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THE EFFECTS OF TWO INSTRUMENT LIGHTING SYSTEMS ON DARK ADAPTATION

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THE EFFECTS OF TWO INSTRUMENT LIGHTING SYSTEMS ON DARK ADAPTATION

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Wright Air Development Center
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United States Air Force
Wright-Patterson Air Force Base, Ohio

FOREWORD

This report was prepared by the Psychology Branch, Aero Medical Laboratory, Directorate of Research, Wright Air Development Center, in connection with Research and Development Order No. 694-41, "Visual Requirements of Aircraft Lighting." The authors, Major Lawrence R. Wilcox and Major Edward L. Cole, were the project engineers.

The authors wish to express their appreciation to Captain Billy B. McIntosh for his assistance in gathering the data for this study.

ABSTRACT

Four pilots with normal vision were tested for the effects of the standard indirect red and red-flood aircraft lighting systems on dark adaptation. Data were gathered in a completely blacked-out cockpit while the aircraft was in a hangar and also during conditions of normal night flight. Significant differences in dark adaptation thresholds were found between the hangar and flight phases and between the low and high levels of light intensity used. No significant differences were found between the types of lighting systems used. It is concluded that the flight conditions of starlit night sky affect dark adaptation levels to a significant degree.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDING GENERAL:

Robert H Blount
ROBERT H. BLOUNT
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Research

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I. INTRODUCTION

The problem of lighting of aircraft cockpits for night flying presents a somewhat paradoxical situation. On the one hand, low illumination levels are required so that vision outside the aircraft is impaired as little as possible; on the other, higher illumination levels are necessary to allow the pilot to read his instruments quickly and accurately. A constant effort to improve visual conditions in the cockpit has brought about many modifications of instruments and the methods of lighting them. The preservation of dark adaptation has been one of the main considerations governing these modifications and has been stressed whenever discussions of night lighting have taken place. In the development of instrument lighting systems it has been the goal of the lighting engineer to create a system that will have as little effect as possible on the level to which the pilots' eyes have been dark adapted. Dark adaptation is a chemical process which takes place in the retina of the eye, allowing the individual gradually to see more and more of his surroundings as time expires after he has gone from a well-lighted environment into a darker one. The process is, for all practical purposes, completed after a period of 35 minutes in total darkness. When the eye has been dark adapted, i. e. in total darkness for 35 minutes, extremely dim objects can be seen. As the retina is subjected to illumination higher in intensity than this faintest possible stimulus, the reverse chemical process is started and retinal sensitivity decreases to a point where the original stimulus can no longer be seen. When the eye becomes adapted to the higher illumination, this level, which is between the totally dark adapted state and the completely light adapted one, is referred to as the adaptation level. There are, of course, numerous possible adaptation levels.

There has been no attempt as yet to determine the decrease in retinal sensitivity brought about by exposure of the dark adapted eye to the various levels of night-sky brightness; nor has it been adequately determined what happens to the dark adaptation level of the pilots' eyes when exposed to the various available instrument lighting systems. It is possible that under many conditions of night-sky brightness the adaptation thresholds resulting from exposure to the light from outside the cockpit will be above the level brought about by the lighting systems alone. Accurate data on these two subjects will provide a basis for judging the effectiveness of our present lighting systems.

To date, the evaluation of lighting conditions in aircraft cockpits has been more or less a subjective one, wherein surveys or discussions have been conducted to find out how pilots react to a specific system, i. e. like or dislike it. On the other hand theoretical considerations have, and justly so, played a very important part in lighting system development. The present acceptance of red light as the primary method of illumination was supported by studies (2, 5) which show that dark adaptation is affected less by light from the red end of the visible spectrum than that of other wave lengths. To repeat, however, the magnitude of the loss of dark adaptation under actual night flying conditions has not been determined.

II. PURPOSE OF THE STUDY

The purpose of this study was (1) to determine the effect of two different instrument lighting systems on adaptation levels, (2) to determine the effect of night sky brightness plus the lighting systems on the adaptation level of the eyes of the pilot, and (3) to compare the two resulting sets of data to determine the effectiveness of these lighting systems.

III. APPARATUS

Instrument Lighting System:

The two lighting systems under consideration in this study, red flood, and indirect red, are both installed in the Aero Medical Laboratory's Airborne Psychology Laboratory, a specially equipped C-47 aircraft. The red flood lighting system is the standard one installed in service aircraft and consists of fixtures installed so as to flood the instrument panel with red light. The indirect red system is composed of small red lamps strategically located around the instruments and covered by an overlay panel. This installation differs from the individual lighting shields now in service use. The illumination of the instruments, however, is comparable. This indirect red installation provides excellent individual instrument illumination with light falling only on the face and pointers of the instruments.

Portable Adaptometer:

The instrument used to determine the decrease in retinal sensitivity, a portable adaptometer, was designed and constructed by Major L. R. Wilcox to be used under actual flight conditions (Figure 1). It was installed above the glare shield in front of the co-pilot's position in the C-47. It incorporates a wedge filter of known density to reduce the brightness of a constant light source. This variable light is projected, within the instrument, onto a milkglass test field in the front surface of the adaptometer. The brightness of the test field is varied by rotating a knob mounted to the left of the test field. This knob controls the position of the wedge in the beam of light between the light source and the test field. The position of the wedge is transmitted through a system of gears to a calibrated dial on the top surface of the instrument in order that the wedge position can be determined.

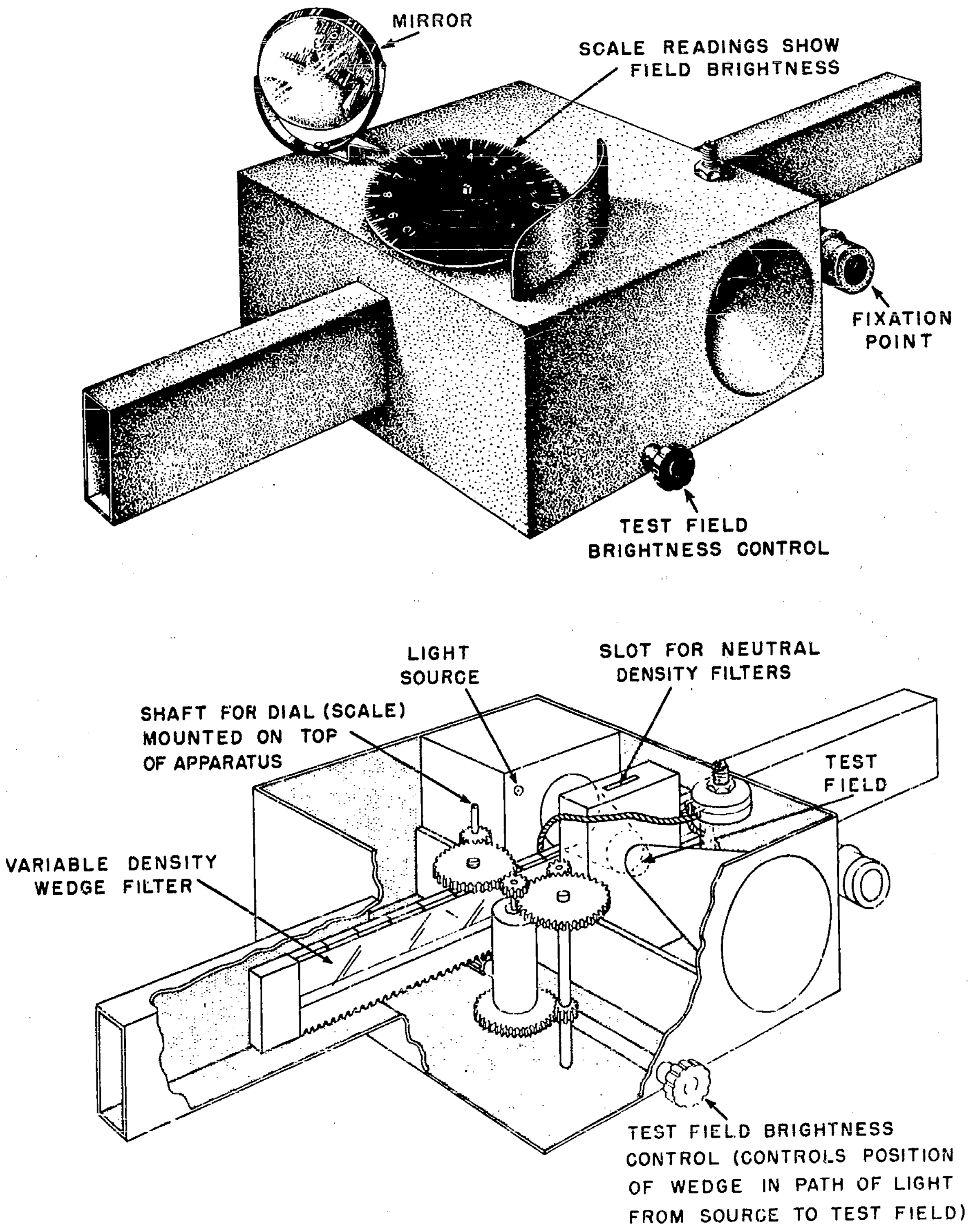

MIRROR
SCALE READINGS SHOW FIELD BRIGHTNESS
FIXATION POINT
TEST FIELD BRIGHTNESS CONTROL
LIGHT SOURCE
SLOT FOR NEUTRAL DENSITY FILTERS
SHAFT FOR DIAL (SCALE) MOUNTED ON TOP OF APPARATUS
TEST FIELD
VARIABLE DENSITY WEDGE FILTER
TEST FIELD BRIGHTNESS CONTROL (CONTROLS POSITION OF WEDGE IN PATH OF LIGHT FROM SOURCE TO TEST FIELD)

Figure 1

A red fixation point of adjustable intensity is located to the right of the test field. It is so positioned that when viewed from a distance of 18 inches the angle between the fixation point and the center of the test field subtended at the eye of the observer is seven degrees.

Seven neutral density filters are included with the adaptometer. These may be placed, one at a time, in the beam of light cast on the test field. A range in brightness of the test field from 3.4126 to 7.4103 log micro-micro lamberts is thus provided.

The light source, a "grain of wheat" bulb, powered by three flash light batteries, is set at a constant intensity by aligning the pointer of a milli-amp-meter to a reference line on the face of the meter. The pointer's position is controlled by a rheostat.

The calibration of the adaptometer was made with a Macbeth Illuminometer by measuring the brightness of the test field at relatively high levels. The lower brightness range was computed from the known values of the neutral density filters incorporated. This method of calibration was necessary because of the extreme difficulty encountered in making precise photometric measurements at low scotopic levels. Threshold measurements made first with the portable adaptometer and then immediately with a standard Hecht Schlaer adaptometer validated the calibration of the entire range of the portable instrument.

IV. PROCEDURE

To perform a reliable evaluation of the two lighting systems, it was necessary first to determine which levels of illumination would be used for threshold measurements, and second, to equate these illumination levels for each of the two systems. In an earlier study (3) using the Airborne Psychology Laboratory, 12 subjects, all rated pilots, were required to select three different levels of illumination for each of the two lighting systems. By manual control of the light intensity they selected:

1. The minimum illumination level -- the lowest level consistent with safe flight, for use under night flying conditions.

2. The normal illumination level — that which they considered normal for typical night flight.

3. The maximum illumination level -- the illumination they would use under night instrument flying conditions.

These three levels were found for both the red flood and the indirect red lighting systems. In the present study, dark adaptation thresholds were measured at each of the three illumination levels for both of the lighting systems.

In order to find the decrement in dark adaptation brought about by: (1) the instrument lighting systems alone, and (2) by the instrument lighting systems and the various conditions of night sky brightness combined, it was necessary to create two different situations. The first was done by excluding completely any outside light from the cockpit. The windshield, windows, astrodome, and all other sources of outside light were covered with many layers of black paper. The aircraft was in a hangar for this phase of the study. In the second situation threshold measurements were made during flight at night, where night sky brightnesses and the light from the lighting systems both affected dark adaptation. This part of the study was called the flight phase.

The procedure for obtaining threshold measurements in each of the phases was the same. The pilot subjects were first dark adapted for thirty-five minutes in total darkness. Thresholds were then determined before they were exposed to any light. The next step was to light adapt the subjects and take threshold measurements for each of the various levels of illumination in the order listed below:

1. Minimum illumination — indirect red lighting.
2. Minimum illumination — red flood lighting.
3. Normal illumination — indirect red lighting.
4. Normal illumination — red flood lighting.
5. Maximum illumination — indirect red lighting.
6. Maximum illumination — red flood lighting.

The subjects were light adapted to each level of illumination for a period of time long enough to produce stable thresholds by scanning the instrument panel as they would in flight for the hangar phase and by actually flying the aircraft in the flight phase. Ten threshold measurements were made. The average of these ten was considered the threshold for a particular illumination level. On completion of these measurements each subject was dark adapted for a short period of time, and his thresholds were checked until the original resting thresholds were reached. Then the subject was light adapted to the next illumination level. The flight phases for all subjects were approximately the same duration and were flown at the same altitude. In addition, the same routes were flown in each case with departure times also approximately the same.

The threshold determination was made by the subject. He fixated on the red fixation point and decreased the brightness of the test field (by rotating the knob) until the test field was no longer visible. This method will be recognized as the method of average error and was selected because of its simplicity and because of the nature of the data being collected. The subject was instructed to make "first choice" determinations since delay - selection and manipulation of the sensitivity of the test field - would produce variations in thresholds as a function of time.

V. RESULTS

The intensity values selected for the red flood and indirect red lighting systems were taken from a previous study as representative of those values used by pilots in actual night flight. These are given in Tables I and II. The dark adaptation thresholds obtained immediately prior to the hangar phase and used thereafter as the base levels for each subject are given in Table III. Figures 2, 3, 4 and 5 give comparison data of indirect red and red flood between the hangar and flight phases for each subject. A quadruple analysis of variance was done and the results obtained given in Table IV. Table V gives the night-sky brightness of the four nights the subjects were flown.

Discussion of Results:

As shown in Table IV the between-group variance attributable to light intensity, phase (hangar vs. flight) and individuals is significant at greater than the .01 level of confidence. Kind of light, i.e., red-flood vs. indirect-red, had no significant effect on dark adaptation thresholds. Light intensity effects were to be expected, of course. Individual differences, while significant, show an interesting parallel. Figures 2, 3, 4 and 5 which give the individual thresholds for the conditions of the study indicate that three of the subjects were relatively alike in terms of thresholds obtained before and during the experiment. However, subject #4, although responding similarly to the other three, started with a markedly higher threshold and remained so throughout the experiment. Thus, it appears quite evident that the individual variance is due almost entirely to subject #4. The phase variance, i. e., flight vs. hangar as indicated above, is significant at better than the .01 level of confidence. It will be noted from Figures 2, 3, 4 and 5 that the thresholds for the flight conditions are consistently higher than for the hangar phase. Thus it would appear that the conditions of night-sky brightness and transient ground lights had an effect on the dark adaptation thresholds of the subjects. Further, it appears that the flight conditions had a greater effect on the dark adaptation thresholds than did either the red flood or indirect-red lighting systems themselves. If this is true, and the data reported here tend to support this view, then it can be stated that the present state of development of lighting systems for aircraft is satisfactory insofar as dark adaptation is concerned.

TABLE I

MINIMUM	.0125
NORMAL	.034
MAXIMUM	.061

Intensity Values in Foot-Lamberts Used for Indirect Red

TABLE II

MINIMUM	.003
NORMAL	.020
MAXIMUM	.084

Intensity Values in Foot-Lamberts Used for Red Flood

TABLE III

SUBJECT #1	4.02
SUBJECT #2	4.00
SUBJECT #3	4.00
SUBJECT #4	4.27

Dark Adaptation Thresholds in Log Micro-Micro Lamberts of Four Subjects Used in the Study

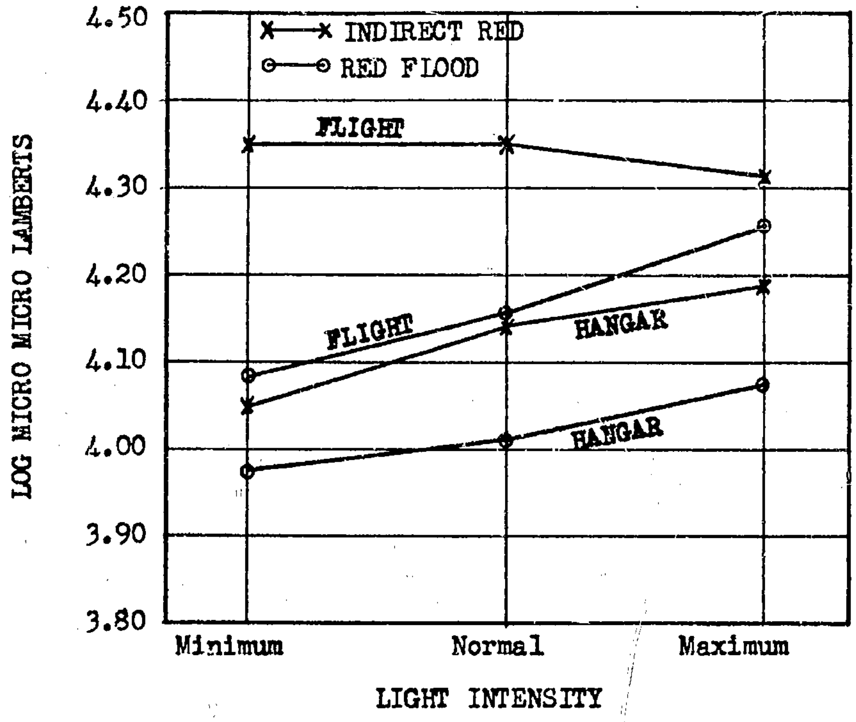


Figure 2

DARK ADAPTATION THRESHOLDS AFTER
EXPOSURE TO THREE LIGHT INTENSITIES
DURING FLIGHT AND HANGAR PHASES.
Subject #1

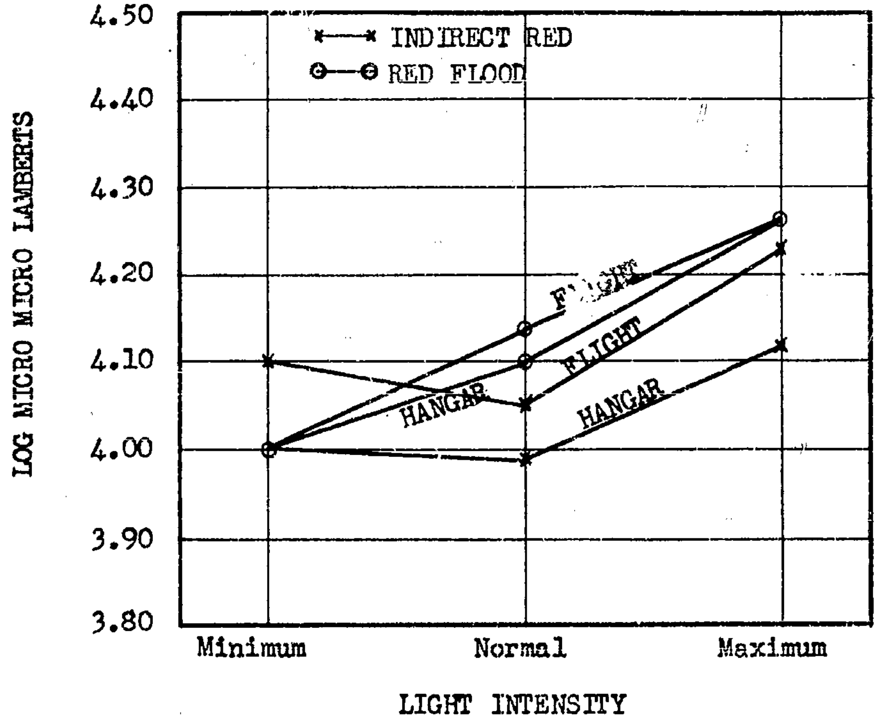


Figure 3

DARK ADAPTATION THRESHOLDS AFTER EXPOSURE TO THREE LIGHT INTENSITIES DURING FLIGHT AND HANGAR PHASES.
Subject #2

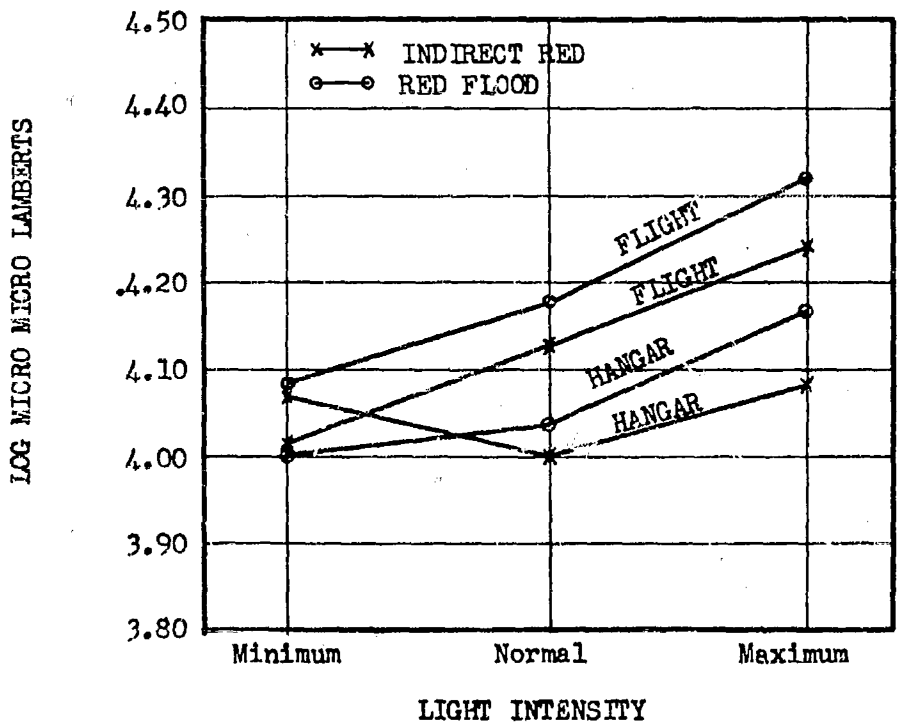


Figure 4

DARK ADAPTATION THRESHOLDS AFTER EXPOSURE TO THREE LIGHT INTENSITIES DURING FLIGHT AND HANGAR PHASES
Subject #3

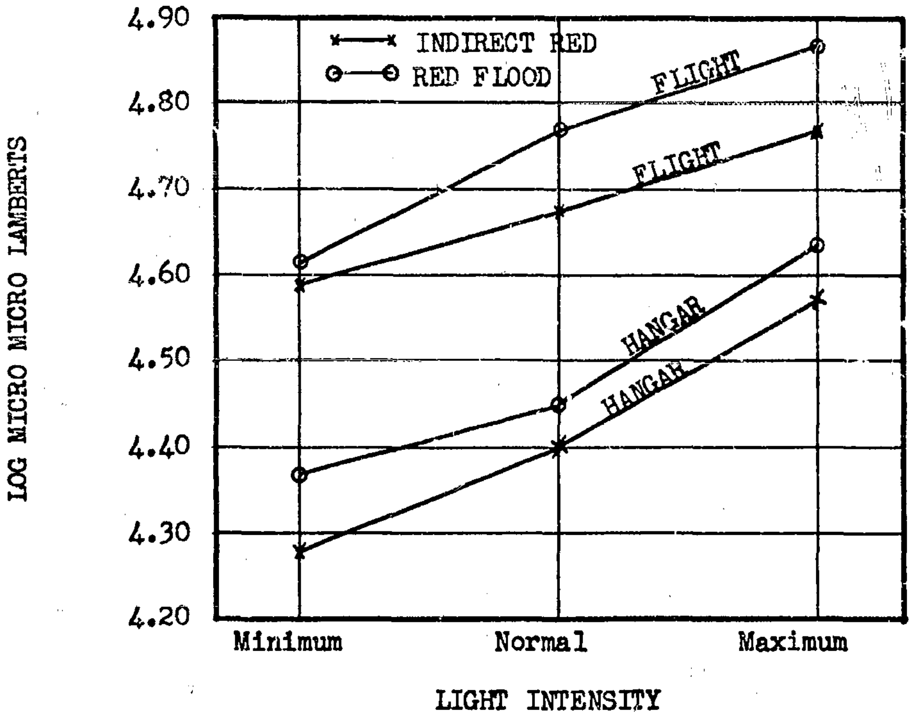
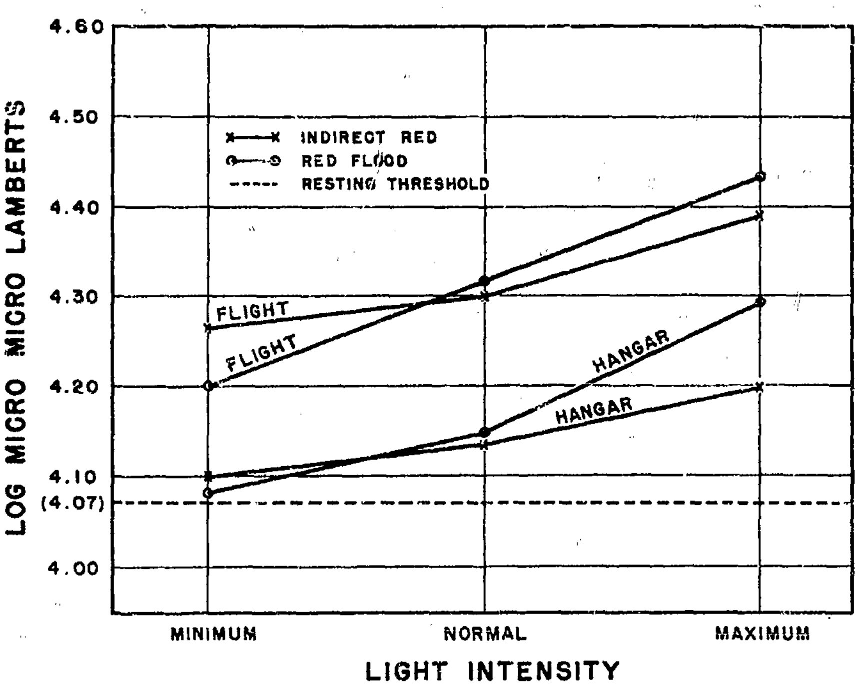


Figure 5

DARK ADAPTATION THRESHOLDS AFTER EXPOSURE TO THREE LIGHT INTENSITIES DURING FLIGHT AND HANGAR PHASES. Subject #4.

SUBJECT	INDIRECT RED FLIGHT			INDIRECT RED HANGAR			RED FLOOD FLIGHT			RED FLOOD HANGAR		
	MIN	NOR	MAX	MIN	NOR	MAX	MIN	NOR	MAX	MIN	NOR	MAX
1	4.35	4.35	4.32	4.05	4.14	4.18	4.08	4.16	4.26	3.97	4.01	4.08
2	4.10	4.05	4.23	4.00	3.98	4.12	4.00	4.14	4.26	4.00	4.10	4.26
3	4.02	4.13	4.24	4.07	4.00	4.08	4.09	4.18	4.32	4.00	4.04	4.17
4	4.59	4.68	4.77	4.27	4.40	4.58	4.61	4.77	4.87	4.37	4.45	4.64
TOTAL	17.06	17.21	17.56	16.39	16.52	16.96	16.78	17.25	17.71	16.34	16.60	17.15
MEAN	4.26	4.30	4.39	4.10	4.13	4.24	4.20	4.31	4.43	4.08	4.15	4.29



MEAN DARK ADAPTATION RESTING THRESHOLD AND MEAN THRESHOLDS AFTER EXPOSURE TO THREE LIGHT INTENSITIES DURING FLIGHT AND HANGAR PHASES FOR ALL SUBJECTS.

Figure 6

TABLE IV

SOURCE	SQUARES	d.f.	Variance ESTIMATES	F RATIO	P
Between Groups					
Intensity of lighting	2078.38	2	1039.19	16.72	.01
Kind of lighting	70.08	1	70.08		NS*
Phase (Hangar or Flight)	918.75	1	918.75	14.77	.01
Individuals	3274.25	3	1091.42	17.55	.01
Single Interactions					
Intensity of lighting x Individuals	836.12	6	139.35		NS
Kind of lighting x Individuals	442.25	3	147.42		NS
Phase x Individuals	9723.58	3	3241.19	52.13	.01
Kind of lighting x Phase	184.09	1	184.09		NS
Intensity of lighting x Kind of lighting	397.04	2	198.52		NS
Intensity of lighting x Phase	164.62	2	82.31		NS
Triple Interactions					
Intensity of light x Kind of Light x Individuals	302.13	6	50.36		NS
Intensity of light x Phase x Individuals	414.55	6	69.09		NS
Kind of lighting x Phase x Individuals	321.58	3	107.19		NS
Intensity of lighting x Kind of lighting x Phase	28.79	2	14.40		NS
Quadruple Interactions					
Intensity of lighting x Kind of lights x Phase x Individuals	373.04	6	62.17		NS
Total Sums of Squares	19529.25	47			

*NS - Not Significant

VARIANCE TABLE
QUADRUPLE ANALYSIS OF VARIANCE

TABLE V

FIRST NIGHT	.0017
SECOND NIGHT	.001
THIRD NIGHT	.001
FOURTH NIGHT	.0015

Night Sky Brightness in Foot-Lamberts

Taken together, the results of this study can be fairly well summed up by stating that the effects of the present standard Air Force lighting systems on dark adaptation are functions of intensity and not the kind of system employed. Further, the conditions of night-sky brightness and other factors associated with night flying seem to have a greater effect on dark adaptation than the lighting system employed. The fact that dark adaptation thresholds are significantly affected by intensity levels of red light was well as by night-sky brightness of the order reported in this study does not answer the question as to the degree of dark adaptation loss that can be tolerated. Further investigations are planned to gather data relating to dark adaptation thresholds and visibility for dim objects under conditions of night flight.

VI. CONCLUSIONS

1. Indirect red or red-flood instrument panel lighting systems produce no differing effects on levels of dark adaptation.

2. Intensity of red light affects dark adaptation significantly but to an unknown degree in terms of loss of visibility for dim objects.

3. Night-sky brightness conditions of clear, moonless sky affect dark adaptation significantly.

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