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Low-Visibility Visual Simulation with Real Fog

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An environmental fog simulation (EFS) attachment was developed to aid in the study of natural low-visibility visual cues and subsequently used to examine the realism effect upon the aircraft simulator visual scene. A review of the basic fog equations indicated that the two major factors must be accounted for in the simulation of low visibility—one due to atmospheric attenuation and one due to veiling luminance. These factors are compared systematically by 1) comparing actual measurements to those computed from the fog equations, and 2) comparing runway-visual-range-related visual-scene contrast values with the calculated values. These values are also compared with the simulated equivalent equations and with contrast measurements obtained from a current electronic fog synthesizer to help identify areas in which improvements are needed. These differences in technique, the measured values, the features of both systems, a pilot opinion survey of the EFS fog, and improvements (by combining features of both systems) that are expected to significantly increase the potential as well as flexibility for producing a very high-fidelity, low-visibility visual simulation are discussed.

Nomenclature

B_h	= ambient sun luminance as observed toward horizon, cd/m^2
B_0	= object-scene display luminance, cd/m^2
B_0	= background-display-scene luminance, cd/m^2
B_R	= object-scene luminance at pilot's eye position, cd/m^2
B_R	= background-scene luminance at pilot's eye position, cd/m^2
C_R	= apparent contrast
C_R/C_0	= contrast transmittance ratio or contrast modulation
R	= horizontal range, m
RVR	= runway visual range, m
R_V	= horizontal fog visual range, m
t	= time, s
Z	= aircraft altitude, m
Z_V	= vertical oscillator signal from computer, V
Z_{VR}	= vertical breakout altitude of aircraft relative to RVR, m
α'	= display field of view through windscreen, deg
δ_i	= pilot control input variables to aircraft equations of motion, rad
θ_M	= motor drive position of environmental chamber faceplate, deg
σ	= extinction coefficient, 1/m
σ_1	= scattering coefficient, 1/m
σ_2	= absorption coefficient, 1/m
ω_Z	= vertical altitude oscillator frequency, rad/s

Introduction

POOR visibility is a major contributing factor in many terminal-area landing approach accidents. Recent National Transportation Safety Board (NTSB) accident statistics show that 48.3% of all air-carrier accidents are caused by or related to adverse weather conditions.[1,2] According to another NTSB 10-year statistical analysis, 41% of all fatalities were caused by weather conditions.[3] A summary of 17 low-visibility accidents showed that 80% occurred when visibility was less than 1609 m (5278 ft) because of fog and rain, and 60% of these incidents occurred in nighttime conditions.[2] The underlying factor may be the result of faulty visual perception caused by distorted or reduced visual inputs occurring under conditions of rain and fog.[4]

An early attempt to use the natural effects of actual fog was made at the University of California at Berkeley (under the sponsorship of the FAA). Workers there constructed a large building (circa 1964) in which actual fog was produced and used in studies of airport lighting systems.[5-7] The presence of actual fog served to increase the "realism" required for a balanced lighting system investigation under low-visibility conditions. Because actual fog was being used, conditions were present that could not be successfully reproduced by other methods.

The FAA has recently considered the benefits of upgrading and promoting the additional use of simulators to expand training and certification to improve safety, to increase fuel conservation, and to reduce training costs as well as airport congestion (according to an FAA-NPRM, 14 CFR parts 61 and 121). A DOT/FAA Final Rule 121-14C, effective August 29, 1980, declares three major phases for upgrading current simulators to permit and present realistic training in various abnormal and weather flight conditions that may be encountered during line operations. The phase 2 visual-scene weather presentations required realistic fog representations. The phase 3 visual-scene presentations additionally include the sound, visual, and motion effects of entering light, medium, and heavy precipitation below an altitude of 610 m (2000 ft). Thus implementation of visibility conditions of sufficient realism is required to fulfill both phase 2 and 3 training requirements.

What is not clear from the above requirements is how the low-visibility visual cues are to be improved, or what level of realism is required, or how the realism level is to be measured. Furthermore, there is confusion among those working in flight simulation about the properties of fog that are needed to accurately create simulation models of fog. As a result, the following basic discussion is intended to provide a needed basis from which a low-visibility model can be simulated and applied in the construction of simulation hardware devices.

Background

Types of Fog and Characteristics

The most common types of fog are 1) radiation, 2) advection, and 3) frontal. Radiation fog is formed when the ground surface is colder than the air temperature; it can be

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further classified as "shallow" (single layered) or "mature" (deep multilayered). Advection fog is formed when a warm, moist air mass moves over a cold surface. Sea fogs are actually advection fogs. Frontal fog is formed as a boundary between a cold and warm air mass. Reference has sometimes been made to an "upslope" fog, but it is the early stage of a cloud that is forming as a result of convective adiabatic expansion.[8] Patchy fog could be formed from any one of the above three types because of local differences between the surface and air temperature.

It has been recognized for a long time that a wide divergence of opinion exists pertaining to the measurement techniques for recording and defining the optical viewing properties of fog.[9,10] To clarify some misrepresented facts concerning fog, objects illuminated in bright daylight and observed in clear air and in fog would not have undiffused edges because the intense daylight veiling luminance is considered to mask the halo luminance and therefore could not be observed. Figures 1 and 2 show a sample nighttime scene taken at the Arcata (Calif.) Airport commencing from a light fog (Fig. 1) to heavy fog (Fig. 2). These photographs show 1) the presence of a halo that rapidly diminishes in heavy fog; and 2) a contraction of the apparent size of the halo light between light and heavy fog. A brief explanation of these effects is presented in Fig. 3, which shows how a distant light would be observed at night in the presence of a light fog to produce both an attenuation (loss of luminance) and the halo effect mentioned previously. Rays of light emanating from the point-source light are partially absorbed and diffracted by the fog droplets along the path to the observer. With each fog droplet encounter, the luminance of the light decreases, and at the same time the light spreads. The spreading of this light becomes the halo as seen by the observer.

The observed optical characteristics of fog are known to include the following factors: 1) attenuation of scene brightness, and 2) the veiling luminance effect from an ambient light source, such as from the sun or from aircraft landing lights. The veiling luminance is caused by light rays that may be multiply refracted and diffracted from one fog particle onto other particles to produce a scattering of the light as though it was emanating from all directions. Consequently, any scene to be viewed through the fog would not be visible until the contrast between the fog and scene improved above a certain contrast value.

Equations for Actual Fog

Atmospheric attenuation is a function of many variables: wavelength, path length, pressure, temperature, humidity, and the composition of the atmosphere.[11] The factor commonly used to describe the density of the fog is called the extinction coefficient. It is known to be composed of two parts: a scattering component, σ_1, and an absorption component, σ_2, so that (from Refs. 11-13)

$$\sigma = \sigma_1 + \sigma_2 \tag{1}$$

The dominant term, σ_1, is that due to scattering from both the air molecules (Rayleigh scattering) and scattering by the aerosol particles (Mie scattering).[11] The average extinction coefficient for the visible spectrum (0.38-0.72 μm) at sea level depends as follows on the horizontal visibility range R_V:

$$\sigma = 3.41/R_V \tag{2}$$

(Koschmieder assumed a contrast threshold value of 2%; that value, which resulted in the present computation of $3.91/R_V = (1/R_V)\ln(1/0.02)$, has tended to persist in meteorological circles, although it has been the subject of considerable doubt.[14] In another more recent study, Politch[15] found that the extinction coefficient should be $\sigma = 3.41/R_V$. This implies that the average value of the contrast threshold should be 3.3% as computed from $(1/R_V)\ln(1/0.033) = 3.41/R_V$, which represents an average value for the visibility.)

This extinction coefficient is used to help formulate the luminance of an object seen in daylight and is composed of two parts: 1) attenuation; and 2) veiling luminance, as shown in the following equation[11,14]:

$$B_R = \overbrace{B_0 e^{-\sigma R}}^{\text{attenuation}} + \overbrace{B_h(1 - e^{-\sigma R})}^{\text{veiling luminance}}$$

$$B_R = B_0 e^{-\sigma R} + B_h(1 - e^{-\sigma R}) \tag{3}$$

Fig. 1 Effects of fog on runway lights—Arcata (Calif.) Airport.

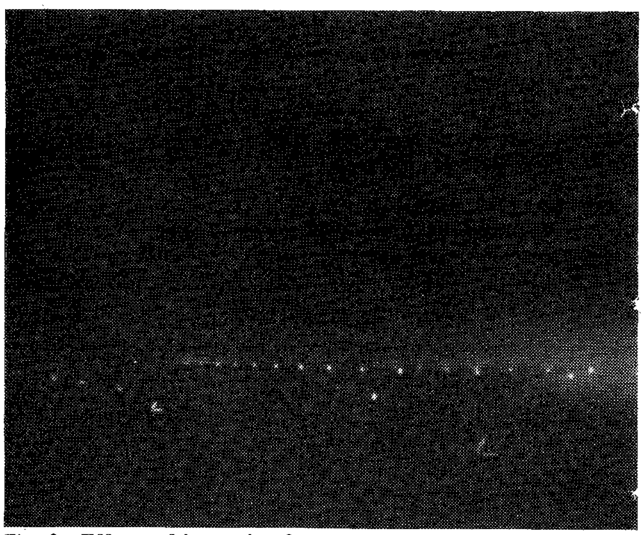

Fig. 2 Effects of increasing fog on runway lights—Arcata (Calif.) Airport.

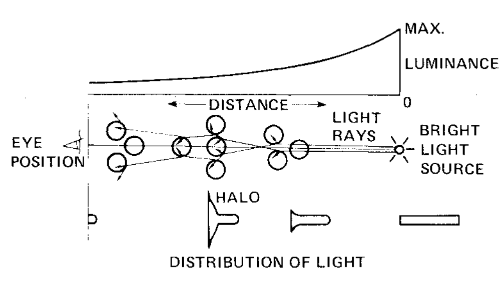

Fig. 3 Light attenuation in presence of fog.

Inherent contrast:

$$C_0 = (B_0 - B_0)/B_0 \tag{4}$$

Apparent contrast:

$$C_R = \frac{(B_0 - B_0)e^{-\sigma R}}{B_R} = \frac{C_0 B_0 e^{-\sigma R}}{B_R} \tag{5}$$

Contrast transmittance or contrast modulation:

$$\frac{C_R}{C_0} = \frac{B_0 e^{-\sigma R}}{B_0 e^{-\sigma R} + B_h(1-e^{-\sigma R})} = \frac{1}{1 + B_h(1-e^{-\sigma R})/B_0 e^{-\sigma R}} \tag{6}$$

The first term in Eq. (3) pertains to the luminance of the object and to its attenuation caused by the absorption and scattering coefficients of fog or cloud conditions. Similarly, the second part of Eq. (3) is the veiling effect. The main reason it is so difficult for a daytime observer to distinguish an object is that the sunlight falls on a cloud or fog and produces an intense scattering of light. The veiling luminance of the fog so greatly exceeds the reduced luminance of the object scene that it makes it difficult if not impossible to see. The method used to better describe how well an object can be seen can be determined by examining the contrast transmittance ratio or contrast modulation, C_R/C_0, shown in Eq. (6).

Equations for Electronic Fog

An example of a modified raster system now in use at Ames Research Center operates by switching the proportional fog and background scene video inputs through a gain-changing amplifier before it terminates at the display monitor.[16] Circuitry to maintain pitch and roll is synchronized to overlay the fog with the horizon and ground-view scene presented on the final display scene monitor. Although details of the following material are beyond the scope of this report, a brief discussion is justified in order to demonstrate the simplified fog and contrast equations which are currently represented by electronic methods and which can be directly compared with the actual fog equations presented earlier.

The equation of an object and the background seen in simulated daylight is represented as

$$\begin{aligned} B_R &= B_0 + B_h[1 - 0.1(R_V/R)] \\ B_R &= B_0 + B_h[1 - 0.1(R_V/R)] \end{aligned} \tag{7}$$

for $0.1\, R_V \leq R < R_V$.

The contrast transmittance or contrast modulation is

$$\begin{aligned} \frac{C_R}{C_0} &= \frac{B_0}{B_0 + B_h[1-0.1(R_V/R)]} \\ &= \frac{1}{1 + B_h[1-0.1(R_V/R)]/B_0} \end{aligned} \tag{8}$$

Variations of the above method are in use with current computer-image-generated (CIG) displays that also include raster-driven displays. Some CIG displays may use algorithms to change visibility by modifying each picture element of the display; however, they may be limited in a real-time generation of the low-visibility scene.

Perceptual Limitations of Electronic Fog

Although electronic contrast adjustment could be done according to the correct contrast equations, it would still have limitations. The synthesized veiling luminance caused by the sun, moon, or landing lights is wrongly placed in the optical plane of the CRT, which is usually collimated near infinity. The pilot would then be less subject to the Mandelbaum effect—the accommodation to a nearby resting distance in the absence of strong distant cues.[17] Also, contrast adjustment of the electronic fog does not simulate the halo effects that are prominent at night. Furthermore, the fog is two-dimensional and is homogeneous.

Because these differences in the present electronic fog method presented conflicting low-visibility visual cues compared with the natural cues of actual fog, it seemed reasonable to attempt to construct a simulation device that would use actual fog. It was also recognized that this new device might also have limitations and might require some elements of the electronic method for precisely producing a high-fidelity, low-visibility simulation. In order to examine the low visibility environment in greater detail, an apparatus from which low-visibility measurements are obtained for comparison with the actual fog equations is described, and the modifications needed for reproducing a high-fidelity, low-visibility visual simulation are discussed.

Environmental-Effects Fog Chamber

Description

Many of the conventional simulators currently in use are constructed with top-mounted display CRT's viewed through mirror beam splitters and a spherical reflective mirror positioned in the simulator windshield. Although the above optical system could be designed to accept an environmental or fog and rain attachment, it was convenient, for experimental purposes, to use a previously successful optical system, which uses either a color television model-board or computer-image-generated (CIG) scene monitor located at the focal plane of the collimating lens (Fig. 4). In this arrangement, the empty space between the beam splitter and the windshield seemed an appropriate place to experimentally position a small environmental fog and rain chamber. The subject device was conceived and developed—within the Man-Vehicle Systems Research Division, Ames Research Center—for use in conducting research on the low-visibility scene. The device (U.S. patent 4313726—NAS-ARC-11158-1) is capable of providing fog, rain, or both fog and rain combined. For the purposes of this report, however, only the details of the low-visibility, fog-generating system are presented.

In referring to Fig. 4, the components needed to support and test the operation of the new environmental attachment are 1) a main-frame digital computer; 2) a display generator; 3) a color display monitor, such as a beam-penetration-type or a color television monitor; 4) collimating lens arrangement; 5) the environmental chamber and fog generators; and 6) an ambient light source. For the purposes of evaluation, the small digital computer within the display generator was used to provide the longitudinal aircraft dynamics and control laws to the chamber. Interior to the chamber, at the sides, are two primary environmental effects fog generators (not shown). Positioned between the top of the environmental chamber and the face of the display monitor is a fluorescent lamp for simulating the ambient veiling luminance; the brightness of the lamp is controlled by the digital computer.

Figure 5 is a photograph of the experimental hardware developed for installation in the windshield area of the aircraft simulator cab. An example of what the pilot would see is shown in Figs. 6 and 7. Figure 6 is a runway view looking through the chamber (without fog) of a TV model-board visual scene; Fig. 7 is the same scene observed through a 305-m (1000-ft) visibility (RVR). Although the above discussion pertains to only one aircraft windshield window, it should be emphasized that multiple environmental chambers can be positioned at each window of the simulator cab, each of which could operate independently with varying visibilities, if so desired.

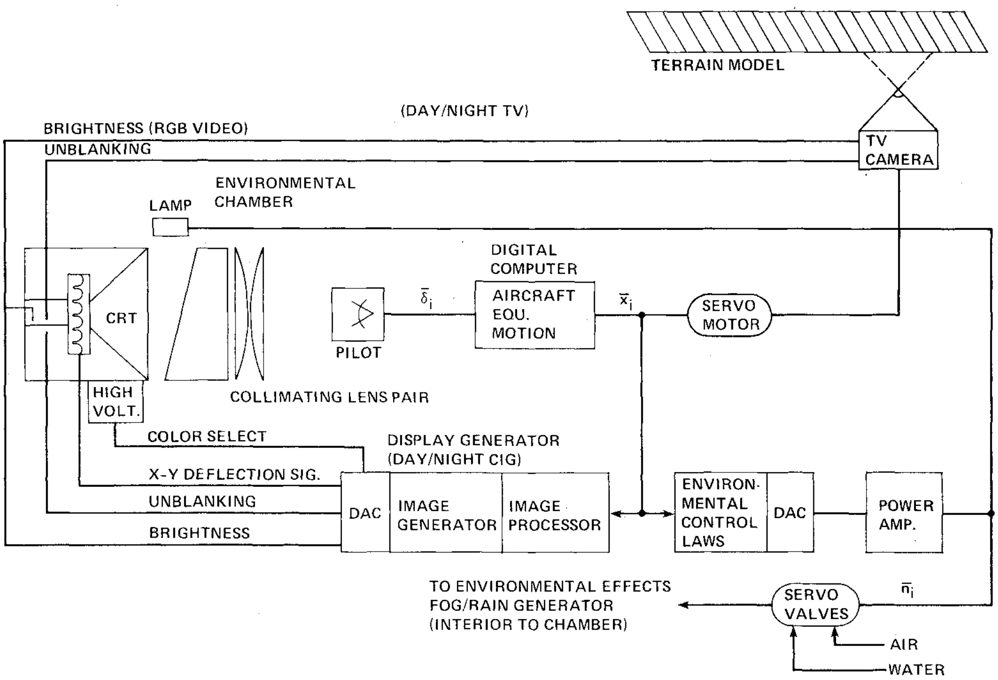

Fig. 4 Piloted closed-loop environmental effects visual display system.

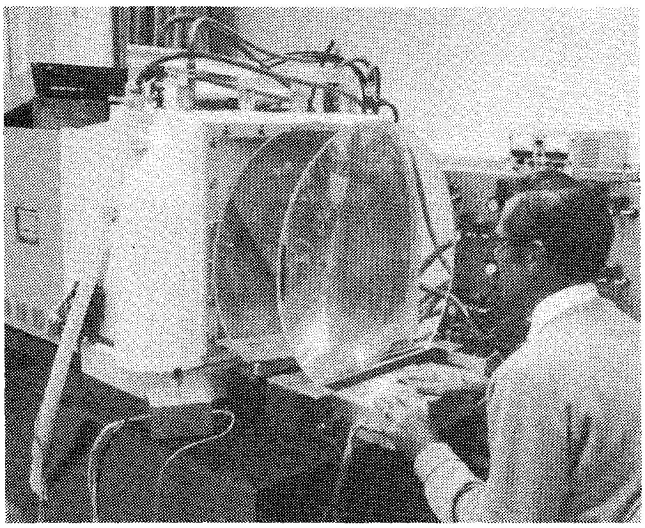

Fig. 5 Arrangement of experimental component hardware.

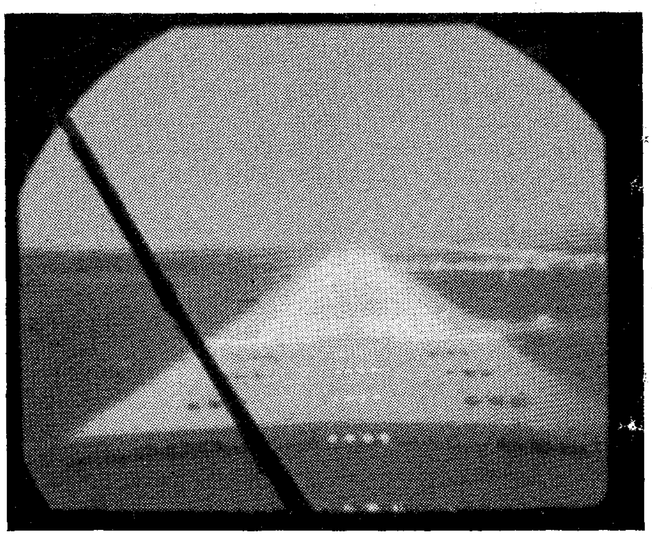

Fig. 6 Virtual display observed through collimating lens pair and chamber without fog.

Method of Operation

The device that produces the natural low-visibility environment is discussed in more detail in ARC 11158-1. However, it is this device that manufactures the fog (which is composed of minute aerosol droplets). The droplets are ejected at a low velocity—about 0.3 m/s—into the environmental chamber. As the number of these fog droplets within the chamber increases, they become more tightly packed within the constant volume of the environmental chamber, changing the attenuation coefficient $\sigma \cdot R$. Consequently, the maximum density is reached as the attenuation coefficient approaches 20; at that point, it becomes impossible for an observer to see any object through the small central thickness (0.24 m) of the environmental chamber. A single 12-W overhead fluorescent lamp produces an effect that can make the fog appear even more dense, when it is properly controlled; the lamp is used to simulate the effect of sunlight falling upon the fog or cloud.

The details of the primary mechanism that can precisely remove and replace portions of air from the environmental chamber are also discussed in ARC 11158-1. Briefly, however, assume the chamber is filled with fog and is at the maximum density ($\sigma \cdot R = 20$). A computer-generated, variable-altitude oscillator signal ω_Z produces an output signal which is converted to an analog voltage signal Z_V. This oscillating voltage signal commences to repeatedly energize an external relay, whereupon dry air at pressure P and moving at velocity V is admitted in pulses to the bottom of the environmental chamber to mix with the fog. As a result, both the dry air and fog are forced to exit at the top via pressure relief valves. The frequency of the altitude oscillator, ω_Z, changes as a function of altitude and RVR in order to produce digital pulses based on the following equation:

$$\omega_Z = \frac{30[Z - (Z_{VR} - 15.24)]}{30.48} \tag{9}$$

where Z_{VR} is a function of RVR. The oscillator output signal produces voltage pulses Z_V through a digital-to-analog converter; the voltage pulses are frequency dependent:

$$Z_V = 5(1 - \cos\omega_Z t) \tag{10}$$

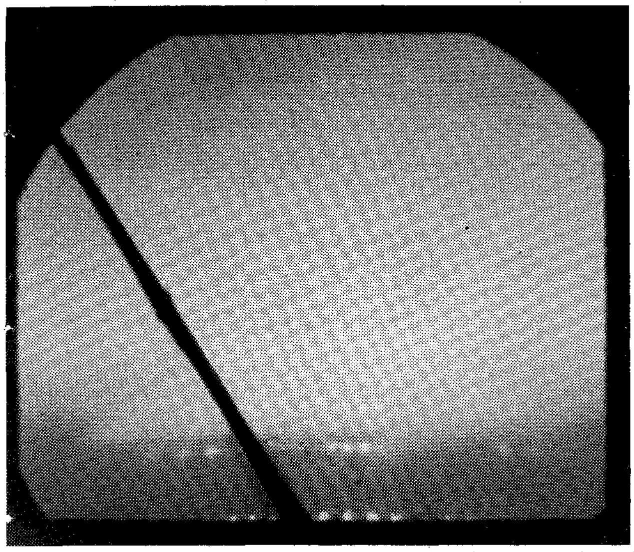

Fig. 7 Display scene observed through collimating lens pair and chamber with fog calibrated to 305-m (1000-ft) RVR.

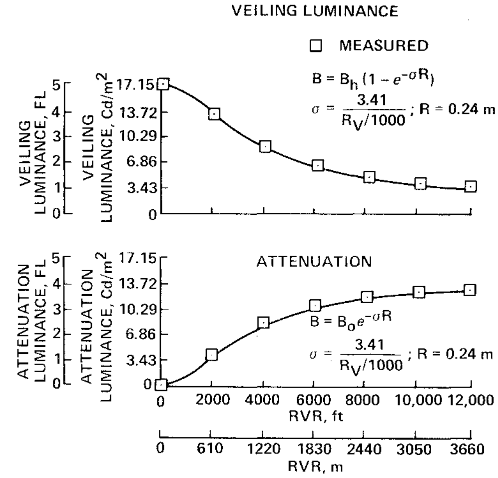

Fig. 8 Changes in veiling luminance and attenuation with RVR: a) veiling luminance; b) attenuation.

Thus the shift in frequency is then made to correspond to a specific number of air pulses relative to the RVR condition. This method of calibration allows clean dry air to enter the chamber in proportional air pulses and displaces a compact volume of fog within the chamber, resulting in calibrated changes in visibility.

Improvements in Fog Simulation Fidelity

Earlier, in Eq. (3), two factors were shown to be present in a daylight scene: 1) that due to the object and its attenuation through the fog; and 2) that due to the ambient light upon the fog, referred to previously as the veiling luminance. In order to determine the degree of validity for the simulated low-visibility environment, the individual contributions of attenuation and veiling luminance were measured at the pilot's eye position. To examine the pure *veiling luminance* contribution only, a Pritchard photometer was positioned at the pilot's eye position to record the luminance values (obtained by reducing B_0 to zero in Eq. (3) with the use of a black velvet cloth equal in area to the CRT monitor scene and positioned at the collimating lens focal plane) while the visibility was made to change. The precision injection of calibrated pulsed air into the chamber causes the fog density to change—changing the extinction coefficient—and the ensuing visibility change is then compared with the veiling luminance term in Eq. (3). The calibrated RVR values recorded by the photometer for RVR's ranging between 0 and 3660 m (12,000 ft) is shown in Fig. 8a. This measurement compares and demonstrates both analytically and empirically that as the fog becomes more dense, the ensuing brightness increases to a maximum value at zero visibility. Also, it should be noted that no correction for altitude has been added so this effect is what would be expected along a horizontal path at sea level and in a shallow radiation fog along the ground.[11] This veiling luminance can also be expected to change somewhat, depending on other types of fog and by considering the choice of an altitude-related extinction coefficient correction (discussed in more detail in Ref. 11).

The other factor is that caused by *attenuation*. To obtain an attenuation response through the fog, a 17.15-cd/m^{2} (5-fL) fiber optic point-source light (2-mm diameter) was positioned at the collimating lens focal plane and the ambient veiling lamp was turned off. Again, air was pulsed into the environmental chamber under computer control to change the visibility. The photometer was used to record the attenuation values, which are presented in Fig. 8b. This demonstrates that a decrease in brightness occurs with a reduction in simulated RVR. To illustrate characteristic properties of actual fog that

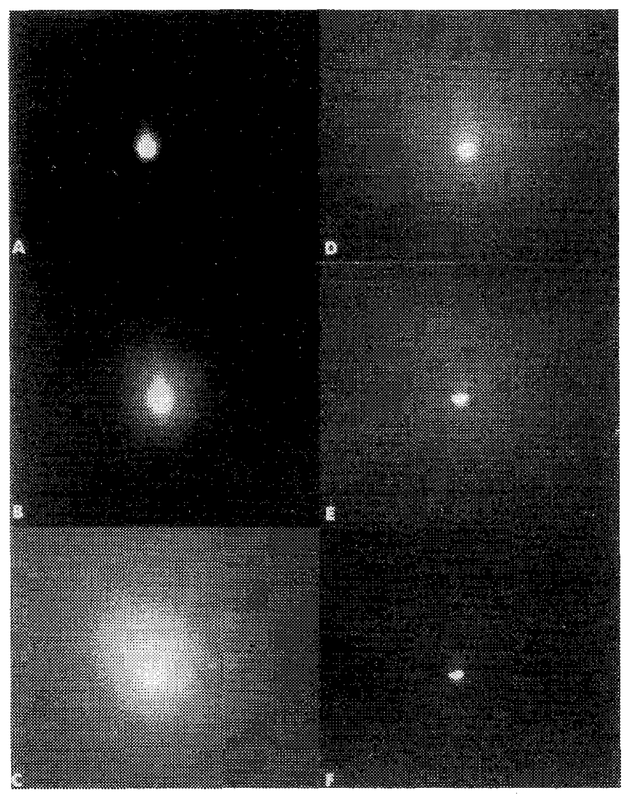

Fig. 9 Sequence of a single point-source light attenuated by increasing fog density: a) no fog; b) very light fog; c) light fog; d) medium fog; e) heavy fog; f) dense fog.

are present, Fig. 9 shows a sequence of six photographs of a fiber optic point-source light recorded with increasing fog density. Of particular interest are the similarities, as shown in Figs. 1-3 for three phenomena: 1) a halo becomes more prominent with light fog and disappears for heavy fog; 2) an apparent contraction of the size of the halo light occurs as the fog becomes more dense; and 3) the edge sharpness of the light inside the halo appears to contract in size and to be well defined. The halo may actually be expanding, but the change in luminance, as the fog becomes more dense, may be below the limit of perception and hence not readily visible.

Fidelity Limitations

The environmental chamber was initially designed for use in investigating 1) the physical characteristics of fog; 2) a method for generating fog and introducing it within the chamber; 3) a control law to rapidly change visibilities within the chamber; 4) an anticipated blending with electronic methods to partially veil the background in order to improve the fidelity; and 5) a means for ultimately producing combinations of both fog and rain. Consequently, the environmental chamber was originally constructed with a fixed-position faceplate (Fig. 4). The author believed also that this configuration could be used to simulate a mature-radiation-type fog with the use of a fixed faceplate position with the support of some electronic veiling of the background. It can be shown that the extinction coefficient for this type of fog increases with altitude, and therefore the fog becomes much more dense with altitude.[11] Thus the visibility that the pilot may encounter may very well be practically zero for some altitudes. Furthermore, another reason for providing an initial zero visibility in the simulator was to insure that no scene elements could be observed by the pilot (as the aircraft descended through the fog) until objects on the ground were within the RVR.

Fidelity Improvements with Electronic Techniques

It should be pointed out that the electronic method was shown—from examination of the fog equation [Eq.(3)] and contrast equation [Eq.(6)], and comparison with the electronic equation [Eq.(7)] and contrast equation [Eq.(8)]—to be incapable of producing a realistic fog. However, by utilizing the vertical sweep signal as it relates to RVR, a harmonious screening or veiling of the background scene used in conjunction with the actual intervening fog can be used to create a more realistic three-dimensional fog depth. Furthermore, because an intervening fog is actually present, the overall veiling luminance of the sky will be technically more correct for all visibilities.

Performance of Environmental Fog Chamber

Pilot Evaluations

To obtain preliminary information on the effectiveness of the low-visibility simulation, six airline pilots participated in a fixed-base simulation study. All pilots were on current flight status and qualified in similar type aircraft. A DC-8 jet transport aircraft was simulated with dynamics that included only the longitudinal dynamics and auto-pilot. This was because 1) the resident display generator computer limited the number of real-time calculations, and 2) the flights were made without the usual instrument assistance, thereby forcing the pilot to establish dependence on the vertical and longitudinal out-the-window visual cues within the display scene.

The evaluation used two principle test conditions. These (Table 1) were 1) a color television model-board dynamic scene; and 2) a color computer-image-generated (CIG) dynamic nighttime scene of the San Jose (Calif.) Municipal Airport. A pilot opinion survey, pertaining to the fidelity of the visual simulation, was used to help evaluate the dis and to help isolate deficiencies where necessary.

Table 1 Test conditions

Ambient light environment	RVR visibility (maximum visibility), m (ft)	Display scene, dynamic
Day	3,218 (10,558)	TV
	1,609 (5,279)	
	805 (2,641)	
	402 (1,319)	
	61 (200)[a]	
Night	3,218 (10,558)	CIG
	1,609 (5,279)	
	805 (2,641)	
	402 (1,319)	
	61 (200)[a]	

[a] Low ceiling.

Results of Pilot Evaluations

The test conditions shown in Table 1 were presented tc pilots who rated the display conditions for fidelity on a s of one (high fidelity) to four (low fidelity) at the end of flight session. Only one 2-h session was required for the to complete the test sequence and to record his answers.

The pilot's cursory responses relative to the two dis conditions presented in Table 1 are summarized in Fig.

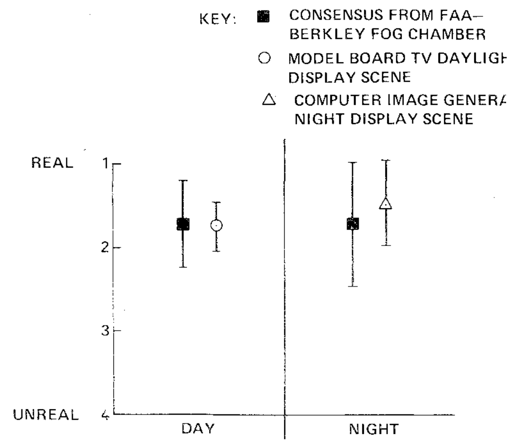

Fig. 10 Pilot opinions of low-visibility visual simulation fi compared with that of the real world.

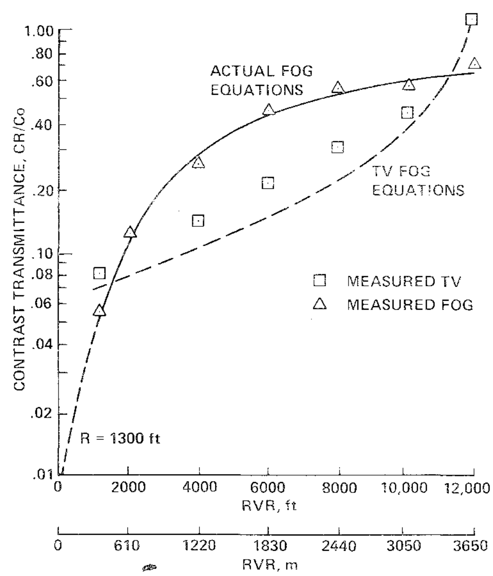

Fig. 11 Contrast transmittance for actual fog and electronic fo, function of visibility.

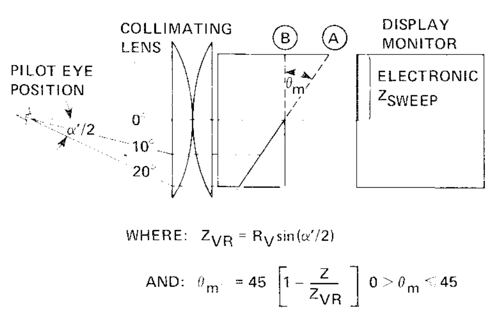

Fig. 12 Faceplate position and motor drive equation for help provide a natural fog gradient.

For convenience and comparison, the results of a similar fidelity survey, which was conducted in the previously described University of California/FAA fog facility, are also presented in Fig. 10.

For the dynamic televised daylight scene, the mean level of realism was 1.83 with a standard deviation of 0.37. This was nearly equivalent to the FAA fog facility fidelity, with more agreement among the pilots, as evidenced by the much smaller standard deviation. Figure 10 includes also the nighttime fidelity ratings obtained from the FAA fog facility; they show a mean of 1.65 and a standard deviation of 0.53. No differences were noted in the ratings obtained from the computer-image-generated (CIG) nighttime display, which had a mean fidelity of 1.5 and a standard deviation of 0.5. The CIG standard deviations and a symmetric distribution showed that the pilots were equally divided, half of them believing that this nighttime low-visibility simulation was as real as they had experienced. This increase in low-visibility realism, the author believes, may be partially attributed to the intensity modulation of the distant lights relative to the RVR and to their appearance as they emerged through the intervening fog.

Contrast Measurement

Another measure of the effect of the display scene on the low-visibility simulation is provided by the previously developed contrast transmittance equations for both actual fog [Eqs. (3-6)] and electronic fog [Eqs. (7-8)]. These equations can be used to predict the transmitted contrast of a scene through either the actual fog or electronic fog. A comparison of the results could then be used to differentiate between the two methods for simulating low visibility.

To measure the contrast transmittance, the TV runway scene shown in Fig. 6 was used. The position designated as $\boldsymbol{B_0}$ was actually the left-most touchdown zone hash mark at the runway threshold, and $\boldsymbol{B_0}$ designated a position just outside the runway apron. Thus the measurements were taken between B_0 and B_0 through the actual fog and at the same positions for the electronic fog. These results and the predicted values calculated from the contrast transmittance equations for actual fog [(Eq. (6)] and electronic fog [(Eq. (8)] are presented in Fig. 11. It can be seen that the measured values are very close to the predicted values and that the fog chamber appears to produce a valid contrast. The contrast for the electronic fog is shown to be unrealistic.

Suggested Improvements

The underlying pilot comments pertaining to the low-visibility display scene and those that appeared to divide the fidelity ratings were derived from the absence of a *fog gradient*, which becomes more prominent when close to the ground. Figure 12 shows an improved environmental chamber designed to accommodate a fog gradient through the use of a movable faceplate, which changes positions according to altitude and RVR. When in position *B*, there would be a maximum fog in the chamber until the aircraft altitude Z reached a predetermined RVR-derived vertical breakout altitude Z_{VR}. At that altitude, the faceplate would begin to rotate to position A, according to the motor drive (θ_m) equation shown in Fig. 12. As the aircraft descended, the observed composite scene would not only have the appearance of a realistic fog gradient, but would also have a background obscured in the right proportions to the RVR. This modification has been incorporated in a new chamber; preliminary observations are very favorable.

Summary

Currently, there is an emphasis on conducting all pilot training in flight simulators, principally because of 1) the high costs of actual aircraft training flights and certification; and 2) the need for reducing airport congestion and improving air safety. Associated with this emphasis is the demand for mo realism in the visual simulation display environment. Th low-visibility physics and the methods for synthesizing th environmental or meteorological conditions have not bee well understood nor coordinated. As a result, the simulate environment has been aesthetically created and calibrate without standards to create unnatural visibility condition Furthermore, because the physical atmosphere or the a mosphere dynamics have not been present or included in th aesthetically adjusted landing displays, the validity and lev of low-visibility realism using current methods is high questionable. Therefore this author conceived that a sma environmental chamber containing actual fog particles cou be constructed within the space between the display monito and the windshield-positioned collimating lens. It was felt th this technique would allow further exploration and u derstanding of the physics of low-visibility atmospher conditions as well as providing a means for increasing th validity of the visual scene contrast effects as perceived by th pilot. Consequently, a device was constructed that 1) produc actual fog; 2) includes an environmental chamber to entra the fog, resulting in RVR values from "clear" down to "zer zero"; 3) includes an RVR control system that has bee calibrated and found to be accurate within 2% of th theoretical atmospheric values; and 4) allows the pilot t make unconstrained, closed-loop trajectory, final approac or takeoff maneuvers under any day or night visibility co dition.

To further explore a new technique for synthesizing a mo realistic low-visibility environment and to make constructiv modification to the equipment by documenting both favo able and adverse potential user comments, a prelimina study using six senior airline pilots was conducted. The resul of this cursory study showed that the above two displa conditions for both day and night were a significant im provement over current methods and that they were ve realistic. The adverse comments indicated that an im provement in representing a fog gradient would be desirable.

The pilots believed that the realism effect with the presen of actual fog enhanced the displays; they considered t computer-image-generated (CIG) nighttime display to nearly the equal of their real experience. The pilots' fidelity realism ratings for both the daytime and nighttime series low-visibility conditions, by comparison, were found to equivalent to the ratings taken from the FAA fog facilit which also used actual fog. Contrast measurements of t display scene observed through actual fog were in very hig agreement with the theoretical values. Therefore the subje low-visibility environmental chamber attachment appears have the potential for reproducing a wide range of realist visibility conditions as well as for providing an increase flexibility to conduct terminal-area piloted flight maneuve under other adverse environmental conditions. Further hig fidelity improvement can now be obtained by including variable-position faceplate and by combining the scene wi some of the electronic fog synthesizing methods (now in us to enhance the fog gradient and contrast perception needed provide a better three-dimensional effect. These resu support the hypothesis that in the simulation of low visibilit the presence of actual fog enhances the perception of t visual scene cues in a manner that portrays more realism.

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