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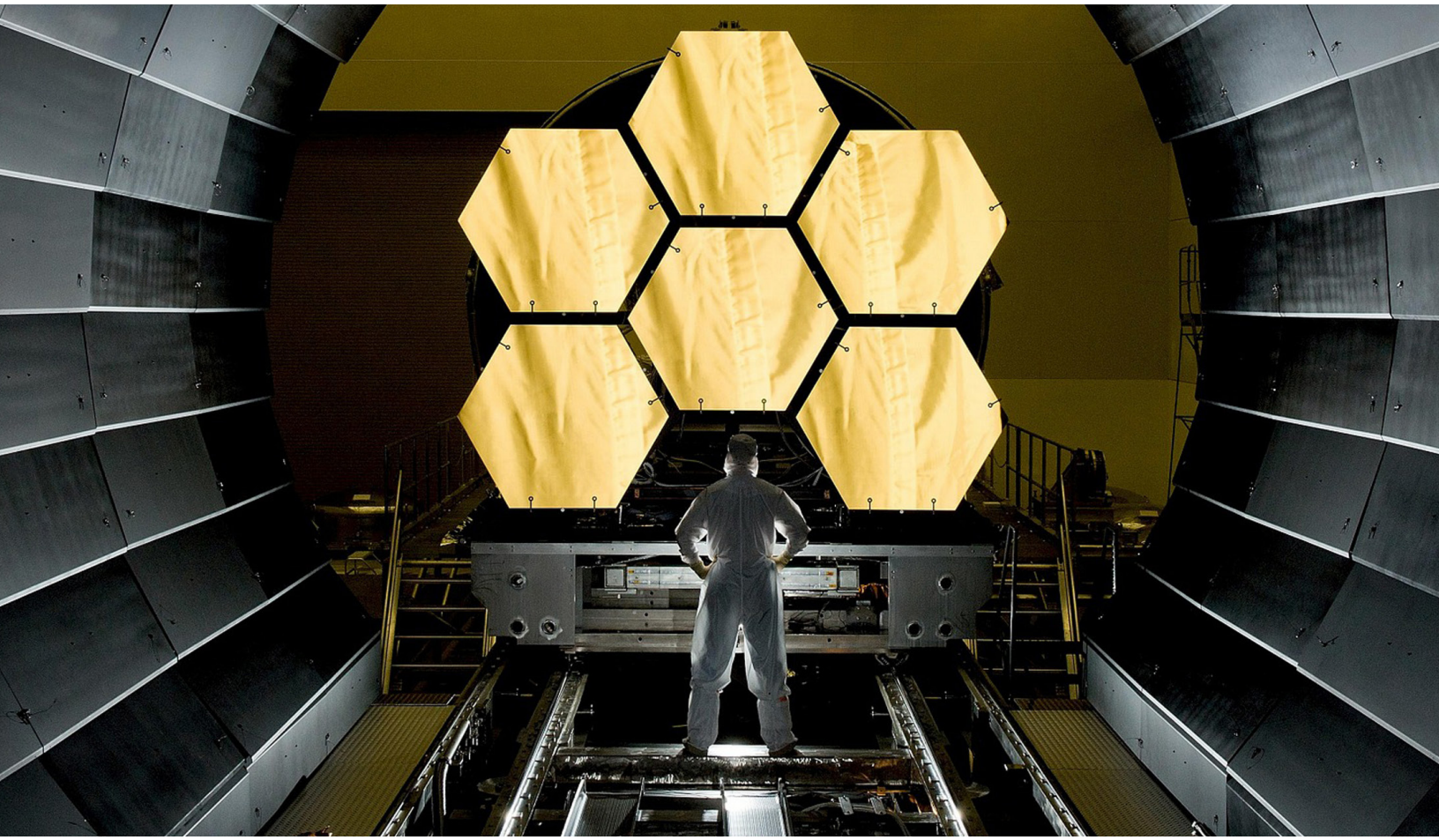
# Gain critical accuracy and speed in STOP analysis with the OpticStudio STAR Module



Zemax

# Introduction

Engineering teams that design and build optical components take great care to model, simulate, and virtually test all aspects of their designs prior to manufacturing. They do this to ensure each final product will perform in real-world conditions. To be successful, teams that build optical systems must constantly weigh accuracy and speed to get efficient results. Speed is obviously important for getting new systems into manufacturing on a timetable that serves the company's mission. But accuracy is also vital, particularly in cases where environmental factors are likely to have structural or thermal impacts on the optics, such as high-powered laser, aerospace systems, or other applications where the optics are exposed to a wide range of temperature or structural change. The engineers who build these systems must also accurately account for all structural and thermal conditions that might affect their optical design—in many cases, they only have one chance to get it right.

Structural, thermal, and optical performance (STOP) analysis can provide the data needed for effective system performance that withstands predictable structural and thermal conditions. Still, effective STOP analysis remains out of reach for many optical design teams. The trade-off is often accuracy for speed: top engineers can spend weeks or even months performing analysis on a single design. Also, the analysis generally takes place using systems that are isolated from the team's central optical design, CAD, and finite element analysis (FEA) workflows, introducing more delays and opportunities for error when incorporating STOP analysis into their optical design workflow.

Without a capability for both accuracy and speed, STOP analysis becomes a tricky workflow obstacle. In the past, some companies ultimately haven't even bothered—they'd take their chances in manufacturing and go to market without it. But as demand grows for miniaturized optical systems that deliver maximum performance, more companies are seeking ways of getting the most out of their designs. This market force is increasingly requiring design teams to follow through with STOP analysis, no matter how tedious and time-intensive it is to perform.

Zemax carefully studied these challenges and worked with customers to provide a solution: the OpticStudio Structural, Thermal, Analysis and Results (STAR) Module. The STAR Module extends OpticStudio capabilities to include STOP analysis inside the most widely used optical design platform. With an easy-to-use interface and OpticStudio integration, you can now reduce human errors and wasted time spent recreating designs and confusing data transfers.

### The OpticStudio STAR Module enables:

- Direct data import from any FEA package
- Robust analysis of structural and thermal loads on any optical system design
- Workflow automation using Zemax application programming interfaces (API)

This paper provides an overview of these capabilities, along with details on how the OpticStudio STAR Module helps optical engineers easily and accurately integrate STOP analysis into optical system design workflows.

# Simplifying and democratizing STOP analysis without sacrificing quality

In designing the STAR Module, Zemax did the complex work of making STOP analysis accessible to any optical design project by allowing the import of results into OpticStudio using a simple, tab-delimited text output file from any FEA package. By exporting data from your FEA package of choice, and then seamlessly building this data into other design validation activities, your design teams can more comprehensively study the impact of thermal and structural deformation on their optical component designs.

The OpticStudio STAR Module is fully native to OpticStudio, at both the user interface and application programming interface (API) levels. As a part of OpticStudio rather than a standalone tool, the STAR Module interacts seamlessly with all other OpticStudio sequential tools and analyses. To see the impacts of the FEA data on the systems they design, engineers can simply load the FEA data and immediately view the effects.

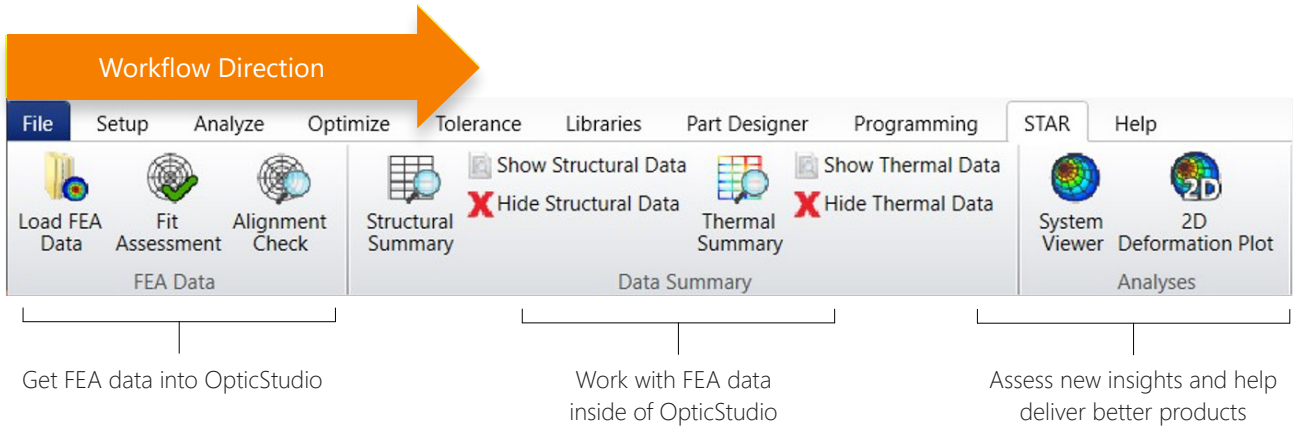



**Figure 1.** The OpticStudio STAR Module adds an intuitive STOP analysis workflow tab to your existing OpticStudio user interface.

In this way, the STAR Module also empowers optical engineers to readily collaborate on design changes across teams within a single shared optical design file, saving the extra steps required for incorporating external validation cycles and any re-work caused by missed communications.

# **Customer Example:** Exploring UV spectrums and searching for life on other planets

A team led by 2021 SPIE Fellow Dr. Daewook Kim, Associate Professor of Optical Sciences and Astronomy at University of Arizona, designs and analyzes optical systems like space high-contrast coronagraph systems such as CDEEP[1], and UV space telescope projects, both for research and for use on actual NASA missions such as Aspera[2]. Their current projects are focused on UV spectroscopy, exoplanet discovery and exploration.

Kim and his team have used OpticStudio for many years to produce complex optical designs using ray tracing. With the OpticStudio STAR Module, they can perform STOP analysis quickly and easily by importing FEA data directly into their existing OpticStudio implementation to make design revisions that account for structural and thermal complexity, such as the deformation of optical surfaces within a certain temperature gradient environment.

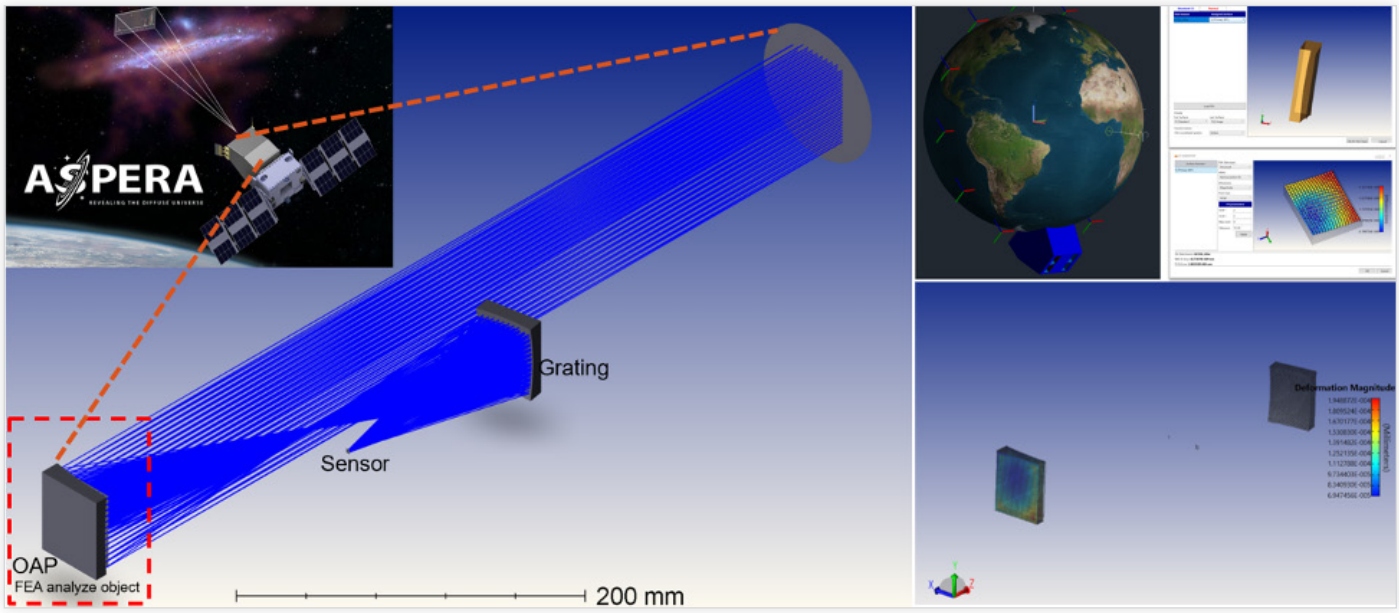



**Figure 2.** Exploratory STOP analysis work for NASA performed by 2021 SPIE Fellow Dr. Daewook Kim and his team using OpticStudio and the STAR Module.

1 Erin R. Maier, Ewan S. Douglas, Dae Wook Kim, Kate Su, Jaren N. Ashcraft, James B. Breckinridge, Heejoo Choi, Elodie Choquet, Thomas E. Connors, Olivier Durney, Kerry L. Gonzales, Charlotte E. Guthery, Christian A. Haughwout, James C. Heath, Justin Hyatt, Jennifer Lumbres, Jared R. Males, Elisabeth C. Matthews, Kian Milani, Oscar M. Montoya, Mamadou N'Diaye, Jamison Noenickx, Leonid Pogorelyuk, Garreth Ruane, Glenn Schneider, George A. Smith, Christopher C. Stark, "Design of the vacuum high contrast imaging testbed for CDEEP, the Coronagraphic Debris and Exoplanet Exploring Pioneer," Proc. SPIE 11443, Space Telescopes and Instrumentation 2020: Optical, Infrared, and Millimeter Wave, 114431Y (13 December 2020); https://doi.org/10.1117/12.2560878

2 Haeun Chung, Carlos J. Vargas, Erika Hamden, Tom McMahon, Kerry Gonzales, Aafaque R. Khan, Simran Agarwal, Hop Bailey, Peter Behroozi, Trenton Brendel, Heejoo Choi, Tom Connors, Lauren Corlies, Jason Corliss, Ralf-Jürgen Dettmar, David Dolana, Ewan S. Douglas, John Guzman, Dave Hamara, Walt Harris, Karl Harshman, Carl Hergenrother, Keri Hoadley, John Kidd, Daewook Kim, Jessica S. Li, Manny Montoya, Corwynn Sauve, David Schiminovich, Sanford Selznick, Oswald Siegmund, Michael Ward, Ellie M. Wolcott, Dennis Zaritsky, "Aspera: the UV SmallSat telescope to detect and map the warm-hot gas phase in nearby galaxy halos," Proc. SPIE 11819, UV/Optical/IR Space Telescopes and Instruments: Innovative Technologies and Concepts X, 1181903 (3 August 2021); https://doi.org/10.1117/12.2593001

"STOP analysis is essential to what we do here and using our homegrown systems to do in-house processing really took a lot of time—we just had to check and check and check," said Kim. "With the STAR Module, we have great confidence in the accuracy of the analysis we perform on the FEA data—the uncertainty is eliminated, and we can look at the various analyses right away in the OpticStudio interface."

The result of Kim's team using the STAR Module is speed and accuracy, together. Accuracy is achieved by forgoing the need to manually transfer output from one system as input into another, and the risk of human error that comes with it. Speed is achieved by reducing the hours and expertise required to perform those manual calculations.

On Zemax's focus on improving the optical design workflow with the OpticStudio STAR Module, Daewook had this to say: "The process is now streamlined; there's no uncertainty anymore, and all the features we need are provided within a single software package," said Kim. "It saves us several days on smaller projects, and whole months on larger ones. And with the graphical representations in the user interface, we can clearly confirm that the data we're using in the design is exactly as we saw it in our FEA software."

The STAR Module exemplifies Zemax's mission of producing technology focused on real-world applications—talking to customers and industry leaders like Dr. Kim and giving them solutions that directly address the biggest problems they face. By continuing to foster this kind of dialogue and prioritize actual, real-world requirements, Zemax maintains its leadership role in creating tools and capabilities for companies to succeed across all industries that depend on optics design and manufacturing.

"Now we get the data from the FEA software into OpticStudio and use the STAR module for STOP analysis. We can quickly and easily see the structural and thermal impacts and ensure our optical designs are accurate."

**Daewook Kim**
2021 SPIE Fellow and University of Arizona Assistant Professor of Optical Sciences and Astronomy

# How it works

As Zemax found in its research, many engineering teams avoid investing in new workflow optimization techniques because they fear losing the value of their investment in existing tools. Familiarity with a particular FEA solver, for example, can make a company and its workers hesitant to commit to any optical design workflow changes that would entail purchasing and retraining on a whole new tool.

Zemax carefully considered this obstacle when innovating the OpticStudio STAR Module, and decided the best way to ensure seamless STOP analysis integration with OpticStudio workflows was to make the STAR Module compatible with any FEA solver on the market. To integrate as universally as possible, the STAR Module accepts FEA analysis data in the form of a simple, tab-delimited text file—a format any FEA package is capable of exporting.

Very frequently, Zemax found that design teams were concerned with the change in performance stemming from either thermal or structural effects. The STAR Module provides users the flexibility to model thermal analysis and structural deformation separately, if you prefer, rather than together. This means you can perform an in-depth STOP analysis just as easily as you would a faster verification analysis. Alternatively, an engineer who creates their own text files or lacks FEA can supply the text file as an output from a scripting language like MATLAB.

**This section describes the concepts and capabilities that make the OpticStudio STAR Module effective and unique.**

- Universal FEA data import
- Visualizations for aligning FEA data with your OpticStudio design
- Fitting and analyzing FEA impacts for STOP analysis
- Ease of use with OpticStudio-integrated workflow
- Ease of automation using the STAR Module API

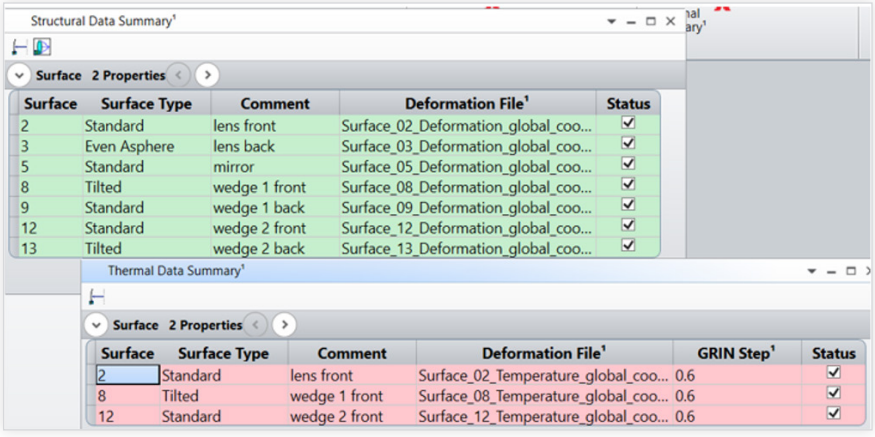



**Figure 3.** Example FEA data summary in the OpticStudio STAR Module UI, based on structural and thermal text files exported from any FEA solver and imported into OpticStudio.

# Align, visualize, and fit FEA impacts, including non-uniform data

As you import the FEA data into OpticStudio, you can align the coordinate systems and, with one click, match the FEA data to the correct optical surfaces in your design. As soon as that's done, the OpticStudio STAR Module will perform a numeric fit and apply the relevant changes to the optical surfaces.

With the design updates in place, the analyses will show the effects from the loaded FEA data and you can readily quantify the impact to your optical performance. In special cases where even lower fitting errors are required, you can fine-tune the FEA fitting as needed to reduce the residual error further. The STAR Module provides fitting controls and a graphic representation of the quality of fit over the entire optical surface.

Let's take a closer look at each of these three steps in detail.

## 1. Aligning the coordinates

The coordinate systems used during the FEA simulation can often differ from the one used in OpticStudio. Zemax research showed that the complicated mismatch of local and global coordinate systems, and the difficult calculations required for resolving the mismatch, presented a major obstacle for optical design teams seeking to account for FEA data effects in their OpticStudio design. The STAR Module enables automatic calculation of transformation matrices for mis-aligned FEA data—all with a single click within the OpticStudio user interface.

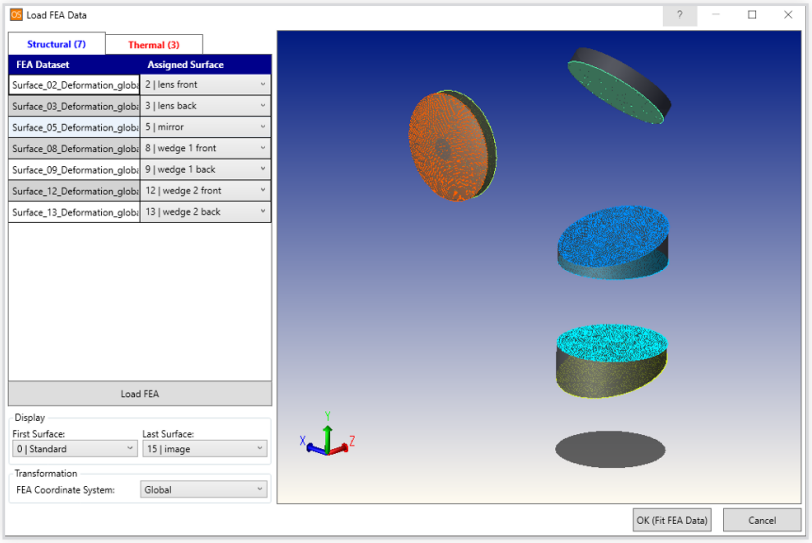



**Figure 4.** The Load FEA Data tool in the OpticStudio STAR Module lets you import data from an FEA solver via a tab-delimited text file and perform one-click mapping of coordinate systems and optical surface matching.

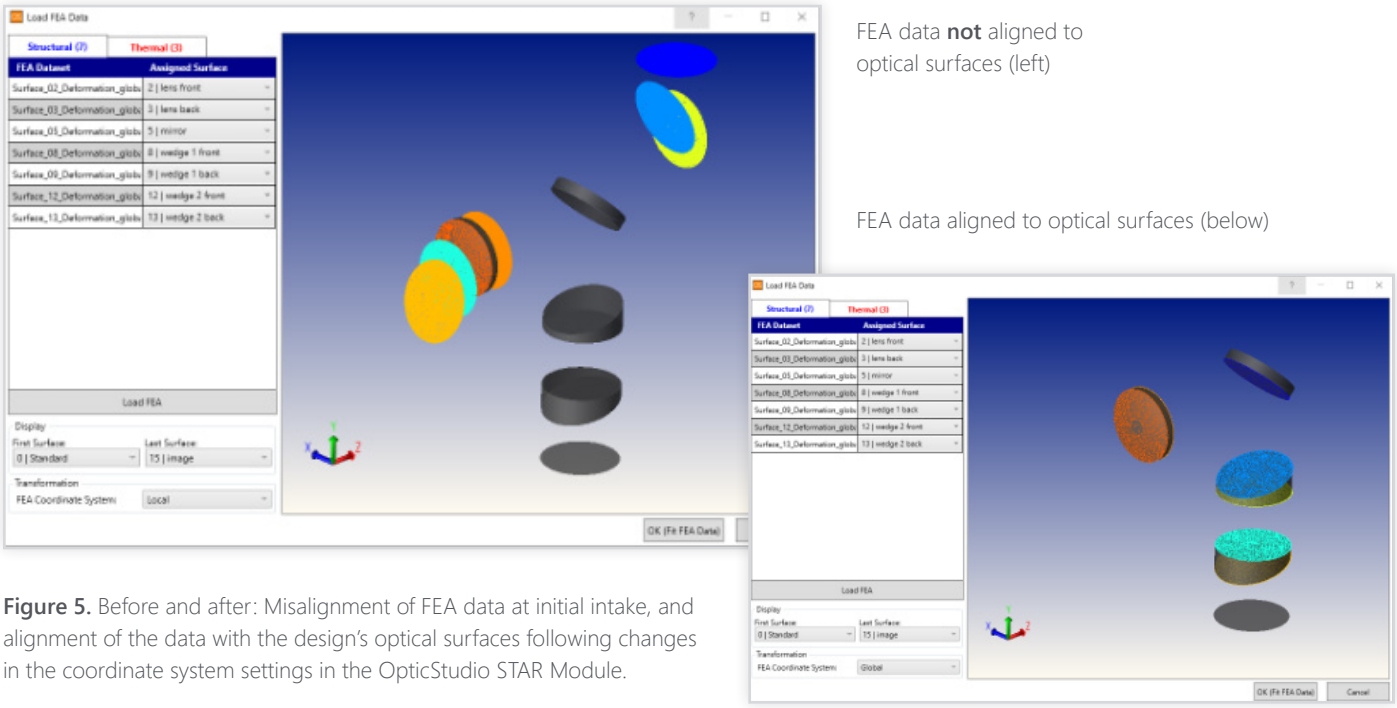



**Figure 5.** Before and after: Misalignment of FEA data at initial intake, and alignment of the data with the design's optical surfaces following changes in the coordinate system settings in the OpticStudio STAR Module.

By enabling the conversion between these coordinate systems with a single click, the OpticStudio STAR Module ensures the orientation of the FEA data is translated correctly between the FEA and optical design software packages. Using a graphical area within the Load FEA Data tool, included with the STAR Module, you can easily verify that the data you imported is aligned to the optical surfaces. In changing the coordinate system between local and global settings, the STAR Module will calculate the relevant transformation matrix automatically so that the subsequent numeric fit is represented by the graphical area. As shown in Figure 4, structural and thermal analysis results are displayed on separate tabs within the tool.

Figure 5 shows an example of how the STAR Module automatically calculates the transformation required for matching local and global coordinate systems and fixing alignment issues after you load the FEA data.

## 2. Loading the data and fitting it to the design

Once you have imported and aligned the FEA data, the next step enabled by the OpticStudio STAR Module is ensuring that the automatic numeric fit of the FEA data is good enough for your application. For high-precision applications, adjusting the fit is critical for getting accurate results: the better the fit quality, the better the quality of your STOP analysis.

To enable this, the OpticStudio STAR Module provides a visual representation of the quality of fit to help verify that the numeric fit is sufficient for your needs. By visualizing the fit and rendering it in the integrated Fit Assessment tool, the STAR Module provides a powerful and intuitive way for engineers to feel confident they are maximizing the quality of the FEA data for STOP analysis, now inside of OpticStudio, and incorporating the effects into their optical design.

The module performs complex fitting by applying powerful numeric 2-D and 3-D fitting algorithms across the non-uniform structural deformations and thermal profiles from your FEA analysis. The algorithm converts surface deformations into non-uniform grid sag data, and 3-D temperature profiles into non-uniform gradient index representations. This combination enables you to see the effect of structural deformations and thermal profiles, either separately or at the same time.

As shown in Figure 6, the STAR Module's Fit Assessment tool displays the difference between the original FEA data and the numeric fit of the FEA data; a perfect fit would yield a difference of zero. The relevant controls for the fit parameters are also available so that you can easily visualize the changes in the graphics area.

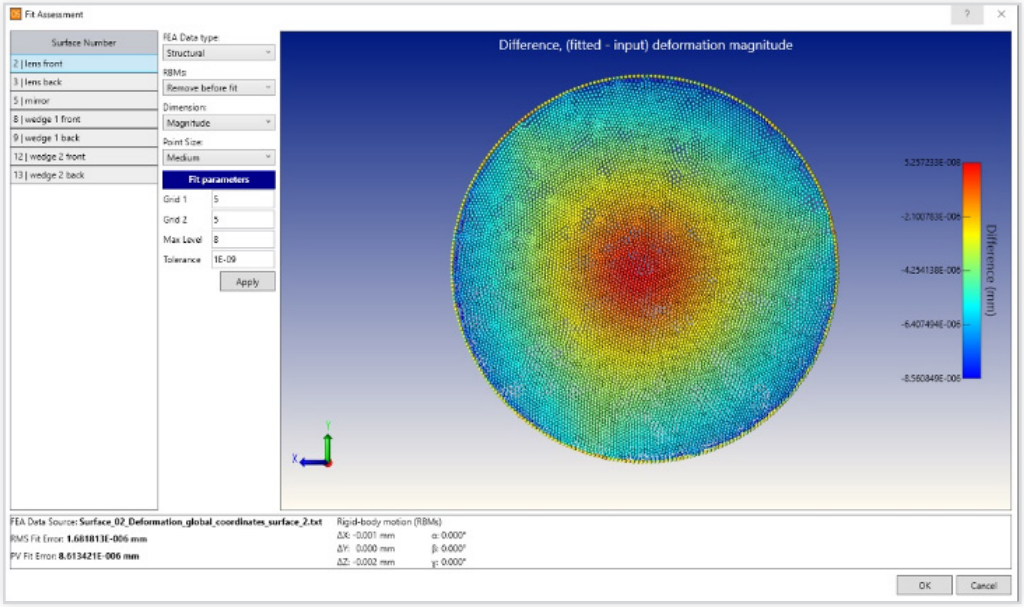



**Figure 6.** The Fit Assessment tool in the OpticStudio STAR Module helps you visualize and fine-tune errors in the fit between your FEA data and the optical surfaces in your design.

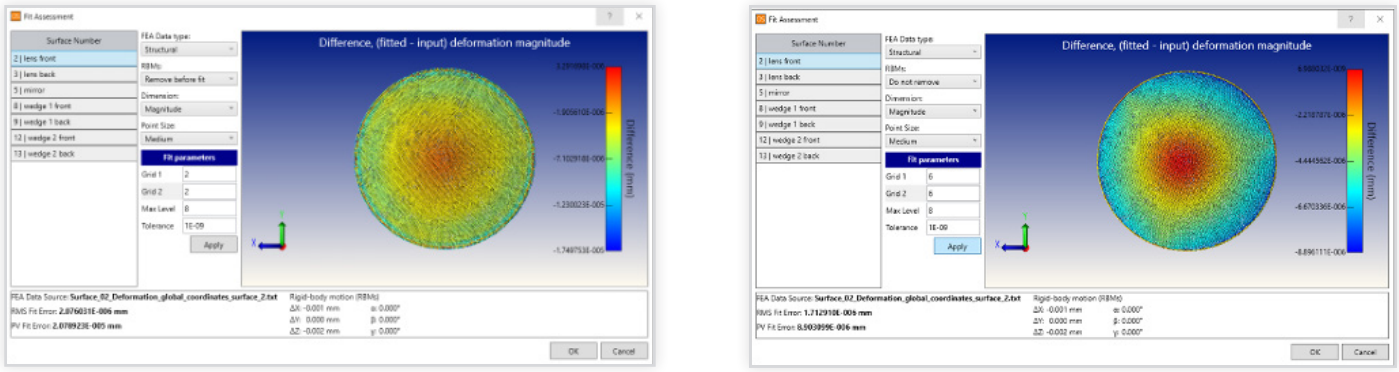



**Figure 7.** Fit quality of FEA data with the design, before and after using the STAR Module Fit Assessment tool.

For some parameters, such as rigid body motion, the STAR Module calculates and removes them automatically prior to performing the numeric fit. In cases where removing the rigid body motions can be detrimental to the fit quality, you can easily change the setting and refit to see the effects and ultimately reduce the overall error in the system.

By referring to the visualization, you can fine-tune your fit by adjusting the control parameters in the Fit Assessment tool, such as grid parameters or fit tolerances. Each time you do this and click Apply, the tool refreshes the visualization to show the revised fit. In this way, the STAR Module provides an easy way to "smooth out" any errors that occur during fitting FEA data until the final fit is within acceptable limits or residuals for your design.

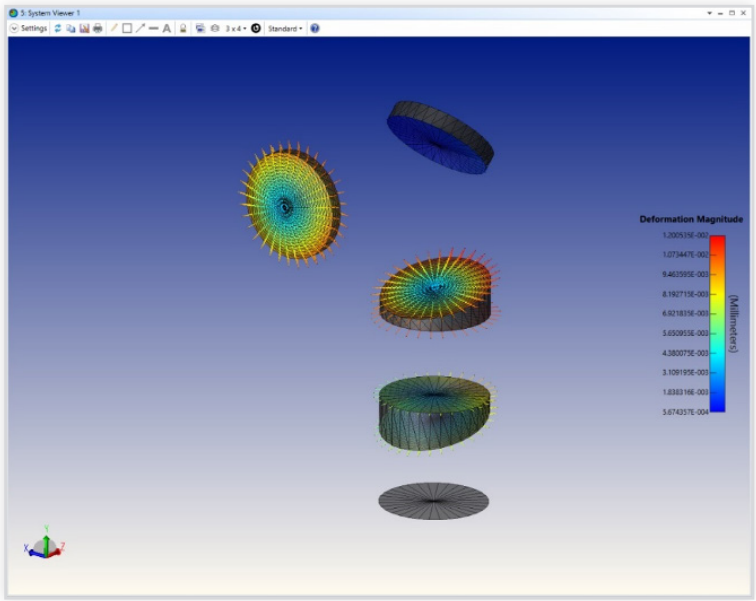



**Figure 8.** Example visualization in the OpticStudio STAR Module following FEA data import.

## 3. Visualizing FEA data impacts on your design

With the fitting process complete, you're ready to observe and draw insights from the STOP analysis. The OpticStudio STAR Module includes the System Viewer tool, which visualizes deformation magnitude and change in refractive index along with the optical design. This can quickly show hotspots where structural and thermal impacts are predicted to significantly effect changes to the optical performance. This tool displays these hotspots on a color-coded range of deformation magnitude, as shown in Figure 8.

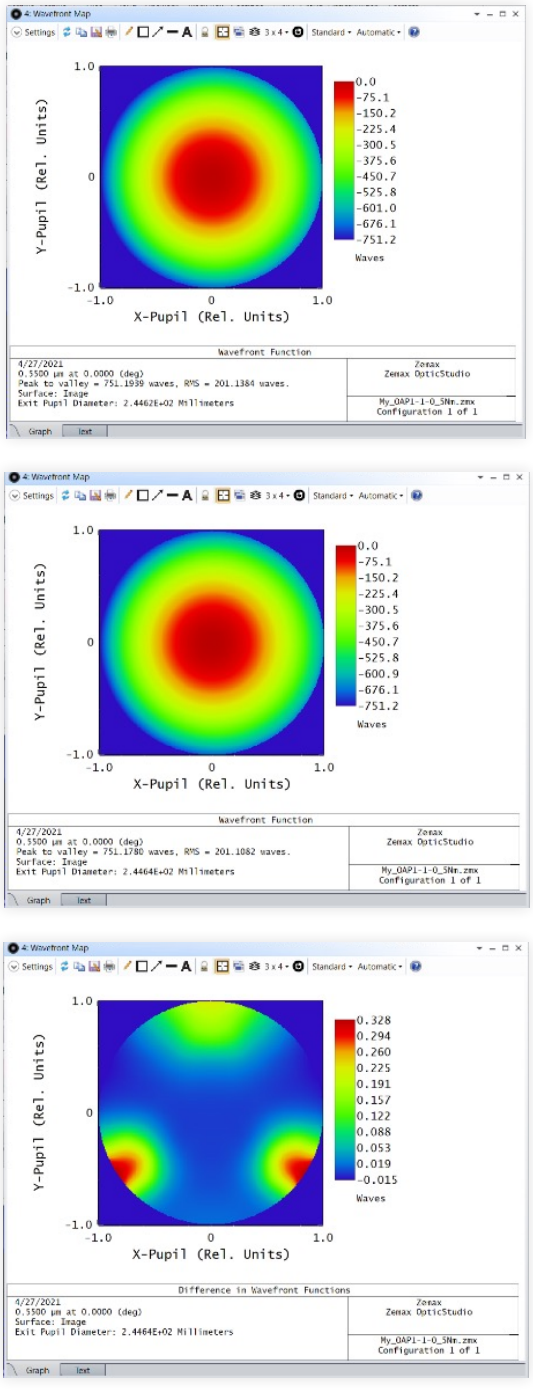



**Figure 9.** Top: The original wavefront error from the optical design. Middle: The wavefront error with the FEA data added; Zemax found that users couldn't easily see whether any changes were reflected, so a STAR Module option calculates the difference. Bottom: Post-calculation visual showing the impact to the wavefront error magnitude and shape.

Likewise, OpticStudio enhancements built into the STAR Module allow you to easily analyze the surface sag and wavefront map, before and after the FEA data is applied, providing insight into the changes imposed by the data set on these as well. An example wavefront error map is shown in Figure 9.

You now have clear, accurate visibility into the impacts of the FEA data on your optical system via STOP analysis inside of OpticStudio. You can also see how different directional vectors contribute to these changes, as well as viewing thermal data voxels and planes. The OpticStudio STAR Module generated the visualizations that enable these insights from a simple text file you exported from the FEA solver in your current design workflow, and you're ready to carry the insights forward to the next iteration of your design—all in just a few clicks, and all without ever leaving OpticStudio.

## Streamline your workflow: Ease of use, and ease of automation

Three key usability goals drove development of the OpticStudio STAR Module: Making STOP analysis accessible to optical engineers of all experience levels, integrating it into existing toolsets and workflows, and enabling automation.

To provide this level of usability, Zemax equipped the STAR Module with an intuitive user interface that exists as a new tab within OpticStudio, as well as a powerful API that can be scripted for use with automation. On the next page, we'll learn how optical design teams can benefit from using these two interface types.

## Working with existing tools

The OpticStudio STAR Module's universal capability to work with basic tab-delimited output from any FEA package lets companies integrate STOP analysis without committing to additional software or training investments. In the same way, because the STAR Module lives within OpticStudio, teams can leverage their existing familiarity with Zemax workflows to seamlessly integrate FEA loading and analysis into their existing workflows. This familiarity includes the ability to perform STOP analysis while working within the original OpticStudio design file created for the system.

## Simplifying and democratizing STOP analysis

Importing the FEA data with one click means engineers can streamline STOP analysis by performing it entirely inside of OpticStudio. The visual tools and analytics built into the OpticStudio STAR Module make it intuitive for any optical engineer to readily visualize and gain insights on a solution's structural and thermal impacts. Together, these factors make STOP analysis accessible to a wider range of engineers and reduce a team's dependency on unpredictably long external FEA analysis processes that create bottlenecks in producing timely system designs.

## Automating STOP analysis within larger workflows

The OpticStudio STAR Module includes an API called STAR-API that lets you automate tasks and workflow steps such as the stages of thermal lensing in high-powered laser applications. For an analysis of this type, you can easily automate the assignment of the FEA data at different time points and then pull the optical metrics of interest such as spot size, wavefront error, or optical path length and gain the insight of how those metrics change over time and temperature.

The STAR-API can talk natively to the OpticStudio ZOS-API, written in the same programming language, to streamline connections between OpticStudio and the other engineering simulation tools in a typical optical design environment, enabling workflow automation without a loss in fidelity.

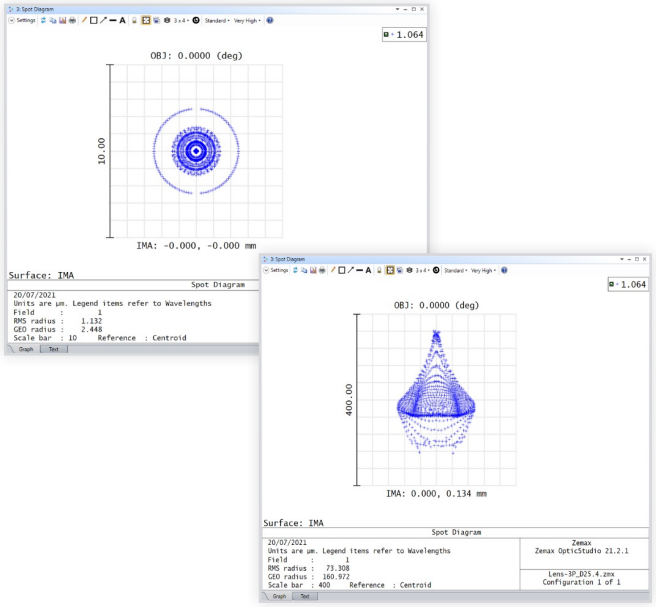



**Figure 10.** Example STAR Module display of a focused laser beam size over time, accounting for structural and thermal effects. This first image shows the initial STAR Module readings, and the second image shows the same readings after 10 seconds have elapsed.

# Conclusion

The OpticStudio STAR Module gives optical engineers many powerful and unique features that improve design workflows and product performance in ways that might previously have been out of reach. By gaining critical speed and accuracy in the ways you analyze thermal and optical performance, your team can make better design and manufacturing decisions, faster and with greater confidence. Consider the benefits that the Zemax platform delivers when extended to include the OpticStudio STAR Module:

## Powerful STOP analysis

Gain timely, next-level insights into your optical system designs by applying best-in-class numeric fitting algorithms to analyze the impact of structural and thermal loads on system performance.

## Automation-ready

Gain even greater efficiency by automating STOP-related tasks in your workflow using the STAR Module (STAR-API) and OpticStudio (ZOS-API) application programming interfaces.

## Ease of use

Integrate STOP analysis as part of your existing workflow, utilizing your existing FEA systems investment by accepting data from any FEA package, and easily gain insights into STOP impacts using intuitive visual analytics built into the OpticStudio UI.

## Data democratization

Reduce your dependence on experts' valuable time to check and re-check STOP analysis calculations, and empower all engineers to easily and accurately validate STOP analysis data between your FEA and Zemax solutions.

Get the speed and accuracy you need when designing challenging optical systems where structural and thermal influences play a key role in performance. By extending OpticStudio capabilities with the OpticStudio STAR Module, any optical design team can reduce STOP analysis activities from months to days, while ensuring high levels of accuracy in simulating their product's performance under simulated structural and thermal conditions.

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## 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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