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IMPROVING U. S. ARMY AIRCRAFT PROPELLER AND TAIL ROTOR BLADE CONSPICUITY WITH PAINT

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ABSTRACT

Rotating propellers and tail rotors represent a potential hazard for personnel while aircraft are on the ground. This study was conducted to ascertain if rotating blades could be visually detected more easily by the judicious application of paint. A total of twenty-two observers rated nine different paint schemes for effectiveness. The results showed that (1) the two schemes presently being used on Army aircraft rated the poorest of all those investigated, and (2) the most conspicuous scheme was one which had (from the tip toward the hub) a four inch section painted red-orange fluorescent, with the remaining surface divided into thirds and painted alternately flat black and gloss white. The black and white sections of the other half of the blade were reversed to provide a non-concentric pattern.

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IMPROVING U. S. ARMY AIRCRAFT PROPELLER AND TAIL ROTOR BLADE CONSPICUITY WITH PAINT

I. PURPOSE

Although no reference has been found, there is no doubt that Orville and Wilbur Wright were aware of the potential hazards associated with their revolving aircraft propeller. Since that time, many individuals have had physical contact with turning propellers, with the individual seldom emerging unscathed. Since the advent of the helicopter, the high speed tail rotor blade has introduced an additional hazard for those associated with aviation.

The purpose of this study is to investigate ways and means of improving the conspicuity of these revolving devices and thereby, hopefully, reduce the probability of an accident.

II. BACKGROUND

Previous studies[1,2,3] by this Laboratory have dealt with overall aircraft conspicuity as a deterrent to the midair collision problem. In the course of these studies, the works of Lazo[4,5], Malone[6,7], Applied Psychology Corporation[8], Middleton[9], and others were reviewed.

One approach to increase aircraft attention-getting was made by a series of studies to develop patterns by the judicious application of paints to the fuselage of fixed and rotary wing aircraft as well as the main rotor blades of the latter. The paint schemes selected for fleet application were the result of this research and field studies conducted in the operational environment utilizing the best possible scientific methods available[1,2].

The use of paint as an engineering variable was based upon providing peak visual stimulation by maximizing:

(a) Color contrast within the propeller blade scheme.

(b) Color contrast between the aircraft or propeller and the background.

(c) Brightness contrast within the color scheme.

(d) Brightness contrast between the aircraft or propeller and the background.

(e) The visual stimulus effect of pattern by inducing motion or flicker.

(f) The rotational speed of the blades.

(g) The retinal area considered.

These variables were given prime consideration in the original studies dealing with helicopter main rotor blades and aircraft fuselages. They are equally applicable to helicopter tail rotor blades and fixed wing aircraft propellers.

In Lazo's[3] original study, a scheme incorporating black, white and red located concentrically on the propeller blade of fixed wing aircraft was found to be superior to all others tested. In our in-flight studies[1,2] dealing with helicopter main rotor blades, we found that modifying the proportionate areas of the blade painted and using a fluorescent red-orange paint in place of gloss red lacquer, improved conspicuity significantly.

Based upon our recommendations, the upper surfaces of the main rotor blades of the helicopter training fleet (approximately six hundred aircraft) located at Fort Rucker, Alabama were painted with the superior scheme. For the subsequent four year period, daytime midair collisions have fallen from an average of fourteen per year to one per year. Although there is no way to determine the exact contribution of painted blades to this safety improvement, pilot acceptance has been exceptionally high and the accident record notable. During this four year period it has been necessary to modify the original paint scheme somewhat. It was found that the fluorescent paint:

(1) Became a gummy, viscous layer that tended to shift position on the blade after coming in contact with ever-present transmission fluid. It is not unusual for a quantity of this fluid to be on the blade, and the associated shift in paint position adversely affected the balance and tracking of the blade.

(2) In the gummy state, tended to attract debris which further contributed to the blade imbalance problem.

(3) Faded and became ineffective two to four months after exposure to sunlight.

(4) Significantly increased the maintenance upkeep costs for each aircraft.

After duly considering the above facts, it was decided to recommend the second best rank order paint scheme which incorporated gloss yellow lacquer in place of the red-orange fluorescent material. Although the overall conspicuity was somewhat reduced, the use of the lacquer resolved the maintenance problems and was considered a reasonable compromise. In terms of accident rates, this substitution appears not to have adversely affected our previous results, at least at the training bases where a high density of helicopter traffic exists and our recommended scheme has been applied.

It should be noted that in addition to fluorescent paints, we evaluated fluorescent tapes on the aircraft. These tapes have a reported effective life of twenty-four to forty-eight months while exposed to sunlight. Installation of tape on the main rotor blade was not found to be feasible due to a tendency to peel after a few hours. However, installation on the fuselage, to date, has been successful and longevity studies are presently being conducted on this application technique.

In reference to the inherent personal danger associated with fixed wing propellers and helicopter tail rotors, we have obtained the most recent injury-fatality data available from the U. S. Army Agency for Aviation Safety (formerly the U. S. Army Board for Aviation Accident Research). During the period 1 January 1967 to 15 August 1971, the Army has had four propeller strikes. These are broken down as follows:

(a) Period - Day (2), Night (2)
(b) Injury unknown - 1 (propeller struck rifle)
(c) Fatalities - three
(d) Aircraft involved - U6-A (Beaver) - 3
OV-1 (Birddog) - 1

For the same time frame, there have been thirty-one tail rotor strikes. These are categorized as:

(a) Period - Day (30), Night (1)

(b) No injuries - 6 (usually involved striking a piece of equipment such as a radio or rifle)

(c) Injury unknown - 5 (These mostly involved foreign nationals and complete data unavailable.)

(d) Injuries - Major (7), Minor (4)

(e) Fatalities - 9

(f) Aircraft involved - AH-1G - 3. OH-6A - 9, OH-13E - 1, OH-23G - 3, UH-1D - 5, and UH-1H - 10.

Total aircraft damage cost for fixed and rotary wing blade strikes amounted to $237,000.

Considering the need for further research in this area based upon sound physiological optics principles, this Laboratory decided to conduct the following study.

III. METHODOLOGY

A. Observers - The observers were both military and civilian personnel. There were twelve used for the first day and ten the second day.

B. Apparatus

1. Aircraft - Five T-41 single engine fixed wing aircraft (similar to the Cessna 182) and five TH-13 helicopters.

a. Measurements of the propeller blade were:

chord - 6.25 inches

hub-to-tip - 33.25 inches

b. Measurements of the tail rotor blades were:

chord - 5.75 inches

hub-to-tip - 33.0 inches

NOTE: A small portion (4.50 inches) of the tail rotor adjacent to the hub was not painted since this area must be fluxed for inspection.

2. Paints used in this study were as follows:

    a. White, lacquer, gloss, color number 17875

    b. Black "Velvet Coating" manufactured by the 3-M Corporation having a reflectance value of approximately 1.5 percent.

    c. Red-orange fluorescent "Day-Glo", color number 633

    d. Yellow, lacquer, gloss, color number 13538

    e. Red, lacquer, gloss, color number 11136

3. Paint schemes developed for use in this study are shown in Figure 1.

C. Procedure

1. This project was conducted on two separate days. The first day involved the comparison of propeller blades in the morning and tail rotor blades in the afternoon. The second day, only propeller blades were used. The test propellers and blades were observed against the following backgrounds:

    a. Buildings and other ramp-parked aircraft.

    b. Open runway viewing with sky being the primary background.

    c. Green trees with the aircraft on or adjacent to green grassy areas.

2. The propellers were observed while rotating at 600 and 1200 revolutions per minute as indicated on the aircraft tachometer. This approximately corresponds to, respectively, ground idle and fast idle or "run up" speed for the T-41 aircraft. The tail rotors were observed while rotating at 2400 and 3200 engine

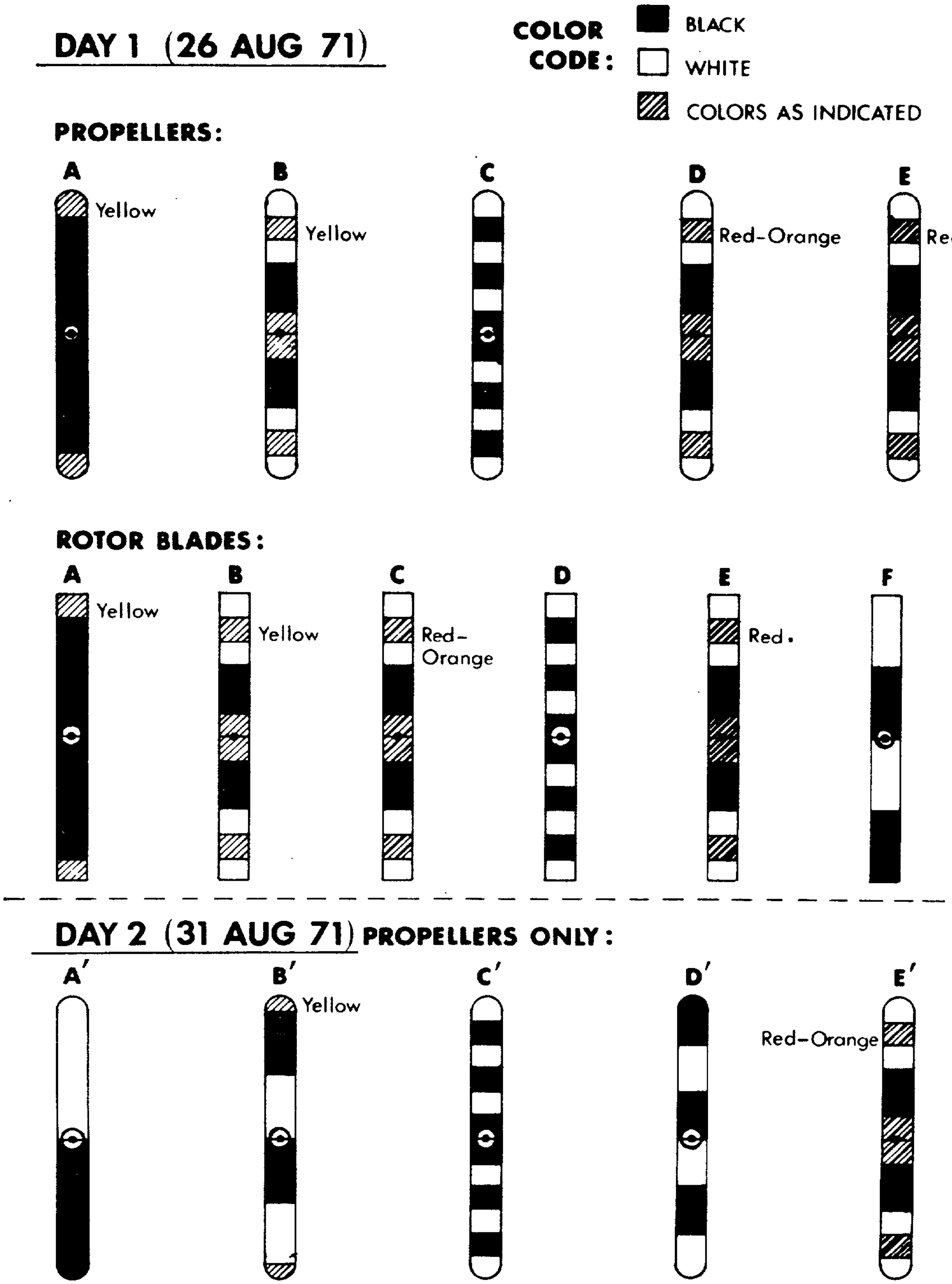
DAY 1 (26 AUG 71)
COLOR CODE:
BLACK
WHITE
COLORS AS INDICATED
PROPELLERS:
A
Yellow
B
Yellow
C
D
Red-Orange
E
Red
ROTOR BLADES:
A
Yellow
B
Yellow
C
Red-Orange
D
E
Red.
F
DAY 2 (31 AUG 71) PROPELLERS ONLY:
A′
B′
Yellow
C′
D′
E′
Red-Orange

Figure 1.

revolutions per minute. This corresponds to ground idle and operating speed for the TH-13 helicopter.

3. While the blades were rotating at the lower range, the observers were instructed to compare all of them simultaneously from a distance of approximately one hundred feet. They then approached to within five feet of the aircraft and viewed each revolving blade both directly and peripherally, marking their response sheet at this time. This procedure was repeated for both blade speeds and with each type of background.

4. Each observer received a rating sheet (Figure 2) which required that they make a "forced choice" decision, rating the schemes from 1 (best) to 5 (poorest). The observers were instructed to avoid any discussion of their ratings until completion of the project.

5. The aircraft were identified by a letter marked on the fuselage. The rating sheets randomly presented these letters for selection and the random sequence was different for each background.

IV. DISCUSSION

1. During the initial observations of the T-41 aircraft the first day, "A" aircraft, having the standard painted propeller, caught fire. This was immediately extinguished and the first background observations completed. While making observations against the second background it caught fire again and sustained extensive damage necessitating that it be eliminated from the remainder of the study. Sufficient data was collected from these observations to conclude that this scheme was the poorest of those being presented.

2. Weather conditions were:

a. First day - The sky was fairly heavy overcast for the propeller observations in the morning. The tail rotor observations in the afternoon were made under essentially clear sky conditions.

b. Second day - There were scattered clouds with light overcast during the second propeller blade observations.

Name ____________________ Date 26 August 1971

PROPELLER CONSPICUITY QUESTIONNAIRE

BACKGROUND

Tree Line

RPM	600	1200
B		
C		
D		
A		
E		

Open Field

RPM	600	1200
D		
E		
A		
B		
C		

Other Aircraft, Buildings, etc.

RPM	600	1200
E		
B		
C		
D		
A		

Name ____________________ Date 26 August 1971

TAIL ROTOR CONSPICUITY QUESTIONNAIRE

BACKGROUND

Tree Line

RPM	2400	3200
B		
C		
D		
A		
E		
F		

Open Field

RPM	2400	3200
D		
E		
A		
F		
C		
B		

Other Aircraft, Buildings, etc.

RPM	2400	3200
F		
B		
C		
D		
A		
E		

Name ____________________ Date 31 August 1971

PROPELLER CONSPICUITY QUESTIONNAIRE

BACKGROUND

Tree Line

RPM	600	1200
B'		
C'		
D'		
A'		
E'		

Open Field

RPM	600	1200
D'		
E'		
A'		
B'		
C'		

Other Aircraft, Buildings, etc.

RPM	600	1200
E'		
B'		
C'		
D'		
A'		

Figure 2

3. While observations were being conducted the morning of the first day (T-41), it was hypothesized that perhaps a different scheme involving the use of black and white sections painted non-concentrically to induce the perception of movement might increase visual stimulation. A blade was repainted to evaluate this hypothesis and the results indicated that it was indeed quite conspicuous. Therefore it was decided to modify the design to include this scheme in the remaining test matrix. Since the standard paint scheme used for most helicopter tail rotors by the Army is very similar to the red-black-white scheme in this study, this scheme ("E") was repainted to scheme "F" (see Figure 1). For scheme "E" it was decided to simply turn one of the helicopters around and present the standard scheme which is also painted on the opposite side of the blade. The results of the study indicate that this standard scheme using red-black-white was the poorest of those presented.

4. Based upon the information obtained during the first day of tail rotor blade observations, it was decided to compare the three best schemes selected with two additional schemes utilizing the non-concentric patterns of black and white. This was accomplished on the second day using T-41 propeller blades (see "Day 2", Figure 1).

5. Photographic coverage included 16mm color movies and 35mm slides. The original speed at which the movies were taken was 64 frames per second (fps). The results indicated that 64 fps was much too fast since the blades appear stroboscopic in pattern. The 24 fps was much better, but still possibly could be improved by shooting at 16 fps or 8 fps to provide a photographic reproduction more nearly resembling the live visual experience.

V. RESULTS

Table IA shows the averaged responses of the preference study made on the first set of painted propeller blades on 26 August 1971. It is important to remember that the lower the number in a particular column, the higher the ranking of that color scheme. Color scheme "C" is by far the most conspicuous of the five tested under every condition of background and engine RPM except where we have a tree line associated with an RPM of 1200. In this case, "D" is ranked slightly higher, indicating that in certain instances of higher blade speed there is probably a change in the relative conspicuity of the two patterns.

TABLE IA

Preference Study of Painted Propellers

Averaged Responses - Part 1

(n = 13)

Background:	Tree Line		Open Field		Buildings & A/C		
RPM*:	600	1200	600	1200	600	1200	
Color Scheme							Total Rank
A					4.9	4.8	4.85
B	3.7	3.6	4.0	4.0	3.5	3.7	3.75
C	1.2	1.9	1.5	1.6	1.0	1.0	1.37
D	2.1	1.2	1.9	1.9	2.5	2.2	1.97
E	3.0	3.2	2.6	2.5	3.1	3.2	2.93

(* denotes engine RPM.)

Although we were able to test color scheme "A" only against a background of buildings and aircraft because of a fire in this particular aircraft, it definitely appears to be the least effective of the five. In the last column, which gives the total rank of all the patterns averaged over all backgrounds and RPM's, "B" was ranked fourth, "E" was third, "D" was second, and "C" was the best.

Table IB gives the results of the statistical analysis of the preference study of the same five color schemes that were considered in Table IA. The values obtained for X^2 ranks are so large that a definite color effect exists. There is less than one chance in a thousand that the results obtained could be the result of chance alone.

In order to determine the extent to which the observers agreed in their preferences, Kendall's[10] statistic, W, the "coefficient of concordance", was computed for every combination of background and rotational speed. Basically, W is defined as the variance of rank sums divided by the maximum possible variance of rank sums. The range of W is from 0 to 1. If $W = 1$, there is complete agreement among the judges; if $W = 0$, complete disagreement. In this study, W varied from 69% to 81%, with its average value $(W)_{av}$, being 74%. This indicates that there is apparently a fairly high degree of "concordance" among the thirteen observers.

Kendall's statistic is related to the average intercorrelation between the rankings assigned by the observers and this relationship is given by

$$F = (nW-1)/(n-1),$$

where n is the number of observers. While W corresponds to a correlation ratio, the average correlation coefficient, F, corresponds to a rank-difference correlation. Taking all of the possible $\binom{13}{2}$ or 78 pairs of observers, we find that the average rank correlation runs from about 0.67 to 0.80 with an average of 0.71. Thus, we can say that in the majority of instances observer-pairs do give relatively similar rankings.

Tables IIA and IIB give the results of the preference study of the second set of painted propeller blades which were observed on 31 August 1971. It is quite obvious that color scheme D' represents the pattern rated the highest in conspicuity under all conditions, while A' and E' were rated the lowest. Again, the X^2-test demonstrates that there is a

TABLE IB

Preference Study of Painted Propellers

Analysis of Variance - Part 1

Background: RPM	Tree Line	Open Field	Buildings & A/C
600	X^2 ranks = 27.00 W = 0.6923 F = 0.6667	X^2 ranks = 28.66 W = 0.6923 F = 0.6667	X^2 ranks = 42.27 W = 0.8130 F = 0.7974
1200	X^2 ranks = 29.03 W = 0.7443 F = 0.7230	X^2 ranks = 27.00 W = 0.6923 F = 0.6667	X^2 ranks = 40.52 W = 0.7793 F = 0.7609

$(W)_{av} = 0.7356$

$(F)_{av} = 0.7136$,

where

W = coefficient of concordance

F = average correlation coefficient

TABLE IIA

Preference Study of Painted Propellers

Averaged Responses - Part 2

(n = 10)

Background:	Tree Line		Open Field		Buildings & A/C		
RPM*:	600	1200	600	1200	600	1200	
Color Scheme							Total Rank
A'	3.8	3.2	4.1	4.1	3.7	3.3	3.70
B'	2.3	2.2	2.4	2.1	2.5	2.3	2.30
C'	3.2	3.7	2.8	3.3	2.9	3.3	3.20
D'	1.2	1.1	1.1	1.1	1.2	1.3	1.17
E'	4.5	4.8	4.5	4.4	4.7	4.8	4.62

* - denotes engine RPM as indicated by the aircraft tachometer.

TABLE IIB

Preference Study of Painted Propellers

Analysis of Variance - Part 2

Background:	Tree Line	Open Field	Buildings & A/C
RPM			
600	X^2ranks = 26.64	X^2ranks = 27.48	X^2ranks = 27.52
	W = 0.6660	W = 0.6870	W = 0.6880
	F = 0.6289	F = 0.6522	F = 0.6533
1200	X^2ranks = 32.08	X^2ranks = 30.72	X^2ranks = 27.20
	W = 0.8020	W = 0.7680	W = 0.6800
	F = 0.8911	F = 0.7422	F = 0.6444

$(W)_{av} = 0.7152$

$(F)_{av} = 0.7020$

definite color effect at the 0.999 probability level. Both W and F are around the 70% level, so there is a moderately high level of agreement among the observers.

In Tables IIIA and IIIB we consider the results of the preference study of painted tail rotor blades in which the same five color schemes were used as in Table I, but with the addition of one more pattern, F. Color scheme F was by far the most superior of any of the six patterns used under all conditions, while patterns A and E were the worst. One interesting fact is the reversal of the rankings of C and D when compared to the preference study of the painted propellers. It appears that D is more conspicuous at the higher speeds of the tail rotor than C is, although there may be a small effect due to the difference in area between the tail rotor and the T-41 propellers.

The values of X^2 ranks are significant at the 99.9% level, denoting a very definite color effect. The average values of W and F are around 0.85, indicating a high degree of agreement among the 13 observers.

It was apparent after the first day of observations that the scheme using concentric black and white sections (1/6) of the blade surface, and the scheme using "Da-Glo", white and black were the primary choices.

Observations on the second day revealed that the superior scheme was D', Figure 1. It was shown in the study that color contrast was significant under certain background conditions. Therefore, based upon the results of this study and an application of past experience, the recommended pattern for blade and tail rotor painting is as follows (in order of preference):

1. From the blade tip to the hub, paint a four inch area of red-orange fluorescent ("Da-Glo"), while dividing the remaining surface into thirds and painting alternately flat black and gloss white. The black and white sections of the other half of the blade are reversed to provide a non-concentric pattern. This scheme would be the best provided the "Da-Glo" were repainted every 3 - 4 months. This latter problem may or may not be a major consideration.

2. Same as scheme in Paragraph 1 above, except substitute yellow lacquer paint for "Da-Glo."

3, Same as scheme in Paragraph 1 above, except leave off the colored tip.

TABLE IIIA

Preference Study of Painted Tail Rotors

Averaged Responses

(n = 12)

Background:	Tree Line		Open Field		Buildings & A/C		
RPM*:	2800	3200	2800	3200	2800	3200	
Color Scheme							Total Rank
A	5.6	5.7	5.8	5.8	5.8	6.0	5.78
B	3.9	3.8	4.0	4.0	4.0	3.9	3.93
C	2.2	2.6	2.4	2.3	2.8	2.8	2.52
D	2.9	2.3	2.1	2.1	2.2	2.1	2.28
E	5.4	5.3	5.2	5.0	5.1	4.8	5.13
F	1.3	1.3	1.5	1.8	1.3	1.5	1.45

* - denotes engine RPM as indicated by the aircraft tachmoter.

TABLE IIIB

Preference Study of Painted Tail Rotors

Analysis of Variance

Background:	Tree Line	Open Field	Buildings & A/C
RPM			
2400	X^2 ranks = 58.69	X^2 ranks = 50.36	X^2 ranks = 52.19
	W = 0.9782	W = 0.8393	W = 0.8699
	F = 0.9762	F = 0.8247	F = 0.8581
3200	X^2 ranks = 51.48	X^2 ranks = 49.29	X^2 ranks = 49.91
	W = 0.8580	W = 0.8214	W = 0.8318
	F = 0.8451	F = 0.8052	F = 0.8165

$$(W)_{av} = 0.8664$$

$$(F)_{av} = 0.8543$$

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