When the Boeing Company and the FAA needed to develop innovative, efficient lighting solutions, they turned to Rensselaer’s Lighting Research Center

By Jodi Ackerman-Frank

The Dreamliner is a sleek, next-generation Boeing 787, a long-range twin-engine jetliner equipped with much of what the latest technology has to offer. The aircraft’s modern carbon composite frame is at least 10 tons lighter than its traditional counterpart. It is also the most fuel-efficient commercial jet in the global market. Perhaps the most attractive aspect of the Dreamliner, though, is the interior—most noticeably the cabin—where passengers are greeted by a spacious domed entryway that’s illuminated by dramatic overhead lighting, which resembles an infinite blue sky.

Passengers can dim or lighten the electronic shading embedded in the windows with the touch of a button. Along the sidewalls, subtle LED fixtures provide full-color spectrum lighting, and upgraded reading lights dot the spaces where the 200 or so seats are situated on either side of the aisle.
Nadarajah Narendran, LRC director of research and principal investigator of the partnership established between the LRC and Boeing.
Many of these new cabin features are a result of advanced lighting technology and design. The Rensselaer Lighting Research Center (LRC) has played a central role in Boeing’s ability to successfully incorporate this new state-of-the-art aircraft lighting that is already enhancing the airline passenger experience.

“Boeing’s focus was to find ways to take the passenger flying experience to the next level, and lighting is a big part of that,” says Nadarajah Narendran, LRC director of research and the principal investigator of the partnership established between the LRC and Boeing.

The LRC and Boeing partnership began in 2005, when the world’s largest aerospace manufacturer was searching for collaborators to assist in the development of innovative, efficient lighting solutions for its commercial aircraft.

The LRC leads the globe in university-based research and education devoted to sustainable lighting. Since 1988, it has built an international reputation for its expertise in advanced lighting technologies, application demonstrations, and product testing and evaluations. As world-recognized specialists in the field of vision science, LRC researchers also focus on how light affects visual perception, cognition, and overall human health.

“There are experts around the world who specialize in these different areas, from
LED lighting is a key element in Dreamliner’s cabin. Boeing has targeted this type of solid-state lighting because of the technology’s potential for significant weight reduction and lower maintenance costs over traditional light sources.

LEDs, or light-emitting diodes, are made from semiconductor chips, the size of sand grains. They are covered with mini-plastic lenses and connected to an electrical circuit. Unlike incandescent bulbs (which include traditional household light bulbs and halogen lamps), LEDs don’t have a filament that burns out easily. They also can last more than 50 times longer than the incandescent bulb if designed correctly, and they demand far less electric power to produce the same amount of light.

LEDs also can emit virtually any color of light without the use of filters, and in many cases, they offer better quality light and deliver it more efficiently. The color of the LED light depends on the material from which it is made. A blue LED, for example, is most commonly composed of indium gallium nitride. One way to create a white LED is to combine a blue LED with a...
yellow phosphor. For decades, colored LEDs have been used as simple indicator lights for TVs, phones, radios, and other electronics. Over the last several years, however, white LEDs have become bright enough to replace the standard incandescent light bulb in many everyday uses.

Despite the many promising applications of LEDs, assisting Boeing in turning solid-state lighting into standard aviation lighting for the Dreamliner was a monumental task. For one thing, the type of LEDs used on the aircraft did not exist when Boeing and the LRC embarked on their partnership seven years ago.

“The technology was not quite ready at that time, so we had to explore and combine various off-the-shelf technologies—and ‘dream up,’ if you will, alternatives that Boeing could possibly use during the concept design stage. Then we had to evaluate them,” says Narendran.

The LRC research team’s first task was to acquire a comprehensive understanding of the benefits, drawbacks, and perceptual differences of LEDs and how they could be best integrated into the cabin area of the new aircraft. LEDs are inherently different from other forms of light sources. For example, LEDs are easily affected by temperature changes.

Realizing the complexity in the practical application of this technology, LRC researchers explored the dynamics of LEDs in nearly every aspect, from the brightness of their light and their thermal management mechanics to how they affect human circadian rhythms. They conducted lab experiments, created mock-ups of aircraft interior, and tested new lighting concepts and prototypes on volunteer participants.

“We wanted to know if an LED lighting system would be able to produce adequate light,” Camp says. “The Lighting Research Center reviewed the overall LED industry and provided the technical recommendations needed for an LED system to meet our interior lighting requirements.”

LEDs have been efficient and long-lasting as indicator lights in electronics for decades, but using them to create stable high-quality white light for general lighting purposes presented new challenges.

One issue that had to be worked through was how to dissipate the heat produced through the LED and its circuitry. While LEDs may be cool to the touch, the internal part of the device can quickly overheat when high current passes through the junction, causing irreversible damage. Heat buildup is a byproduct of using high-power LEDs for white light, and that heat must be removed in order to maintain good performance over a long period.

To address this challenge, LRC researchers explored different lightweight heat-sink concepts. Heat sinks are attached to the back of an LED fixture, can be designed to serve as a reflector to direct the light beam while drawing the heat away from the LED.

“We showed Boeing a couple of simple lighting options and then offered specifications so Boeing’s design team could develop new solutions,” Narendran says.

**RIGHT LIGHT AT THE RIGHT TIME**

It is well-known that light exposures regulate our biological or circadian rhythms that repeat themselves about every 24 hours, including the sleep-wake cycle. But, on long air flights, these cycles can become disturbed and become out of sync, the reason that many passengers experience jet lag.

“Our circadian rhythms are governed by retinal exposures to light and dark. Short-wavelength (blue) light is the most potent, so by controlling the timing and duration of blue light exposure, we can adjust the biological clock to different time zones,” says LRC Director Mark Rea, who specializes in visual and circadian processes related to lighting. “We can also activate the brain at night with long-wavelength (red) light, much like a jolt of caffeine, without affecting the biological clock at all.”

In other words, using the right light for the right time of day can enhance a person’s comfort level and alertness. Use the wrong lighting, however, and a passenger’s favorable flying experience could fly out the window. Equipped with this knowledge,
standard fluorescent lighting in full force. “The great thing about LED lighting is that it can be ‘tuned’ to different colors, unlike traditional light sources,” Figueiro says. “The idea is that using the right light during the right time of day can enhance or hinder a person’s well-being.”

“Boeing is proud of its partnership with RPI and its Lighting Research Center,” says Wanda Denson-Low ’78, Rensselaer trustee and senior vice president of Boeing’s Office of Internal Governance. “The work of the LRC has played an important role in helping Boeing advance aviation through the effective use of lighting technology. The Rea and LRC colleague Mariana Figueiro ’98 offered recommendations, including defining which colors could benefit passengers most during a flight and also how window shading can add to a superior flying experience.

“There are some simple guidelines you can follow to prevent jet lag,” Figueiro says. “Say you’re flying from New York to Paris, and the plane is ready to land. The first reaction might be to open the shade and look outside. But that’s probably the worst thing you can do for jet lag. You want to protect yourself from light as you’re landing in Paris.”

The attractive electrochromic windows in the Dreamliner are 60 percent bigger than in traditional airplanes as a way for passengers to reconnect to the flying experience. With five different tint settings at their fingertips, passengers can control the amount of light that comes through the window. The airline crew has ultimate control over the windows from a central point.

The color of light produced by the versatile LED system on the upper walls and ceiling also can be controlled by crew members, who can then provide the most optimal environment for passengers during different stages of a flight. For instance, a sunset might be simulated around dinnertime. Or, during landing a sunrise might be composed that slowly alerts passengers of their arrival time—a much gentler approach than switching on use of LED lighting in Boeing commercial aircraft is helping to improve the overall passenger experience and reduce aircraft maintenance costs.”

A NEW ERA OF CREATIVITY

The Dreamliner, the first midsize airplane capable of flying long-range routes, completed its first commercial flight, from Tokyo to Hong Kong, last fall. Since then, 843 Dreamliner orders have been placed by 57 airline companies from around the world. Already the Boeing aircraft has earned international accolades over the past year by such prominent organizations as the American Institute of Aeronautics and Astronautics and the National Aeronautic Association. This spring, the Dreamliner was recognized by the European Institute for Creative Strategies and Innovation, which gave Boeing its top award. Awards are given to companies or organizations whose ideas and products help advance society. The jury of judges was impressed by Boeing’s creative research and development methods, which included input from international passenger organizations, university studies, and industry experts.

This is the first time the organization has recognized an aviation company with such a prize. Last year, the institute gave the grand prize to French Director Jacques Perrin for the movie Oceans.

“Boeing’s focus in designing the airline cabin was all about aesthetics for a great passenger experience,” says LRC Associate Director Russ Leslie, who led the lighting design team in the Boeing-LRC partnership.

To produce the effect of the blue-sky dome in the Dreamliner’s entryway, Leslie’s design team studied the works of various artists, including James Turrell, who is well-known for his experiential pieces that explore light and space. Based on such artwork, the team focused on how to make the ceiling more spacious using color and in the design of the overhead bins.

“We worked hard on how the framing of the luggage bin area would allow you to see the ceiling and then came up with a defined wash,” Leslie says. “It can be a very saturated blue, and when it’s in that mode, it really does seem like you’re staring into a blue sky. You can’t tell whether that’s a
SAFETY IS NOT JUST A LIGHTING ISSUE, BUT THE FAA WANTED TO LOOK INTO WAYS THAT BETTER VISUAL CUES COULD HELP PILOTS LAND SAFELY IN RURAL AND REMOTE AIRFIELDS.

Nadarajah Narendran

half a mile or just a few feet above you.”

“The LRC played an important role in the overall lighting and interior architecture development of the Dreamliner’s cabin,” Camp says. “When the design process was complete, we knew how the lighting and architecture would work together for the passenger cabin illumination. The blue sky lighting has a dramatic effect and was precisely what we needed to introduce a new airplane to the market.”

In addition to working with Boeing, the LRC has conducted notable work for the Federal Aviation Administration (FAA) over the last decade, providing important insights and guidance that have been driving changes in aviation lighting across the United States and the world.

In 2005, the LRC was selected to join the FAA Centers of Excellence program, created to solicit partnerships with world-class academic institutions and industry to coordinate research and development in aviation technology. Academic institutions are selected on a competitive basis. The LRC was called to apply its expertise in technology, visual performance, and application of LEDs in airfield lighting.

In particular, the FAA was interested in the potential of LEDs to replace existing incandescent lighting on airfields.

“At the time, solid-state lighting was a new light source,” says Donald Gallagher, the FAA visual guidance program manager for airport safety research and development. “Even in our own agency, there was a lot of speculation that LEDs couldn’t match up to the standards of incandescent lighting. Our work with the LRC was to show the facts of what LEDs are really capable of.”

Since that time, the LRC has conducted lab and full-scale field studies in collaborations with the FAA, universities, and industry specialists to determine how new LED technologies can be applied to runways, taxiways, approaches, and other airfield areas.

In its work with the FAA, the LRC has been shedding light on improving visibility in remote airfields. In Alaska, for instance, dozens of tiny airfields serve as points of landing in areas that cannot be easily accessed by road. For reasons ranging from cost and an unreliable grid or generator power to damaged light bulbs due to harsh weather, many of these landing areas do not have proper lighting to help pilots land safely. In fact, Alaska has the highest aviation accident rate in the nation, according to the Alaska Department of Transportation & Public Facilities.

“Safety is not just a lighting issue, but the FAA wanted to look into ways that better visual cues could help pilots land safely in rural and remote airfields,” says Narendran, also the principal investigator of the LRC’s work in the Centers of Excellence program.

The LRC team—Andrew Bierman ’89 and Zongjie Yuan ’07, along with Rea—developed prototype airfield light fixtures, which were placed at the corners of runways in flight tests in Florida, Alaska, and North Dakota. The LRC and FAA collaborated on these field studies with Embry-Riddle Aeronautical University in Florida, along with the University of North Dakota and the University of Alaska to confirm the accuracy of the new metrics.

In 2010, the FAA remote airfield lighting team installed a lighting system, designed and built by LRC and FAA researchers, at a small airport in the native village of Napaimute in Alaska. In November of the same year, the value of the lighting system became clear. A pilot, en route from McGrath to Aniak, was able to land with confidence at Napaimute’s airfield to pick up a critically ill resident well after sunset because the pilot could see the outline of the runway from several miles away.

A key challenge in replacing traditional incandescent lighting with LED technology in airfields is that the type of light emitted from each source is different. Filters are used to produce colored light in incandescent lamps. The colored light from LEDs, however, is produced by the light source itself. As a result, the spectrum of the light produced by the two technologies is remarkably different.

Chromaticity standards (based on the quality of a color related to its hue) for “aviation white” were established in the 1960s based on incandescent light sources. Therefore, even though white LEDs offer

A study subject views a scale model simulation of a remote airfield and surrounding community at night.
better visibility and color recognition, the existing boundary for aviation white excludes certain ranges of white that LEDs produce.

“Only a small subset of commercially available white LEDs meet the current chromaticity requirements for aviation white, making it difficult to adopt this energy-efficient technology for airfields,” Narendran says.

To tackle the issue, LRC senior scientist John Bullough ’91 led a team of researchers and conducted several studies to reformulate the chromaticity boundaries that people perceive as white and for other colors as well. These newly formulated color boundaries are now being considered in airfield lighting standard revisions.

“Obviously, everyone wants to save energy. But more important, we noticed that LED lighting gave a better visual signal to pilots, so adopting new standards in order to better integrate LED technology is a critical part of advancing airfield lighting systems,” Gallagher says.

One way that the LRC is initiating new lighting standards is through its work with runway guard lights. These flashing yellow lights are used to help pilots detect the presence of taxiway and runway intersections. Busy airports typically construct taxiways, marked pavement along which aircraft taxi to or from a runway, to allow aircraft to leave the runway at higher speeds so that another plane can land or depart more quickly.

In a multistage project, LRC scientists conducted lab and field studies to understand and compare lighting parameters between incandescent lamps and LEDs. Researchers also studied how LED lights appear to pilots in certain weather conditions compared to halogen lamps.

The project encompassed collecting reaction times and visibility data from participants tested in a lab setting that simulated a scaled-down airfield under different visibility conditions. The results showed that for all the weather conditions studied, the existing requirements for the light intensity (perceived brightness) of halogen bulbs are sufficiently noticeable to pilots.

To maintain the same perceived brightness in LEDs, however, the researchers had to reduce the light intensity by more than 60 percent, among other changes, which in the end resulted in good news: LEDs provided better visibility than incandescent lamps while significantly cutting energy demand. To confirm the lab findings, the LRC conducted a field experiment at the Schenectady County Airport in Glenville, N.Y. New specifications for LED runway guard lights were developed based on this and other research.

Last year, the FAA funded Embry-Riddle to conduct the last stage of the three-year research project—a large field evaluation at Daytona Beach International Airport to validate the previous findings. Built using the new specifications, LED runway guard light fixtures were installed at the airport.

“Embry-Riddle faculty collected the data and found that their research replicated everything we had simulated in the lab and at the Schenectady airport,” Narendran says.

INTERNATIONAL COMMUNITY TAKES NOTE

Last fall, during an International Civil Aviation Organization (ICAO) conference, hosted by Rensselaer on campus, the FAA shared these and other LRC research findings with ICAO representatives. A specialized agency of the United Nations, the ICAO sets international aviation standards and regulations.

Among suggested changes to several standards, including color boundary guidelines, the FAA shared a new formula for calculating the most effective intensity (perceived brightness) for the LED flashing signal fixtures.

“Our ICAO working group accepted our recommendations, with some minor changes,” says Gallagher, who added that these color-boundary changes already have been added to FAA airfield regulations.

“We are very enthusiastic in our collaborations with the aviation industry in realizing the undeniable potential for solid-state lighting,” says Narendran. “Every time we can demonstrate the possibilities and benefits of new types of lighting, we take another step in creating a positive legacy for society.”