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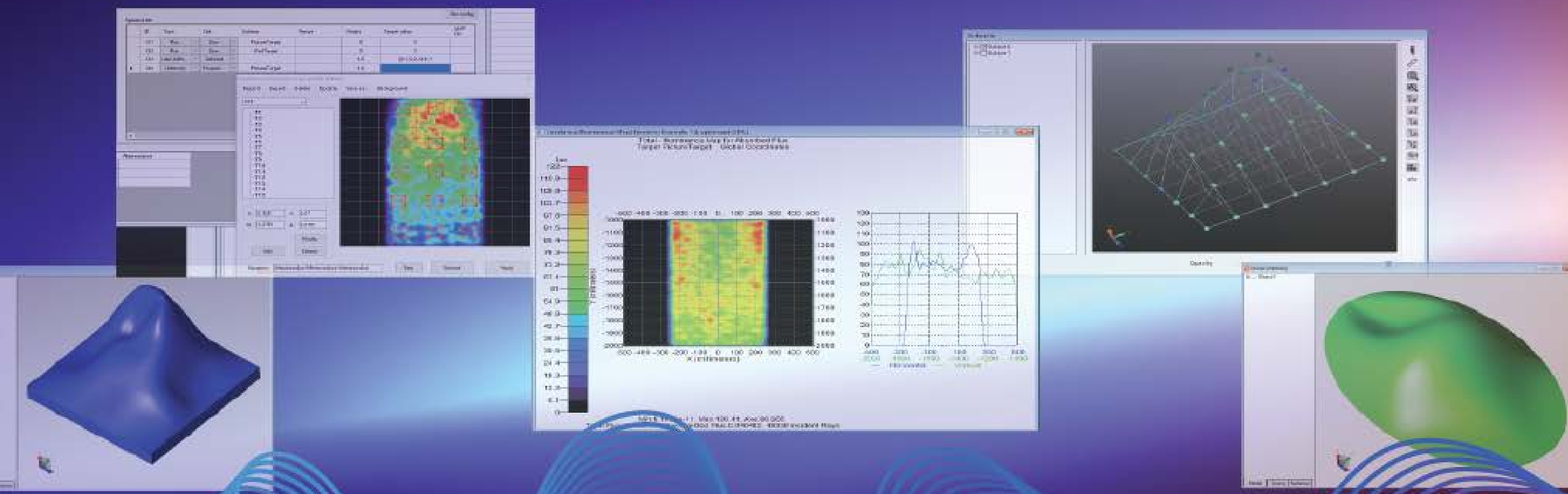

Freeform Optics Design for Illumination Applications

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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, and process control, as well as designing spectroscopy systems for biomedical applications.

Abstract: Freeform optical elements give optical designers new and exciting degrees of freedom when it comes to designing optics for illumination applications. These same freeform elements can also add a new layer of complexity to the design process due to added degrees of freedom. This dramatically increases the number of possible solutions to the problem. Modern optical design software can help in this process by allowing the user to automatically test and optimize a large number of parameters to meet a user defined goal.

I. Freeform Optics Basics

The use of freeform optical elements for illumination applications is a relatively new use for these types of optical elements. Freeform optics can be defined as optical designs with at least one freeform surface and have no translational or rotational symmetry about axes normal to the mean plane[1]. Freeform optical elements give optical designers extra degrees of freedom to solve complex problems or to simplify designs. Freeform optics can be made of materials such as glass, plastic, silicone, or other materials. Manufacturing methods can include molding, diamond turning, and other methods.

Uses of freeform optics are varied, including illumination and lighting, laser applications, laser beam shaping, imaging systems, and automotive applications including headlights and taillights. Freeform optics can also allow for smaller, lighter, and simpler optical systems. In this paper we will focus on freeform lenses for illumination and lighting applications.

II. Freeform Surface Examples

There are many options for surface types for freeform lenses. Some examples are: BSpline, XY polynomials, radial type freeforms, and slice type freeforms. The BSpline surfaces can also offer the option of a free BSpline where there is no symmetry or a BSplines where there is symmetry across one of the axes. The following figures show some of the options for freeform surfaces.

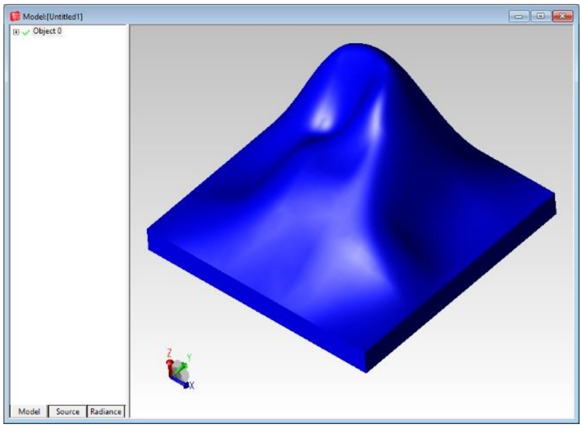


Figure 1: Free BSpline

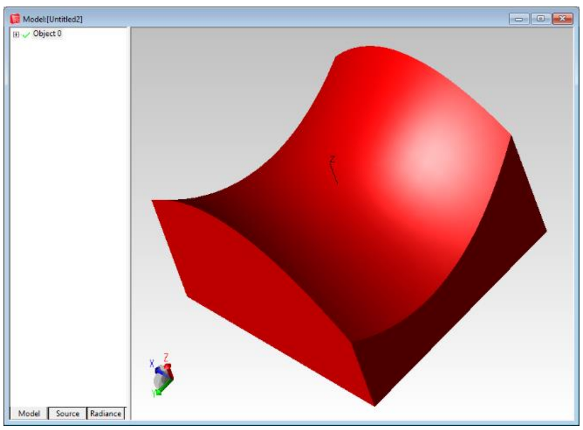


Figure 2: XY Polynomial

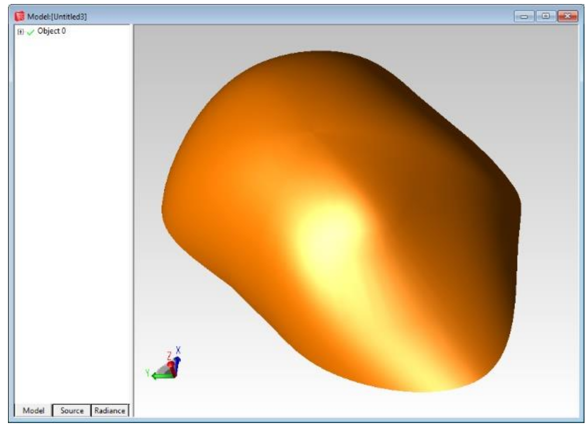


Figure 3: Radial type

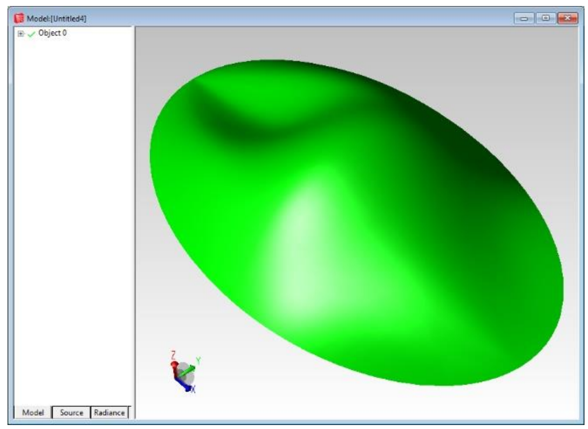


Figure 4: Slice type

III. Advantages and Disadvantages of Freeform Optics

As is often the case there are advantages and disadvantages to freeform optical elements. Many times, it will be up to the optical designer to determine if the advantages outweigh the potential disadvantages.

Advantages

- Extra degrees of design freedom
- Possibility of smaller, simpler, and lighter optical systems
- Designs with fewer surfaces/elements
- Improved performance

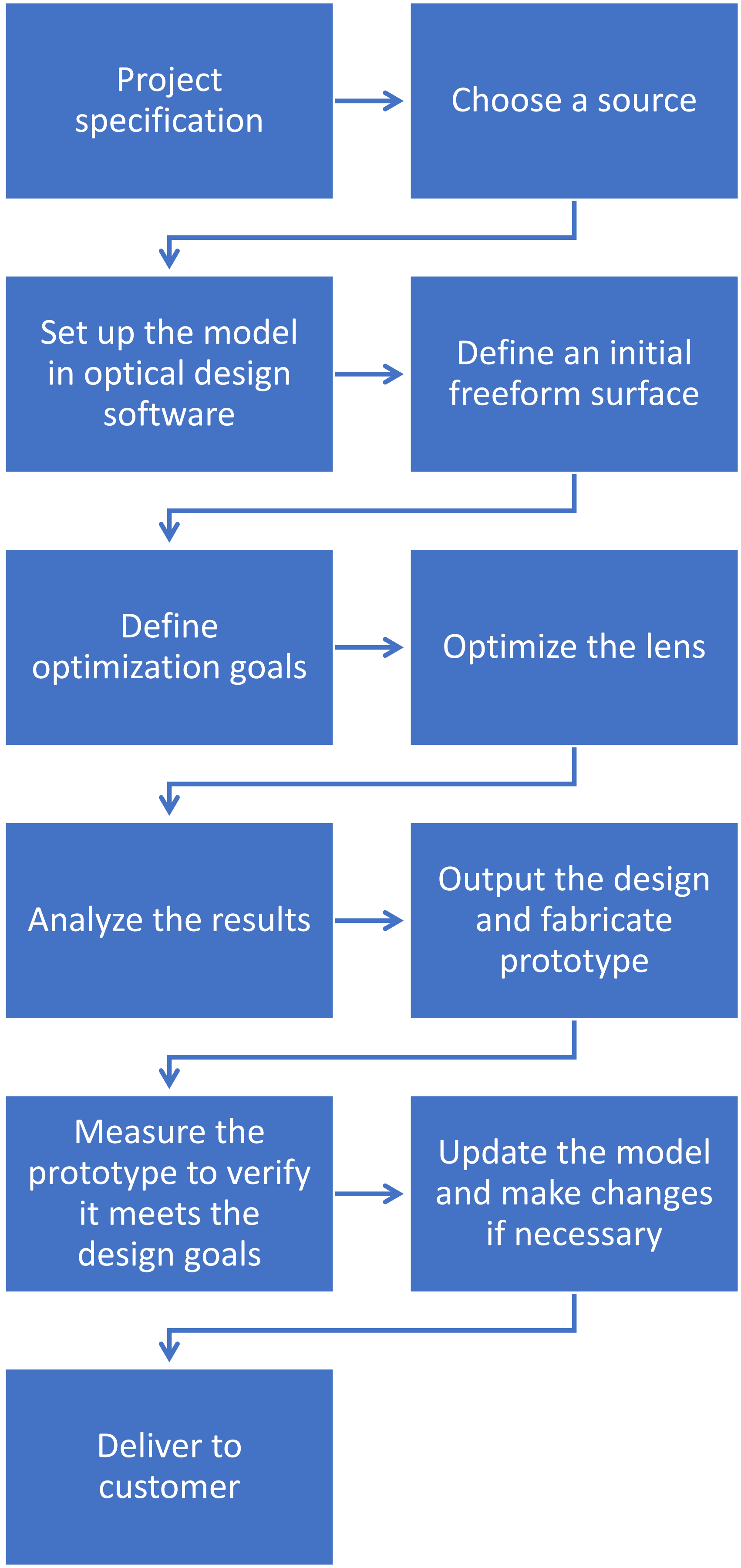
Disadvantages

- Extra degrees of freedom adds to added design complexity
- More demanding of the designer's skill
- Potential for increased manufacturing cost
- Manufacturing tolerances and variation may be an issue

IV. Designing Freeform Optics

Due to its complexity, the process of designing freeform optical elements lends itself well to optical design and analysis software. Optical software allows for a large number of variations to be tested in a relatively short time, especially when compared to a manual trial and error process. Many optical design programs include optimization routines such as the Downhill-Simplex method to improve the accuracy and efficiency of this process. Optical software can help simplify the process though it is still beneficial for the design engineer to make good choices for the starting conditions or initial freeform design.

The basic design process can be broken down into the following steps.


Project specification
Choose a source
Set up the model in optical design software
Define an initial freeform surface
Define optimization goals
Optimize the lens
Analyze the results
Output the design and fabricate prototype
Measure the prototype to verify it meets the design goals
Update the model and make changes if necessary
Deliver to customer

One of the first steps is to start with an initial freeform surface profile. This could be based on a previous example, a published design, experience, educated guess, etc…

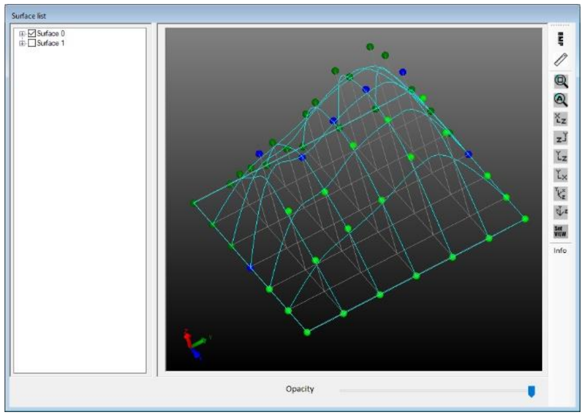


Figure 5: Initial freeform surface

The next step would be to add a range to the variables. In the example shown below the variable ranges would be sag values for the variables. During the optimization process the variables can move within these ranges.

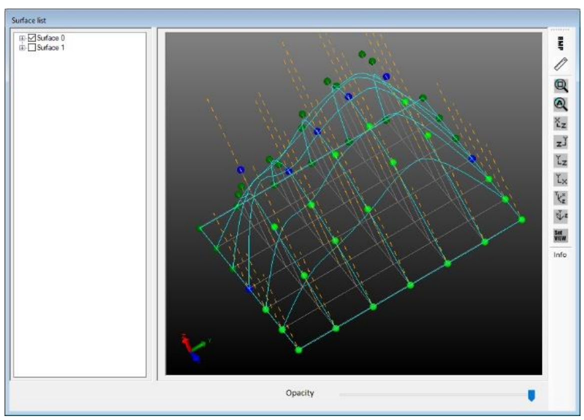


Figure 6: Variable ranges

If there will also be a freeform surface on the other side of the lens, this can be added in the same manner along with the relevant variable ranges.

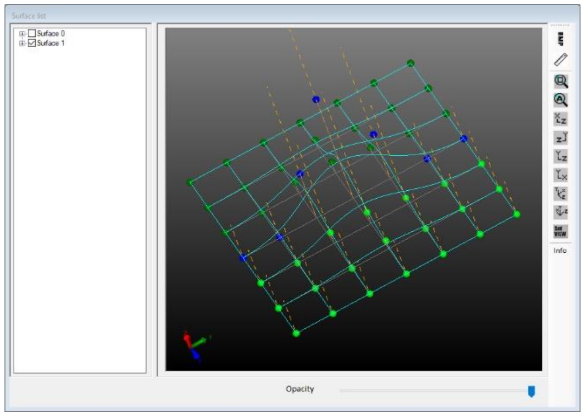


Figure 7: Second surface freeform profile

The surfaces can then be converted to a solid object. Appropriate material and surface properties are also applied at this time.

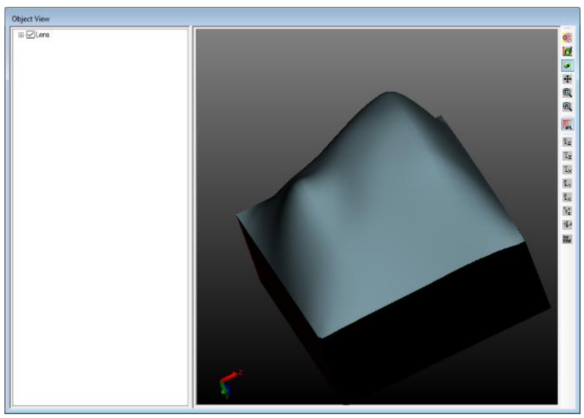


Figure 8: Initial freeform 3D solid object

At this point the model can be set up in the optical design software including the lens, source, and a target if necessary.

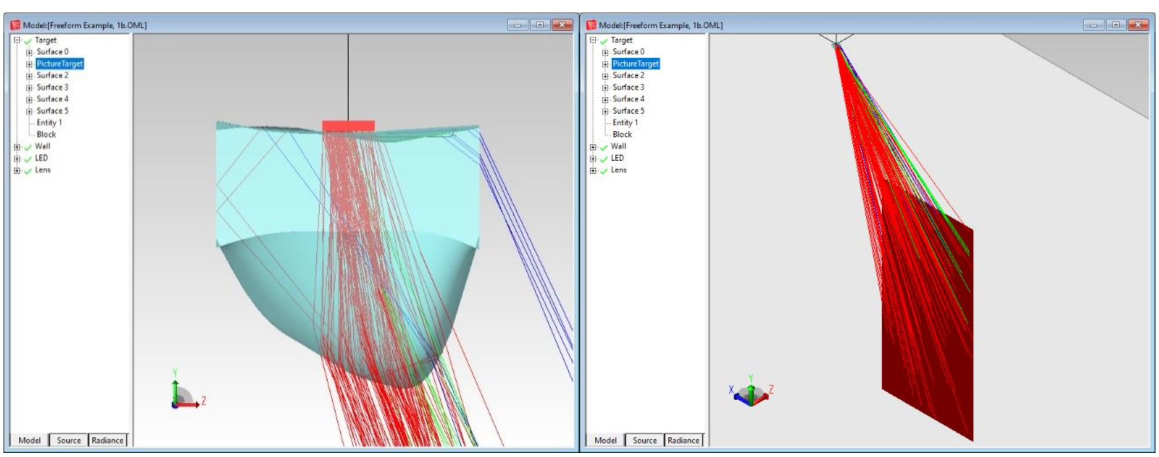


Figure 9: Initial optical model

The optimization goals or operands can then be defined. In this example the goals are to have as much flux as possible on the target area and for the flux to be as uniform as possible.

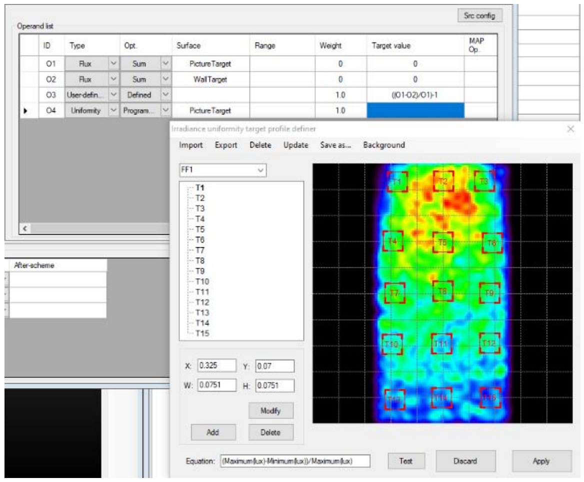


Figure 10: Optimization operands

During the optimization process the lens is modeled, a raytrace run, and an error value is calculated. The error value is based on how close the simulated results are to the design goal. The lower the error value the closer the design is to being optimized. The design is then changed based on the variables and their ranges and the process is repeated. Here is the optimization log for this example after about 2000 iterations.

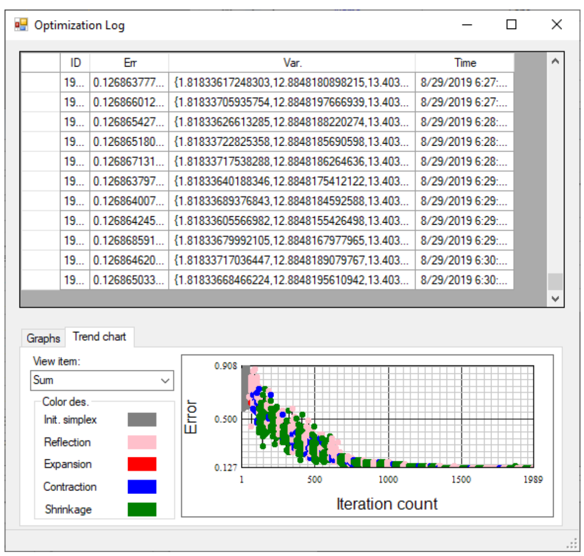


Figure 11: Optimization log

After the optimization process has been completed and the performance of the resulting lens analyzed in the software.

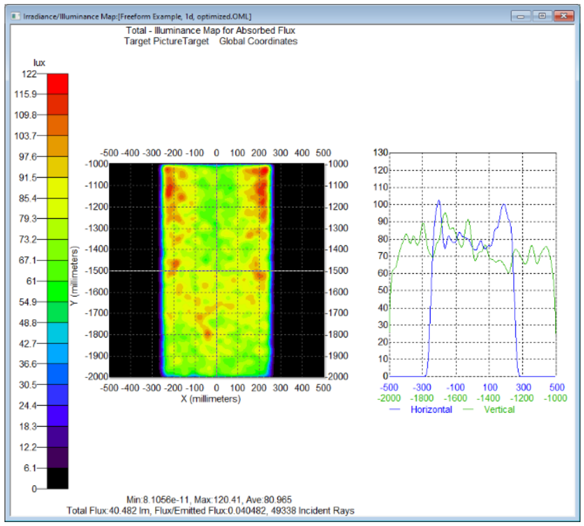


Figure 12: Illuminance map

If the design goals have been met, the resulting lens model can be exported, typically as a 3D solid model, and sent to manufacturing. A prototype could then be produced and tested. If changes need to be made the model could be adjusted or improved based on these results. The example shown above has room for improvement in terms of efficiency, so there is possibly more work to be done in this case.

V. Helpful Design Tips

There are some basic tips or suggestions that can be helpful when designing freeform optics for illumination applications. These can be especially useful if someone is new to the process, though they are also applicable for more experienced designers.

- Start with a small number of variables and then increase the number if necessary
- Avoid using too many variables as it can lengthen the optimization process and lead to potentially un-manufacturable design
- Use an accurate source model – avoid models such as point sources
- Trace enough rays to get an accurate answer, both during the optimization and in the final analysis
- Define an optimization goal with multiple operands, such as uniformity and total flux, to improve the results
- Use the analysis tools in the optical design software to verify the results
    - Irradiance/Illuminance Maps
    - Candela Plots
    - Luminance/Radiance Maps
    - Photorealistic Rendering

VI. Summary

Freeform optical elements can give optical designs new and exciting capabilities. Optical design and analysis software provide those designers the tools to aid in this process. Some of the benefits of optical design and analysis software for these tasks include:

- A faster and more efficient design process
- Better designs when compared to a trial an error method
- The ability to try multiple designs for a minimal extra cost
- Lower development costs

1) The Center for Freeform Optics