OUTPUT

The format of the main input/output file is simple ASCII text, with descriptions for each parameter, in order to allow the user to easily check the values with a normal text editor.

Exporting capabilities are also available, allowing for the 3d model of the optical objects or the structures to be loaded into Autodesk Inventor.

All sort of data produced by the software can also be exported into text files. For example figure 14 shows the dialog box to export a cloud of points from an optical surface.

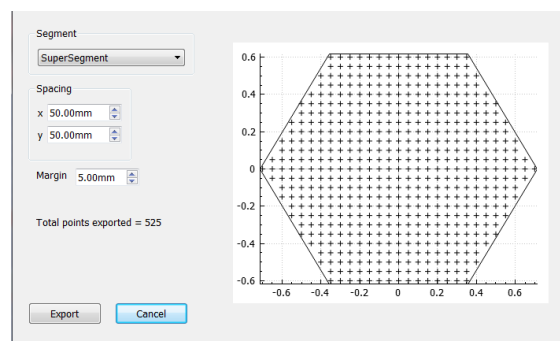


Figure 14. Surface points export dialog

For segmented mirrors, plenty of data is produced and all of that can be tabulated and charted as shown in figure 15 and figure 16.

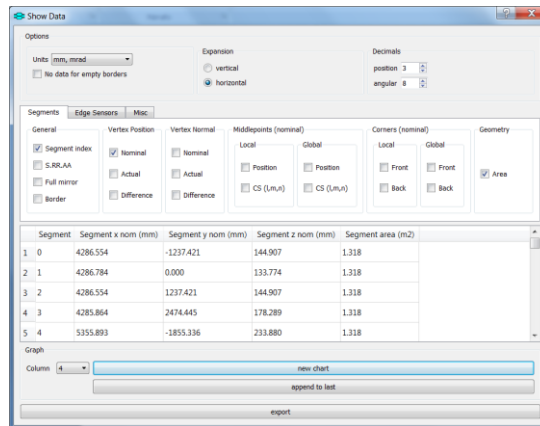


Figure 15. Dialog box for data shown in tabulated form

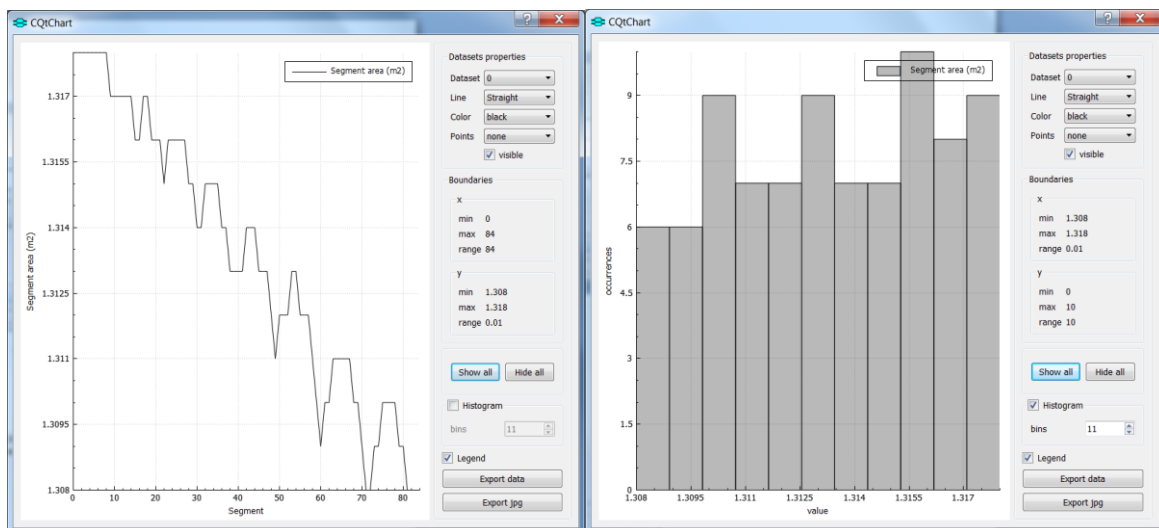


Figure 16. Dialog box for charted data, including histogram

7. FUTURE WORK

The software is expected at some point to acquire the following functionality:

- Optimization of support points positions and forces.
- Surface error budget automatic generation.
- Import Zemax definition files.
- Integrated FEM code.
- Simulation of a wide range of supporting conditions.
- Creation wizards to generate well known configurations.
- Any suggestion is welcome.

REFERENCES

- [1] Lluís Cavaller; Juan Marrero; Javier Castro; Esteban Morante; Mariano Ronquillo; Elvio Hernández., "Design of the primary mirror segment support system for the E-ELT" Proc. SPIE 7012, doi:10.1117/12.789784 (2008).