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CONSPICUITY ASSESSMENT OF SELECTED PROPELLER AND TAIL ROTOR PAINT SCHEMES

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16. Abstract

An investigation was conducted to rank the conspicuity of three paint schemes for airplane propellers and two schemes for tail rotor blades previously recommended by the U.S. military and British Civil Aviation Authority. Thirty volunteer subjects with normal vision viewed rotating propellers at 6.1 m (20 ft) and tail rotor blades at 9.1 m (30 ft) under bright sunlight conditions. Observations of the grouped airplanes and helicopters were made from three angles that included (i) viewing upward from a crouched position, (ii) at eye level while standing, and (iii) downward from an elevated platform.

At all viewing angles, the propeller design consisting of black and white stripes asymmetrically placed on opposing blades was judged "most conspicuous" by a wide margin. The red and white stripe design (symmetrically placed) was considered slightly more effective than the yellow tip design.

Of two designs for tail rotors, the black and white asymmetrical stripe scheme was chosen "more conspicuous" (9 to 1 ratio) than a red, white, and black stripe design.

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CONSPICUITY ASSESSMENT OF SELECTED PROPELLER AND TAIL ROTOR PAINT SCHEMES

I. Introduction.

The U.S. National Transportation Safety Board (NTSB) has reported that accidents from propeller and tail rotor blades have resulted in 82 fatalities and 158 serious injuries from 1965 to 1974 (3). Furthermore, NTSB data indicate that propeller/rotor contact injuries have steadily increased from 17 in 1965 to 30 in 1974. Causative factors associated with helicopter rotor accidents involving 17 fatalities are discussed in an article by Kiel (2).

Federal Aviation Regulations (FAR) Parts 27 and 29 (par. 1565) for Normal Category Rotorcraft and Transport Category Rotorcraft, respectively, state that, "Each tail rotor must be marked so that its disc is conspicuous under normal daylight ground conditions." However, FAR Parts 23 and 25 (par. 905) for Normal, Utility, and Acrobatic Category Airplanes and Transport Category Airplanes, respectively, do not specify requirements to enhance conspicuity of airplane propellers. In addition, no conspicuity requirements were found in FAR Part 35 pertaining to airworthiness standards for aircraft propellers.

In 1975, the FAA initiated a study designed to evaluate the effectiveness of several paint schemes. However, the investigations were halted prematurely when the DC-3 test aircraft was damaged during takeoff in March 1975. The present requested study was conducted to rank the visual effectiveness (see and avoid) of three paint schemes for airplane propellers and two schemes for helicopter tail rotor blades currently used by the U.S. military services.

II. Methods.

Paint scheme specifications for each of three airplane propellers (Figures 1-3) were taken from: (i) U.S. Army, TB-746-93-2, (ii) U.S. Air Force, T.O. 1-1-4, and (iii) U.S. Navy, MIL-M-25047-C, (ASG). Specifications for two helicopter tail rotor blades (Figure 4) include U.S. Navy, MIL-M-25047-C, (ASG) and U.S. Army, TB-746-93-2. Propeller/tail rotor specifications recommended by the British Civil Aviation Authority

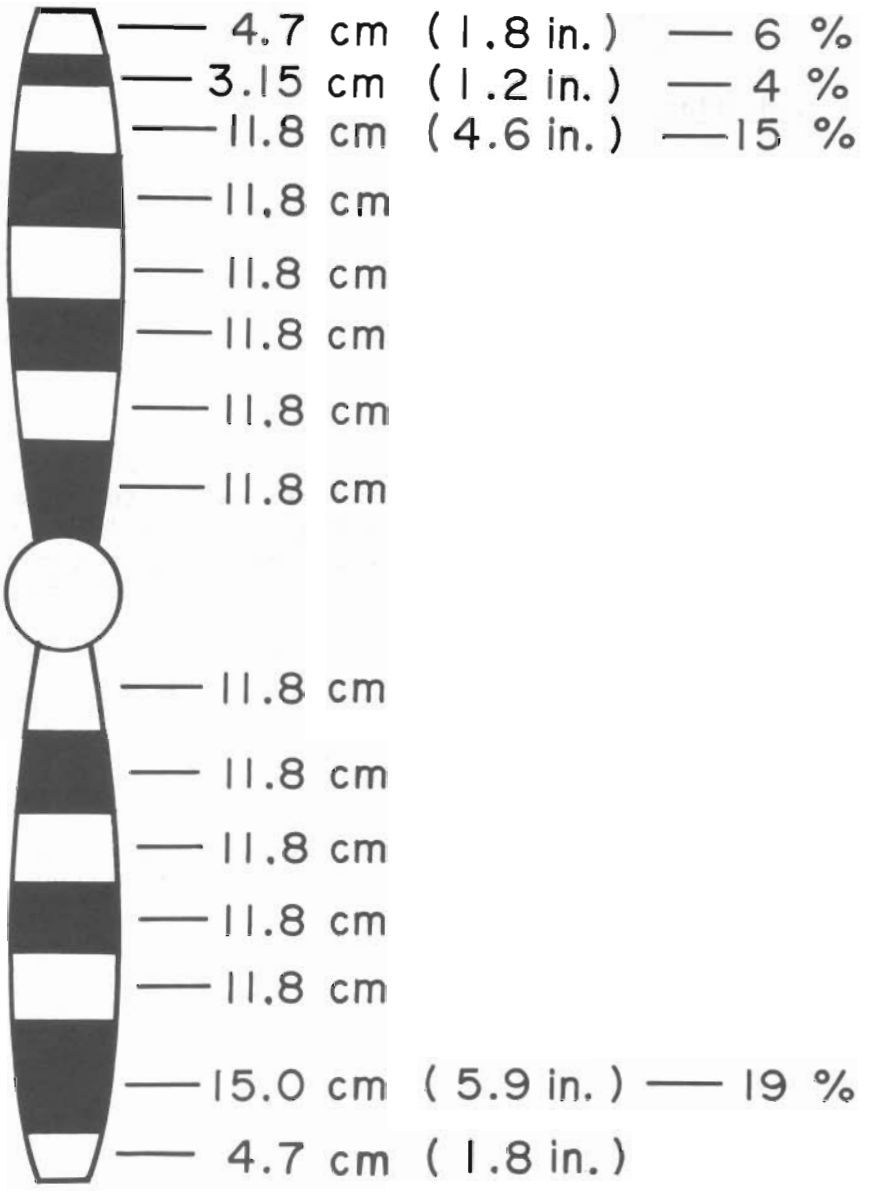

FIGURE 1. Propeller with black and white paint scheme and asymmetrical stripes taken from U.S. Army, TB-746-93-2.

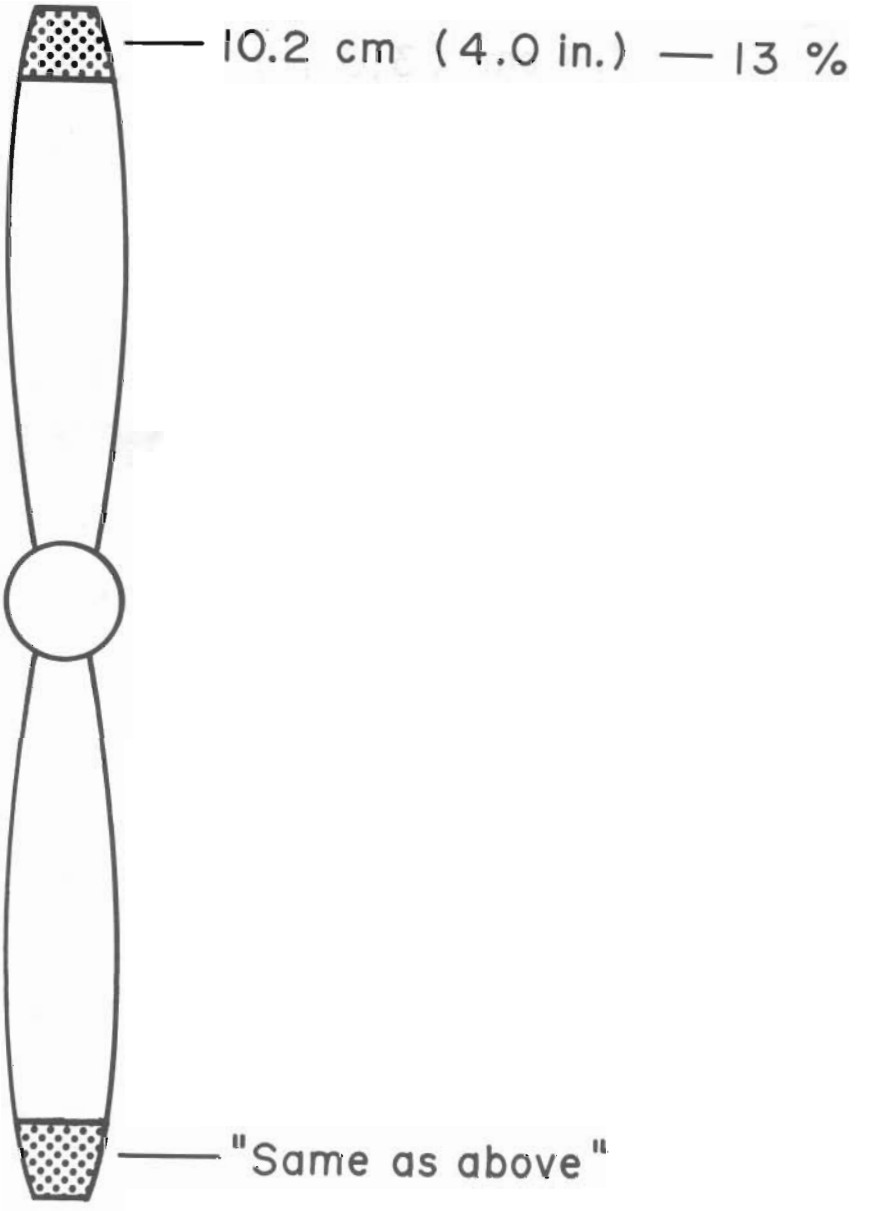

FIGURE 2. Propeller with yellow tip paint scheme (stippled area) taken from U.S. Air Force, T.O. 1-1-4.

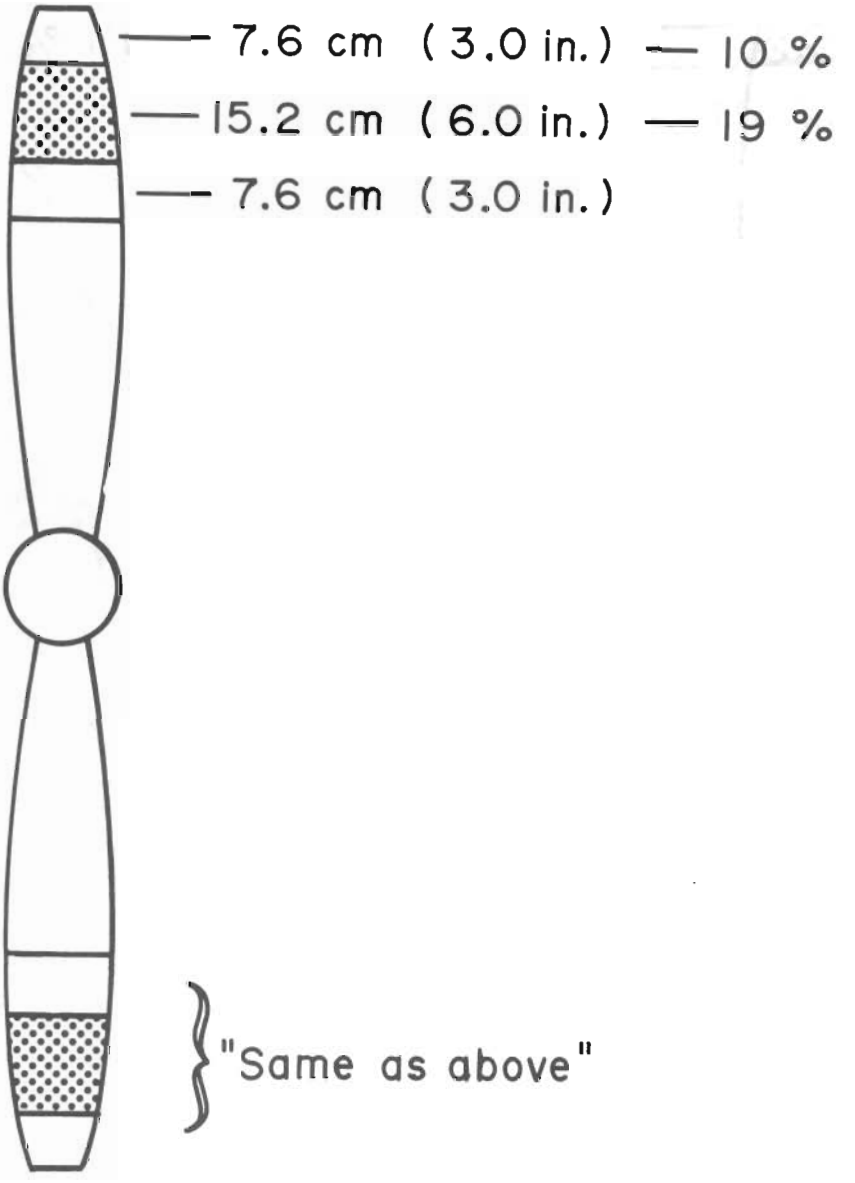

FIGURE 3. Propeller with red (stippled area) and white paint scheme taken from U.S. Navy MIL-M-25047-C (ASG).

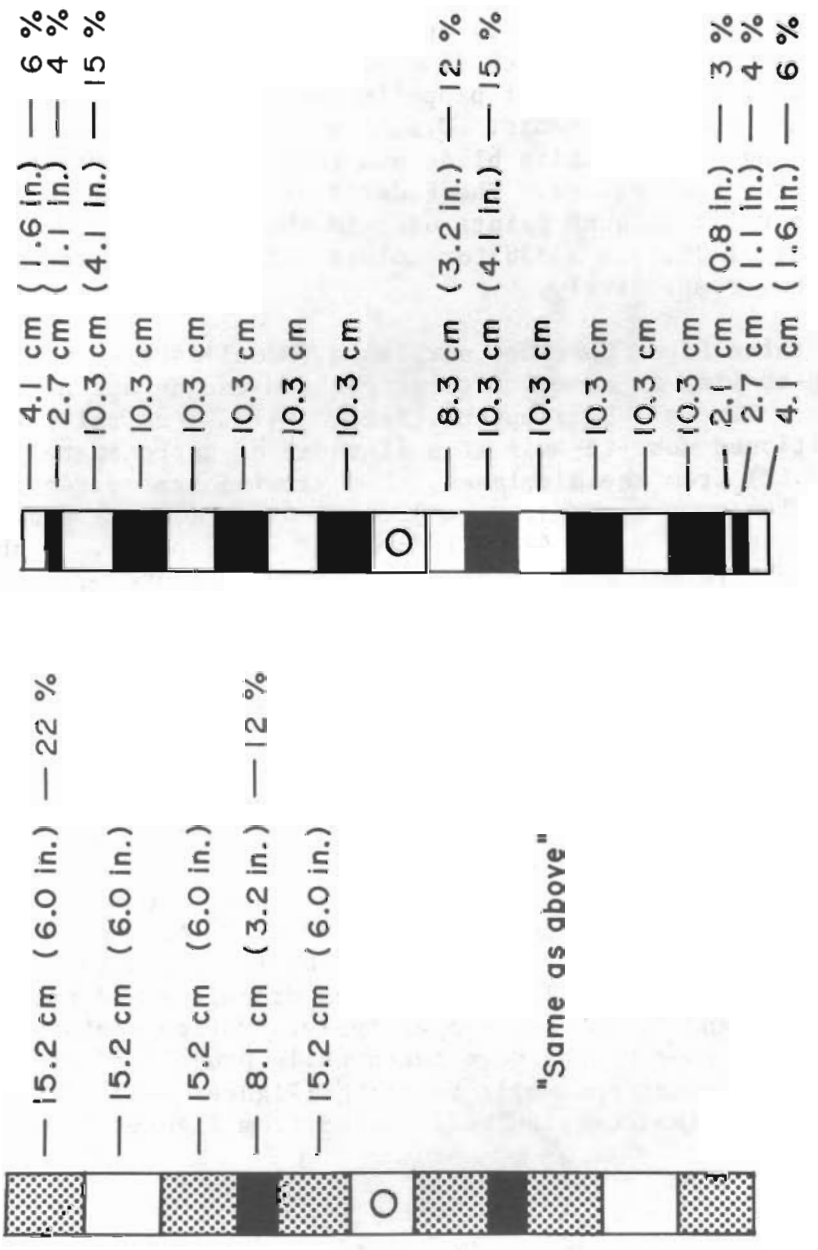

FIGURE 4. Two helicopter rotor paint schemes. (Left) U.S. Navy scheme taken from MIL-M-25047-C (ASG) with stippled area in red. (Right) U.S. Army scheme with black and white asymmetrical stripes taken from TB-746-93-2.

(Info. Circular 104/1973) approximate those used by the U.S. Army. Stripe width dimensions are specified in fixed values for all sizes of propeller/rotor blades in U.S. Navy and Air Force documents. U.S. Army specifications require painting of the entire blade and therefore give stripe widths in percentage values. The Federal Standard Color numbers for the acrylic lacquer paints used in the evaluation were 17875, 37038, 31136, and 33538 for colors white, black, red, and yellow, respectively.

Three Piper Cherokee airplanes (Model 140) were positioned wing-to-wing in a semicircular fashion facing a central viewing area. Two Bell helicopters (Series B47G, open tail) were positioned nose-to-tail at a distance of approximately 90 m (300 ft) from the airplanes. The viewing areas, sectioned off by pylon-type markers, were located 6.1 m (20 ft) from the airplanes and 9.1 m (30 ft) from the helicopters. A photograph of the airplane viewing area is shown in Figure 5.

Thirty naive volunteer FAA employees with normal distant visual acuity and color vision were transported in groups of five to the viewing areas. Subjects viewed the propellers and rotors from three positions that included: (i) looking upward from a crouched position, (ii) while standing, and (iii) viewing downward from a maintenance stand. The background for each aircraft varied somewhat and consisted of shadows cast by the aircraft, the surrounding landscape including hangars, and other aircraft on the ramp. Observations were made looking generally northward between 1300 and 1530 (CST) on November 17, 1977, under clear sky conditions. During the observation periods, contract pilots maintained propeller and rotor speeds at 1,000 and 2,300 rpm, respectively. Motion picture sequences and still photographs were taken while propeller/rotor blades were stationary and while rotating (Figures 6-15). Viewing areas for the helicopters can be inferred from Figures 12-15.

III. Results.

The distribution of the relative conspicuity rankings of the three propeller paint schemes is shown in Table 1, and the frequencies with which each scheme was ranked "most conspicuous" at each viewing angle are expressed as percentage values in Figure 16.

The black and white asymmetrically striped scheme was judged "most conspicuous" more frequently at all three viewing

FIGURE 5. Three Piper Cherokee, Model 140, airplanes positioned in the viewing area with an elevated viewing platform.

FIGURE 6. Propeller painted with the black and white asymmetrical paint scheme, U.S. Army TB-746-93-2.

FIGURE 7. Conspicuity of rotating propeller (1,000 r/min) painted with the black and white asymmetrical paint scheme, U.S. Army TB-746-93-2.

FIGURE 8. Propeller painted with yellow tip paint scheme, U.S. Air Force T.O. 1-1-4.

FIGURE 9. Conspicuity of rotating propeller (1,000 r/min) painted with yellow tip paint scheme, U.S. Air Force T.O. 1-1-4.

FIGURE 10. Propeller painted with red and white symmetrical paint scheme, U.S. Navy MIL-M-25047-C (ASG).

FIGURE 11. Conspicuity of rotating propeller (1,000 r/min) painted with red and white symmetrical paint scheme, U.S. Navy MIL-M-25047-C (ASG).

FIGURE 12. Helicopter tail rotor with black and white asymmetrical paint scheme, U.S. Army TB-746-93-2.

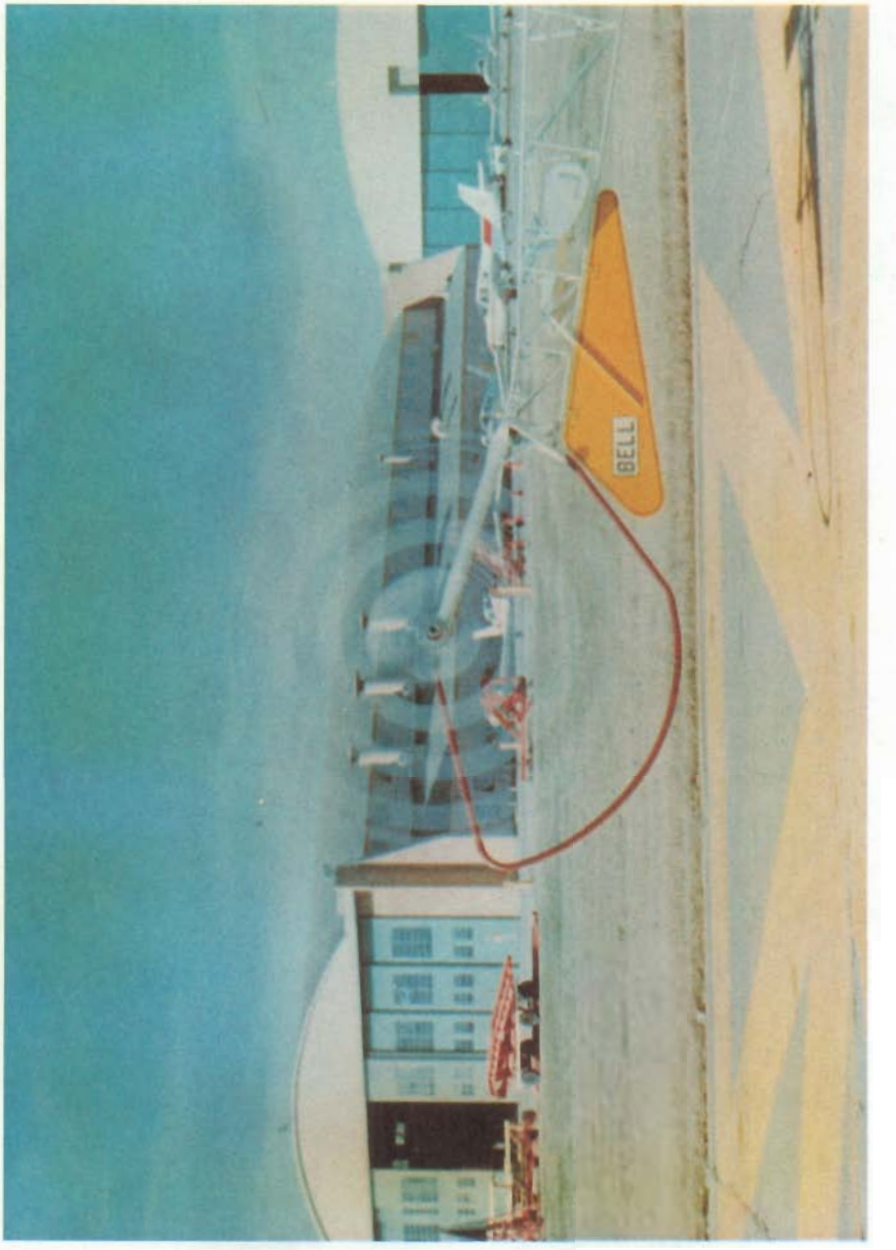

FIGURE 13. Conspicuity of rotating helicopter tail rotor (2,300 r/min) with black and white asymmetrical paint scheme, U.S. Army TB-746-93-2.

FIGURE 14. Helicopter tail rotor with red, black, and white symmetrical paint scheme, U.S. Navy MIL-M-25047-C (ASG).

FIGURE 15. Conspicuity of rotating helicopter tail rotor (2,300 r/min) with red, black, and white symmetrical paint scheme, U.S. Navy MIL-M-25047-C (ASG). Rotor rotation is 2,300 r/min.

TABLE 1. Distribution of Relative Conspicuity Rankings of Three Airplane Propeller Paint Schemes

VIEWING ANGLE	SUBJECTIVE RANKINGS	PAINT SCHEME B&W	R&W	YELLOW
Upward	Most	19	9	2
	Less	6	18	6
	Least	5	3	22
Eye Level	Most	24	3	3
	Less	4	24	2
	Least	2	3	25
Downward	Most	24	5	1
	Less	4	22	4
	Least	2	3	25
Combined	Most	67	17	6
	Less	14	64	12
	Least	9	9	72

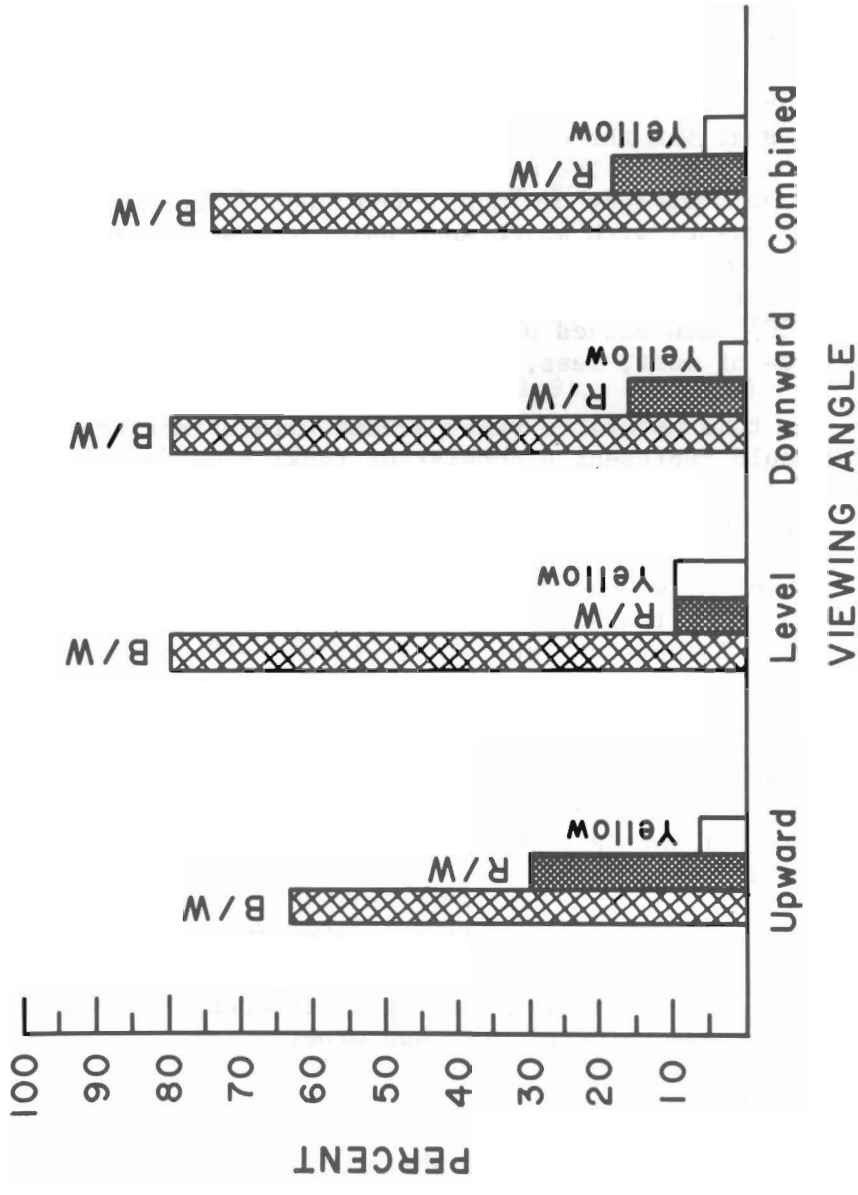

FIGURE 16. Percent frequencies for each propeller paint scheme judged "most conspicuous" at each viewing angle and for combined angles.

angles than the other two schemes combined. The red and white stripe scheme was judged "most conspicuous" slightly more often than the yellow tip scheme except at the eye-level viewing angle, when the two schemes received an equal number of such rankings.

Table 2 presents the mean rank orders of the three paint schemes at the three viewing angles, as well as the combined viewing angles. The mean rank orders take into account not only the frequency of "most conspicuous" judgments, but also the frequency with which each paint scheme was ranked "less conspicuous" (second) and "least conspicuous" (third). Values shown for each paint scheme represent the mean of all responses (N = 30) when values of 1.0, 2.0, and 3.0 are assigned for choices of most, less, and least conspicuous, respectively.

By this method, a paint scheme with a rank order value of 1.0 would represent a consistent ranking of "most conspicuous" while a value of 3.0 would be equivalent to a unanimous ranking of "least conspicuous."

Using a two-way analysis of variance for ranked data (Friedman Analysis), perceived differences between paint schemes were significant at the .001 level at each viewing angle and for combined angles.

The distribution of conspicuity rankings of the two tail rotor paint schemes is presented in Table 3. Chi square analysis showed that perceived differences between the paint schemes are significant ($P < .01$) at all three viewing angles, and for combined angles.

Under the viewing conditions described previously, our results indicate that the black and white (U.S. Army) paint scheme provides significantly greater conspicuity levels for propeller and rotor blades than other paint schemes evaluated.

IV. Discussion.

Although the black and white paint scheme with asymmetrical stripes on opposing blades was consistently judged most conspicuous, the question remains as to the predominant mechanism involved. Observations by the authors support the conclusion that the flickering sensation clearly dominates contrast enhancement of the propeller arc as the primary warning cue. First, the subjects frequently volunteered statements concerning the "out of balance" sensation of the aforementioned paint

TABLE 2. Mean Rank Order of Propeller Conspicuity at Each Viewing Angle and for Combined Viewing Angles

VIEWING ANGLE	PAINT SCHEME B&W	R&W	YELLOW
Upward	1.53	1.80	2.67
Eye Level	1.27	2.00	2.73
Downward	1.27	1.93	2.80
Combined	1.36	1.91	2.73

TABLE 3. Distribution of Relative Conspicuity Rankings of Two Tail Rotor Paint Schemes

VIEWING ANGLE	SUBJECTIVE RANKING	PAINT SCHEME B&W	R&W
Upward	Most	26	4
Eye Level	Most	26	4
Downward	Most	29	1
Combined	Most	81	9

scheme. Second, the deep red and white stripe scheme (symmetrically striped) was chosen a distant second, even though observations and densitometry readings from slides indicates that the arc contrast was comparable to that of the black and white scheme. The dominance of the black and white scheme may also be related to the Brucke-Bartley effect (1). This phenomenon can be described as a perceived increase in brightness of a target (offset portion of the white stripes) when the target is pulsed or fluctuates at 4 to 16 cycles per second (cps). The 16-cps value corresponds to the engine speed of approximately 1,000 rpm, the propeller rotation speed used in this study.

Conspicuity factors other than arc contrast and/or perceived oscillation may provide effective warning cues. These factors include but are not limited to: (i) hue and saturation of various colors including bright orange and yellow-green, (ii) reflectivity of the propeller surface, and (iii) optimizing color contrast between propeller arc and the aircraft fuselage. Furthermore, consideration should be given to propeller/rotor conspicuity as a function of the various illumination levels, more oblique viewing angles, and while viewing at distances less than 2 m (6.5 ft).

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