Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-AM-81-	AD-A103191	

4. Title and Subtitle
EMERGENCY CABIN LIGHTING INSTALLATIONS. AN ANALYSIS OF CEILING- VS. LOWER CABIN-MOUNTED LIGHTING DURING EVACUATION TRIALS

5. Report Date
Feb[redacted]981

6. Performing Organization Code

7. Author(s)
Burton P. Chesterfield, Paul G. Rasmussen, and Robert D. Dillon

8. Performing Organization Report No.

9. Performing Organization Name and Address
FAA Civil Aeromedical Institute
P. O. Box 25082
Oklahoma City, Oklahoma 73125

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
Office of Aviation Medicine
Federal Aviation Administration
800 Independence Avenue, S.W.
Washington, D.C. 20591

13. Type of Report and Period Covered

14. Sponsoring Agency Code

15. Supplementary Notes
Reported research was conducted under Task AM-B-78/79/80-PRS-38 and Request for RD&E Effort (FAA Form 9550-1) entitled Technical Support for Transport Emergency Lighting Evaluation (ARD-500-76-2).

16. Abstract
Six series of human subject evacuation tests were conducted to compare the evacuation rates with two different emergency lighting systems in an aircraft cabin filled with nontoxic white smoke. Cabin emergency lighting and exit signs mounted near the ceiling were almost completely obscured by smoke, which layered most heavily in the upper one-half of the cabin. A comparison lighting system mounted below layered smoke in aisle seat armrests, with exit signs mounted at and below the cabin midpoint, provided light directly in the aisle and cross aisle. Results indicated that lights and signs mounted lower in the cabin were more readily visible in smoke and enabled subjects to evacuate from a smoke-filled cabin more rapidly than conventional ceiling-mounted lights and signs.

17. Key Words
Lighting, Exit signs, Smoke stratification, Vision in smoke, Aviation safety, Postcrash fire, Aircraft accident

18. Distribution Statement
Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	40	

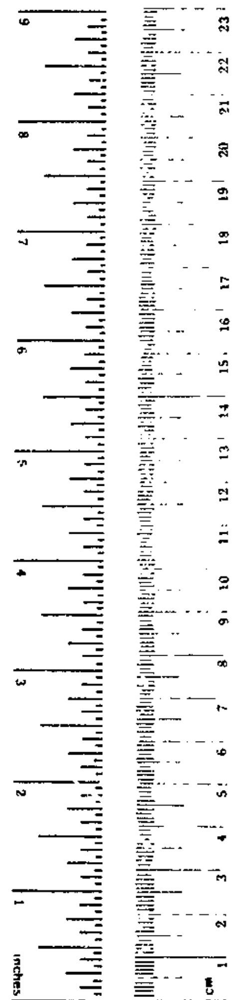
Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

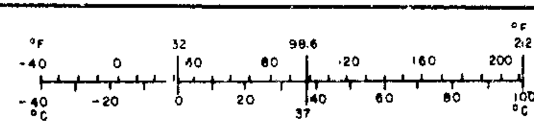


TABLE OF CONTENTS

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of Mrs. Linda Alexander, Protection and Survival Laboratory, for her assistance as the Civil Aeromedical Institute (CAMI) flight attendant during testing. Acknowledgment is also given to Gregg Winters, Lee Forrest, Jr., and Bill Nixon, Protection and Survival Laboratory, for photometric support. Additional thanks to the many other CAMI employees who contributed their varied talents to the test program.

EMERGENCY CABIN LIGHTING INSTALLATIONS: AN ANALYSIS OF CEILING- VS. LOWER CABIN-MOUNTED LIGHTING DURING EVACUATION TRIALS

INTRODUCTION

Post-crash fire has been the single most important factor contributing to loss of life in survivable air carrier and commuter aircraft accidents for survivors of the crash impact. Many fatalities have occurred because the cabin filled with smoke with a resulting loss of visual reference, panic, and eventual incapacitation due to the toxic properties of the smoke. Particulate matter (smoke) in the cabin may absorb, reflect and refract emergency lighting to the extent that emergency lighting and exit signs provide little or no visual evacuation information. The loss of visual cues for direction and distance to the nearest usable exit can significantly prolong the time required to evacuate the aircraft, thus subjecting passengers to irritants and toxic by-products of combustion for longer periods (1).

The Protection and Survival Laboratory of the Civil Aeromedical Institute (CAMI) initiated a program to study cabin lighting in response to a request from the Federal Aviation Administration's Systems Research and Development Service, Washington, D.C. (2). The purpose of the study was to evaluate the relative effectiveness of emergency cabin lighting under conditions of stratified or layered smoke in an aircraft cabin with respect to passenger evacuation rates. Two lighting systems, one a conventional ceiling-mounted system and the other an aisle-mounted system were compared during evacuation trials in the CAMI evacuation simulator. The program, which began in 1976, evaluated the effectiveness of present lighting requirements in dense cabin smoke typical of a post-crash fire environment. A CAMI memorandum report was published in 1977 as an interim report (3) outlining specific emergency lighting systems to be evaluated in relation to the adequacy of current lighting requirements when exposed to a smoke environment and with specific application to human evacuation performance.

Before launching into the full series of evacuation tests, which form the basis for this report, evacuation tests were conducted to evaluate the use of light-filtering goggles as an alternative to white smoke in evacuation testing. The smoke goggle development was completed in 1978 and cited in a CAMI memorandum report (4). The goggle was developed in an attempt to overcome the difficulty of record test subject movement in the cabin on film when actual smoke was used to restrict visibility. Test subjects were each given a pair of smoke goggles designed to decrease light transmission and provide a haze factor. Preliminary tests were conducted on July 20 and August 10, 1978, to evaluate the visibility limitations of both goggles and white smoke under emergency lighting conditions. The results of these tests were reported in a CAMI research task quarterly report (5). After completing this preliminary evaluation, it was concluded that the smoke goggles should not be used to simulate the effects of smoke or evaluate alternate lighting systems because of the goggles' inability to simulate the layering or the depth effects of smoke as a light attenuating medium. It was also concluded that photographic recording of test subject movements with layered smoke in the cabin could be accomplished by using image intensifying devices on the cameras.

During the same time period, the FAA Technical Center, formerly the National Aviation Facilities Experimental Center (NAFEC), conducted engineering tests of emergency lighting in black smoke but could not conduct human subject evacuations due to the toxic properties of the smoke. The study, published in a NAFEC Technical Letter Report (6), found that ceiling-mounted lights and signs are effectively blocked from view by layered smoke and there is a significant decrease in effective cabin illumination levels even though cabin air temperatures are still at a survivable level. Aisle lighting was evaluated in the forms of armrest-mounted fluorescent lights and floor-mounted electroluminescent strip lights with the conclusion that, in a smoke-filled cabin, aisle lighting mounted near floor level provides passenger awareness, exit location information, and cabin illumination for a longer period of time than ceiling or bulkhead-mounted lights.

With the previously mentioned work laying the foundation, the following study was undertaken to evaluate the relative effectiveness of two types of emergency cabin lighting under conditions of stratified or layered smoke in an aircraft cabin. To relate emergency lighting installation locations with evacuation performance, a test program consisting of six series of four trial evacuations each were conducted at CAMI during June and July 1980. This report describes the conduct of those tests and the results of the program.

METHODS

Subjects. A group of 40 subjects was used for each evacuation series with the exception of the first series which used 20 subjects, for a total of 220 subjects. The subjects were furnished under contract which required that they meet the criteria of a representative mix of the flying public by age and sex and had not participated in an emergency evacuation within the preceding 6 months as specified in Federal Aviation Regulation (FAR) Sections 25.803 (7), and 121.291, Appendix D (8). Table 1 breaks the subject population down by sex and mean age for each test series.

Cabin Configuration and Lighting. The evacuation simulator was maintained in a level attitude at ground level. A 4.9m (16 ft) by 2.4m (8 ft) by 1.2m (4 ft) black plastic shroud was placed outside the Type A exit to form a tunnel to prevent outside light from entering the cabin (Figure 1). A floor-to-ceiling partition was placed just inside the exit, effectively blocking from subject view the actual exit as they evacuated along the aisle and also served to further block any external light at the exit.

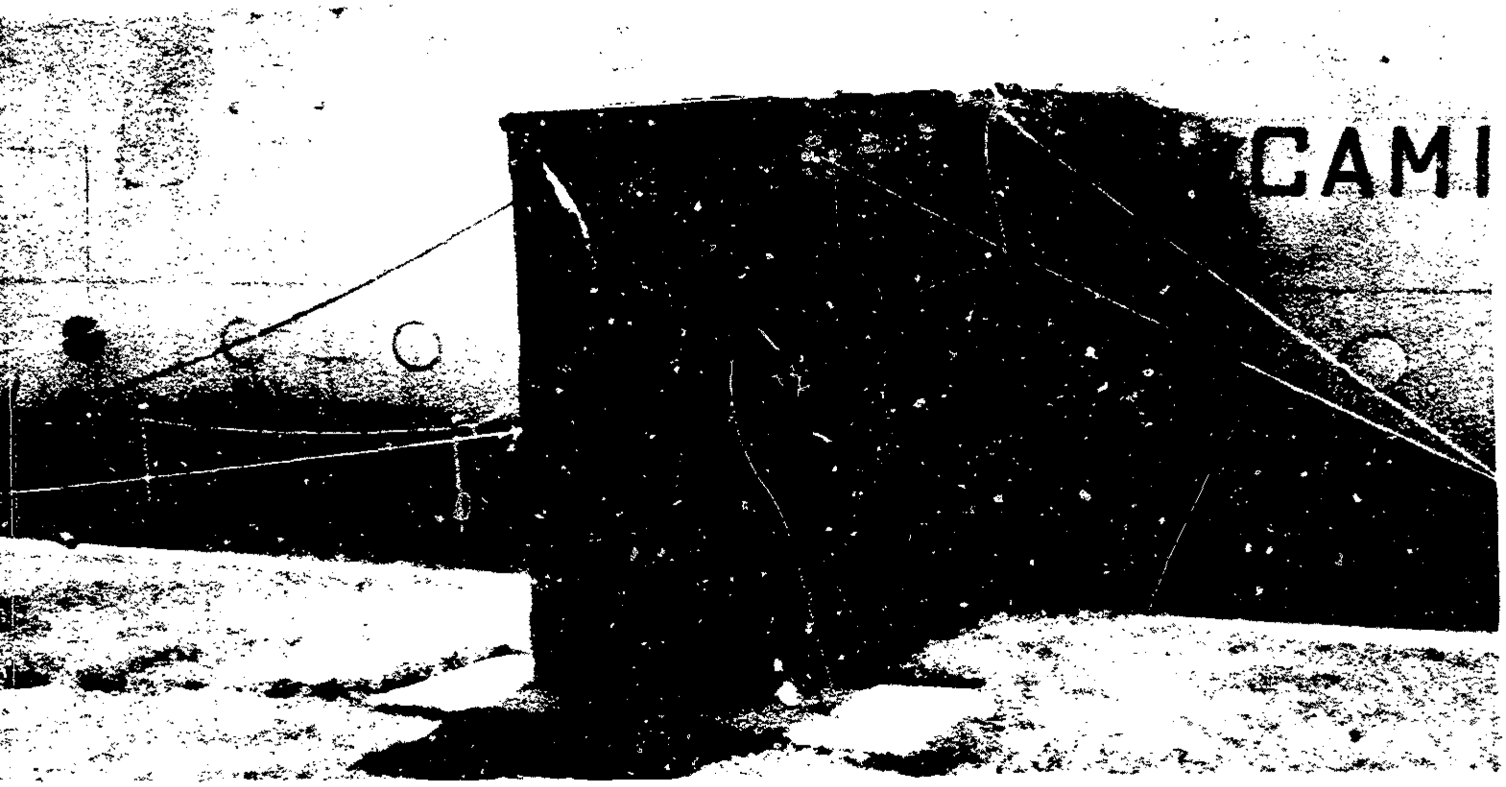


Figure 1. Type A exit shroud blocked light from entering cabin, simulating night evacuations. Subjects passed through darkened tunnel before stepping into bright sunlight. Tunnel evacuation times were not included in total evacuation times.

TABLE 1. Subject Description

Test Series	Number of Subjects Male	Female	Total	Mean Age (Yrs)
A	8	12	20	28.8
B	18	22	40	23.6
C	15	25	40	25.6
D	24/23*	15	39/38	23.2/23.2
E	17	23/22**	40/39	29.0/29.5
F	15	25	40	35.2

*A boy, age 10, dropped out after the first control evacuation and was not included in the mean age calculation. A 25-year-old male dropped out after the third evacuation when he reinjured an old knee injury.

**A 7-year-old female dropped out after the second evacuation because of apprehension about the vigorous activity and the smoke environment.

The system of lower cabin-mounted emergency lighting consisted of armrest-mounted aisle lights and bulkhead-mounted exit locator signs. The cabin interior was configured with double and triple seats the full length of the coach cabin. Alternate left and right seat rows were equipped with an aisle light assembly built into the armrest (Figure 2). The light units were 8-watt fluorescent tubes mounted behind an edge-lit prismatic Lumipane (TM)* lens. This upper lens contained a directional arrow and the words "EMERGENCY EXIT." Each unit also had a lower prismatic light panel that illuminated the aisle and lower portion of the armrest. In the forward part of the cabin two twin seats had newer prototypes of aisle lighting designs. The left side twin seat had a 4-watt fluorescent tube behind a Lumipane (TM)* lens built into the top of the armrest and a lower aisle flood panel which provided light on the aisle (Figure 3). The right side twin seat had a 4-watt fluorescent tube enclosed on three sides by a white reflector and mounted under the aisle seat bottom cushion.

Two 8-watt fluorescent exit locator signs (directional arrows) were mounted on the cross-aisle bulkhead (Figure 4), at and below the midpoint of the cabin floor-to-ceiling distance. The upper sign shown at midpoint of the cabin was located 122cm (approximately 48 in) above the cross aisle. The lower sign was located 42cm (approximately 16.5 in) above the aisle, and provided floor level illumination as well as exit location information to the subjects.

*American Optic Light Corp., Fort Worth, Texas

Figure 2. Alternating left and right seat rows with light units mounted in armrests showing light on carpeted aisle.

Figure 3. Newer prototype aisle light built into seat armrest with upper lens in top of armrest and flood panel below which directs light into aisle.

Figure 4. Two 8-watt fluorescent exit locator signs mounted on the cross-aisle bulkhead at and below the midpoint of the cabin.

The lighting system used for comparison was composed of ceiling-mounted fixtures with incandescent bulbs providing general aisle illumination of 1.2 lux (0.11 foot candle) at seat armrest height without smoke in the cabin. This value is more than twice the minimum value required by FAR 25.812(c)(9). A single incandescent cross-aisle exit locator sign and two exit identification signs were also used as part of the conventionally mounted emergency lighting system. The cross-aisle sign (Figure 5) was a Luminator (TM)* unit located 245cm (96.5 in) above the floor and provided 0.32 lux (0.03 foot candle) on the cross aisle which is also above the minimum specified by FAR 25.812(d). One of the two exit identifier signs was a cabin sidewall-mounted Luminator (TM)** unit located 137cm (54 in) above the floor. The other exit identifier was a Grimes*** unit mounted 198cm (78 in) above floor level and above the Type A exit (Figure 6).

Figure 5. Cross-aisle exit locator sign mounted above the intersection of main and cross aisle at ceiling height.

*Luminator Div., Gulton Industries Inc., Plano, Texas. Model L-20419-3
**Luminator Div., Gulton Industries Inc., Plano, Texas. Model L-20482-7
***Grimes Mfg. Co., Urbana, Ohio. Model 10-0067-9

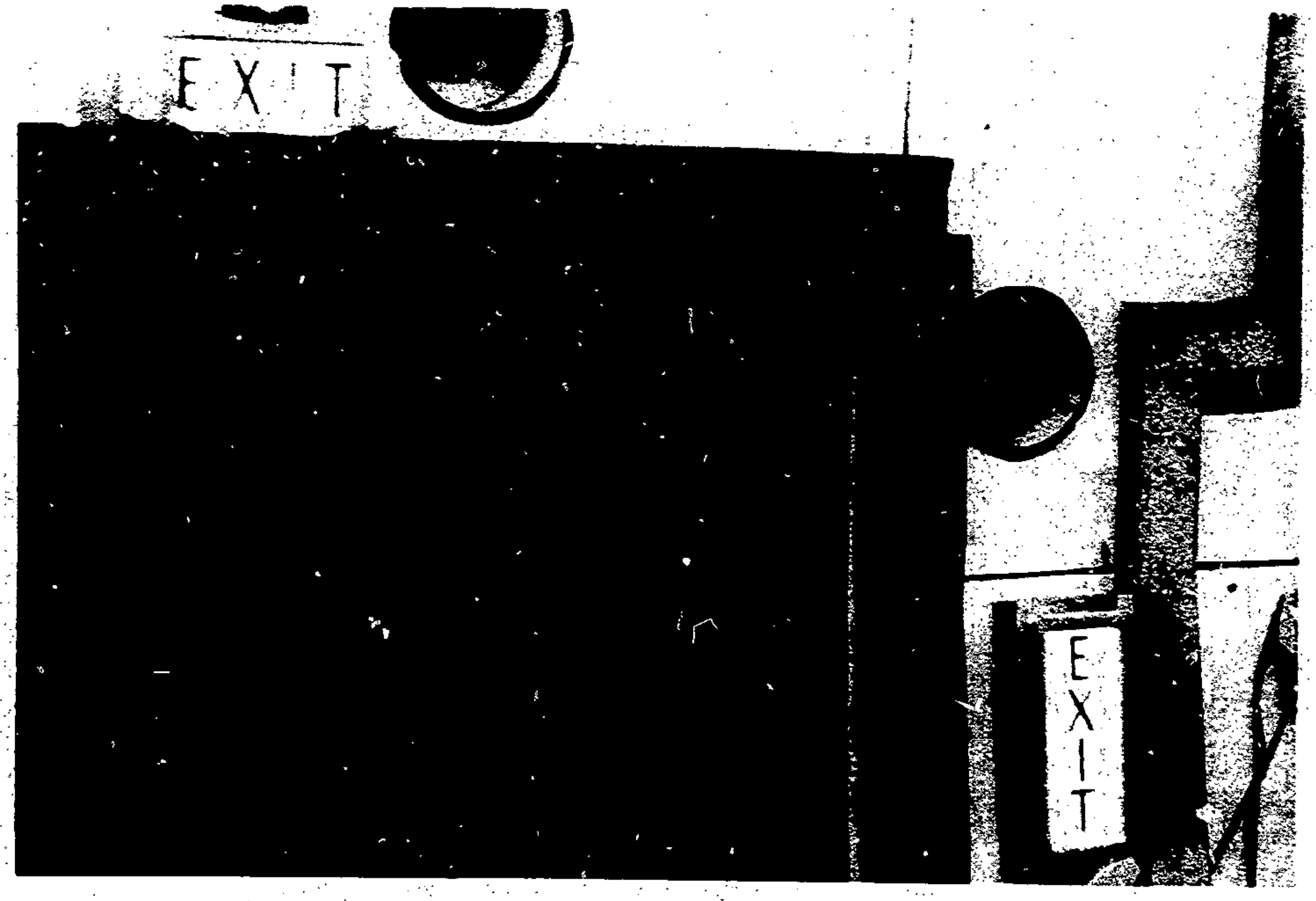


Figure 6. Exit was identified with two conventionally mounted exit signs. Sign on left is mounted directly over the exit. Sign on right is mounted to right side of Type A exit on cabin sidewall.

The FAR requirement is a minimum value, stating that cabin emergency lighting must be provided so that "....at seat armrest height and 1.02 meter (40 inch) intervals, the average illumination is not less than 0.54 lux (0.05 foot candles)...." along the centerline of the main passenger aisle. The regulation also defines minimum cross-aisle lighting requirements as 0.22 lux (0.02 fc) along the centerline of the cross aisle 15.2cm (6 inches) above the floor.

Layered Smoke. The inert, white, nontoxic smoke was generated by a Pepper Fog (TM)* smoke generator. The discharge nozzle was placed into the intake of a smoke distribution system which consisted of a squirrel cage fan and 110v motor which forced the smoke into a plenum forming a "Y" into two 6-inch diameter ducts (Figure 7). The orifice of the upper duct directed smoke towards the aft cabin. The lower orifice was equipped with vanes giving the smoke a counterclockwise vortex in the forward cabin. Preliminary work, including smoke optical density measurements, had shown this to be an effective and reproducible method for creating a layered smoke environment in the cabin of the evacuation simulator (see Appendix A).

Figure 7. Smoke distribution system ductwork shown with white smoke being discharged.

*Smith & Wesson, General Ordnance Equipment Corp., Pittsburgh, Pennsylvania. Model MK X11 B

Photometric Instrumentation. Each trial of each evacuation series was recorded on 16mm motion picture film with one exterior and two interior cameras. During the trials with smoke, the interior cameras were equipped with Javelin Model 220 Night Viewing Devices* to permit low light level photography. A timing clock was placed in the field of view of the exterior camera and the rear interior camera was equipped with numeric timing along the film margin. The rear camera angle covered the subjects as they reached the end of the 12.5m (41 foot) main aisle, turned into the cross aisle, and exited through the Type A exit (Figure 8, interior view).

Figure 8. Interior view of cross aisle at the Type A exit showing entrance into exit shroud (darkened tunnel).

*Javelin Electronics Div., Apollo Lasers Inc., Los Angeles, California.

The forward camera faced aft and covered the subjects as they arose from their seats, stepped into the center aisle, and moved toward the exit. The 16mm motion picture cameras were operated at 24 ± 1/2 frames per second.

Evacuation Alarm and Timing System. The evacuation alarm bell, flashbulbs, and the timing clocks were interconnected to form the timing system which was controlled from the aft cabin by a master switch. The switch activation started the timing clocks, fired the flashbulbs to identify the first film frame of the trial, and activated the remote alarm bell in the forward cabin signaling the start of the trial to the subjects. The lapsed time from start of the trial to the time the last subject moved from the seat row into the main aisle was recorded on hand-held stopwatches.

PROCEDURE

The subjects were given a briefing about the purpose of testing, the general nature of the task they would be required to perform, the potential minor hazards they might be exposed to, and the general experimental environment. No information was given about the specific nature of the project or what lighting or smoke condition they could expect on a given trial. The primary instructions were to listen to the CAMI flight attendant's instructions, do as they were told, and evacuate the simulator as rapidly as possible. Each subject wore a numbered vest for identification and occupied an assigned seat with a corresponding number for each trial.

Following the test protocol (Appendix B), full bright cabin lighting was employed on the two control evacuation trials in each series. The full bright lighting was also used on the third and fourth trials with smoke until after the smoke had been introduced into the cabin for 60 seconds and had layered uniformly in the upper half of the cabin. The bright cabin lights were then turned off and the emergency lighting appropriate for that particular trial was turned on. As the layered smoke began to settle into the lower half of the cabin, the evacuation bell was sounded. The time the lights were switched to emergency until the bell sounded was approximately 10 to 15 seconds, limiting time for visual dark adaptation by the subjects.

The use of each emergency lighting system was counterbalanced throughout the six series of evacuations to minimize bias resulting from presentation order, residual learning effects, and subject fatigue or boredom. Upon reboarding from the previous trial, the subjects were briefed on their performance on the previous trial and were encouraged to imagine themselves in a real emergency during the upcoming trial. Different versions of a basic questionnaire were given to each subject after each trial to record their subjective impressions of various aspects of the just completed trial, including their feelings and evaluations of a number of environmental features in the cabin (see Appendix C). In addition to the CAMI flight attendant, at least three additional test personnel supervised the subjects to insure their safety.

RESULTS

The times from the start of each trial until the last subject crossed the exit threshold are shown in Table 2. Also shown are the elapsed times until the last subject moved from the seat row into the main aisle. The first and second control evacuations averaged 32.7 and 24.8 seconds respectively for all series of evacuations for an overall improvement of 7.9 seconds or 24.2 percent on the second trial. These trials were intended to bring the groups up to a common experience level and minimize the interaction of learning effects with the main variable during subsequent trials. Such initial improvement was in general agreement with the results of a previous study of learning during several successive evacuation repetitions (10). This training experience also allowed those persons who had reservations about participating, or who encountered a physical problem moving rapidly in a crowded aisle, to withdraw from the tests before the paramount trials with emergency lighting and white smoke. Withdrawals are noted for Series D and E at the bottom of Tables 1 and 2.

Series A trials were to be a complete series scaled down to half size (20 test subjects) to verify evacuation procedures, checklists, and teamwork of the CAMI crew. Series A evacuation trials 1-4 were completed without problems, and individual evacuation rate data (seconds/subject) were recorded on film. Series A data have been included in the analysis of rates of evacuation where total evacuees and total times are secondary to the individual performance. When total times and group rates are discussed, appropriate notes are made for Series A.

Table 3 shows overall evacuation times for groups of 40 experienced subjects. Aisle-mounted lighting shows significant improvement over conventional ceiling-mounted lighting under smoke conditions. An overall performance improvement of 18.54 percent for the aisle lighting was evident when combining averages for the counterbalanced trials.

Average evacuation rates per subject are shown in Figure 9 as combined trials of counterbalanced tests and also with trials of all series combined. Table 4 shows the percentage improvement in average evacuation rates per subject, using aisle lighting compared to ceiling-mounted lighting.

Direct aisle lighting resulted in shorter time per subject evacuation rates regardless of whether it was employed before (16.8 percent) or subsequent to (21.9 percent) the trial employing ceiling-mounted lights. An overall performance improvement of 19.7 percent is indicated for the combined third and fourth aisle lighting trials compared to the ceiling-mounted lights.

DISCUSSION

As early as 1966, concern for upgrading cabin lighting criteria became apparent. A series of FAA and industry conferences were held to review regulations involving crashworthiness and passenger evacuation. As a result of these meetings, the regulation on emergency lighting, FAR Part 25.812, was extensively rewritten and amended October 24, 1967.

TABLE 2. Total Evacuation Times Per Trial

Test Series	Trial	Total Time for Last Subject to Reach Exit Threshold (sec)	Time for Last Subject Into Aisle (sec)	Number of Subjects
A	1	27.5	14.6	20
	2	17.7	8.6	20
	3 Ceiling	29.8	7.8	20
	4 Aisle	21.3	4.4	20
B	1	33.4	19.2	40
	2	25.3	17.2	40
	3 Aisle	37.0	13.2	40
	4 Ceiling	40.4	20.6	40
C	1	34.0	no data	40
	2	28.1	14.4	40
	3 Ceiling	44.5	17.8	40
	4 Aisle	36.5	12.0	40
D	1	34.0	14.0	40
	2	24.7	10.4	39
	3 Aisle	28.6	13.4	39
	4 Ceiling	34.6	no data	38
E	1	32.0	17.4	40
	2	26.4	10.2	40
	3 Ceiling	38.9	13.8	39
	4 Aisle	30.5	10.6	39
F	1	35.4	24.2	40
	2	26.3	21.0	40
	3 Aisle	33.0	17 [illegible]	40
	4 Ceiling	44.1	21.4	40

NOTES: Total evacuation times for Series A are not comparable to other series because of smaller number of subjects.

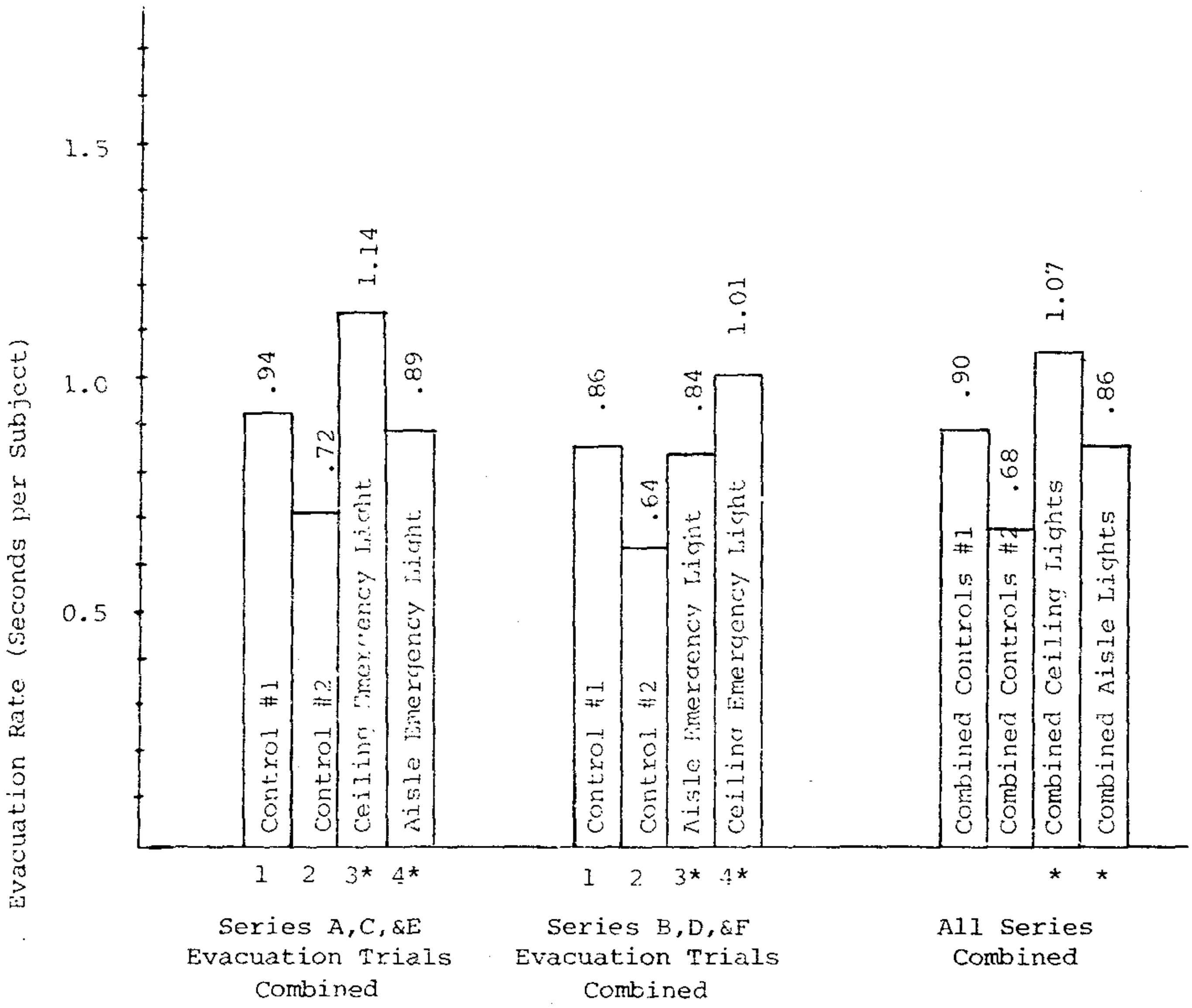
Ceiling - Ceiling-mounted emergency lights
Aisle - Aisle-mounted emergency lights

Uneven number of subjects in Series D and E are the result of subjects withdrawing from voluntary participation.

TABLE 3. Percent Improvement of Overall Evacuation Rate With Direct Aisle Lighting vs. Ceiling-Mounted Illumination Using Experienced Subjects With Layered Smoke

Test Series*	Lighting System Sequence	Total Evacuation Time (seconds)	Improvement
B,C,D, E & F	Control Trial 1 average	33.79	
	Control Trial 2 average	26.14	22.6%
B,D, & F	Aisle Lights Average third trials	32.85	17.2%
	Ceiling Lights Average fourth trials	39.70	
C & E	Aisle Lights Average fourth trials	33.49	19.7%
	Ceiling Lights Average third trials	41.73	
B,C,D, E & F	Aisle Lights Combined third and fourth trials	33.17	18.54%
	Ceiling Lights Combined third and fourth trials	40.72	

*Series A has been eliminated from this data as the first series used only 20 test subjects per trial.



*Trials with smoke in the cabin.

Figure 9. Combined Trials Evacuation Rates (Seconds/Subject). The method used to counterbalance trials is shown graphically with Series A, C, and E having ceiling lighting as the third trial and Series B, D, and F where ceiling lights were used as the fourth trial.

TABLE 4. Percent Improvement in Evacuation Rates With Direct Aisle Lighting vs. Ceiling-Mounted Emergency Lighting Using Experienced Subjects With Layered Smoke in the Cabin

Lighting System Sequence	Average Evacuation Rate (Seconds/Subject)	Percentage Improvement
Aisle lights - third trials	0.84	16.8
Ceiling lights - fourth trials	1.01	
(118 Subjects)		
Aisle lights - fourth trials	0.89	21.9
Ceiling lights - third trials	1.14	
(99 Subjects)		
Aisle lights - combined trials	0.86	19.7
Ceiling lights - combined trials	1.07	
(All 217 Subjects)		

In May 1972, the lighting criteria was again revised to upgrade emergency lighting system requirements for wide-bodied aircraft. Since that time no significant changes have been made in emergency lighting requirements. There has been no requirement that general cabin emergency lighting or exit locator and identification signs be proven effective in a cabin smoke environment.

Depending on its density and distribution in an aircraft cabin, smoke can become a considerable restriction to effective visibility. Because smoke tends to stratify in an aircraft cabin, with progressively increasing optical densities from floor-to-ceiling levels, emergency lighting and internally illuminated signs mounted in the upper one-third to upper one-half of the cabin may be rendered ineffective even though the smoke densities in the lower part of the cabin may be considerably less visually restrictive. Lights and signs which are restricted from view by smoke offer little guidance during the evacuation. This is reflected in the increase in evacuation times recorded for trials using ceiling-mounted lights, as shown in average evacuation rates in Figure 9 and Table 4.

Relocating emergency exit signs and locator signs lower in the cabin would appear to fulfill the requirement of FAR 25.811(c), reference[11] which states that means must be provided to assist occupants in locating the exits in conditions of dense smoke. The criteria for dense smoke are not defined but the results of studies on the effect of smoke on the visibility of exit signs [12,13] indicate that signs similar to those meeting the criteria of FAR 25.312(b)(1)(i) are not readable with any degree of certainty when the total optical density of the smoke between the observer and the signs exceeds approximately 3.5. This value is based on otherwise optimal viewing conditions and therefore probably exceeds the density that would render the signs ineffective in an actual emergency situation involving smoke in the cabin. The presence of even very low concentrations of irritant gases in the cabin will produce a loss of visual acuity and impairment of vision (14). Larger or brighter signs are a relatively ineffective, or at least inefficient, approach to compensating for higher smoke densities though such signs may be more effective in meeting their intended purpose at lower optical densities. With this limitation, the most apparent method for improving the visibility of the signs in the presence of smoke is to locate them lower in the cabin where the smoke is normally less dense, but high enough above floor level to be seen without obstruction from view by interior features such as seat backs or the movement of passengers through the cabin. The decreases shown in evacuation times for trials using armrest-mounted aisle lighting in this study indicates the effectiveness of lighting systems mounted below the layered smoke (see percent improvement in Table 4).

By mounting signs, aisle lights, and cross-aisle markers at or below the midpoint of the cabin, illumination in the aisle can be achieved in layered smoke at or above present minimum levels with proper sizing and spacing of lights. The option for alternate mounting locations of emergency exit marking signs and emergency illumination of the aisleway presently exists in the regulatory requirements of Part 25.811(d)(2,3) and 25.812(c). At least one such adoption of this concept has been accomplished on modifications to several Gulfstream American G-1C aircraft with certification by FAA Southern Region in December 1980 (see Appendix D). The modification included mounting emergency light units under every third-seat row, flooding the aisleway with illumination at a level above that which is required by regulation. This certification was granted with technical guidance on emergency lighting from the FAA Technical Center's Fire Safety Branch, ACT-350.

FAR 25.812(c) does not require that general emergency lighting systems be mounted at the ceiling or other overhead locations even though the requirement for measurement of illumination levels might be interpreted to imply such a location. A direct aisle-lighting system, such as was used in this study and as found on the Gulfstream aircraft, concentrates the general emergency lighting in the aisle space below armrest level. Similarly, FAR 25.812(d) does not specify the mounting position for the signs that provide illumination of the cross-aisle passageways to the floor level exits. However, to the extent that the passageway lighting is provided from the same fixtures as provide exit location and/or identification information, FAR 25.811(d)(1) specifies that such signs be located above the cross aisles or at other overhead locations. Locating the exit locator signs lower in the cabin area may or may not meet this requirement depending on the particular definition of "overhead." If "overhead" is defined as above the passenger's seated head height, the exit locator signs could be mounted lower in the cabin and still meet the requirement of being mounted above (higher than) the aisle. An exit locator sign mounted halfway down a bulkhead or galley partition would still be visible from the passenger's seated position. During the evacuation trials, with smoke layered most heavily in the upper third of the cabin, subjects tended to crouch down or stoop over to avoid the smoke, and were looking for the exit from just above seatback height. Those individuals who were first down the aisle had the greatest need to see exit locator signs below the layered smoke. Other subjects followed in trail as documented on 16mm film coverage of each trial evacuation. During trials with ceiling-mounted lights and signs engulfed in smoke, subjects had no visual reference as to exit location from a crouched body position, thus both individual and group evacuation times were slower than on trials where signs were mounted at cabin midpoint or below.

Results of subject questionnaires, although subjective in nature, showed a favorable reaction to the aisle-mounted lighting system. Reported disorientation was less with the aisle-mounted lights. The effects of the smoke on the overhead-mounted signs and lights were judged twice as severe as on the signs and lights mounted at the midpoint of the cabin or below.

CONCLUSION

The traditional interpretation of lighting requirements has been restricted to ceiling and high cabin-mounted installations.

Evacuation times can be reduced in a smoke-filled cabin when emergency lighting and exit locator signs are mounted at or below the midpoint of the cabin, directly illuminating main and cross aisleways.

Test subjects reported an overall reduction in disorientation during evacuation with aisle lighting, according to subjective responses to the questionnaires, as reported in Appendix C.

REFERENCES

1. Hill, R. G., Johnson, G. R., and Sarkos, C. P.: Postcrash Fuel Fire Hazard Measurements In a Wide Body Aircraft Cabin, FAA-NA-79-42, 1979.

2. Request for RD&E Effort, FAA Form 9550-1, Technical Support for Transport Emergency Lighting Evaluation, ARD-520 Project No. 181-521-095 (ARD-500-76-2).

3. Garner, J. D.: Interim Progress Report: Technical Support for Transport Emergency Lighting Evaluation, ARD-520 Project 181-521-095, Request for RD&E Effort ARD-500-76-2, Civil Aeromedical Institute Memorandum Report No. AAC-119-77-7(E), 1977.

4. Blethrow, John G.: Smoke-Simulating Goggles, Civil Aeromedical Institute Memorandum Report No. AAC-119-78-11(E), 1978.

5. Garner, J. D.: Civil Aeromedical Institute Research Task Quarterly Report, Task AM-B-78-PRS-38, July - September, 1978.

6. Demaree, James E.: A Preliminary Examination of Interior Aircraft Emergency Lighting Under Simulated Postcrash Fire and Smoke Conditions, NAFEC Technical Letter Report NA-79-46-LR, 1979.

7. FAR Part 25.803, Emergency Evacuation.

8. FAR Part 121.291, Appendix D, Criteria For Demonstration of Emergency Evacuation Procedures.

9. FAR Part 25.812, Emergency Lighting.

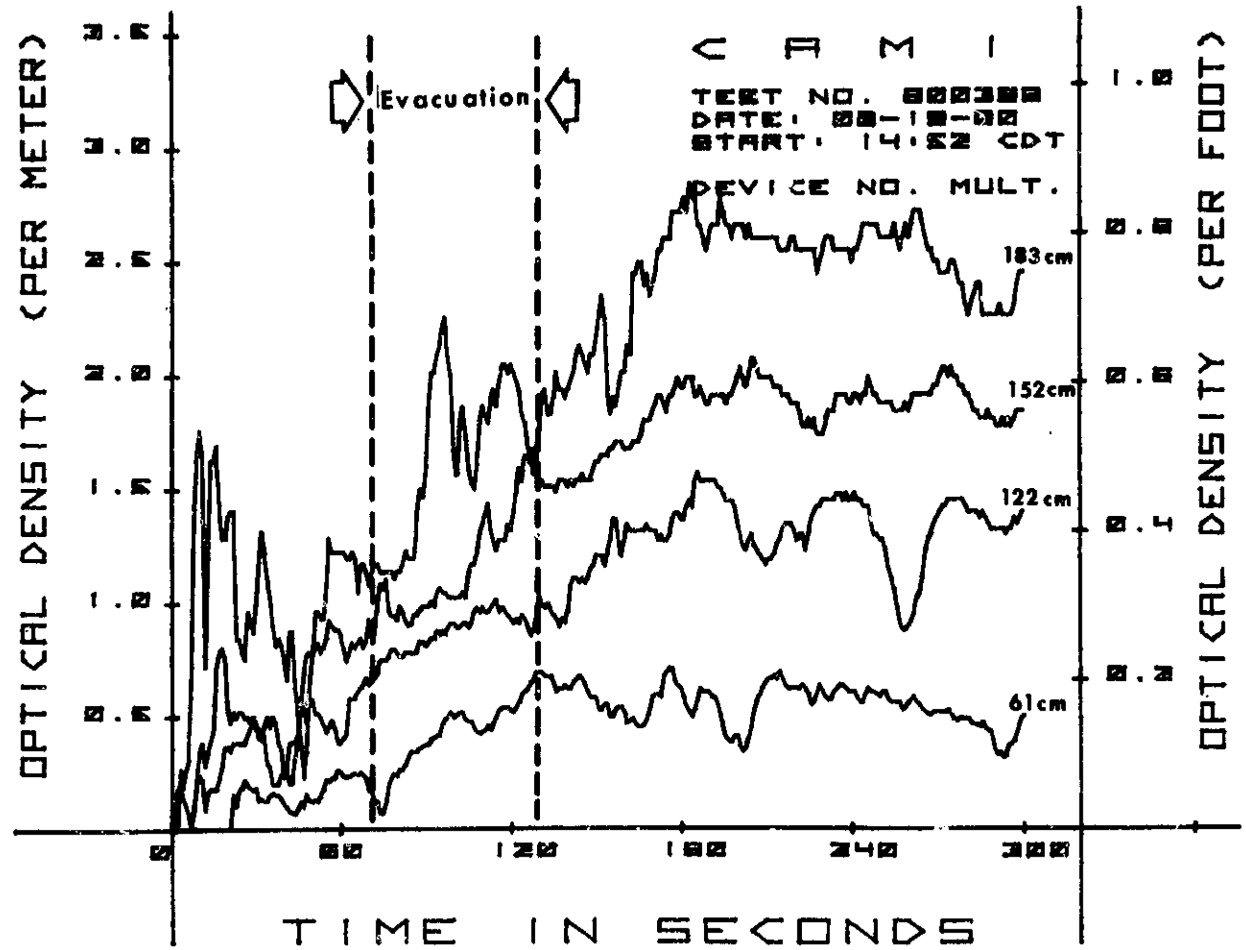
10. Chesterfield, B. P., P.E., Garner, J. D., Blethrow, J. G., Cook, E. A.: Preliminary Examination of Aircraft Evacuation Simulator Test Subject Learning Curve Data, Civil Aeromedical Institute Memorandum Report AAC-119-80-3, 1980.

11. FAR Part 25.811, Emergency Exit Marking.

12. Rasmussen, P. G., Garner, J. D., Blethrow, J. G., and Lowrey, D. L.: Readability of Self-Illuminated Signs In A Smoke-Obscured Environment, FAA Office of Aviation Medicine Report No. AM-79-22, 1979.

13. Rasmussen, P. G., Chesterfield, B. P., and Lowrey, D. L.: Readability of Self-Illuminated Signs Obscured By Black Fuel-Fire Smoke, FAA Office of Aviation Medicine Report No. AM-80-13, 1980.

14. Grant, V. M.: Toxicology of the Eye, Springfield, Illinois, Charles C. Thomas, 1974, p. 922.



Layered Smoke Density Profiles. The smoke density measurements above illustrate smoke profiles experienced at four elevations above the floor during evacuation trials with white smoke. Smoke was introduced into the cabin during the first 60 seconds and evacuations were completed as indicated. Note on the bottom curve that at seat armrest height, 61cm above the floor, smoke density remained low for the entire evacuation period. At 122cm above the floor, approximately seated head height, smoke density was still at or below 1.0/m.[10,11] At 152cm, about standing shoulder height, smoke optical density increased to above 1.0/m and at 183cm, standing head height, smoke density approached 2.0/m or higher. Any sign or light located above this level was almost completely blocked from view by increasing smoke density near the ceiling.

APPENDIX B

EVACUATION RESEARCH UNIT PROTOCOL, 80-02

Title: Emergency Cabin Lighting Installations - An Analysis of Ceiling-Mounted vs. Lower Cabin-Mounted Lighting During Evacuation Trials, FAA Form 9550-1, ARD-500-76-2.

Introduction: CAMI's continuing investigations into commercial aircraft crashworthiness and cabin fire safety is in response to the FAA Technical Center's Fire Safety Program Plan and FAA Form 9550-1, Technical Support for Transport Emergency Lighting Evaluation, ARD-520 Project No. 181-521-095 (ARD-500-76-2). The effectiveness of FAR Part 25.812 exit sign and cabin emergency lighting locations/installations will be analyzed in dense cabin smoke typical of a post-crash fire environment.

Preliminary work has stressed the development of a means to uniformly distribute white smoke in the cabin of the evacuation simulator consistently during each test. Smoke optical density measurements have been made as part of our effort to replicate layered smoke in the cabin during successive evacuation trials. From these preliminary efforts, we have developed repeatable test methodology which will allow consistent smoke distribution and stratification throughout the evacuation simulator aft cabin.

Problem: Smoke in an aircraft cabin, whether from a cabin fire or from an external fire, quickly obscures visibility. Exit signs, cross-aisle signs, directional arrows, and exit wash (flood) lighting become less effective in providing evacuation information to passengers when the cabin fills with smoke. Results of FAA Technical Center (formerly NAFEC) tests published in NA-79-46-LR, "A Preliminary Examination of Interior Aircraft Emergency Lighting Under Simulated Post-Crash Fire and Smoke Conditions," found that the lowering of exit signs and lights closer to the floor may increase their usefulness during times when the aircraft cabin fills with layered smoke. The study found that ceiling-mounted lights and signs are effectively blocked from view and there is a significant decreased emergency cabin illumination even though cabin air temperatures are still at a survivable level. Aisle lighting was evaluated in the forms of armrest-mounted fluorescent lights and floor-mounted electroluminescent strip lights with the conclusion that, in a smoke-filled cabin, aisle lighting mounted near the floor provides passenger awareness, exit location information, and cabin illumination for a longer period of time than ceiling- or bulkhead-mounted lights. However, no testing was conducted with actual passengers due to the toxic properties of the smoke being used.

CAMI, recognizing the problems with smoke stratification in the cabin, conducted human subject evacuation testing on July 20 and August 10, 1978, to evaluate evacuation problems with obscured vision. Four tests were conducted using 40 subjects on each of two test dates. Results were preliminary in nature, having been reported in the July-September 1978 Research Task Quarterly Report under task AM-B-78-PRS-38. For these tests, 40 test subjects, in a representative mix of the flying public,

APPENDIX B

EVACUATION RESEARCH UNIT PROTOCOL, 80-02

Title: Emergency Cabin Lighting Installations - An Analysis of Ceiling-Mounted vs. Lower Cabin-Mounted Lighting During Evacuation Trials, FAA Form 9550-1, ARD-500-76-2.

Introduction: CAMI's continuing investigations into commercial aircraft crashworthiness and cabin fire safety is in response to the FAA Technical Center's Fire Safety Program Plan and FAA Form 9550-1, Technical Support for Transport Emergency Lighting Evaluation, ARD-520 Project No. 181-521-095 (ARD-500-76-2). The effectiveness of FAR Part 25.812 exit sign and cabin emergency lighting locations/installations will be analyzed in dense cabin smoke typical of a post-crash fire environment.

Preliminary work has stressed the development of a means to uniformly distribute white smoke in the cabin of the evacuation simulator consistently during each test. Smoke optical density measurements have been made as part of our effort to replicate layered smoke in the cabin during successive evacuation trials. From these preliminary efforts, we have developed repeatable test methodology which will allow consistent smoke distribution and stratification throughout the evacuation simulator aft cabin.

Problem: Smoke in an aircraft cabin, whether from a cabin fire or from an external fire, quickly obscures visibility. Exit signs, cross-aisle signs, directional arrows, and exit wash (flood) lighting become less effective in providing evacuation information to passengers when the cabin fills with smoke. Results of FAA Technical Center (formerly NAFEC) tests published in NA-79-46-LR, "A Preliminary Examination of Interior Aircraft Emergency Lighting Under Simulated Post-Crash Fire and Smoke Conditions," found that the lowering of exit signs and lights closer to the floor may increase their usefulness during times when the aircraft cabin fills with layered smoke. The study found that ceiling-mounted lights and signs are effectively blocked from view and there is a significant decreased emergency cabin illumination even though cabin air temperatures are still at a survivable level. Aisle lighting was evaluated in the forms of armrest-mounted fluorescent lights and floor-mounted electroluminescent strip lights with the conclusion that, in a smoke-filled cabin, aisle lighting mounted near the floor provides passenger awareness, exit location information, and cabin illumination for a longer period of time than ceiling- or bulkhead-mounted lights. However, no testing was conducted with actual passengers due to the toxic properties of the smoke being used.

CAMI, recognizing the problems with smoke stratification in the cabin, conducted human subject evacuation testing on July 20 and August 10, 1978, to evaluate evacuation problems with obscured vision. Four tests were conducted using 40 subjects on each of two test dates. Results were preliminary in nature, having been reported in the July-September 1978 Research Task Quarterly Report under task AM-B-78-PRS-38. For these tests, 40 test subjects, in a representative mix of the flying public, were all brought up to the same learning level by four trial runs earlier in the afternoon. From this baseline, subjects participated in four tests of various lighting levels and visibility conditions as follows:

1978 Emergency Lighting Tests

Visibility Limitation	Lighting Conditions	Evacuation Times, July 20	Evacuation Times, August 10
Smoke goggles	Full cabin lighting	32.2 s	30 s
Smoke goggles	Ceiling-mounted emergency light system (0.05 FL)	42.8 s	43.0 s
Smoke goggles	Armrest-mounted fluorescent light system from American Optic Light, Inc. (Plumbly Industries)	35.6 s	34.0 s
White smoke	Ceiling-mounted emergency light system (0.05 FL)	37.2 s	34 s

Data on the smoke goggles used to limit vision have been published in CAMI Memorandum Report AAC-119-78-11(E), December 11, 1978.

Using these tests and the work conducted by the FAA Technical Center as background, the present test series has been programed to begin June 1980.

Equipment and Facilities: The evacuation simulator has been configured with double and triple seats the full length of the aft cabin. Every other seat row is equipped with a fluorescent light assembly manufactured by American Optic Light which lights the aisle as well as provides a lighted surface area at knee height to illuminate the aisle passageway and mark seat positions.

Overhead cabin incandescent lighting provides the minimum 0.05 FL of illumination at armrest height typical of FAR Part 25.812 requirements. Standard commercially available incandescent exit signs will be provided above three exits and one cross-aisle light will be installed at the intersection of the main aisle with the cross aisle. The incandescent lights will be evaluated as a complete lighting system and compared to the fluorescent lighting system under smoke conditions.

Trials 1 and 2 will be with the 2.43m fluorescent light fixtures in the ceiling of the simulator. Trial 3 on June 17 will use the incandescent ceiling-mounted lighting system and Trial 4 will be with the aisle-mounted fluorescent system. On June 19, Trial 3 will be fluorescent and Trial 4 incandescent (counterbalanced). The test series on June 24 and July 1 will be the same as June 17 and June 26 and July 2 will be the same as June 19.

The exit used will be a "Type A" (110.5 cm X 182.8 cm) design. Aisle will be approximately 12.5 meters long. Airline-type seats will be spaced at 86.3 cm pitch.

A partition has been installed just inside the left rear exit to block sunlight from entering the forward part of the cabin when the exit is opened. A wooden structure has been erected just outside, adjacent to the exit, which is covered with black plastic and has black plastic baffles hanging from the ceiling inside. This structure will serve as a shroud around the exit to prevent sunlight from entering the evacuation simulator. The aircraft attitude will be wings level with the simulator remaining on the ground. Escape slide and safety net will not be used.

Twenty paid volunteer subjects will be used on June 17 and 40 subjects on successive tests on June 19, 24, 26, and July 1 and 2. Passengers will be briefed about the general test conditions they will be exposed to in the lobby of the CAMI Building. When both subjects and the test vehicle are ready, subjects will be led to the simulator and assigned seats. The same seat assignment will be maintained throughout the test series. Seating will be 4, 5 and 6 abreast in the forward part of the cabin.

Cameras will be prepositioned in the forward and aft sections of the simulator and outside, viewing the test subjects as they egress the black plastic shroud covering the exit. One camera will be equipped with numeric timing equipment and flash bulbs will go off, giving a visual signal to the cameras that the test has begun. Motion picture cameras will shoot 24 frames/second with camera accuracy being ± ½ frame/s. Rates of movement down the aisle and total time will be obtained from both film coverage and stopwatches.

Test Sequence Checklist

1. Check subject seated position.
2. Brief subjects "Do as they are told."
3. Photo team reset cameras.
4. Reset clocks.
5. Replace two flashbulbs.
6. Change outside and inside run numbers.
7. Turn on tape recorder.
8. Readiness check from each crewmember.
9. Turn on smoke fan.*
10. Turn off air conditioner.*
11. Start smoke generator.*
12. Smoke cabin for 60 seconds.*
13. Turn off smoke fan.*
14. Turn on special lighting for that trial.*
15. Turn off overhead fluorescent lights.*
16. Turn on Night Viewing Devices.*
17. Five-second countdown (cameras start).
18. Ring bell.
19. Remove door covering.
20. Shout evacuation instructions.
21. Stop clocks.
22. Turn off Night Viewing Devices.*
23. Record stopwatch readings.
24. Record clock readings.
25. Turn on exhaust fans.*
26. Debrief passengers and reboard.

*On third and fourth trials with smoke only.

APPENDIX C

Summary of Results of Selected Questionnaire Items:

The percentage of subjects reporting experiencing an impression or feeling of the existence of a real emergency during the trial evacuations increased from 43 percent on the first control to 67 percent on the second control evacuation. This may be the result of the encouragement given the subjects to improve their performance on subsequent trials. The reported incidence of such impressions increased to 83 percent on the third trial when smoke was first introduced into the cabin but decreased to 75 percent on the fourth trial, which was also with smoke. There were essentially no differences in the reported frequencies of impressions of an actual emergency attributable to the specific type of emergency lighting employed. The weighted strengths of the reported impressions were in approximately the same ratio as the frequency of occurrence.

The frequency of reports of having experienced disorientation during the trial decreased from 29 percent on the first trial to 18 percent on the second trial. The frequency increased to 67 percent on the third trial when ceiling lights were used with the first introduction of smoke. On the fourth trial the frequency decreased to 42 percent when aisle lighting was used with smoke. When the aisle lights were used on the third trial the reported frequency was 47 percent and increased to 53 percent on the fourth trial with ceiling lights. In both sequences the reported frequency of disorientation was less with aisle lighting than with ceiling lights. This also suggests a sequence effect with reported disorientation being more prevalent when the first experience with smoke is coupled with the use of ceiling lighting.

Almost all reports of disorientation were associated with moving through the cabin but a few reported onset with the sound of the alarm bell. It is possible these subjects interpreted their alerting reaction for disorientation.

The ceiling-mounted emergency lighting was rated inadequate by 52 percent of those responding to the question while 28 percent rated the aisle lighting inadequate. The aisle lighting fared somewhat better when presented on the fourth trial when 22 percent rated it inadequate compared to 33 percent when it was presented on the third trial. This difference can be attributed to the subjects making a comparative evaluation against ceiling lighting rather than an absolute judgment. Interestingly, a small number of responses judged the full bright cabin lighting on the control trials as inadequate.

More than half judged the effects of the smoke on the ceiling lights to be severe while only a little more than a third judged the effect on aisle lights to be severe. This difference was most pronounced when aisle lighting was employed on the fourth trial. The effects of the smoke on the overhead emergency locator signs was judged severe twice as often as for the bulkhead signs mounted lower in the cabin. The smoke was also judged to severely affect access to the exits twice as often with ceiling lighting as with aisle lighting. Awareness of exit signs appeared relatively low and may have been the result of the subjects' stated practice of simply following the person ahead of them.

TRIAL 1. Questionnaire Results, Control Lighting No. 1

NAME: ____________________ VEST NO. ____________

AGE: ________ SEX: ______ DATE: ______ TEST NO.: ___

Please respond to every item on this questionnaire according to your best judgment on each item.

How many times have you flown as a passenger on a commercial airlines during the past two years?

- 53 I have never flown
- 57 I have not flown during the past two years
- 46 Once or twice
- 35 Three to five times
- 28 More than five times

(219)

As a passenger, have you ever participated in a real emergency evacuation?

5 Yes 213 No 1 No Answer

Before the bell sounded, were you aware of your seat location in relation to the exit?

146 Yes 64 No 9 Don't remember

Do you feel that the briefing on the evacuation procedures was:

142 Adequate	22 Inadequate
5 Too long	8 Too short
0 Too technical	37 Not specific enough
10 Confusing	71 Helpful

Did you have a feeling or an impression that a real emergency existed during the evacuation?

94 Yes 124 No 1 No Answer

If you answered yes to the above question, how strong was the feeling or impression?

39 Slight 45 Moderate 10 Strong 1 No Answer

Did you feel disoriented or confused at any time during the test?

_64_ Yes _153_ No _2_ No Answer

If you felt disoriented or confused, when was that feeling strongest?

_154_ Not applicable
_9_ When first seated in simulator
_38_ When bell sounded
_16_ While moving through the cabin
_2_ No Answer

While you were seated, before the bell rang, were you aware of the exit signs?

_138_ Yes _74_ No _6_ Don't remember _1_ No Answer

After the bell rang and you got up from your seat, were you aware of the exit signs?

_80_ Yes _126_ No _12_ Don't remember _1_ No Answer

Did the type of lighting affect your confidence and speed of evacuation?

_52_ Yes _103_ No _42_ Don't know _2_ No Answer

Do you think the lighting was:

_17_ Inadequate _60_ Barely adequate _150_ More than Adequate _2_ No Answer

for a quick and safe evacuation?

How well could you see the exit when you first moved into the aisle after the bell rang?

_96_ Not at all _61_ Barely _60_ Distinctly _2_ No Answer

TRIAL 2. Questionnaire Results, Control Lighting No. 2

NAME: ______________________ VEST NO. ______ TEST NO. ________

Please respond to every item on the questionnaire according to your best judgment on each item for the test just completed.

Did you have a feeling or an impression that a real emergency existed during the evacuation?

147 Yes 72 No

If you answered yes to the above question, how strong was the feeling or impression?

59 Slight 55 Moderate 33 Strong

Did you feel disoriented or confused at any time during the test?

40 Yes 179 No

If you felt disoriented or confused, when was that feeling strongest?

179 Not applicable
2 When first seated in simulator
23 When bell sounded
14 While moving through the cabin
1 No Answer

While you were seated, before the bell rang, were you aware of the exit signs?

174 Yes 39 No 5 Don't remember 1 No Answer

After the bell rang and you got up from your seat, were you aware of the exit signs?

100 Yes 109 No 9 Don't remember 1 No Answer

Did the type of lighting affect your confidence and speed of evacuation?

44 Yes 147 No 28 Don't know

Do you think the lighting was:

12 Inadequate 58 Barely adequate 149 More than adequate

for a quick and safe evacuation?

How well could you see the exit when you first moved into the aisle after the bell rang?

92 Not at all   56 Barely   71 Distinctly

TRIAL 3. Ceiling Lighting

NAME: ______________________ VEST NO. ______ TEST NO. ________

Please respond to every item on the questionnaire according to your best judgment on each item for the test just completed.

Did you have a feeling or an impression that a real emergency existed during the evacuation?

83 Yes   16 No

If you answered yes to the above question, how strong was the feeling or impression?

19 Slight   38 Moderate   26 Strong

Did you feel disoriented or confused at any time during the test?

66 Yes   33 No

If you felt disoriented or confused, when was that feeling strongest?

33 Not applicable
2 When first seated in simulator
4 When bell sounded
59 While moving through the cabin
1 No Answer

While you were seated, before the bell rang, were you aware of the exit signs?

73 Yes   25 No   1 Don't remember

After the bell rang and you got up from your seat, were you aware of the exit signs?

33 Yes   64 No   2 Don't remember

Did the type of lighting affect your confidence and speed of evacuation?

66 Yes   29 No   4 Don't know

Do you think the lighting was:

53 Inadequate   35 Barely adequate   11 More than adequate

for a quick and safe evacuation?

How well could you see the exit when you first moved into the aisle after the bell rang?

80 Not at all   16 Barely   3 Distinctly

How much did the presence of smoke in the cabin affect your access to the exit?

4 Not at all   16 Very little
30 Moderately   36 Severely
13 No Answer

How much did the smoke affect the lighting in the cabin?

1 Not at all   4 Very little
29 Moderately   52 Severely
13 No Answer

How much did the smoke affect the visibility of the exit signs?

1 Not at all   7 Very little
20 Moderately   58 Severely
13 No Answer

Did you experience any physical reactions to the smoke?

18 Yes   68 No

If yes, how so: (Please describe reaction)

TRIAL 4. Aisle Lighting

NAME: ______________________ VEST NO. ________ TEST NO. ________

Please respond to every item on the questionnaire according to your best judgment on each item for the test just completed.

Did you have a feeling or an impression that a real emergency existed during the evacuation?

75 Yes   24 No

If you answered yes to the above question, how strong was the feeling or impression?

18 Slight   39 Moderate   18 Strong

Did you feel disoriented or confused at any time during the test?

42 Yes   57 No

If you felt disoriented or confused, when was that feeling strongest?

57 Not applicable
1 When first seated in simulator
6 When bell sounded
35 While moving through the cabin

While you were seated, before the bell rang, were you aware of the exit signs?

79 Yes   18 No   1 Don't remember   1 No Answer

After the bell rang and you got up from your seat, were you aware of the exit signs?

68 Yes   29 No   2 Don't remember

Did the type of lighting affect your confidence and speed of evacuation?

57 Yes   39 No   3 Don't know

Do you think the lighting was:

22 Inadequate   46 Barely adequate   31 More than adequate

for a quick and safe evacuation?

How well could you see the exit when you first moved into the aisle after the bell rang?

53 Not at all   31 Barely   15 Distinctly

How much did the presence of smoke in the cabin affect your access to the exit?

5 Not at all   25 Very little
40 Moderately   16 Severely
13 No Answer

How much did the smoke affect the lighting in the cabin?

2 Not at all   20 Very little
38 Moderately   26 Severely
13 No Answer

How much did the smoke affect the visibility of the exit signs?

14 Not at all   18 Very little
31 Moderately   23 Severely
13 No Answer

Did you experience any physical reactions to the smoke?

10 Yes   74 No   15 No Answer

If yes, how so: (Please describe reaction)

TRIAL 3. Aisle Lighting

NAME: ______________________ VEST NO. ______ TEST NO. ______

Please respond to every item on the questionnaire according to your best judgment on each item for the test just completed.

Did you have a feeling or an impression that a real emergency existed during the evacuation?

98 Yes   20 No

If you answered yes to the above question, how strong was the feeling or impression?

26 Slight   37 Moderate   35 Strong

Did you feel disoriented or confused at any time during the test?

55 Yes   63 No

If you felt disoriented or confused, when was that feeling strongest?

63 Not applicable
2 When first seated in simulator
3 When bell sounded
50 While moving through the cabin

While you were seated, before the bell rang, were you aware of the exit signs?

105 Yes   12 No   1 Don't remember

After the bell rang and you got up from your seat, were you aware of the exit signs?

68 Yes   47 No   3 Don't remember

Did the type of lighting affect your confidence and speed of evacuation?

74 Yes   36 No   8 Don't know

Do you think the lighting was:

39 Inadequate   54 Barely adequate   25 More than adequate

for a quick and safe evacuation?

How well could you see the exit when you first moved into the aisle after the bell rang?

77 Not at all 28 Barely 13 Distinctly

How much did the presence of smoke in the cabin affect your access to the exit?

19 Not at all
22 Very little
51 Moderately
25 Severely
1 No Answer

How much did the smoke affect the lighting in the cabin?

5 Not at all
10 Very little
49 Moderately
53 Severely
1 No Answer

How much did the smoke affect the visibility of the exit signs?

14 Not at all
22 Very little
42 Moderately
38 Severely
2 No Answer

Did you experience any physical reactions to the smoke?

18 Yes 99 No 1 No Answer

If yes, how so: (Please describe reaction)

TRIAL 4. Ceiling Lighting

NAME: ________________________________ VEST NO. ______ TEST NO. _________

Please respond to every item on the questionnaire according to your best judgment on each item for the test just completed.

Did you have a feeling or an impression that a real emergency existed during the evacuation?

88 Yes 30 No

If you answered yes to the above question, how strong was the feeling or impression?

13 Slight 39 Moderate 36 Strong

Did you feel disoriented or confused at any time during the test?

63 Yes 55 No

If you felt disoriented or confused, when was that feeling strongest?

55 Not applicable
0 When first seated in simulator
4 When bell sounded
59 While moving through the cabin

While you were seated, before the bell rang, were you aware of the exit signs?

96 Yes 20 No 1 Don't remember 1 No Answer

After the bell rang and you got up from your seat, were you aware of the exit signs?

50 Yes 64 No 3 Don't remember 1 No Answer

Did the type of lighting affect your confidence and speed of evacuation?

84 Yes 25 No 9 Don't know

Do you think the lighting was:

59 Inadequate 43 Barely adequate 16 More than adequate

for a quick and safe evacuation?

How well could you see the exit when you first moved into the aisle after the bell rang?

86 Not at all   22 Barely   10 Distinctly

How much did the presence of smoke in the cabin affect your access to the exit?

13 Not at all   11 Very little
24 Moderately   68 Severely
1 No Answer

How much did the smoke affect the lighting in the cabin?

2 Not at all   7 Very little
38 Moderately   70 Severely
1 No Answer

How much did the smoke affect the visibility of the exit signs?

7 Not at all   20 Very little
25 Moderately   65 Severely
1 No Answer

Did you experience any physical reactions to the smoke?

14 Yes   103 No

If yes, how so: (Please describe reaction)

APPENDIX D

Gulfstream American Corporation's Gulfstream 1C (Stretched) G-159 Aircraft Emergency Aisle Lighting System Test Results.

The following is a narrative description of the aisle lighting system test results obtained from FAA/ASO-213 records of the FAA Conformity Inspection and Certification approval on the first Gu fstream 1C (G-1C) to be modified with seat-mounted aisle lighting.

The extended fuselage of the G-1C modification necessitated the installation of additional cabin emergency lighting. Commercially available lights were installed under aisle seats on seat rows 1, 4, 7 and 10 of the first aircraft to be modified. Lights were round incandescent dome units made by Grimes,* P/N B-7545, containing both a 28-volt bulb for normal illumination and a 6.5-volt bulb for emergency illumination. The frosted lens cast light down and out into the aisle. Tests were conducted using aircraft battery power only.

Measurements of general emergency cabin illumination were taken at seat armrest height with a Spectra Photometer, Model FC-200 supplied by the FAA Technical Center The lens of the photometer was oriented downward and fixed at armrest height for initial readings. The photometer was then rotated 90° up and aft at the same height to record additional readings. Illumination readings were taken in accordance with FAR Part 25.812(c) and (d) at 14 positions along the aisleway, Table D-1. The average illumination measured, looking down at armrest height, was 0.96 lux (0.089 foot candles) and viewing aft was 1.02 lux (0.095 foot candles), which were both well above the minimum FAR requirements of 0.54 lux (0.05 foot candles). Light cast in the cross aisles from the exit lights also far exceeded the minimum 0.215 lux (0.02 foot candle) requirement.

The illumination measurements were made during the FAA Conformity Inspection of the Gulfstream 1C, S/N 116 on October 28, 1980, by the manufacturer, FAA Southern Region and FAA Technical Center personnel. The report on the installation and testing of the emergency lighting system was published as Gulfstream American Report No. 159-GER-14 on November 13, 1980. The FAA Form 8110-3, Statement of Compliance with Federal Aviation Regulations, was also issued on November 13, 1980, and recommended approval of data gathered during the Conformity Inspection. Gulfstream American Corporation submitted the report and the FAA Form 8110-3 to the Southern Region by letter dated November 25, 1980. FAA/ASO-213 Engineering and Manufacturing Branch acknowledged receipt of the letter December 2, 1980, and approved the recommendation for certification with the aisle-mounted lighting system installed.

*Grimes Manufacturing Co., Urbana, Ohio

TABLE D-1. Measured Illumination Levels of the Gulfstream American G-1C Aircraft*

Aisle Position	Photometer Orientation: Section 25.803(c) Aisle lighting at armrest level — Looking Down	Photometer Orientation: Section 25.803(c) Aisle lighting at armrest level — Rotated 90^{o} Aft	Photometer Orientation: Section 25.803(d) Exit signs at 15.24 cm (6 inches) above cross-aisle floor.	Aisle Location
1	-	-	.225	Entrance to cockpit
2	-	-	.16	Baggage compartment
3	.009	.009	.27	Fwd cabin door
4	.14	.073	-	Seat row 1
5	.026	.044	-	
6	.145	.139	-	Seat row 4
7	.095	.325	-	
8	.125	.11	-	
9	.127	.046	.55	Seat row 7 and overwing exits
10	.081	.074	-	
11	.147	.034	-	Seat row 10
12	.038	.035	-	
13	.030	.192	-	
14	.039	.057	.37	Rear door
Average	0.081	0.095	0.315	

*Readings in foot candles.

☆U.S. GOVERNMENT PRINTING OFFICE : 1981 O - 349-244