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USAAVSCOM Technical Report 75-46

STUDY TO ASSESS COCKPIT INDICATOR
MARKING AND LIGHTING REQUIREMENTS
OF U.S. ARMY HELICOPTERS

R. R. Strock
SPERRY FLIGHT SYSTEMS
SPERRY RAND CORPORATION
PHOENIX, ARIZONA

February 1976

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Prepared for
Technical Integration Branch, Systems
Development and Qualification Division, RD&E Directorate,
US Army Aviation Systems Command
St. Louis, Missouri

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This project used the results of an initial examination of various types of aircraft indicator lighting systems and an evaluation of dial marking philosophies to construct 16 lighted indicator mockups. The mockups were constructed to facilitate subsequent investigations of indicator display and lighting requirements of U.S. Army aircraft on night missions, nap-of-the-earth flights, and flights utilizing night vision goggles. A simulated aircraft panel and a lighting control assembly were constructed.		

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20. ABSTRACT (continued)

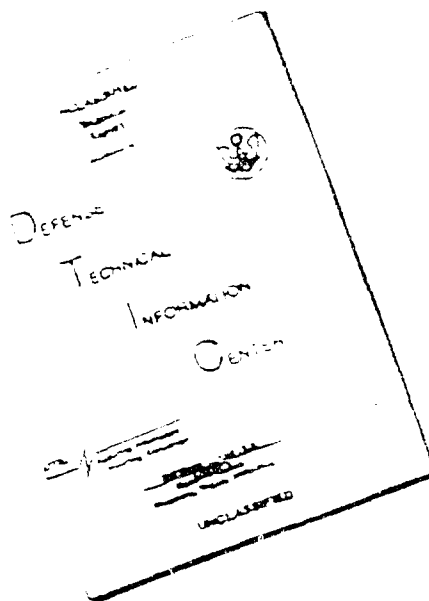
for use with the mockups. Two additional tasks were also included in this project: a survey of the readability through night vision goggles of various types of displays which might be used in Army aircraft, and a measurement of the lighted intensities of various colors of fluorescent paint when illuminated by Aviation Red lighting.

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PREFACE

This study was conducted by the Flight Instrument Systems Department, Sperry Flight Systems Division, Sperry Rand Corporation, Phoenix, Arizona, under Contract DAAJ01-74-C-0967(P1G), "Study to Assess Cockpit Indicator Marking and Lighting Requirements of U.S. Army Helicopters". This report summarizes the work accomplished under contract to the U.S. Army Aviation Systems Command (AVSCOM), Technical Integration Branch, Systems Development and Qualification Division, RD&E Directorate, St. Louis, Missouri. The study was initiated in June, 1974, and completed in November, 1975.

The author is indebted to numerous U.S. Army and industry personnel who made this study possible. Key Army personnel who contributed greatly to this study were Mr. A. M. Poston of U.S. Army Human Engineering Laboratory (HEL), Aberdeen Proving Ground, Aberdeen, MD, the contract Technical Monitor, and Mr. J. F. Hatcher, formerly the Contracting Officer.

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SECTION I
INTRODUCTION

This report presents the results of a program to establish requirements for improving integral lighting systems and dial marking schemes applicable to U.S. Army aircraft. The effects of marking size, marking configuration and color of the integral lighting system were assessed for maximum low-illumination readability.

It is intended that the results of this study be used to generate new specifications or revise existing documents to reflect the unique requirements of Army aircraft. These requirements have resulted from the increasing emphasis on Nap-of-the-Earth (NOE) operations and night flights.

The program was conducted by Sperry Flight Systems Division of the Sperry Rand Corporation under the auspices of the Technical Integration Branch of the Systems Development and Qualification Division of RD&E Directorate, USAAVSCOM. It was conducted during the period from 27 June 1974 through 30 November 1975.

The objectives of this program include:

- Selection of an integral lighting system
- Assessment of two dial marking schemes
- Construction of indicator mockups, using the selected lighting system and marking scheme, and lighting measurements of these mockups.
- Construction of an indicator mockup mounting panel and lighting control assembly.
- Survey of the readability of various types of displays using night vision goggles.
- Lighting measurements of fluorescent paints when illuminated with Aviation Red lighting.

SECTION II

SUMMARY

1. PROGRAM DESCRIPTION

The program consisted of eleven specific tasks:

- Task A - Lighting system study
- Task B - Lighting system selection
- Task C - Dial marking study
- Task D - Indicator mockup construction
- Task E - Indicator mockup lighting measurement
- Task F - Night vision goggle survey
- Task G - Indicator mockup mounting panel construction
- Task H - Indicator mockup delivery
- Task I - Red-lighted fluorescent paint measurements
- Task J - Lighting control assembly construction
- Task K - Final report

a. Lighting System Study (TASK A)

Five different types of integral instrument lighting systems were evaluated for:

- Uniformity of light distribution across the dial face
- Excitation voltages required to obtain the same illuminance (total flight flux) from all the lighting systems at two levels of intensity.
- Ease of conversion of the lighting system to other indicator sizes
- Amount of stray light (unwanted visible light)
- Suitability for anti-reflection coatings
- Relative production costs
- Electrical current drain at 5.0-volt excitation
- Ease of maintenance

b. Lighting System Selection (TASK B)

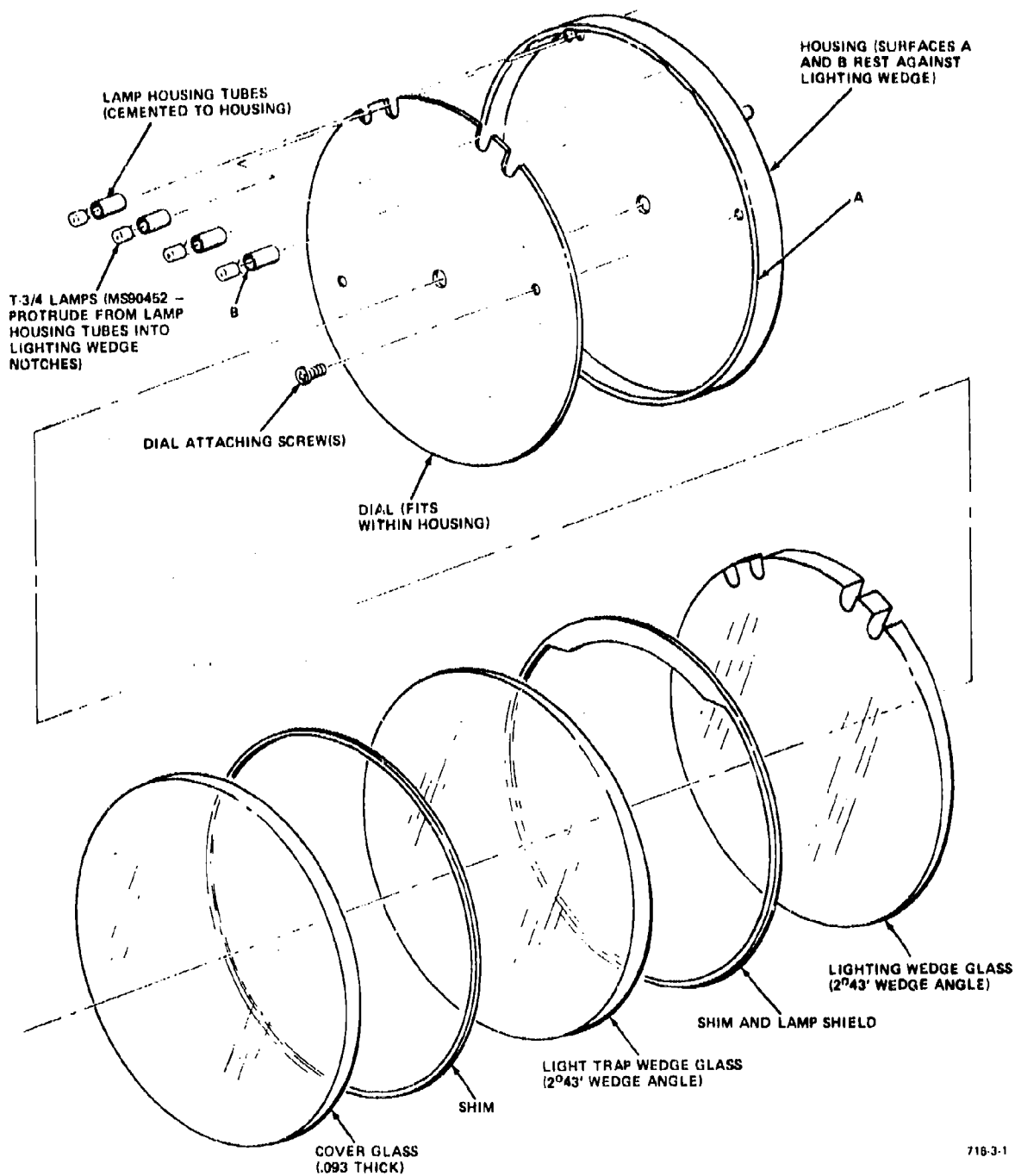
A tradeoff analysis was made of the factors in Section a. This evaluation resulted in the selection of the lighting system shown in Figure 1.

c. Dial Marking Study (TASK C)

This task consisted of the following three phases:

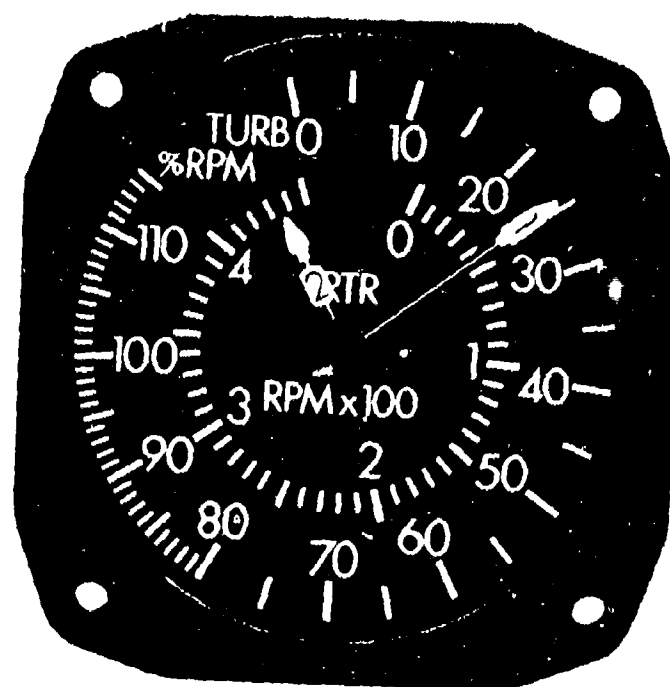
- A selection, based upon a subjective evaluation, of two candidate dial graduation philosophies and dial legend character fonts.
- Experimental evaluation of the two candidate dial marking schemes against the criteria of the total light flux emitted from the face of the mockup at the level of threshold readability for dark-adapted subjects. The less the total flux emitted for a readable display, the more desirable the marking scheme.
- Construction and evaluation of several types of shape-coded markings to denote caution and warning areas on a dial face when viewed under conditions where color-coding is impractical, such as with night vision goggles or with Aviation Red illumination.

The two candidate dial marking schemes selected for experimental evaluation are shown in Figures 2 through 5. The two marking schemes used are shown in Table 1. The experimental evaluation of these two schemes showed that there was no statistically significant difference between the two schemes. That is, Scheme A required less voltage for threshold readability than did Scheme B but the total light flux emitted by the two were identical when the lighting systems were set to the threshold readability voltages. Scheme B was selected for use in the remainder of the program. The rationale for this selection is shown in Section III.2.a.



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Figure 1
Selected Indicator Lighting System



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Figure 2
Dual Rotor RPM Indicator Mockup, Marking Scheme A



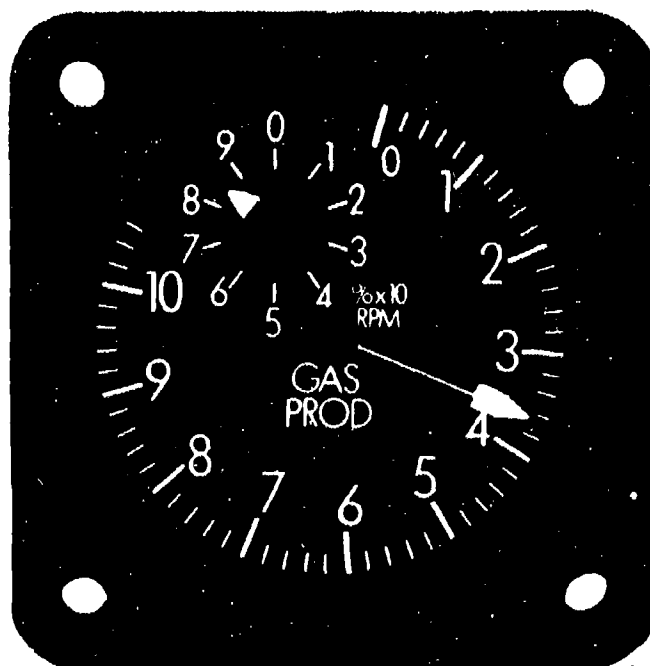
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Figure 3
Dual Rotor RPM Indicator Mockup, Marking Scheme B



716-3 4

Figure 4
Gas Producer Indicator Mockup, Marking Scheme A



716-3-6

Figure 5
Gas Producer Indicator Mockup, Marking Scheme B

TABLE 1
DIAL MARKING SCHEMES FOR EVALUATION

Feature	Scheme A	Scheme B
<u>Dual Rotor RPM Mockup:</u>		
Outer Dial Graduations		
Major	.200 x .035	.154 x .019
Intermediate	.160 x .030	.108 x .014
Minor	.100 x .025	.076 x .011
Inner Dial Graduations		
Major	.160 x .035	.154 x .019
Intermediate	.140 x .030	.108 x .014
Minor	.100 x .025	.076 x .011
All Numerals	.180 high, Futura Medium	.154 high, Futura Book
Legends	.150 high, Futura Medium	.108 high, Futura Book
<u>Gas Producer Mockup:</u>		
Main Dial Graduations		
Major	.160 x .035	.154 x .022
Minor	.100 x .025	.076 x .011
Sub-Dial Graduations	.080 x .023	.076 x .011
Main Dial Numerals:		
"0"	.090 high, Futura Medium	.076 high, Futura Book
"1" through "10"	.150 high, Futura Medium	.154 high, Futura Book
Sub-Dial Numerals	.100 high, Futura Bold	.108 high, Futura Book
Legends:		
"GAS PROD"	.150 high, Futura Medium	.108 high, Futura Book
"% x 10 RPM"	.100 high, Futura Medium	.076 high, Futura Book

Shape-coded caution/warning area markings were generated for future evaluation. These are shown in Figure 6 and detailed in Figure 7.

d. Indicator Mockup Construction (TASK D)

Using the indicator lighting system, Figure 1, and dial marking scheme B, shown in Figures 3 and 5 and tabulated in Table 1, the twelve mockups shown in Figures 8 through 19 were constructed. These mockups contained externally settable pointers. Both an unfiltered incandescent and an Aviation Red light block were provided for each mockup.

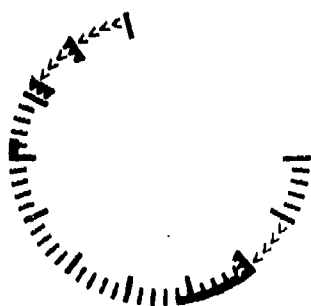
In addition to the twelve 2- and 3-inch mockups, a 5-inch Attitude Indicator mockup and a 4-inch Horizontal Situation Indicator mockup were constructed. The Attitude Indicator mockup, Figures 20 and 21, contains the presentation, markings, and colors used in the prototype VSI (Vertical Situation Indicator) used in the Boeing Vertol UTTAS helicopter. The Horizontal Situation Indicator mockup, Figures 22 and 23, represents a typical commercial indicator of this type. Insofar as possible, both unfiltered incandescent and Aviation Red lighting capabilities were provided with these two mockups.

e. Indicator Mockup Lighting Measurements (TASK E)

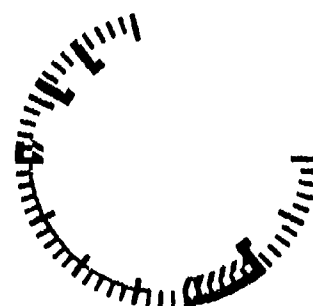
On each of the fourteen mockups the following lighting measurements were made using unfiltered incandescent light:

- The voltages required to produce .02 footlamberts and .05 footlamberts at a selected representative point on the presentation
- Luminance readings, in footlamberts, of six selected presentation points at excitation voltages of 1.5, 2.0, 2.5, and 5.0 volts dc

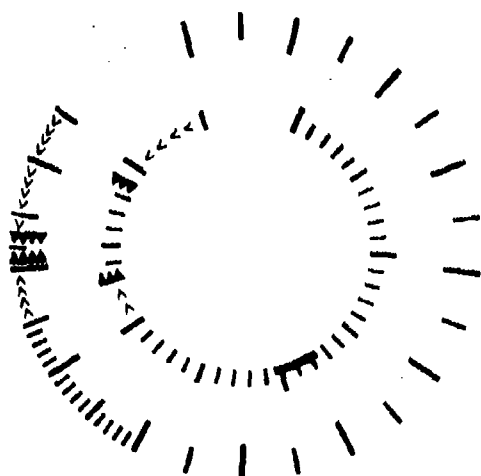
A 2-inch mockup, the Fuel Quantity Indicator, and a 3-inch mockup, the Airspeed Indicator, were then converted from unfiltered incandescent lighting to Aviation Red lighting and the above lighting measurements were taken again, corrected for color. The results were then compared to the white light measurements. These comparisons are shown in Figures 24 and 25. Because there was a reasonable and explainable correlation between the white and red lighting data, it was determined that making further mockup conversions to red lighting and taking additional lighting measurements of the converted units was not warranted.



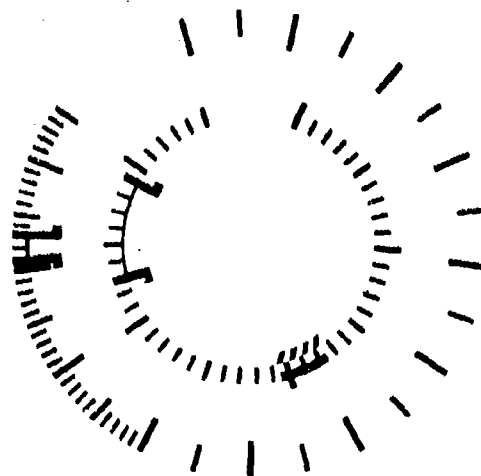
(a)



(b)



(c)



(d)

SEE FIGURE 7 FOR DETAILS

716-3-6

Figure 6
Shape-Coded Caution/Warning Area Dial Marking Configurations
(Scale 1:1)

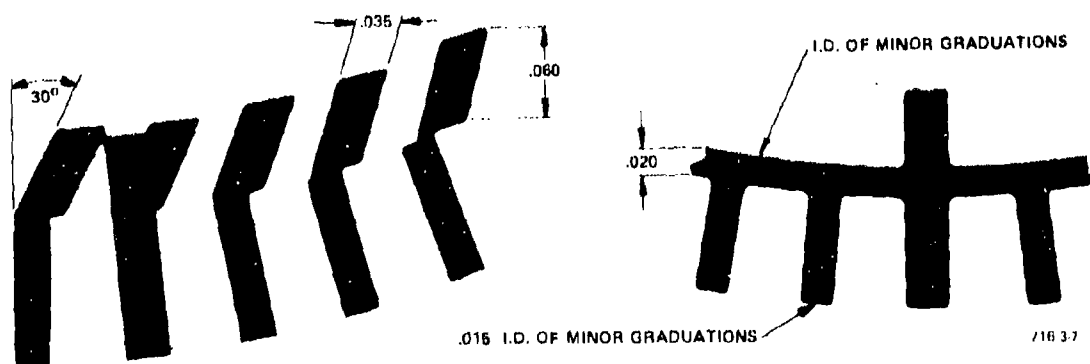
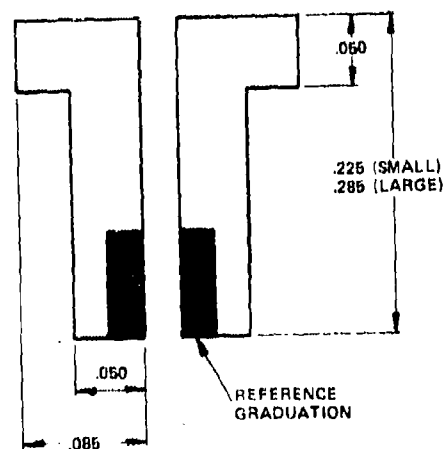
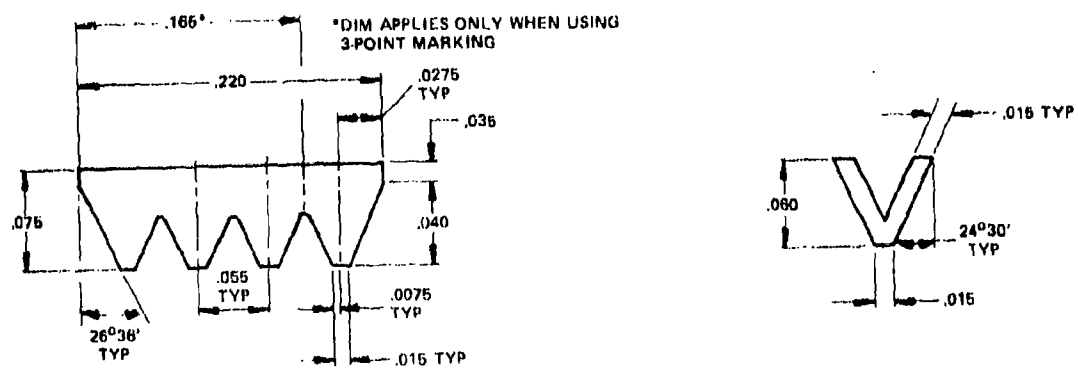
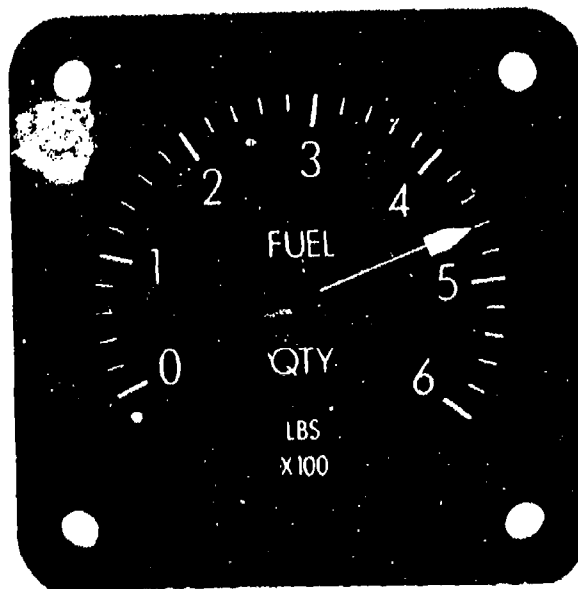
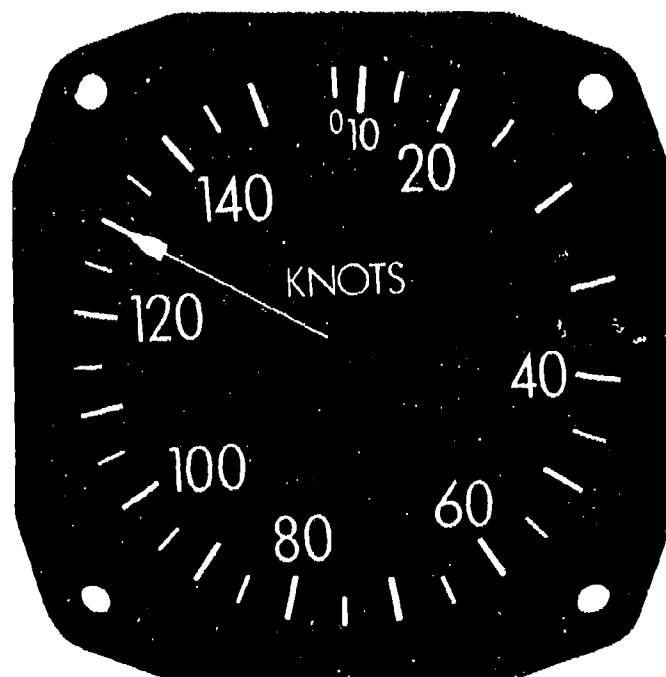


Figure 7
Details of Shape-Coded Dial Markings



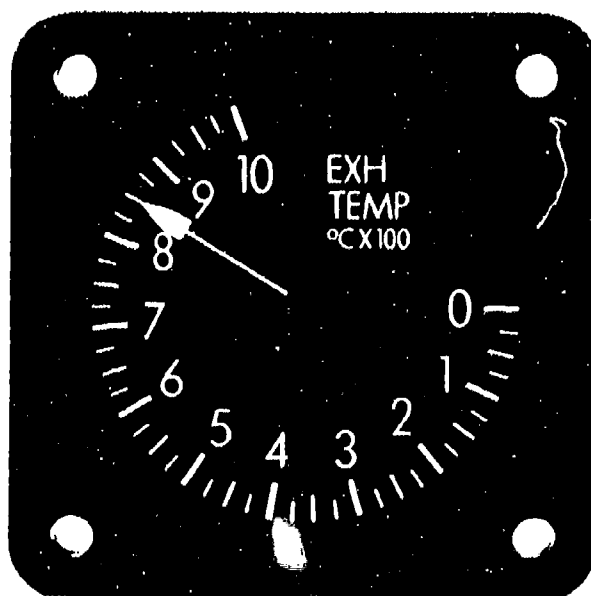
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Figure 8
Two-Inch Fuel Quantity Indicator Mockup



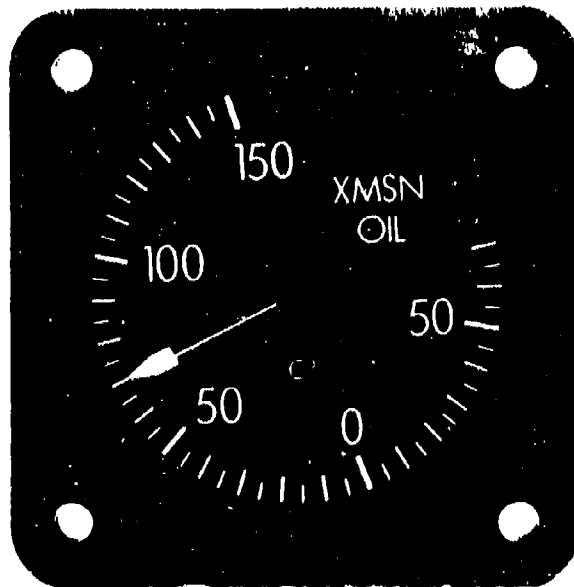
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Figure 9
Three-Inch Airspeed Indicator Mockup



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Figure 10
Two-Inch Exhaust Gas Temperature Indicator Mockup



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Figure 11
Two-Inch Transmission Oil Temperature Indicator Mockup



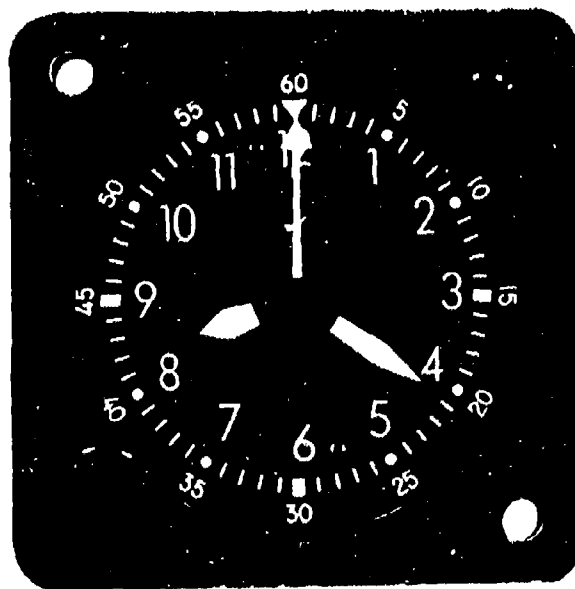
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Figure 12
Two-Inch Transmission Oil Pressure Indicator Mockup



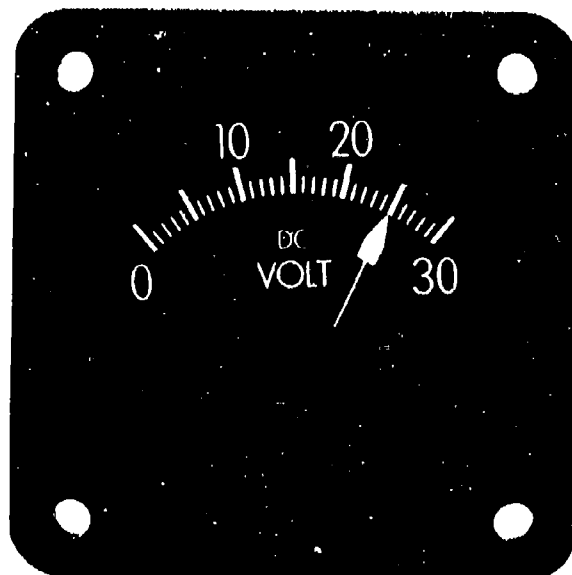
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Figure 13
Two-Inch Fuel Pressure Indicator Mockup



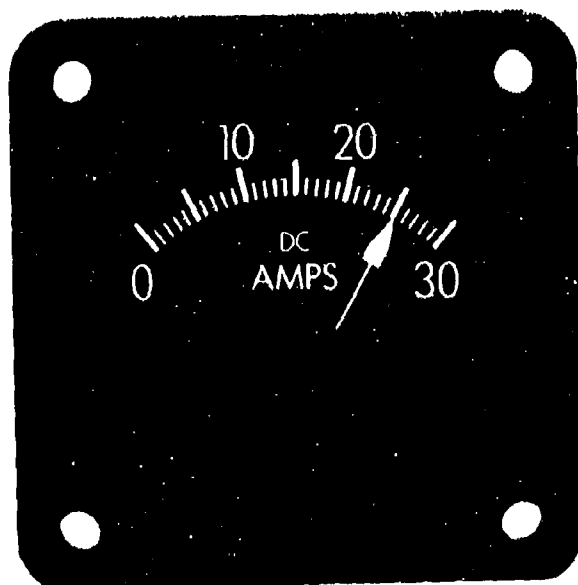
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Figure 14
Two-Inch Modified Clock



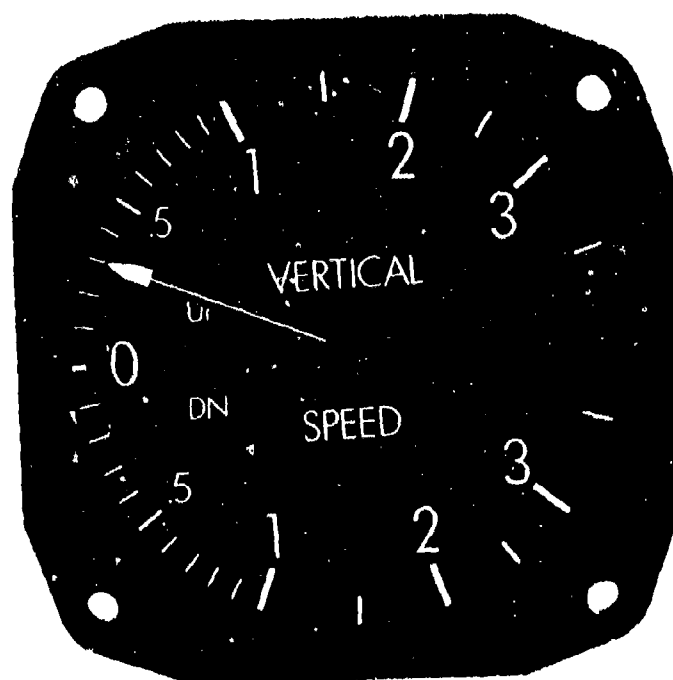
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Figure 15
Two-Inch Voltmeter Hockup



716 3-16

Figure 16
Two-Inch Ammeter Mockup



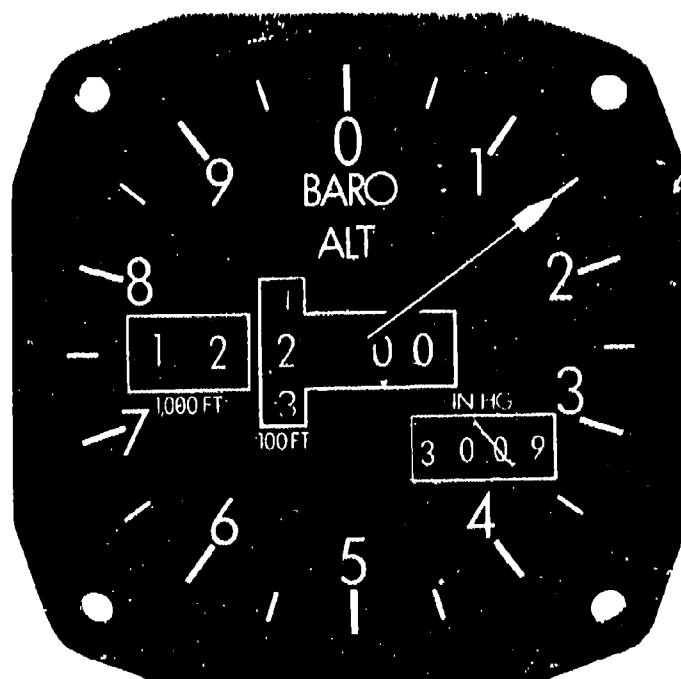
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Figure 17
Three-Inch Vertical Speed Indicator Mockup



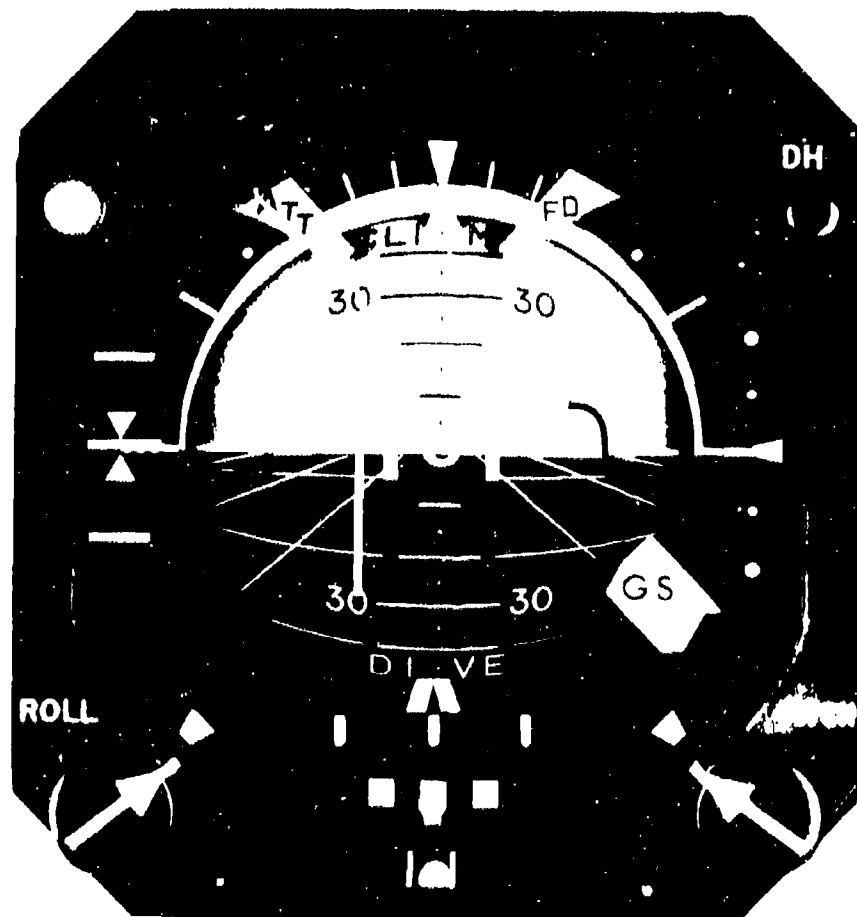
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Figure 18
Three-Inch Torque Meter Modulator



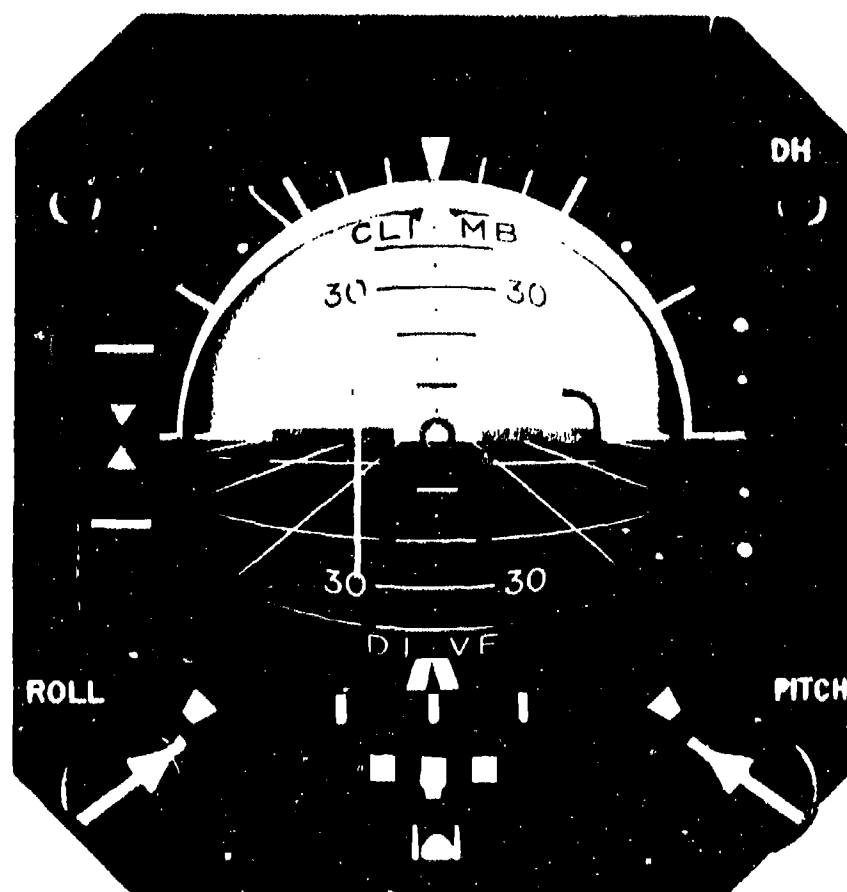
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Figure 19
Three-Inch Barometric Altimeter Mockup



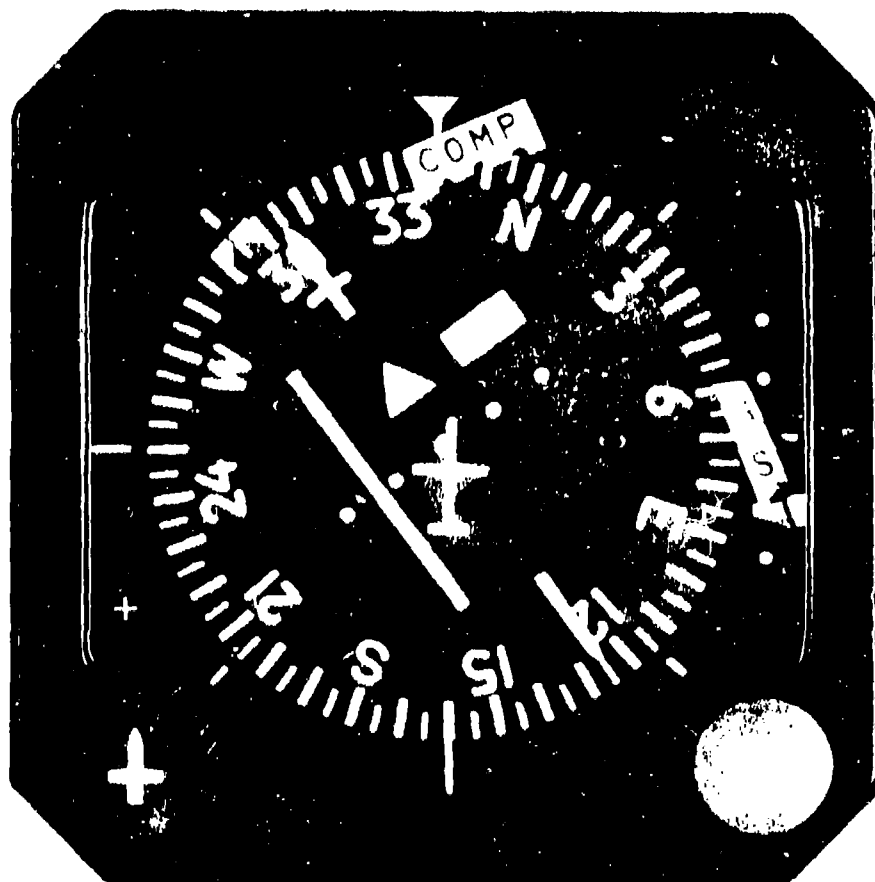
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Figure 20
Five-Inch Attitude Indicator Mockup, Flags in View



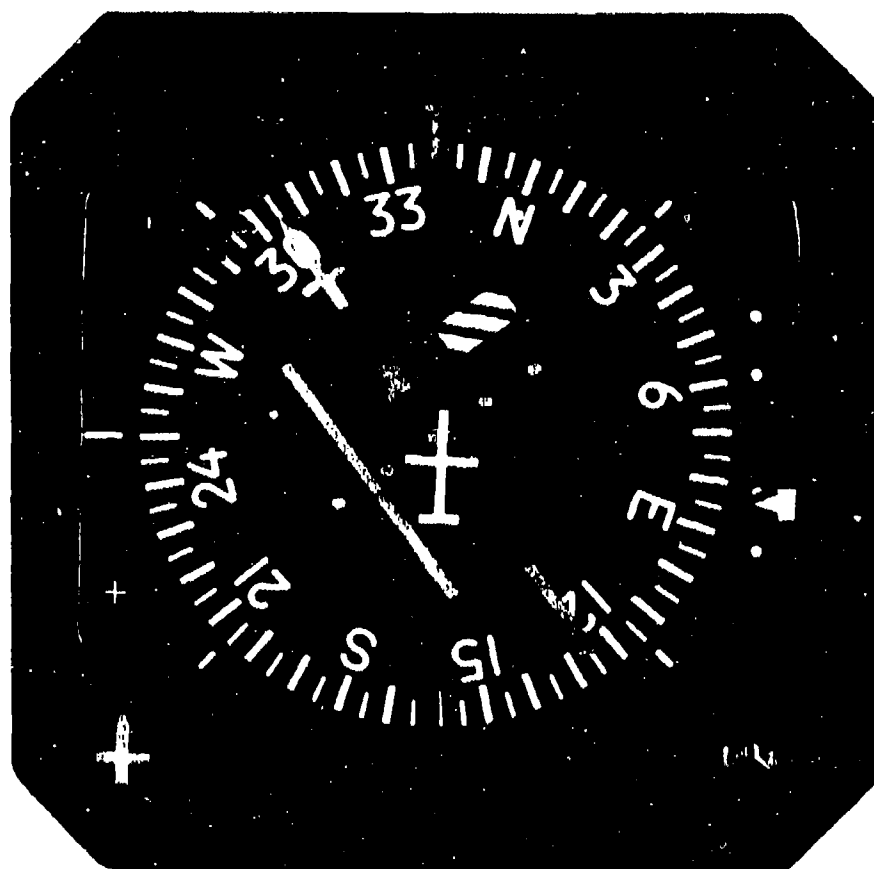
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Figure 21
Five-Inch Attitude Indicator Mockup, Flags Out of View



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Figure 22
Four-Inch Commercial Horizontal Situation
Indicator Mockup, Flags in View



716 3 23

Figure 23
Four-Inch Commercial Horizontal Situation
Indicator Mockup, Flags Out of View

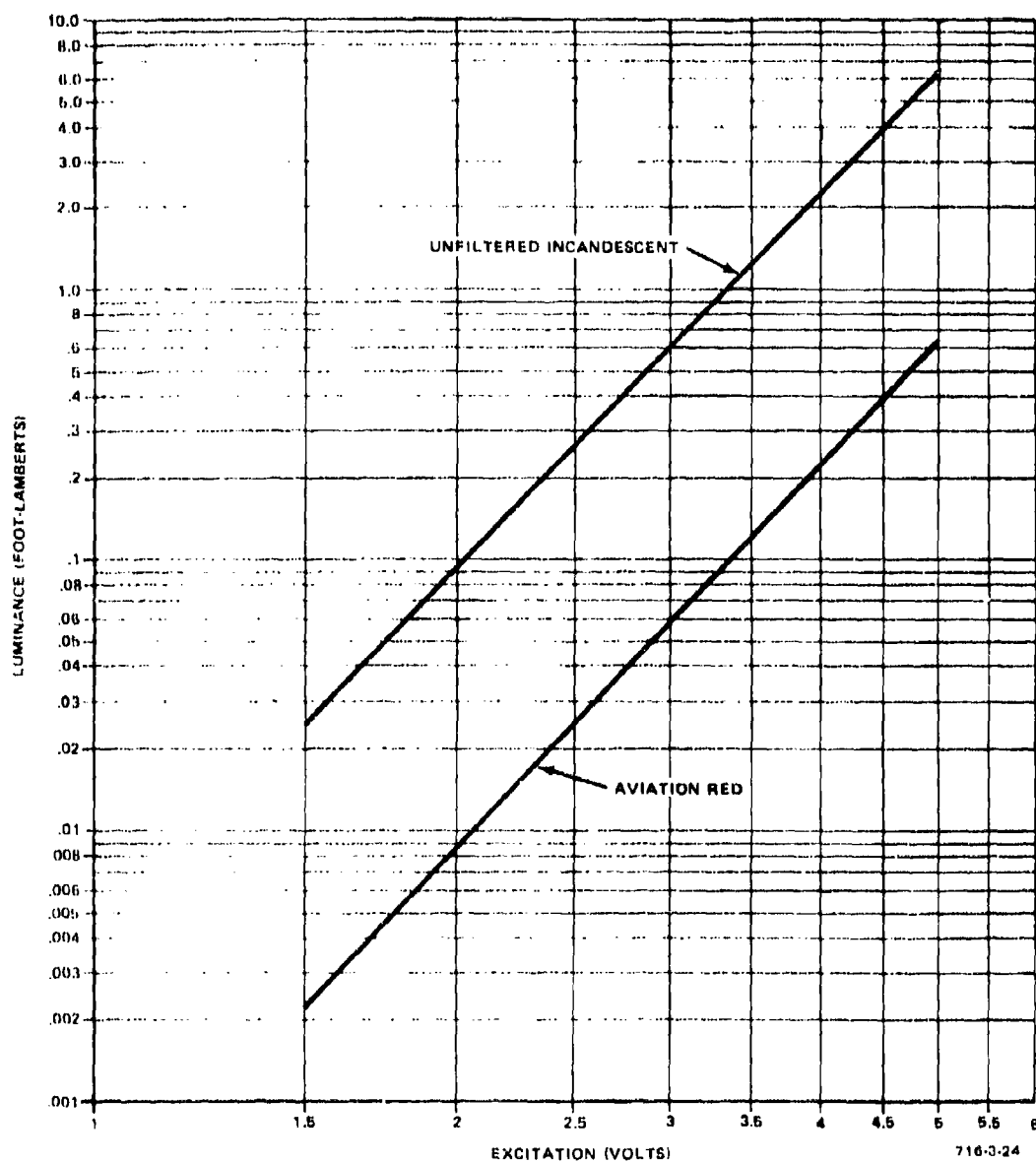


Figure 24
Unfiltered Incandescent Versus Aviation
Red Lighting, 2-Inch Fuel Quantity Indicator

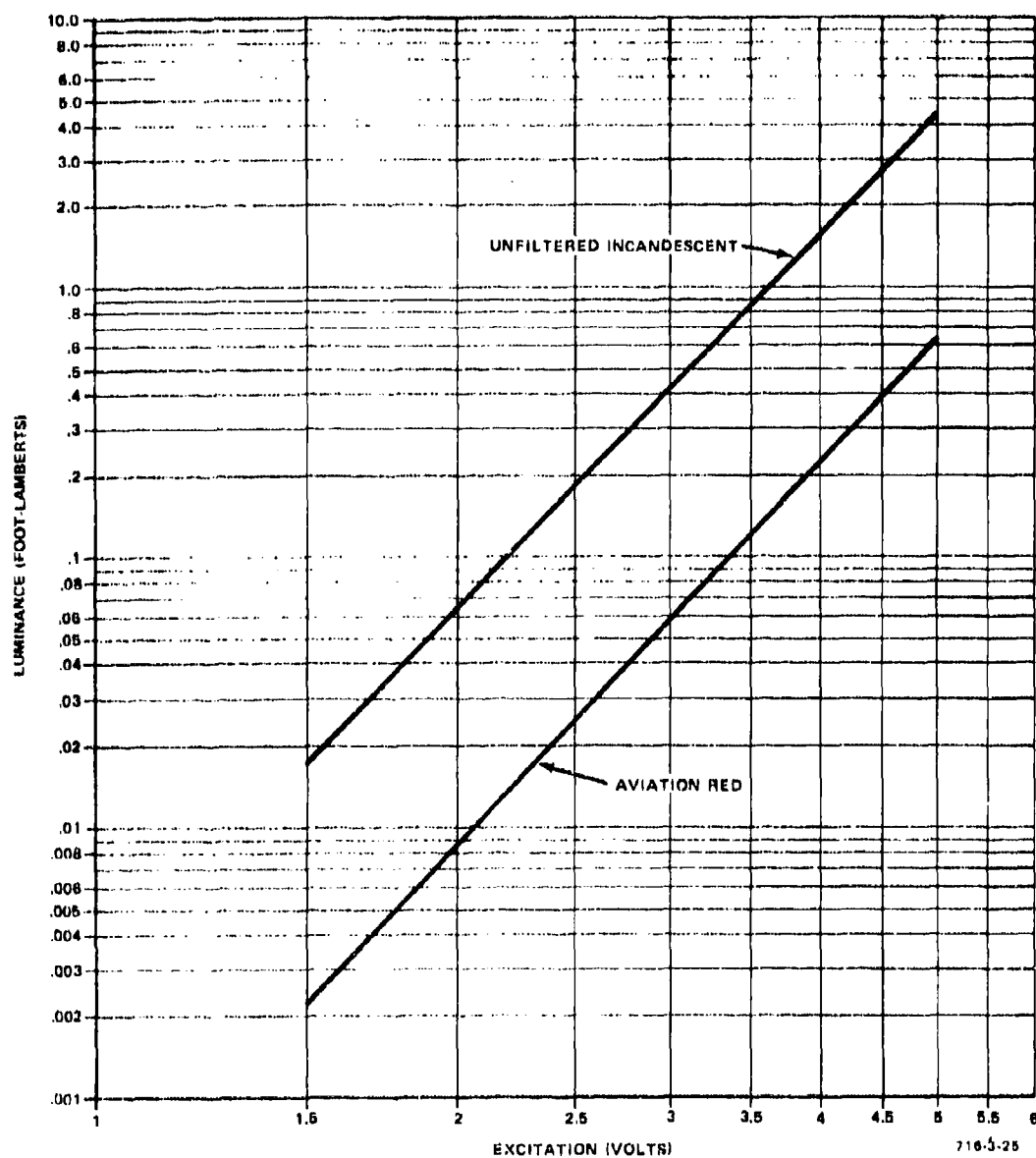


Figure 25
Unfiltered Incandescent Versus Aviation
Red Lighting, 3-Inch Airspeed Indicator

f. Night Vision Goggle Survey (TASK F)

Various types of LED, incandescent, and gas tube readout displays were assembled and viewed with night vision goggles. This survey provided qualitative information for future use when assessing the operational range of these displays and their compatibility with a cockpit designed for night vision goggles.

g. Indicator Mockup Mounting Panel (TASK G)

The panel, shown in Figure 26 with the indicator mockups installed, was fabricated. The Attitude Indicator and Horizontal Situation Indicator mockups are clamp-mounted; all other mockups are bezel-mounted as shown.

h. Indicator Mockup Delivery (TASK H)

All indicator mockups, mounting panel, and associated hardware and equipment were delivered to HEL.

i. Red-Lighted Fluorescent Paint Measurements (TASK I)

A 3-inch mockup, shown in Figure 27, was constructed for these tests. This mockup used the lighting system shown in Figure 1 with Aviation Red lighting. A color strip, viewed through an aperture in a matte black dial mask contained eight different fluorescent paint color samples plus black and white paint samples complying with FED-STD-595 color numbers 37038 and 37875, respectively. Each paint sample was measured for luminance, corrected for color, at 1.5, 2.0, 2.5 and 5.0 volts dc excitation on the lighting system.

These measurements were taken to provide data for future use. The increasing military interest in fluorescent paints is evidenced by the addition of a few fluorescent paint specifications to Revision A of FED-STD-595.

j. Indicator Mockup Lighting Control Assembly (TASK J)

The lighting control assembly shown in Figure 28 was fabricated to control the illumination levels of the indicator mockups shown in Figure 26. It was designed to operate from a 115-volt ac, 60-Hz source. With it, the illumination level of each mockup may be individually controlled and the lighting level of the entire mockup panel assembly may be raised or lowered.

k. Program Final Report (TASK K)

This document is generated in response to this requirement.

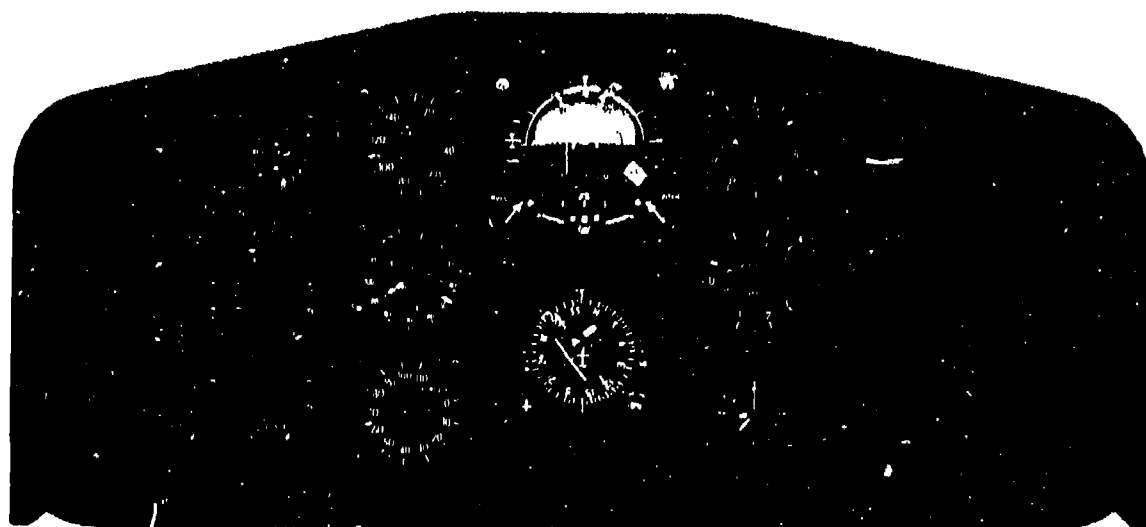
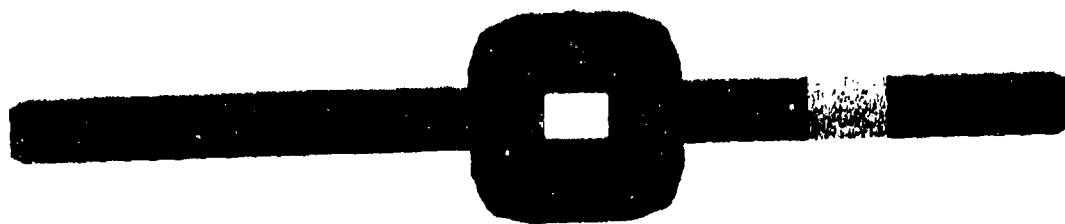


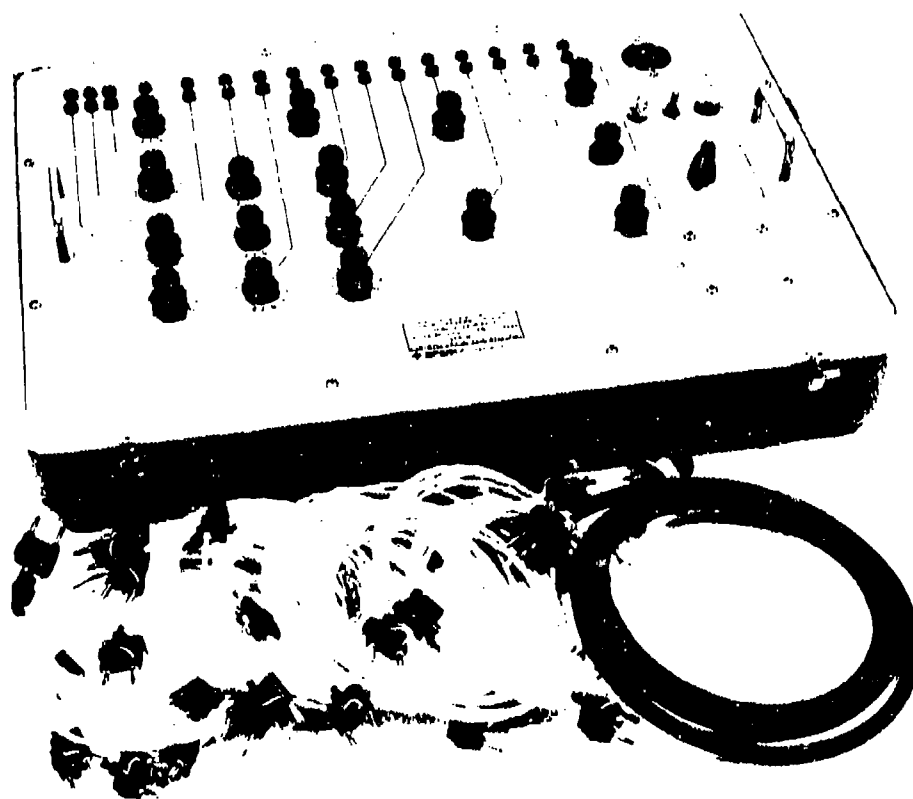
FIG. 26

Figure 26
Indicator Mockup Mounting Panel, Indicator Mockups Installed



716 2 27

Figure 27
Red-Lighted Fluorescent Paint Mockup



716-3-28

Figure 28
Indicator Mockup Lighting Control Assembly

2. CONCLUSIONS AND RECOMMENDATIONS

a. Conclusions

The following conclusions can be drawn from this project:

- The current U.S. Army specifications for indicator integral lighting systems are too loose in the area of brightness uniformity across the dial face.
- Instrument lighting using "eyebrow" or post lighting is inferior to a lighting system integral with and tailored to the specific instrument.
- Red lighting prohibits color coding of displays, and other techniques, such as shape-coded markings, need to be explored to improve dial readability.
- Current instrument marking criteria are inadequate for U.S. Army use.
- A standardized dial marking philosophy needs to be established and applied to all indicators on the aircraft panel.
- The dial marking philosophy to be adopted must be selected using the criteria of readability with both the unaided eye and with night vision goggles. These requirements demand an uncluttered dial, markings and legends readable with the restricted resolution of night vision goggles, and shape-coded warning/caution areas easily recognizable through night vision goggles.
- The total light flux emitted by the panel indicators is independent of the stroke-to-width ratio of the marking scheme used under conditions of comparable readability.
- The current U.S. Army lighting specifications provide an insufficient number of lamp types to design satisfactory integral lighting systems.

- Under Aviation Red lighting, Day-Glo® Aurora Pink, Saturn Yellow, Arc Yellow, Blaze Orange, Lightning Yellow, and Fire Orange are all more visible than matte white.
- Horizon Blue and Signal Green appear almost black under red light.
- The three best colors to use with Aviation Red lighting, in order of preference, are Aurora Pink, Saturn Yellow, and Arc Yellow.
- The visibility of fluorescent paints under red lighting is more than just a function of the amount of red in the color; the deepness or paleness of the color (saturation) is also a consideration.

b. Recommendations

The recommendations are twofold:

(1) Since this project did not address all of the unknowns associated with the design of an optimum indicator panel for U.S. Army missions, further studies should be made of:

- Lighting system voltages and intensities for optimum night vision goggle use.
- Lighting system color to verify the findings of this study.
- Caution/Warning area marking schemes for enhanced recognition with and without night vision goggles.
- Individual dial marking requirements to remove clutter for night vision goggle readability while retaining readability accuracy.
- Integration of LED, incandescent and glow discharge (gas tube) displays into the cockpit.

(2) Incorporate the results of this program, and others, in new or revised specifications for U.S. Army flight indicators. Specific recommendations are:

- Revise integral lighting specifications to require that the standard deviation of the brightness readings of a selected number of uniformly distributed markings not exceed some percentage of the mean. The selected markings would have to be determined by the individual display; the number of markings selected for a voltmeter, for example, would probably be different than the number selected for an attitude indicator. The specified percentage deviation from the mean requires a cost-effectiveness study for each specific indicator display.
- Revise integral lighting specifications to permit the use of MS90451 and MS90452 lamps.
- Require an anti-reflection coating in accordance with MIL-C-14806 on all optical glass-to-air interfaces in U.S. Army aircraft panel indicators.
- Require an integral lighting system in all U.S. Army aircraft panel indicators.
- Permit the use of a Prime Standard in U.S. Army indicator specifications in a manner similar to that described in paragraphs 3.12 and 4.6.21 of MIL-I-27193 and paragraphs 3.11.4 and 4.6.14 of MIL-A-27623.
- Tighten the tolerance on the voltage used to measure a lighting system by an order of magnitude. MIL-L-25467, for example, specifies measuring lighting characteristics at $5.00 \pm .10$ volt; this should be changed to $5.00 \pm .01$ volt.
- Plastic lighting wedges and light trap wedges should not be used in U.S. Army indicators at the present state of fabrication and coating technology.
- If colored fluorescent paints are used in Aviation Red-illuminated indicators, Day-Glo® Aurora Pink, Saturn Yellow, or Arc Yellow are the recommended colors.

SECTION III

DETAILED TASK ACTIVITIES

1. LIGHTING SYSTEM STUDY (TASKS A and B)

The initial step in this program was the selection of an indicator lighting system to be used throughout the program.

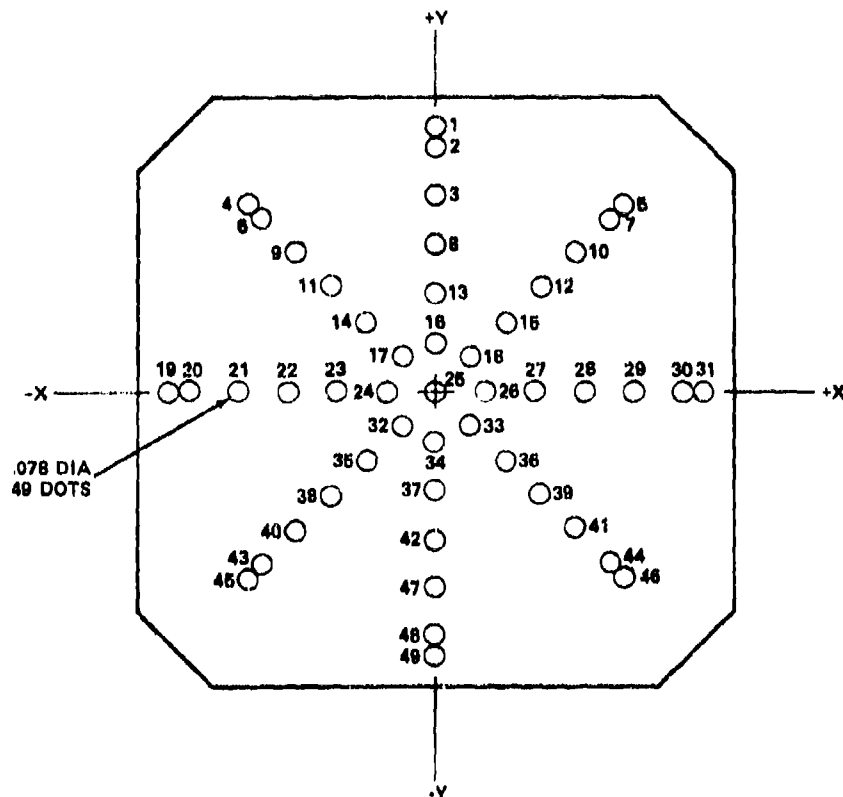
a. Task Activities

Five unfiltered incandescent white indicator lighting systems representing current production units were assembled for comparative evaluation. All five systems were fitted with the same dial face consisting of a pattern of matte white painted dots, FED-STD-595 Color No. 37875, on a flat black background, FED-STD-595 Color No. 37038. This dial face is shown in Figure 29. All lighting systems were for a nominal 3-inch indicator. The five systems were:

System A: Spherical-Plano per SFS (Sperry Flight Systems) 4013149 - This system is similar to that shown in Figure 1 except that the lamps are T-1 (MS90451) instead of T-3/4 (MS90452), the two glass components have the off-axis spherical surface shown in Figure 30, and the lamps, instead of being housed in tubes, are secured flush to a printed wiring board placed in contact with the inner surface (toward the dial) of the lighting wedge glass. Further, this system did not use a separate cover glass; the light trap wedge was the bezel glass.

System B: Plano-Plano per SFS C-6E Indicator - System B is also similar to that shown in Figure 1 except that the lamps are size T-1 (MS24367), are housed in a monolithic light block instead of tubes, and are placed in the shrouded recesses in the lighting wedge glass shown in Figure 31. The light trap wedge glass has the same configuration as that shown in Figure 1. Further, this system did not use a separate cover glass; the light trap wedge was the bezel glass.

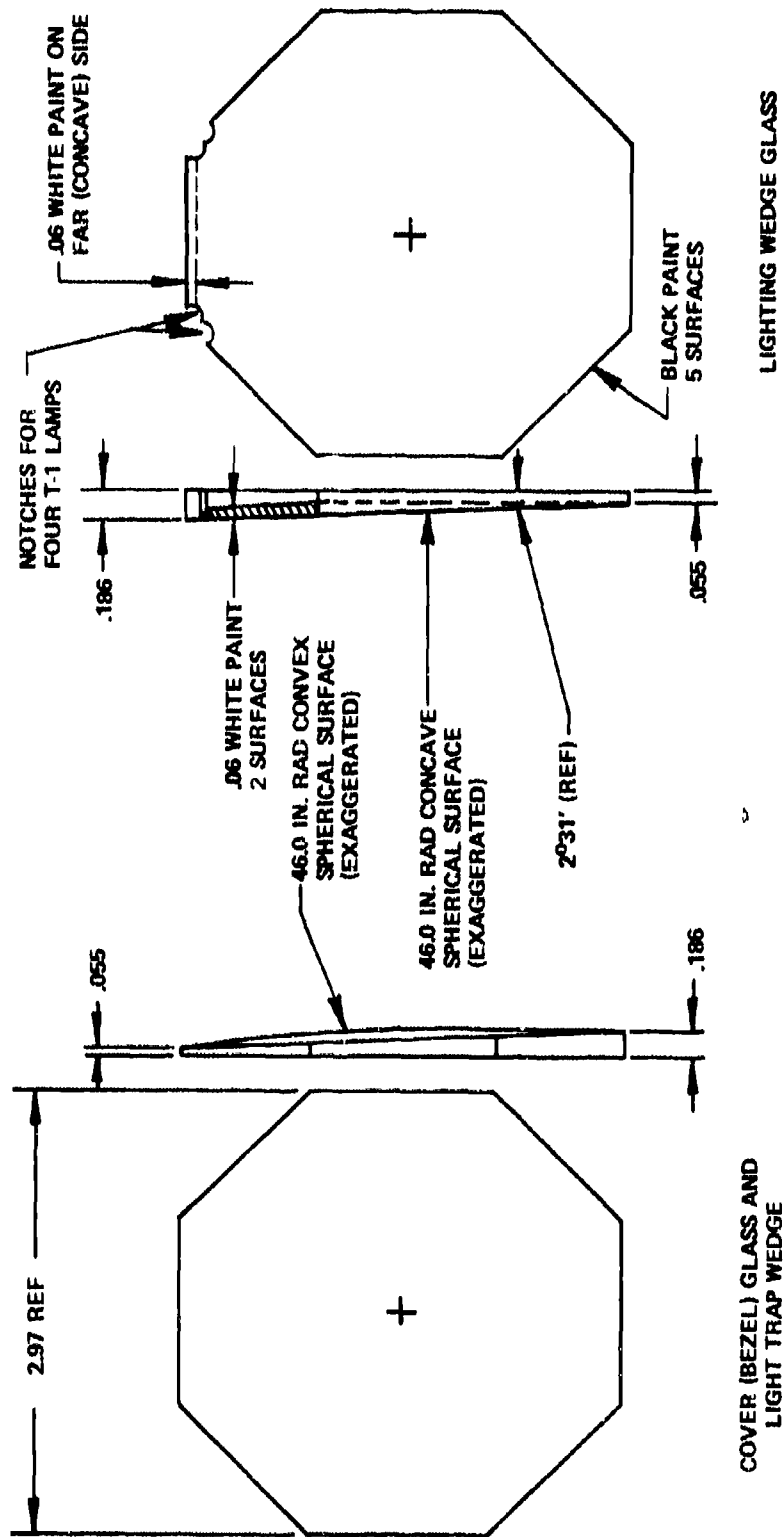
System C: Hensleigh per SFS 4003330 - This is a proprietary system covered by Patent No. 3,246,133, Illuminating System, invented by Robert H. Hensleigh. The lighting wedge and light trap wedge are usually made of a clear plastic material and supplied by the vendor as an assembled matched set. This lighting system consisted of this assembled matched set behind a .070-inch thick cover glass and illuminated with two T-3/4 lamps (MS90452).



DOT LOCATION TABLE					
DOT	X	Y	DOT	X	Y
1	.000	1.350	26	.250	.000
2	.000	1.250	27	.500	.000
3	.000	1.000	28	.750	.000
4	-.955	.955	29	1.000	.000
5	.955	.955	30	1.250	.000
6	-.884	.884	31	1.350	.000
7	.884	.884	32	-.177	-.177
8	.000	.750	33	.177	-.177
9	-.707	.707	34	.000	-.250
10	.707	.707	35	-.354	-.354
11	-.530	.530	36	.354	-.354
12	.530	.530	37	.000	-.500
13	.000	.500	38	-.530	-.530
14	-.354	.354	39	.530	-.530
15	.354	.354	40	-.707	-.707
16	.000	.250	41	.707	-.707
17	-.177	.177	42	.000	-.750
18	.177	.177	43	-.884	-.884
19	-1.350	.000	44	.884	-.884
20	-1.250	.000	45	-.955	-.955
21	-1.000	.000	46	.955	-.955
22	-.750	.000	47	.000	-1.000
23	-.500	.000	48	.000	-1.250
24	-.250	.000	49	.000	-1.350
25	.000	.000			

718-3-20

Figure 29
Lighting Evaluation Dial Face



716-3-30

Figure 30
Spherical-Plano Lighting System Per SFS4013149
(System A)

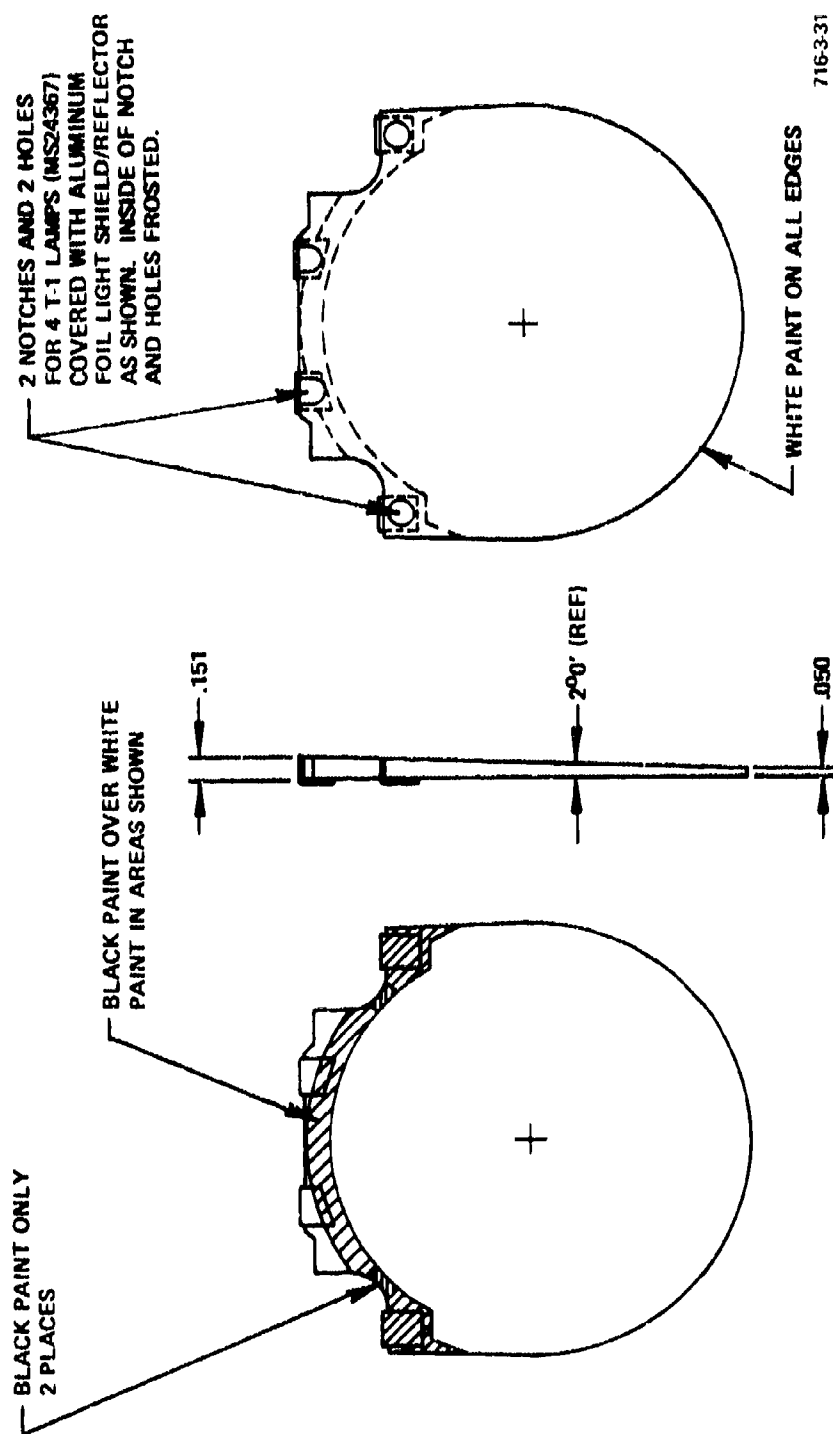


Figure 31
Lighting Wedge Glass, Plano-Plano
System Per SFS C-6E Indicator (System B)

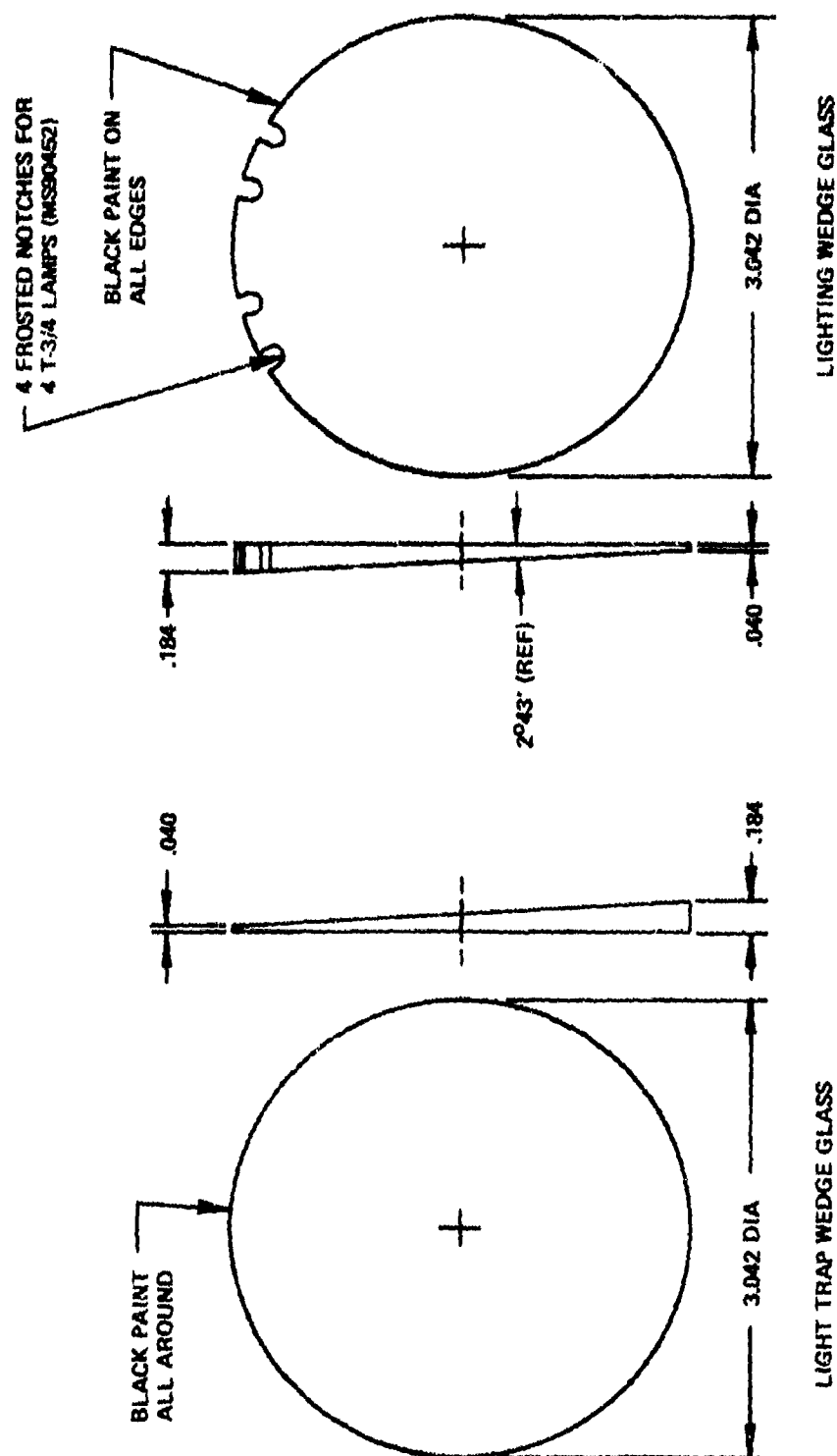
System D: Plano-Plano per INSCO 109 System - This is the system shown in Figure 1. It was adapted from a lighting system obtained from Instrument Specialties Co., Inc. (INSCO), Federal Manufacturer's Code No. 34641. The lighting wedge and light trap wedge glass are detailed in Figure 32.

System E: Hensleigh INSCO Add-On System - The same proprietary lighting system used in System C forms the basis of System E. In System E, however, the assembled matched set of wedges is packaged together with the lamps in a bezel to produce a non-repairable bezel/cover glass/lighting system assembly. This assembly is designed to be secured to a flange on the front of an open indicator case directly in front of the indicator dial and pointer presentation. Electrical connections to the lighting system are through a 2-conductor cable integral with the bezel/lighting assembly and external to the indicator case.

The light measurement procedure consisted of setting the excitation voltage on System A to 1.5 volts dc and measuring the illuminance, in footcandles, emitted from the display at a distance of 28 inches in front of the mockup. This illuminance was then recorded and the excitation voltage changed to 4.75 volts dc. The illuminance at this voltage was also recorded. The excitation voltages on all lighting systems were then adjusted to produce these same values of illuminance, and the required voltages recorded. Using the excitation voltages thus determined, luminance readings, in footlamberts, were taken on each dot on the display. This data is shown in Figure 33. The term UNAVAILABLE in Figure 33 denotes that either the mockup dial aperture or the dial mounting screws obscured the noted points.

The mockup excitation voltage was checked before each reading shown in Figure 33 and the photometer calibration was verified before each column of data was obtained. The readings were taken with a 20-minute aperture on the photometer. This gave a measurement of luminance averaged over an approximately .020-inch diameter spot.

Calculations of the mean and standard deviations for this data are shown in Table 2.



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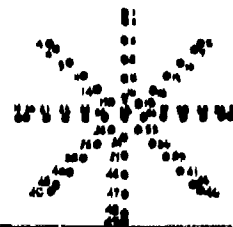
Figure 32
Lighting Wedge and Light Trap Wedge
Glass, Plano-Plano Per INSCD 109 System (System D)



TASK 1 - LIGHTING SYSTEM EVALUATION
CONTRACT NO. DAAG01-74-C-0287 (P1)
(UNFILTERED INCANDESCENT WHITE LIGHTING)

EQUIPMENT

PHOTOMETER: Pritchard, Model 1980/OPPL, Ser. A256
 CONTROL CONSOLE: Pritchard, Model 1980/CDSP1, Ser. A256
 COSINE INTEGRATOR: Photo Research, Model CR-100, Ser. A256
 LENS (Luminance Measurements): Spectar LP, Ser. A256
 VOLTMETER: Hewlett-Packard Model 3440A, Ser. 617-06915



FOOT-LAMBERTS													22		
SYSTEM	SPHERICAL-PLANO PER SFS 4013119			PLANO-PLANO PER SFS C-38 IND.			HENSELIGH PER SFS 4003330			PLANO-PLANO PER INSCO 109 SYSTEM			HENSELIGH PER INSCO ADD-ON SYSTEM		
DATE:	12 MAR 76			12 MAR 76			12 MAR 76			2 APR 76			13 MAR 76		
TECH:	R. STROCK			R. STROCK			R. STROCK			R. STROCK			R. STROCK		
FT-CANDLES:	1.5V	4.35V	1.61V	4.35V	1.84V	5.69V	1.48V	4.33V	2.11V	6.98V	fc	fc	fc	fc	
VOLTS:	1.5V	4.35V	1.61V	4.35V	1.84V	5.69V	1.48V	4.33V	2.11V	6.98V	V	V	V	V	
POINT	1	.0021 .57	UNAVAILABLE	UNAVAILABLE	.0021 .57	UNAVAILABLE	.0021 .57	UNAVAILABLE	.0021 .57	UNAVAILABLE					
2	.013 3.47	.069 9.24	.0021 .57	.0021 .57	.0021 .57	.0021 .57	.0021 .57	.0021 .57	.0021 .57	.0021 .57					
3	.011 5.45	.013 3.61	.016 2.65	.016 2.65	.016 2.65	.016 2.65	.016 2.65	.016 2.65	.016 2.65	.016 2.65					
4	.016 5.76	UNAVAILABLE	.006 .808	.006 .808	.014 3.55	.010 3.96	.014 3.55	.010 3.96	.014 3.55	.010 3.96					
5	.016 5.68	UNAVAILABLE	.006 .808	.006 .808	.044 10.18	.027 4.80	.044 10.18	.027 4.80	.044 10.18	.027 4.80					
6	.026 6.71	.077 11.21	.005 .802	.010 3.01	.020 3.13	.021 3.19	.020 3.13	.021 3.19	.020 3.13	.021 3.19					
7	.014 5.15	.072 11.03	.007 .72	.013 3.22	.018 2.88	.012 3.06	.018 2.88	.012 3.06	.018 2.88	.012 3.06					
8	.039 3.47	.011 3.44	.012 3.06	.018 2.88	.012 3.06	.018 2.88	.012 3.06	.018 2.88	.012 3.06	.018 2.88					
9	.031 5.86	.016 4.01	.007 1.10	.016 2.42	.007 1.10	.016 2.42	.007 1.10	.016 2.42	.007 1.10	.016 2.42					
10	.016 5.66	.015 3.83	.008 1.14	.012 3.80	.008 1.14	.012 3.80	.008 1.14	.012 3.80	.008 1.14	.012 3.80					
11	.046 7.41	.021 3.31	.010 1.64	.019 1.96	.010 1.64	.019 1.96	.010 1.64	.019 1.96	.010 1.64	.019 1.96					
12	.036 7.74	.010 3.02	.011 1.76	.020 3.13	.011 1.76	.020 3.13	.011 1.76	.020 3.13	.011 1.76	.020 3.13					
13	.046 7.73	.013 3.88	.011 1.87	.021 3.19	.011 1.87	.021 3.19	.011 1.87	.021 3.19	.011 1.87	.021 3.19					
14	.046 7.66	.013 3.80	.011 1.88	.021 3.30	.011 1.88	.021 3.30	.011 1.88	.021 3.30	.011 1.88	.021 3.30					
15	.048 8.06	.021 3.38	.012 2.04	.021 3.27	.012 2.04	.021 3.27	.012 2.04	.021 3.27	.012 2.04	.021 3.27					
16	.054 11.33	.016 3.83	.012 2.08	.021 3.41	.012 2.08	.021 3.41	.012 2.08	.021 3.41	.012 2.08	.021 3.41					
17	.080 10.49	.018 3.90	.012 1.94	.023 3.46	.012 1.94	.023 3.46	.012 1.94	.023 3.46	.012 1.94	.023 3.46					
18	.080 10.51	.018 3.88	.012 2.02	.022 3.36	.012 2.02	.022 3.36	.012 2.02	.022 3.36	.012 2.02	.022 3.36					
19	.019 6.15	UNAVAILABLE	.007 1.38	.020 4.56	.007 1.38	.020 4.56	.007 1.38	.020 4.56	.007 1.38	.020 4.56					
20	.019 6.17	.009 8.95	.010 1.56	.027 4.11	.010 1.56	.027 4.11	.010 1.56	.027 4.11	.010 1.56	.027 4.11					
21	.023 7.01	.012 4.48	.010 1.61	.023 3.46	.010 1.61	.023 3.46	.010 1.61	.023 3.46	.010 1.61	.023 3.46					
22	.039 8.16	.021 3.30	.011 1.68	.023 3.52	.011 1.68	.023 3.52	.011 1.68	.023 3.52	.011 1.68	.023 3.52					
23	.043 9.00	.011 3.47	.011 1.77	UNAVAILABLE	.011 1.77	UNAVAILABLE	.011 1.77	UNAVAILABLE	.011 1.77	UNAVAILABLE					
24	.047 9.78	.016 3.93	.012 1.90	.024 3.59	.012 1.90	.024 3.59	.012 1.90	.024 3.59	.012 1.90	.024 3.59					
25	.063 11.05	.017 4.11	.012 1.96	UNAVAILABLE	.012 1.96	UNAVAILABLE	.012 1.96	UNAVAILABLE	.012 1.96	UNAVAILABLE					
26	.047 9.79	.012 3.64	.012 1.93	.023 3.80	.012 1.93	.023 3.80	.012 1.93	.023 3.80	.012 1.93	.023 3.80					
27	.038 8.12	.012 3.32	.011 1.93	UNAVAILABLE	.011 1.93	UNAVAILABLE	.011 1.93	UNAVAILABLE	.011 1.93	UNAVAILABLE					
28	.033 6.91	.012 3.32	.010 1.63	.023 3.39	.010 1.63	.023 3.39	.010 1.63	.023 3.39	.010 1.63	.023 3.39					
29	.018 6.07	.018 4.33	.010 1.46	.022 3.40	.010 1.46	.022 3.40	.010 1.46	.022 3.40	.010 1.46	.022 3.40					
30	.016 5.84	.043 9.78	.009 1.30	.016 4.03	.009 1.30	.016 4.03	.009 1.30	.016 4.03	.009 1.30	.016 4.03					
31	.019 6.08	UNAVAILABLE	.008 1.22	.019 4.61	.008 1.22	.019 4.61	.008 1.22	.019 4.61	.008 1.22	.019 4.61					
32	.047 9.77	.018 4.35	.012 1.84	.025 3.71	.012 1.84	.025 3.71	.012 1.84	.025 3.71	.012 1.84	.025 3.71					
33	.046 9.66	.016 3.91	.012 1.79	.025 3.73	.012 1.79	.025 3.73	.012 1.79	.025 3.73	.012 1.79	.025 3.73					
34	.045 9.39	.018 3.90	.012 1.81	.020 4.14	.012 1.81	.020 4.14	.012 1.81	.020 4.14	.012 1.81	.020 4.14					
35	.043 8.96	.016 3.82	.011 1.70	.025 3.70	.011 1.70	.025 3.70	.011 1.70	.025 3.70	.011 1.70	.025 3.70					
36	.041 8.49	.017 4.08	.011 1.69	.026 3.98	.011 1.69	.026 3.98	.011 1.69	.026 3.98	.011 1.69	.026 3.98					
37	.041 8.48	.018 4.18	.010 1.61	.026 3.96	.010 1.61	.026 3.96	.010 1.61	.026 3.96	.010 1.61	.026 3.96					
38	.039 8.17	.016 3.79	.010 1.56	.027 4.10	.010 1.56	.027 4.10	.010 1.56	.027 4.10	.010 1.56	.027 4.10					
39	.037 7.75	.017 4.14	.010 1.55	.026 3.97	.010 1.55	.026 3.97	.010 1.55	.026 3.97	.010 1.55	.026 3.97					
40	.038 7.17	.013 5.00	.010 1.53	.028 4.28	.010 1.53	.028 4.28	.010 1.53	.028 4.28	.010 1.53	.028 4.28					
41	.030 6.34	.015 5.28	.010 1.52	.027 4.13	.010 1.52	.027 4.13	.010 1.52	.027 4.13	.010 1.52	.027 4.13					
42	.038 8.01	.019 4.38	.009 1.47	.026 4.11	.009 1.47	.026 4.11	.009 1.47	.026 4.11	.009 1.47	.026 4.11					
43	.033 6.71	.061 9.18	.010 1.62	.023 5.08	.010 1.62	.023 5.08	.010 1.62	.023 5.08	.010 1.62	.023 5.08					
44	.027 5.57	.061 9.16	.009 1.44	.023 4.87	.009 1.44	.023 4.87	.009 1.44	.023 4.87	.009 1.44	.023 4.87					
45	.030 6.24	UNAVAILABLE	UNAVAILABLE	.026 5.51	.013 3.16	.013 3.16	.013 3.16	.013 3.16	.013 3.16	.013 3.16					
46	.016 5.48	UNAVAILABLE	.006 1.12	.024 5.31	.016 3.63	.016 3.63	.016 3.63	.016 3.63	.016 3.63	.016 3.63					
47	.038 7.46	.018 5.25	.009 1.43	.028 4.46	.016 3.66	.016 3.66	.016 3.66	.016 3.66	.016 3.66	.016 3.66					
48	.010 6.34	.054 8.15	.009 1.41	.024 5.18	.027 3.71	.027 3.71	.027 3.71	.027 3.71	.027 3.71	.027 3.71					
49	.018 5.98	UNAVAILABLE	.009 1.36	.030 4.65	.025 3.51	.025 3.51	.025 3.51	.025 3.51	.025 3.51	.025 3.51					

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Figure 33
 Lighting System Evaluation

TABLE 2
MEAN AND STANDARD DEVIATION CALCULATIONS,
LIGHTING SYSTEM EVALUATION DATA

System		Volts $\bar{X}$, Mean σ , Standard Deviation		N, Number of Points	
A	Without Point 1	1.5v	.0360	.0093	48
		4.75	7.6154	1.8423	
	With Point 1	1.5v	.0353	.0104	49
		4.75v	7.4716	2.0824	
B		1.61v	.0329	.0158	41
		4.78v	5.0195	2.3688	
C		1.84v	.0099	.0026	47
		5.69v	1.5696	.3965	
D	*	1.48v	.0250	.0047	42
		4.33v	3.8405	.7145	
	All Points	1.48v	.0260	.0058	46
		4.33v	4.1339	1.3328	
E		2.21v	.0380	.0212	49
		6.92v	5.3402	2.7803	

* - Without points 1, 2, 5 and 7 (face of lamp housing tube not flush with surface of lighting wedge glass, producing excessive light leakage).

Two additional comments on the data of Figure 33 can be made. First, excessively high excitation voltages are required on System E to produce the same illuminance as the other systems. Secondly, the low luminance readings for a given illuminance level for System C could have been due to a general haze which appears when the lamps are lit and is very difficult to remove. Another contributing factor could be the large amount of stray light produced by System C.

To further evaluate these candidate lighting systems the following factors were considered:

- Amount of stray light produced
- Ease of conversion to other sizes of indicators
- Suitability for antireflection coatings on the optical elements
- Relative production costs
- Power consumption requirements
- Ease of maintenance

This evaluation is shown in Figure 34.

b. Conclusions and Recommendations

It was concluded that System D was the best lighting system to use for the remainder of the project.

The stray light from System D may have been lower than that from some other systems because of the .093-inch added thickness of the cover glass. This added cover glass was used because it was a part of the lighting system design used by INSCO; it was their total design that was being evaluated. This placed the lighting wedge farther back in the mockup than the other lighting systems. This is not normal indicator practice; usually the light trap wedge is the cover glass as well as acting to reduce stray light. Following this more standard practice would reduce the number of glass-to-air surfaces between the viewer and the display from 6 to 4. This would result in at least two benefits:

- Since each glass-to-air surface contributes to reflections which tend to obscure the presentation, even with anti-reflective coatings, this would reduce reflections in this system by 30 percent.

LIGHTING MOCKUP CHARACTERISTICS

CHARACTERISTIC		SYSTEM									
		A		B		C		D		E	
	Volts	4.75V	5.00V	4.75V	5.00V	5.69V	5.00V	4.75V	5.00V	6.92V	5.00V
Stray Light	Top	.14	.17	.81	.71	.21	.12	.018	.03	.15	.045
	Bottom	5.9	7.1	8.8	10.1	13.5	7.9	2.0	3.6	2.8	.81
ft-l.	Right	2.0	2.4	2.3	2.7	7.0	4.2	1.1	1.9	1.4	.42
-Note 1-	Left	2.2	2.7	3.2	3.9	9.4	5.7	.61	1.1	1.2	.35
Ease of Conversion to 2-, 4-, or 5-inch System (1 = easiest)		3		5		4		2		1	
Anti-reflection Coating Suitability		yes		yes		no		yes		no	
Relative Production Costs (estimated), 3-inch system		1.70X		1.88X		1.18X		2.72X		1.00X	
-Note 3-											
Current	2"	.46 A		.46 A		.23 A		.46 A		.23 A	
Req'd m't.	3"	.46 A		.46 A		.23 A		.46 A		.23 A	
@ 5.00V.	4"	.69 A		.69 A		.23 A		.69 A		.23 A	
-Note 4-	5"	.92 A		.92 A		.35 A		.92 A		.35 A	
Maintenance Considerations (Ranking: 1 = easiest to maintain)		Lamp/printed wiring board assembly easily removed from rear of bezel/lighting assembly. Requires partial disassembly of indicator. Rank: 2		Lamp/printed wiring board assembly removable after partial disassembly of indicator. Disassembly more extensive than for System A. Rank: 4		Lamp/printed wiring board assembly removable after partial disassembly of indicator. Disassembly intermediate between Systems A and B. Rank: 3		Lamps individually unsolderable after partial disassembly of indicator. Disassembly intermediate between Systems B and C. Rank: 5		Bezel/lighting system replaceable as a unit without disassembly of indicator. Rank: 1	

NOTES:

1. Stray light was measured at two voltages: the voltage giving uniform illuminance (foot-candles) and at 5.00 volts. Stray light was measured with a Photo Research UB 1/2 photometer, with a supplementary SL-20 lens, aimed at a Kodak R-27 matte-white reflectance card placed parallel with the axis of mockup and adjacent to the appropriate edge of the bezel. The readings covered a spot approximately 0.17 inch diameter. The card was scanned to locate the maximum reading. This procedure is essentially a practical compromise of the procedures given in para. 3.3.7 of MIL-L-25467C, para. 4.5.5.5 of MIL-L-27160C, and para. 5.6.2.1 of SAE ARP 1161.
2. System E is ranked as easiest to convert primarily because a 2-inch system already exists. System B is ranked most difficult because of the complexity of the glass shape. Converting system A would require the availability of commercial glass grinding equipment to develop suitable 2-, 4-, or 5-inch systems; this development would be sub-contracted. System D is a straight-forward design requiring a minimum of experimental work to convert. All systems, except possibly system D, would require a new matched bezel/glass/lamp/paint design to convert to 2-, 4-, or 5-inch systems.
3. Example: System A is 1.70 times the cost of System E. Production cost estimates do not include the cost of any new tooling or fixtures required, for example, for anti-reflection coating of the glass parts; these costs are, within reason, independent of indicator size. Production running costs are likewise reasonably independent of indicator size. Estimates are for a bezel/glass/lighting system assembly.
4. Current requirements are based on the use of .15 Spherical Candle Power lamps, e.g., MS24367-715, MS24515-716, MS90451-7152, or MS90452-7153. Currents for 3-inch systems are actuals for the test units used; currents for 2-, 4-, and 5-inch systems are estimates of the number of lamps which would be required in these systems.

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Figure 34
Lighting Mockup Characteristics

- Removing the cover glass and letting the light trap wedge perform this function would move the display forward by the amount of the thickness of the cover glass. This would increase the display viewing angle.

It was observed that a halo of light is present around the periphery of the display if the edges of the light trap wedge glass and cover glass, if used, are not blackened.

The edges of the lighting wedge glass in System D, shown in Figures 1 and 32, were painted black because this was the paint system used on the vendor's design from which this was derived. The usual practice is to paint the edges of lighting wedge glasses white to increase the back-scatter of light onto the presentation and, hence, increase the efficiency of the lighting system. However, the lighting system for each indicator is tailored to that specific indicator. Many techniques are used, such as judicious use of white and black paint, reflectors, chamfers and notches in the lighting wedge glass, auxiliary light blocks, combinations of wedge and transillumination lighting, etc. Figure 31 shows some of the complexity that can result from tailoring a lighting system to a specific indicator. No attempt was made in this project to optimize any of the lighting systems used. The results are, therefore, not to be construed as the best that can be obtained.

It is recommended that the results of this task be used as the basis for generating lighting specifications suitable for Army aircraft use. The data obtained and the foregoing comments should be borne in mind when generating such specifications.

2. DIAL MARKING STUDY (TASK C)

The purpose of this study was to determine the better of the two contending marking schemes shown in Table 1, page 9, and Figures 2 through 5. A further purpose of this task was to evaluate the caution/warning dial marking schemes shown in Figures 6 and 7.

a. Task Activities

(1) Graduation and Legend Study

This task began with the investigation of the characteristics of various available type fonts for use with indicator dial legends. Twenty-seven fonts were surveyed for stroke-to-height ratio and width-to-height ratio. The results

of this survey are shown in Table 3. Based upon these figures and a subjective evaluation of the fonts, Futura Book and Futura Medium were chosen for use in the dial marking study. These two fonts are shown in Figure 35.

Using these fonts, the dial graduation scheme shown in Table 1, page 9, and the selected lighting system shown in Figure 1, the four indicator mockups shown in Figures 2 through 5 were constructed. All four indicator mockups used Aviation Red lighting. The mockups were then designated A through D as defined in Table 4. The four mockups were then evaluated in the light laboratory using eight subjects and the setup shown in Figure 36.

The eight subjects all had approximately 20/20 uncorrected vision and were dark-adapted for approximately 20 to 25 minutes prior to the tests. One subject was then seated 28 inches from one of the instrument mockups with the illumination intensity at zero and out of view of the remaining subjects in the room. The subject was then asked to gradually increase the lighting intensity, with a control provided, until the pointer positions could be read. After the pointer position readings were verified, the voltage was recorded. This procedure was repeated two more times at different pointer settings for a total of three trials per mockup. This process was repeated for all four mockups for each subject. The mockups were presented to the subjects in the order shown in Figure 37.

Following the establishment of the minimum voltage settings, illuminance measurements, uncorrected for color ratio, were taken at a distance of 28 inches on each mockup at each of the eight average tabulated voltage settings for the eight subjects. These are recorded in Figure 37. A statistical t-test was then performed on the illuminance measurements to determine the statistical significance, if any, between the two marking schemes on the two types of indicators at a .05 significance level. The results of these calculations also are recorded in Figure 37.

Luminance measurements were then made at six selected points on each mockup at excitation voltages of 1.5, 2.0, 2.5, and 5.0 volts. These are recorded in Figure 38.

TABLE 3
CHARACTERISTICS OF REPRESENTATIVE TYPE FONTS

Name	<u>Stroke Height</u>	<u>Width Height</u> (See Note 1)
Univers 39	.05	.22
Futura Light	.06	.73
Univers 45	.07	.61
Univers 49	.08	.25
Univers 47	.08	.40
News Gothic Condensed	.09	.42
News Gothic	.10	.56
Futura Book	.10	.60
Eurostile Light	.11	.73
MS 33558	.12	.61
Eurostile Light Extended	.12	1.12
Univers 59	.13	.37
Futura Medium Condensed	.13	.44
Univers 55	.13	.65
Futura Medium	.13	.74
Univers 53	.13	.90
Univers 57	.15	.48
Univers 65	.19	.72
Futura Demi-Bold	.19	.75
Univers 67	.21	.54
Futura Bold Condensed	.22	.53
Univers 75	.26	.75
Eurostile Bold	.26	.79
Futura Bold	.26	.81
Univers 73	.26	.87
Eurostile Bold Extended	.30	1.17
Univers 83	.32	.94

Note 1: Ratios vary with character; those tabulated are for "7", where available, or for "5" where "7" was not available.

Futura Book
abcdefghijklmnopqrstuvwxyz
ABCDEFGHIJKLMNOPQRSTUVWXYZ
1234567890 (&.,:;!?'"" - *\$¢%/)

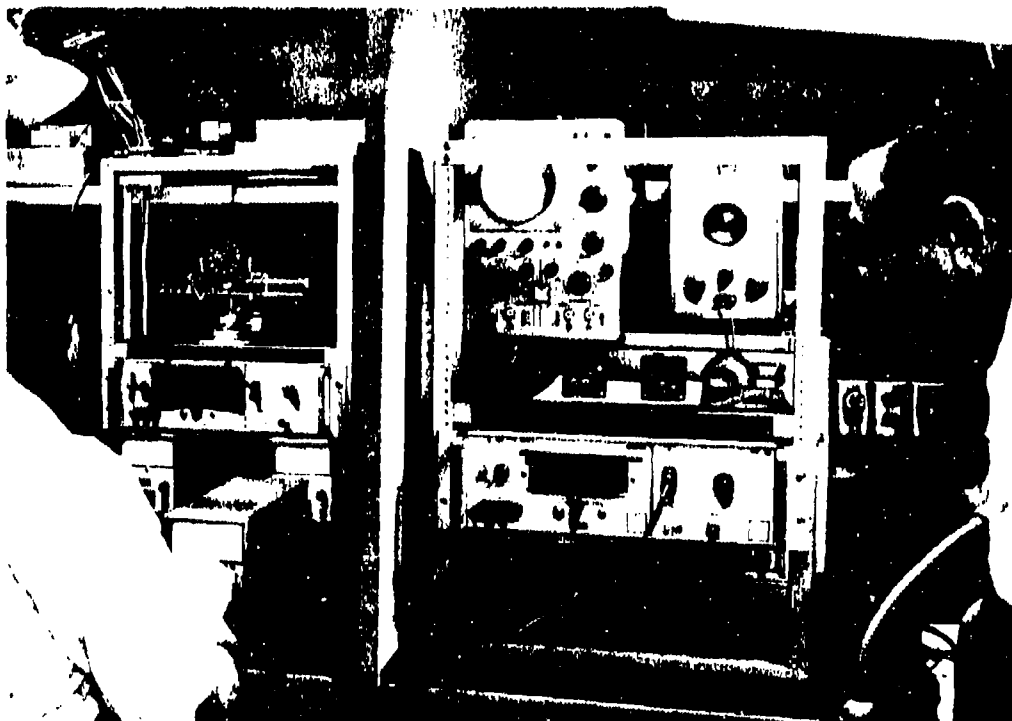
TF 54

Futura Medium
abcdefghijklmnopqrstuvwxyz
ABCDEFGHIJKLMNOPQRSTUVWXYZ
1234567890 (&.,:;!?'"" - *\$¢%/£)

TF 20

716-3-35

Figure 35
Futura Book and Futura Medium Type Fonts



210, 1-16

Figure 36
Graduation and Legend Study Laboratory Setup

THRESHOLD AND ILLUMINANCE MEASUREMENTS

SUBJECT	INSTRUMENT A		INSTRUMENT B		Δf_c	INSTRUMENT C		INSTRUMENT D		Δf_c
	VOLTS	f_c	VOLTS	f_c		VOLTS	f_c	VOLTS	f_c	
NAME: (A)	$V_1 = 2.186$		$V_1 = 2.327$			$V_1 = 1.926$		$V_1 = 2.442$		
DATE: 14 JUL 78	$V_2 = 2.182$	0.63×10^{-5}	$V_2 = 2.332$	0.60×10^{-5}	0.03	$V_2 = 1.976$	0.41×10^{-5}	$V_2 = 2.312$	0.46×10^{-5}	-0.05
INSTRUMENT ORDER:	$V_3 = 2.030$		$V_3 = 2.457$			$V_3 = 1.982$		$V_3 = 2.282$		
A, B, C, D	AVG: 2.163		AVG: 2.372			AVG: 1.961		AVG: 2.335		
NAME: (B)	$V_1 = 2.031$		$V_1 = 2.540$			$V_1 = 2.007$		$V_1 = 2.434$		
DATE: 16 JUL 78	$V_2 = 2.046$	0.58×10^{-5}	$V_2 = 2.163$	0.60×10^{-5}	-0.02	$V_2 = 1.821$	0.38×10^{-5}	$V_2 = 2.215$	0.42×10^{-5}	-0.04
INSTRUMENT ORDER:	$V_3 = 2.049$		$V_3 = 2.366$			$V_3 = 1.891$		$V_3 = 2.247$		
B, C, D, A	AVG: 2.042		AVG: 2.390			AVG: 1.906		AVG: 2.319		
NAME: (C)	$V_1 = 2.080$		$V_1 = 2.460$			$V_1 = 1.823$		$V_1 = 2.182$		
DATE: 18 JUL 78	$V_2 = 2.128$	0.63×10^{-5}	$V_2 = 2.461$	0.66×10^{-5}	-0.03	$V_2 = 1.803$	0.32×10^{-5}	$V_2 = 2.072$	0.32×10^{-5}	0
INSTRUMENT ORDER:	$V_3 = 2.129$		$V_3 = 2.380$			$V_3 = 1.785$		$V_3 = 2.129$		
C, D, A, B	AVG: 2.102		AVG: 2.420			AVG: 1.794		AVG: 2.128		
NAME: (D)	$V_1 = 1.897$		$V_1 = 2.068$			$V_1 = 1.851$		$V_1 = 1.798$		
DATE: 18 JUL 78 (A, B, C)	$V_2 = 1.930$	0.44×10^{-5}	$V_2 = 2.068$	0.38×10^{-5}	0.06	$V_2 = 1.638$	0.16×10^{-5}	$V_2 = 1.749$	0.13×10^{-5}	0.03
INSTRUMENT ORDER:	$V_3 = 1.816$		$V_3 = 1.990$			$V_3 = 1.686$		$V_3 = 1.838$	(CALL)	
D, A, B, C	AVG: 1.881		AVG: 2.042			AVG: 1.625		AVG: 1.795		
NAME: (E)	$V_1 = 1.768$		$V_1 = 1.997$			$V_1 = 1.695$		$V_1 = 1.983$		
DATE: 14 JUL 78	$V_2 = 1.889$	0.36×10^{-5}	$V_2 = 2.030$	0.34×10^{-5}	0	$V_2 = 1.668$	0.28×10^{-5}	$V_2 = 1.835$	0.27×10^{-5}	0.01
INSTRUMENT ORDER:	$V_3 = 1.766$		$V_3 = 2.010$			$V_3 = 1.710$		$V_3 = 1.892$		
A, B, C, D	AVG: 1.808		AVG: 2.012			AVG: 1.691		AVG: 1.897		
NAME: (F)	$V_1 = 1.909$		$V_1 = 2.340$			$V_1 = 1.985$		$V_1 = 2.383$		
DATE: 18 JUL 78	$V_2 = 2.046$	0.49×10^{-5}	$V_2 = 2.161$	0.54×10^{-5}	-0.06	$V_2 = 1.894$	0.36×10^{-5}	$V_2 = 2.167$	0.38×10^{-5}	-0.02
INSTRUMENT ORDER:	$V_3 = 1.955$		$V_3 = 2.309$			$V_3 = 1.837$		$V_3 = 2.180$		
B, C, D, A	AVG: 1.970		AVG: 2.304			AVG: 1.895		AVG: 2.213		
NAME: (G)	$V_1 = 2.121$		$V_1 = 2.597$			$V_1 = 1.686$		$V_1 = 2.121$		
DATE: 18 JUL 78	$V_2 = 2.170$	0.68×10^{-5}	$V_2 = 2.563$	0.79×10^{-5}	-0.11	$V_2 = 1.890$	0.32×10^{-5}	$V_2 = 2.132$	0.35×10^{-5}	-0.03
INSTRUMENT ORDER:	$V_3 = 2.208$		$V_3 = 2.523$			$V_3 = 1.914$		$V_3 = 2.124$		
C, D, A, B	AVG: 2.166		AVG: 2.541			AVG: 1.810		AVG: 2.186		
NAME: (H)	$V_1 = 2.083$		$V_1 = 2.182$			$V_1 = 2.000$		$V_1 = 2.100$		
DATE: 16 JUL 78 (A, B, C, D)	$V_2 = 2.083$	0.64×10^{-5}	$V_2 = 2.270$	0.88×10^{-5}	-0.01	$V_2 = 1.906$	0.40×10^{-5}	$V_2 = 2.114$	0.39×10^{-5}	0.01
INSTRUMENT ORDER:	$V_3 = 1.891$		$V_3 = 2.375$			$V_3 = 1.815$		$V_3 = 2.324$		
D, A, B, C	AVG: 2.010		AVG: 2.309			AVG: 1.927		AVG: 2.244		
SIGNIFICANCE:	$E(\Delta f_c) = 0.14$, $N = 8$, $t = -0.146$					$E(\Delta f_c) = 0.09$, $N = 8$, $t = -1.136$				

NOTES:

1. Illuminance (foot candle) measurements taken at a distance of 28 inches without correction for color ratio.

2. Instrument mockup pointer settings:

Trial	Mockup A and B		Mockup C and D	
	No. 1 Pointer	No. 2 Pointer	Main Dial	Sub-Dial
1	25	3.7	3.4	7
2	97	1.8	6.6	2
3	55	0.7	8.8	4

3. POINTER SETTINGS FOR POSTONI:

1	45	3.5	6.2	3
2	83	2.0	2.8	5
3	105	1.5	8.2	3

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Figure 37
Threshold and Illuminance Measurements, Graduation and Legend Study

LUMINANCE, INSTRUMENT MOCKUPS A AND B, DUAL TACH.
(NO. 1 POINTER SET AT 40, NO. 2 POINTER SET AT 3.5)

LOCATION	FOOT-LAMBERTS, MOCKUP A											
	1.5 VOLTS			2.0 VOLTS			2.5 VOLTS			5.0 VOLTS		
	READ- ING	WITH 3114	CORR. FT-L	READ- ING	WITH 3114	CORR. FT-L	READ- ING	WITH 3114	CORR. FT-L	READ- ING	WITH 3114	CORR. FT-L
CENTER, "20" GRADUATION	.0016	.0010	.0031	.0120	.0088	.0141	.0349	.0281	.0410	.5680	.3990	.6622
DIAL ABOVE "RTR"	.000046	.000035	.000054	.000113	.000188	.00028	.00064	.00047	.00075	.0116	.0082	.0135
CENTER, NO. 2 POINTER TIP	.0019	.0014	.0022	.0089	.0066	.0105	.0276	.0199	.0324	.5130	.3600	.6007
ABOVE "1", NO. 1 POINTER	.0016	.0012	.0019	.0071	.0051	.0083	.0212	.0153	.0249	.3750	.2690	.4402
CENTER, "2" GRADUATION	.0016	.0012	.0019	.0070	.0052	.0082	.0210	.0150	.0246	.3730	.2630	.4370
CENTER, "80" GRADUATION	.0014	.0011	.0019	.0069	.0049	.0061	.0202	.0149	.0238	.3690	.2610	.4326

LOCATION	FOOT-LAMBERTS, MOCKUP B											
	READ- ING	WITH 3114	CORR. FT-L	READ- ING	WITH 3114	CORR. FT-L	READ- ING	WITH 3114	CORR. FT-L	READ- ING	WITH 3114	CORR. FT-L
CENTER, "20" GRADUATION	.0016	.0013	.0018	.0077	.0057	.0091	.0235	.0177	.0277	.4240	.3100	.4988
DIAL ABOVE "RTR"	.000041	.000032	.000051	.000180	.000138	.00021	.000519	.000399	.00061	.0093	.0067	.0109
CENTER, NO. 2 POINTER TIP	.0021	.0016	.0025	.0083	.0061	.0090	.0239	.0177	.0282	.4130	.3000	.4855
ABOVE "1", NO. 1 POINTER	.0016	.0012	.0019	.0078	.0058	.0089	.0214	.0168	.0264	.3970	.2970	.4683
CENTER, "2" GRADUATION	.0015	.0010	.0017	.0065	.0037	.0075	.0189	.0134	.0221	.3280	.2420	.3863
CENTER, "80" GRADUATION	.0010	.0018	.0024	.0084	.0060	.0099	.0238	.0176	.0280	.4030	.2860	.4728

LUMINANCE, INSTRUMENT MOCKUPS C AND D, GAS PRODUCER
(MAIN DIAL POINTER SET AT 3, SUB-DIAL POINTER SET AT 7)

LOCATION	FOOT-LAMBERTS, MOCKUP C											
	READ- ING	WITH 3114	CORR. FT-L	READ- ING	WITH 3114	CORR. FT-L	READ- ING	WITH 3114	CORR. FT-L	READ- ING	WITH 3114	CORR. FT-L
CENTER, "1" GRAD., MAIN DIAL	.0016	.0019	.0031	.0114	.0088	.0135	.0338	.0274	.0373	.5960	.4500	.7037
CENTER, SHORT POINTER TIP	.0036	.0031	.0035	.0169	.0129	.0200	.0481	.0378	.0564	.7600	.5800	.8985
CENTER, LONG POINTER TIP	.0021	.0017	.0023	.0108	.0083	.0128	.0319	.0242	.0377	.5560	.4170	.6560
DIAL BELOW "PROD"	.000071	.000062	.000086	.00048	.00033	.00053	.00096	.00071	.00113	.0189	.0124	.0188
CENTER, "8" GRAD., MAIN DIAL	.0030	.0023	.0035	.0131	.0100	.0125	.0372	.0284	.0446	.5930	.4410	.6990
CENTER, "5" GRAD., MAIN DIAL	.0018	.0010	.0033	.0118	.0089	.0126	.0337	.0257	.0398	.5690	.4260	.6712

LOCATION	FOOT-LAMBERTS, MOCKUP D											
	READ- ING	WITH 3114	CORR. FT-L	READ- ING	WITH 3114	CORR. FT-L	READ- ING	WITH 3114	CORR. FT-L	READ- ING	WITH 3114	CORR. FT-L
CENTER, "1" GRAD., MAIN DIAL	.0012	.0018	.0024	.0127	.0098	.0150	.0378	.0292	.0448	.7150	.5470	.8456
CENTER, SHORT POINTER TIP	.0015	.0018	.0029	.0108	.0079	.0127	.0317	.0250	.0367	.5600	.4510	.6232
CENTER, LONG POINTER TIP	.0021	.0017	.0023	.0094	.0073	.0111	.0293	.0232	.0337	.5560	.4380	.6454
DIAL BELOW "PROD"	.000057	.000048	.000066	.00014	.00019	.00028	.00076	.00059	.00090	.0145	.0111	.0171
CENTER, "8" GRAD., MAIN DIAL	.0022	.0017	.0026	.0095	.0069	.0112	.0269	.0203	.0318	.4770	.3570	.5626
CENTER, "5" GRAD., MAIN DIAL	.0021	.0016	.0025	.0094	.0072	.0111	.0279	.0219	.0326	.5280	.4180	.6078

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Figure 38
Lumiance Measurements, Graduation and Legend Study Mockups

TABLE 4
LIGHTING MOCKUP IDENTIFICATION,
GRADUATION AND LEGEND STUDY

Mockup Designation	Figure Number	Indicator Name	Marking Scheme (See Table 1, Page 9)
A	2	Dual Rotor RPM	A
B	3		B
C	4	Gas Producer	A
D	5		B

Also requested was the average luminance of the dial markings at the average voltage of all eight subjects for each mockup. The average of five points on each mockup produced the following data:

Mockup	Excitation Voltage	Average Dial Luminance, fL
A	2.010	.010
B	2.299	.016
C	1.826	.009
D	2.203	.020

For reference, the red brightness correction curve for the photometer used in these measurements is shown in Figure 39.

(2) Caution Warning Area Marking Study

The candidate marking configurations shown in Figures 6 and 7 were generated and supplied to HEL for evaluation. These configurations were supplied in the form of 1:1 white-on-black prints, 1:1 black-on-white prints, and 1:1 film negatives (clear markings on an opaque background) for light-table evaluation.

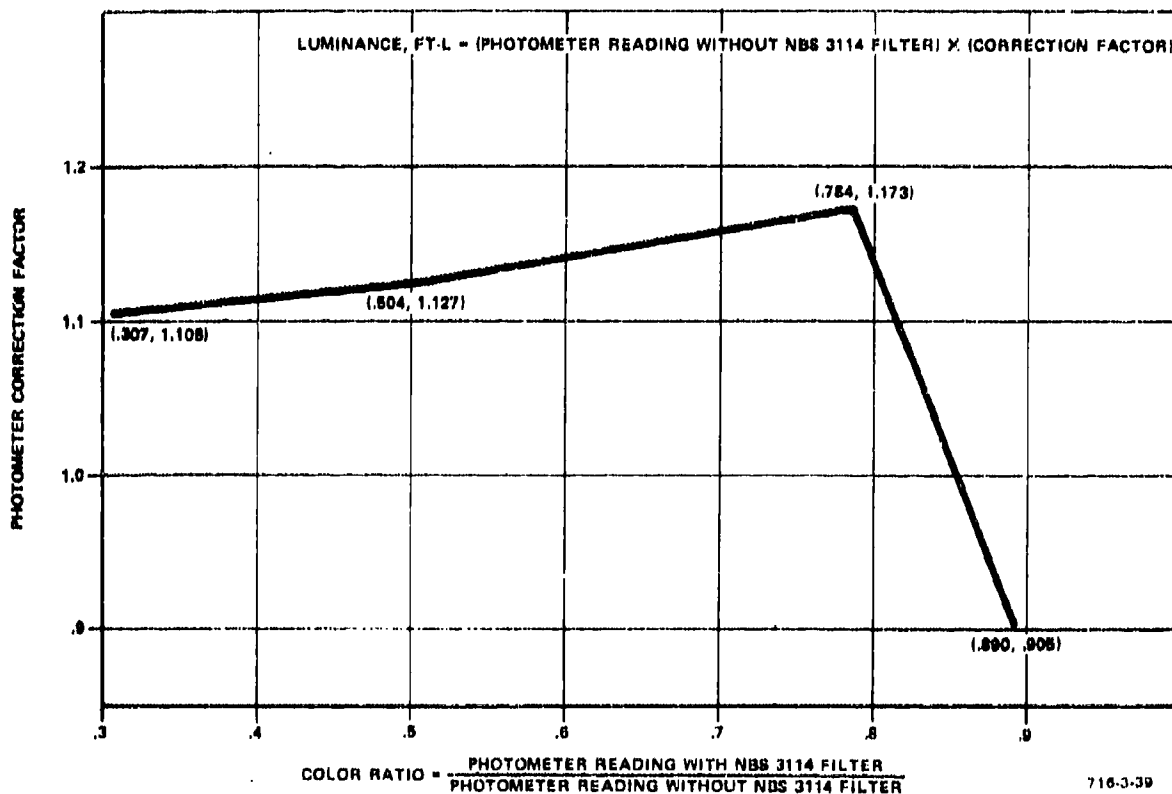


Figure 39
Photometer Red Brightness Correction Curve

b. Conclusions and Recommendations, Graduation and Legend Study

Examination of the data in Figure 37 shows:

- More voltage is required to read the units using marking scheme B (instruments B and D) than those using marking scheme A (instruments A and C).
- The total light flux from the face of the 3-inch mockups (instruments A and B) is greater than for the 2-inch mockups (instruments C and D).
- At the threshold of readability, the total light flux from the face of the mockup is the same for both marking schemes.
- The statistical t-test shows no difference in the dial marking schemes at a significance level of even 20 percent (two-tailed test), based on illuminance measurements.
- Based on these tests, additional study on marking schemes is required to establish criteria to be used for U.S. Army aircraft indicators.

3. INDICATOR MOCKUPS (TASKS D, E AND H)

The purpose of this phase of the program was to construct indicator mockups utilizing the results of the lighting system study and the marking scheme study, and then to make lighting measurements on them.

a. Task Activities

Using the indicator lighting system, Figure 1, and dial marking scheme B, shown in Figures 3 and 5 and tabulated in Table 1, the 12 mockups shown in Figures 8 through 19 were constructed. These mockups contained externally settable pointers. Both an unfiltered incandescent and an Aviation Red light block were provided for each mockup. All optical surfaces contained an antireflection coating in accordance with MIL-C-14806A.

In addition to the 12 2- and 3-inch mockups, a 5-inch Attitude Indicator mockup and a 4-inch Horizontal Situation Indicator mockup were constructed. The Attitude Indicator mockup, Figures 20 and 21, contains the presentation, markings, and colors used in the prototype VSI (Vertical Situation Indicator) used in the Boeing Vertol UTTAS helicopter. The Horizontal Situation Indicator mockup, Figures 22 and 23, represents a typical commercial indicator of this type. Insofar as possible, both unfiltered incandescent and Aviation Red lighting capabilities were provided with these two mockups. All optical surfaces on these two mockups contained a high-efficiency antireflection coating.

On each of the 14 mockups the following lighting measurements were made, using unfiltered incandescent light:

- The voltages required to produce .02 footlambert and .05 footlambert at a selected representative point on the presentation.
- Luminance readings, in footlamberts, of six selected presentation points at excitation voltages of 1.5, 2.0, 2.5, and 5.0 volts dc.

These measurements are shown in Figure 40 through 53.

A 2-inch mockup, the Fuel Quantity Indicator, and a 3-inch mockup, the Airspeed Indicator, were then converted from unfiltered incandescent lighting to Aviation Red lighting and the above lighting measurements were taken again, corrected for color using the curve of Figure 39. These measurements are shown in Figures 54 and 55. If it could be shown from these measurements that there is a correlation between the lighting intensities measured with unfiltered incandescent lighting and those measured with Aviation Red lighting, further conversion of the mockups to red lighting and subsequent light measurements would not be necessary. The following analyses were then performed.

LIGHT MEASUREMENTS, 2-INCH FUEL QUANTITY INDICATOR
(Pointer set at 460 pounds)

EQUIPMENT:
PHOTOMETER: Pritchard, Model 1980/OPPL, Ser. A256
CONTROL CONSOLE: Pritchard, Model 1980/CDHPI, Ser. A256
LENS: Spectar LF-19, Ser. A256
FILTER: NBS No. 3114
VOLTMETER: Hewlett-Packard Model 3440A, Ser. 637-06915

DATE: 30 OCT 75
MEASURED BY: R. STAN
LIGHTING COLOR:
☐ Aviation Red
☒ Unfiltered Incandescent

VOLTAGES FOR SPECIFIED LUMINANCES: (Unfiltered Incandescent Lighting)
Location: Center of the 100-pound graduation
1.554 volts dc for .02 foot-lamberts
1.824 volts dc for .05 foot-lamberts

LOCATION	LUMINANCE, FOOT-LAMBERTS											
	1.5 VOLTS DC			2.0 VOLTS DC			2.5 VOLTS DC			5.0 VOLTS DC		
	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.
Center, 300 Grad.	.058			.257			.254			14.98		
Center, 100 Grad.	.015			.071			.212			4.45		
Center, Pointer Tip	.021			.091			.275			5.53		
Junction in "T" of QTY	.010			.043			.128			2.91		
Center, Zero Grad.	.022			.102			.305			6.34		
Center, 600 Grad.	.025			.109			.322			6.61		

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Figure 40

LIGHT MEASUREMENTS, 1-INCH AIRSPEED INDICATOR
(Pointer set at 130 Knots)

EQUIPMENT:
PHOTOMETER: Pritchard, Model 1980/OPPL, Ser. A256
CONTROL CONSOLE: Pritchard, Model 1980/CDHPI, Ser. A256
LENS: Spectar LF-19, Ser. A256
FILTER: NBS No. 3114
VOLTMETER: Hewlett-Packard Model 3440A, Ser. 637-06915

DATE: 30 OCT 75
MEASURED BY: R. STAN
LIGHTING COLOR:
☐ Aviation Red
☒ Unfiltered Incandescent

VOLTAGES FOR SPECIFIED LUMINANCES: (Unfiltered Incandescent Lighting)
Location: Center of 50-knot graduation
1.557 volts dc for .02 foot-lamberts
1.833 volts dc for .05 foot-lamberts

LOCATION	LUMINANCE, FOOT-LAMBERTS											
	1.5 VOLTS DC			2.0 VOLTS DC			2.5 VOLTS DC			5.0 VOLTS DC		
	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.
Center, Zero Grad.	.021			.097			.203			5.71		
Center, Pointer Tip	.015			.064			.186			3.68		
Center, 30 Grad.	.008			.037			.107			2.16		
Center, 100 Grad.	.018			.077			.232			4.64		
Center, 50 Grad.	.045			.168			.199			4.05		
Center, 70 Grad.	.017			.079			.232			4.77		

718341

Figure 41

LIGHT MEASUREMENTS, 2-INCH EXHAUST GAS TEMPERATURE INDICATOR
(Pointer set at 850°C)

EQUIPMENT:
PHOTOMETER: Pritchard, Model 1980/OPPL, Ser. A256
CONTROL CONSOLE: Pritchard, Model 1980/CDRPI, Ser. A256
LENS: Spectar LF-19, Ser. A256
FILTER: NBS No. 3114
VOLTMETER: Hewlett-Packard Model 3440A, Ser. 637-06915

DATE: 30 OCT 75
MEASURED BY: R. J. HARRIS
LIGHTING COLOR:
☐ Aviation Red
☒ Unfiltered Incandescent

VOLTAGES FOR SPECIFIED LUMINANCES: (Unfiltered Incandescent Lighting)
Location: Center of the 700 graduation
1.65 volts dc for .02 foot-lamberts
1.95 volts dc for .05 foot-lamberts

LOCATION	LUMINANCE, FOOT-LAMBERTS											
	1.5 VOLTS DC			2.0 VOLTS DC			2.5 VOLTS DC			3.0 VOLTS DC		
	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.
Center, 1000 Grad.	.043			.183			.526			10.71		
Center, Pointer Tip	.016			.069			.203			4.08		
Center, 700 Grad.	.013			.059			.174			3.57		
Center, Zero Grad.	.010			.084			.241			4.79		
Center, 500 Grad.	.015			.106			.306			6.02		
Center, 100 Grad.	.019			.139			.376			7.40		

716342

Figure 42

LIGHT MEASUREMENTS, 2-INCH TRANSMISSION OIL TEMPERATURE INDICATOR
(Pointer set at +70°C)

EQUIPMENT:
PHOTOMETER: Pritchard, Model 1980/OPPL, Ser. A256
CONTROL CONSOLE: Pritchard, Model 1980/CDRPI, Ser. A256
LENS: Spectar LF-19, Ser. A256
FILTER: NBS No. 3114
VOLTMETER: Hewlett-Packard Model 3440A, Ser. 637-06915

DATE: 30 OCT 75
MEASURED BY: R. J. HARRIS
LIGHTING COLOR:
☐ Aviation Red
☒ Unfiltered Incandescent

VOLTAGES FOR SPECIFIED LUMINANCES: (Unfiltered Incandescent Lighting)
Location: Center of the +100°C graduation
1.63 volts dc for .02 foot-lamberts
1.92 volts dc for .05 foot-lamberts

LOCATION	LUMINANCE, FOOT-LAMBERTS											
	1.5 VOLTS DC			2.0 VOLTS DC			2.5 VOLTS DC			3.0 VOLTS DC		
	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.
Center, +150 Grad.	.044			.195			.572			11.40		
Center, +100 Grad.	.013			.059			.177			3.79		
Center, -70 Grad.	.021			.030			.261			5.22		
Center, Pointer Tip	.030			.146			.430			8.66		
Center, -20 Grad.	.030			.131			.382			7.55		
Center, +20 Grad.	.030			.131			.383			7.77		

716343

Figure 43

LIGHT MEASUREMENTS, 2-INCH TRANSMISSION OIL PRESSURE INDICATOR
(Pointer set at 60 psi)

EQUIPMENT:
PHOTOMETER: Pritchard, Model 1980/OPPL, Ser. A256
CONTROL CONSOLE: Pritchard, Model 1980/CDRPI, Ser. A256
LENS: Spectar LP-19, Ser. A256
FILTER: NBS No. 3114
VOLTMETER: Hewlett-Packard Model 3440A, Ser. 637-06915

DATE: 30 Oct 75
MEASURED BY: R. J. Stank

LIGHTING COLOR:
☐ Aviation Red
☒ Unfiltered Incandescent

VOLTAGES FOR SPECIFIED LUMINANCES: (Unfiltered Incandescent Lighting)
Location: Center of the 40 psi graduation
1.476 volts dc for .02 foot-lamberts
1.716 volts dc for .05 foot-lamberts

LOCATION	LUMINANCE, FOOT-LAMBERTS											
	1.5 VOLTS DC			2.0 VOLTS DC			2.5 VOLTS DC			5.0 VOLTS DC		
	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.
Center, 80 Grad.	.037			.160			.51			10.19		
Center, 100 Grad.	.018			.092			.289			6.46		
Center, Pointer Tip	.029			.134			.395			8.18		
Center, 40 Grad.	.021			.103			.299			6.31		
Junction in "L" of OIL	.021			.092			.283			5.99		
Center, 20 Grad.	.029			.133			.398			8.44		

716344

Figure 44

LIGHT MEASUREMENTS, 2-INCH FUEL PRESSURE INDICATOR
(Pointer set at 29 psi)

EQUIPMENT:
PHOTOMETER: Pritchard, Model 1980/OPPL, Ser. A256
CONTROL CONSOLE: Pritchard, Model 1980/CDRPI, Ser. A256
LENS: Spectar LP-19, Ser. A256
FILTER: NBS No. 3114
VOLTMETER: Hewlett Packard Model 3440A, Ser. 637-06915

DATE: 30 Oct 75
MEASURED BY: R. J. Stank

LIGHTING COLOR:
☐ Aviation Red
☒ Unfiltered Incandescent

VOLTAGES FOR SPECIFIED LUMINANCES: (Unfiltered Incandescent Lighting)
Location: Center of the 20 psi graduation
1.671 volts dc for .02 foot-lamberts
1.846 volts dc for .05 foot-lamberts

LOCATION	LUMINANCE, FOOT-LAMBERTS											
	1.5 VOLTS DC			2.0 VOLTS DC			2.5 VOLTS DC			5.0 VOLTS DC		
	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.
Center, 40 Grad.	.028			.131			.396			8.43		
Center, Pointer Tip	.017			.076			.226			4.86		
Center, 50 Grad.	.016			.074			.216			4.40		
Center, 20 Grad.	.016			.073			.217			4.65		
Center, Zero Grad.	.021			.096			.286			5.89		
Center, 10 Grad.	.026			.118			.355			7.48		

716345

Figure 45

LIGHT MEASUREMENTS, 2-INCH CLOCK
(Time set to 8:20, elapsed time pointer zeroed)

EQUIPMENT:
PHOTOMETER: Pritchard, Model 1980/OPPL, Ser. A256
CONTROL CONSOLE: Pritchard, Model 1980/CDBPI, Ser. A256
LENS: Spectar LF-19, Ser. A256
VOLTMETER: Hewlett-Packard Model 3440A, Ser. 617-06915

DATE: 29 Oct 75
MEASURED BY: R. J. [unclear]
LIGHTING COLOR:
☐ Aviation Red
☒ Unfiltered Incandescent

VOLTAGES FOR SPECIFIED LUMINANCES: (Unfiltered Incandescent Lighting)
Location: Center of the 30-second dot
1.476 volts dc for .02 foot-lamberts
1.477 volts dc for .05 foot-lamberts

LOCATION	LUMINANCE, FOOT-LAMBERTS											
	1.5 VOLTS DC			2.0 VOLTS DC			2.5 VOLTS DC			5.0 VOLTS DC		
	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.
Center, 60 mark	.011			.046			.132			2.71		
Center, 50 dot	.033			.103			.209			6.37		
Center, 10 dot	.0046			.010			.063			1.36		
Center, 40 dot	.017			.078			.221			4.88		
Center, 20 dot	.012			.051			.157			3.38		
Center, 30 mark	.012			.100			.296			6.28		

716-346

Figure 46

LIGHT MEASUREMENTS, 2-INCH VOLTMETER
(Pointer set at 25 volts)

EQUIPMENT:
PHOTOMETER: Pritchard, Model 1980/OPPL, Ser. A256
CONTROL CONSOLE: Pritchard, Model 1980/CDBPI, Ser. A256
LENS: Spectar LF-19, Ser. A256
FILTER: NBS No. 3114
VOLTMETER: Hewlett-Packard Model 3440A, Ser. 617-06915

DATE: 30 Oct 75
MEASURED BY: R. J. [unclear]
LIGHTING COLOR:
☐ Aviation Red
☒ Unfiltered Incandescent

VOLTAGES FOR SPECIFIED LUMINANCES: (Unfiltered Incandescent Lighting)
Location: Center of the 10-volt graduation
1.727 volts dc for .02 foot-lamberts
1.031 volts dc for .05 foot-lamberts

LOCATION	LUMINANCE, FOOT-LAMBERTS											
	1.5 VOLTS DC			2.0 VOLTS DC			2.5 VOLTS DC			5.0 VOLTS DC		
	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.
Center, Zero Grad.	.0092			.043			.132			2.97		
Center, 5 Grad.	.0091			.043			.135			3.00		
Center, 10 Grad.	.0093			.044			.132			2.90		
Center, 20 Grad.	.0097			.045			.135			3.00		
Center, Pointer Tip	.017			.083			.251			5.66		
Center, 30 Grad.	.0085			.040			.126			2.86		

716-347

Figure 47

LIGHT MEASUREMENTS, 2-INCH AMMETER
(Pointer set at 25 amps)

EQUIPMENT:
PHOTOMETER: Pritchard, Model 1980/OPPL, Ser. A256
CONTROL CONSOLE: Pritchard, Model 1980/CDRPI, Ser. A256
LENS: Spectar LP-19, Ser. A256
FILTER: NBS No. 3114
VOLTMETER: Hewlett-Packard Model 3440A, Ser. 637-06915

DATE: 30 Oct 75
MEASURED BY: R. J. Tuck

LIGHTING COLOR:
☐ Aviation Red
☒ Unfiltered Incandescent

VOLTAGE FOR SPECIFIED LUMINANCES: (Unfiltered Incandescent Lighting)
Location: Center of the 10-amp graduation
1.678 volts dc for .02 foot-lamberts
1.051 volts dc for .05 foot-lamberts

LOCATION	LUMINANCE, FOOT-LAMBERTS											
	1.5 VOLTS DC			2.0 VOLTS DC			2.5 VOLTS DC			5.0 VOLTS DC		
	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.
Center, Zero Grad.	.0084			.041			.126			2.79		
Center, 5 Grad.	.0092			.043			.130			2.89		
Center, 10 Grad.	.011			.049			.146			3.17		
Center, 20 Grad.	.011			.051			.151			3.25		
Center, Pointer Tip	.029			.133			.404			834		
Center, 30 Grad.	.011			.051			.153			3.26		

716340

Figure 48

LIGHT MEASUREMENTS, 3-INCH VERTICAL SPEED INDICATOR
(Pointer set at 100 FPM UP)

EQUIPMENT:
PHOTOMETER: Pritchard, Model 1980/OPPL, Ser. A256
CONTROL CONSOLE: Pritchard, Model 1980/CDRPI, Ser. A256
LENS: Spectar LP-19, Ser. A256
FILTER: NBS No. 3114
VOLTMETER: Hewlett-Packard Model 3440A, Ser. 637-06915

DATE: 7 Nov 75
MEASURED BY: R. J. Tuck

LIGHTING COLOR:
☐ Aviation Red
☒ Unfiltered Incandescent

VOLTAGE FOR SPECIFIED LUMINANCES: (Unfiltered Incandescent Lighting)
Location: Center of the zero graduation
1.586 volts dc for .02 foot-lamberts
1.054 volts dc for .05 foot-lamberts

LOCATION	LUMINANCE, FOOT-LAMBERTS											
	1.5 VOLTS DC			2.0 VOLTS DC			2.5 VOLTS DC			5.0 VOLTS DC		
	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.
Center, 1500 UP Grad.	.021			.094			.285			6.41		
Center, Pointer Tip	.022			.094			.271			5.26		
Center, 3000 UP Grad.	.0074			.035			.102			2.20		
Center, Zero Grad.	.014			.062			.180			3.50		
Center, 500 DN Grad.	.010			.086			.252			5.06		
Center, 3000 DN Grad.	.015			.065			.193			4.09		

716340

Figure 49

LIGHT MEASUREMENTS, 3-INCH TORQUE METER
(Pointer set at 84 psi)

EQUIPMENT:
PHOTOMETER: Pritchard, Model 1980/OPPL, Ser. A256
CONTROL CONSOLE: Pritchard, Model 1980/CDBPI, Ser. A256
LENS: Spectar LP-19, Ser. A256
FILTER: NBS No. 3114
VOLTMETER: Hewlett-Packard Model 3440A, Ser. 637-06915

DATE: 7 Nov 75
MEASURED BY: R. J. Leek

LIGHTING COLOR:
☐ Aviation Red
☒ Unfiltered Incandescent

VOLTAGES FOR SPECIFIED LUMINANCES: (Unfiltered Incandescent Lighting)
Location: Center of the zero graduation
1.715 volts dc for .02 foot-lamberts
1.945 volts dc for .05 foot-lamberts

LOCATION	LUMINANCE, FOOT-LAMBERTS											
	1.5 VOLTS DC			2.0 VOLTS DC			2.5 VOLTS DC			5.0 VOLTS DC		
	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.
Center, 114 Grad.	.032			.162			.529			13.70		
Center, Pointer Tip	.024			.098			.286			5.77		
Center, Zero Grad.	.0095			.046			.141			3.07		
Center, 56 Grad.	.013			.059			.178			3.87		
Center, 20 Grad.	.015			.062			.209			4.33		
Center, 18 Grad.	.016			.074			.222			4.89		

716-360

Figure 50

LIGHT MEASUREMENTS, 1-INCH BAROMETRIC ALTIMETER
(Pointer set at 15 feet, counters at 12,000 and 30,09)

EQUIPMENT:
PHOTOMETER: Pritchard, Model 1980/OPPL, Ser. A256
CONTROL CONSOLE: Pritchard, Model 1980/CDBPI, Ser. A256
LENS: Spectar LP-19
FILTER: NBS No. 3114
VOLTMETER: Hewlett Packard Model 3440A, Ser. 637-06915

DATE: 7 Nov 75
MEASURED BY: R. J. Leek

LIGHTING COLOR:
☐ Aviation Red
☒ Unfiltered Incandescent

VOLTAGES FOR SPECIFIED LUMINANCES: (Unfiltered Incandescent Lighting)
Location: Center of the 15-foot graduation
1.588 volts dc for .02 foot-lamberts
1.870 volts dc for .05 foot-lamberts

LOCATION	LUMINANCE, FOOT-LAMBERTS											
	1.5 VOLTS DC			2.0 VOLTS DC			2.5 VOLTS DC			5.0 VOLTS DC		
	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.
Center, Zero Grad.	.016			.076			.239			5.61		
Center, 85 ft. Grad.	.053			.076			.076			1.73		
Center, Pointer Tip	.015			.071			.212			4.65		
Center, 65 ft. Grad.	.013			.064			.199			4.43		
Center, 35 ft. Grad.	.014			.068			.209			4.56		
Center, 50 ft. Grad.	.017			.078			.240			5.36		

716-361

Figure 51

LIGHT MEASUREMENTS, 5-INCH ATTITUDE INDICATOR (Plugs in view)

EQUIPMENT:
PHOTOMETER: Pritchard, Model 1980/OPPL, Ser. A256
CONTROL CONSOLE: Pritchard, Model 1980/CDBPI, Ser. A256
LENS: Spector LF-19, Ser. A256
FILTER: NBS No. 3114
VOLTMETER: Hewlett Packard Model 1440A, Ser. 617 06915

DATE: 29 OCT 75
MEASURED BY: R. J. [unclear]
LIGHTING COLOR:
☐ Aviation Red
☒ Unfiltered Incandescent

VOLTAGES FOR SPECIFIED LUMINANCES: (Unfiltered Incandescent Lighting)
Location: Center of the roll (bank) pointer
1.441 volts dc for .02 foot-lamberts
1.784 volts dc for .05 foot-lamberts

LOCATION	LUMINANCE, FOOT-LAMBERTS											
	1.5 VOLTS DC			2.0 VOLTS DC			2.5 VOLTS DC			5.0 VOLTS DC		
	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. ING
Center, Roll Pointer	.015			.111			.331			6.77		
OS Scale, 2nd dot up	.014			.067			.201			4.17		
Roll, Cmd. UP mark	.010			.092			.272			5.54		
OS Scale, 2nd dot DN	.017			.079			.234			4.74		
LOC Dev. Middle Grad.	.031			.147			.436			7.97		
Roll Trim Grad.	.015			.066			.199			4.13		

716052

Figure 52

LIGHT MEASUREMENTS, 4-INCH COMMERCIAL HORIZONTAL SITUATION INDICATOR (Plugs in view)

EQUIPMENT:
PHOTOMETER: Pritchard, Model 1980/OPPL, Ser. A256
CONTROL CONSOLE: Pritchard, Model 1980/CDBPI, Ser. A256
LENS: Spector LF-19, Ser. A256
FILTER: NBS No. 3114
VOLTMETER: Hewlett Packard Model 1440A, Ser. 617 06915

DATE: 29 OCT 75
MEASURED BY: R. J. [unclear]
LIGHTING COLOR:
☐ Aviation Red
☒ Unfiltered Incandescent White

VOLTAGES FOR SPECIFIED LUMINANCES: (Unfiltered Incandescent Lighting)
Location: Center of the "W" graduation
2.481 volts dc for .02 foot lamberts
3.016 volts dc for .05 foot-lamberts

LOCATION	LUMINANCE, FOOT-LAMBERTS											
	1.5 VOLTS DC			2.0 VOLTS DC			2.5 VOLTS DC			5.0 VOLTS DC		
	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.
Center, "N" Grad.	.0005			.0016			.0072			.166		
Center, "W" Grad.	.0011			.006			.021			.458		
Center, 50 Grad.	.0014			.0066			.022			.433		
Center, Airplane Symbol	.0017			.013			.040			.845		
Center, 210 Grad.	.0013			.009			.029			.660		
Center, 150 Grad.	.0018			.009			.029			.615		

716153

Figure 53

LIGHT MEASUREMENTS, 2-INCH FUEL QUANTITY INDICATOR

(Pointer set at 460 pounds)

EQUIPMENT:
PHOTOMETER: Pritchard, Model 1980/OPPL, Ser. A256
CONTROL CONSOLE: Pritchard, Model 1980/CDBPI, Ser. A256
LENS: Spectar LP-19, Ser. A256
FILTER: NBS No. 3114
VOLTMETER: Hewlett-Packard Model 3440A, Ser. 637-06915

DATE: 30 OCT 75

MEASURED BY: R. S. HARRIS

LIGHTING COLOR:

☒ Aviation Red
☐ Unfiltered Incandescent

VOLTAGES FOR SPECIFIED LUMINANCES: (Unfiltered Incandescent Lighting)

Location: Center of the 100-pound graduation

volts dc for .02 foot-lamberts

volts dc for .05 foot-lamberts

LOCATION	LUMINANCE, FOOT-LAMBERTS											
	1.5 VOLTS DC			2.0 VOLTS DC			2.5 VOLTS DC			5.0 VOLTS DC		
	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.
Center, 100 Grad.	.0033	.0034	.0018	.018	.013	.0009	.053	.037	.060	.933	.657	.002
Center, 100 Grad.	.0013	.0010	.0015	.0043	.0047	.0074	.021	.015	.014	.297	.289	.462
Center, Pointer Tip	.0017	.0013	.0020	.0029	.0060	.004	.018	.021	.033	.482	.356	.562
Junction in "T" of OTY	.0008	.0006	.0009	.0043	.0073	.0049	.014	.010	.016	.113	.166	.260
Center, Zero Grad.	.0017	.0013	.0020	.0029	.0067	.0102	.017	.010	.031	.505	.373	.589
Center, 600 Grad.	.0018	.0014	.0021	.0029	.0065	.0104	.018	.010	.033	.512	.375	.596

71834

Figure 54

LIGHT MEASUREMENTS, 1-INCH AIRSPEED INDICATOR

(Pointer set at 130 knots)

EQUIPMENT:
PHOTOMETER: Pritchard, Model 1980/OPPL, Ser. A256
CONTROL CONSOLE: Pritchard, Model 1980/CDBPI, Ser. A256
LENS: Spectar LP-19, Ser. A256
FILTER: NBS No. 3114
VOLTMETER: Hewlett-Packard Model 3440A, Ser. 637-06915

DATE: 30 OCT 75

MEASURED BY: R. S. HARRIS

LIGHTING COLOR:

☒ Aviation Red
☐ Unfiltered Incandescent

VOLTAGES FOR SPECIFIED LUMINANCES: (Unfiltered Incandescent Lighting)

Location: Center of 50-knot graduation

volts dc for .02 foot-lamberts

volts dc for .05 foot-lamberts

LOCATION	LUMINANCE, FOOT-LAMBERTS											
	1.5 VOLTS DC			2.0 VOLTS DC			2.5 VOLTS DC			5.0 VOLTS DC		
	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.
Center, Zero Grad.	.0029	.0022	.0034	.016	.011	.019	.050	.035	.058	.979	.625	.1125
Center, Pointer Tip	.0019	.0013	.0022	.0027	.0064	.0101	.026	.019	.030	.480	.329	.536
Center, 30 Grad.	.0027	.0025	.0028	.0027	.0026	.0043	.0120	.0085	.014	.243	.167	.291
Center, 100 Grad.	.0016	.0012	.0019	.0027	.0065	.0102	.026	.019	.030	.516	.356	.598
Center, 50 Grad.	.0014	.0010	.0016	.0025	.0048	.0076	.021	.016	.025	.410	.293	.476
Center, 70 Grad.	.0015	.0011	.0017	.0029	.0060	.0092	.026	.019	.030	.498	.382	.598

7183-66

Figure 55

It is a well-established fact that the luminance of a tungsten filament, operating about its design voltage, can be expressed as an exponential function of the applied voltage, i.e.

$$(\text{footlamberts}) = a (\text{voltage})^b$$

Therefore, a regression analysis ("best fit") was performed on the data to determine the coefficients a and b. These are shown in Table 5 for the indicators examined.

TABLE 5
COEFFICIENTS a AND b IN THE FORMULA
(footlamberts) = a (voltage)^b
AVIATION RED VERSUS UNFILTERED INCANDESCENT (WHITE) LIGHTING

Figure Numbers	Lighting Color	Remarks	<u>a</u>	<u>b</u>
54 and 24	Red	All measured points	.00035	4.636
54	Red	Ignoring data for center of the 300 graduation and the junction in "T" of QTY (For reference only)	.00035	4.648
40 and 24	White	All measured points	.00371	4.615
40	White	Ignoring data for center of the 300 graduation and the junction in "T" of QTY (For reference only)	.00350	4.633
55 and 25	Red	All measured points	.00032	4.704
55	Red	Ignoring data for center of the 30 graduation (For reference only)	.00037	4.685
41 and 25	White	All measured points	.00264	4.590
41	White	Ignoring the data for center of the 30 graduation (For reference only)	.00298	4.591

These functions, appropriately labeled, are plotted in Figures 24 and 25 as noted in Table 5.

The rationale for using a regression analysis to generate the curves of luminance versus voltage is that there are too many uncontrolled variables to make a point-by-point comparison of Aviation Red and unfiltered incandescent lighting. When the mockup is disassembled, the light block changed, and the mockup again re-assembled, at least two variables occur:

a. All four lamps are replaced with four different lamps, each new lamp probably different in intensity than the one it replaces because of tolerances on lamp characteristics.

b. The axial, angular, and rotational positions of the lamp filaments with respect to the centerline of the lighting wedge are probably different when a new light block is installed.

Because of these uncontrolled variables, an average, or "best fit" curve is required to reduce the data to usable form.

Examination of Figures 24 and 25 show that the luminance versus voltage curves for Aviation Red and unfiltered incandescent lighting are indeed parallel, for all practical purposes, for both the 2-inch and 3-inch mockups. The difference in the offset between the red and white lighting curves for the 2-inch and 3-inch indicators is the result of the multiplicity of variables involved in converting the mockups from one color of lighting to another. It is almost impossible to duplicate lighting system configurations and lamp characteristics in all details. It was therefore concluded that further mockup conversions to red lighting were not warranted.

b. Conclusions and Recommendations

It was concluded that for a particular lighting system the lighting intensity of the display is approximately predictable when the lighting color is changed from Aviation Red to unfiltered incandescent white or vice versa.

It is recommended that the mockups supplied to HEL be used for further studies of U.S. Army aircraft indicator requirements.

4. INDICATOR MOCKUP PANEL AND CONTROL ASSEMBLY (TASKS G AND J)

One purpose of this task was to provide a panel into which indicator mockups could be mounted. A further purpose was to supply a lighting control assembly to regulate the lighting of the mockups installed in the panel.

Figure 26 shows the panel, with the mockups mounted therein, that was produced under this task. The face of the panel is tilted backward 10 degrees from the vertical. Referring to Figure 26, all mockups except the 5-inch Attitude Indicator and the 4-inch Horizontal Situation Indicator are flange-mounted from the front; the latter two mockups are clamp-mounted from the front.

The indicator lighting control assembly is shown in Figure 28. The schematic diagram for this assembly is shown in Figure 56. It was designed to operate from a 115-volt, 60-Hz source and provide both zero-to-5 volt control for each of 16 mockups and control of overall voltage levels to raise or lower the voltages of all 16 mockups simultaneously. Supplied with the control assembly, as seen in Figure 28, are 16 cables to connect the control assembly to the mockups. Each cable is ten feet long.

5. RED-LIGHTED FLUORESCENT PAINT STUDY (TASK I)

The purpose of this task was to document for future use the intensities of various colors of fluorescent paint when illuminated by Aviation Red lighting at various excitation voltages.

a. Task Activities

Figure 27 shows the mockup constructed for these tests. It consisted of the lighting system of Figure 1, with Aviation Red lamps, a paint sample strip inserted into the mockup through slits in the sides of the mockup case, a blank dial face with a .75 by 1.00 inch aperture through which to view the paint samples, and a spring-loaded backing plate to press the paint sample strip against the rear of the aperture. The paint sample strip contained the following colors (unless otherwise noted, the paint color names are those of the Day-Glo Color Corporation, FSCM listing No. 58825 of Cataloging Handbook H4-1):

- Black per FED-STD-595 Color No. 37038 (Ref. only)
- Fire Orange
- Blaze Orange
- Arc Yellow
- Saturn Yellow
- White per FED-STD-595 Color No. 37875 (Ref. only)
- Signal Green
- Lightning Yellow
- Horizon Blue
- Aurora Pink

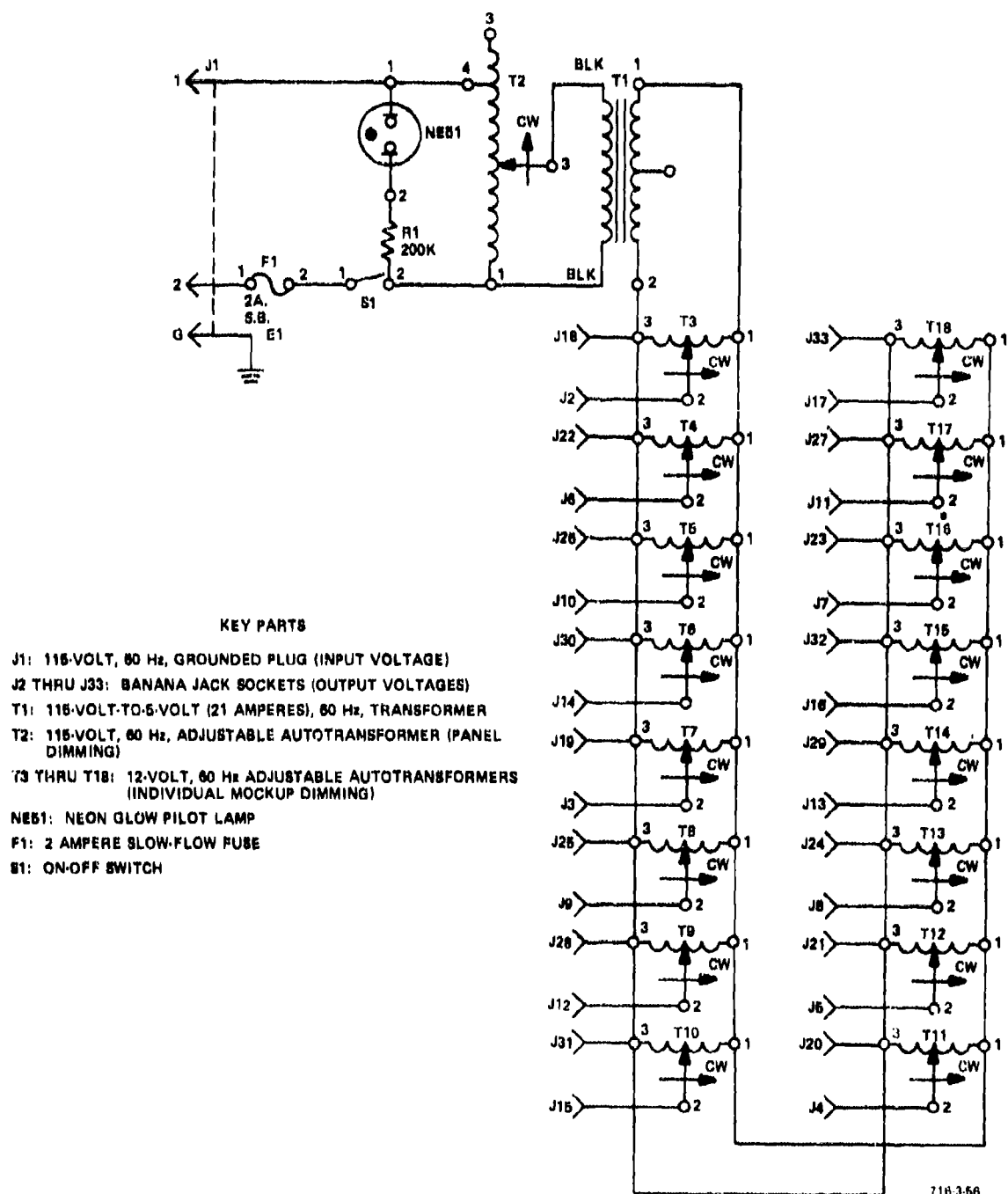


Figure 56
 Schematic Diagram, Lighting Control Assembly

The lighting intensity for each of these paint samples was measured at the center of the aperture (center of the mockup) at lighting system excitation voltages of 1.5, 2.0, 2.5 and 5.0 volts dc. The measurements were corrected using the curve of Figure 39 and are shown in Figure 57.

b. Conclusions and Recommendations

Listed in descending order of visibility under Aviation Red lighting, the paint colors are as shown in Table 6.

TABLE 6
FLUORESCENT PAINT VISIBILITY ILLUMINATED
BY AVIATION RED LIGHT

Color (Fluorescent color names are Day-Glo Trademarks)	Luminance, fL at 5.0 vdc (Reference only)
Aurora Pink	.597
Saturn Yellow (chartreuse)	.591
Arc Yellow (light orange)	.578
Blaze Orange (deep orange)	.569
Lightning Yellow	.564
Fire Orange (red)	.555
White (non-fluorescent)	.546
Horizon Blue	.082
Signal Green	.071
Black (non-fluorescent)	.026

The following conclusions can be drawn from an examination of Table 6:

- Under Aviation Red lighting, Day-Glo® Aurora Pink, Saturn Yellow, Arc Yellow, Blaze Orange, Lightning Yellow, and Fire Orange are all more visible than matte white.
- Horizon Blue and Signal Green appear almost black under red light.

LIGHT MEASUREMENTS, DAY-GLC[®] FLUORESCENT COLORS

EQUIPMENT:
 PHOTOMETER: Pritchard, Model 1980/OPPL, Ser. A256
 CONTROL CONSOLE: Pritchard, Model 1980/CDBPT, Ser. A256
 LENS: Spectar LF-19, Ser. A256
 FILTER: NBS No. 3114
 VOLTMETER: Hewlett-Packard Model 3440A, Ser. 637-06915

DATE: 29 OCT 78
 MEASURED BY: R. STARK

LIGHTING COLOR:
☒ Aviation Red
☐ Unfiltered Incandescent

VOLTAGE FOR SPECIFIED LUMINANCES:

Color: White (non fluorescent)
 2.320 volts dc for .02 foot-lamberts, corrected for color
 2.745 volts dc for .05 foot-lamberts, corrected for color

LOCATION	LUMINANCE, FOOT-LAMBERTS											
	1.5 VOLTS DC			2.0 VOLTS DC			2.5 VOLTS DC			5.0 VOLTS DC		
	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.	READ- ING	WITH 3114	CORR. FT-L.
Black	.0007	.0013	.0011	.0005	.0003	.0006	.0013	.0010	.0015	.0226	.170	.016
Fire Orange	.0017	.0013	.0010	.0021	.0014	.0014	.025	.020	.018	.474	.369	.555
Blaze Orange	.0017	.0014	.0013	.0024	.0015	.0018	.026	.020	.020	.486	.370	.561
Arc Yellow	.0017	.0015	.0017	.0024	.0016	.0018	.027	.020	.032	.494	.376	.578
Saturn Yellow	.0017	.0015	.0013	.0022	.0014	.0103	.028	.022	.033	.525	.386	.591
White (non-fluorescent)	.0017	.0013	.0010	.0021	.0014	.0014	.026	.019	.030	.467	.357	.546
Signal Green	.0028	.0018	.0017	.0011	.0009	.0012	.0033	.0024	.0018	.061	.047	.071
Lightning Yellow	.0017	.0014	.0011	.0027	.0017	.0102	.026	.020	.030	.482	.367	.564
Horizon Blue	.0027	.0011	.0012	.0015	.0013	.0015	.0038	.0030	.0044	.070	.054	.081
Aurora Pink	.0022	.0017	.0016	.0015	.0014	.0111	.029	.022	.024	.510	.391	.597

718287

Figure 57

- The three best colors to use with Aviation Red lighting, in order of preference, are Aurora Pink, Saturn Yellow, and Arc Yellow.
- The visibility of fluorescent paints under red lighting is more than just a function of the amount of red in the color; the deepness or paleness of the color (saturation) is also a consideration.

It is recommended that Day-Glo® Aurora Pink, Saturn Yellow, or Arc Yellow be used if colored fluorescent paints are desired in Aviation Red-illuminated indicators.

6. NIGHT VISION GOGGLE SURVEY (TASK F)

a. Task Activities

The displays listed below were viewed by several lighting engineers using night vision goggles (NVG). The purpose of this phase of the project was to subjectively evaluate each of these displays for NVG compatibility. Each display consisted of a 3-digit numeric readout. The illumination of the readout was decreased while observations were being made of the quality of the display as viewed through the NVG. The results of this evaluation were:

- Burroughs "Nixie" Gas Tube - This display tended to wash out due to stray ambient light producing reflections from the glass envelope. The display also tended to "break up" at low excitation voltages and produced a "tunneling effect" because of the digits being stacked.
- Tung-Sol "Digivac" Fluorescent - This display emitted blue light, to which the NVG are insensitive. This made the display unreadable. This display was also subject to the "tunneling" effect.
- Pinlite "Midgi-lite" Direct-View Incandescent - The small lighted circles making up this display became more pronounced at the low intensities required for compatibility with NVG. This distracted significantly from the readability of this display.
- Sperry DC-Planar Gas Tube - This display was not dimmable; it was therefore not compatible with NVG.

- The following displays had good readability, were compatible with NVG, and were deemed suitable for night usage:

Master Specialties Fiber Optic Incandescent

Tung-Sol Light Pipe Incandescent

Monsanto MAN-10 Gallium Arsenide LED (Dot segments)

Monsanto MAN-7 Gallium Arsenide LED (Bar segments)

b. Conclusions and Recommendations

From the results of this task, it has been determined that:

- Some displays are incompatible with NVG. Of those observed, the following were found to be compatible:

Master Specialties Fiber Optic Incandescent

Tung-Sol Light Pipe Incandescent

Monsanto MAN-7 and MAN-10 Gallium Arsenide LED,
both dot and bar segments

- Tunneling effects occur with the Burroughs "Nixie" and the Tung-Sol "Digivac" displays.
- Any 7-segment display requires a monitoring system to detect inoperative segments.
- Reflections of ambient light can make a 7-segment display unusable if the display is not designed to operate in high ambient illumination. These reflections can not only swamp the entire display, as with the Burroughs "Nixie" Gas Tube and the Tung-Sol "Digivac" Fluorescent, but can cause an unilluminated segment to appear lighted.
- LED displays tend to "wash out" in high ambient illumination.
- Further research is needed in this area.

APPENDIX A

DATA REDUCTION PROCEDURES

A1. Mean and Standard Deviation

- a. $\bar{X}$, mean = arithmetic average of all points

$$= \frac{1}{n} \sum_{i=1}^n X_i$$

where X_i = data point i

n = number of data points

- b. s , standard deviation = root mean square of the deviations of a set of data points from the mean, $\bar{X}$.

$$= \sqrt{\frac{\sum_{i=1}^n (X_i - \bar{X})^2}{n-1}}$$

where X_i = data point i

$\bar{X}$ = mean (as defined above)

n = number of data points

A2. Student's t-Distribution Test

To determine the degree of statistical significance, if any, between two sets of data, the following calculation is made:

$$t = \frac{\sum (X_i - Y_i)}{\sqrt{\frac{n \sum_{i=1}^n (X_i - Y_i)^2 - \left[\sum_{i=1}^n (X_i - Y_i) \right]^2}{n-1}}}$$

2. Straight Line

$$y = b_0 + b_1 x$$

For a straight line fit by the method of least squares, the values b_0 and b_1 are obtained by solving the normal equations

$$nb_0 + b_1 \sum x_i = \sum y_i$$

$$b_0 \sum x_i + b_1 \sum x_i^2 = \sum x_i y_i$$

The solutions of these normal equations are

$$b_1 = \frac{n \sum x_i y_i - (\sum x_i)(\sum y_i)}{n \sum x_i^2 - (\sum x_i)^2}$$

$$b_0 = \frac{\sum y_i}{n} - b_1 \frac{\sum x_i}{n} = \bar{y} - b_1 \bar{x}$$

3. Exponential Curve

$$y = ab^x$$

or

$$\log y = \log a + (\log b)x$$

For an exponential curve fit by the method of least squares, the values $\log a$ and $\log b$ are obtained by fitting a straight line to the set of ordered pairs

$$[(x_i, \log y_i)]$$

4. Power Function

$$y = ax^b$$

or

$$\log y = \log a + b \log x$$

For a power function fit by the method of least squares, the values $\log a$ and b are obtained by fitting a straight line to the set or ordered pairs $[(\log x_i, \log y_i)]$.

APPENDIX B

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