Accuracy in Optical Design Software

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Some common questions new users of optical design and analysis software have are "How accurate are the results?" or "Can I trust the results I get?" The simple answer is that it can be very accurate, but a better answer is that it depends. The accuracy will depend on factors such as the accuracy of the model, the accuracy of the properties used, the accuracy of the source model, as well as the accuracy potential of the optical design and analysis or ray-trace software itself. There is an acronym sometimes used in computer simulation and programming, GIGO, meaning Garbage In = Garbage Out. This is true in optical design and analysis software as well.

Let's take a closer look at some of the factors that can affect the accuracy of the results as well as some examples. The first factor is the accuracy of the model itself. The simple version of this is, does the model in the optical design and analysis software match the designer's intent? An exaggerated example would be a design that uses a parabolic reflector, but the reflector is modeled as a spherical reflector in the optical software. Please note the difference in the beam patterns and peak intensity between a parabolic and spherical reflector in figures 1 and 2 below.

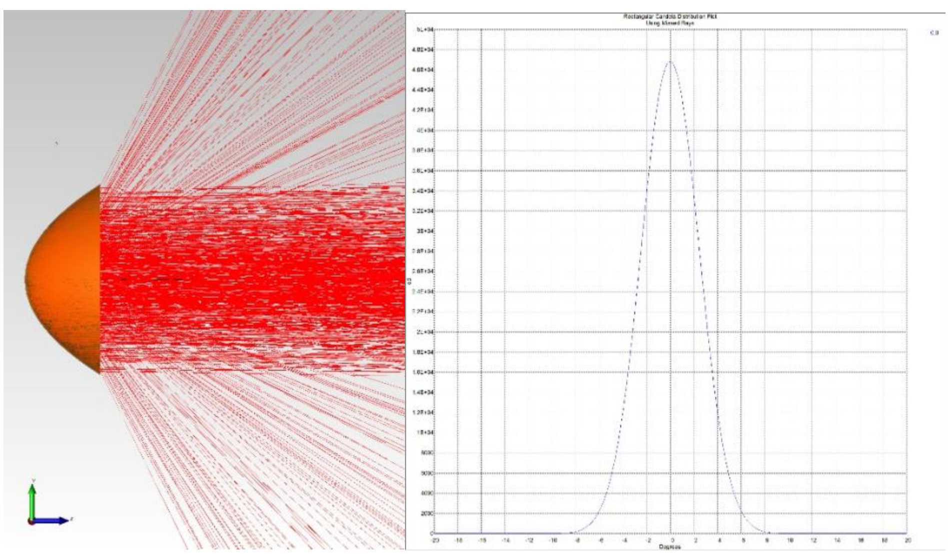

Figure 1: Intensity plot for parabolic reflector

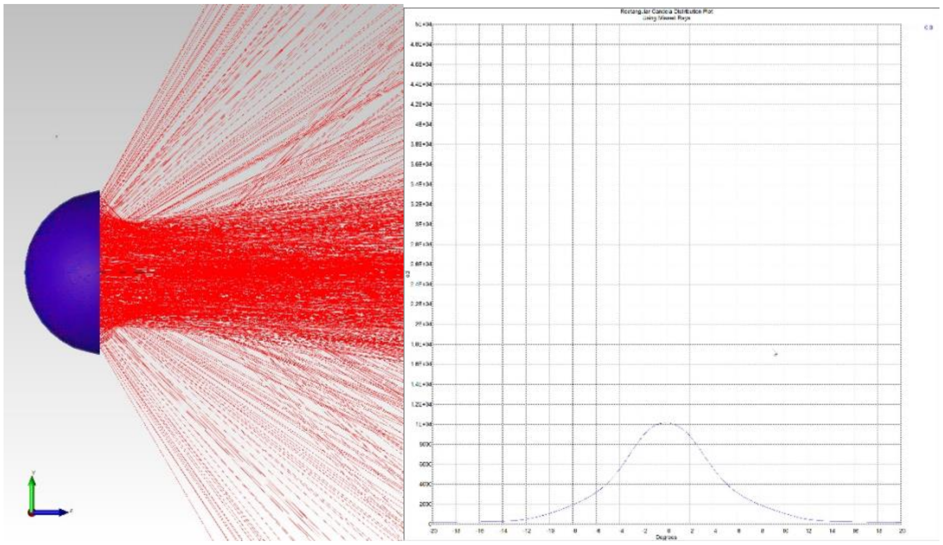

Figure 2: Intensity plot for spherical reflector

Hopefully, in most cases errors in the geometry of the model will be more subtle, but they can influence the results. For example, an aspheric surface is modeled using a spline curve. This difference will cause the results to not fully match the expectation.

Another area of concern is properties applied to the model. If the properties used in the simulation, such as material and surface properties, are not accurate representations of the actual components, then the results cannot be expected to be correct. This could be using the wrong glass material when modeling a lens. For example, selecting Schott B270 glass instead of Schott FK54.

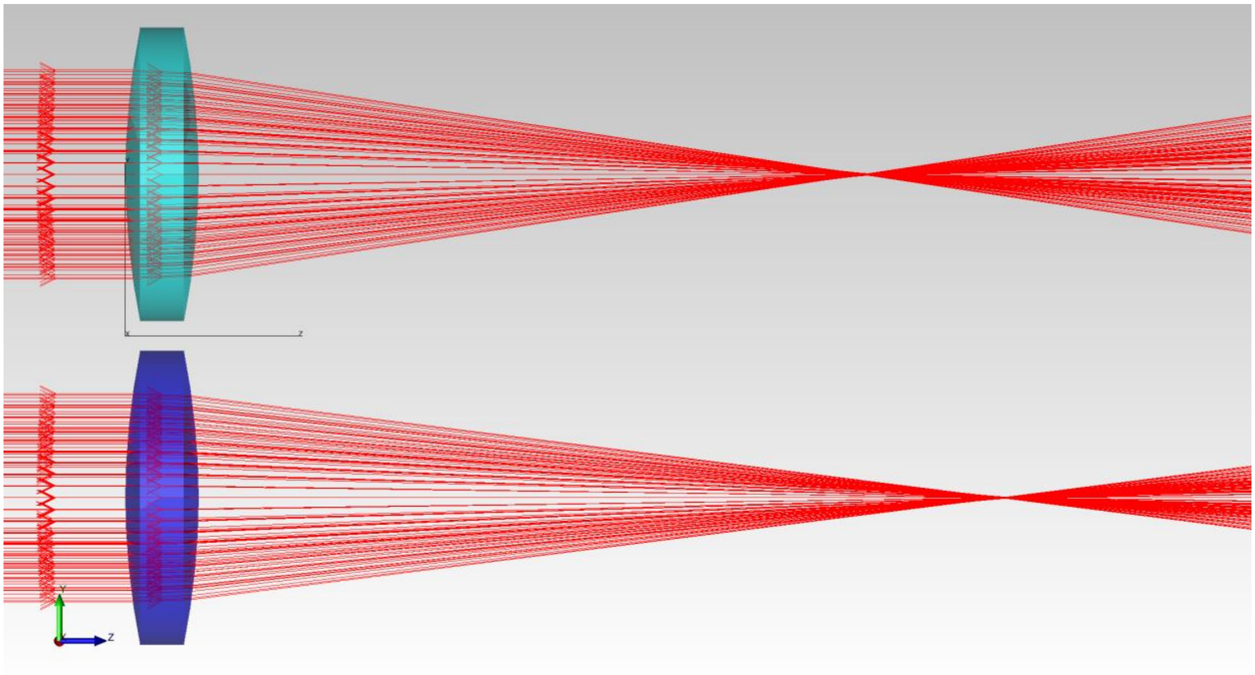

Figure 3: Focal length changes due to different glasses. Schott B270 on top. Schott FK54 on bottom

In the above case the effect of the different glass on the focal length is easy to see. In other instances, the effects may be small or more difficult to discern.

The surface finish of a mirror or reflector is an important factor in the performance of the reflector. If the surface is modeled with a perfect mirror type property, a mirror with no absorption or scattering that is available in optical design software, but not truly realistic, the resulting simulation may not reflect reality. Figures 4 shows the difference in reflected rays from a perfect mirror surface and a mirror surface with a scattering component. The mirror with scattering will generally better match real world results as all surfaces will typically have some amount of scattering, even if it is a very small amount.

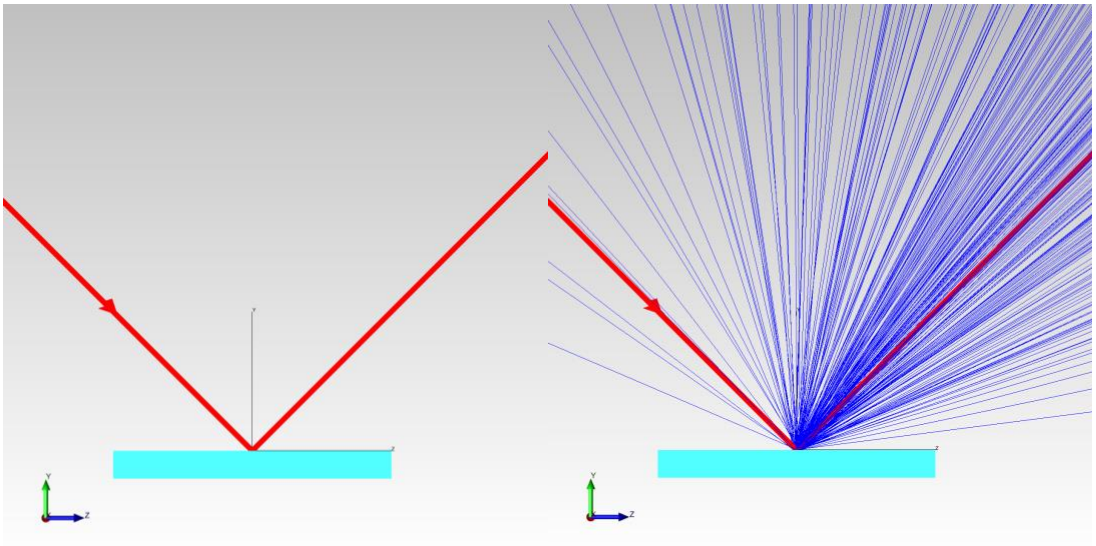

Figure 4: 100% specular surface versus mirror with scattering

Figure 5 shows the effect of changing the surface property on an elliptical reflector. Differences in the irradiance plot of the focused spot can easily be seen. In this example the most specular reflector is on the left and the least specular reflector is on the right.

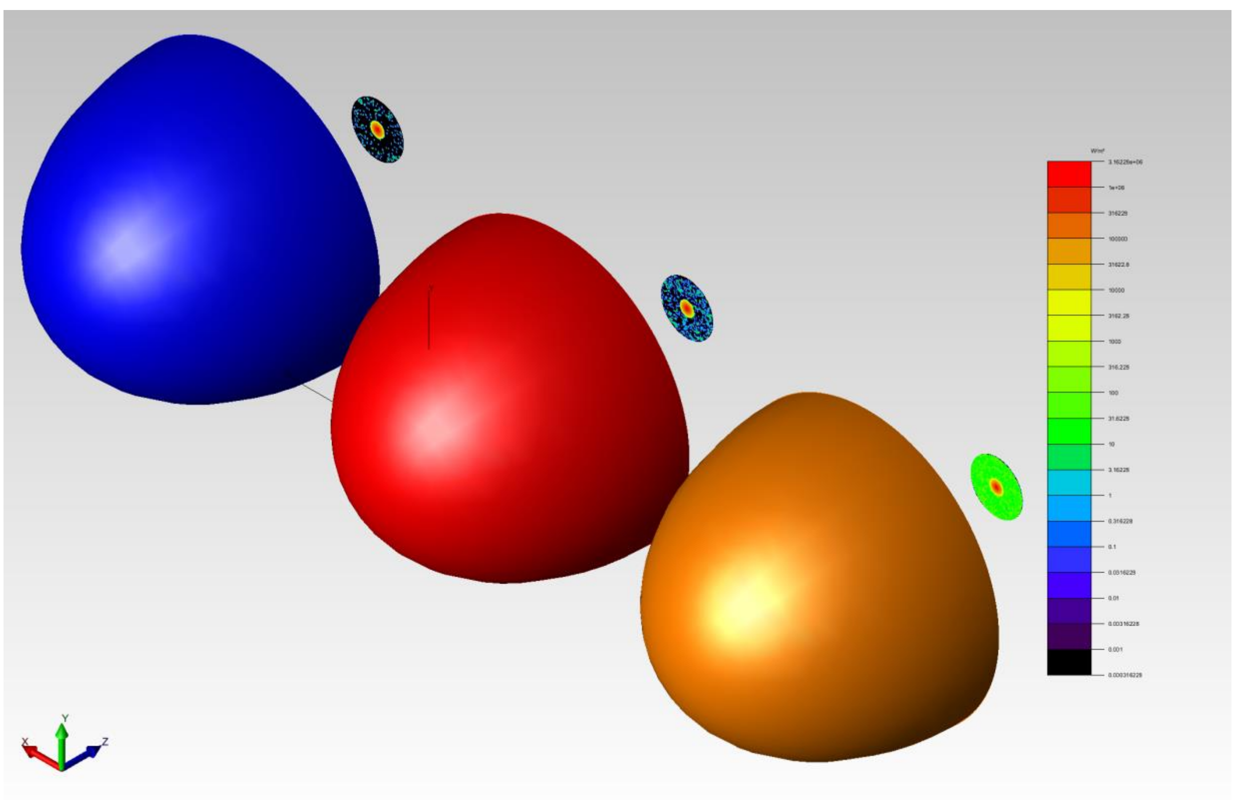

Figure 5: Irradiance plots for elliptical reflectors with different surface properties

An accurate source model is vital to getting good results from your simulation. Even if the model is correct and the appropriate properties have been applied, if the source model is not accurate, the simulation results will not match the real-world results. Some examples of this would be modeling a light source as a point source or modeling all the rays as parallel. These are options in optical analysis software, but in most applications, these will not be the best choices. These types of source models can be useful when setting up a model or doing an initial analysis, but changing to a more realistic source model that reflects the behavior of the source used in the actual application will be necessary to arrive at an accurate answer. Fortunately, there are numerous tools available for accurately model light sources including ray files from the light source manufacturer and surface source properties that fully model the spectral and angular distribution of the source.

Figure 6 shows a TIR hybrid lens with the source modeled as a point source and using a ray file for the actual LED. Note that the intensity is almost 4x lower when the ray file is used. In this case the emitting area of the LED is relatively small, about 1mm^2, but the difference in the results is obvious. If a point source was used for the design and analysis of this lens, the results when the product is manufactured would be disappointing.

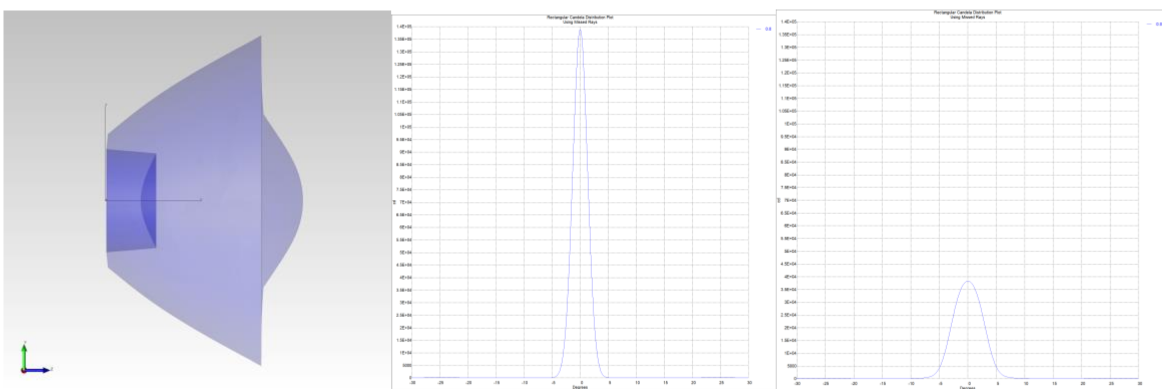

Figure 6: Intensity plots for TIR hybrid lens with point source and ray file

Another example of the effect of accuracy in source modeling is the solar concentrator shown in figures 7 and 8. It may be tempting to model sunlight as parallel light, but this again does not match reality. Even though sunlight has a relatively small divergence angle, it makes a large difference in the results. Figure 7 shows the spot size and irradiance using parallel light. Figure 8 shows the results when a solar source is used. Note that the spot size is now much larger, and the peak irradiance is reduced by a factor of 185x.

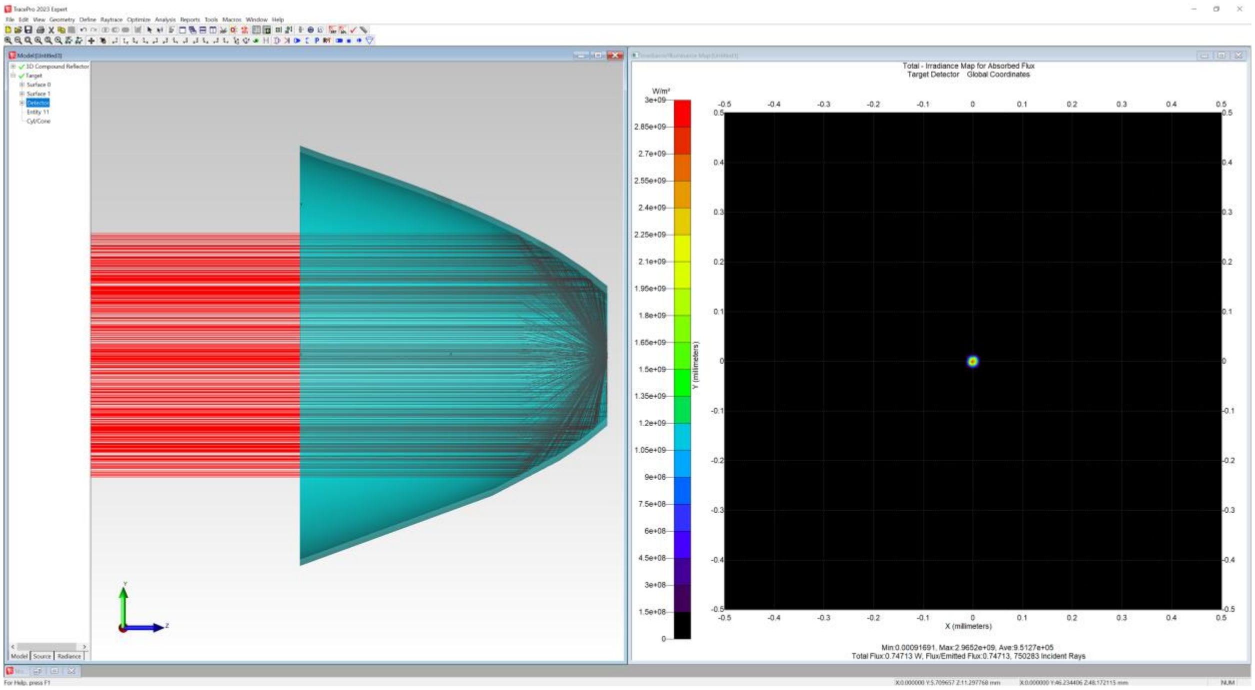

Figure 7: Irradiance plot for solar concentrator with parallel rays

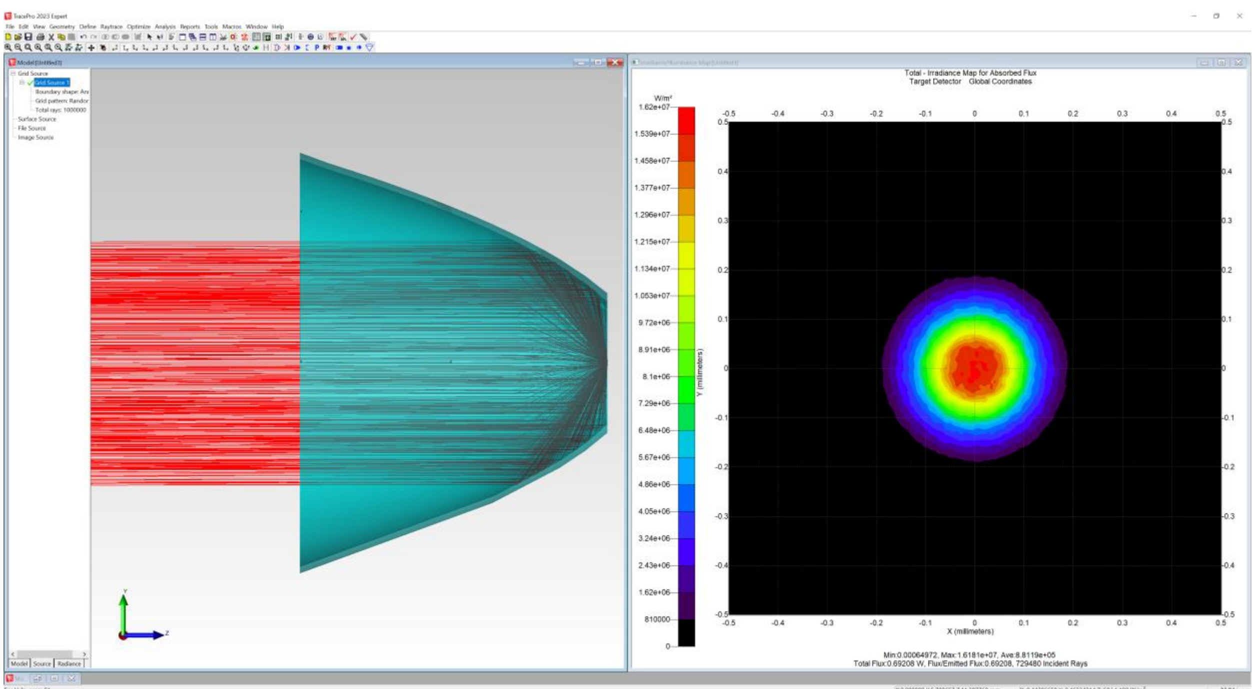

Figure 8: Irradiance plot for solar concentrator with solar source

In both of these examples, small differences in the sources models can have major consequences on the simulation models.

A final example shows tying all these factors together and including measurements of the actual part. Figures 9 shows an image of a pulsed xenon flashlamp and the optical model of the same lamp. Appropriate material and surface properties were then applied to the parts of the flashlamp.

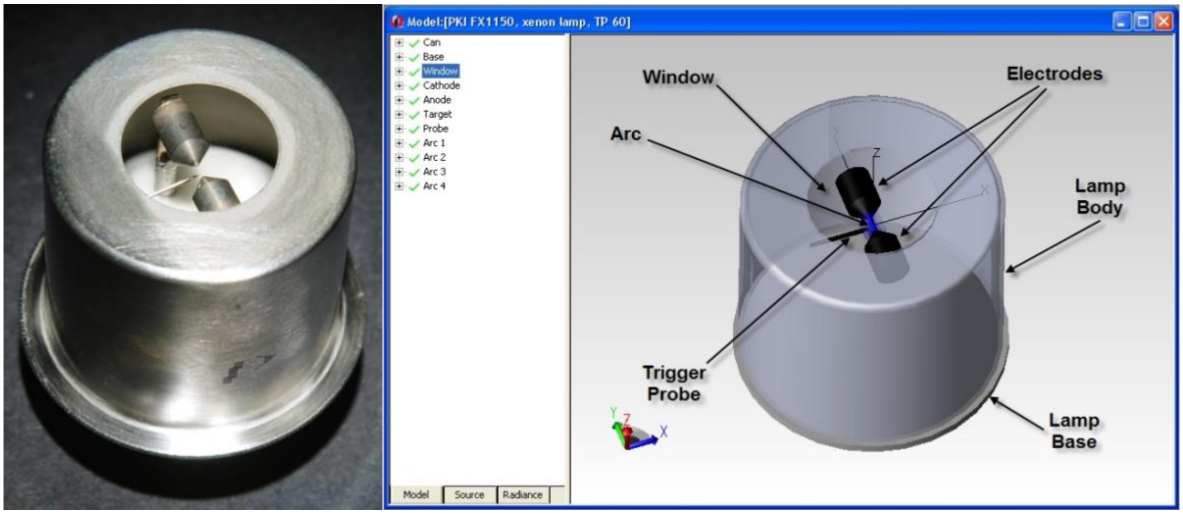

Figure 9: Pulsed xenon flashlamp image and 3D optical model

A model of the xenon arc was generated using actual images of the arc itself. The spectrum of the lamp was also measured and used in the analysis.

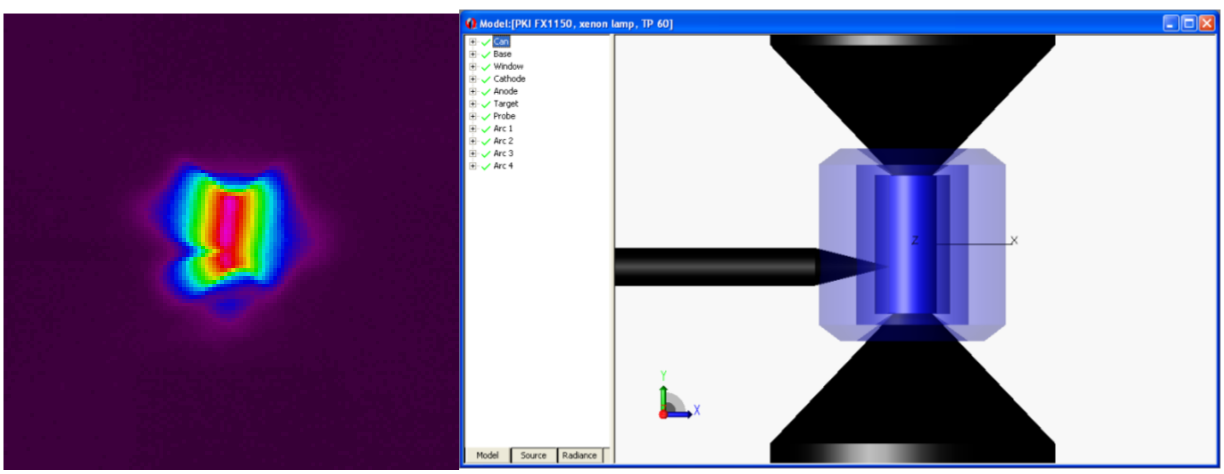

Figure 10: Image of xenon arc and 3D optical model of the arc

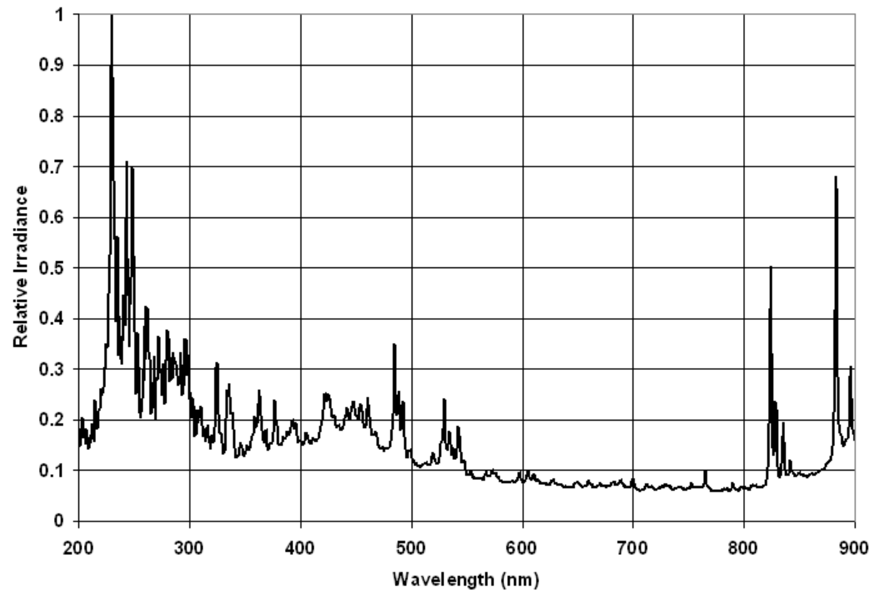

Figure 11: Spectrum of xenon flashlamp

Figure 12 shows the model versus measured results for the angular distribution. There is excellent agreement between the modeled and measured results, including the effect of the probe used to stabilize the arc. The effect of the white base in the lamp assembly is also modeled well as evidenced by the small area of higher intensity in the center of the plot. This also matches the measured results well. Figure 13 shows the spectrum used in the model. It is a lower resolution than the data in figure 11, but again, the agreement with the actual data is very good.

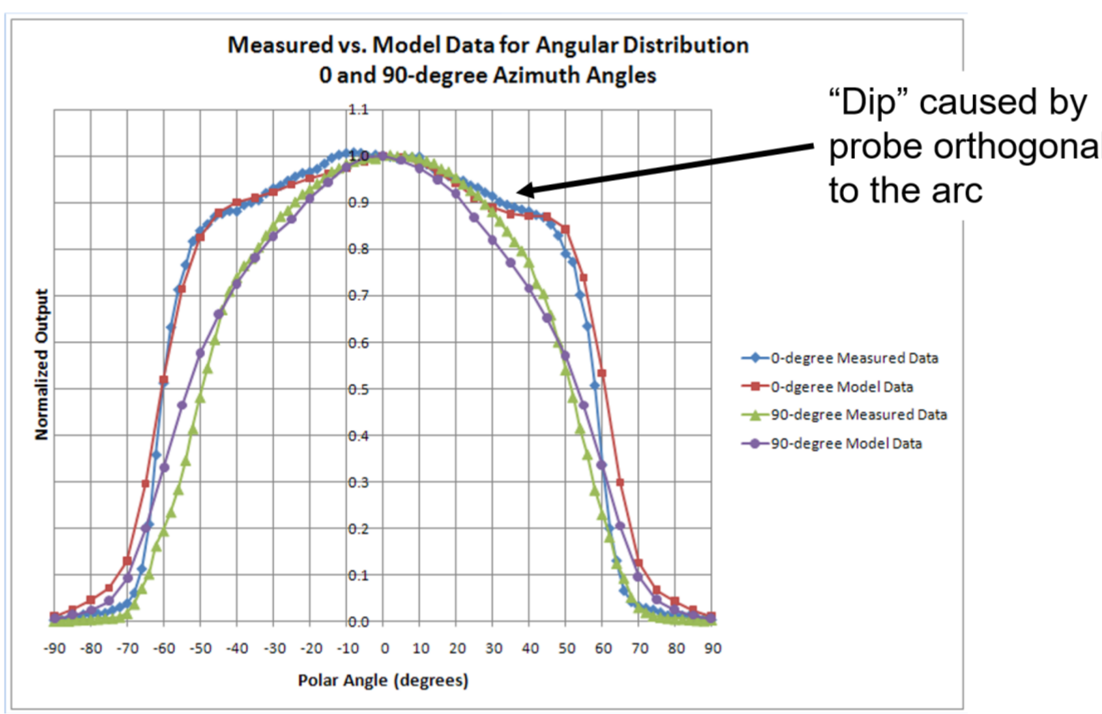

Figure 12: Model vs. measured data for angular distribution

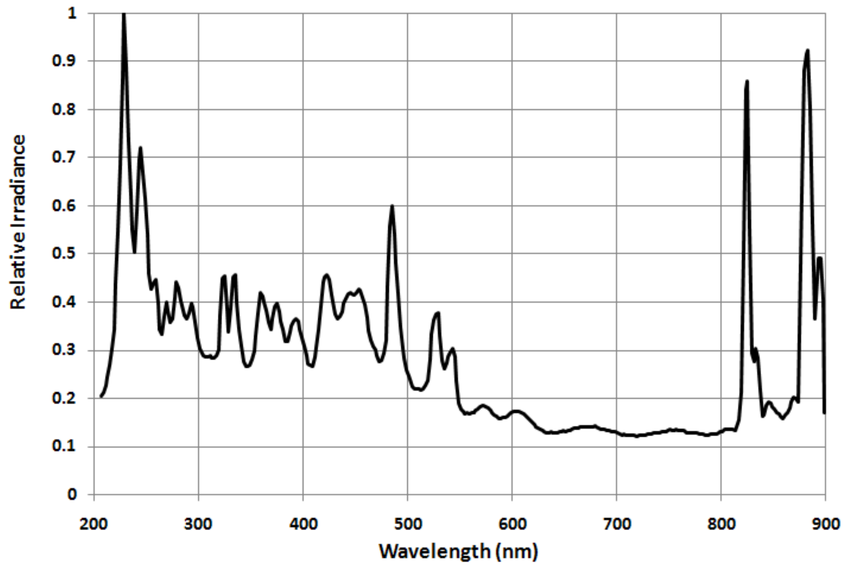

Figure 13: Spectrum from optical model

One last point is on the exactness of the ray-trace algorithm itself. For best results it is important to use an optical design and analysis program that features exact raytracing and does not make approximations for the sake of speed.

Optical design and analysis software is an excellent tool for speeding the design and development process as well as allowing users to test multiple designs in a short time and in a virtual environment. This allows users to find and correct mistakes in a software environment before committing to physical prototypes. It is always better and less expensive to make your mistakes in software. A key to being able to do this though is having the ability to trust the results obtained in the optical design and analysis software. The user needs to remember that parameters such as point sources and perfect surfaces only exist in the software environment. Care needs to be taken and designers and engineers need to realize that the results using parameters such as these may not translate into reality. In order to trust the results, the user needs an accurate model, accurate properties, accurate source models, and accurate software.

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Author Bio: Dave Jacobsen is a Senior Applications Engineer at Lambda Research Corporation with over 30 years of optical engineering experience. Dave is Lambda Research Corporation's senior sales engineer and teaches many TracePro training classes, both in the US and worldwide. Prior to coming to Lambda Research Corporation, Dave worked as a Principal Optical Engineer at PerkinElmer, formerly EG&G, working with xenon flashlamp based systems for illumination, machine vision, UV sterilization, and process control, as well as designing spectroscopy systems for biomedical applications.