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# Easily Factoring Structural and Thermal Impacts Into High-power Laser System Design

Zemax

Companies that build high-power laser systems need a fast, reliable way to model and simulate all aspects of their optical components during design, including structural and thermal impacts on the products they create.

The OpticStudio STAR Module makes it simple to import structural and thermal data into OpticStudio workflows, yielding significant time savings and new possibilities for system analysis. This paper walks you through the five stages of a Zemax-enabled laser system design and virtual testing through FEA analysis, showing how our integrated tools, including the new OpticStudio STAR Module, help streamline this workflow by reducing the time, expertise, and risk of errors associated with incorporating STOP analysis into high-power laser system design.

# Introduction

High-power lasers are widely used in applications such as laser cutting, marking, welding, and drilling, as well as in specialty manufacturing markets such as medical devices. As with all optical systems, the engineers who design the optical and mechanical components for these laser applications must model, simulate, and virtually test all aspects of their design prior to manufacturing, so they can know how the final product will perform in real-world conditions. The validation activities enabled by this modeling yield the insights into complex impacts that engineers need for iteratively and continuously improving and optimizing their designs.

In the case of high-power laser systems, this modeling must include structural, thermal, and optical performance (STOP) analysis. This is because optical systems in high-power lasers are frequently degraded by heating from the laser itself, either due to bulk absorption of the lens materials or surface absorption via coatings. This impacts product performance in two ways: refractive index changes caused by the increased temperature in the lens materials, and structural deformation caused by mechanical stress. These impacts in turn can lead to changes in focal length stability, as well as laser beam quality and size.

The data needed for STOP analysis is typically gathered using finite element analysis (FEA) tools. With FEA results in hand, engineers can evaluate and revise their designs based on the predicted structural and thermal impacts. But this process can be time consuming and error prone if STOP modeling takes place manually outside of other tolerancing and design validation cycles, and if the optical and mechanical design teams lack a common platform for sharing the iterative changes.

# Welcome to the OpticStudio STAR Module

The OpticStudio Structural, Thermal, Analysis and Results (STAR) Module lets engineers easily and accurately integrate FEA results into OpticStudio using a simple, text-delimited output file from any FEA solver such as Ansys, NASTRAN, or Abaqus FEA. By seamlessly building this data into their other design validation activities, engineers can more comprehensively study the impact of thermal and structural deformation caused by laser heating.

Because the new module is native to the Zemax suite of tools, engineers can also readily collaborate on design changes across teams within a single shared file, saving the extra steps required for incorporating external validation cycles and any re-work caused by missed communications.

With OpticStudio, OpticsBuilder, and the OpticStudio STAR Module, design teams can understand physical impacts on optical performance by seamlessly integrating FEA data into their optical and optomechanical design workflow. For laser applications, this means companies can use Zemax software end-to-end to:

- Design and optimize optics for high-power laser systems.
- Easily share optical designs and analyze optomechanical packaging within their existing CAD platform.
- Analyze absorbed power in optics and mechanics.
- Integrate with FEA packages to perform detailed impact assessment of analysis of structural and thermal effects on optical performance.

## Let’s take a tour

This paper walks you through the Zemax-based design cycle for high-power lasers using a typical example—a material processing laser device for cutting or engraving—and briefly describes how Zemax helps to integrate and streamline this workflow at each stage.

As shown in Figure 1 on the next page, we’ll cover the following:

1. **Optical design** using OpticStudio
2. **Optomechanical design** using OpticStudio and OpticsBuilder
3. **Preparation for FEA** using OpticsBuilder
4. **Finite element analysis (FEA)** using your tool of choice (Ansys in this example)
5. **FEA data import** and STOP analysis using the OpticStudio STAR Module

Once designers have the STOP analysis insights they need from the OpticStudio STAR Module, they can return to stage 1 and reiterate the optical design—all without disrupting productivity or creating “process churn” within their own efforts or across teams.

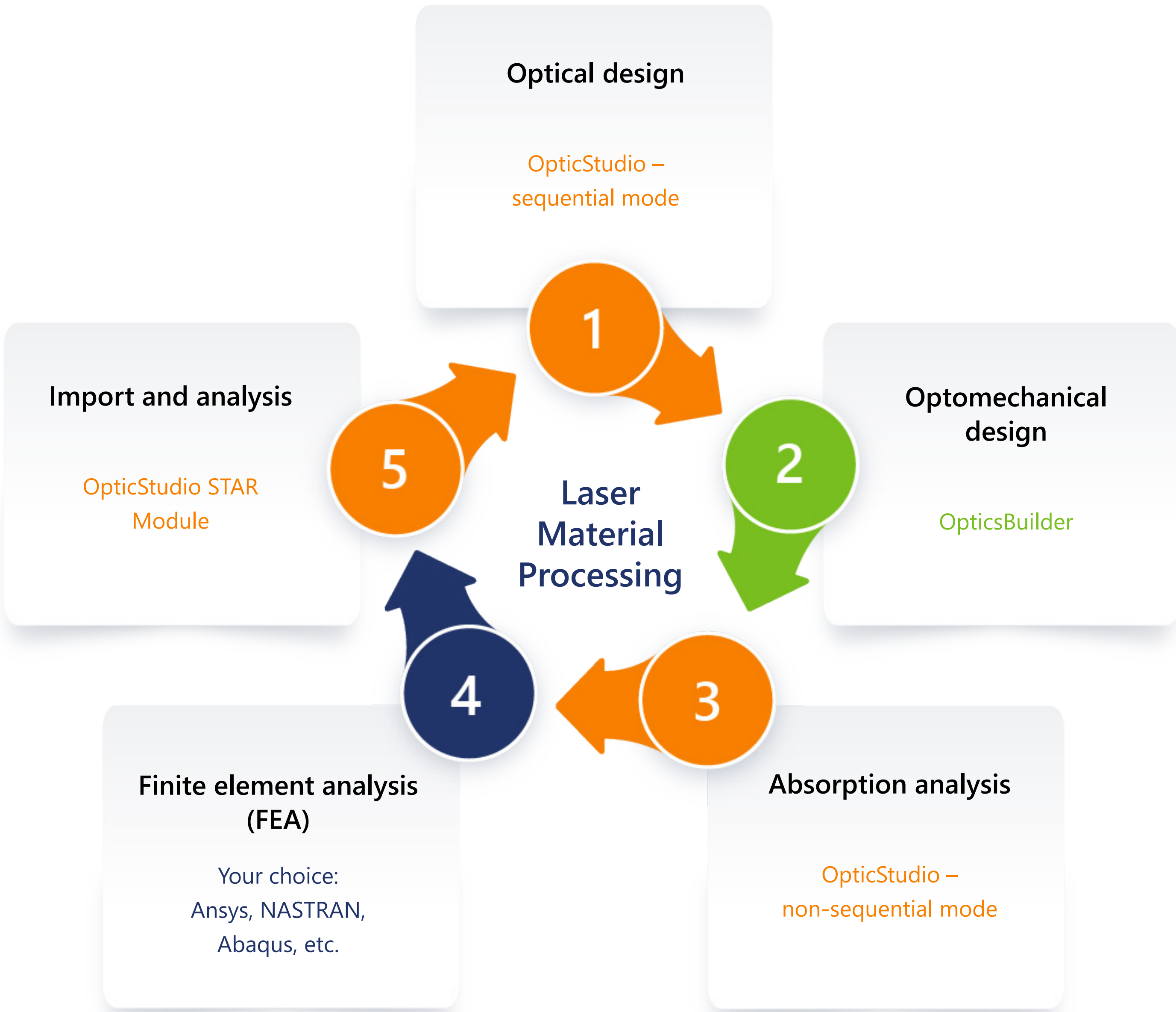


**Figure 1.** Integrated workflow for design, evaluation, and improvement of a high-power laser system.

# 1. Creating (or iterating) the optical design

In any high-power laser design, the optical system must deliver the laser beam to the workpiece in a highly controlled manner. OpticStudio has all the tools needed to design such a system for optimal performance. The following sections describe the system specifications we'll be considering for the example used in this paper, and how Zemax can play a role in optimizing design workflow at this stage.

## Optical system setup for this example

In our example, the laser has a power of 800W. The focusing lens is an adapted F-Theta lens, which ensures a consistently tight focus, and therefore high laser power.

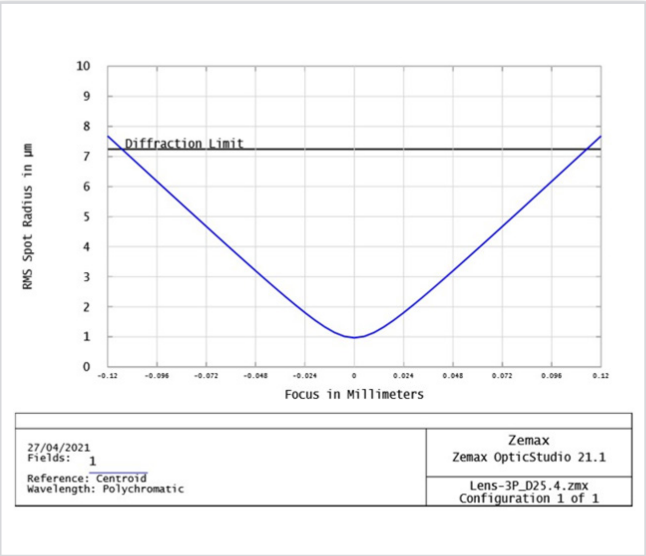


**Figure 2.** Laser system performance (spot size versus focus).

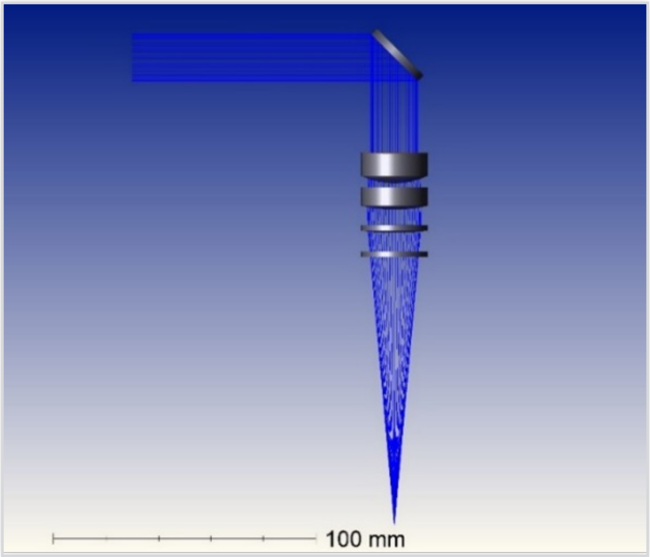


**Figure 3.** Laser system layout.

The lens has an effective focal length of 100 mm at a wavelength of 1064 nm, as shown in Figures 2 and 3. Performance is diffraction-limited and, without considering thermal or structural effects, remains so over a range of +/- 0.12mm, as shown by root mean square (RMS) spot size versus focus analysis.

## Modeling considerations for this example

Absorption from coatings, along with the presence of defects and dirt, are the most common causes of thermal effects in high-power laser applications. Assuming new, clean, defect-free lenses are used, we can apply a combination of Zemax tools to analyze the impact of absorption in both the coatings and substrates. We start this process in OpticStudio by applying anti-reflection coatings to all lens surfaces, applying high-reflectivity coating for the mirror, and using accurate transmission data for specifying the lens materials.

For complete modeling in this example, we also need some additional information, such as thermal conductivity of the optical and the mechanical components and details on how the lenses are mounted. We'll use sample information later in this paper to calculate thermal and structural effects in the FEA package for our example design.

# 2. Preparing the optomechanical parts

Once the optical design is complete, the next stage is creating a mechanical housing for the optics. This stage further alters the considerations for structural and thermal impacts on the design in two key ways. First, in addition to providing protection and arrangement of the optical system, the mounting design for the lenses and mirror introduces an additional source of mechanical load. Second, the mountings can also serve as a heat sink to dissipate heat from the optics.

Success in this stage relies on effective and efficient communication between optical and mechanical designers as they navigate the design changes required for mitigating these risk scenarios. The seamless interaction between OpticStudio and OpticsBuilder significantly streamlines this process by making it easy for all involved to share their work.

Using the Prepare for OpticsBuilder tool in OpticStudio, the optical team can convert the optical system and builds into a shareable format, which the optomechanical engineers can then open directly in their CAD tool with

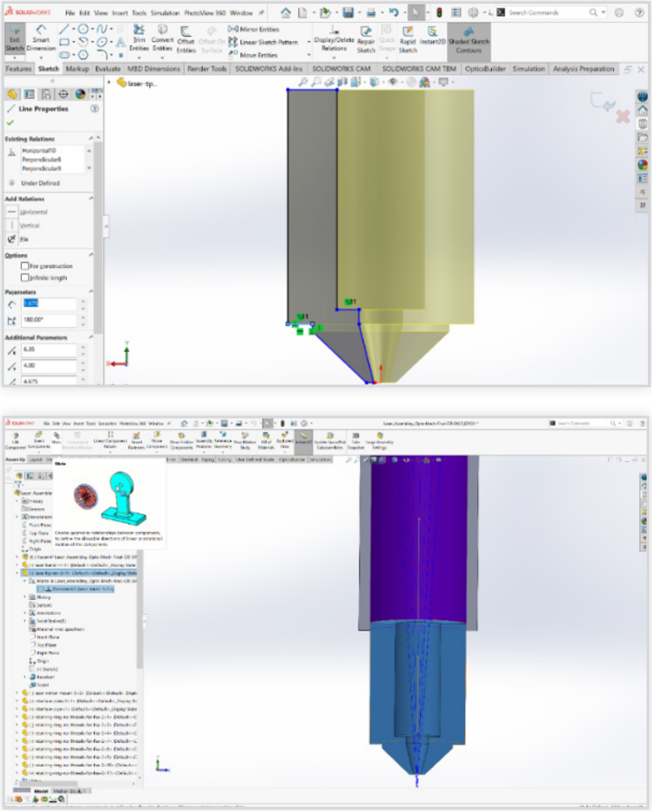

**Figure 4.** Creation of optomechanical components in SOLIDWORKS and analysis with OpticsBuilder.

OpticsBuilder. Optical components are automatically converted to native CAD parts with all the information needed to create the housings. All changes made by any optical or mechanical design team member are shared in a single file, greatly reducing the opportunity for miscommunication and wasted work cycles.

After creating the mechanical components using sketches and other tools such as Revolve and Extrude, as would be done for any other project, the engineer can mate the optics to the components, and the components to one another, to create the complete optomechanical system design. Figure 4 shows this process.

Using OpticsBuilder, the mechanical engineer can then assess whether the housing has impacted the optical performance in any way by running a ray trace within the CAD environment that includes interaction with both the optics and the optomechanical components.

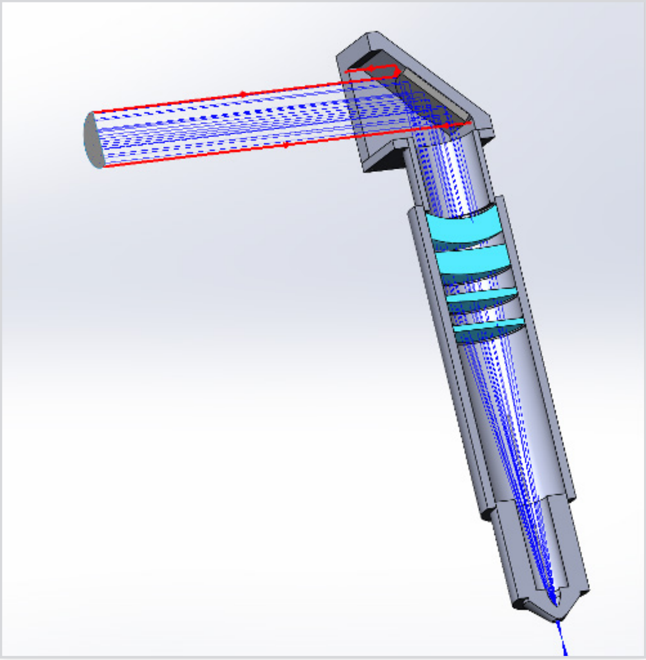

**Figure 5.** Ray trace in OpticsBuilder to evaluate impact of mechanical housing.

Rays can also be filtered by their path in the system and color-coded, as shown in Figure 5, making it easy to discern the blue rays passing through the system from the red rays that are being clipped, either by a CAD part or by an optical element. The mechanical engineer can then identify and resolve optomechanical issues without going back to the optical engineer for further analysis.

# 3. Preparing the design for FEA

Once the housing is complete, the entire design can easily be exported to OpticStudio in non-sequential mode to generate the input data for the FEA tool. This part of the process comprises three stages:

1. Modifying of the model to record absorbed flux.
2. Ray tracing the laser beam.
3. Exporting the data in a format easily accepted by the FEA tool of your choice, including:
    - Absorbed power on the detectors (from OpticStudio in non-sequential mode)
    - System geometry, as CAD parts (from OpticStudio non-sequential or OpticsBuilder)

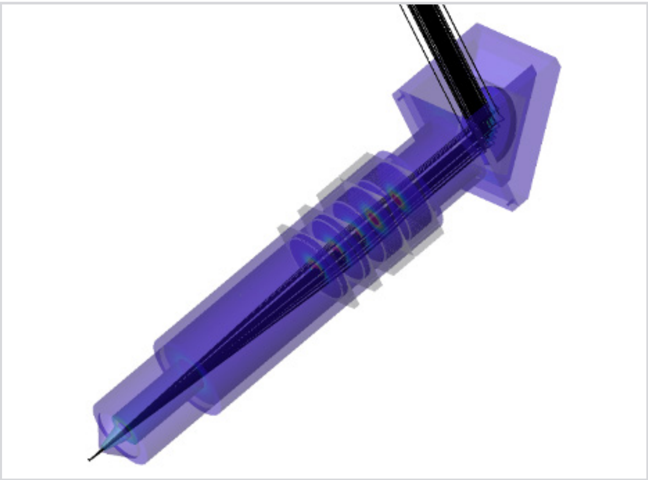

**Figure 6.** Computing laser power absorbed by the optical system.

OpticStudio can treat every object as a detector to compute the absorbed flux on every optical and mechanical surface in the system, as shown in Figure 6. Additional detectors can record the absorbed flux inside the volume of lenses. Following this, Gaussian beams are propagated through the system as ray bundles and their every interaction with the components is recorded.

To automate this stage using the Zemax application programming interface, ZOS-API, you can generate a script to retrieve the data stored on the detectors and configure the output to meet the input requirements of your FEA package.

The entire system geometry is then exported to the FEA tool as a collection of CAD parts.

# 4. Performing FEA

This stage can take place in any suitable FEA package. Your FEA tool imports the absorbed flux data from OpticStudio and the CAD model of the entire system, and uses these to perform a transient analysis of the thermal distribution and static structural analysis at each time step. For our example, we'll use Ansys as the FEA platform, applying the imported data points to compute a thermal distribution on a tetrahedral mesh created in Ansys from STEP files of the optical and mechanical components, as shown in Figure 7.

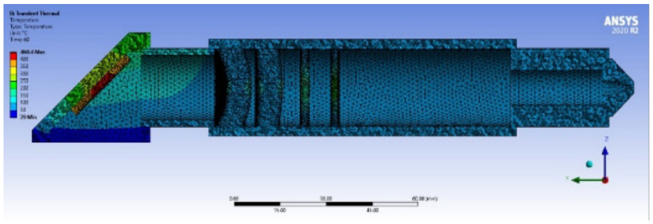


**Figure 7.** Temperature profile from thermal analysis in Ansys.

Once this analysis is completed, any FEA tool can simply output the analysis results as a series of simple, tab-delimited text files. These output files are now ready to be imported and analyzed by the OpticStudio STAR Module.

# 5. Analyzing for STOP impacts using the OpticStudio STAR Module

As Figure 8 shows, the OpticStudio STAR Module reads the FEA data directly into the original sequential optical model, where you can use a wide range of OpticStudio tools to visualize and verify the alignment of the data sets and the quality of the structural and thermal fitting. You can now observe structural effects that change the shapes of optical surfaces, and the complex temperature distributions that can cause non-uniform changes to the refractive index of components.

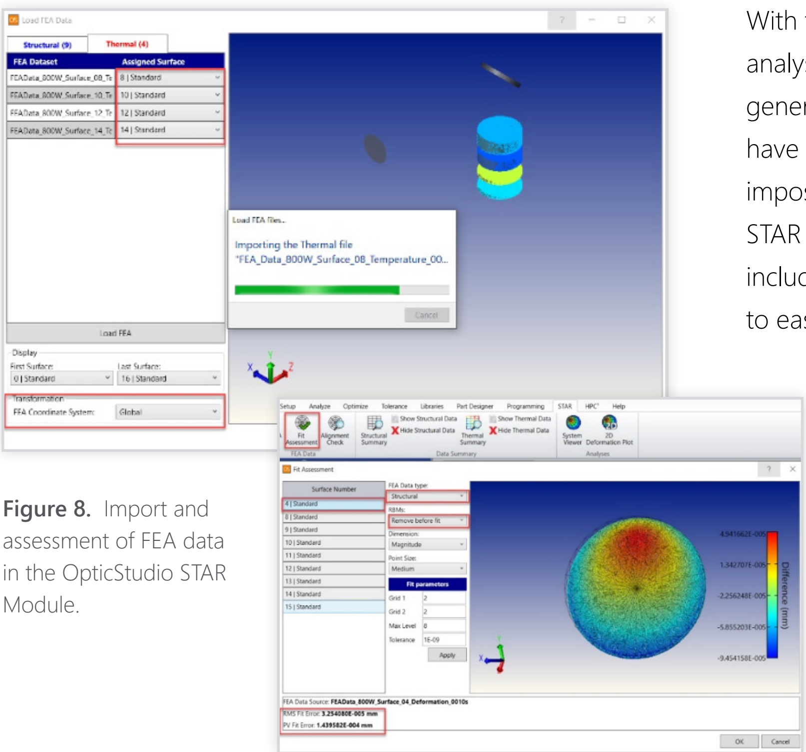

**Figure 8.** Import and assessment of FEA data in the OpticStudio STAR Module.

With the data loaded, the whole range of OpticStudio analyses are available to interrogate the system and generate insights into the behavior that would previously have been extremely time-consuming or even impossible. For example, Figure 9 shows the OpticStudio STAR Module enabling a wavefront map in OpticStudio, including the ability to turn the module's effects on or off to easily compare "before" and "after" performance.

To help companies achieve even greater efficiency, the OpticStudio STAR Module features its own API that communicates natively with the ZOS-API, which can be used to automate the import of FEA data. Using the STAR-API saves engineers time when designing complex systems and enables data analysis and comparison across multiple time steps to see how system performance evolves.

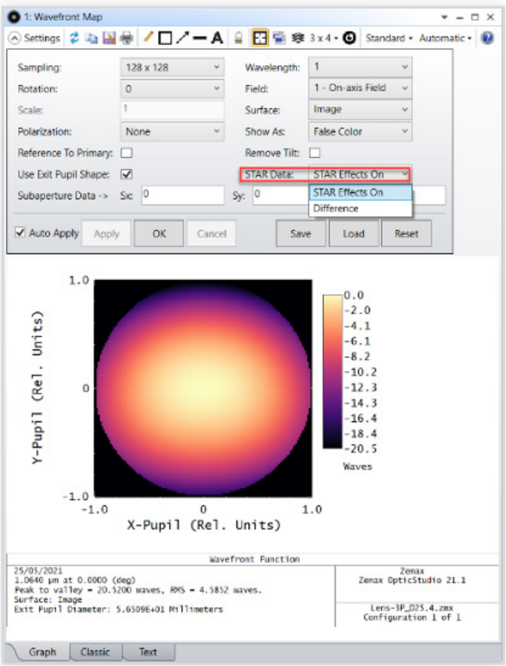


**Figure 9.** Wavefront map including impact of structural and thermal effects.

When analyzing the FEA data, it's especially powerful to see the ways thermal impacts happen over time, rather than simply as a snapshot. The OpticStudio STAR Module readily enables this level of analysis without adding further steps to your overall workflow. In our example system, after ten seconds of operation, we can see using the OpticStudio STAR Module that the thermally induced effects result in a significantly larger focused spot and reduced system efficiency, as shown in Figures 10 and 11.

Understanding thermal and structural impacts over time enables even more profound insights that can lead to greater design integrity much more quickly. For example, to mitigate the effects shown in Figures 10 and 11, an engineer might opt for a higher transmission optical coating, or modify the system housing to improve the cooling. The integrated workflow enabled by OpticStudio, OpticsBuilder, and the OpticStudio STAR Module makes it straightforward to evaluate these and other potential design enhancements, and iterate quickly to the optimum solution.

At the end of this stage, when the design teams have completed their analysis of the FEA data for STOP impacts, they can return to stage 1, updating their design and repeating the cycle for further validation. In this way, they have seamlessly woven STOP analysis into their workflows with minimal disruption by:

- Staying within the Zemax toolset for all stages except the FEA processing itself.
- Optimizing the FEA stage by easily exporting to and importing from any FEA package.
- Sharing all work across teams in a single file using OpticsBuilder to greatly reduce wasted cycles.
- Reducing the level of expertise needed to perform and accommodate STOP analysis in design.

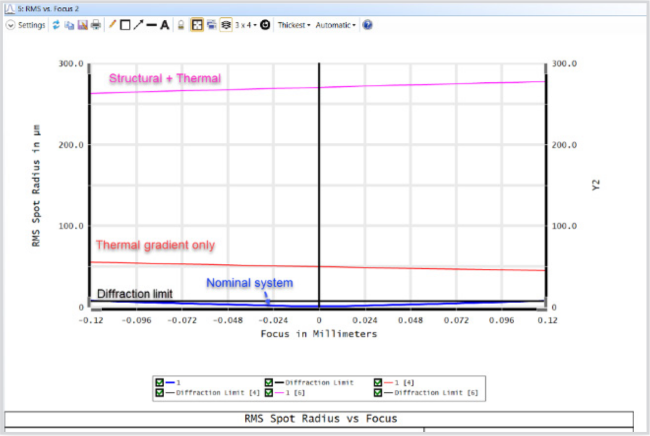


**Figure 10.** Comparison of focused beam size with and without structural and thermal effects (after 10 seconds of laser operation).

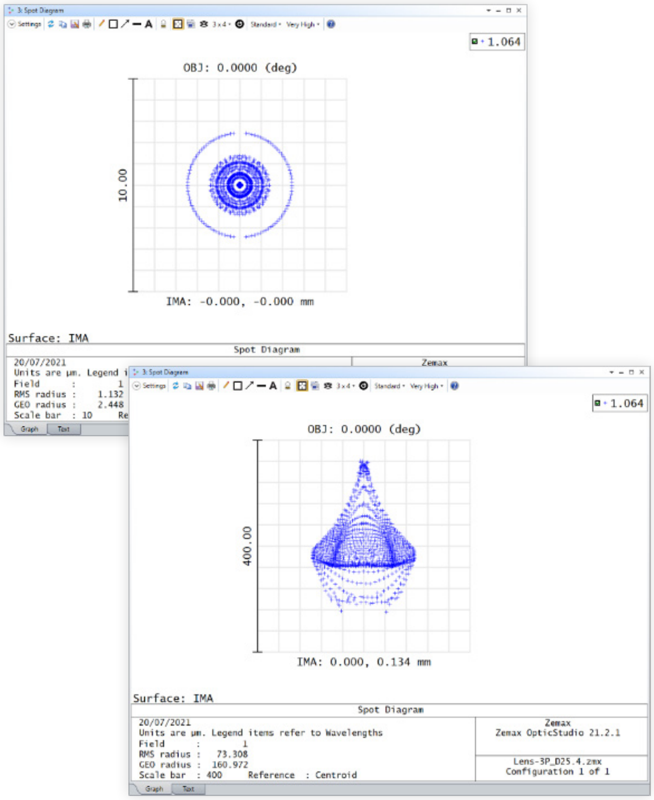


**Figure 11.** Focused laser beam size over time, accounting for structural and thermal effects. This first image shows the initial OpticStudio STAR Module readings, and the second image shows the same readings after 10 seconds have elapsed.

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# Conclusion

The OpticStudio STAR Module makes it simple to import structural and thermal data into OpticStudio, enabling significant time and cost savings, and new possibilities for system analysis. By performing optical system design validating on levels that were previously impractical or impossible for many companies, this module integrates Zemax even more closely into the optimized product development cycles they need to be competitive and successful. When combined, OpticStudio, the OpticStudio STAR module, and OpticsBuilder help engineering teams create a comprehensive workflow for designing, analyzing, and improving complete optical systems, including those for high-power laser applications and the unique structural and thermal considerations they present.

## About Zemax

Zemax's industry-leading optical product design and simulation software, OpticStudio®, OpticStudio® STAR Module, OpticsBuilder™, and OpticsViewer™, helps optical, mechanical, and manufacturing engineering teams turn their ideas into reality. Standardizing on Zemax software reduces design iterations and repeated prototypes, speeding time to market and reducing development costs. Zemax is headquartered in Kirkland, Washington, USA and has offices in the United Kingdom, Germany, Japan, Taiwan, and China. For more information: **www.zemax.com**.




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