FloEFD™ Shines a Light on Automotive Lighting

Condensation and Radiation Modeling Technologies in Automotive CFD Simulation

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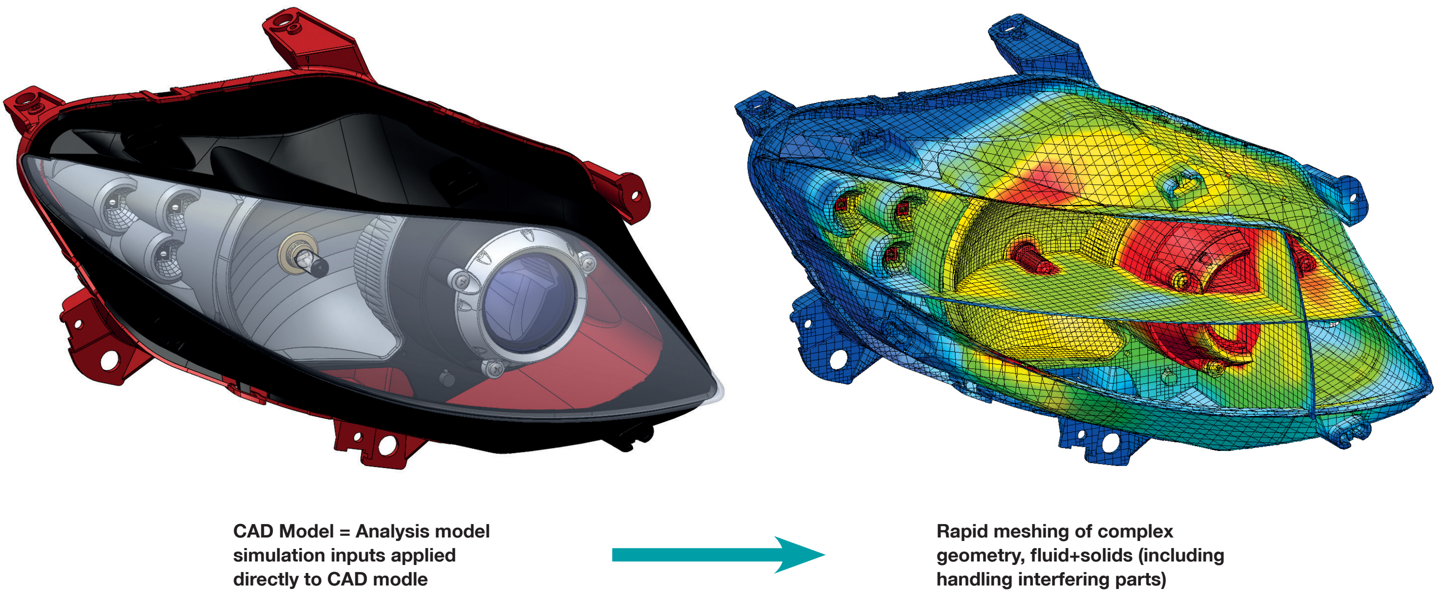

Figure 1. CAD model to final mesh

Mentor Graphics was approached several years ago by a leading automotive lighting supplier to help them find a better way of numerically simulating their headlights. Like most automotive suppliers and OEMs they already had existing commercial CFD tools which they had been attempting to use in their engineering process. However, the time and effort involved in conducting these analyses needed to be reduced. The biggest bottlenecks in the process were related to handling the complex geometries inherent in headlights and in turn creating a computational mesh of those geometries that could be effectively analyzed. Of course the source of the geometry for one of these headlights is a CAD model, and an assembly defining one of these models can be comprised of scores of parts, including many sweeping, stylized components that are used in modern lights. The intersections of all of these parts can create complex geometrical conditions that are often quite challenging to mesh with traditional approaches.

FloEFD, Mentor Graphics' general purpose CFD software, has several key strengths that aggressively address the difficult, time consuming aspects of preparing a headlight model for analysis that make it attractive. The first benefit is that the users can work directly on the native CAD model in their CAD tool. This eliminates the step of transferring a neutral file format model to the analysis tool, followed by the typical need to clean up any translation errors due to this process. Next, the benefit of the immersed boundary style of meshing used by FloEFD also impacts the geometry preparation. Because of this mesher the laborious step of simplifying and de-featuring the model can be greatly reduced. Geometric conditions that give other meshers difficulties, like interfering parts, small gaps and sharply pointed objects are handled by the FloEFD mesher

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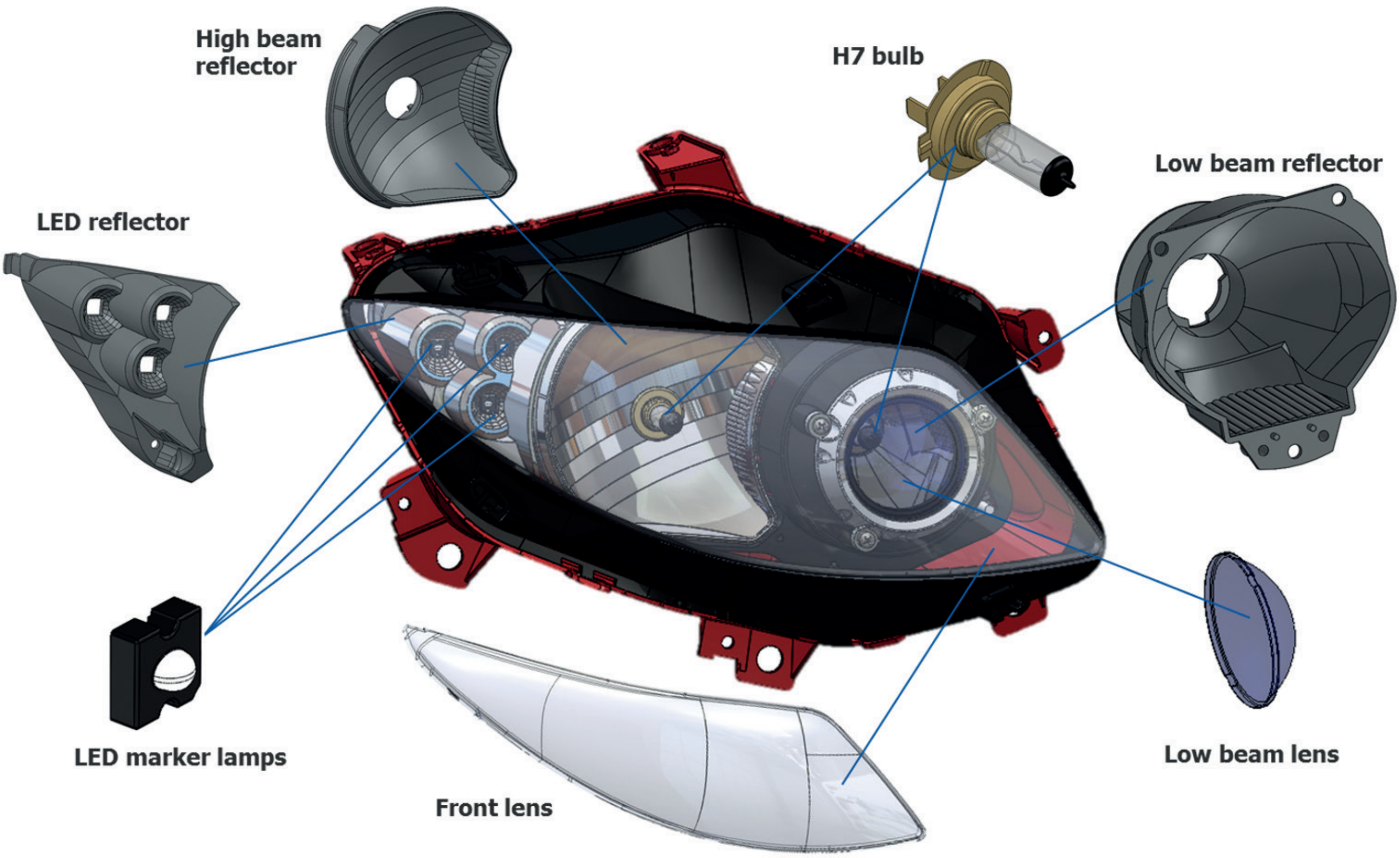

Figure 2. Assembly and relevant parts

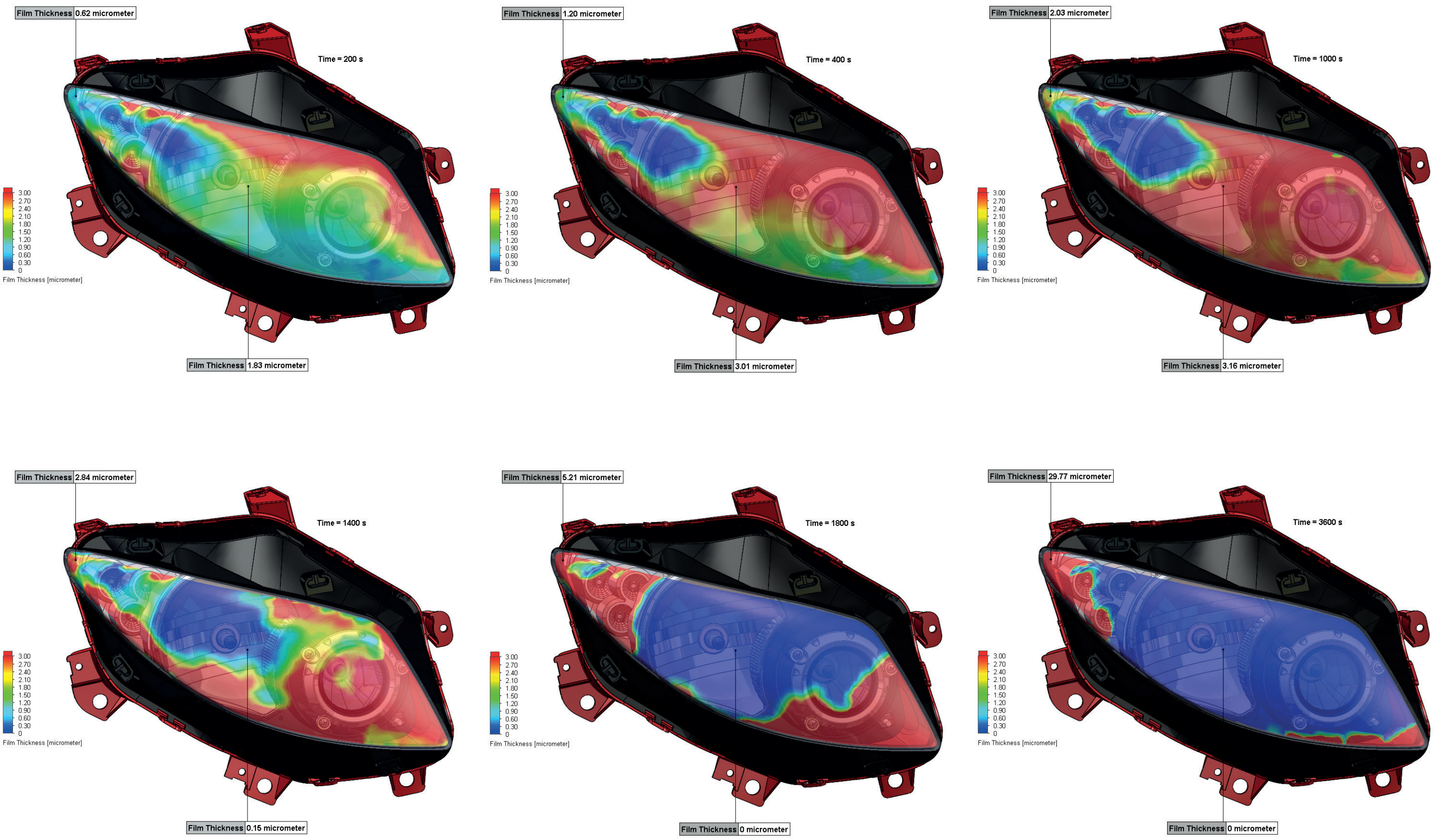

Figure 3. Film thickness development at different points in time

and solver. The net effect is a tool that can efficiently and quickly overcome the most user-intensive, time consuming hurdle of conducting these types of analyses.

So the automotive lighting supplier began adopting FloEFD to tackle these problems. Since the main bottleneck in their process had been addressed by FloEFD, as can be human nature after a relatively brief "honeymoon" period, these strengths became accepted as the "new norm" and the attention shifted to adding advanced functionality to address the demands of a complete headlight analysis. The Mentor Graphics FloEFD development team worked closely with the customer to understand their requirements, and in each of the successive releases of FloEFD enhancements were added to help make it a complete, expert tool to tackle automotive lighting applications. Many of these enhancements focused on advanced radiation capabilities, like spectral dependencies for radiative properties, like absorptivity and emissivity (implemented in a sophisticated ray-based approach), reflectivity options like diffuse, spectral, and Gaussian reflection, and improved handling of focusing and refraction for cases in which optical effects are important as well as thermal effects in semi-transparent solids. A module to FloEFD was introduced that included these enhancements as well providing the ability to create LED compact models, in which thermal and optical data from Mentor Graphics' T3ster® and TeraLED® devices could be used to create a more accurate representation of an LED in a CFD model. The LED compact model is unique in that the user simply assigns the forward current to the device (rather than the typical input of heat generation rate, which may not be clearly defined) and the output from the analysis will include the junction temperature of the LED, its resulting heat power, and the luminous flux.

Another capability added to FloEFD to address an area of concern for headlight designers is the ability to simulate condensation. As newer headlight designs have incorporated lighting sources that generate less heat (in particular LEDs), condensation on the lenses of headlights can become a bigger issue. FloEFD's water film evolution capability is able to model condensation, evaporation, and phase change (allowing for icing predictions), and display this information in a variety of quantitative and qualitative means.

Headlight Example

The following example highlights FloEFD's capabilities in simulating headlights, with a particular focus on surface condensation modeling. Figure 2 displays the model and the relevant parts that were included in the simulation.

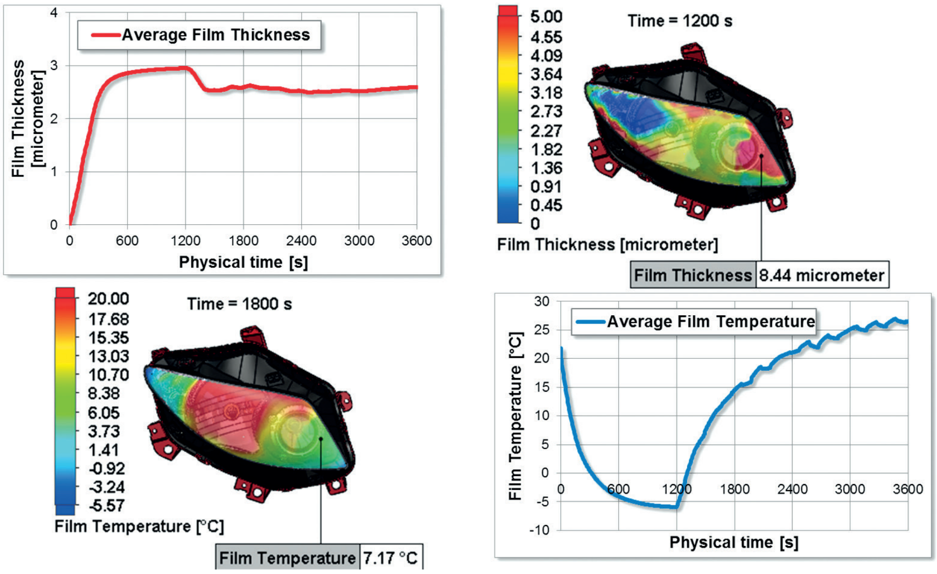

Figure 4. Development of film mass and temperature over time

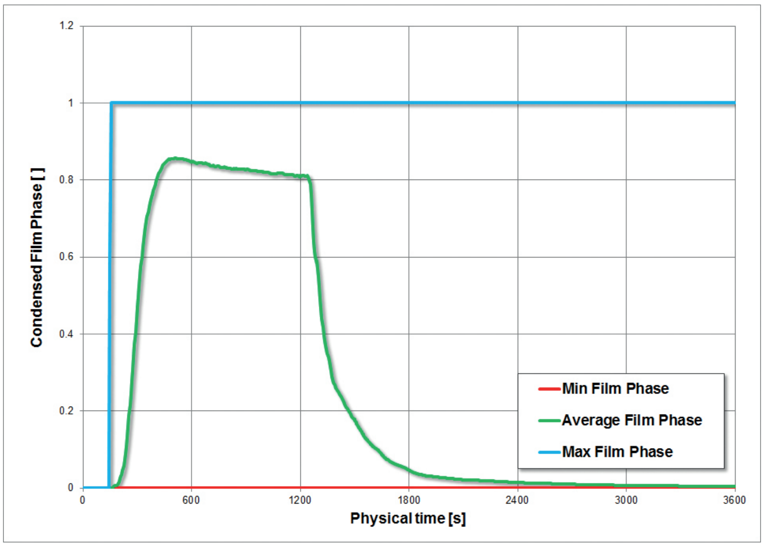

Figure 5. Transient history of film phase

The full conjugate heat transfer problem is modeled, including convection, conduction, and radiation. Appropriate material and radiative properties are assigned to each of the parts, including the lenses being modeled as semi-transparent to radiation with a specular dependency. The air space within the headlamp assembly is modeled. Transient heat transfer boundary conditions on the external faces of the assembly are used in this example, although the external air domain could have been included as part of the analysis as well. The pressure and temperature of the air within the assembly are initialized to 101325 Pa and 25°C respectively, the initial external temperature is set to -10°C, and the relative humidity is set to 95%. The inside surface of the front lens is set as "wettable" and is the region of interest to determine whether condensation occurs. The simulation scenario being modeled is:

1. A vehicle stopped in a cold humid environment: condensation starts;
2. After 750 seconds the LEDs are switched on; and
3. After 20 minutes (1200 seconds) the engine and lights are switched on: melting starts.

As the simulation begins the solid components start to cool due to the cold external temperature. Since the air within the headlamp is initialized with a high relative humidity, condensation begins to form on the inside surface of the front lens. Figure 3 shows the progression of the film thickness of the condensation at different points in time. At 1200 seconds the halogen bulbs, as well as the engine, are turned on. This starts to add heat to the system, and it is seen from these images that the film begins to be cleared, especially in the region in front of the high beam reflector.

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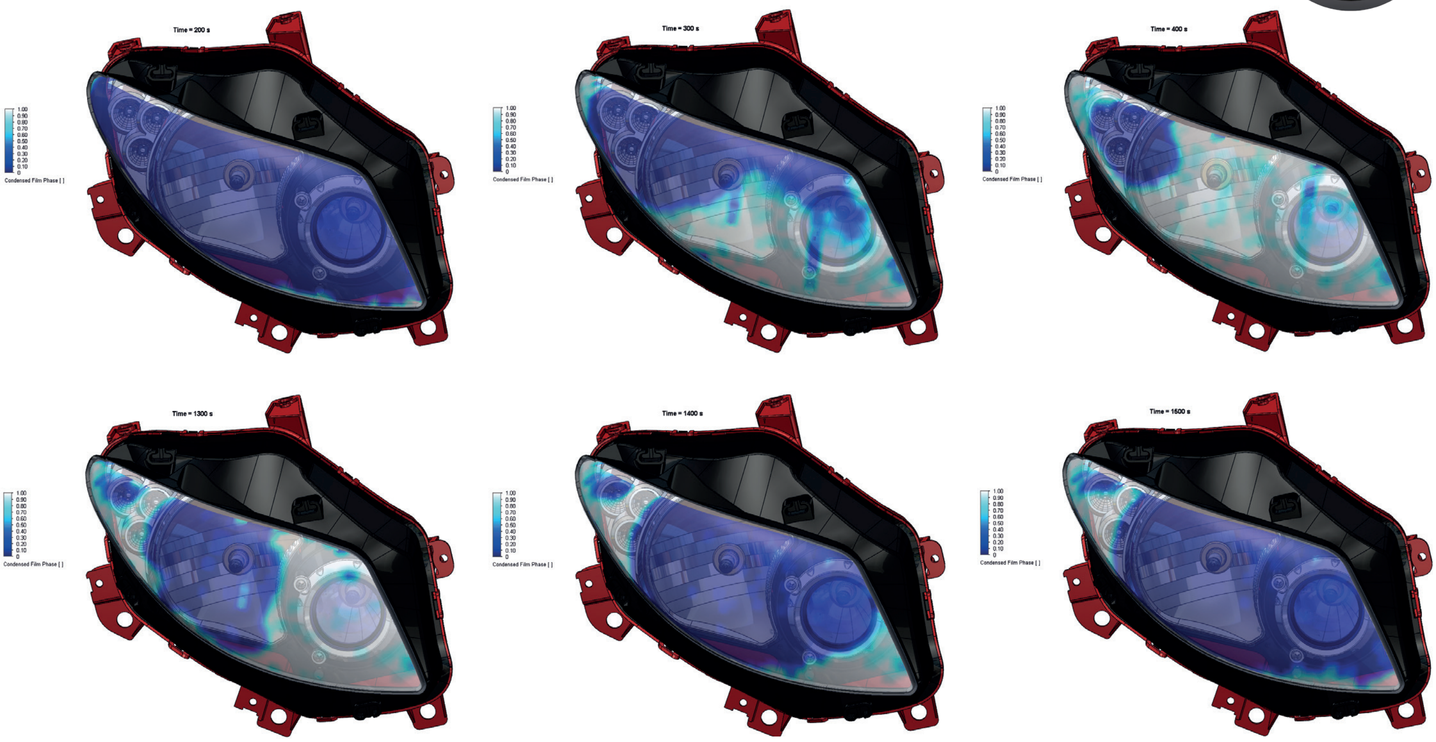
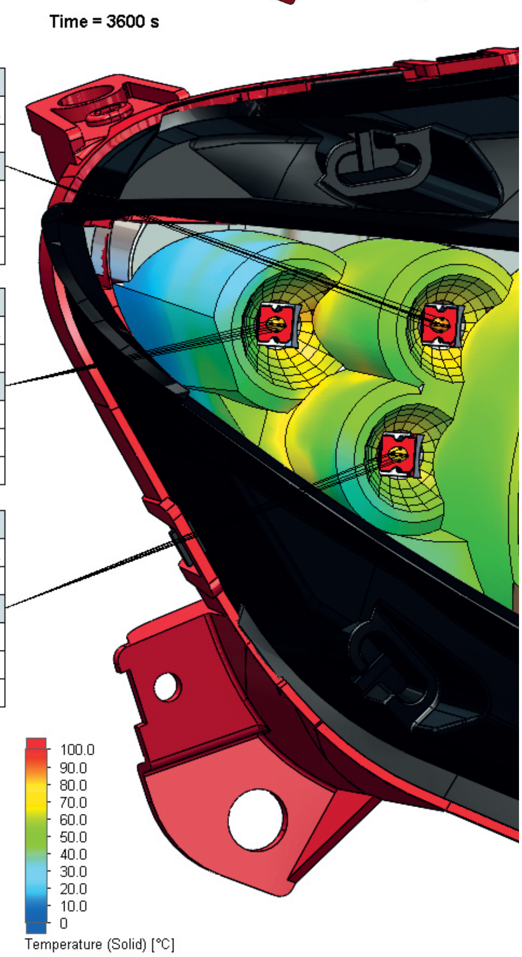


Figure 6. Development of condensed film phase on inner surface of outer lens over time



LED (Input)	
Type	Osram Golden Dragon QA
Current	Dependency
LED (Output)	
T junction	102.0 °C
LED Heat Generation Rate	0.915 W
Luminous Flux	96.92 lm

LED (Input)	
Type	Osram Golden Dragon QA
Current	Dependency
LED (Output)	
T junction	100.2 °C
LED Heat Generation Rate	0.914 W
Luminous Flux	97.41 lm

LED (Input)	
Type	Osram Golden Dragon QA
Current	Dependency
LED (Output)	
T junction	101.5 °C
LED Heat Generation Rate	0.915 W
Luminous Flux	97.07 lm

Figure 7. LEDs performance

Besides the contour plots that show the distribution of condensation, FloEFD can output integrated information about the film history as well. Figure 4 shows the progression of the film thickness over time. As expected the average film thickness grows initially, ultimately flattens, and at 1200 seconds (when the lights and engine turn on) begins to decrease. However, after an initial decrease the film thickness flattens again. If one examines the contour plots of film thickness it appears that most of the lens is cleared. So why does the film thickness graph seem to not reflect this? As the heat from the bulb immediately clears the condensation from the lens in front of the bulb, this moisture is re-introduced into the airspace with the headlamp and increases its humidity. This humidity in the air is able to re-condense on colder surfaces in the corners of the headlamp. So although the overall area that contained condensation was substantially reduced once the engine/lights were started, there were some smaller colder regions in the corners that allowed a thicker film of condensation to re-form.

Another interesting phenomenon being shown in this simulation is that not only does condensation form on the inside of the outer lens, but this condensation freezes. The graph shown in Figure 5 tracks the phase of the film over time, and clearly by around 500 seconds most of the film has frozen. This continues to 1200 seconds when the lights/engine turn on and are able to melt the frost from the lens.

The images in Figure 6 show contour plots of the condensed film phase (with 0 being liquid and 1 being solid). They show the development and distribution of the ice forming on the lens and ultimately melting.

Additionally, the LEDs were modeled using FloEFD's LED compact model (based on T3ster and TeraLED data). So the simulation is able to quantify various parameters of interest as seen in the image in Figure 7. FloEFD's fundamental strength of easily meshing complex native CAD models coupled with functionality introduced to meet the requirements of lighting applications make it the ideal tool for automotive lighting simulation.

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