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SURVIVING HELICOPTER CRASHES AT SEA:

A Review of Studies of Underwater Egress from Helicopters

by

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SCIENCE NEWS NOTE

Surviving Helicopter Crashes at Sea: A Review of Studies of Underwater Egress from Helicopters

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The problem of escaping from a submerged helicopter is discussed. The effectiveness of illuminated escape hatches in facilitating escape has been demonstrated. The relative advantages of different types of lights are compared. Escape training, illuminating the emergency exits, and providing breathing devices should greatly enhance the chances of survival in a helicopter crash at sea.

W HEN A HELICOPTER crashes in the water, it almost always rolls over (Fig. 1). The sea begins to rush in, and the cabin fills with turbid water, oil, fuel, and debris. Within a minute—even in as few as 20 seconds—the helicopter will often begin to sink to a depth from which no one can survive. Although few, if any, of the passengers and crew will have been injured by the crash, as Rice and Greear pointed out, many of them will not escape (1). What can be done to prevent such needless deaths? This report summarizes the results of six published studies carried out over the past 10 years to determine how to facilitate escape from submerged helicopters.

Reasons For the High Number of Fatalities

In 1975, the Naval Air Systems Command asked the Naval Submarine Medical Research Laboratory to determine exactly what difficulties were encountered in trying to escape from a submerged helicopter and to develop methods to overcome them. Interviews with survivors of such crashes and a review of relevant reports confirmed that most passengers and crew members survive the crash, but may be unable to release their seat-belts; and if they do, the confusion and disorientation resulting from inrushing water, poor visibility, and darkness often prevents them from finding the escape hatches (2). It seemed likely that a combination of proper training and the illumination of the escape hatches would markedly reduce the number of fatalities. For example, it is pointless to struggle against the inrushing water, and personnel should be trained to remain strapped in their seats until the flooding is completed. In a 1973 memorandum, Spinks noted that the British had found that the confusion and disorientation are significantly reduced by training. Illuminated escape hatches should then point the way to safety.

At this time the only available trainer for water escapes was the Dilbert Dunker. A trainee is strapped into the cockpit of a simulated fixed-wing aircraft which is "crashed" into the water, and inverted. The escapee is trained to wait until all motion has ceased and the air bubbles have cleared before releasing his harness and making his way to the surface.

From January 1969 to February 1975, more than 400 men were involved in helicopter crashes in the water. The Naval Safety Center, Norfolk, VA, reports that fewer than 8% of those who had received training in the Dilbert Dunker died in such crashes, compared to more than 20% who had not (Table I). Such training gives the escapee some familiarity with the crash environment and some confidence in his ability to handle the situation. It

Fig. 1. A helicopter crash at sea. (Photo courtesy of the Naval Safety Center.)

TABLE I. SURVIVAL RATES FOR UNTRAINED MEN AND THOSE TRAINED IN THE DILBERT DUNKER BETWEEN 1969 AND 1975.

	Trained	Untrained
Fatalities	13	54
Survivors	157	200

is this feeling of confidence which is probably the most important contribution of training.

In 1961, the United States Marines built a prototype helicopter dunker and attempted to train combat troops; this training was discontinued. In 1962 the British put an escape trainer into operation and made training mandatory for all flight personnel. Subsequently, it was widely recommended that such training be given to all personnel flying in United States Navy helicopters, and escape trainers are now in use in Naval training centers in Florida, Virginia, and California.

Although training can greatly reduce egress fatalities, it does not directly address problems related to disorientation, darkness, and lack of visibility. The most direct solution to this problem seemed to be to illuminate the escape hatches with lights which would be activated by contact with water. The first question to be

answered was whether or not lights around the escape hatches would facilitate escape.

The Effectiveness of Escape Hatch Lighting

Our initial experiment (3) compared the times taken to escape from the helicopter when the escape hatches were illuminated with when they were not. Because of the risks, 24 highly experienced SEAL Team divers served as subjects in this initial experiment. There was no doubt that if their performance were improved by the lights, inexperienced individuals would benefit even more.

The Lights: We considered three types of lights for use in the study: tritium, chemoluminescent, and electroluminescent. The electroluminescent ones were selected as being the most promising. These panels are flat and thin, and can be made in any shape, so it is easy to configure them for mounting around an escape hatch. The lights can be powered by battery packs and readily waterproofed. Thus, they would be unaffected by submersion in salt water, could be varied in intensity, and they remained illuminated when the strip was punctured or otherwise damaged. Further, their color approximated that considered to be optimal for underwater viewing (4).

Method: The subjects were divided into 3-man teams. The fuselage of an H-3 helicopter (Fig. 2) was used as an escape simulator. It was suspended on the surface of the Thames River at the Naval Submarine Base,
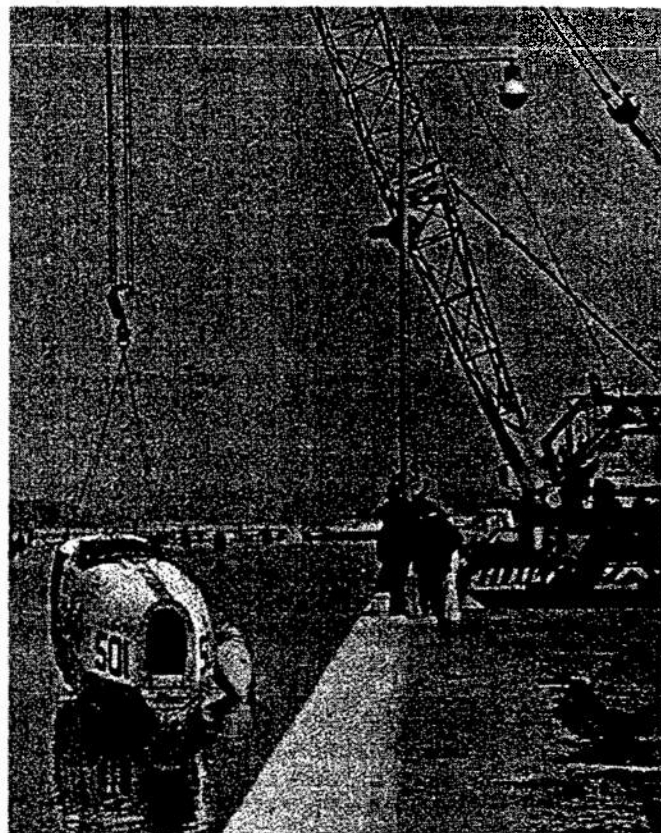

Fig. 2. Tests of the ability to escape from a submerged cabin were carried out with the fuselage of an H-3 helicopter which was submerged and inverted by a crane.
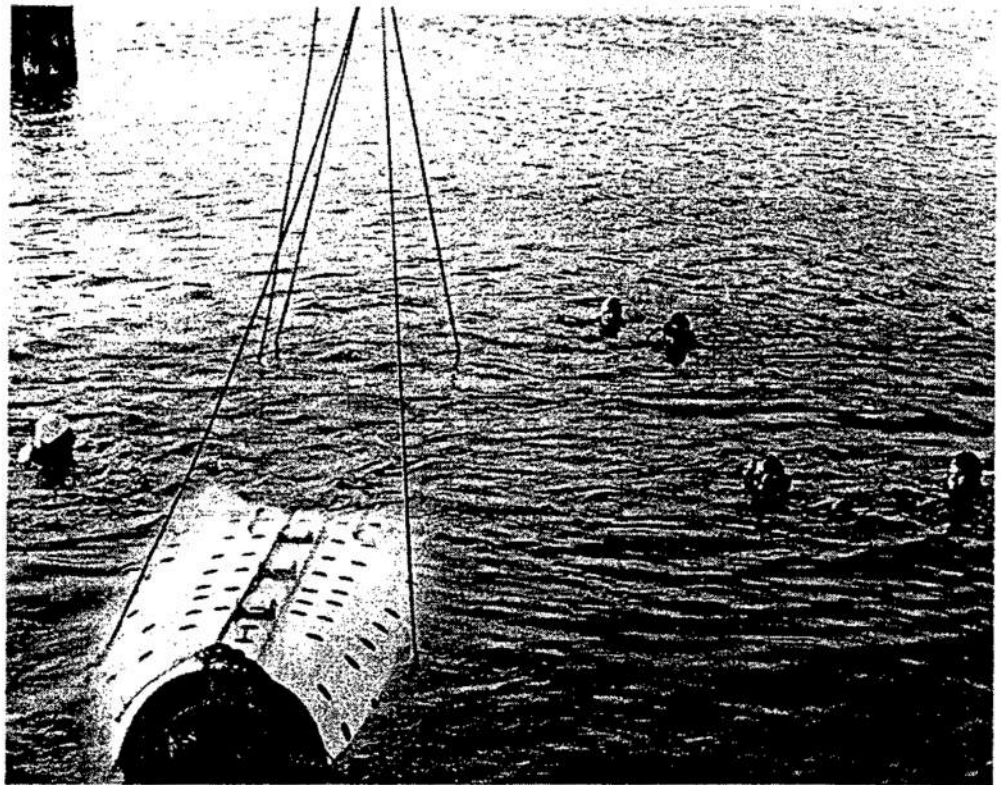
Fig. 3. Subjects clearing the surface after emerging from the helicopter fuselage.

Groton, CT, by a crane, and a team of three divers was seated inside. Each man wore a color-coded scuba hood, was assigned to a given seat, and was instructed to emerge from a specified escape hatch. The Naval Air Development Center provided the subjects with a prototype breathing device containing a 4.5-min air supply.

When the subjects were ready, the crane turned the fuselage upside-down and lowered it below the surface. The divers were instructed to unbuckle their seat-belts and begin their escape as soon as the water had stopped rushing into the cabin. Signals were automatically sent to a timer on the dock when a diver unbuckled his seat-belt and again when he went through his assigned escape hatch. When the diver reached the surface (Fig. 3), observers on the dock stopped the clock. Thus, for each of the three divers, we obtained the time taken to get from his seat through the escape hatch and then the time taken to reach the surface.

A team of safety divers was stationed in the water to go to the rescue of a subject if he did not appear within 1 min after the helicopter had been inverted. The highly experienced divers considered this procedure to be child's play, however. They were confident that it would pose no problem for them. In fact, on 16 occasions (all but one without the lights) they became disoriented, and required the assistance of the safety divers and the use of the air supply. The air supply was subsequently highly recommended by the divers. These incidents clearly dramatized the difficulties involved, for if highly experienced Seal Team divers could experience problems in this simulated, controlled, situation, much more serious difficulties would be faced by untrained and inexperienced men in an unexpected emergency.

Results: Fig. 4 shows that the escape times were significantly shorter when the escape hatches were illuminated; the difference was particularly large on day 1.
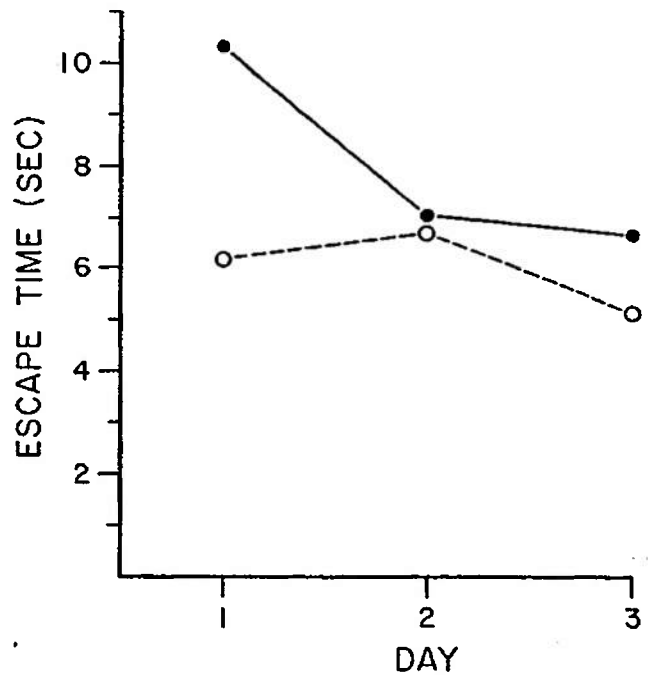

Fig. 4. Mean times required to escape from the submerged helicopter on three successive days through lighted (o) and unlighted (•) escape hatches.

As part of this study, two measures of anxiety were administered to the subjects prior to and after each day of testing. These provided a measure of the relative level of anxiety on each of 3 tests days. The level of anxiety decreased significantly between days 1 and 2, providing further support for the effectiveness of training in facilitating escape.

Conclusion: As a result of this experiment, we recommended the escape training of all crew members and passengers, the use of an escape breathing device, and the use of lights around the escape hatches.

Optimal Characteristics of the Lights

We still did not know, however, the optimal characteristics of such lights: how intense they should be, their size, and whether one configuration was better than another.

We first turned our attention to the question of what intensity the lights must be for general use. How visible a light will be under water depends primarily on four factors. The first is its intensity. Obviously, the more intense a light, the more likely that it will be seen. However, more power is needed to produce a more intense light, which usually requires a heavier power supply. Since weight is an important consideration in

aircraft design, the light should be no brighter than necessary.

Second is the viewing distance. The farther away from the light, the less likely that the observer will see it. On a typical helicopter troop carrier, the farthest distance that a passenger sits from an escape hatch is about 12 ft. This is, then, approximately the distance at which an escape light should be visible.

Third is the turbidity of the water. Under natural conditions, this varies through the entire range of possibilities from perfectly clear in some fresh water springs to virtually opaque in polluted harbors. Nevertheless, even though a helicopter may crash in relatively clear water, the water in the cabin may be very turbid owing to leaks of fuel, oil, hydraulic fluid, and debris. There are reports from survivors that visibility was no more than 2 ft for this reason.

The fourth major factor which affects the visibility of the light is the state of light or dark adaptation of the observer. Observers who are completely dark-adapted will be able to detect lights which are much dimmer than can observers whose eyes are adapted to a bright light level. Men on helicopters may be in any conceivable state of adaptation when a crash occurs. If it happens at night, they may be almost completely dark adapted; during the day, they may be adapted to the most intense
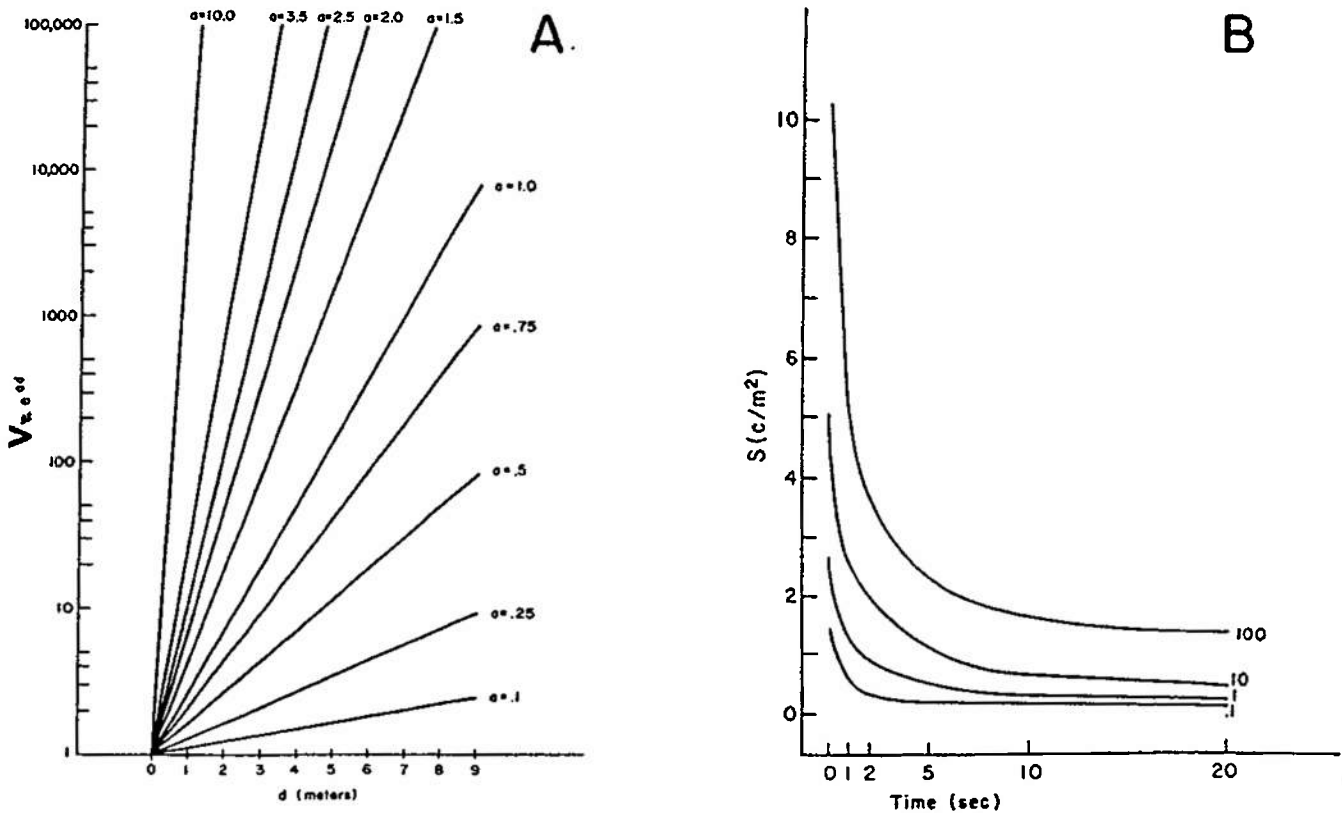

Fig. 5. Nomograms for estimating the threshold luminance of a light in the water for an observer without a facemask. Threshold luminance will be a product of the observer's sensitivity (S) and the degree of transmittance of the light through the water (V). The degree of transmittance, which can be estimated from Panel A, is a function of the distance the light must travel to the observer (d) and the turbidity of the water (a). An "a" of 0.1 indicates very pure water, whereas an "a" of 3.0 is characteristic of turbid harbor water. The sensitivity (S) of the observer is a function of the light intensity to which he has been adapting and the time since the light was extinguished. Panel B gives the curves for adapting luminances of 0.1 to 100 fL.

light levels found in the summer sky—10,000 fL.

Method: It might be assumed that it should be possible to simply calculate what the intensity of the light should be from the results of previous work on visibility, both in air and in water. The problem is that the visibility thresholds which must be determined are for observers under water without a facemask. Although some work had been done on vision in the water without a facemask, there has been no measurement of intensity thresholds. We, therefore, first carried out a parametric study using electroluminescent panels (5) to specify the intensity necessary for visibility as the viewing distance, turbidity, and state of adaptation varied. Seven staff members of the laboratory served as the subjects in one study, and five served in a second study.

Results: Our findings are presented in the set of nomograms (Fig. 5) which give the intensity thresholds for values of viewing distance, turbidity, and adaptation. If the light in question is similar to the test light in size and color, then the values taken from the nomograms give the absolute visibility threshold. In general, we found that the visibility thresholds in water were higher than thresholds obtained in air under the same conditions by a factor of about 30. The main reason for this is, undoubtedly, the loss of two-thirds of the focusing power of the eye exposed to water. This loss greatly increases the focal length of the eye and makes it impossible to focus a target on the retina. Thus, one does not see a sharply defined target but a diffuse blur whose apparent size is much larger than it would be in air. The spread of the available energy is too large to be compensated for by spatial summation in the retina and results in an increase in the luminance required for detection.

Comparison of Flashing and Steady Lights

Method: In 1979, the Naval Air Development Center requested that we test lights which could serve as alternates to electroluminescent light. We compared two steady lights and two flashing lights (6). The steady lights were a high intensity collimated beam, and a chemoluminescent light stick; the flashing lights were a large and a small xenon strobe light with a flash rate of about 1 flash $\cdot s^{-1}$. Five staff members of the laboratory served as subjects.

Results: The flashing lights were significantly more difficult to localize in water of both moderate and high turbidity; as their distance from the observer increased, their relative disadvantage increased. All the subjects agreed that the flashing lights were confusing and the constant lights more desirable. Of the four lights, the chemoluminescent were the most desirable. However, there was a rapid perceptible decrease in their luminance with time. Fig. 6 shows the mean time the subjects took to decide which lights were closest when more than one light (all of a given type) was present in turbid water.

Configuration of the Lights

We next investigated the optimal configuration of lights around the escape hatch, the maximum light intensity which should not be exceeded, the effect of viewing angle on visibility, and the characteristics required of decals which are used for instructions (7).
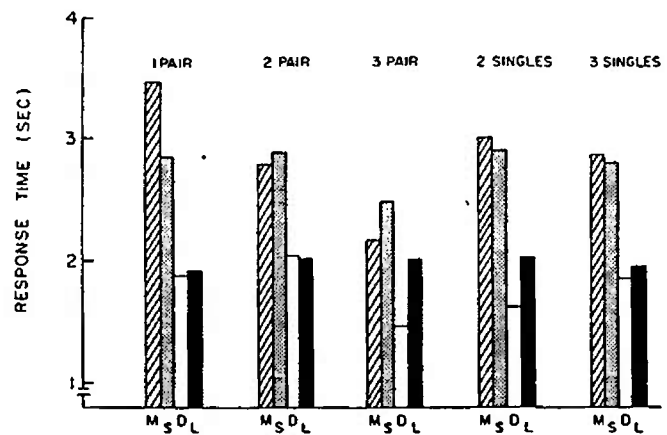

Fig. 6. Mean times required to respond to different lights tested separately in turbid water. The lights were presented at distances from the observer corresponding to the different locations of escape hatches. A "hatch" was illuminated by either one light or a pair of lights, one on either side of the hatch. Thus, "1 pair" indicates that one of the hatches was illuminated by a light on either side. "3 pair" indicates that three hatches were illuminated, each by a light on either side. "3 single" indicates that three hatches were illuminated, each by one light. M and S are flashing lights; D and L are steady lights (Ref. 6.)

Escape hatches can be lighted on one, two or three sides. It is not only important to find the hatch but also to be able to locate the handle which opens it. This is usually at the bottom. If the helicopter is inverted or on its side, a disoriented passenger might be confused as to which side of the hatch was the bottom. Leaving the bottom unlighted or having a different light at the bottom should serve to indicate the location of the handle.

Method: Three configurations were selected to be tested. In one, the bottom light was much shorter than the other three. In the other two configurations, the bottom was not illuminated at all; the difference between them was that in one case the three lights were of equal size, and in the other the lights on the sides were much shorter than the top light.

To test these alternatives, frames the size of helicopter escape hatches were made (about 2 ft²) and the experimental lights were mounted in the three configurations (Fig. 7). The hatches were presented at different distances in water at three levels of turbidity, with the hatch "bottom" presented randomly at the four different positions. Three subjects, staff members of the laboratory, were asked to identify the "bottom" as quickly as possible. We recorded whether or not they could, without a facemask, identify in which position the hatch was being presented and how long it took them to respond.

Results: Fig. 7 shows the percentage of errors made for only the electroluminescent panels in moderately turbid water, but we invariably found Configuration II to be best for all the lights tested.

Shape of the Lights

Another question was what shape would be best? For this evaluation we used the electroluminescent panels since they can be made in any size and shape, and the
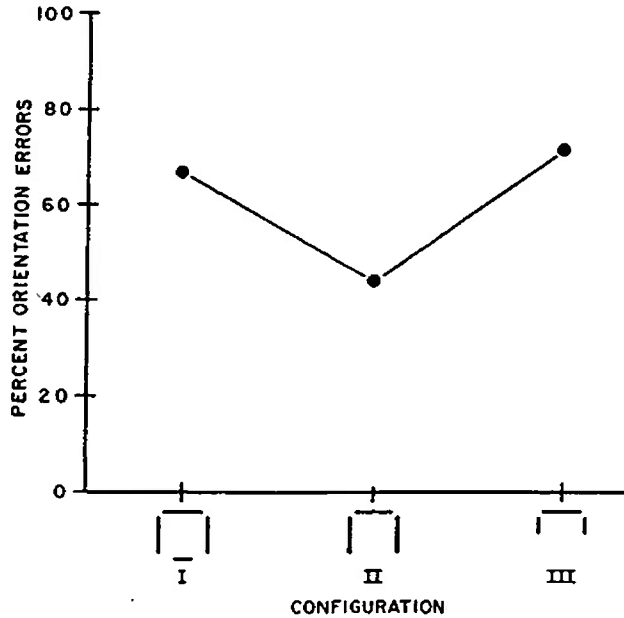
Fig. 7. Percentage of trials on which subjects could not correctly identify the orientation of each configuration in moderately turbid water. (Ref. 7.)

power required to light them depends only on the area to be illuminated, not the way that area is configured.

Method: We set up a series of panels in which the same areas appeared in different dimensions (8). The intensity of these panels was easily varied by changing the power applied. We measured the minimum intensity of the various configurations which could be seen by the three staff members in turbid water at a distance of 10 ft.

Results: We found that, as shown in Fig. 8, short wide panels were more visible than long, narrow panels of the same total area. The 2 × 10 in. panel (A) and the 1 × 20 in. panel (C) both presented 20 in. of lighted surface; the former was more easily seen. The 1 × 10 in. panel (D) and the 1/2 × 20 in. panel (E) both present 10 in² of surface; again, the shorter, wider panel was more easily seen. Finally, consider the 1.5 × 10 in.
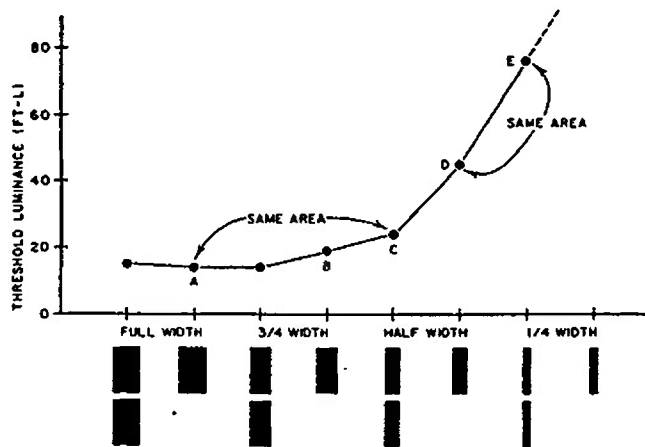

Fig. 8. Mean luminance thresholds for electroluminescent panels of various lengths and widths. (Ref. 9, reprinted courtesy of the Psychonomic Society).

panel (B) and the 1 × 20 in. panel (C). In this case the later presents the greater area of lighted surface, yet the former is more easily seen. It is worth noting that these findings would not be expected on the basis of light-readings with a photometer; they are the result of the neural workings of the human visual system.

Usefulness of Printed Instructions

Method: The next experiment (7) dealt with the legibility of printed instructions under water. It is common to place a decal, such as the one in Fig. 9, beside the handle of an escape hatch which instructs the user how to open the hatch. The letters are about 3/8 in. high and are quite legible in air and would be legible in water if the reader were wearing a facemask. But could it be read by someone underwater without a facemask? We made a series of signs reading either "push" or "pull" in a range of sizes. They were either black letters on a metallic background or they were cut out and illuminated from behind.

Results: When the black letters were presented to the three staff members just below the surface in bright sunlight, the smallest lettering which could be seen was about 2.25 in. high. At night, the smallest back-lighted letters which could be read were 3 in. high. It is clear that if such letter sizes are required, very little information can be presented which is legible under water.

Effect of Viewing Angle

Usually, the occupant of a helicopter will not be sitting directly across from the hatch and will, therefore, not be looking directly at the hatch lights. It is important to know the effect of viewing angle on the visibility of the lights. With our three staff members (7), we found that more light is needed as the viewing angle becomes less direct, but, particularly in less turbid water, the increase is not very great until the viewing angle becomes quite oblique (Fig. 10). In another study (9), we measured detection times at different viewing angles for three new subjects. Again, the time taken to detect the light does not increase very much until the viewing angle is quite oblique.

Conclusions

These experiments show that the disorientation and poor visibility that make escape from a helicopter crash at sea so difficult can be alleviated by three simple solutions. Proper training of crewmembers and passengers will reduce disorientation and panic; a breathing device will provide crash survivors adequate
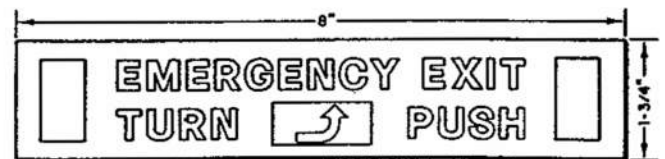

Fig. 9. An instruction decal from a helicopter emergency exit hatch. (Ref. 7.)
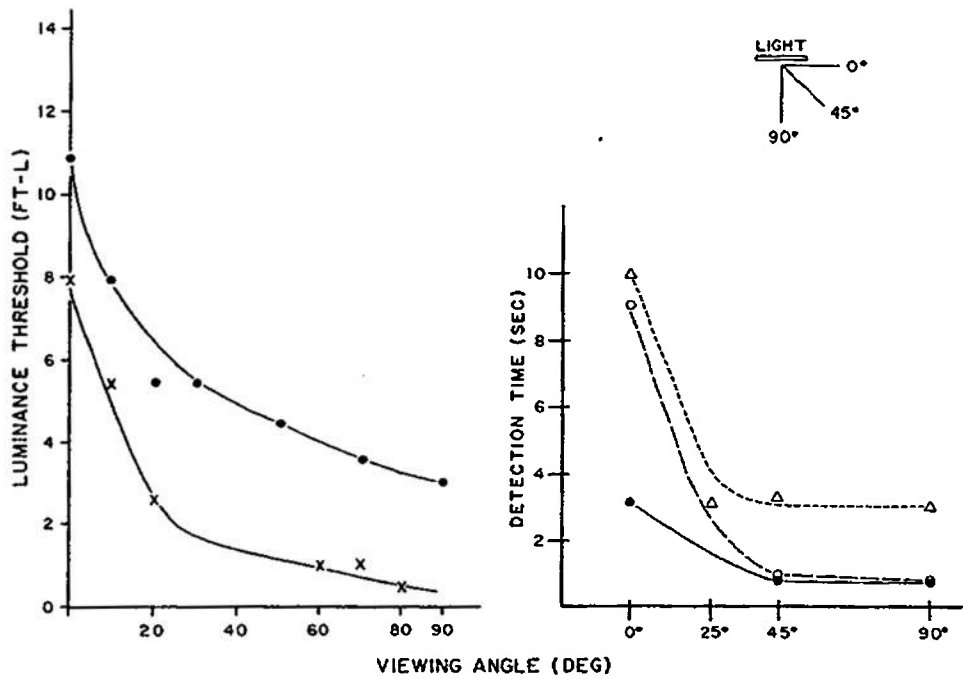
Fig. 10. (Left) Threshold luminance of electroluminescent panels at different viewing angles in turbid (●) and moderately turbid (x) water. (Right) Detection times at various viewing angles for electroluminescent panels in water of low (●), medium (○), and high (Δ) turbidity.

time to act appropriately; and the installation of proper lights at escape hatches will point the way to safety. These actions would reduce the number of deaths in helicopter crashes at sea.

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