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THE EFFECTS OF ELIMINATING MINOR GRADUATIONS ON DIAL READING PE--ETC(U)

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# THE EFFECTS OF ELIMINATING MINOR GRADUATIONS ON DIAL READING PERFORMANCE

Alan M. Poston



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U. S. ARMY HUMAN ENGINEERING LABORATORY
Aberdeen Proving Ground, Maryland

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An investigation was made to determine dial reading performance using two dial marking schemes; one as they appear in current aircraft and the other with the minor graduation marks eliminated. Four instruments (DC voltmeter, fuel pressure indicator, exhaust gas temperature indicator, and transmission oil temperature indicator) were used to examine each scheme. Results indicated that performance was significantly better with the modified designs (minor graduations eliminated). A second result was that, regardless of the design used, some instruments are significantly more difficult to read than others.

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September 1977

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# THE EFFECTS OF ELIMINATING MINOR GRADUATIONS ON DIAL READING PERFORMANCE

## INTRODUCTION

The current tactical doctrine of night nap-of-the-earth flight has created the demand for improvements in cockpit lighting systems in order to maintain dark adaptation and thereby improve external vision. The amount of light flux in the cockpit is the main factor in determining the ability of a crewmember to see outside the cockpit at night. A high light flux could have three adverse effects: (1) with a high light level in the cockpit, the eye is adapting to this high level and therefore could miss the detection or discrimination of certain external objects, (2) it may cause reflections on the windscreen which might impair external vision, and (3) it will increase the probability of enemy detection.

One of the initial attempts to limit the amount of light flux is the inclusion of integral lighting for the instruments of the new production helicopters (AAH and UTTAS) as well as several modernization programs (AH-1S, OH-58C, and CH-47D). Integral lighting provides for better distribution of the light which will allow lower levels of instrument brightness to be selected.

Another method of reducing the overall light level in the cockpit would be to reduce the number of markings on the instruments thereby reducing the amount of reflective area. In "An Aircraft Instrument Marking Concept to Improve Legibility Under Low Illumination" (4), it has been proposed that many of the subsystem (engine, electrical, hydraulic, etc.) instruments could have their minor graduations removed without affecting the crewmembers ability to read the instrument. This concept would particularly be true for temperature and pressure gauges where the crewmember is not always concerned with an exact reading.

A concept of this nature provides two benefits: (1) the amount of light-reflecting area in the cockpit is reduced thereby reducing the total light flux, and (2) the limiting factor on how low the instrument light level can be is the ability to discriminate the minor graduations. With the minor graduations removed, the limiting factor becomes the ability to discriminate the intermediate graduations. As the intermediate graduations are longer and wider than the minor graduations, the instrument brightness can be turned to a lower level. This, in turn, causes the total light flux in the cockpit to be reduced.

The purpose of this investigation is to determine whether this concept is feasible. Of prime concern is the assurance that the ability to read the instruments, with acceptable tolerances, has not been degraded.

## METHOD

Four instrument dial designs were chosen. The four were the exhaust gas temperature, fuel pressure, transmission oil temperature, and the DC voltmeter. These instruments are shown in Figures 1 through 4 respectively. In each figure the dial face is displayed as it actually is and again with the minor graduations removed. Each of the instruments has a movable pointer so that different readings could be presented to the subjects. The sizes of the markings are identical within each instrument pair.



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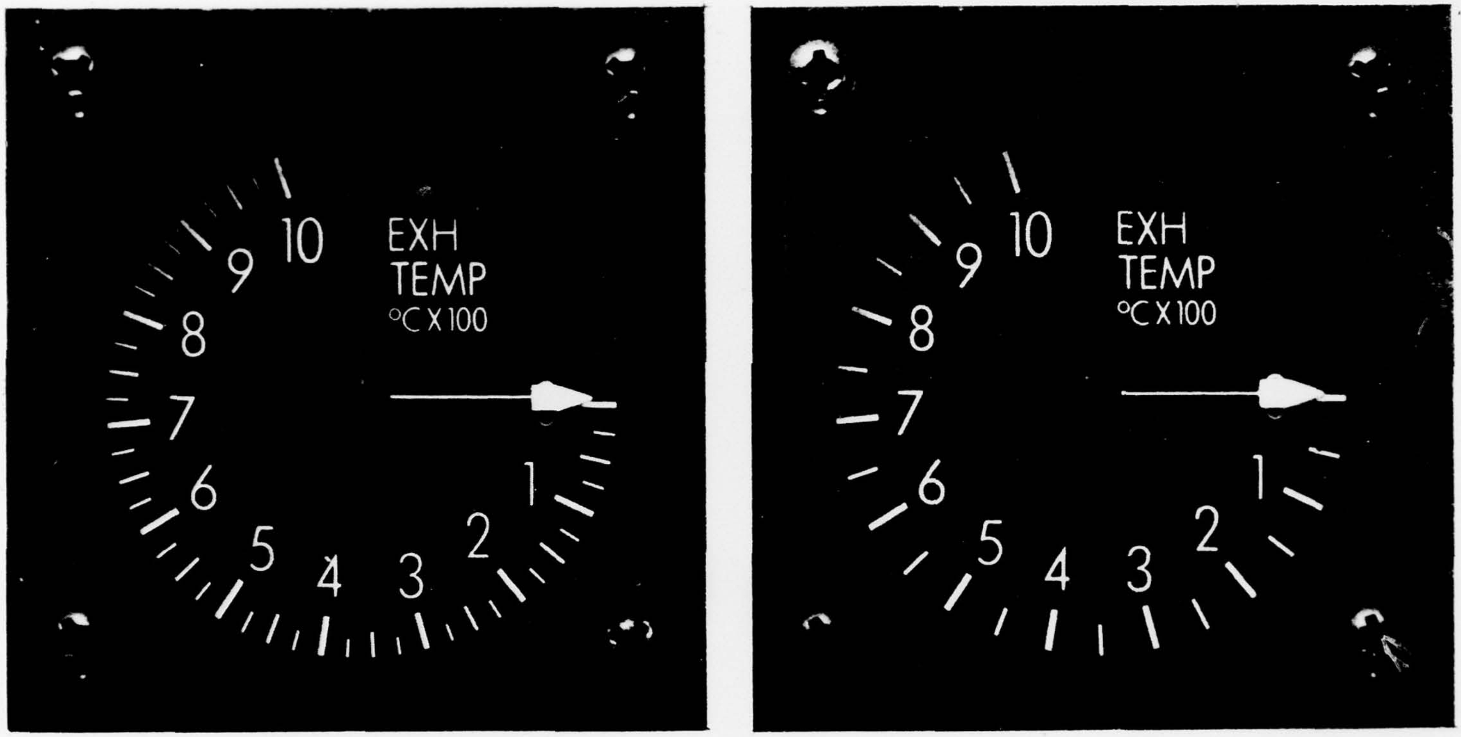


Figure 1. Exhaust gas-temperature indicator.

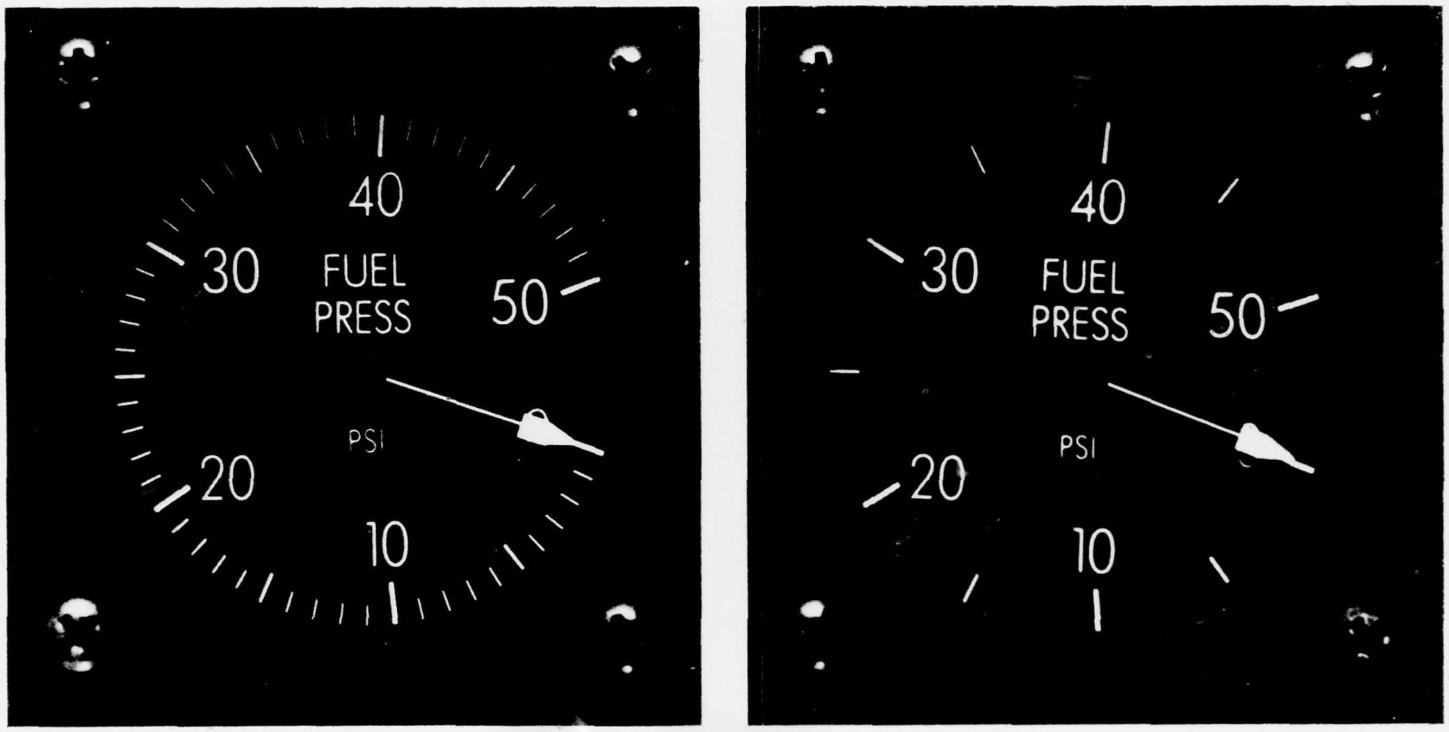


Figure 2. Fuel pressure indicator.

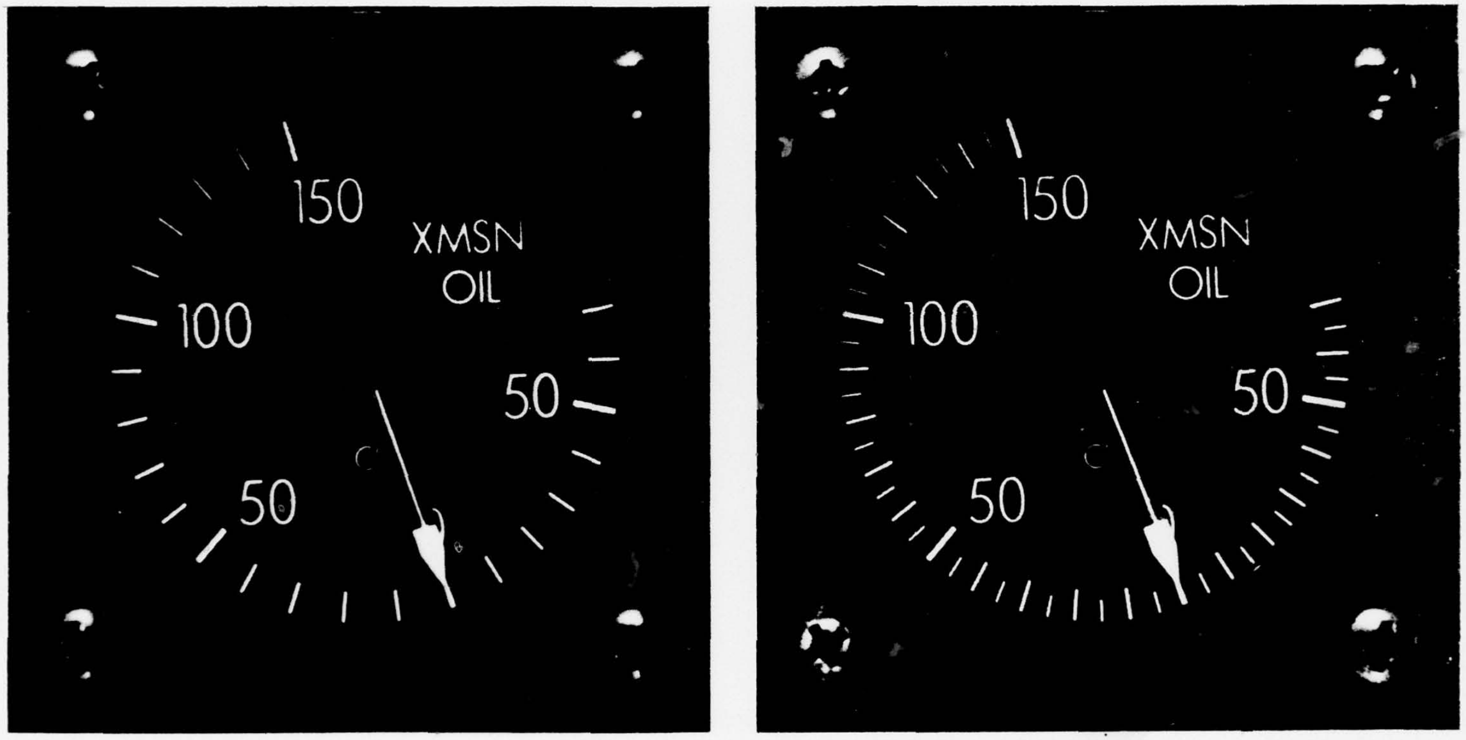


Figure 3. Transmission oil temperature indicator.

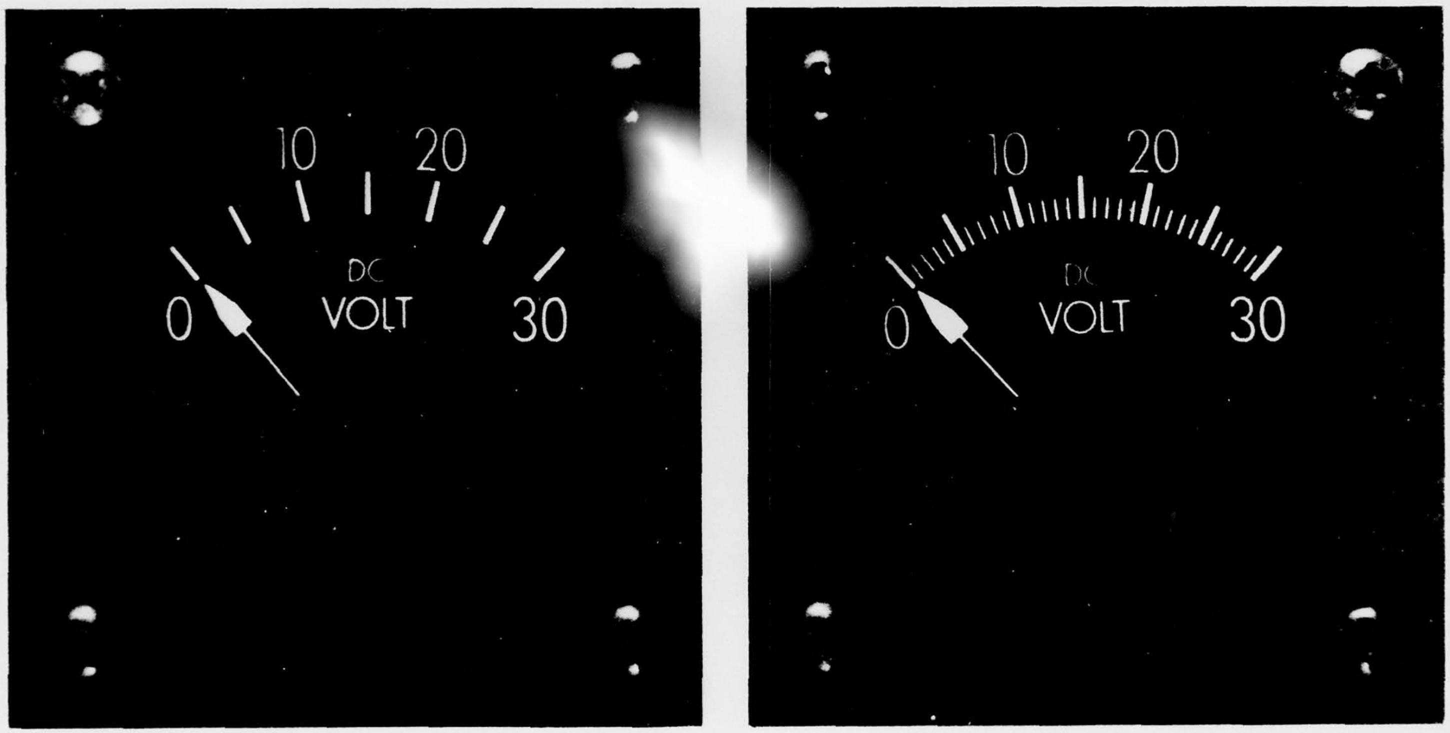


Figure 4. DC voltmeter.

The eight instruments (four with the actual design and four with the minor graduations removed) were placed on the left-hand side of a generic instrument panel as shown in Figure 5. All of the instruments in the panel are lighting mockups. All instruments, except the ADI and HSI, were integrally wedge lighted and all were illuminated with unfiltered white light. The test control panel for the instruments had rheostats so the brightness of each instrument could be individually controlled as well as a single rheostat which controlled the brightness of the entire panel.

### Subjects

Fifteen subjects were used in this investigation. All subjects were members of the U.S. Army Human Engineering Laboratory or aviators from Phillips Army Air Field, Aberdeen Proving Ground, MD.

### Procedure

The investigation was conducted in a light-tight trailer. During the experiment, none of the overhead lights were on. The only illumination present was that produced by the instrument panel.

Each subject was brought into the trailer and explained the procedures of the experiment. The subject was given as much time as desired to study the four instrument pairs and become familiar with the ranges and increments. At this time, the subject was dark adapted for about 20 minutes. All of the instruments on the panel were balanced such that subjectively, to the subject, they were all equally bright. With the individual balancing complete, the brightness level of the entire panel was raised to any point which was comfortable to the subject. As each subject served as his own control by using the same light level to view both instrument designs, the fact that different subjects may have chosen different light levels did not affect the analysis.

The data collection process was then ready to begin. The eight instruments connected with the investigation were turned off. The remaining instruments were illuminated so the subject was able to maintain a level of adaptation. The pointers on each of the eight instruments were set to random readings, which were recorded. Then, randomly, one of the instruments was illuminated for a period of 1.8 seconds. At the end of the 1.8 second interval, the instrument was turned off and the subject was to respond by giving the instrument reading as accurately as possible. This response was recorded. Before the data collection trials, the subject was given as many practice trials as desired to assure they understood the task. The process continued until each of the eight instruments had been viewed by the subject. The pointers were reset and the whole process began again. The entire test for each subject consisted of three trials where each trial consisted of one viewing of each of the eight instruments.

## RESULTS AND DISCUSSION

Comparing the subjects' response to the actual reading yielded the number of correct responses for each subject on each instrument. A response was considered correct if it was within one minor graduation increment on the original dial face design. The DC voltmeter and fuel pressure indicator are incremented by 1's, the exhaust gas temperature by 2½'s, and the transmission oil temperature indicator by 5's. Therefore, the tolerances allowed on each response

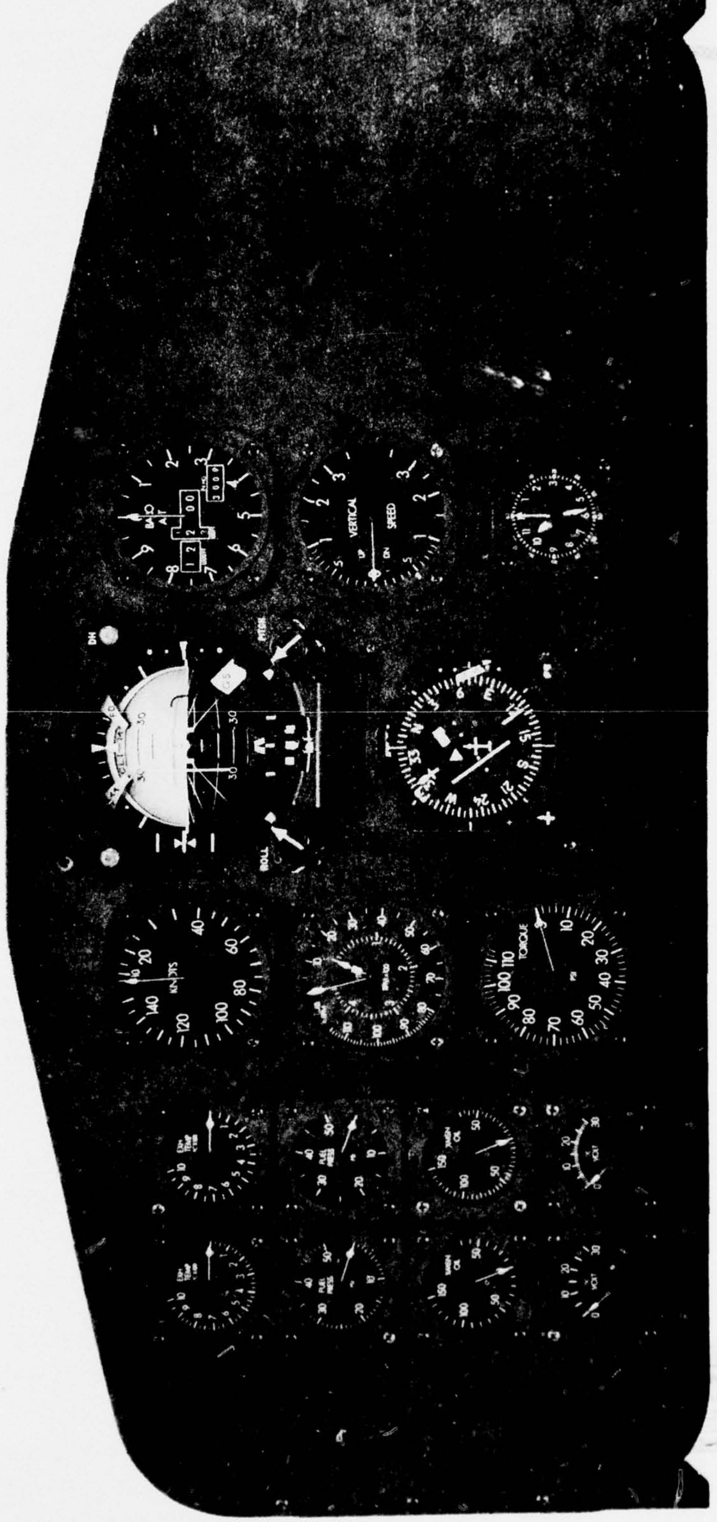


Figure 5. Instrument panel.

to be considered correct were voltmeter and fuel pressure ± 1, exhaust gas temperature ± 2, and transmission oil temperature ± 5. The number of correct responses is shown in Table 1.

Analysis of variance of these responses was made using the treatment-by-treatment-by-subjects design (1). The results of this analysis are shown in Table 2. From this table it can be concluded that:

1. There is a significant difference between the two dial schemes in the number of correct responses.

2. There is a significant difference, within either of the two schemes, in the number of correct responses between instruments.

In order to examine the second conclusion a bit closer, a Tukey test ([illegible]) was run. The results of the Tukey are shown in Table 3. An analysis of the Tukey test indicates that in the original design, there is a significant difference in the number of correct responses between the transmission oil temperature indicator and each of the other three instruments. The only significance with the modified design was between the voltmeter and the transmission oil temperature.

It should be mentioned that, although significantly more errors (less correct responses) were made with the original designs, a separate analysis showed there was no significant difference in the magnitude of the errors.

The above analyses were repeated with a different criteria to define an error. Now, an error was any response greater than one unit (one volt, one psi fuel pressure, one degree exhaust gas temperature (times the 100° scale factor), and one degree transmission oil temperature) from the actual reading. The number of correct responses for the narrow tolerance band is presented in Table 4 and the analysis summary table is presented in Table 5. From the results, it can be concluded that:

1. There is a significant difference in the number of correct responses between the two dial schemes.

2. There is a significant difference in the number of correct responses between instruments. A Tukey test indicates that there is a significant difference in the number of correct responses, with either the original or modified designs, between the transmission oil temperature indicator and each of the other three instruments.

3. The interaction between the instruments and the schemes is significant. This means that the choice of instruments is one variable which significantly affects the difference between the marking schemes.

An analysis of the magnitude of the errors indicated that there was a significant difference in the magnitude of the errors between instruments, but no significant difference between marking schemes. Under both the original scheme and the modified scheme, significant differences were found in the magnitude of the errors between the transmission oil temperature indicator and each of the other three instruments.

Another set of trials was taken with a smaller number of subjects and the time interval for viewing the instrument increased to 2.4 seconds. An analysis of variance of these results showed no significance either between schemes or between instruments within a scheme. Therefore, as

TABLE 1

Number of Correct Responses

| | Voltmeter | | Fuel Pressure | | Exh. Gas Temperature | | Trans. Oil Temperature | |
|---|---|---|---|---|---|---|---|---|
| | Original | Modified | Original | Modified | Original | Modified | Original | Modified |
| $S_1$ | 3 | 3 | 3 | 3 | 2 | 3 | 1 | 3 |
| $S_2$ | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 |
| $S_3$ | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 |
| $S_4$ | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 3 |
| $S_5$ | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| $S_6$ | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 |
| $S_7$ | 3 | 3 | 2 | 3 | 2 | 3 | 2 | 3 |
| $S_8$ | 3 | 3 | 3 | 3 | 2 | 2 | 1 | 3 |
| $S_9$ | 3 | 3 | 3 | 3 | 3 | 3 | 1 | 3 |
| $S_{10}$ | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 3 |
| $S_{11}$ | 3 | 3 | 2 | 2 | 2 | 3 | 3 | 3 |
| $S_{12}$ | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 |
| $S_{13}$ | 3 | 3 | 2 | 3 | 3 | 3 | 2 | 2 |
| $S_{14}$ | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 |
| $S_{15}$ | 3 | 3 | 3 | 3 | 3 | 3 | 1 | 3 |
| Total | 45 | 45 | 41 | 44 | 41 | 44 | 32 | 39 |

TABLE 2

Summary Table of Analysis

| Source | SS | df | MS | F | P |
|---|---|---|---|---|---|
| Total | 30.00 | 119 | --- | --- | --- |
| Subjects | 2.13 | 14 | --- | --- | --- |
| Instrument | 6.70 | 3 | 2.23 | 12.39 | <.001 |
| Scheme | 1.42 | 1 | 1.42 | 6.17 | <.05 |
| Instrument & Scheme | 0.81 | 3 | 0.27 | 1.42 | NS |
| Error for Instrument | 7.67 | 42 | 0.18 | --- | --- |
| Error for Scheme | 3.20 | 14 | 0.23 | --- | --- |
| Error for instrument & scheme | 8.07 | 42 | 0.19 | --- | --- |

TABLE 3

Tukey Test Results

| | Original Scheme | Modified Scheme |
|---|---|---|
| $\bar{X}$ (voltmeter) - $\bar{X}$ (fuel pressure) | 0.27 | 0.07 |
| $\bar{X}$ (voltmeter) - $\bar{X}$ (exh. gas temp.) | 0.27 | 0.07 |
| $\bar{X}$ (voltmeter) - $\bar{X}$ (trans. oil temp.) | 0.87[a] | 0.40[a] |
| $\bar{X}$ (fuel pressure - $\bar{X}$ (exh. gas temp.) | 0.00 | 0.00 |
| $\bar{X}$ (fuel pressure - $\bar{X}$ (trans. oil temp.) | 0.60[a] | 0.33 |
| $\bar{X}$ (exh. gas temp.) - $\bar{X}$ (trans. oil temp.) | 0.60[a] | 0.33 |

$q\sqrt{MS_w/n} = 0.41$

[a]Indicates significance to the .05 level.

TABLE 4

Number of Correct Responses (Narrow Tolerance Band)

| | Voltmeter | | Fuel Pressure | | Exh. Gas Temperature | | Trans. Oil Temperature | |
|---|---|---|---|---|---|---|---|---|
| | Original | Modified | Original | Modified | Original | Modified | Original | Modified |
| $S_1$ | 3 | 3 | 3 | 3 | 2 | 3 | 1 | 3 |
| $S_2$ | 3 | 3 | 3 | 3 | 3 | 3 | 1 | 2 |
| $S_3$ | 3 | 3 | 3 | 3 | 2 | 3 | 1 | 0 |
| $S_4$ | 3 | 3 | 3 | 3 | 3 | 3 | 1 | 3 |
| $S_5$ | 3 | 3 | 3 | 3 | 3 | 3 | 1 | 3 |
| $S_6$ | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 |
| $S_7$ | 3 | 3 | 2 | 3 | 2 | 3 | 1 | 3 |
| $S_8$ | 3 | [illegible] | 3 | 3 | 2 | 2 | 1 | 2 |
| $S_9$ | 3 | [illegible] | 3 | 3 | 2 | 3 | 0 | 1 |
| $S_{10}$ | 3 | 3 | 2 | 3 | 2 | 3 | 2 | 2 |
| $S_{11}$ | 3 | 3 | 2 | 2 | 1 | 3 | 2 | 2 |
| $S_{12}$ | 3 | 3 | 3 | 3 | 2 | 3 | 1 | 2 |
| $S_{13}$ | 3 | 3 | 2 | 3 | 3 | 2 | 1 | 0 |
| $S_{14}$ | 3 | 3 | 3 | 3 | 2 | 3 | 0 | 2 |
| $S_{15}$ | 3 | 3 | 3 | 3 | 3 | 3 | 0 | 3 |
| Total | 45 | 45 | 41 | 44 | 35 | 43 | 15 | 30 |

TABLE 5

Summary Table of Analysis (Narrow Tolerance Band)

| | SS | df | MS | F | P |
|---|---|---|---|---|---|
| Total | 81.97 | 119 | - | - | - |
| Subjects | 4.72 | 14 | - | - | - |
| Instruments | 41.10 | 3 | 13.70 | 50.74 | <.001 |
| Scheme | 5.63 | 1 | 5.63 | 25.59 | <.001 |
| Instruments & Scheme | 4.30 | 3 | 1.43 | 5.10 | <.005 |
| Error for Instrument | 11.15 | 42 | 0.27 | - | - |
| Error for Scheme | 3.12 | 14 | 0.22 | - | - |
| Error for Instrument & Scheme | 11.95 | 42 | 0.28 | - | - |

the time interval for viewing the instrument is increased from 1.8 to 2.4 seconds, statistical significance between the two schemes is lost.

Figure 6 shows the percentage of correct responses for each marking scheme as the time interval for viewing is increased. The dashed portion of the curve is an extrapolation and indicates that at some point in time, the percent correct responses will be equal and reach 100 percent.

## CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the previous section, it can be concluded that for a task which requires accuracy in a short time interval, the modified dial face schemes yielded better performance than the original dial face schemes. The reason for this could be that there were not as many graduations which needed to be counted to confuse the subjects. The accuracy of the responses indicated that interpolation over larger areas was not a problem. A report on a previous study (2) indicates that interpolation of fifths, and maybe even tenths, may yield satisfactory accuracy.

When the time interval available for viewing the instruments is increased, there is no statistical significance between the ability to read the original and modified marking schemes. As there is no degradation in reading performance, it is recommended that the modified scheme be adopted in order to gain the benefits of a reduced level of light flux in the cockpit.

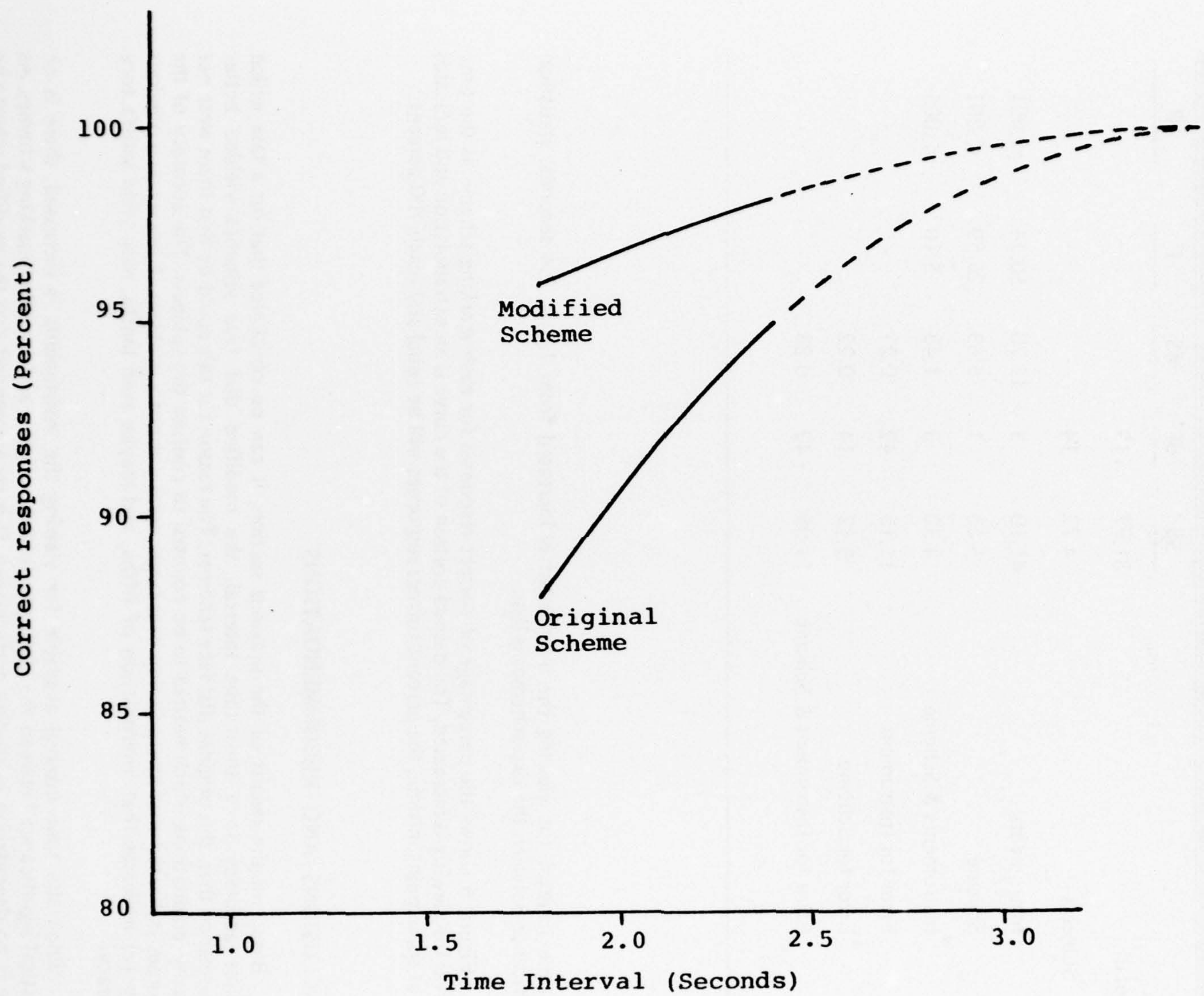


Figure 6. Correct responses versus time.

Critics might contend that this was not a realistic test, that these types of instruments are almost always shape and/or color coded to denote operating ranges (the instruments used in this investigation were not) and the pilot will only check for an indication of operating range and not try to read the instrument. On this point, the critics would be correct. Since the instruments in the aircraft will be shape or color coded and if the pilot is not going to read the instrument, the minor graduations are of little consequence. The use of shape/color coding provides strong justification for eliminating the minor graduations, and therefore, derive the benefits of reducing light flux.

A word of caution should be ad[illegible] On some aircraft, some minor graduations are needed for operational and maintenan[illegible] points need to be investigated before a blanket elimination of all minor graduat[illegible]ted.

A secondary conclusion from the results [illegible], regardless of whether or not the minor graduations are eliminated, some instruments are harder to read than others. This seems to be a function of the numbers and increments of the graduations and the number of major graduations. The seriousness of this effect may be negated by the fact that these instruments are usually not read, but viewed for an indication of operating range.

In summary, as the performance is not degraded in reading instruments with the minor graduations eliminated, it is recommended that consideration be given to eliminate the minor graduations from many engine, electrical, and hydraulic instruments in order to reduce the total light flux in the cockpit and increase night vision compatability.

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