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Performance Demonstrations of Zinc Sulfide and Strontium Aluminate Photoluminescent Floor Proximity Escape Path Marking Systems

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16. Abstract

Transport category aircraft are required by 14 CFR 25.812 to have emergency lighting systems, including floor proximity marking systems. Typical floor proximity marking systems installed on transport category aircraft have been primarily comprised of incandescent luminaries spaced at intervals on the floor, or mounted on the seat assemblies, along the aisle. The requirement for electricity to power these systems has made them vulnerable to a variety of problems, including battery and wiring failures, burned-out light bulbs, and physical disruption caused by vibration, passenger traffic, galley cart strikes, and hull breakage in accidents. Attempts to overcome these problems have led to the proposal that non-electric photoluminescent materials be used in the construction of floor proximity marking systems. To assess the viability of this proposal, performance demonstrations of systems made with such materials were conducted. It was found that strontium aluminate photoluminescent marking systems can be effective in providing the guidance for egress that floor proximity marking systems are intended to achieve; in contrast, zinc sulfide materials were found to be ineffective.

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Performance Demonstrations of Zinc Sulfide and Strontium Aluminate Sulfide Photoluminescent Floor Proximity Escape Path Marking Systems

INTRODUCTION

Title 14, Code of Federal Regulations (14 CFR) 25.812(a)(1) specifies that airplanes type-certificated for transport category operations must have emergency lighting systems independent of the main lighting system, including a floor proximity escape path marking system. 14 CFR 25.812(e) requires that such escape path marking systems furnish emergency evacuation guidance for passengers when all sources of illumination more than 4 feet above the floor are totally obscured (by smoke). Further, floor proximity escape path marking systems should enable passengers in dark of night conditions to visually identify the emergency escape path along the aircraft cabin aisle floor and to distinguish between the escape path and the associated exit by reference only to markings and visual features not more than 4 feet above the floor. These requirements are reaffirmed for air carrier operations in 14 CFR 121.310.

Since the November 26, 1986, 14 CFR 121.310 compliance date, typical floor proximity marking systems installed on transport category aircraft have been primarily comprised of incandescent luminaries spaced at intervals on the floor, or mounted on the seat assemblies, along the aisle. These systems light the aisle and seats alongside, providing the required visual guidance for passengers in emergencies. However, the requirement for electricity to power these systems has made them vulnerable to a variety of problems. These include battery and wiring failures, burned-out light bulbs, and physical disruption caused by vibration, passenger traffic, galley cart strikes, and hull breakage in accidents. This circumstance has led to attempts to develop other types of marking systems, one of which is based on photoluminescent technology. Current photoluminescent marker designs consist of a continuous, paper-thin strip of the material about an inch wide attached to a rubber backing. This strip is encased in a clear housing affixed to the floor alongside the aisle. The strips can be of any length required.

The fundamental principle of photoluminescent technology is the ability of the photoluminescent material to absorb and store ambient energy coming from the aircraft lighting systems at night, and through the windows during the day, then emit the stored energy as visible light when all other light is extinguished. Two particular photoluminescent materials have been utilized in the development of marking systems, zinc sulfide and strontium aluminate. Both afford a pale, flat yellow-green color when viewed in lighted conditions; in darkness the zinc sulfide material glows with a more yellow-tinged light, as compared with the greener emissions of the strontium aluminate. While neither may be said to provide significant levels of illumination, their use as markers has become widespread for many types of applications.

Zinc sulfide was the first of these materials to be examined for use aboard transport category aircraft. This material was identified early in the initial search for exit marking systems; however, its efficacy was limited. Investigations at the Civil Aeromedical Institute (CAMI) showed that while zinc sulfide materials were quickly charged by low levels of ambient energy, they also emitted very low levels of light and for only a relatively short duration. Thus, they were deemed inadequate for providing the visual guidance necessary, and this led to the aforementioned acceptance of powered, typically incandescent, lighting systems as the only viable technology, (J. D. Garner, personal communication). Advances in zinc sulfide photochemistry have now resulted in the possibility that this material can be proven effective for use in floor proximity escape path marking systems, especially where particular aircraft operations provide minimal time for charging the photo-luminescent material.

Strontium aluminate is a newer photo-luminescent material that was not investigated during the initial search for marking system technologies. It is somewhat slower to charge than zinc sulfide, but after a short initial discharge interval in which the zinc sulfide is slightly superior, the light output level of strontium aluminate is greater and more sustained. This increased light output suggests that marking systems made of strontium aluminate might also make effective aircraft floor proximity escape path marking systems, especially where aircraft operations allow longer system charging times.

As a consequence of these developments, manufacturers of photoluminescent materials have approached the FAA and its international regulatory partners to allow the use of these materials in the manufacture of floor proximity escape path marking systems. These requests have resulted in the need to demonstrate the performance characteristics of the photo-luminescent materials in an aircraft operational environment, using both photometric insertments and human observers to validate that the photoluminescent marking systems provide the required visual/perceptual guidance. Such a demonstration was recently conducted at CAMI. In attendance were regulatory personnel from the FAA, as well as representatives from the aviation authorities of Britain, France, and Germany. A description of that effort follows.

METHODS

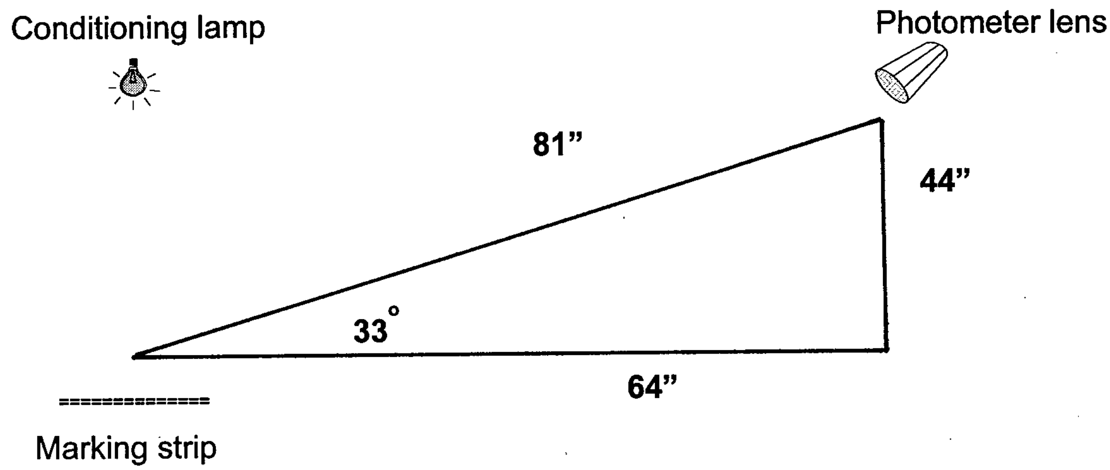
Photometric Evaluations. Initial investigations of the photometric properties of state-of-the-art zinc sulfide and strontium aluminate photo-luminescent marking materials were made with a Spectra® Pritchard Photometer, Model 1980A. The photometer lens aperture was set at 6' of arc and positioned at a height 44 inches above, and 64 inches horizontal to, the test strip, creating a total measurement distance of 81 inches and a measurement angle of 33° (Figure 1). Ambient light levels of 5, 10, 50, and 100 lux were applied for 15, 30, and 60 minutes; the light was then extinguished and *snapshot* photometer readings were made immediately. This procedure was performed to evaluate potential differences in light levels the photoluminescent materials would emit in different ambient lighting conditions relevant to aircraft operations. It also established the minimum time required to achieve reasonably complete system charging.

Human Observations. The effectiveness of the photoluminescent marking systems in providing visual guidance to human observers, ranging in age from 19 to 51 years, was demonstrated in the CAMI Aircraft Cabin Evacuation Facility (ACEF). The center aisle was fitted along its entire length with two marking strips, i.e., one along each side of the aisle. Each strip had 8-foot alternating sections of zinc sulfide and strontium aluminate marking strips; this configuration was chosen to compare the relative efficacy of the materials as the observers moved along the aisle. Regulatory personnel were stationed inside the ACEF cabin to witness (as much as possible in the darkness) the human observers during the demonstration; more importantly, an infrared camera (and operator) stationed at the front of the ACEF cabin recorded the interactions of the human observers with the aisle and its photo-luminescent escape path marking system during the demonstrations.

The charging protocol for the photo-luminescent marking system demonstrations was developed, using data from the photometric evaluations, and applied in a hypothetical emergency scenario in which a nighttime flight of intermediate duration results in a *lights-out* condition of 150 minutes before an emergency landing is made in darkness. This scenario achieved consensus among the attending regu-

Figure 1

Photometric Evaluation Set Up



latory personnel as constituting a *worst-case* situation for landing at night. The ambient light level used to charge the system was 25 lux; this value was based on the light level expected in a B-737 aircraft during an extended flight late at night, where the cabin light levels would be lowered to aid passenger sleeping. The system charging time was set at 30 minutes, which was shown in the earlier photometric evaluations to be the minimum time required to achieve a reasonably complete photo-luminescent system charge. The lights-out interval after the system had been charged until the beginning of the human observations was set to 150 minutes to reflect the emergency scenario. Note that exit identifier lights and illuminated signs were also extinguished, and that in conformance with Advisory Circular (AC) 25.812-1A, clear air was assumed from floor level upward to a height of 4 feet.

Prior to entering the ACEF, each observer group was given instructions for the demonstration. They were informed that they would be blindfolded (to prevent them from viewing the system while being led to their seats), then escorted into the ACEF cabin by a researcher, and seated. They would then be told to remove the blindfold, to get up and move into the aisle, and then go forward to the next exit. After the instructions were given and any questions answered, groups of 6 or 7 observers were brought into an ACEF anteroom for visual dark-adaptation. Heavy curtains were placed between the anteroom and the entry to the ACEF cabin to prevent stray light from entering the cabin when the observers entered the anteroom, as well as to prevent the observers from seeing the photoluminescent marking strips before the formal observation procedure began. Each observer was thusly conditioned for a period of not less than 10 minutes, after which time the observers entered the ACEF cabin individually.

Note that the successive nature of the individual observations, which lasted about 2 minutes each, allowed a small, incremental amount of dark-adaptation for observers in each group. Also because of the successive nature of the observations, the total number of demonstrations required more than an hour to complete. Thus, while the period of dark adaptation extended for most observers beyond the 10-minute standard originally chosen, the performance of the photoluminescent marking systems likewise continued to degrade beyond the so-called *worst case* scenario chosen. Given the operational nature of the scenario, this trade-off was considered to be an acceptable procedural compromise.

After answering any last-minute questions, the first observer was blindfolded, then led into the ACEF cabin and seated in the outboard seat of a seat row near the back end of the aisle. Upon the *start* command by the researcher, each observer removed the blindfold, left his/her seat and began the excursion along the aisle toward the forward exit. When he/she had moved along the aisle to the point at which the infrared camera was located, the camera operator instructed the observer to stop and return back to the starting point. After returning along the aisle, the observer was led back into the anteroom and seated, whereupon the next observer began the process. After each group of observers had completed the demonstrations, individually-structured, open-ended interviews were conducted to obtain their perceptions about the performance of the photoluminescent escape path marking systems.

RESULTS

The performance of the photoluminescent marking materials was found to be both better and worse than expected. In general, the zinc sulfide materials emitted more light than the analogous materials tested in the original search for floor proximity marking systems, and their charging rate was fast. However, their photoluminescent emissions declined at an equally quick rate. Conversely, the strontium aluminate materials were somewhat slower to charge, but were far superior in the amount of light emitted. This performance difference was progressively enhanced as the time from the end of the charging period increased. These effects were revealed in initial evaluations, using the spectrophotometer, before the demonstrations with human observers began; Table 1 shows the results of those initial photometric evaluations.

TABLE 1

Photoluminescent Material Charging Times and Light Levels at Multiple Charging Levels and Durations

Luminance of the Photoluminescent Strips									
Charge light level	Saf-T-Glo Suprabrite (SA)			Saf-T-Glo Ultrabrite (ZS)			L.T. Guide-lines (SA)		
	1	2	3	1	2	3	1	2	3
5 lux	2.1×10^{-3}	2.2×10^{-3}	2.2×10^{-3}	2.2×10^{-3}	2.7×10^{-3}	2.9×10^{-3}	2.0×10^{-3}	2.1×10^{-3}	2.2×10^{-3}
10 lux	2.4×10^{-3}	2.7×10^{-3}	3.1×10^{-3}	3.4×10^{-3}	3.4×10^{-3}	3.6×10^{-3}	2.1×10^{-3}	2.5×10^{-3}	2.9×10^{-3}
50 lux	8.3×10^{-3}	13.9×10^{-3}	13.9×10^{-3}	14.7×10^{-3}	15.3×10^{-3}	15.3×10^{-3}	7.7×10^{-3}	13.1×10^{-3}	13.9×10^{-3}
100 lux	32.2×10^{-3}	42.2×10^{-3}	50.5×10^{-3}	36.5×10^{-3}	42.5×10^{-3}	52.0×10^{-3}	32.0×10^{-3}	41.5×10^{-3}	48.5×10^{-3}

*Strips dark-adapted for 24 hours prior to tests; Strip light levels in foot Lamberts
SA = Strontium Aluminate; ZS = Zinc Sulfide; 1 = 15 min, 2 = 30 min, 3 = 60 min

The additional photometric results in Table 2 are directly related to the demonstrations with human observers. Subsequent to a 70-hour period of darkness conditioning, each of the photoluminescent materials was subjected to the 30-minute, 25 lux charging regimen and then measured using the photometer with the lights-out for a period of 150 minutes. Note that after the demonstrations with human observers were completed using only the other 3 sample materials, Table 2 test sample FSCM F9503 was provided for comparison by photometric analysis.

The performance of the 19 human observers who participated in the test scenario was generally consistent across groups, as the observers were able to move from their seats and along the aisle with minimal hesitation, except at the junctions of the interleaved photoluminescent material types. There the discontinuities in the luminance level of the floor proximity marking system elements appeared to affect observer performance when they approached the elements with lower luminance. However, it also appeared that since the observers could see photoluminescent elements with higher luminance farther along the aisle, this effect was minimized. In fact, only in one case did an observer appear to be seriously confused about advancing along the aisle; in one other case the observer surprisingly turned from the aisle and sat down by the Type-III overwing exit. While none of the instructions had mentioned this exit, this latter observer indicated that she thought a *pin hole* of light at the Type-III exit was the cue for her to go in that particular direction.

All observers later reported that they could, in fact, see the differences in the photoluminescent emergency lighting system levels, although 47% of the observers responded to the interview questions with statements reflecting the darkness of the cabin and their general inability to see the cabin interior. Further, they also indicated that more light would be beneficial. In contrast, it should be noted again that they were generally able to use the system as intended. Table 3 provides the human observer responses.

DISCUSSION

The ability of strontium aluminate photoluminescent materials used in floor proximity escape path marking systems to support simulated egress in darkened aircraft cabins has been demonstrated. The demonstration scenario was designed to model a flight of

TABLE 2

Photoluminescent Strip Light Emission Levels After Exposure to 25 lux incandescent light for 30 Minutes

Measurements Made at Time Indicated After Lights Turned Out						
Photoluminescent Type	Time					
	0	30 min	60 min	90 min	120 min	150 min
Saf-T-Glo Suprabrite (SA)	$4.0x10^{-3}$	$1.1x10^{-3}$	$8.9x10^{-4}$	$8.0x10^{-4}$	$7.2x10^{-4}$	$7.0x10^{-4}$
Saf-T-Glo Ultrabrite (ZS)	$6.5x10^{-3}$	$9.5x10^{-4}$	$5.1x10^{-4}$	$4.9x10^{-4}$	$4.2x10^{-4}$	$3.9x10^{-4}$
L.T. Guidelines (SA)	$4.5x10^{-3}$	$8.5x10^{-4}$	$7.5x10^{-4}$	$6.5x10^{-4}$	$4.8x10^{-4}$	$4.5x10^{-4}$
FSCM F9503 (ZS)	$4.3x10^{-3}$	$4.8x10^{-4}$	$3.2x10^{-4}$	$2.6x10^{-4}$	$2.4x10^{-4}$	$2.1x10^{-4}$

* Strips dark soaked for 70 hours prior to tests; Light levels in Foot Lamberts
SA = Strontium Aluminate; ZS = Zinc Sulfide

TABLE 3
Human Observations

Demo	Age	How often do you fly?	Did you visually ID the emergency light system?	What did the emergency light system look like?	Did the emergency system help you move down the aisle?	What was the most important thing in the cabin that guided you down the aisle?
1	37	4x/year	YES	White lines down aisle on both sides	YES	1. Lighting 2 Seat backs ---------------- Real bright liked it on both sides
2	35	1x/3 years	YES	Green (dull)	YES	1 Seats 2. Lights ----------------
3	35	1x/2 years	YES	Solid row of light - could tell it was the aisle way	Confused as to which direction to go. Red & Green lights would have been much better	1. Lights 2. Seats ---------------- Awful dark in the cabin
4	42	1x/year	YES	Real soft light green	YES	Lights - black hole effect at end of strips ----------------
5	38	1x/Year	YES	R. R. Track	YES	1. Lights 2. Seats ---------------- Could not really see anything
6	49	7x/Year	YES	Looked like an alley	YES	1. Lights 2. Seats ----------------
7	43	1x/2 Year	YES	Blue/Green color ------------------- kind of fuzzy	YES	1. Lights --------------- Ran into the back of several seats during the exit
8	27	5x/Year	YES	2 white strips	YES	1. Lights 2. Seats --------------- Looking for something red to ID the exit
9	34	2x/Year	YES	Glowing white strips	YES	1. Lights 2. Seats --------------- Hard to focus eyes

TABLE 3 (Cont'd)

Demo	Age	How often do you fly?	Did you visually ID the emergency light system?	What did the emergency light system look like?	Did the emergency system help you move down the aisle?	What was the most important thing in the cabin that guided you down the aisle?
10	35	1x/2 Years	YES	White line	YES	Lights --------------- Lights need to be brighter
11	43	1x/Year	YES	Yellow Stripes	YES	1. Lights 2 Seats ---------------
12	30	1x/4 Years	YES	White Strips	YES	1. Lights 2. Seats --------------- Dark
13	51	2x/Year	YES	Gray/white lines bordering the aisle way	Told me where the aisle was - didn't necessarily help me move down the aisle	Lights --------------- Very dark
14	27	1x/10 Years	YES	Green light	Yes - could see aisle way clearer (where it was)	Lights --------------- Dark
15	26	3x/Year	YES	Very dimly lit - hard to see	YES	Lights --------------- Didn't like the lighting system
16	47	2x/Year	YES	Real pale bluish glow look	YES	Lights ---------------
17	21	Never flown	YES	Greenish Strip	YES	Lights --------------- Noticed 2 strips
18	19	Never flown	YES	Neon green	Yes	Lights --------------- Noticed 1 strip black- scary. Changed answer, thinks she saw 2 strips
19	44	4x/Year	YES	Thin line	YES	Lights --------------- Really dark - couldn't see anything; saw 1 strip

intermediate range, in which the cabin occupants are afforded no other illumination than that provided by the floor proximity escape path marking system, after which an emergency evacuation must be performed. The scenario further assumed an intact cabin environment, using a total lack of supplemental illumination to model smoke in the cabin from the ceiling down to 4 feet above the cabin floor with clear air comprising the space from 4 feet down to the floor.

The configuration of the escape path marking system and the type of photoluminescent material in use were important in the demonstrations. The photoluminescent materials were placed along both sides of the aisle, creating a two-sided pathway for observers to follow. Also important to the obtained results was the fact that both the zinc sulfide and strontium aluminate photoluminescent materials were used in an interleaved manner along the aisle. This created discontinuities in luminance levels, since the amount of luminance emitted by the zinc sulfide material after the 150-minute lights-out period was noticeably different from that emitted by the strontium aluminate. These discontinuities appear to account for most instances where observers ceased to continue steadily along the aisle, and this suggests that escape path marking systems that utilize photoluminescent materials should be made exclusively from the relatively brighter strontium aluminate.

In absolute terms, both types of photoluminescent materials provided levels of luminance low enough to often cause observers to report that the cabin was very dark and that more illumination would be beneficial. Importantly, however, the strontium aluminate photoluminescent materials were shown to provide better behavioral cues to guide the individual human observer movements along the aisle toward the exit. These self-report versus performance effects appear somewhat at odds, but human reports have often been shown in such situations to differ from actual human performance. The lack of exit illumination, *per se*, may have contributed to the reports of low observer confidence in this emergency escape path marking system.

Providing exit illumination to augment the escape path marking system would be a typical situation for operational transport category aircraft; such illumination offers one possible solution to the mediocre confidence reported, as well as any related impediment to movement along the aisle that the dim escape path illumination may have produced. Combining both types of marking systems may offer the required escape path marking intended by 14 CFR 25.812(a)(1).

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