AF TECHNICAL REPORT No. 6031 August 1950

BRIGHTNESS LEVELS OF THREE INSTRUMENT LIGHTING SYSTEMS USED BY PILOTS FLYING AT NIGHT

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FOREWORD

This is a report describing an investigation conducted under Expenditure Order 694-31 by the Psychology Branch, Aero Medical Laboratory, Engineering Division, Air Materiel Command. The purpose of this investigation is to gather data concerning the various levels of light intensity that pilots use while flying at night. From this data an attempt will be made to establish norms that may be used in a future study to determine the effects of such intensity levels on dark adaptation.

The authors wish to express their appreciation to the individuals who gave assistance in conducting this study: to the Air Force pilots who served as subjects; to Lieutenants J. L. Milton, L. D. Pigg, and J. F. Gardner of the Aero Medical Laboratory who assisted as control pilots; and to Mr. David Craig for the many helpful suggestions regarding this report.

ABSTRACT

Information obtained from twelve pilots flying a C-47 aircraft at night using three different instrument lighting systems is presented. These systems were: 1) Red Flood, 2) Indirect Red, and 3) Ultra-Violet. Brightness levels used by the pilots were recorded for the three systems under varying flying conditions. These conditions were 1) normal night flying, 2) night instrument (maximum), and 3) minimum brightness necessary for safe flight. For normal conditions the lowest brightness level used occurred under Red Flood and highest under Indirect Red. At minimum levels Indirect Red was lowest followed by Ultra-Violet and Red Flood. At maximum levels (night instrument condition) Red Flood was highest, Indirect Red next and Ultra-Violet the lowest although this position of Ultra-Violet represented the maximum available brightness range for this system. Pilot opinion showed varying preferences for the different conditions. Indirect Red was preferred as being the most pleasant and comfortable system and Red Flood was preferred as being the most effective of the three.

PUBLICATION APPROVAL

For the Commanding General:

Walter A. Carlson
WALTER A. CARLSON
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Engineering Division

BRIGHTNESS LEVELS OF THREE INSTRUMENT LIGHTING SYSTEMS
USED BY PILOTS FLYING AT NIGHT

I. INTRODUCTION

The problem of aircraft instrument lighting has interested various research agencies for a number of years. Aircraft manufacturers, commercial airlines, the Air Force and the Navy, along with interested government agencies have devoted and still are devoting considerable time and expense in an effort to provide a suitable method of illuminating aircraft instruments and controls. Recently the Air Force and the Navy agreed to a standardized installation which includes Indirect Red Incandescent Lighting as a primary system and Red Flood Lighting as a secondary or alternate system. With the exception of the latest production models, most present day service aircraft have the standard Ultra-Violet installation as the primary lighting system. These three systems, that is, Red Flood, Indirect Red and Ultra-Violet, were employed in the present study not for the purpose of making a critical evaluation of the systems, but to gather information concerning the way in which they are used and concerning the way they are rated by pilots.

II. PURPOSE OF THE STUDY

The purpose of this study was (1) to gather information concerning the average brightness levels used by pilots under various lighting and operational conditions; (2) to gather information concerning the range of brightness levels preferred by pilots and (3) to gather information concerning the evaluation of the three systems in terms of pilot opinion.

III. PROCEDURE

The three lighting systems used in this study were (1) Ultra-Violet, (2) Red Flood, and (3) Indirect Red. The Ultra-Violet and Red Flood systems represented the normal installation in service aircraft. The Indirect Red Lighting System approximates the individual shield system presently being adopted by the services. The installation used in this investigation consisted of individual red lamps placed in strategic locations around the instruments and concealed by an overlay panel, thus providing the indirect system. The aircraft used was a C-47 known as the Airborne Psychology Laboratory. This aircraft is used for the express purpose of gathering experimental data during flight on a large variety of subject matter and was ideally suited for the present investigation.

Both the pilots' and co-pilots' instrument panels employed an Indirect Red Lighting System. However, the Indirect Red System described above was installed only on the co-pilots' panel, consequently the pilots serving as subjects flew from the right seat and used this same panel under the three different lighting systems. Each lighting system was separately controlled by a rheostat, around which was placed a cardboard ring marked and numbered in such a way as to allow placing the control in any position and identifying that position from the number opposite the rheostat reference mark. In order to calibrate the rheostat setting, measures of brightness were taken by four separate investigators using a Taylor Model B, Low Brightness Meter with the diffusing lens removed in order to obtain more accurate readings. For this calibration the airplane cockpit was completely blacked-out by placing black paper on the side windows and windshield. Five instruments were measured by each investigator. These were 1) air speed indicator, 2) cross-pointer (ILAS indicator), 3) flight indicator, 4) altimeter, and 5) rate of climb indicator. The pointers of the airspeed, altimeter and rate of climb indicators were used for obtaining the brightness data of these instruments. The horizon bar of the flight indicator and the point of intersection of the pointers on the ILAS indicator were the locations used on these latter two instruments. A red filter, consisting of plexiglass, was used to obtain a color match for the measurements made of the red lighting systems. The low-brightness meter was re-calibrated to the transmission qualities of the filter in order to take into account the lowered brightness of the comparison light. The plexiglass was cut into a strip that fit over the neutral filter gradient so that the comparison light appeared red in color.

Three positions of each rheostat were selected for the brightness calibration. These positions were selected arbitrarily to gain values of a suitable character to plot curves of the brightness range of each lighting system. Each investigator took two readings of each instrument at each rheostat setting for each of the three systems. Thus a total of eighteen readings per instrument were made per investigator and a total of seventy-two readings per instrument by the entire group. With five instruments read this made a total of 360 readings for the panel as a whole. An assistant recorded the brightness values in foot-lamberts for each investigator. At no time was information given the investigator concerning the values obtained. In this way it was felt that knowledge of previous readings would not be a factor. The different investigators randomized their procedure from system to system as well as the sequence of rheostat settings used within each system. All investigators were familiar with the use of the Taylor Model B Low Brightness Meter and all were dark adapted before beginning the readings. The values thus obtained were then averaged and plotted to form curves for each of the lighting systems (Fig. 1). These graphs made possible the translation of rheostat positions recorded for each subject into corresponding brightness values without resorting to the rather difficult and tedious procedure of taking brightness readings while in actual flight. The minimum and maximum brightness values for each system are shown in Table I and represent the adjustable range available to the subjects.

Sky brightness readings were taken each night to provide an index of the possible effect nighttime sky conditions may have on the brightness levels required within the cockpit (Table II). These values in foot-lamberts, represent the average of two investigators each taking three readings. The investigators used a Taylor Low Brightness Meter and collected the data from the aircraft while the subjects were being flown.

Twelve pilots, flown two at a time on successive nights, served as subjects. No attempt was made to select the subjects to meet certain experience levels or other criteria, with the exception that they had to be qualified to perform normal flying duties. Each subject was asked to set the lighting systems to meet a condition described by the observer. There were three such conditions, the same for each system. These conditions were 1) minimum brightness required for safe flight, 2) brightness the pilot would use for normal operation, 3) maximum brightness to meet a situation such as flying instruments at night

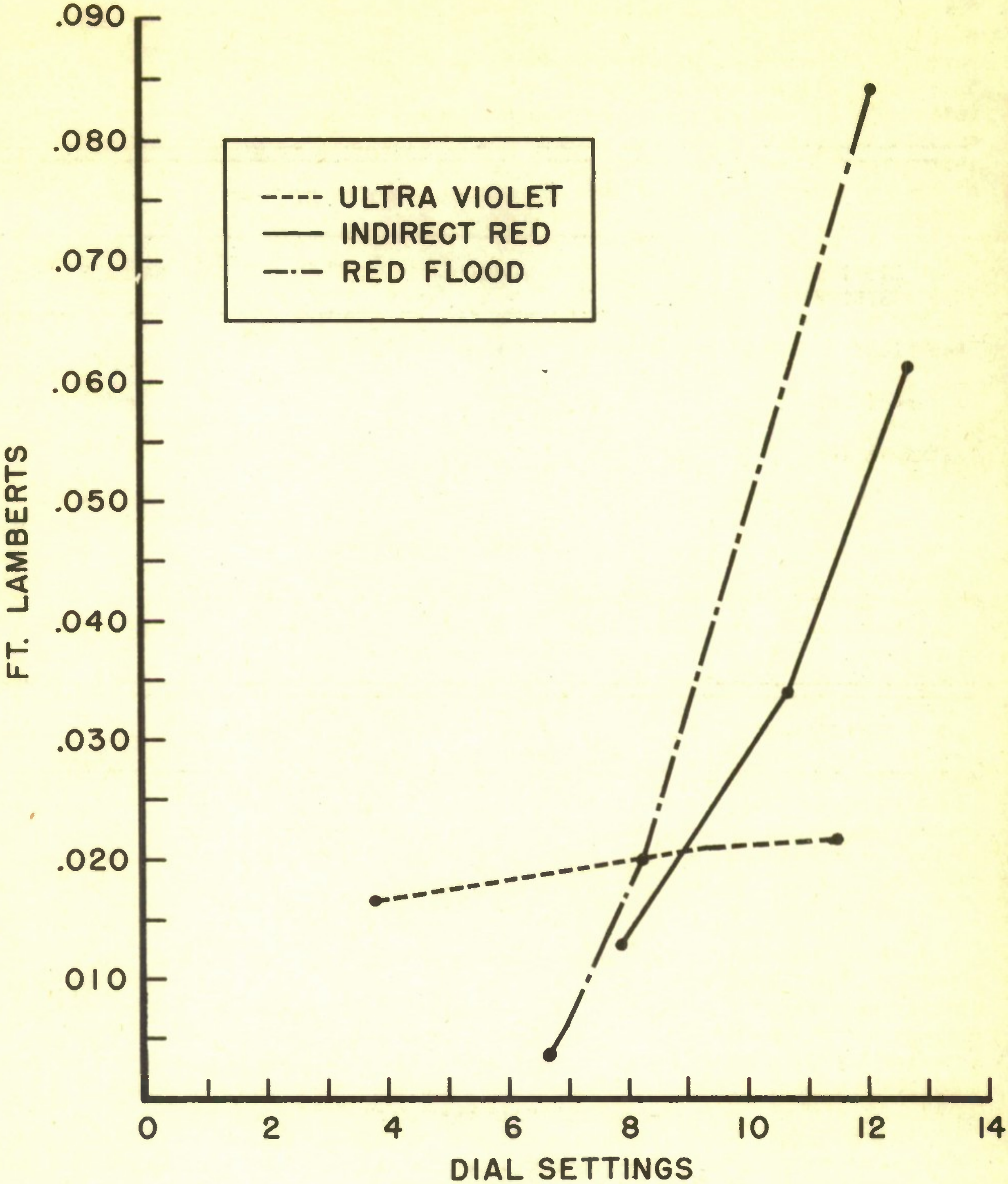

Figure 1: Calibration curves showing brightness level as a function of dial setting for the three different lighting systems.

TABLE I

AVAILABLE RANGE OF BRIGHTNESS OF THE THREE LIGHTING SYSTEMS

LIGHTING SYSTEM	FOOT LAMBERTS	
	MINIMUM	MAXIMUM
Red Flood	.000	.1039
Indirect Red	.000	.0689
Ultra-Violet	.0039	.022

TABLE II

SKY BRIGHTNESS MEASUREMENTS FOR SIX SUCCESSIVE NIGHTS

NIGHTS	FOOT LAMBERTS*
1	.005
2	.0053
3	.004
4	.0018
5	.0028
6	.0025

* Average of four readings

(Readings taken at Sea Level ranged from .00013 foot-lamberts for moonless nights to .003 foot-lamberts for moonlit broken overcast nights. Institute of Optics, University of Rochester (1).)

wherein outside vision is of no concern. Instructions to adjust to the various conditions were randomized as the subject proceeded through the three systems. Likewise, the order of presentation of the lighting systems was counterbalanced. Four subjects used the sequence Ultra-Violet, Indirect Red and Red Flood. Four more subjects used Indirect Red, Red Flood and Ultra-Violet. The remaining four subjects used Red Flood, Indirect Red and Ultra-Violet. Each subject was permitted to take as long as he liked to adjust the system under investigation and likewise was permitted to make any changes until he was perfectly satisfied. Each subject flew three minutes under a given condition. In every case final adjustment was accomplished considerably before this three minute period was completed. Recording of the rheostat settings was done with the aid of a red flashlight in order to preserve the dark adaptation of the subject. After each setting was recorded the rheostat was turned to the "OFF" position. This was done in an attempt to overcome the influence of any one setting on subsequent ones. At the conclusion of the experimental period the subject was given a short questionnaire and asked to rate the systems under which he had flown (Appendix II).

IV. RESULTS

Table III shows the dial settings used by each subject for Ultra-Violet, Indirect Red and Red Flood Systems, his experience level in terms of flying hours and the sky-brightness that prevailed. Table IV gives the average brightness values in foot-lamberts for the three systems under the three conditions for the twelve subjects. These values are graphically presented in Fig. 2.

The nine questions which made up the rating questionnaire covered those items considered to be major requirements of a good lighting system. The subjects were asked to rank each system by placing the numbers 1, 2 and 3 in the boxes provided in answer to each question. Thus, for example, in response to a particular question a subject might rank Indirect Red - 1, Red Flood - 2, Ultra-Violet - 3. There is a possibility that any one system could have received a given ranking 108 times on the basis of twelve subjects giving nine responses each. This, of course, does not happen, but tabulating the number of responses by rank position and by system, we find Indirect Red received 39 first choices, Red Flood received 16 first choices and Ultra-Violet received 13 first choices (Table V). Inasmuch as the subjects were permitted to indicate a non-preference choice between any two or three systems there occurred several instances wherein the different systems were ranked equally as well. Seven of the twelve subjects answered at least one question by indicating a "no preference" between two systems. No instance occurred where all three systems were given a "no preference" ranking to any of the systems. Every question received at least one "no preference" response with the exception of question seven. Question seven asked which system provided the best lighting under minimum intensities and all twelve subjects gave a definite 1-2-3 ranking in indicating a definite preference. The occurrence of non-preference responses is shown in Table VI. Only first and second choices are indicated since with any one system given a ranking of 1, the remaining two systems would be rated equally as a second choice. Similarly, if the "no preference" category was a first choice, then the remaining system would be a second choice.

TABLE III

RHEOSTAT SETTINGS, TOTAL FLYING HOURS AND SKY BRIGHTNESS VALUES
FOR EACH SUBJECT UNDER EACH CONDITION

SUBJECT	ULTRA VIOLET			INDIRECT RED			RED FLOOD			TOTAL FLYING HRS.	SKY BRIGHTNESS
	Min.	Nor.	Max.	Min.	Nor.	Max.	Min.	Nor.	Max.		
1	2.0	6.8	13.0	6.0	10.2	13.0	7.0	8.0	13.0	2900	.005
2	5.0	13.0	13.0	10.0	12.0	13.0	8.0	10.0	11.0	2033	.005
3	5.1	11.2	13.0	7.8	11.8	13.0	7.8	10.0	13.0	1850	.005
4	4.4	10.5	13.0	6.5	11.0	13.0	6.5	8.75	10.0	2160	.0053
5	5.0	8.5	10.0	8.75	9.75	12.0	6.5	7.5	9.0	2007	.0053
6	3.5	6.0	13.0	8.75	10.0	12.75	6.8	7.9	11.0	1300	.004
7	4.0	8.0	13.0	9.0	12.75	13.0	6.0	8.0	12.0	900	.004
8	1.8	8.2	9.2	8.0	11.5	13.0	6.8	8.0	10.0	1200	.0018
9	3.8	9.0	9.2	9.3	11.3	12.6	6.2	7.8	9.6	900	.0018
10	4.5	13.0	13.0	7.0	9.0	13.0	7.5	9.0	13.0	2050	.0028
11	4.2	13.0	13.0	6.2	10.5	13.0	5.6	8.0	13.0	1400	.003
12	2.8	4.8	5.8	8.4	9.0	11.3	6.0	7.2	9.3	1300	.0025
Average	3.8	9.3	11.5	7.9	10.7	12.7	6.7	8.3	12.1	1666	

ERRATA SHEET

To be attached to AF Technical Report No. 6031, dated August 1950, (Brightness Levels of Three Instrument Lighting Systems Used by Pilots Flying at Night).

2. CORRECTION: Page 3, Figure 1 - this caption belongs under Figure 2 on page 8.

3. CORRECTION: Page 8, Figure 2 - this caption belongs under Figure 1 on page 3.

ERRATA SHEET

To be attached to AF Technical Report No. 6031, dated August 1950.

1. CORRECTION: Page 5, paragraph 3, 14th and 15th lines from the bottom. Correct the numerical values so as to read: 47 first choices, Red Flood received 31 first choices and Ultra-Violet received 21 first choices.

TABLE IV

AVERAGE BRIGHTNESS LEVELS SELECTED BY TWELVE SUBJECTS FOR THREE LIGHTING SYSTEMS

LIGHTING SYSTEM	CONDITION		
	MINIMUM	NORMAL	MAXIMUM
	Foot-Lamberts	Foot-Lamberts	Foot-Lamberts
Red Flood	.003	.020	.064
Indirect Red	.0125	.034	.061
Ultra-Violet	.0165	.021	.0215

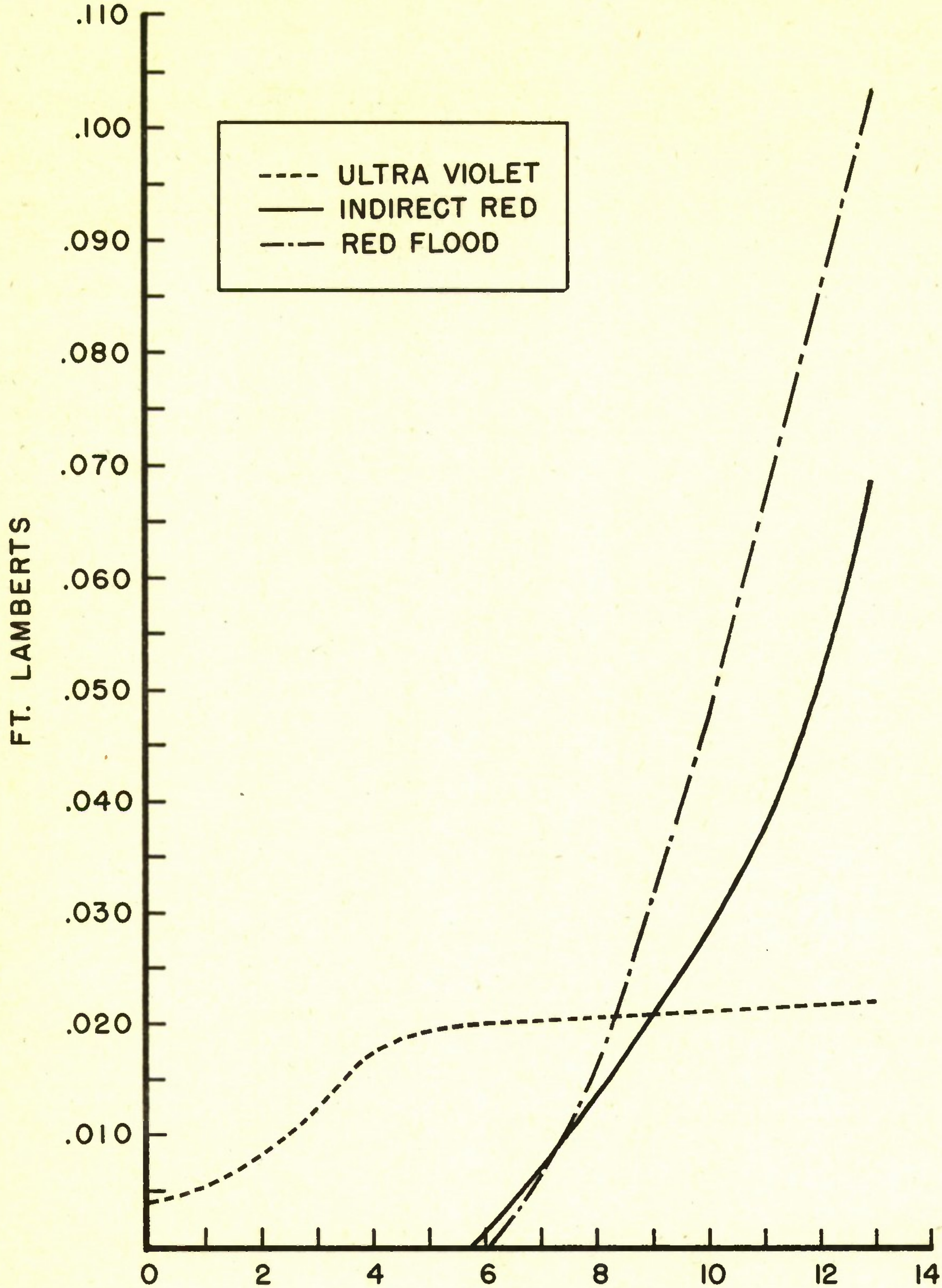

Figure 2: Average "minimum", "normal" and "maximum" brightness levels selected by twelve subjects under three different lighting systems.

TABLE V

RANKING OF LIGHTING SYSTEMS BY TWELVE SUBJECTS
ON EACH OF NINE CHARACTERISTICS

SYSTEM CHARACTERISTIC*	SYSTEM	FIRST CHOICE	SECOND CHOICE	THIRD CHOICE	NO PREFERENCE
1. Best for numeral legibility	UV	0	1	11	0
	RF	7	4	0	1
	IR	4	7	0	1
2. Best for determining pointer position	UV	0	2	9	1
	RF	8	2	0	2
	IR	2	7	1	2
3. Best distribution of light	UV	0	4	7	1
	RF	6	3	1	2
	IR	4	4	3	1
4. Least panel glare	UV	3	2	6	1
	RF	0	6	4	2
	IR	9	2	0	1
5. Least window reflection	UV	4	5	0	3
	RF	1	1	8	2
	IR	7	3	1	1
6. Most pleasant	UV	0	1	9	2
	RF	3	7	1	1
	IR	7	2	0	3
7. Best under minimum intensities	UV	2	2	8	0
	RF	4	5	3	0
	IR	6	5	1	0
8. Most effective under highest intensities	UV	9	1	1	1
	RF	1	3	7	1
	IR	1	8	3	0
9. Least interference to outside vision	UV	3	4	4	1
	RF	1	4	4	3
	IR	7	2	1	2

* Refer to Appendix I for complete question asked subject.

TABLE VI

FREQUENCY DISTRIBUTION OF NON-PREFERENCE PAIRINGS OF LIGHTING

QUESTION	UV - RF Both First Choice	UV - RF Both Second Choice	UV - IR Both First Choice	UV - IR Both Second Choice	RF - IR Both First Choice	RF - IR Both Second Choice	TOTAL
1. Best for numeral legibility					1		1
2. Best for determining pointer position	1		1		1		3
3. Best distribution of light	1				1		2
4. Least panel glare						2	2
5. Least window reflection		2		1			3
6. Most pleasant			1	1	1		3
7. Best under minimum intensities							0
8. Most effective under highest intensities	1						1
9. Least interference to outside vision		1			1	1	3

NOTE: A combination of any two systems rated equally reduces the ranking to but First and Second Choices.

V. DISCUSSION OF RESULTS

Of the three systems, Red Flood showed the greatest range of brightness levels used. The average for the minimum setting was .003 foot-lamberts to .084 foot-lamberts for the maximum setting. Ultra-Violet showed the least range in this respect, .0165 foot-lamberts representing the minimum setting and .0215 foot-lamberts the maximum**. The Indirect Red System averaged from .0125 foot-lamberts to .061 foot-lamberts***.

A comparison of the three systems shows the Indirect Red System ranging somewhat higher than the Red Flood at minimum and normal levels, but lower at the maximum, and higher than Ultra-Violet at the normal and maximum levels but slightly lower at the minimum level. Thus, there seemed to be no significant nor consistent trend with respect to the brightness used throughout the range for the three systems. Taking Red Flood and Indirect Red together we can say that the brightness levels selected were consistently higher than Ultra-Violet at the normal and maximum levels and consistently lower at the minimum level. This may be due to the better lighting qualities of red light in that it permits lower intensities without strain at the minimum end, and higher intensities without glare and reflections at the maximum end. The efficiency by which each system illuminated the instruments must be taken into consideration as a possible factor in the brightness levels used. Thus, Red Flood, which was set lower than either of the other two systems at the minimum and normal settings, provided a greater lighted area at a lower intensity because of the flooding characteristics of the system. Similarly, Indirect Red may have been set higher because only the instruments were illuminated, and possibly less effectively than under Red Flood.

There was a strong preference for the Indirect Red Lighting System, although it was not the system under which the lowest brightness levels were selected. An evaluation of the questionnaire shows that the preference for the Indirect Red System follows the pattern of "pleasantness" and "comfort" rather than effectiveness of the system as such. Judgements of the systems with respect to the former characteristics are contained in the answers to questions 4, 5, 6 and 9. Combining these results gives Indirect Red 30 first choices and Red Flood 5 first choices. Question 4 referred to "least panel glare," question 5 referred to "least reflection," question 6 to the "most pleasant and comfortable" system and question 9 to "least interference to outside objects." Questions 1, 2 and 3,

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** The range from the minimum to the maximum in this latter case could have been restricted by the available range of the Ultra-Violet System.

*** It is interesting to note that Chalmers, Goldstein and Kappauf in a recent study on The Effect of Illumination on Dial Reading (3) found that when using white flood lighting for the illumination of 2.8" dials the threshold for increased reading errors was .0070 foot-lamberts and the time required to read the dials increased at .0140 foot-lamberts. This compares favorably with the minimum settings of .0125 foot-lamberts for Indirect Red and .0165 for Ultra-Violet used by the twelve subjects in actual flight. Chalmers, Goldstein and Kappauf offered subjective data, wherein subjects were asked to judge the amount of illumination required before errors increased. The findings suggest that sophisticated subjects can judge with reliability the level of illumination at which gross errors in dial reading will appear.

TABLE VII

COMBINED RESPONSES TO QUESTIONS REFERRING TO SIMILAR CHARACTERISTICS

QUESTION CATEGORY	SYSTEM CHARACTERISTIC	FIRST CHOICE		
		UV	RF	IR
Effectiveness of system	1. Best for numeral legibility 2. Best for determining pointer position 3. Best distribution of light	0	21	10
Most pleasant and comfortable system	4. Least panel glare 5. Least window reflection 6. Most pleasant 9. Least interference to outside vision	10	5	30

on the other hand, concerned themselves with an analysis of the effectiveness of the lighting systems. In these instances Red Flood received 21 first choices as against 10 for Indirect Red and 0 for Ultra-Violet. Table VII shows the results of combining the responses to the questions that refer to similar characteristics. The point should be made here that for many of the subjects the red lighting systems were novel and represented new experiences whereas the Ultra-Violet was subject to prejudices already well-established. This may explain the tendency to rate Ultra-Violet down and Red Lighting up. Question 8, which asked for the system requiring the highest intensity for the most effective use, gave Ultra-Violet this somewhat dubious distinction, although the actual brightness measurements showed Indirect Red and Red Flood at higher levels except at the minimum settings****. The feeling that Ultra-Violet had to be set higher for effective use may be due in part to the nature of the light itself rather than its effectiveness as an illuminating agent.

In several instances two systems were rated as equally good. Most of these instances paired Red Flood and Indirect Red. This tendency served to place the two red systems in preference over the Ultra-Violet in that the necessity of making a choice between Red Flood and Indirect Red was eliminated. The most frequently encountered non-preference rating involving Ultra-Violet was the Red Flood - Ultra-Violet pairing. Here the indication is that floodlighting has certain advantages in effectiveness over the Indirect Red. Such advantages are 1) greater legibility, 2) more even illumination of dials and pointers, and 3) more effective distribution of light.

VI. CONCLUSIONS

1. The average brightness levels used by pilots while flying under normal night conditions with each of the three different lighting systems are:

a.	Red Flood	.020 foot-lamberts
b.	Indirect Red	.034 foot-lamberts
c.	Ultra-Violet	.021 foot-lamberts

2. The range of brightness levels preferred by pilots is:

a.	Red Flood	.003 to .084 foot-lamberts
b.	Indirect Red	.0125 to .061 foot-lamberts
c.	Ultra-Violet	.0165 to .0215 foot-lamberts

3. Pilots' opinions of the three lighting systems indicate the Indirect Red System as being the most preferred. The Red Flood System was ranked second and the Ultra-Violet System was ranked last. So far as effectiveness of the systems is concerned, Red Flood was rated the highest with Indirect Red and Ultra-Violet following in that order.

**** This again may be due to the somewhat restricted range of the available Ultra-Violet settings.

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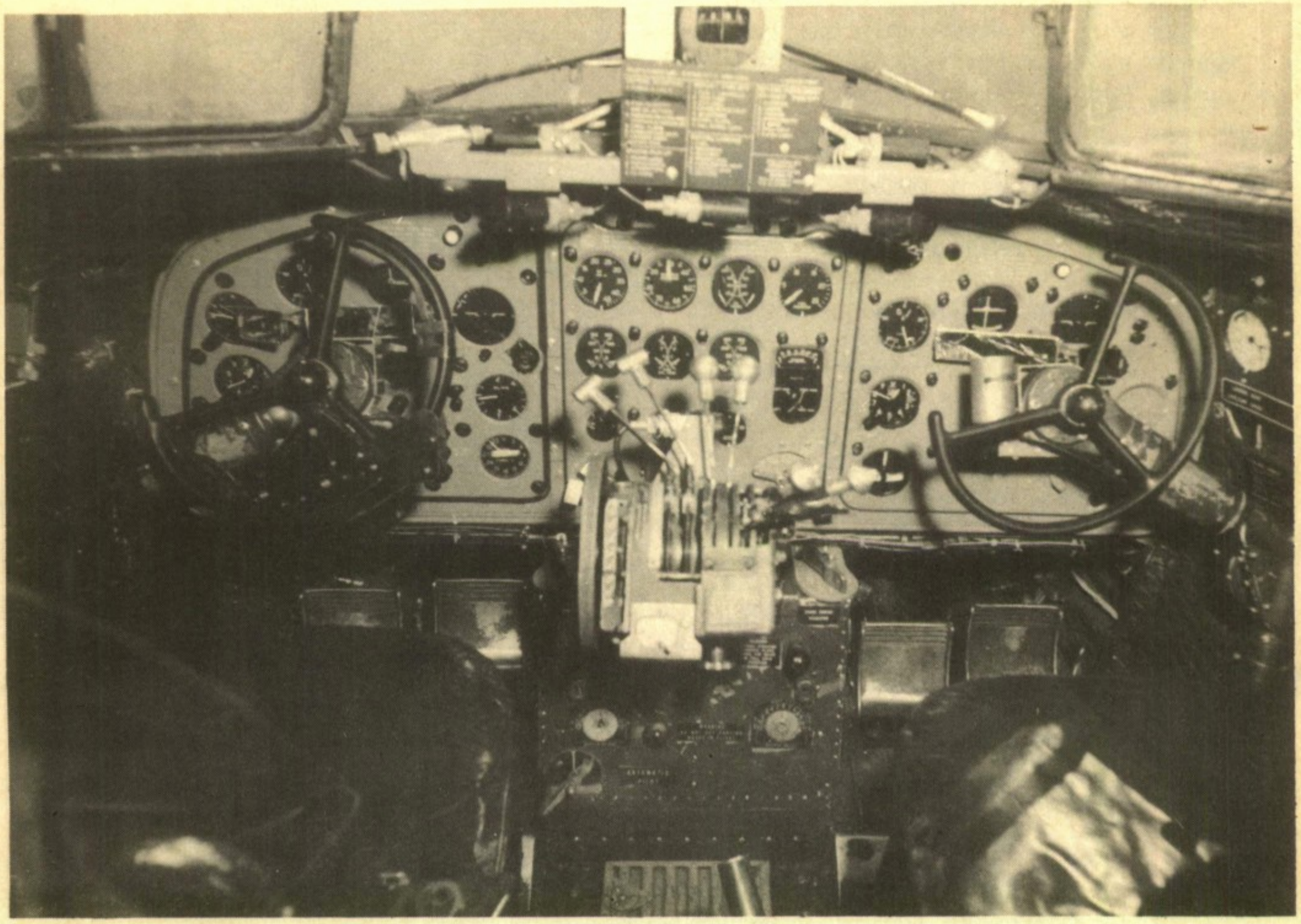
APPENDIX I



Cookpit of C-47 Airborne Psychology Laboratory. Mirrors were removed for the light study and the instrument panel was painted black to conform to present AF usage. Note that co-pilot, as well as pilot has complete flight instrument group.

APPENDIX II

QUESTIONNAIRE

The questions below refer to the three types of lighting systems which you used in the experiment. You are asked to rank the three systems in order of preference in answer to each of the questions. Place the number (1) in the square opposite the system you think is best, number (2), next best and so on. If you have no preference merely place a check mark in the squares provided. If you find one system preferred and no difference between the remaining two, rank the system you prefer and check the other two.

1. Under normal intensity the numerals are most legible under:

    ____ Ultra Violet ____ Indirect Red ____ Red Flood.

2. Under normal intensity the position of the pointers is most quickly and accurately determined under: ____ Red Flood ____ Ultra-Violet ____ Indirect Red.

3. The most satisfactory distribution of light on the instruments is under:

    ____ Indirect Red ____ Red Flood ____ Ultra-Violet.

4. The least glare from the panel is under.

    ____ Ultra-Violet ____ Indirect Red ____ Red Flood.

5. The least reflection from the windows and windshield is under:

    ____ Red Flood ____ Ultra-Violet ____ Indirect Red.

6. The most "pleasant" and "comfortable" system is:

    ____ Indirect Red ____ Red Flood ____ Ultra-Violet.

7. The best lighting under minimum intensities is:

    ____ Ultra-Violet ____ Indirect Red ____ Red Flood.

8. The highest intensity required for most effective use is under:

    ____ Red Flood ____ Ultra-Violet ____ Indirect Red.

9. The least interference to vision of objects outside of the cockpit is under:

    ____ Indirect Red ____ Red Flood ____ Ultra Violet.

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ABSTRACT:

The red flood, indirect red, and ultra-violet instrument lighting systems installed in C-47 transports were investigated by several pilots during night flights. Brightness levels used by the pilots were recorded for the three systems under the conditions of normal night flying, night instrument (maximum), and minimum brightness necessary for safe flight. For normal conditions the lowest brightness level used occurred under red flood and the highest under indirect red. At maximum levels (night instrument condition) red flood was highest, indirect next and ultra-violet and lowest brightness. At minimum levels, indirect red was the lowest followed by ultra-violet and red flood. Indirect red was preferred by the pilots as being the most pleasant and comfortable system and the red flood system was preferred as being the most effective of the three.

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