OPTICAL SOFTWARE

Illuminating optics

Paul Schreier reviews a sample of the applications and breakthrough products that advanced optics software have made possible

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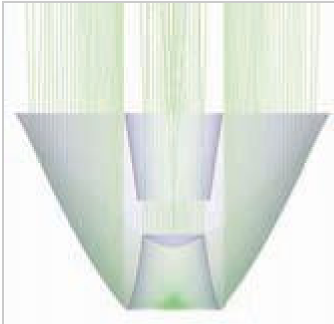


Zemax EE analysis of a TIR lens in an LED flashlight (courtesy of Optics for Hire).

It doesn't surprise us that state-of-the-art optics software has made contributions to the development of impressive projects such as futuristic space telescopes or in the cockpit illumination of next-generation airliners, but we often overlook how such software lets us enjoy the benefits of everyday products whether automobile headlamps or LED flashlights. By examining those applications, you can gain an appreciation of the multitude of areas where this class of software can be applied.

Collecting scattered light

If you peer into the lighting end of a traditional flashlight with a filament bulb, you'll probably look through a flat piece of protective plastic and see the reflector that gathers and concentrates the light into a beam. In contrast, look into an LED flashlight and you may instead see a very complex lens. Such a lens is needed because an LED is far from a perfect optical source; many radiate over as much as 180° and also have a 'batwing' profile: most light leaves at an angle between 40 and 50° with less coming out straight ahead and little coming at 90°. This pattern might be good for front-panel controls where the operator wants to see the LED from many angles but with a flashlight or a projector you want a collimated beam that projects the illumination straight ahead without any halo effects – and the lens that creates this column of light from the output of an LED is a complex, highly engineered piece of optics whose aspheric structure varies considerably over the aperture.

Using the Zemax-EE software from Zemax Development Corp, it is possible to arrive at an optimised lens that increases brightness within the beam by a factor of 10x in only a few minutes, reports Mark Nicholson, VP of operations. You start with the requirements for the flashlight, including the beam diameter (e.g. three inches) and angular diversion (e.g. < 5°). Next you create a merit function, based on these specifications and enter a starting design that can at least trace rays through the system. Activating the software's optimisation routines then varies the parameters of the starting design to provide an initial result, and users can also perturb the parameters to simulate manufacturing tolerances. One interesting aspect is that, as Nicholson states, 'ray tracing is embarrassingly parallel' because the rays don't interact with each other, and you can divide the several million rays in the analysis among the number of cores in a machine. As do recent versions of other optics packages, Zemax-EE checks with the operating system to see how many cores are available for the work and transparently divides the computational work among them – and the speed increase is roughly proportional to the number of cores, assuming the PC has enough memory to keep all the cores busy.

The figure above shows the cross section of a TIR (total internal reflection) lens that sits on top of and literally envelopes an LED. This analysis was performed by the company Optics for Hire (OFH) using Zemax EE. The complete lens is a hybrid of a reflector and small lens, which is placed at the centre to collect low-angle rays while high-angle rays are reflected by the side of the complete lens without the need for a reflective coating. 'Without this kind of software,' explains OFH president John Ellis, 'engineers would need to calculate by hand each path of the 10,000 to 1 million rays of light – which would take months compared to minutes or hours with the software.'

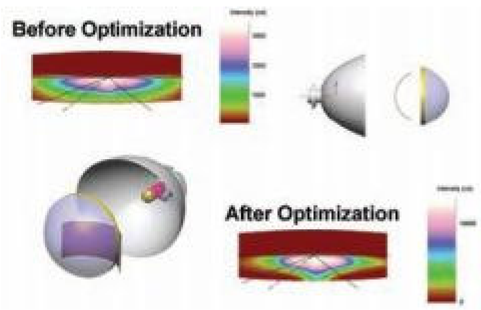
Balancing styling with functionality

We might take automobile headlamps for granted, but their design can be very complex. They must provide adequate illumination of the travel lane and the side of the road along with enough light to read signs, all without blinding oncoming drivers. Meeting these conflicting requirements is a delicate balance, states Mike Zollers of Optical Research Associates (ORA). If given enough volume for the headlamp, the design task is relatively trivial, he adds. However, a headlamp is a crucial aspect of a car's styling, so generally the design team creates a small cavity into which the headlamp must fit. But if the lens area is too small, it can't collect enough light.

The goal is to please the styling department yet meet legal requirements that regulate things such as vibration, thermal aspects, electrical as well as optical standards. Other questions that arise include: are high/low beams implemented with the same bulb? What is the light source: one of the many types of halogen bulbs, HID (xenon) lamps, or LEDs? Is there just one cavity for low/high beams, and do both beams use the same optics? Even more important, the headlamp must be manufacturable at a reasonable price. Clearly, headlamp design is a very interdisciplinary task.

ORA's illumination-design software for this job, LightTools, works with ray tracing techniques. The geometry exists as thousands of B-spline surfaces. For optical analysis, you must determine where light hits each surface as well as the surface normal at that location. The software must determine which surfaces the light hits first, examine to what extent the light reflects or refracts, and then finds the next surface to analyse. This involves many thousands of calculations that also include the effects of materials and surface qualities. Beyond ray tracing, LightTools includes an optimisation module that helps zoom in on the best possibilities. You select the light source, some reflector or lens optics and note the headlamp's output requirements. The software then makes thousands of modifications to the reflector and optics and eventually converges on a design or points out where major problems are.

To illustrate the power of such software, Zollers recalls a recent design for a projectortype headlamp and recounts that he was in a sense replicating work he did five years ago when still active in the automobile industry. In a projector headlamp, a filament is located at one focus of a reflector that is parabolic in one axis and elliptical in the other; the light passes through a condenser lens. A shade that creates a very sharp low-beam cut-off is located at the lens' focal point. Not only must the design optimise the shape of the reflector and the lens, a curved shield can compensate for field curvatures (a flat cut-off shield produces a 'smiling' cut-off pattern). Zollers explains that, when interacting with the software for only a few hours and letting it run for roughly a day, he arrived at a very satisfactory solution. At his previous job, in contrast, he spent weeks working fulltime with earlier optics software to achieve similar results.



A simple road schematic is overlaid on the output of LightTools analysis of a headlamp; it shows the driver's lane (right-hand traffic), the oncoming traffic lane and the horizon. In addition to the absolute magnitude of the light being >3x more in the optimised system, there is more foreground light just in front of the car, and the brightest portion of the beam has been shifted into the driver's lane of traffic.

When regulations rule

In applications such as automobiles, proper illumination is a factor that can lead to a product's consumer acceptance and thus market success, but in other areas regulations in this regard can be quite strict. One example concerns the flight decks of commercial airliners, where aircraft manufacturers prefer to perform simulations in software and thereby reduce the number of physical mockups, even though simulation does not replace the requirement for mockups in the certification process. This is to ensure that the pilot can see instruments clearly at all times under extreme conditions: bright direct sunlight must not wash out an instrument's display, and at night reflections and glare on the windshield can be particularly annoying and can also affect instrument readability by causing glare on the glass of an instrument face.

Simulations are also useful because aircraft manufacturers typically subcontract various elements including instrument panels and windshields, so nobody has an overall view of the design until it all comes together. Final testing is done with test pilots flying real aircraft, and if contrast is lost or there are bothersome reflections, it can be extremely expensive to rectify such situations. Not only might it entail moving instruments around and rewiring them, it could also mean that hydraulics, ventilation or electrical systems must be repositioned.

Because mechanical elements and systems are often designed and evaluated with MCAD software such as CATIA, one optical package that has become popular is SPEOS CAAV5 Based from Optis, a company that believes it was the first to integrate the simulation of light, based 100 per cent on a physical model, within CAD software. This proves especially useful, for example, if it is determined that the shield on top of an instrument panel is not large enough or has the wrong shape to block sunlight. In CATIA, designers can make the necessary geometry changes in minutes and relaunch the simulation process without the need to import any new data. On top of the CATIA materials library, Optis adds information related to surfaces and each material's optical properties. Users simply add information regarding the type of sources – whether LEDs, displays or ambient light. The software works with ray tracing for photometric analysis as well as visual ergonomics to integrate the overall scene and get the pilot's point of view. It not only does physics-based rendering, it performs quantitative and spectral analysis as well as examines chromaticity and luminance levels – all of which are tightly regulated by aerospace authorities, so it is important to know in advance if a flight deck will be approved.

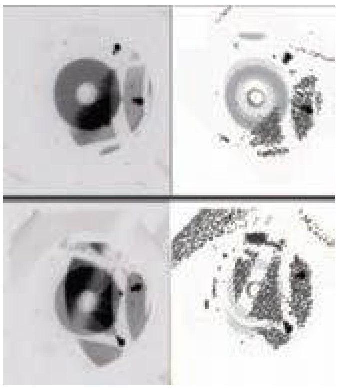
The multitude of cockpit instruments must be legible in any ambient light conditions, from bright sunlight to darkness. (Photo courtesy of Bombardier)

Designers at Bombardier in Montreal, Canada, choose SPEOS CAAV5 Based software because it shows the crew interface as it will be seen in its final context. It simulates visual perception based on a physiological human vision model and predicts visual obstructions, glare and reflection; it improves perceived quality by optimising colour, contrast, harmony, light uniformity and intensity as well as cabin lighting; it takes into account ambient conditions for sun, clouds, day and night vision; and it checks that the design complies with aerospace standards. Richard Heppell, manager of core systems engineering at Bombardier Aerospace, says that it took his group just two weeks to become operational with the SPEOS software, and he expects design times to be reduced by 50 per cent.

Telescope design need not be baffling

In any telescope, it's important to keep stray light, such as that coming from sources that are located near, but not in, the desired field of view, from reaching the mirrors and thus the detection elements, whether the human eye or an electronic sensor. Stray light is particularly significant when considering very bright sources, such as the sun, that can be many orders of magnitude brighter than the object of interest.

The primary tool for controlling stray light is the baffle, which is a shade, blade or vane with a non-reflective coating placed around or inside a telescope. A well-designed baffle can drop light intensity by several orders of magnitude, but some stray light does reflect and/or scatter and continue towards the detector. Therefore many modern telescopes employ baffles containing two or three vanes that block the path of stray light to a high degree.



With experienced use, there is a high degree of correlation between actual images taken by modern telescopes and simulation results produced by current state-of-the art analysis software. Here, you can compare an actual image (top left) and FRED simulated image (top right) of the Apache Point Telescope looking 1° north of Jupiter, which is a source of stray light, as well as an actual image (bottom left) and FRE D simulated image (bottom right) looking 2° north of Jupiter. In this comparison you can see why stray-light problems vary from different out-of-field sources.

When designing baffles it is necessary to find the optimum shape, spacing, alignment and coating. Interestingly, the baffles for the original Hubble Space Telescope, which went into service 20 years ago, were initially designed without computer assistance. Analysts using crude stray-light analysis software then came up with a solution that had three times fewer vanes in the baffles, yet considerably improved stray-light reduction. Today, the use of modern analysis software has become routine to optimise the performance of these incredibly expensive instruments. In the design of the LSST (Large Synoptic Survey Telescope), scientists at NOAO (the National Optical Astronomy Observatory) have turned to the FRED software package from Photon Engineering. Expected to start operation from its mountaintop site in Chile in 2015, the LSST is unique among large telescopes due to its very wide field of view: 3.5° in diameter (by comparison, both the Sun and Moon, as seen from the Earth, subtend 0.5°.) Taking more than 800 panoramic images each night, it can cover the sky twice each week. Hundreds of images of each part of the sky will be used to construct a database, making it far easier to identify celestial bodies ranging from exploding supernovae to potentially hazardous near-Earth asteroids. Its imaging system employs the world's largest digital camera, with 3,200 Mpixels. To achieve its very wide undistorted field of view requires three mirrors rather than the two used by most existing large telescopes as well as a very complicated set of baffles.

‘When stray light became an issue 30 years ago, it took designers months to perform hand calculations to determine stray-light rejection of an optical system for just a few off axis angles,’ explains Mike Gauvin, VP of sales and marketing at Photon Engineering. ‘With the first software for stray-light analysis 20 years ago, engineers had to describe the geometry with equations, and it took a month to examine a simplified version of the instrument composed of only the most basic optics and baffles. Today, with CAD-based software such as FRED, scientists can analyse the entire telescope, not just the optics, with millions of rays – and all in a few hours. Without such tools, telescopes like the Hubble would not be able to discover the origins of the universe, find black holes and take the stunning pictures of the cosmos that it has.’