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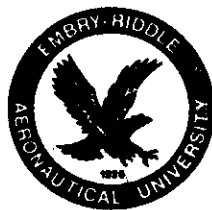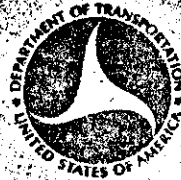
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READABILITY OF SELF-ILLUMINATED SIGNS IN A
SMOKE-OBSCURED ENVIRONMENT

P. G. Rasmussen
J. D. Garner
J. G. Blethrow
and
D. L. Lowrey
Civil Aeromedical Institute
Federal Aviation Administration
Oklahoma City, Oklahoma

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16. Abstract

This study investigates the ability of people with normal distant visual acuity to identify self-illuminated emergency signs in a smoke-obscured environment. The results indicate that signs whose background luminance meets or exceeds the requirements of Federal Aviation Regulation (FAR) 25.812 are readable under favorable conditions when the total optical density of the smoke between the observer and the signs ranges between 3.00 and 3.55. Substantial increases in character sizes in the signs produce only moderate improvement in readability.

Some limitations on the practical application of these data to predicting sign visibility in adverse conditions are discussed.

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READABILITY OF SELF-ILLUMINATED SIGNS IN A
SMOKE-OBSCURED ENVIRONMENT

Introduction.

Minimal design requirements for emergency exit signs used in civil air
transports are specified in Federal Aviation Regulations (FAR) 25.812. These
requirements insure adequate visibility and readability under normal viewing
conditions. However, some emergency conditions, such as postcrash fires, may
introduce smoke into the cabin area and obscure the signs at a time when their
prominent visibility is most critical.

The two major purposes of the present study were to: (i) determine at
what optical densities of smoke internally illuminated signs of various
sizes and background luminance levels are readable, and (ii) establish base-
line data for the use of an inert white screening fog as a research tool to
predict the readability of emergency signs in the presence of black fuel-fire
smoke.

Methods.

Subjects. Subjects consisted of 10 male and 9 female adult volunteers
and paid participants. Nine subjects required spectacle or contact lens
corrections to achieve 20/20 distant visual acuity.

Equipment. The equipment arrangement is schematically illustrated in
Figure 1. The viewing windows of the smoke chamber were 3.2-mm-thick (0.125-
in) plate glass separated by 1.83 m (6 ft). The light source for the display
consisted of six fluorescent bulbs (Westinghouse Cool White F40T 10CW/99)
wired to ballasts regulated by a dimmer control. The fixtures were mounted
as a parallel array in a light box with a flat white interior. With the
light box mounted in place the bulbs were parallel to, and 26 cm (10.2 in)
behind, a white translucent diffusing screen composed of a double layer of
3.2-mm-thick (0.125-in) acrylic panes (Plexiglas Type W2447). A retaining
slot immediately in front of the diffusing screen held the experimental signs.
The plane of the viewing area was 5 cm (2 in) behind the rear viewing window
of the smoke chamber when the signs were in the display position.

The National Bureau of Standards (NBS) Photometric Smoke Measurement
System was mounted near floor level beneath the subject's line of sight but
was physically obscured from view. The system was modified and calibrated
for operation with a 50-cm (19.7-in) separation between the reference light
source and the phototube detector.

An inert white screen fog (Pepper Fog, Smith & Wesson/General Ordnance
Equipment Co.) was used as the obscuring agent and was dispersed evenly
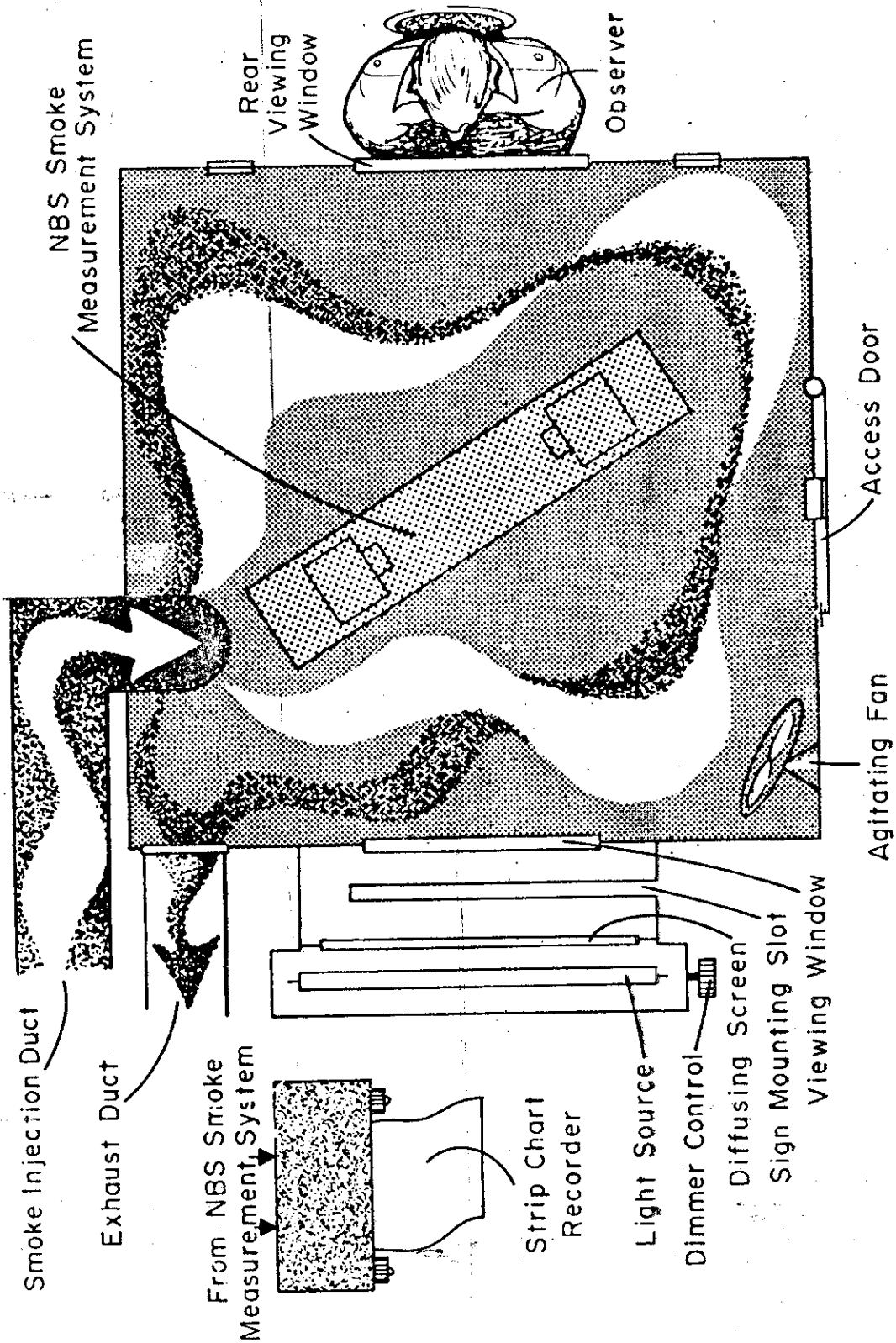throughout the chamber by an agitating fan.

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Figure 1. Diagram of experimental equipment configuration, viewed from above.

Labels in figure:
- NBS Smoke Measurement System
- Rear Viewing Window
- Observer
- Access Door
- Agitating Fan
- Smoke Injection Duct
- Exhaust Duct
- From NBS Smoke Measurement System
- Strip Chart Recorder
- Light Source
- Dimmer Control
- Diffusing Screen
- Sign Mounting Slot
- Viewing Window

Displays. The character format for the experimental signs was based on the Grimes[*] exit sign commonly found on commercial aircraft. Table 1 gives the height and stroke width of the characters together with the corresponding visual angles for the 197-cm (77-in) viewing distance. The dimensions for Sign No. 4 also approximate those of the characters in the Grimes sign.

The characters were hand drawn and reproduced on film negatives and photographically enlarged or reduced to the desired sizes. The signs were affixed in mounting boards to provide a lighted margin 2.5 cm (1 in) above and below the characters and 5 cm (2 in) to the left of the first character and to the right of the last character in the sign. The signs were composed of the characters "E,X,I,T" except that the largest sign was limited to two characters. Character sequence was varied for some signs to minimize antici- patory identification before the subject could actually read the sign.

The four luminance levels were the average of 24 equally spaced grid points on the observer's side of the available 44- by 32-cm (17.3- by 12.5- in) viewing area of the diffusing screen before a sign was mounted for viewing. The 89 cd/m^2 (26-fL) luminance level was established as an approxi- mation of the background luminance required by FAR 25.812. The 31-, 140-, and 158-cd/m^2 (9-, 41-, and 46-fL) values resulted from 1-V increments and decrements measured at the dimmer control that gave a usable range of lumi- nance levels. The candela (cd) is the International System of Units (SI) unit of luminous intensity. The metric expression cd/m^2 is approximately equivalent to 0.29 fL.

TABLE 1. Character Sizes and Visual Angles of
Experimental Signs

Sign No.	Character Height (mm)	(in)	Visual Angle (min)	Stroke Width (mm)	(in)	Visual Angle (min)
1	211.5	(8.33)	371.4	25.40	(1.00)	44.8
2	108.2	(4.26)	190.1	13.10	(0.52)	23.0
3	52.7	(2.07)	92.6	6.35	(0.25)	11.1
4	46.2	(1.84)	81.2	5.45	(0.21)	9.6
5	26.3	(1.04)	46.2	3.20	(0.13)	5.7
6	13.4	(0.53)	23.6	1.60	(0.06)	2.8
7	6.4	(0.25)	11.3	0.77	(0.03)	1.4
8	3.2	(0.13)	5.7	0.38	(0.01)	0.7

Procedure. At the beginning of each experimental session, the screening fog was introduced into the chamber until it reached a density at which the measuring system no longer yielded a measurable output. The subject was seated behind the rear viewing window with eye height adjusted to give normal line-of-sight viewing of the signs. After the subject had spent several minutes adapting to the ambient lighting conditions the largest sign was inserted in the mounting slot and the light source adjusted to the luminance level for that session. The fog was drawn out of the chamber at a controlled rate until the subject could distinguish the sign light and then was allowed

[*]Grimes Mfg. Co., Urbana, Ohio, Emergency Exit Light 10-0067-9.

to dissipate at a slower rate until the subject correctly identified the sign. On identification of a sign, the next smaller sign was immediately presented until all eight signs had been identified. All glass surfaces within the chamber (panes, lenses, etc.) were cleaned before beginning each of the sessions for the three remaining luminance levels.

The output of the photometric smoke measurement system was recorded on a strip chart recorder. As the output rose from zero in dense fog toward 1-V full-scale deflection in clear air, the chart was indexed to indicate the values at which the subjects responded to each size of sign. The milli-volt (mV) values recorded from the measurement system were converted to optical density values by the formula:

$$\text{Optical Density} = 1/d \log Tc/Ts$$

where: d is the unit distance between the reference light
       and the phototube (0.5 m),

   Tc is the clear air value (1,000 mV),

                   and

   Ts is the value at which the signs were identified.

Results.

The means, standard deviations, and ranges of the optical densities of screening fog at which the subjects could read the eight sizes of signs at four background luminance levels are listed in Table 2, and Figure 2 plots the means for the total density values. Figure 3 depicts the values two standard deviations below the means which are the values at which approxi-mately 98 percent of the general population with 20/20 distant visual acuity can be expected to be able to read similar signs under similar conditions. The density values for the 89-, 140-, and 158-cd/m^2 (26-, 41-, and 46-fL) luminance levels were essentially identical and have been combined to give representative density values for those luminance levels.

Increasing background luminance levels resulted in some improvement in readability as measured by the mean optical density values at which the signs could be read but differences between the three highest luminance levels were minor. The higher luminance levels also resulted in a greater variability in subject responses that effectively eliminated any true differences when consideration is limited to the values two standard deviations below the means.

Increasing character size made it possible to read the signs at somewhat higher density values but the differences in readability between adjacent sign sizes are, at least in part, an artifact of the experimental procedure. The true differences between adjacent sizes are probably somewhat less than those shown by the data.

TABLE 2. Means, Standard Deviations, and Ranges of the
Optical Densities of Screening Fog at Which Eight Sizes of Signs
Were Identified When Presented at Four
Background Luminance Levels

| Sign No.	Screening Fog Density (total)			Screening Fog Density (per meter)		
	Mean	S.D.	Range	Mean	S.D.	Range
31 cd/m² (9 fL)						
1	3.79	0.24	3.31 – 4.32	2.07	0.13	1.81 – 2.36
2	3.69	0.24	3.20 – 4.08	2.02	0.13	1.75 – 2.23
3	3.62	0.27	2.89 – 3.99	1.98	0.15	1.58 – 2.18
4	3.57	0.29	2.71 – 3.95	1.95	0.16	1.48 – 2.16
5	3.51	0.29	2.60 – 3.90	1.92	0.16	1.42 – 2.13
6	3.42	0.31	2.43 – 3.82	1.87	0.17	1.33 – 2.09
7	2.96	0.29	2.34 – 3.55	1.62	0.16	1.28 – 1.94
8	2.01	0.49	0.88 – 2.91	1.10	0.27	0.48 – 1.59
89 cd/m² (26 fL)						
1	3.91	0.22	3.51 – 4.33	2.14	0.12	1.92 – 2.37
2	3.80	0.18	3.51 – 4.15	2.08	0.10	1.92 – 2.27
3	3.75	0.16	3.47 – 4.01	2.05	0.09	1.90 – 2.19
4	3.69	0.16	3.44 – 3.91	2.02	0.09	1.88 – 2.14
5	3.62	0.18	3.27 – 3.86	1.98	0.10	1.79 – 2.11
6	3.57	0.18	3.24 – 3.84	1.95	0.10	1.77 – 2.10
7	3.29	0.22	2.87 – 3.77	1.80	0.12	1.57 – 2.06
8	2.25	0.38	1.54 – 3.22	1.23	0.21	0.84 – 1.76
140 cd/m² (41 fL)						
1	3.95	0.18	3.62 – 4.37	2.16	0.10	1.98 – 2.39
2	3.82	0.18	3.51 – 4.37	2.09	0.10	1.92 – 2.39
3	3.77	0.18	3.49 – 4.10	2.06	0.10	1.91 – 2.24
4	3.71	0.20	3.42 – 4.02	2.03	0.11	1.87 – 2.20
5	3.66	0.20	3.31 – 3.93	2.00	0.11	1.81 – 2.15
6	3.60	0.20	3.24 – 3.90	1.97	0.11	1.77 – 2.13
7	3.33	0.20	3.02 – 3.66	1.82	0.11	1.65 – 2.00
8	2.40	0.40	2.03 – 3.27	1.31	0.22	1.11 – 1.79
158 cd/m² (46 fL)						
1	3.99	0.22	3.62 – 4.37	2.18	0.12	1.98 – 2.39
2	3.90	0.22	3.51 – 4.37	2.13	0.12	1.92 – 2.39
3	3.86	0.24	3.47 – 4.37	2.11	0.13	1.90 – 2.39
4	3.80	0.26	3.42 – 4.33	2.08	0.14	1.87 – 2.37
5	3.75	0.27	3.33 – 4.30	2.05	0.15	1.82 – 2.35
6	3.68	0.29	3.18 – 4.21	2.01	0.16	1.74 – 2.30
7	3.36	0.18	3.02 – 3.66	1.84	0.10	1.65 – 2.00
8	2.60	0.29	2.03 – 3.27	1.42	0.16	1.11 – 1.77

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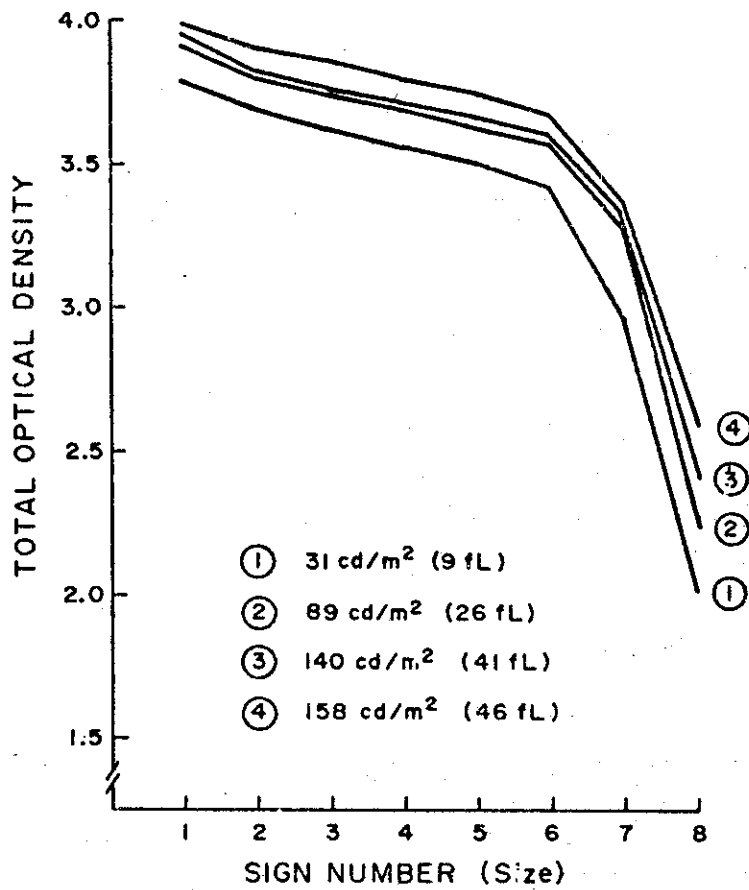
Figure 2. Means of the optical densities of screening fog
at which eight sizes of signs were identified when
presented at four background luminance levels
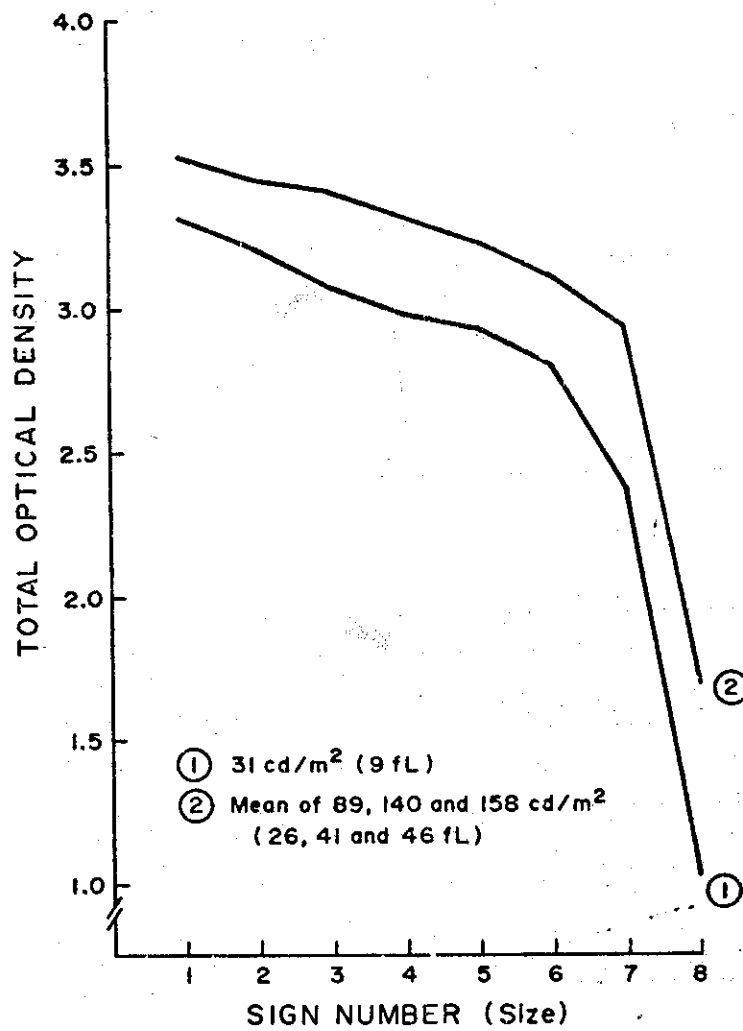(data from Table 2).

Figure 3.   Optical densities two standard deviations below the
means at which signs were identified. Values for the three
highest background luminance levels have been combined.

The range of density values for the seven largest signs at the three highest luminance values as shown in Figure 3 effectively reduce the effective luminance values, and therefore the apparent brightness when viewed by the subject, to between 0.03 and 0.11 percent of the clear air values.

Discussion.

Several precautions must be observed in any attempt to use the present data to predict sign readability in an actual emergency situation. The results are based on the density values of a white screening fog over a relatively short, fixed viewing distance and a single condition of ambient illumination. Readability at other density and distance combinations and for other colors and compositions of obscuring agents cannot be accurately predicted by neutral density filter models or the haze equivalents of the "frosted plate" models where the visual interference is introduced in a fixed plane rather than distributed along the line of sight. The optical density of smoke is partly determined by the interactive effects of particle size and shape and its general refractive index. The same characteristics may also introduce factors that lower the correlation between its transmissivity of light and the ability to distinguish visual details through obscuring smoke.

In the present study there was no direct contact of the eyes with any possible irritating or injurious components of smoke. Such exposure can result in an adverse effect on the visual system that can range from increased lacrimation to transitory superficial keratitis, depending on the composition and concentration of toxic substances in the smoke (1). The reduction of visual efficiency resulting from these effects is highly variable and not satisfactorily documented in the literature but can be extensive. In these more extreme circumstances the question of readability of emergency signs may well be a moot question unless protective devices such as goggles, face masks, or smoke hoods are available.

Reference.

1. Grant, W. Morton: Toxicology of the Eye, Springfield, Illinois, Charles C. Thomas, 1974, p. 922.

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