“Accurately Modeling Surfaces with Large Surface Features using BSDF”

Introduction

The reflected and transmitted scattering of light in a luminaire can play a major role in the performance of the luminaire. Many times, this is the reason the actual luminaire performance does not match the results predicted in optical modeling, design, and analysis software. Typically scattering is measured using a scatterometer and modeled using the BSDF, the bidirectional scattering distribution function. This procedure can be difficult when the scattering features are large when compared to the illuminating beam used in the scatterometer. This paper looks at a method using a combination of BSDF data and CAD models to provide a work around to this limitation.

What is Scattering?

Scattering is a general physical process where some forms of radiation, such as light, sound, or moving particles, are forced to deviate from a straight trajectory by one or more localized non-uniformities in the medium through which they pass. In conventional use, this also includes deviation of reflected radiation from the angle predicted by the law of reflection. Reflections that undergo scattering are often called *diffuse reflections* and unscattered reflections are called *specular* (mirror-like) reflections. [1] Scattering can vary as a function of wavelength, incident angle, and temperature.

In an ideal world, we could model everything as a perfectly specular mirror, a perfectly diffusing surface, a perfectly transmitting surface, or a perfectly absorbing surface. These options exist in software, but not in real life. Scattering can be a tool for the luminaire designer to use when designing a new luminaire. A key factor though is having accurate measurements of the surface and bulk media scattering and using them properly in optical design and analysis software.

Surface Scattering

Surface scattering is scattering at the surface of an object or material. Many times, this is due to microroughness of the surface or from a texture pattern placed on the surface during manufacturing. Examples of microroughness surfaces are the reflective sheet materials available from manufacturers such as Alanod and Alcoa. These materials have different surface finishes, each producing a different scattering pattern. Machined surfaces can also have microroughness scattering due to tooling and machining marks left of the surface. Examples of surfaces with a pattern embossed or molded onto the surface include materials such as Alanod Miro 9, or the textured surfaces available from Mold-Tech.

The size and shape of the of the surface roughness will play a major role in how light is scattered from a surface. For example, a flat, polished surface will have a different scatter pattern than a surface with a triangular profile, or one with a rounded sine-like profile.

Surface scattering is either isotropic or asymmetric. If the scattering is isotropic, the scatter profile does not change when the surface is rotated about its azimuth. If the scattering is asymmetric, the scatter changes as the surface is rotated about its azimuth. Many smooth surfaces are isotropic, or close to isotropic scattering surfaces. Surfaces with grain or structure may be asymmetric scattering surfaces.

The Harvey-Schack ABg model is a common scatter model in many optical design and analysis programs. This model is useful for isotropic scattering surfaces. The A, B, and g terms are used to fit the scatter curve to the measured scatter data. Other common scatter models include: Elliptical ABg, Elliptical Gaussian, Table BSDF, Asymmetric Table BSDF, and composite BSDF. Models such as the Asymmetric Table BSDF are used when the scatter is not isotropic, or asymmetric.

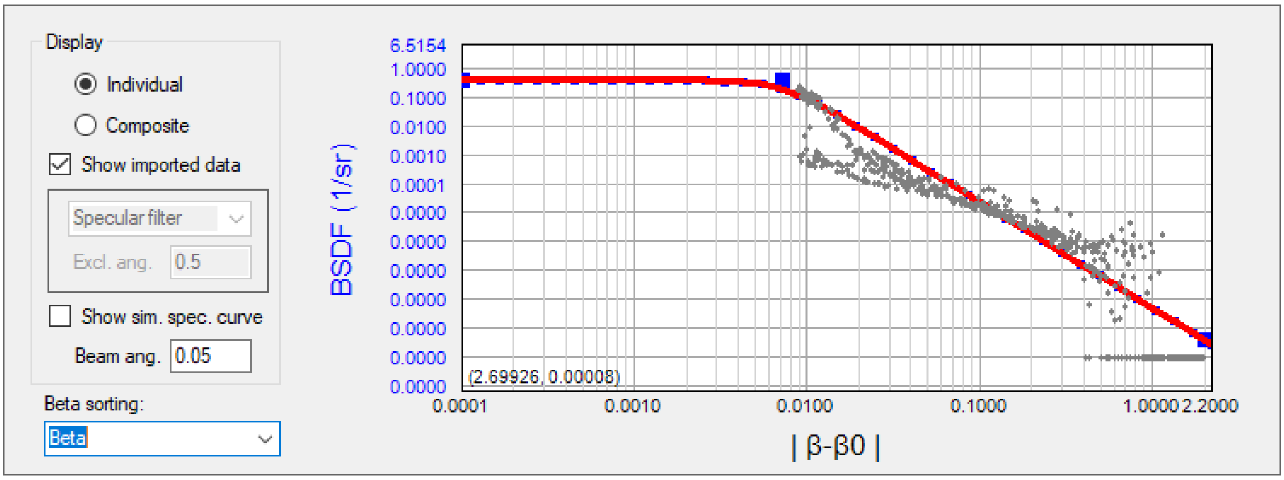

Figure 1: BSDF with fitted ABg curve for Alanod Miro 27 with a 15-degree incident angle

How is scatter measured

Scatter measurements are usually taken using a goniophotometer based instrument called a scatterometer. There are also other methods of taking scatter measurements.

To measure scatter, the sample is illuminated with a light source, typically collimated, or as close to collimated as possible. A detector is then rotated around the specular vector, either reflected or transmitter. This data is then plotted, typically on a log-log plot. This process is repeated for additional incident angles, azimuth angles, out of plane scans, and wavelengths. The resulting measured data makes up the BSDF, the bidirectional scatter distribution function. BSDF can be further broken down into BRDF, bidirectional reflectance distribution function, and BTDF, bidirectional transmittance distribution function. For transmission materials, such as diffusers, it is often best to have measurements for both BRDF and BTDF.

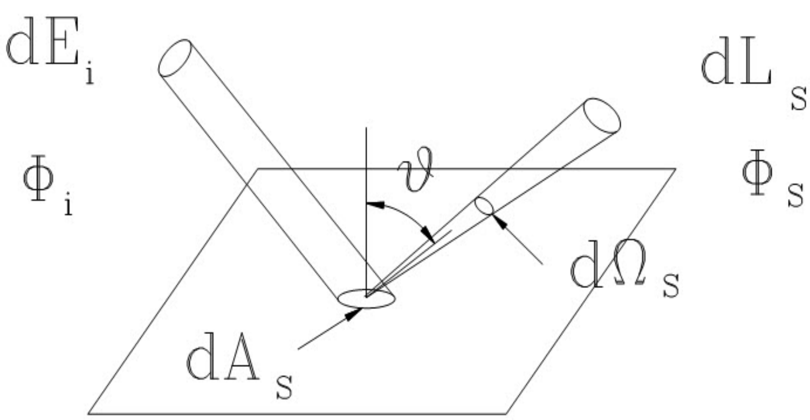

Figure 2: Schematic of typical BRDF scatter measurement

Figure 2 shows a typical reflected scatter measurement for BRDF where dL_s is the radiance scattered from an area dA_s on the sample, dE_s is the incident irradiance on the area dA_s, $\mathbf{r}_i$ is the incident direction, and $\mathbf{r}_s$ is the scattered direction. To measure the scatter, the area dA_s is illuminated, the solid angle $d\Omega_s$ subtended by the measuring detector is calculated, and then the incident flux Φ_i and scattered flux Φ_s is measured. The BRDF is then calculated using these values.

How is scatter data used in optical modeling

Measured BSDF data allows computer modeling software to accurately model the scatter during a raytrace. The more accurate the scatter measurements and resulting scatter models, the more likely the chance that the computer simulation will agree with the actual product produced. This accuracy and fidelity of the surface scattering model will allow for luminaires to be designed and evaluated in a virtual, software environment with a high degree of confidence that the simulation results will match the measured results when a prototype is produced and measured.

Modeling surfaces with large scattering features

When using materials and surface with large features, such as Alanod Miro 9, the traditional method of measuring the BSDF and then using these values to make a scatter property may not work properly. One potential problem is that the laser or other light source used to illuminate the sample may be smaller than the texture features on the surface. The surface finish on the material may actually be highly specular, but the texture features work to scatter and diffuse the light. If the illumination source in the scatterometer does not adequately sample a large enough area, the resulting BSDF model may be more specular overall than the actual surface would be in use.

Figure 3: Alanod Miro 9

A potential work around to this problem is to make a CAD model of a representative area of the surface, apply a surface property to model the scattering of an equivalent flat surface, and then run a raytrace of the model in an optical design and analysis program. The results of this raytrace can then be used to make an equivalent scatter property of the surface. This scatter property can then be applied like any other surface property to surfaces in the optical model and used to model the effects of the large textured surfaces.

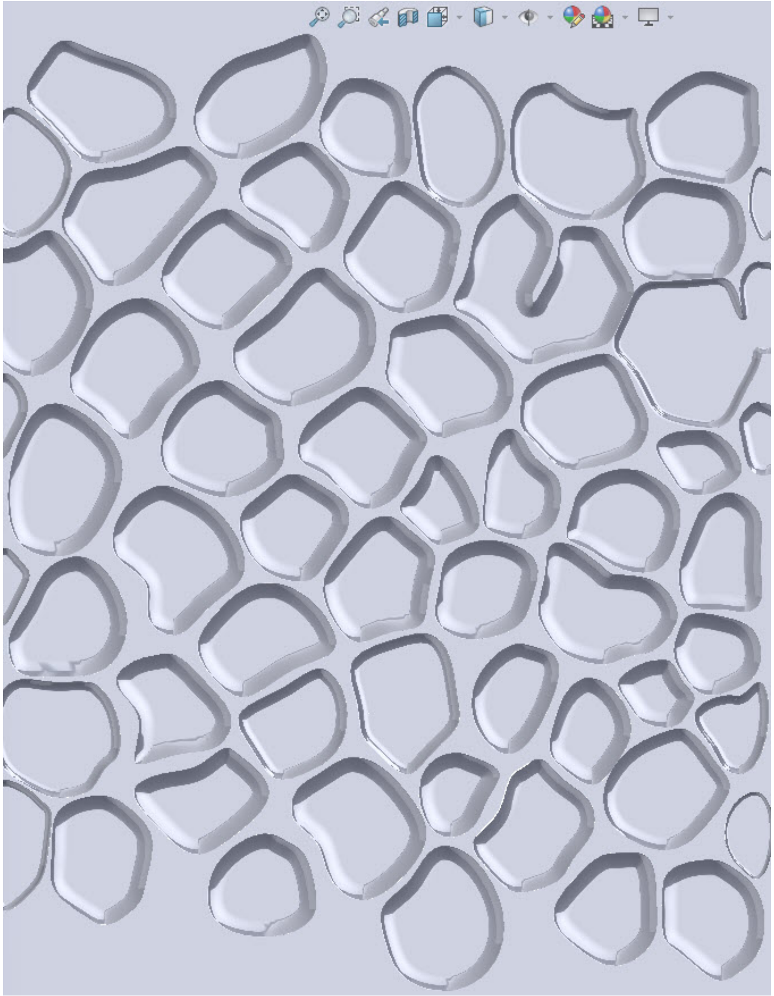

Figure 4: Alanod Miro 9 as modeled in SolidWorks

Figure 4 above shows a CAD model made in SolidWorks of the Miro 9 material. This model was then imported into TracePro. A BRDF measurement was made on a smooth, flat area of the Miro 9 sample, Figure 5. A surface property that was a close match to the specular and scattering characteristics of the smooth areas was then made from the measured data and applied to the CAD model. Raytraces were then run at incident angles from 0-85-degrees.

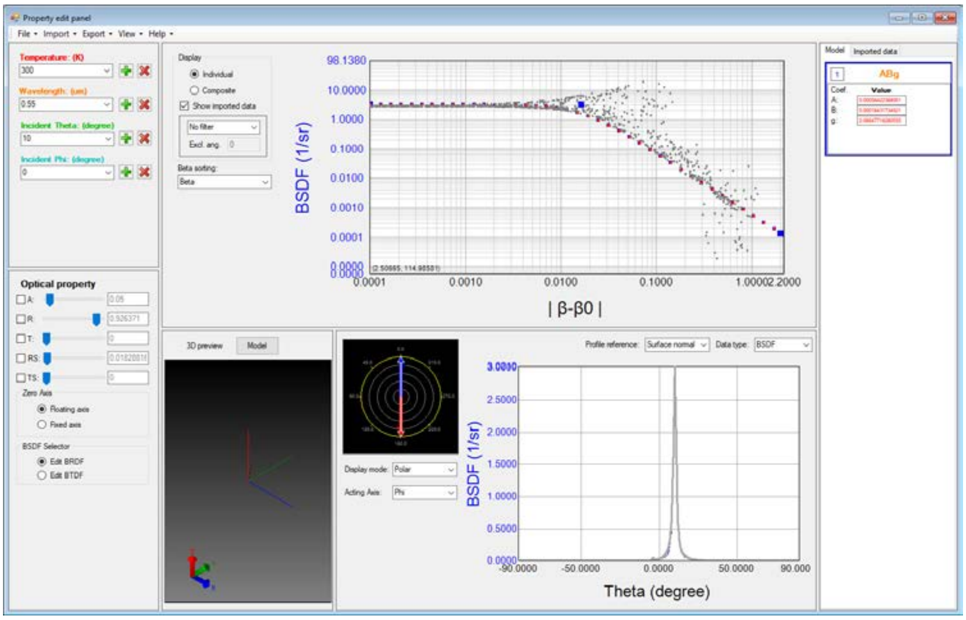

Figure 1: BRDF for smooth, flat area of Miro9

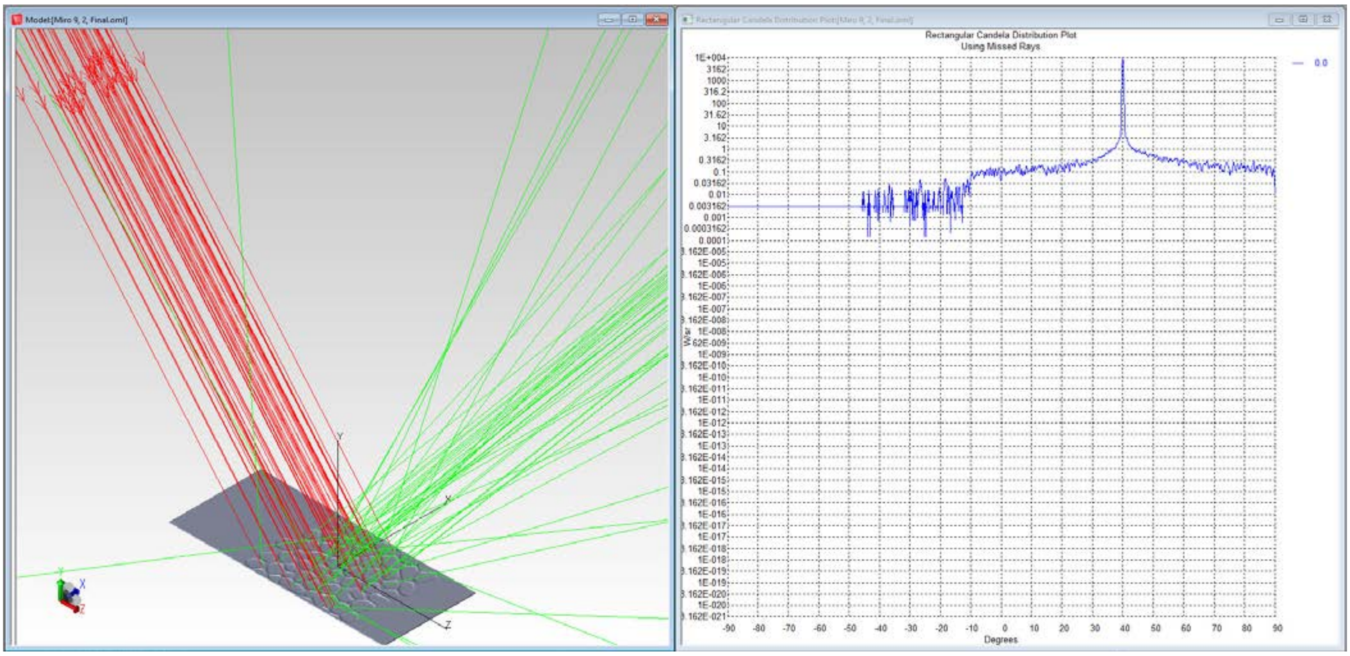

Figure 6: Alanod Miro 9 model in TracePro showing rays and Candela Plot for 40-degree incident beam

Figure 6 shows the Alanod Miro 9 model in TracePro along with some representative rays and the Candela Plot for a 40-degree incident beam. Note that the illumination beam covers a large sampling of the texture features. The candela data for all incident angles was then imported into a BSDF conversion utility where the candela results could be converted into a form that can be used to make a surface scattering property.

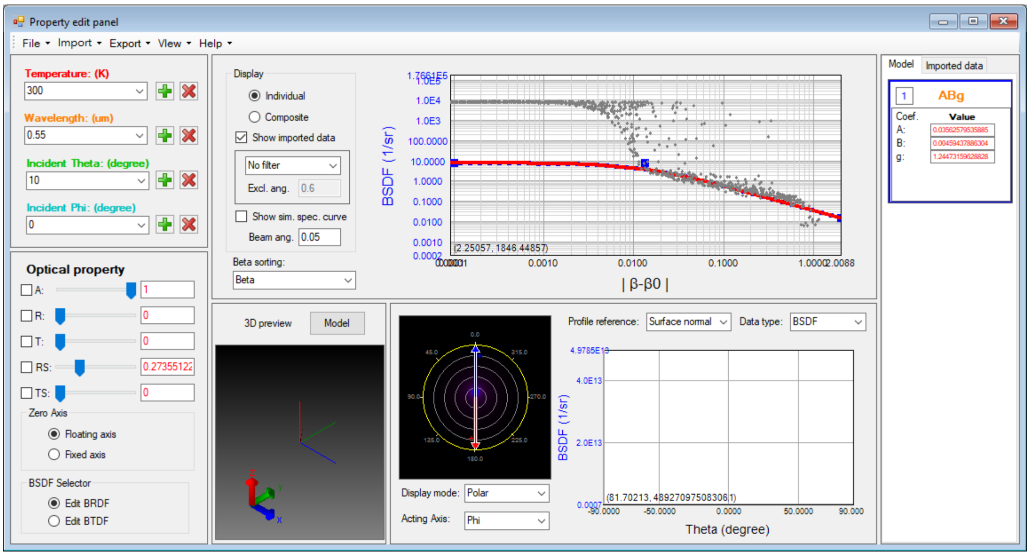

Figure 7: Data from TracePro raytrace in BSDF utility for 10-degree incident beam

Figure 7 shows the candela data for the 40-degree incident beam from the TracePro raytrace in the BSDF utility. It also shows an initial fitting on a ABg BSDF curve to the data. This process is repeated for all of the available incident angle data. After the BSDF curves have been fitted for all incident angles, a surface property is exported from the utility for use in future models. This means that it may not be necessary to make a full CAD model of the reflector with the texture feature, rather the surface property and scattering model accounts for the effect of the scattering due to the features.

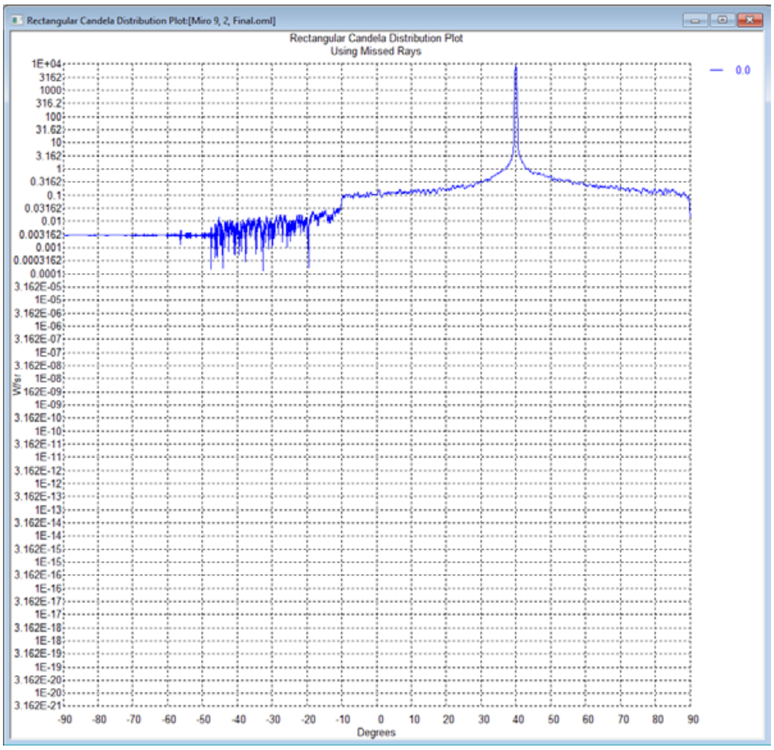

Figure 8: In plane intensity plot for Miro 9 CAD model with 40-degree incident beam

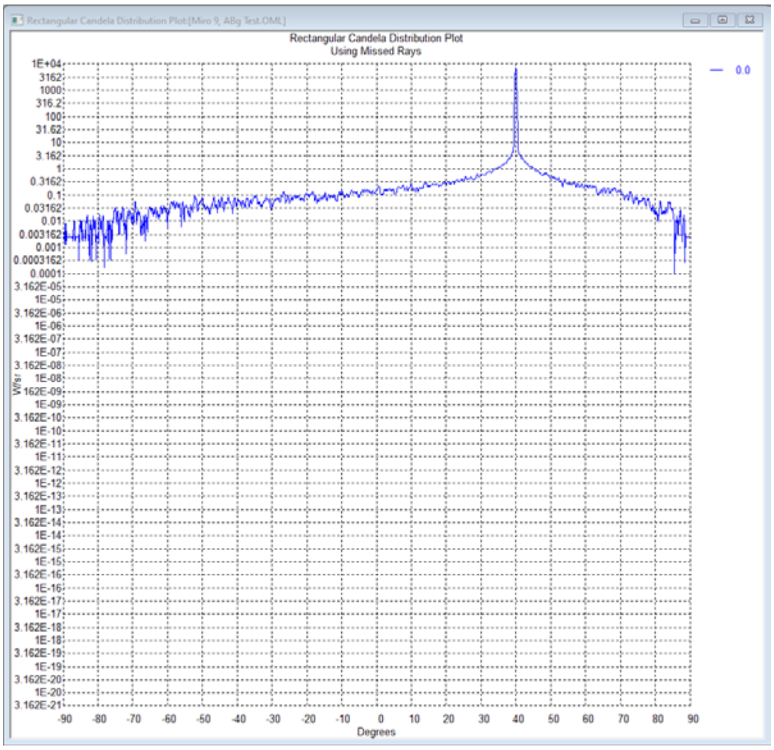

Figure 9: In plane intensity plot for Miro 9 BSDF model with 40-degree incident beam

Figures 8 and 9 show the resulting intensity plots for the CAD model and the BSDF scatter model for the Alanod Miro 9 sample. In this case the results are similar, but there is some differences and some additional fitting of the BSDF parameters may need to be done.

Since the scattering due to the surface structure of the Miro 9 material is now modeled as an ABg property, this property can be applied to any surface in a model, greatly simplifying the modeling process. An additional benefit to modeling the scatter as an ABg model versus the CAD model is a significant decrease in raytrace times. The ABg model raytraced almost 50x faster compared to the CAD model. This may vary with the complexity of the surface features though.

Conclusions

The use of optical design and analysis software allows users to quickly and easily model different luminaire designs, using different materials. A key factor in this capability is the need for accurate scatter characterization of the materials selected and the proper use of that information in the optical software.

Materials with large scattering features can present a challenge to typical BSDF measurements. We have shown a method where surfaces with a large texture patterns can be modeled using combination of CAD models and BSDF measurements. This allows for simpler and easier modeling of these types of materials. An additional benefit of this process is the potential for faster raytraces.

References

[1] Wikipedia definition of Scattering