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A History of Boeing Commercial Transport Flight Deck Lighting and Display Optics Innovation

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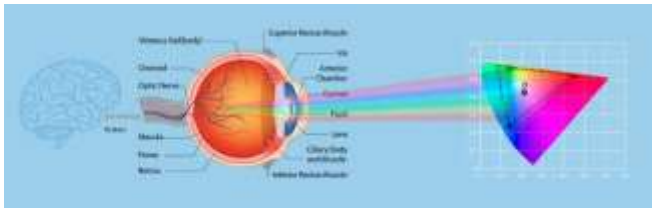
***Abstract* – The past three decades have seen tremendous innovation and advances in aircraft *lighting* technologies, including the implementation of solid-state lighting and display optics into the flight deck. This progress is capping a 100-year technology evolution that began with electromechanical gauges and incandescent bulbs. Improvements over this time have resulted in significant benefit to the customer, their businesses and to the pilot users. In pride, commemoration, and celebration of Boeing's 100th anniversary, and to honor our engineering heritage, it is an appropriate occasion to look back at the past, discuss the present, and look ahead to the future of Boeing flight deck lighting and display optics design innovation.**

***Index Terms* – color, display optics, displays, flight deck, human factors, LCD, LED, light, lighting, optics, readability, visibility, vision, visual human factors.**

I. Introduction

The pilot visual task is critical for efficient and safe operation of the airplane. The design is exceptionally challenging due to tradeoffs between: visual human factors and lighting technology capability; weight, power and cost constraints; the extreme ambient lighting environments ranging from night to bright day; and the dynamic nature of flying (for example, in and out of clouds). The past thirty years have seen remarkable progress in aircraft lighting and display optics due to the application of solid-state LED (light emitting diode) light sources and LCDs (liquid crystal displays). LEDs and LCDs are disruptive innovative technologies.

The lighting and display optics designer's goal is to optimize the visual interface of the flight crew to promote safe operation of the airplane. The purpose is to satisfy the end user and obtain certification. Aircraft flight deck lighting design and performance criteria is to ensure prompt and accurate readability and visibility, color identification and discrimination of needed information under all expected ambient lighting and electrical power conditions.



The desired system for aircraft flight deck lighting and display optics is one that will furnish light of adequate intensity and distribution under all conditions of internal and external lighting so that the crew may read instrumentation, placards, check lists, manuals, maps, instrument color-coding, distinguish controls without confusion and without undue interference with their vision outside of the aircraft.

It can be a difficult task to integrate various lighting component media and light source technologies successfully. See Appendices A, B, and C for:

- System and component lighting & display optics design considerations,
- Flight deck lighting certification, and
- Visual performance factors.

In this paper, an overview of the significant past, present, and future lighting and display technologies and design approaches will be discussed along with their impact to business and crew operations. The primary flight instrument progress takes center stage, telling the flight deck design story. Boeing commercial flight deck design is the paper's focus, with brief mentions of military, exterior, and interior lighting and display optics.

II. Airplane Lighting Past Heritage

A. Incandescent Lamps & Electro-Mechanical Gauges

Even the earliest Boeing airplanes had pilot controls and indications. The U.S. Post Office started commercial aviation, and became a customer pursued by Boeing early in history.

[1] The first Boeing Company airplane, the B&W 1916 cockpit is shown in Figure 1 with round dials. These mechanical instruments had painted white lettering on black background, which were readable in the daytime when the sun was shining due to the reflectivity difference.

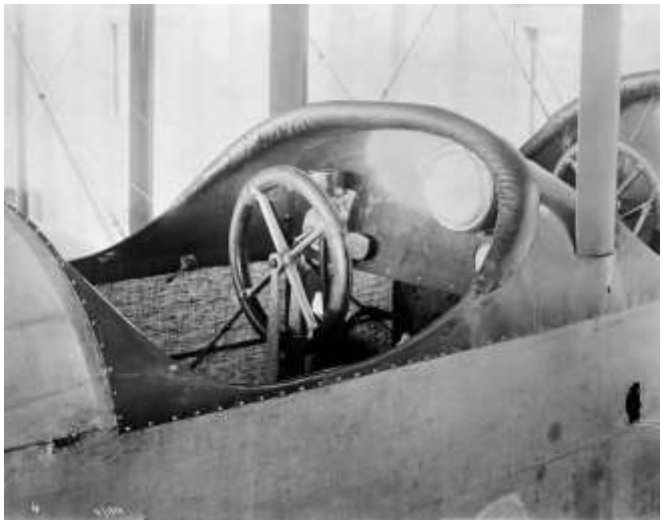


Figure 1. B&W Cockpit

"In the early days of flight, there were no navigation aids to help pilots find their way. Pilots flew by looking out of their cockpit window for visual landmarks or by using automobile road maps. These visual landmarks or maps were fine for daytime, but airmail operated around the clock. In 1919, U.S. Army Air Service Lieutenant Donald L. Bruner began using bonfires and the first artificial beacons to help with night navigation. In February 1921, an airmail pilot named Jack Knight put this to the test with his all-night flight to Chicago from North Platte, Nebraska. Knight found his way across the black prairie with the help of bonfires lit by Post Office staff, farmers, and the public." [2]

"…, by the mid-1920s the swashbuckling days of airmail operations had begun to pass. The lone pilot dressed in a leather flight suit who sat in an open cockpit battling the elements to deliver the mail was romantic but inefficient. The Postal Service began to focus on safety and reliability as well as on expanding operations. It established minimum lighting requirements for all airmail stations: a 500-watt revolving searchlight, projecting a beam parallel to the ground to guide pilots; another searchlight projecting into the wind to show the proper approach; and aircraft wingtip flares for forced landings. … As a final safety device, the requirement for a searchlight to be mounted on airmail airplanes was appended to the Post Office's set of requirements." [2]

In 1925, the first landing lights were installed on a mail plane and powered by a charged car battery. [1]

"In September 1929, Army Lt. James H. Doolittle became the first pilot to use only aircraft instrument guidance to take off, fly a set course, and land. He used the four-course radio range and radio marker beacons to indicate his distance from the runway. An altimeter displayed his altitude, and a directional gyroscope with artificial horizon helped him control his aircraft's orientation, called attitude, without seeing the ground. These technologies became the basis for many future developments in navigation." [2]

The Esterline Company recounts early Boeing history about Boris Korry and cockpit lighting design: [3]

""Aviation was still primitive then. Radio was in its infancy, clouds were a mystery and instrument flying was unknown," according to Lyle A. Wood, now a retired Boeing vice-president who started in engineering about the same time Korry did. Wood and another Boeing engineer, Richard Rouzie, recall that planes of the time had only two or three instruments - altimeter, oil temperature and oil pressure gauges. Later indicators added air speed and rate of climb information, but night flying remained rare into the 1930s and planes had little need for electric power. At most, a magneto would start the engine. At this time Boeing was still building both military and civilian planes, usually bi-planes, all made of wood and canvas. A far cry from what would be considered even minimalistic flying in modern times.

Rouzie remembers the 18-passenger, tri-motor mail plane (affectionately known as the "big box kite'') developed around 1930-31. Still made of wood and canvas, with welded steel tubes, this plane used two pilots and required more instruments and radios as it was required to perform night flying. On the military side, Rouzie remembers the Air Corps sending sketches of possible designs of lights to illuminate the instrument board of the Y1B9A, a single wing bomber that was one of the first all-metal planes. Boris Korry was a member of Rouzie's cockpit controls and instrument group, which worked out an early form of floodlight effect for the panel.

Later in the 1930s, recalls Wood, as planes began to use indicator lights of various kinds for information about landing gear, generators, etc., Boeing selected some indicator lights that were in use at the time by the telephone company. Not being purpose-built for the task, they were very awkward to use in such designs. Rouzie remembers that Boris Korry designed a cockpit enclosure for the commercial plane model 247, which was developed in the mid-thirties at the request of United Air Lines after its separation from Boeing.

Korry continued to puzzle over the problem of awkward indicator lights. According to Wood, Korry would work on designs at his Boeing drafting board during the day, then work far into the night on his machines at home and bring the completed pieces into work the next morning. He insisted on working out the designs himself, rather than turning them over to Boeing's experimental shop.

Korry eventually worked out a bayonet socket cap with spring access to the bulb, where the wires came from behind the panel and the cap could be twisted off easily to replace the bulb. Korry's design was first used in Boeing's 307 Stratoliner, [see Figure 2] the first commercial plane with a pressurized cabin, and purchased by Howard Hughes' TWA in 1937. [1947 first flight, 5] Those Stratoliners, with their Korry indicators, were still in use by El Al Airlines well into the 1970s." [3]

Figure 2. Boeing 307 Stratoliner

During the time of Boris Korry's employment at Boeing, he saw the aviation industry develop from a primitive pre-instrument period of wood and canvas airplanes to the manufacture of metal planes which could fly night and day in all weather and which demanded more and more sophisticated instruments. Shortly after developing his indicator light in 1937, he resigned from Boeing in May 1940, and started his own company that to this day provides Boeing and the industry with flight deck indicators, pushbutton switches, control panels, and displays.

As night flying became more prevalent and available, man-made lighting was increasingly needed for the cockpit instruments. At the same time, greater and greater demand for airfield lighting was driven by the pilots having to perform these difficult tasks. The early years of airplane lighting were based on the incandescent lamp as a light source shining on painted white-on-black electro-mechanical instruments. A cover glass was placed over the dial gauge or readout to protect the pointer and mechanical drum movements. The cover glass needed AR (anti-reflection) coating to minimize reflections from the air-to-glass interface.

Early lighting needs were covered by floodlights, post lights, and flashlights. [1] Figures 3 and 4 show examples of the incandescent cockpit and exterior lighting from the Grimes Hangar Museum. These technologies dominated for over 70 years, into the 1990s, until solid-state lighting devices became mature technologies.

Figure 3. Incandescent Indicator Lights, Map Light, Post Light [Grimes Hangar Museum]

The Boeing 707 flight deck had electromechanical flight and engine instruments. Primary flight instruments were arranged in the basic "T" with round dial engine instruments in vertical rows. Radios were operated from controls on the center aislestand using toggle switches, rotary switches, and dial readouts. Systems (such as hydraulic, electrical, fuel, air conditioning) were operated by the third crewmember at the flight engineer's station.

Figure 4. Incandescent Landing Light [Grimes Museum]

The move into the turbo jet era was significant for many reasons but displays and instruments remained relatively unchanged as illustrated by the 1967 [4] 737-100 flight deck in Figure 5. [5]

Figure 5. 737-100 Flight Deck

After the 707 and DC-8, the turbo jet transport continued to evolve with larger numbers and varieties of lighting leading to designs such as the 1969 747 flight deck that consisted of a 'thousand' lights, gauges, and switches as illustrated in Figure 6. [4]

Figure 6. 747-200 Flight Deck

B. Quest for Electronic & Flat-Panel Displays

The reflective needle-and-dial mechanical gauges and mechanical drums of most early aircraft needed repeated maintenance to keep their intricate 'clock-work' mechanisms operating properly. Yet for all their mechanical complexity, they were still reliant on ambient, aimed, or integral light in order for the pilot to see them. These devices ultimately made use of incandescent lamps shining on or integrally backlighting them for readability at night and in dark ambient lighting conditions. This was a huge step forward for flying in all ambient lighting environments; however, incandescent lamps do not last long because the heated metal filament will degrade over time and break. These lamps can also generate a surprising amount of heat. For these reasons, both Boeing and customers were always interested in some way to improve performance.

To address these design issues, Boeing and aerospace engineers continuously investigated and drove the state-of-the-art technology of the day, always looking for more reliable light sources and instruments. A major step forward for the industry came about in the form of new display types that could provide all the information previously presented via gauges and number readouts. According to industry display expert Larry Tannas, "Boeing was a driving force as a customer for electronic and flat-panel display technology." The flat-panel display concept is a "display which is flat and light, and does not require a great deal of power." [7, pg. 11] 'Electronic' means there are no moving mechanical parts to the device. Panel displays were gaining in prominence in consumer goods at the time, but this was not a case where a new technology could be directly applied as is. Tannas points out that, "The most taxing application for an electronic display is the aircraft cockpit." [6] The vibration, thermal, space and weight demands placed on these devices even in a flight deck environment are extreme. The benefits to their deployment however meant that Boeing had to pursue them.

During the late 1960s and early 1970s, Boeing research considered electronic displays for commercial transport airplanes. Figure 7 pictures an early version of the Boeing Super Sonic Transport mock-up with the implementation of CRTs (cathode ray tubes) for the flight instruments. [8] In this image, one can see the beginnings of what a future aircraft flight deck would look like, with panel displays providing more and more information as a 'primary' information source. Gauges and indicators in turn are reduced and moved increasingly to the peripheries of the displays.

Figure 7. Boeing Super Sonic Transport – CRTs Displays

This early research work ultimately led to the implementation of electronic displays (color CRTs) on the Boeing 757, 767 airplanes. Figure 8 shows an example of the 767 in 1981. The concept caught on beyond Boeing circles, at the time, with McDonnell Douglas later introducing similar approaches with the use of CRTs on the MD-90.

Boeing display and human factors experts Lou Silverstein and Robins Merrifield were instrumental in defining the display optical characteristics needed for the 757, 767 flight

deck during this time. “These displays were to be used as both primary and secondary flight instruments, replacing the legacy (dial and pointer) electro-mechanical instruments in past generations of commercial aircraft.” This was a very bold step for Boeing as these would be the first color CRTs ever used for flight instruments in any type of aircraft, military or commercial. Although the general trend was for avionics and flight deck technology to trickle down from military programs to commercial flight decks, Boeing’s approach totally reversed this. Boeing decided to jump ahead of the military programs and associated government funded research and development to develop the Boeing Electronic Flight Instrument System (EFIS) using color CRTs.” [9]

These changes were so revolutionary that Lou and Robin were honored by SID (Society for Information Display) with a Special Recognition Award for Outstanding Technical Accomplishments in 2004 for "their joint efforts in the conversion of a commercial airplane flight deck from mechanical instruments to color CRT displays, while maintaining safety of flight under all lighting conditions." [9] See Appendix D for more interesting background of their foundational work.

All of this effort led to the introduction of the Boeing 757 and 767 in the 1980s with two-crew glass cockpit for airline service. The term "glass cockpit" came about from this development due to this increasing use of cathode ray tube displays for most of the primary instruments in lieu of the old-fashioned "steam gauge" electromechanical instruments used on other airliners. [10] Coupled with Boeing’s focus on pilot usability, the use of graphical displays significantly reduced the number of individual parts required by the pilots to monitor engines and systems on-board the airplane. [9] This also reduced the airlines’ maintenance costs.

Figure 8. Boeing 757, 767 Flight Deck – CRT Displays

Boeing continued this evolution in electronic displays on Boeing airplanes like the 747-400. Depicted in Figure 9 are two versions of the 747, the original model with a ‘thousand’ lights, gauges, and switches and the upgraded 747-400. These electronic displays enabled the integration of data into information that is far more readily understood and interpreted by the flight crew. [5]

Figure 9. 747-400 and 747-200 Flight Deck Comparison

C. Automatic Brightness Control (ABC)

The use of electronic displays drove development of even more technologies and techniques in order to support their operation. Automatic brightness control was a significant design developed to satisfactorily integrate CRT electronic displays into the flight deck, and addressed, what can be, the dynamic and widely changing lighting environment pilots might experience in flight. The advent of self-luminous displays in the aircraft cockpit created the need to vary the display-generated luminance as the flight deck ambient illumination varies to provide the information to background luminance contrast ratio and symbol luminance required for easy readability. The extreme and dynamic variations in ambient illumination inherent in an aircraft cockpit necessitate some type of automatic brightness control to preclude frequent manual luminance adjustments. Boeing human factors studies, led by Silverstein and Merrifield, coupled with real-world experience concluded that failure to incorporate an automatic brightness control system, or implementation of an inappropriate system, would cause operators to keep the luminance set at a higher level than required during most of the flight. Setting the display brightness to the highest level minimizes the need for nuisance brightness adjustments during high-workload operations. Unfortunately, it also results in a reduction of the operational life of the display. [11] It was also clear that creating a lighting system that could distract pilots by requiring their attention and control would also detract from the primary goal having pilots focus on flying.

Based on pilot human factor studies conducted at Boeing, effective automatic brightness control systems were found to be required to maintain acceptable image brightness without the penalty of frequent manual brightness adjustments. [11] The Boeing ABC system automatically adjusts the displayed-information luminance based on three factors:

- Ambient Illuminance Compensation - changes the display luminance as a function of the level of ambient illuminance incident on the display as

detected by a display bezel-mounted light sensor. The emissive display luminance automatically adjusts to match that of surrounding reflective information like lightplates or to what is needed by the pilot.

- Adaptation Mismatch Compensation - changes display luminance as a function of the luminance level the pilots see out the window, adapted to their forward-field-of-view as illustrated in Figure 10, as measured by a forward facing light sensors mounted on top of the glareshield.

Figure 10. Boeing Sunlight Simulation Facility – Adaptation Mismatch

- Manual Compensation - accommodates the wide range of individual vision differences and preferences in the luminance and contrast sensitivity of pilots as well as the use of sunglasses or sun-visors.

Through careful study and experimentation, equations were developed to blend the input of these three variables properly into one single lighting level for the pilot's task at any time. These specific automatic brightness control requirement equations are then communicated to suppliers.

Another automatic brightness control feature introduced on both 757, 767 flight decks was to have annunciators get brighter and dimmer based on the ambient lighting environment to help ensure the alerts were attention-getting and seen. This automatic feature over-rides the indicator light manual brightness control switch. Due to their importance, annunciators (indicators) are on a dedicated electrical control circuit separate from lightplates and displays. The Boeing annunciator lighting circuit is known as Master Dim & Test (MD&T) and consists of providing 28 VDC nominal for the bright level and a 12 VDC (14 VDC for 737s) nominal level for dim and dark ambient lighting environments. Lightplate lamps' electrical circuit is variable from 0 VAC to 5 VAC. The constant annunciator brightness is higher than the lightplate background brightness, allowing them to be more attention getting. This is also assured with their carefully selected use of red warning (immediate action) and amber caution (immediate attention) color-coding.

D. Solid-State Lighting

As previously discussed, incandescent lamps still had significant problems as they do not last long. Their heated metal filaments break over time, and this breakage is exacerbated by airplane turbulence and vibration as well as voltage fluctuations in the plane. They also radiate heat making them hot to touch. The low reliability of the incandescent lights drove the need to include a test function in Boeing flight decks to check that the annunciator lamps were working. While functional, this feature added weight and complexity to the lighting system. In addition, the instruments and annunciator lights needed to be designed to be fail-redundant and lamps had to be easily replaceable, requiring spare bulbs to be carried on the flight deck to allow burnt-out lamps to be replaced in-the-field.

Well into the 1990s airline customers were dealing with the problem of pilots dropping miniature incandescent lamps or not replacing them correctly. Missing spares and incorrect bulbs also leads to customer frustration. Even today, pilots comment that the incandescent-lamp pushbutton switches are very hot to touch and burn out far too frequently. These issues continued to push Boeing engineers to strive to find better technology light producers.

An example of these attempts at solid-state light sources is shown in Figure 11. This is an EL (electro-luminescent) lamp created to replace incandescent lamps. EL light plates have proven more popular in some military applications and due to their longer life, attempts were made to use them for other lighting applications. It was however, the more ready access to Light Emitting Diode (LED) technology that allowed Boeing engineers to move away from the problems that plague incandescent use. Their combination of low weight, extremely long life and high durability as well as their very stable color and lumen output made this technology an immediate area of interest for Boeing. This is true even to this day, with flight deck lighting almost in its entirety now provided by LEDs.

Figure 11. Grimes First EL Lamp [Grimes Hangar Museum]

III. Current Lighting & Display Optics State-of-the-Art

A. *777 Flight Deck - "AMLCD: The Ultimate Avionics Display"*

A key point to keep in mind is that panel displays, such as CRT, are "electronic," but they are not a flat-panel. These displays—even optimized aerospace versions—are heavy, large, and consume a lot of power. For all the same reasons mentioned in prior sections, these negative qualities of the displays drove intense interest in Boeing to find better solutions. In 1981, Boeing research concluded, "A flat panel display having the best chance for breakthrough to replace CRT's in the next few years is probably Electroluminescent (EL), specifically, Thin-film EL (TFEL)." So began Boeing's very early effort and interest in deploying true "flat screen" displays.

Around 1985, with the rapid pace of display technology progress that was occurring in consumer circles, Boeing selected AMLCDs (active-matrix liquid crystal displays) as the technology to replace CRTs for the next airplane, the 777. Development of AMLCDs for the 777 spanned more than 15 years. [12, pg. 16] The 777 was the first airplane to utilize AMLCDs as primary flight instruments and can be seen in Figure 12. See Appendix E for detailed information about the AMLCD development at Boeing. [13, 14]

Figure 12. 777-200 Flight Deck: AMLCD

As can be seen in the previous sections, the removal of gauges leaves the display as key to the new digital electronic flight deck. Much like older instruments, these aviation displays must be readable any time all of the time within a fraction of a second regardless of the lighting or other environmental or flight conditions. Pilots and FAA certification regulations expect the primary flight instruments to be plainly visible with minimum head movement. [See Appendix B lighting and display optics certification criteria.] For these new digital electronic avionics, gyros cannot tumble or drift, images cannot wash out in bright light in the day or flood the cockpit with light in the night, black hole effects or white shirt glare conditions cannot exist. [6] All of these requirements in combination lead to a very challenging design problem.

Larry Tannas' thesis [6] is that the AMLCD is the only flight deck display that can do all the things ever wanted in the flight deck because it has two new performance features:

- Logarithmic dimmability over the full mesopic (.001 cd/m^2 to 3.4 cd/m^2) and photopic visual range.
- Immunity to ambient illumination without loss of contrast or color separation.

No other display technology to date has this capability without loss of some other significant performance parameter, such as loss in resolution as exhibited in CRTs. The AMLCD can be made as bright or dim as the backlight can be made to perform. A 4,000 to 1 dimming range is available. Hence, the origin of the title of this section comes from Tannas' paper, "AMLCD: the ultimate Avionics display." [6] The AMLCD backlight for these first AMLCDs was fluorescent lamp technology that was located behind the AMLCD in a serpentine shape. All current AMLCDs on Boeing commercial planes are now backlighted with LEDs as this technology has rapidly gained maturity, acceptance, and ability to produce white. The early AMLCDs had problems with: producibility; black-background uniformity; luminance, contrast, and color changes over viewing angle. AMLCD technology has improved tremendously since initial introduction, with LCDs everywhere in our lives now: cell phone, personal computers, laptop computers, and TVs. These successful commercial, large market demand and volume, applications have helped flight deck display technology, MVA (multi-domain vertical alignment) and IPS (in-plane switching), improve with better area and viewing angle uniformity.

The Boeing 777, introduced into service in 1995, was the first all primary flight AMLCD (active-matrix LCD) commercial air transport flight deck. These were not the first AMLCDs on Boeing flight decks. Nineteen ninety-three saw the first AMLCDs to be certified on Boeing commercial flight decks on the 737 and 767. The 3 ATI (3" size) twisted-nematic displays were added to the flight deck to meet a U.S.A. congressional mandate that airlines implement TCAS (traffic collision and avoidance).

Twisted-nematic AMLCD technology for the graphical primary flight displays were not the first LCDs installed on Boeing flight decks. The first LCDs on Boeing flight decks replaced electro-mechanical dynamic readouts using dichroic-dye segmented LCDs in the late 1980s. These basic LCD displays acted as a form of numeric readout, with a one for one replacement based on function. While these early systems showed benefit, they also highlighted the importance of significance of more complex display systems and helped provide lessons for the future.

In 1990, the FAA wrote Boeing a letter saying the segmented LCDs installed were sometimes not very visible at the pilots' design eye position in some ambient lighting environments. Although they would not de-certify existing segmented displays in-service, the FAA wanted to work with Boeing to establish certification criteria for future LCD installations. This work was accomplished by the SAE A-4 Aircraft Instruments industry committee, chaired by Boeing's

Robin Merrifield, to create SAE ARP 4256, "Design Objectives for Liquid Crystal Displays for Part 25 (Transport) Aircraft." [17] This work was the foundation for establishing industry certification criteria guidance for segmented LCDs and is used today along with SAE AS 8034 "Minimum Performance Standard for Airborne Multipurpose Electronic Displays" [18] and AC 25-11 "Electronic Flight Deck Displays." [19]

Boeing suppliers include Honeywell (737 NG and 777) and Rockwell Collins' (provided the first primary flight AMLCDs for the 767-400). It was during airplane taxi tests, that 767-400 pilots reported a surprise result. The display surface was distractingly shiny, like a mirror, making it difficult to read and see the information through the reflection. After considering many display technology solutions, human factors evaluations concluded that adding a light micro-texture to the front surface of the cover glass diffused and reduced the reflection so it was not objectionably distracting enabling on-time airplane certification and delivery. Figure 13 is an in-flight photograph comparing the situation with the solution. [20] This solution has been applied to all subsequent large AMLCDs on Boeing commercial and most military airplanes. As can be seen, these displays have been carefully studied and optimized over their life, with all aspects of their design tested and validated as needed.

Figure 13. 767-400 AMLCD Reflection

Other key lighting features introduced, on the 777, at the same time as these displays were being deployed include:

- Automatic brightness control - for the AMLCDs [11]
- Master brightness control - a single manual brightness control simultaneously adjusts all lighted equipment and displays [15]
- LEDs (light emitting diodes) – long-lasting, highly reliable, solid-state light sources used as a replacement for the majority of incandescent lighting to illuminate lightplates and annunciators on the flight deck. A principle reason for going to LED annunciators and indicators is that the 28 VDC thin filaments kept breaking under turbulence. At that time, the only LEDs available for white neutral color, with proven reliability, was yellow-green [16].
- For suppliers not ready to use LED technology for annunciators and indicators, the MD&T annunciator electrical circuit changed to 5 VDC for bright and 2.2 VDC for dim so lower-voltage-incandescent lamps with a thicker filament would be used for longer life.

B. 787 Flight Deck Lighting & Display Optics

The 787 flight deck, see Figure 14, lighting design state-of-the-art advancement provides significant benefits for the airline customer and pilot's "office in the sky" because it:

- Uses LED (light emitting diode) light sources.
- Implements new brightness control architecture.
- Was designed based on user feedback.
- Takes into account the latest visual human factors.
- Extensively utilized lighting computer modeling for design, analyses, and to visualize the design before metal was bent.

Figure 14. 787 Flight Deck

LEDs improve service life, reliability, touch temperature, reduce power consumption, reduce weight, and maintenance costs. The new brightness control architecture reduces weight, part count, and addresses the historical problem of brightness mismatch between panels.

New psychophysics-based display and area light dimming curves were created to ensure the pilots have the needed brightness and control. Display brightness automatically adjusts to reduce workload, and increase reliability, by compensating for adaptation mismatch and ambient illuminance by using light sensors. Individual manual brightness adjustment is provided to account for user vision capability and personal preference differences. Master brightness control allows simultaneous adjustment of all emissive display lighting. The 787 flight deck also sports a low-gloss, three-layer, new warm-gray reflective color scheme based on human factors research and employed new verification methods. Computer modeling was beneficial to analyze window and display reflections, and to visualize and communicate the area lighting design. [21]

Large-format displays are now being utilized for the:

- 767-2C KC-46A Tanker, modified to be NVIS (night vision imaging system) compatible,
- 767 FedEx cargo planes,
- 737 MAX, and
- 777X, with a touch screen added for touch-enabled display and control.

C. Exterior & Interior Lights

Using LED solid-state lighting for high-intensity landing lights has long been a vision for commercial aircraft and represents a major shift in lighting technology since the first incandescent lights were implemented approximately 90 years ago. Airlines currently replace halogen-landing lights approximately every 100 hours or roughly every two weeks.

In 2015, for the first time, LED Landing, Taxi, and Runway Turnoff lights were certified and delivered on large transport aircraft bringing tremendous benefit to customers due to long life and high reliability compared to current incandescent lamps. The introduction of these lights paves the way for other models to replicate the application, bringing benefits across the entire Boeing fleet. Because of the high intensity required, and the time it took for LED efficiency to improve, landing lights were the last lighting design area on the airplane to go LED. The new LED Landing Lights are a tremendous improvement in maintenance frequency and total labor hours for our airline customers.

Most Boeing commercial planes now use LED light source technology for navigation, position, beacon, anti-collision lights, passenger cabin, cargo, and emergency evacuation. Some Boeing planes use photo-luminescent wireless light source technology for emergency evacuation lighting.

IV. Future Lighting & Display Optics

The BCA commercial flight deck lighting & display optics future strategy includes:

1. Ensure valid optical requirements & requirement verification.
2. Strengthen design & analyses tools & skills.
3. Optimize certification process.
4. Keep abreast of lighting & display optics technology, methods.
5. Implement solid-state light sources.
6. Simplify lighting & display controls.

The current visual human factors and metrics are not perfect representations of the human visual system and performance. Because of this, lighting and display optics designs usually need to be visually evaluated with observers. Scientific progress continues to better understand and model our eye-brain system for colors, color rendering, brightness, glare, gloss, visibility, and alertness.

As an example, at the August 2017 IES (Illuminating Engineering Society) annual conference, a 2020 goal was established to improve the photopic response $V(\lambda)$ because it is based only on the center foveal 2 degrees of our vision and excludes peripheral vision that we know is important affecting vision and health. $V(\lambda)$ was first adopted in 1924 and is the basis for intensity, luminance, and illuminance metrics. It is expected this situation will take three to six more generations to achieve complete understanding and develop the associated metrics and test equipment. This will allow better products to be created to better match human needs from better requirements.

LED light sources and electronic flat-panel displays have enabled significant progress in safety, efficiency, and human interface within the aerospace industry. It is predicted that solid-state LED lighting and LCD disruptive and innovative technology will continue to dominate flight deck visual media technology over the next 20 years. It is expected in the future there will not be any “heated-wires” on the airplane and all light sources will be electronic, solid-state LED. In future flight decks, touch screens integrated with LCDs will be more prevalent.

LEDs and LCDs have been implemented with the promise of high reliability and long life. Significant advances in efficiency and technology make some LEDs and LCDs obsolete, not available, and drive re-design about every three to five years. Obsolescence must be planned for to mitigate re-design costs and production disruptions to ensure part availability.

Camera video systems are becoming more prevalent and will continue to proliferate. Key for good performance is system design integrating the camera, display, and ambient lighting. Better color rendering, brightness, and color dynamic ranges are key.

Displays are not easily readable in some sunshine conditions. Future display improvements are needed to improve this situation.

The future will see continued and more extensive use of lighting modelling using computers. Model based development is used to visualize and communicate the lighting design, it is used to conduct engineering design and analyses before building mockups, prototypes, and hardware. Optical modelling and photometric analyses is the study of electromagnetic radiation, and its interaction (reflection, refraction, diffraction) with objects, and ultimately its perception by the human eye, camera, or sensor. Aircraft have numerous design aspects that rely on predicting the behavior of light. [Boeing Eric Harvey]

The far future for the flight deck may be that there are no pilots on the plane. Then, there would be no need for flight deck lighting and displays on these unmanned vehicles except to make them visible and for maintenance and repair.

V. Conclusion

Traditional flight deck equipment used media that can be viewed by ambient light, and internal lighting was provided to enhance visibility, particularly when the ambient light level is low. Electromechanical-type instruments have been on Boeing flight decks since 1916 and are still in aircraft 100 years later. New solid-state electronic controls and displays have replaced the older type instruments and offer many rewards by reducing crew workload, improved flight operations and safety, reduced cost, and greater flexibility. Table 1. Illustrates the solid-state lighting and display

disruptive innovation seen in the world and adoption by Boeing commercial aviation.

Table 1. Boeing Commercial Airplane Flight Deck Lighting & Display Optics Innovation

1883 - Edison incandescent lamp
1916 - B&W
1962 - Holonyak first visible LED
1964 - Heilmeier first operational LCD
1981 - 757, 767 first electronic color CRT primary flight display
1993 - Nakamura white LED
1995 - 777 first flat-panel color LCD primary flight display
2010 - 787 LED airplane
2014 - Nakamura Nobel Prize in Physics

The past 30 years have been exciting, challenging, productive, and enjoyable for lighting and display engineers working the transition from over 70 years of incandescent-based lighting and gauges to solid-state LED lighting and LC-based, graphical, electronic, flat-panel displays. The technologies, requirements, design and analyses methods, test equipment, and methods have never been better. All of this yields a win-win situation for both Boeing and the customer by enhancing work effectiveness, aesthetics, and crew comfort making an efficient and truly integrated design possible. The future looks bright to meet our goals: 1) hold paramount the safety, health, and welfare of the public, and 2) satisfy our customers and make money. Let there be light!

APPENDIX A. LIGHTING & DISPLAY OPTICS DESIGN CONSIDERATIONS

The flight deck lighting and display optics needs to be designed for the following top-level system considerations: normal lighting systems; non-normal lighting, back up, standby, and battery systems; emergency evacuation; and service and maintenance. System level design considerations include:

- Human visual performance
- Ambient lighting environment
- The visual geometrical considerations include the pilot viewing angle and distance to the lighted components, window and display location for direct sun angles and night reflections.
- The light source and display technology affects the reliability and visibility and must be considered for the following factors: luminance, illuminance, chromaticity, temporal characteristics, thermal characteristics, aging, end of life, luminous maintenance, contrast, and dimming.
- The format and layout affects visibility by font, type, size, luminance, color, and shape.
- Color appearance is a function of spectral characteristics, gloss, texture, and reflectance.
- Glare and reflection.
- Regulation and certification.

After system design considerations are done, the component level requirements and guidance can be considered. The components include:

- Lightplate, integrally lighted information panels
- Switches, knobs
- Annunciators, indicators
- Control panel, keypads, and keyboards
- Touchscreen
- Electronic displays
- Alphanumeric electronics displays
- Head-up displays
- Integrally lighted instruments. Conventional instruments, painted white on black.
- Circuit breaker panel lighting
- Markers, placards
- General area and localized task and flood lighting
- Windows, visors, shades, transparencies.

Other design considerations are lighting control, light source considerations, optical requirement compliance verification, non-optical qualification, and environmental requirements for flight deck lighting.

APPENDIX B. FLIGHT DECK LIGHTING CERTIFICATION

There are regulatory, customer, and company requirements to consider in the optical design of flight decks. The primary pertinent FAA Part 25 lighting airworthiness standards for transport category airplanes Code of Regulations (CFRs) are:

- 25.773(a)(2) Pilot compartment view
- 25.1301(a)(d) Function and installation
- 25.1302 Installed systems and equipment for use by the flight crew
- 25.1303(a) Flight and navigation Instruments
- 25.1309(a) Equipment, systems, and installations
- 25.1321(a)(c)(2)(e) Arrangement and visibility
- 25.1322 Flight crew alerting
- 25.1381 Instrument lights
- 25.1543(b) Instrument markings: general

Certifiable performance to the CFRs of flight deck lighting and display optics is demonstrated on the airplane to FAA, EASA, and or AR (authorized representative) pilots in a conformed installation. The main visual performance items to demonstrate are adequate readability, visibility, color identification, and color discrimination of needed controls and displayed information in all expected ambient lighting environments and in all expected electrical power conditions. In addition, it must be checked that glare, stray light, and reflections do not interfere with crew duties during night and day flight.

Refer to SAE ARP 4103 “Flight Deck Lighting for Commercial Transport Aircraft” for general design and certification guidance. [22]

APPENDIX C. VISUAL PERFORMANCE FACTORS

The visual interface is the most important pilot and airplane interface. Execution of flight crew visual performance tasks and procedures are measured in terms of accuracy, speed, and comfort. Visual performance factors include:

- Task (who, what, when, where, task surface)
- Visibility, readability, legibility
- Font (visual size, viewing angle, distance, amount of lighted area)
- Luminance, illuminance, polarization, contrast
- Color, spectral
- Temporal, flicker, response time
- Glare, stray light, reflections
- Uniformity, balance, and
- Dimming.

APPENDIX D. CRT DEVELOPMENT

Lou Silverstein and Robins Merrifield were honored by SID with a Special Recognition Award for Outstanding Technical Accomplishments in 2004 for their work enabling CRT usage on the 757, 767 flight deck, "their joint efforts in the conversion of a commercial airplane flight deck from mechanical instruments to color CRT displays, while maintaining safety of flight under all lighting conditions." Following is the description of nomination for the award written by John Rupp. [9] Of course CRT development and incorporation on the 757, 767 was not done by two people, it took a large engineering team. The SID nomination write-up provides a good history of Boeing CRT development.

Figure 15. Robin Merrifield and Lou Silverstein accepting 2004 SID Special Recognition Award.

Robin Merrifield and Low Silverstein began working on the color CRT displays for the new Boeing 757/767 aircraft during the fall of 1979. Lou was working at Rockwell Collins in Cedar Rapids, Iowa as a Human Factors Specialist. Robin was at Boeing at the time. Robin and Lou began collaborating since the color CRT development program was between Boeing and Rockwell Collins. At this stage, Robin had proposed a configuration for an automatic brightness and contrast control system for the CRTs and had completed some testing to determine parameter values for the control system. Lou worked with the test data generated by Robin and cast the results in a framework more commensurate with visual psychophysics. From Lou's visual analysis, they were able to re-configure the control system and refine expected parameter values to cover the full ambient operating range of the color CRT-based control system.

After about 8 months at Rockwell Collins and collaboration with Robin at Boeing, Lou was made an offer from Boeing to join their Crew Systems Research and Flight Deck Integration Groups and so left Rockwell Collins and accepted employment at Boeing in May of 1980. At Boeing, Robin and Lou belonged to different engineering groups on the Boeing 757/767 airplane program. Robin was a member of the Avionics Staff, and Lou was re-assigned from the Boeing Crew Systems Research Group to the 757/767 Flight Deck Integration Group. Lou's job was to work on visual and human factors problems related to new technologies used on the 757/767 flight decks. A major part of this job was to coordinate with the Avionics Staff and work with Robin on the specifications and avionics design of the color CRT displays. These displays were to be used as both primary and secondary flight instruments, replacing the legacy (dial and pointer) electro-mechanical instruments in past generations of commercial aircraft. This was a very bold step for Boeing as these would be the first color CRTs ever used for flight instruments in any type of aircraft, military or commercial. Although the general trend was for avionics and flight deck technology to trickle down from military programs to commercial flight decks, this was not the case this time. Boeing decided to jump ahead of the military programs and associated government funded R&D to develop the Boeing Electronic Flight Instrument System (EFIS) using color CRTs.

Robin and Lou quickly realized that they were on their own in uncharted waters. There were no prior programs and specifications to rely on. There were no performance benchmarks available from previous avionics programs. In fact, at the time, there were scarcely any color CRT monitors in any type of system. There were, of course, color televisions, and occasionally one might find a color CRT in very high end CAD/CAM and computer graphics systems. However, there was little relevant background on the measurement, calibration, colorimetry, or visual parameter specification for color CRTs.

So began two years of hard work and very long hours, in both the laboratory and flight simulators, leading up to the flight deck certification of the Boeing 757/767 airplanes. Robin was primarily responsible for the CRT systems, hardware/firmware and measurement instrumentation, while Lou was primarily responsible for determining the visual requirements and measurement criteria for the displays. Together they drove the development of the EFIS system color CRT hardware and display specifications and supported the program up through 767 flight deck certification on July 30, 1982.

They jointly conducted many experiments, made many measurements, wrote many Boeing internal technical reports, and fought many engineering battles along the way. Perhaps their most notable achievements were in the areas of color selection and specification for dynamic ambient lighting environments, cockpit lighting simulation, and the development of automatic display brightness and contrast compensation systems. Their work led to the certification of the first use of color CRT displays in a commercial airplane flight deck on the Boeing 757 and 767 airplanes.

Subsequently, other airplane manufactures such as Airbus and McDonnell Douglas introduced color CRTs in the flight deck of their airplanes. Later, as a result of Robin and Lou's work, the military introduced color CRTs into military aircraft.

Their series of experiments on color selection, color specification, and cockpit lighting simulations were well described in the following papers:

- Silverstein, L. D. & Merrifield, R. M. *Color selection and verification testing for airborne color CRT displays*. Proceedings of the Fifth Advanced Aircrew Display Symposium. Naval Air Test Center, Patuxent River, Maryland, September 1981, 39-81. [23]
- Merrifield, R. M., and Silverstein, L. D. *Color analysis for airborne CRT displays*. Society for Information Display Technical Digest, 1982, 196-197. [24]

Their work on the specification, design and development of automatic brightness and contrast compensation for avionics CRT displays was only published externally quite a few years after the completion of the 757/767 EFIS program. The design of this system was based on sound principles of visual psychophysics and is, if effect, independent of the display technology. This same basic system of light sensors and control algorithms has also been used for LCD-based avionics displays and automotive applications. A thorough description may be found in the following paper:

- Merrifield, R. M. and Silverstein, L. D. *An automatic brightness and contrast control system for vehicular displays*. Society for Information Display Technical Digest, 1988. [11]

The Boeing 757/767 EFIS program was an unqualified technical success, ushered in a new age in avionics displays, and associated systems. The visual and human factors aspects of the 757/767 EFIS program were considered a triumph by the human factors community, and in 1983 Lou Silverstein was awarded the Human Factors Society's Alexander C. Williams Award for "Outstanding Human Factors Contributions to the Design of a Major Operational Systems." Following the completion of the program and the certification of both the 757 and 767 aircraft, Robin and Lou were awarded a contract from the Federal Aviation Administration and the Naval Air Test Center to generate a major technical reference on color display systems for aircraft applications. This contract was a one-year programmatic effort and was described in the following paper:

- Silverstein, L. D., Merrifield, R. M., Smith, W. D. & Hoerner, F. *A systematic program for the development and evaluation of airborne color display systems*. Proceedings of the Sixth Advanced Aircrew Display Symposium, Naval Air Test Center, Patuxent River, Maryland, May 1984, 3-44. [25]

Supportive material:

- Silverstein, L. D. & Merrifield, R. M. *The Development and Evaluation of Color Display Systems for Airborne Applications: Phase I - Fundamental Visual, Perceptual, and Display System Considerations*. Technical Report DOT/FAA/PM-85-19, July 1985. (Also published as Technical Report NADC-86011-60, February 1986.) [26]

These technical reports have been widely used and cited since its publication, they still serve as essential references for color in electronic displays, and avionics display systems.

APPENDIX E. AMLCD DEVELOPMENT

John Rupp was honored with the SID 2007 Special Recognition Award for Outstanding Technical Accomplishments for "the initiative and effort over a multi-year period at both Boeing and Honeywell to develop color twisted nematic AMLCD technology with a ±60° horizontal viewing angle for the Boeing 777 airplane." Following is John Rupp's SID nomination written by Steve Ellersick and John Rupp. [13]

In the late 1970s, during the period that the Boeing Commercial Airplane Group was immersed in the replacement of electromechanical flight deck displays with shadow mask CRTs in the flight deck of the Boeing 757 and 767 airplanes, John Rupp was assigned the task of replacing shadow mask CRT technology with flat panel technology on all Boeing commercial airplanes. At that time, there were very few at Boeing that felt that flat panel technology would ever be suitable for commercial flight deck applications. Nevertheless, the task was undertaken to identify suitable flat panel display technology, evaluate, and understand appropriate interfaces for the various types of candidate technologies. Electronic breadboards were built to optically test these technologies in Boeing laboratories. In addition to developing the hardware and software required to drive the various displays, John led the effort in the development of working relationships with the leading suppliers of display technology in Japan and elsewhere to obtain representative display technology samples for testing the optical and visual performance attributes of these various technologies.

Display technology was acquired from the leading suppliers of flat panel technology primarily in Japan but also in the United States. The performance of flat panel display technology in those days was woefully inadequate so Boeing undertook (in a three-phase program with each phase increasingly sophisticated) a technology evaluation effort in close cooperation with leading display suppliers and then fed back test results in periodic meetings with those display suppliers. The suppliers then undertook technology improvements to meet the stringent visual performance requirements of the commercial airplane flight deck. The objective was to meet the demanding schedule of Boeing 7J7 airplane development.

From his years at Boeing in both avionics and flight deck environments, John understood intimately the visual requirements for flight deck displays with respect to cross-cockpit and other viewing and ambient lighting requirements. To address these issues, it was in the mid-1980s that John conceived of the importance of a sub-first minima, ideal multi-gap twisted nematic (TN) AMLCD cell design to meet the ±60° horizontal viewing angle requirement of the commercial airplane flight deck. Matsushita had patented the ideal multi-gap design at the minima but no one (including Matsushita) had previously seen the value and importance of the sub-first minima design for dramatic improvement of TN

horizontal viewing angle. John patented the unique sub-first minima ideal multi-gap approach in U.S. Patent No. 5,237,437 "Apparatus and Method for a High Contrast, Wide Angle, Color, Flat Panel, Liquid Crystal Display."

In 1986, John presented to the international display community the Boeing intent of introducing color AMLCDs on Boeing commercial airplanes in an invited paper at Japan Display 1986 in Tokyo.

In 1987, Boeing postponed the 7J7 airplane development due to lack of a suitable engine for the proposed 180 passenger, un-ducted fan 7J7 airplane. In early 1988, John was recruited by Honeywell Air Transport Division to manage the Honeywell Display Technology team. As contrasted with Boeing, at Honeywell, he was able to work directly with LCD display manufacturers, like Hosiden, on Honeywell funded programs to develop ideal multi-gap display technology. Over the five-year period (1988-1993), that John led the Display Technology team at Honeywell, the 777 color AMLCDs were developed into a configuration suitable for "red-label" sub-first minima multi-gap production. Later, the Boeing 777 airplane with the sub-first minima multi-gap, twisted nematic (TN) AMLCD design was certified in 1995. The sub-first minima multi-gap design was incorporated into all six (6) 777 D-Size (6.7" x 6.7" active area) primary flight displays (PFDs) on the Boeing 777 flight deck. As a result of the sub-first minima multi-gap design, the horizontal viewing angle achieved was the ±60° horizontal required for cross-cockpit viewing on the commercial airplane flight deck.

With respect to detail technology development, John spent the period from 1988 to 1990 iteratively developing numerous configurations and variations of sub-first minima multi-gap technology with display manufacturer, Hosiden Corporation, and color filter maker, Toppan Printing Company, with each iteration improving the quality of the multi-gap color filter (CF). Of particular interest and importance was the accuracy of the LCD cell gap and different means of distributing cell spacers, in that, as contrasted with "mono-gap" color filters, which space to all R/G/B color filters, multi-gap cell spacers could only contact with the blue color filter over an active area of 50 square inches. The three (3) R/G/B color filter step heights and cell gap had to be held accurately to a tolerance of ± 0.1 microns to achieve the required chromaticity and cell uniformity for normally black, TN multi-gap technology. The cell gap accuracy was critical to achieving the required normally black, twisted nematic background uniformity. In addition, retardation films suitable for use with multi-gap CFs were developed in the 1989-1990 timeframe. A patent, U.S. Patent 5,150,235, "Apparatus for Improving the Angle of View In a Liquid Crystal Display," was filed and issued describing the multi-gap retardation film design and performance benefits. The technique of this patent was instrumental in achieving no gray scale inversions and acceptable contrast over the required ±60° of horizontal viewing angle.

As result of this development at Honeywell and in direct competition with other major avionics suppliers, Honeywell received the displays contract award from Boeing in October 1990 as sole source supplier of flight deck Primary Flight Displays (PFDs) and Flight Management System (FMS) displays for the Boeing 777 airplane. This was the first implementation of color AMLCDs on the flight deck of commercial air transport airplanes and led to other airframe companies such as Airbus/Aerospatiale eliminating shadow-mask CRTs and implementing LCDs on later models of Airbus airplanes. The precedents set on the Honeywell 777 color AMLCD development led to the use of color AMLCDs in the cockpits of military airplanes as well as the flight deck of the United States Space Shuttle fleet.

It should be noted that without John Rupp's concept of sub-first minima ideal multi-gap and the persistence in developing the very difficult production product, color LCDs would not have been ready for the Boeing 777 airplane, the first implementation of color AMLCDs in a commercial airplane flight deck. Failure in this endeavor would have been a significant setback and would have delayed the introduction of color AMLCDs for many years until the next opportunity for a new display technology in a commercial flight deck application, which typically occurs every 15 to 20 years. The success of the Boeing 777 with color AMLCD displays was instrumental in the introduction of LCDs and the replacement of CRTs in airplane flight decks across the worldwide aviation industry - commercial, business/commuter, military, and space.

AMLCD development and implementation on the 777 was not done by a single individual as the SID nomination above may imply. It took a large engineering team. Another key Boeing individual, Dr. Alan Jacobsen, was awarded the 2008 SID Special Recognition Award for Outstanding Technical Accomplishments for "efforts in human-centered design within the aviation industry including the introduction of LCD and LED technologies on commercial airplane flight decks, developing safety-enhancing display formats and flight deck prototyping systems." Following are excerpts and paraphrases from Alan Jacobsen's SID nomination written by Steve Ellersick. [14]

Dr. Alan R. Jacobsen has made distinguished and valued contributions in the field of aviation displays. Dr. Jacobsen's efforts in human-centered design within the aviation industry include flight deck display and lighting systems on Boeing airplanes, the introduction of LCD (liquid crystal display) and LED (light emitting diode) technologies on commercial airplane flight decks, developing safety-enhancing display formats and flight deck display prototyping systems.

Since 1986, Alan has been a leader in the area of human centered design in aviation. He was the key significant contributor and leader in the visual performance design of the Boeing 777 flight deck displays and lighting system that included the first commercial air transport LCD (liquid crystal display) flight deck and the integration of LED (light emitting diode) lighting onto the flight deck.

The Boeing 777, introduced into service in 1995, was the first all AMLCD (active-matrix LCD) commercial air transport flight deck replacing CRT (cathode ray tube) display technology. As lead of the 777 Flight Deck Display Optics & Lighting group, Alan created the optical performance design requirements for the displays by conducting many human factors experiments. He worked closely with display and avionics suppliers to understand the technical characteristics

and boundaries of this emerging technology in order to create realistic but user acceptable requirements. Some of his work led to new metrics and specifications for avionics quality displays, building upon the earlier pioneering work of others during the days of introducing CRTs to the industry. Examples of this work include the update and modification of color metrics, reflection, luminance and color uniformity as well as element defect criteria.

On the Boeing 777, Alan also led the effort to introduce LED lighting as a replacement for the majority of incandescent lighting used to illuminate panels, knobs, annunciators, and switches on the flight deck. Dr. Jacobsen and his team were also responsible for the introduction of the master brightness control system, unique to the aviation industry, for controlling all lighting and displays on the flight deck simultaneously with a single knob. Given the multiple technologies involved and the demanding environment of the flight deck, this was a real achievement.

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BIOGRAPHY

Steven Donald Ellersick is an Associate Technical Fellow, P.E., M.S., L.C., C.L.E.P., C.L.M.C. for the Boeing Company. He works in the Commercial Airplane division Flight Deck Engineering group, Phone: (425) 294-7067. Mr. Ellersick, born in Pullman, WA and raised in Northeastern Washington, first attended Pacific Lutheran University and finished a B.S. in Electrical Engineering at Washington State University in 1983. He has been with The Boeing Company since then. In 1987, he completed an M.S. degree in Physics at the University of Washington.

At Boeing, Steve has worked as an Electromagnetic Compatibility Engineer, an Optical and Infrared Engineer, is currently Associate Technical Fellow for Commercial flight deck display optics and lighting systems and has worked on the 737, 747, 757, 767, 777, KC-46A Tanker, and 787. Steve has flight deck, interior, and exterior lighting experience, is a test witness only FAA AR (authorized representative), has two patents, six published papers, and over 300 Boeing reports and presentations.

He is a member of the SAE A-20 Aircraft Lighting Committee, SID (Society for Information Display) senior member, IES (Illuminating Engineering Society), CIE (International Commission on Illumination), ISCC (Inter-Society Color Council), and CORM (Council for Optical Radiation Measurement).

Steve founded the Boeing Lighting & Display Optics Community of Practice (CoP) in 2006 and continues to be its leader now as a Community of Excellence (CoE). He is a Professional Electrical Engineer (PE), is Lighting Certified (LC) from NCQLP, and holds CLEP, CLMP lighting certifications.