IN-FLIGHT TEST RESULTS ON MISSION-ORIENTED COCKPIT LIGHTING REQUIREMENTS

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FOREWORD

The experimental flight test program described in this report was designed to obtain mission-oriented baseline data on cockpit lighting requirements. This program was sponsored by the Air Force under USAF Contract Number F33615-69-C-1709 with Lear Siegler, Inc. The contract was initiated under Project Number 6190, "Control-Display for Air Force Aircraft and Aerospace Vehicles," which is managed by Mr. John H. Kearns, III (FGR) as Project Engineer and Principal Scientist for FGR. It was administered by the Flight Deck Development Branch (FGR), Flight Control Division, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. The work was performed as a part of Task Number 6190 14, "Cockpit Lighting," under the guidance of Lt. D.L. Turney (FGR) as Task Engineer. Major John E. Colwell served as Test Director for Director of Flight Test, Bomber Operations Branch (FTFB).

The Instrument Division of Lear Siegler, Inc., (LSI) under Contract F33615-69-C-1709 with the Air Force Flight Dynamics Laboratory, Directorate of Laboratories of the Air Force Systems Command, Wright-Patterson Air Force Base, subcontracted to the Management Services Division of Lear Siegler, Inc., the experimental equipment and recording equipment installation, maintenance, and flight test support under LSI Purchase Order Number 18-E-158552. North American Rockwell Corporation, (NR), Columbus, Ohio, under LSI Purchase Order Number 18-E-158537 was subcontracted to design the experimental program plan, conduct experiments, perform data reduction and analyses, and submit a final report. NR Report No. NR71H-193, with some additions by LSI, constitutes this report.

Initially, Mr. Leroy Addis and later Mr. Carl J. DeBruine served as Program Manager at LSI, and Mr. Ben Schohan served as the Project Engineer at NR. Dr. David L. Easley of NR participated in the conceptual stage of this study and in the development of the experimental designs. Mr. Thomas P. Enderwick of NR provided the data reduction and statistical analysis.

Acknowledgement with appreciation is extended to the USAF test pilots at WPAFB who participated in the flying and to the Air Force and Bunker-Ramo personnel who assisted in collecting the data on which this report is based.

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This technical report has been reviewed and is approved.

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ABSTRACT

This report describes an experimental program designed to obtain baseline cockpit illumination data using three types of electroluminescent display lighting. A series of three in-flight experiments was flown in a T-39 aircraft by highly experienced USAF pilots. The mission profiles were designed to simulate different types of operational flights by progressively increasing the external visual task loading on the pilot. Both objective measurements and pilot opinion data were obtained on display illumination under external ambient illumination ranging from twilight to night no-moon conditions. Photometric data collected during the flights showed that the pilots' display lighting requirements were influenced by the outside ambient illumination only when this illumination exceeded .001 foot candles. When the night ambient illumination fell below this level, display illumination was primarily influenced by: 1) the pilots' pre-flight dark adaptation; 2) the type of information required for successful mission completion and the priority the pilots placed on the information available; and 3) the effects of cockpit lighting on display legibility. The experimental results showed that a range of 1.0 to .01 foot lamberts is sufficient for night illumination of displays incorporating either EL-transmitting or EL-reflecting illumination. EL-emitting displays, which must be illuminated under both daylight and night ambient conditions, will require an illumination range of approximately 20.0 to .01 foot lamberts. The effects of mission requirements and display design on cockpit lighting are discussed. Conclusions and recommendations for cockpit lighting based on pilot performance and pilot opinion are also presented.

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I

INTRODUCTION

I. 1 STATEMENT OF THE PROBLEM

One of the basic problems in the specification, design and selection of cockpit lighting hardware for military aircraft is the lack of operational lighting requirements data. The vast majority of the data used in the past has been based on theoretical interpretations and extrapolations from the vision and lighting literature. Indirect derivations of this type have not only led to confusion and controversy (AGARD Symposium, Ref. 1) but have also failed to meet the pilot's needs (Milligan, Ref. 2).

Results of a study by Wilcox and Cole (Ref. 3) suggest that the levels of dark adaptation sensitivity frequently used as criteria for lighting systems are too low. These criteria were based upon the amount of sensitivity obtainable under completely blacked-out laboratory conditions. They found that the absolute threshold sensitivity for flight (as measured with a portable adaptometer) was much higher during night flight than when measured in the cockpit while the aircraft was in a blacked-out hangar.

Several investigations detailed in the AGARD Symposium (Ref. 1) concluded that the selection of a cockpit lighting system should be determined by the level of dark adaptation required in the operational setting. One investigator further pointed out that regardless of the lighting system used, the level of dark adaptation which a pilot achieves is going to be based on his pre-exposure history (Hambacher, Ref. 4). Thus, a differential sensitivity in dark adaptation obtained with two lighting systems, based on theoretical prediction, may be nulled or even reversed in the operational situation, depending on how the pilot uses his cockpit lighting.

It has been recognized for some time that when the pilot is provided control over his cockpit illumination "the determination of the compromise between dark adaptation and instrument reading is placed squarely in the hands of the pilot" and not the illumination or design engineer (Smith and Goodard, Ref. 5). A thorough search of the literature on cockpit illumination revealed only three studies where data were obtained on pilots' use of lighting controls during flight (Cole, et. al, Ref. 6; Dohrn, Ref. 7; and Burnett, Ref. 8). These studies, while attempting to solve the basic problem, were limited in scope and in all cases the lights used were of the incandescent type which confound the brightness data with color shifts. (Planet, Ref. 17; and Bensussen, Ref. 18). If cockpit lighting is to be appropriate for military pilots the data from which the lighting specifications are derived must be based on the actual in-flight environment. This data must also be unambiguous and applicable over a full range of missions and ambient light conditions.

I. 2 APPROACH TO THE PROBLEM

To obtain valid cockpit lighting data four key elements of the operational situation were considered. These elements were (1) the cockpit lights, (2) the external ambient light environment, (3) the mission and (4) the pilot.

In this program, measurement of the light intensity used for illumination of the forward instrument panel was selected as the primary source of data. A prototype electroluminescent (EL) illuminated instrument panel, a pilot's control box containing individual display rheostats, and a visacorder voltage recorder were used as the basic light measurement tools. Three basic types of lighting were investigated -- EL-reflected light, EL-transmitted light, and EL-emitted light. In addition, EL light is unique in that the color of the light remains constant over the total brightness range, thus eliminating the color shift dilemma previously found when using incandescent bulbs. (King, et. al, Ref. 19).

The cockpit light environment was measured throughout each mission by simultaneously recording outputs from outside ambient light sensors and the instrument light rheostats. This permitted a direct comparison of the pilots'instrument light level selections and the external ambient light levels encountered.

Three experiments were designed to investigate a wide range of mission conditions. A fully head-down IFR flight situation was selected as the baseline mission. Subsequent mission profiles were designed to force the pilot to spend more and more time head-up, attending to out-of-the-cockpit tasks.

A group of exceptionally skilled and highly motivated Air Force test pilots served as subjects for the experimental flights. One of the basic assumptions in this program was that if the pilot is instructed to maintain the brightness of his instruments at the minimum level for safe flight, the brightness levels he selects are his lighting requirements for those instruments. Therefore, if different display light intensities are required for different operational conditions, these changes will be shown by the pilot's display brightness selection. The pilots were also given the opportunity to express their opinion through the use of questionnaires and during debriefing sessions following each flight. Thus, efforts were made throughout the program to obtain both pilot performance and pilot opinion data which could be used to define basic cockpit lighting requirements.

II

THE EXPERIMENTAL PROGRAM

II. 1 OBJECTIVES

The primary objective of this program was to collect baseline data on cockpit lighting requirements for a variety of night missions throughout the entire spectrum of night ambient illumination conditions. A secondary objective throughout all experiments was to obtain expert pilot opinion on display lighting techniques and control of cockpit lighting. Three experiments were performed to cover the scope of these basic objectives.

The objective of the first experiment was to obtain data on the pilot's lighting requirements in response to the change of external ambient illumination starting at official sunset and flying until the sky was fully darkened. The objective of the second and third experiments was to obtain detailed data on the pilot's lighting requirements under different levels of night ambient conditions ranging from full moonlight to starlight. Mission profiles for these latter experiments were segmented to represent a spectrum of mission tasks. The sequence of these missions was designed to place progressively increasing out-of-cockpit visual demands on the pilot. In addition, during the second experiment the effects of peripheral cockpit lighting were investigated. Peripheral lights such as the console, pedestal, and overhead panel lights contribute to the overall level of illumination within the cockpit. To determine the effects of peripheral lights on display brightness requirements, flights were made with peripheral lights either on or off under starlight ambient conditions.

II. 2 EQUIPMENT

TEST VEHICLE

A low wing, twin jet USAF T-39 (Aircraft No. 610649) was flown in all experiments (Figure 1). The primary T-39 missions are personnel transportation, flight training, and maintenance of flying proficiency for multi-engine jet crews. The T-39 has a standard side-by-side cockpit for the pilot and co-pilot. It has a normal passenger capacity of seven. The cockpit and cabin compartments are pressurized and soundproofed for comfortable flight at all operational altitudes.

COCKPIT

For this program the aircraft cockpit was modified as follows: 1) the pilot's instrument panel was replaced with a prototype EL instrument panel, 2) a small black curtain was placed between the pilot's and co-pilot's stations to exclude light from the safety

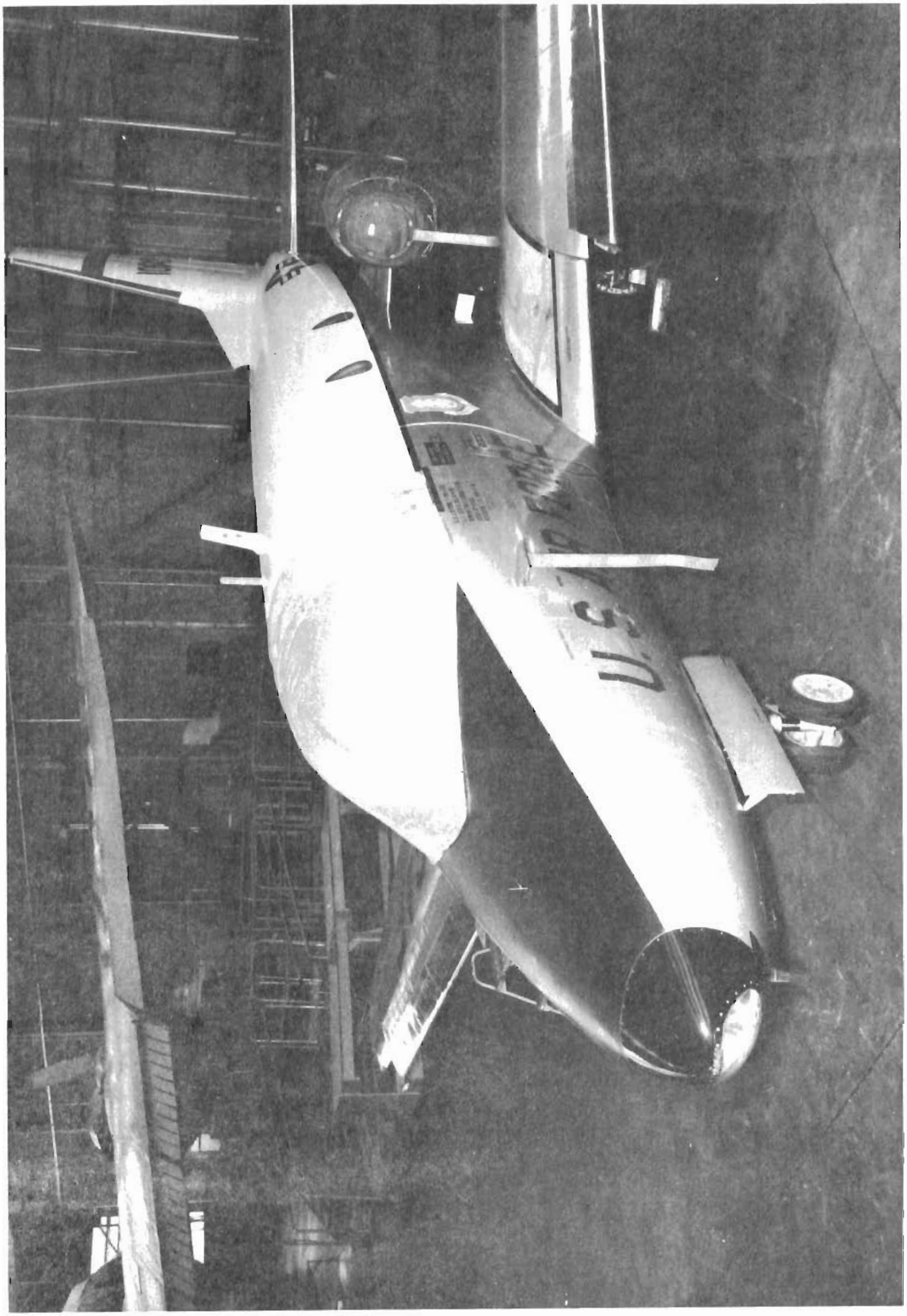

FIGURE 1. USAF T-39 USED IN THE EXPERIMENTS

pilot's (normally the co-pilot's) console and instrument panel, 3) the center portion of the forward panel where the radios are normally located was reconfigured to accept conventional engine and fuel displays, and 4) the radio control heads from the forward panel were relocated to a "swing-down" console located between the two pilots.

The latter two modifications were made to provide redundant engine and fuel displays while permitting both pilots access to the radios.

Pilot's Instrument Panel

A photograph of the pilot's instrument panel is shown in Figure 2. Three different EL techniques were employed to light the displays: reflection, transmission, and emission. The light-reflecting displays contained EL wedge lamps to distribute the light across the display surfaces. The light-reflecting instrument group included the ADI, HSI, Airspeed and Vertical Speed indicators and the Altimeter. These displays used standard formats which were flown during the PIFAX program (References 9 and 10). The light-transmitting displays contained EL lamps mounted on the rear of the plastic diffusing blocks. The light transmission through the plastic blocks was controlled by painting the front surfaces to selectively emit the light. Displays lighted in this manner were the Oxygen Pressure Indicator, the Radio Call Panel, the Clock Panel, the Antenna Oxygen Panel, and the Course-Select/Fuel Quantity Panel.

The light-emitting displays used EL light as the display element. These displays were of high contrast design and employed a circular polarizing filter mounted in front of the lamp to trap reflected light and further increase display contrast. (A detailed description of the high contrast technique employed in these displays is provided by Peteryl, et.al., Ref. 11). The EL-emitted light was of sufficient intensity to contrast with its background under a wide range of ambient illumination levels. Two types of EL-emitting displays were incorporated in the panel, (1) the digital readout clock and (2) the vertical scale engine and fuel displays. The Temperature and RPM displays contained integral limit lines, which were energized during normal operation to provide a horizontal line segment of light across the vertical scales denoting "red line" limits for temperature and RPM. When either limit line value was exceeded for these engine parameters, the entire scale of the respective display flashed until the scale indication dropped below that of the limit line. During the time that a "red line" value was exceeded, the limit line segment was de-energized, thus creating a reference line.

The light-reflecting and transmitting EL displays were illuminated with lunar white light. The light-emitting displays were illuminated with green EL light having a predominant wave length of 530 nanometers (ICI color coordinates are X = .293 and y = .548). Since there is no shift in color as the intensity of EL illumination is

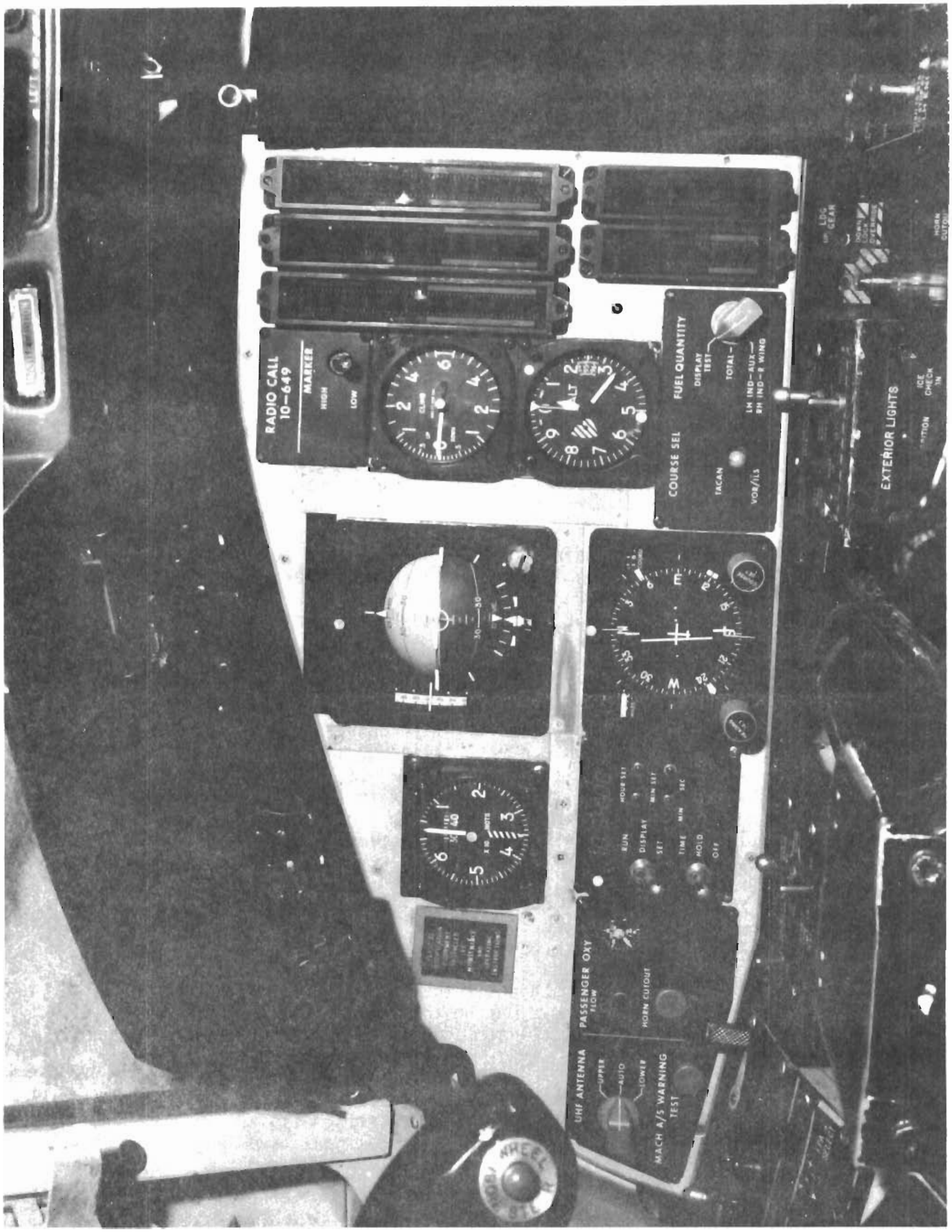

FIGURE 2. PROTOTYPE ELECTROLUMINESCENT INSTRUMENT PANEL

changed, instrument brightness requirements in this study were not contaminated by such shifts.

Pilot's Dimming Control Box

A dimming control box was installed above the left console at the pilot's station (Figure 3). The dimming control box contained individual rheostats for adjusting the light intensity on all displays with the exception of the engine and fuel displays. These vertical displays were grouped on two rheostats; one for the scale markings and numbers, which will be referred to as the "engine legends", the other for the "tape" indicators, hereafter referred to as the "engine indices". The engine indices were made up of small EL segments which illuminated in sequence and gave the appearance of a moving tape. Two rheostats were also provided for adjusting the lighting of the clock; one for the legends, and one for the numbers. The oxygen panel also required two rheostats, one for the panel legends and a second for the small oxygen pressure gage. The control box also contained four inactive rheostats for landing displays which are to be used in subsequent programs.

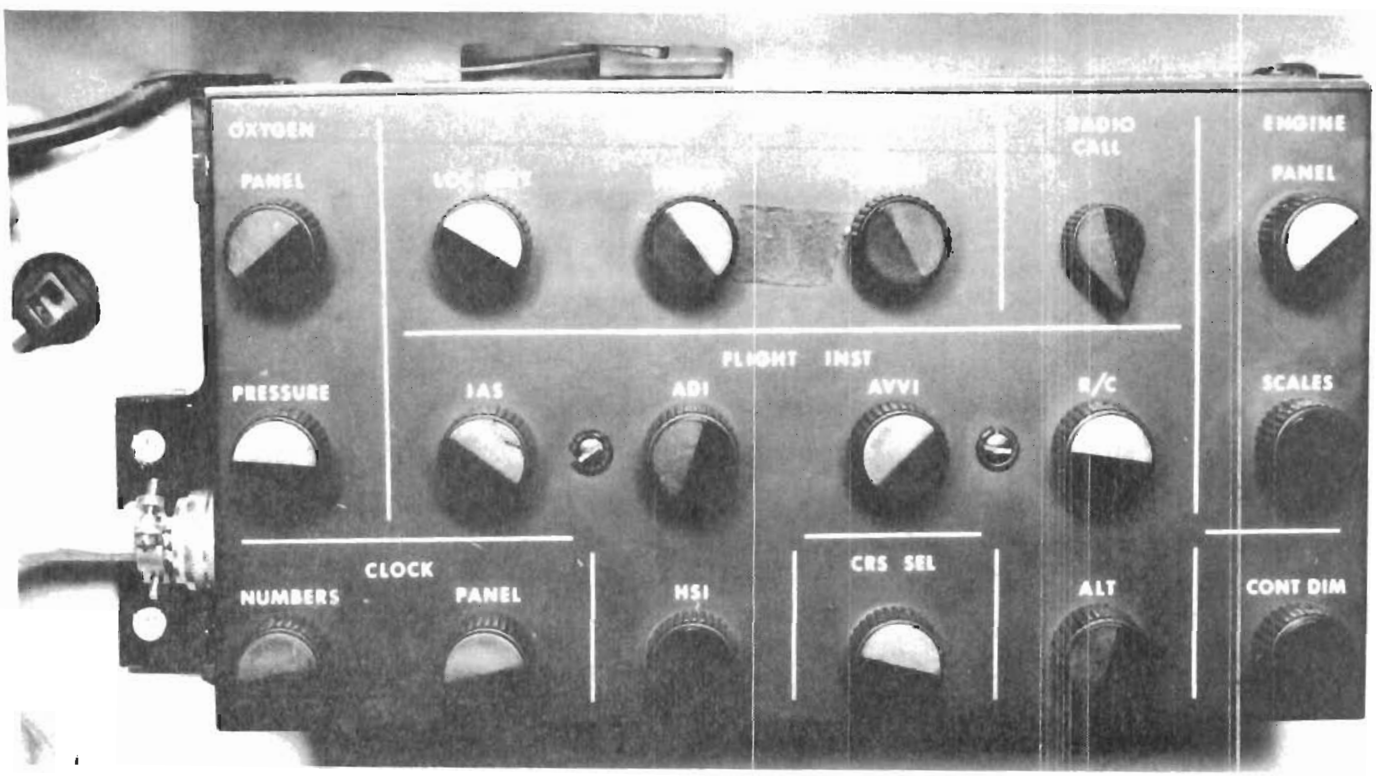

FIGURE 3. PILOT'S DIMMING CONTROL BOX CONTAINING RHEOSTAT'S FOR EL DISPLAYS

The legends on the pilot's dimming box were EL backlighted, and a rheostat on the lower right portion of the panel was provided for adjusting the legend brightness. All dimming control rheostats required a single 360^{0} turn to adjust the brightness from off to maximum intensity.

A new master dimming rheostat for the entire pilot's instrument panel was installed on the left console. For this program the master rheostat was placed in the full on position and all dimming adjustments of the instrument panel display lights were accomplished with the individual display rheostats on the dimming control box. No modifications were made to existing rheostats for the console, overhead, and pedestal lights.

DATA COLLECTION INSTRUMENTATION

The following instrumentation was installed (see Figure 4) in the T-39 to facilitate in-flight data collection:

Recorder - A 24-channel (direct readout) Visacorder and a 20-channel demodulator rack were used. These units were located on an integral mount which replaced the right forward passenger seat.

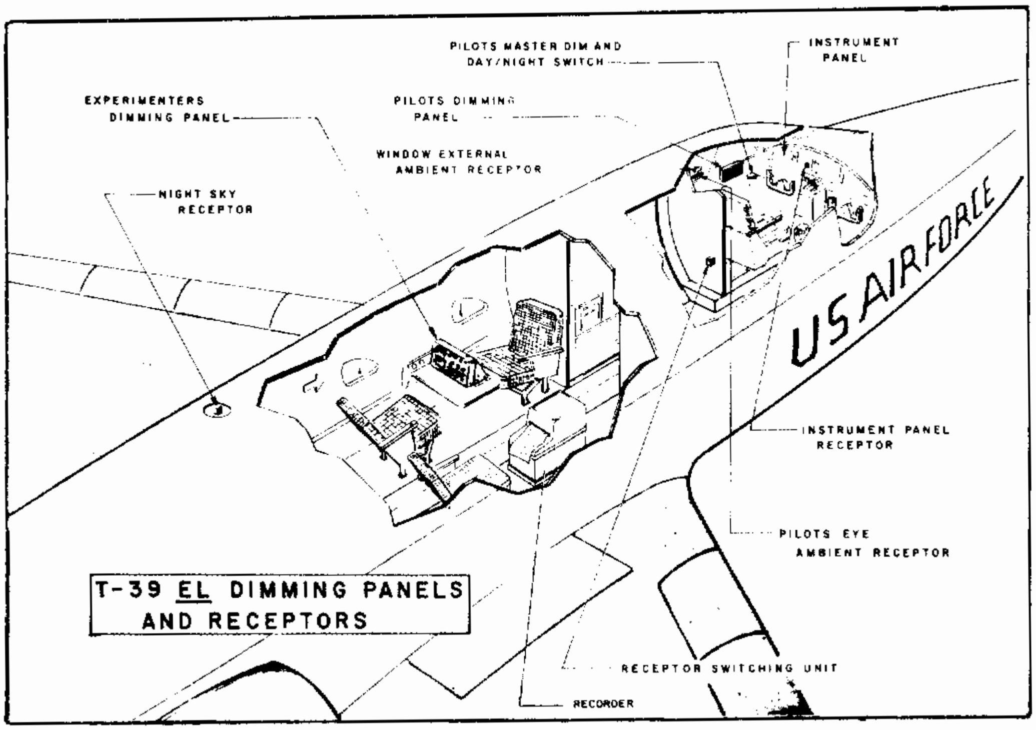

FIGURE 4. DIAGRAM OF DATA COLLECTION AND PHOTOMETRIC RECEPTOR INSTALLATION

Photometeric System - A Gamma Scientific Photometer, Model 2020, was used to obtain measurements of ambient light levels both within and outside the cockpit of the aircraft (Figure 4). Two photomultiplier heads and four receptors (cosine corrected) were used (Figure 5). The photogalvanometer of the photometer was located at the experimenter's console. One photomultiplier head was mounted behind the pilot's seat on the bulkhead of the pilot's cabin (Figure 6). Three receptors directed light into this photomultiplier through fiber optic bundles, providing ambient illumination measurements at each of the following positions: (1) the left side of the aircraft, (2) near the pilot's eye, and (3) on the pilot's instrument panel. The fourth receptor directed light from above the aircraft through a fiber optic cable to the second photomultiplier head which was fixed in the sextant mounting on the rear ceiling of the cabin.

Experimenter's Console - A console for the experimenter (Figure 7) was installed on the navigator's table between the two individual passenger seats on the left side of the cabin (Figure 4). The major features of the console included a direct readout digital voltmeter display with selector switches for individual light control monitoring, rheostats for control of cockpit lights, switching for data recording, an event marker button for the recorder, a clock, and the photogalvanometer and its associated controls. Interphone radio controls and controls for the rear photometer were located to the left of the experimenter's console.

II. 3 GENERAL METHODOLOGY

EXPERIMENTAL PROCEDURES

The following general procedures were employed in all experiments:

All subject pilots were required to complete a general cockpit lighting questionnaire and the personal data form shown in Appendix A, page 82. The cockpit lighting questionnaire, which was employed in a previous study (Milligan, Ref. 2), was used to familiarize the pilots with the type of questions which were to be asked during the post-flight debriefing. It was also used to compare the opinions of the pilots who flew as subjects in this study with the opinions of other Air Force pilots who had previously responded to this same questionnaire.

The subject pilots received an orientation briefing which included a ground checkout with the EL instrument panel, and a general mission briefing. The purpose of the orientation briefing was to acquaint the subject pilots with the objectives of the experiment, brief them on the tasks they were to perform and provide them with background information on the experimental equipment and procedures. The agendum for the orientation briefing is outlined in Appendix A, page 83. During the orientation session, the pilots also filled out an opinion

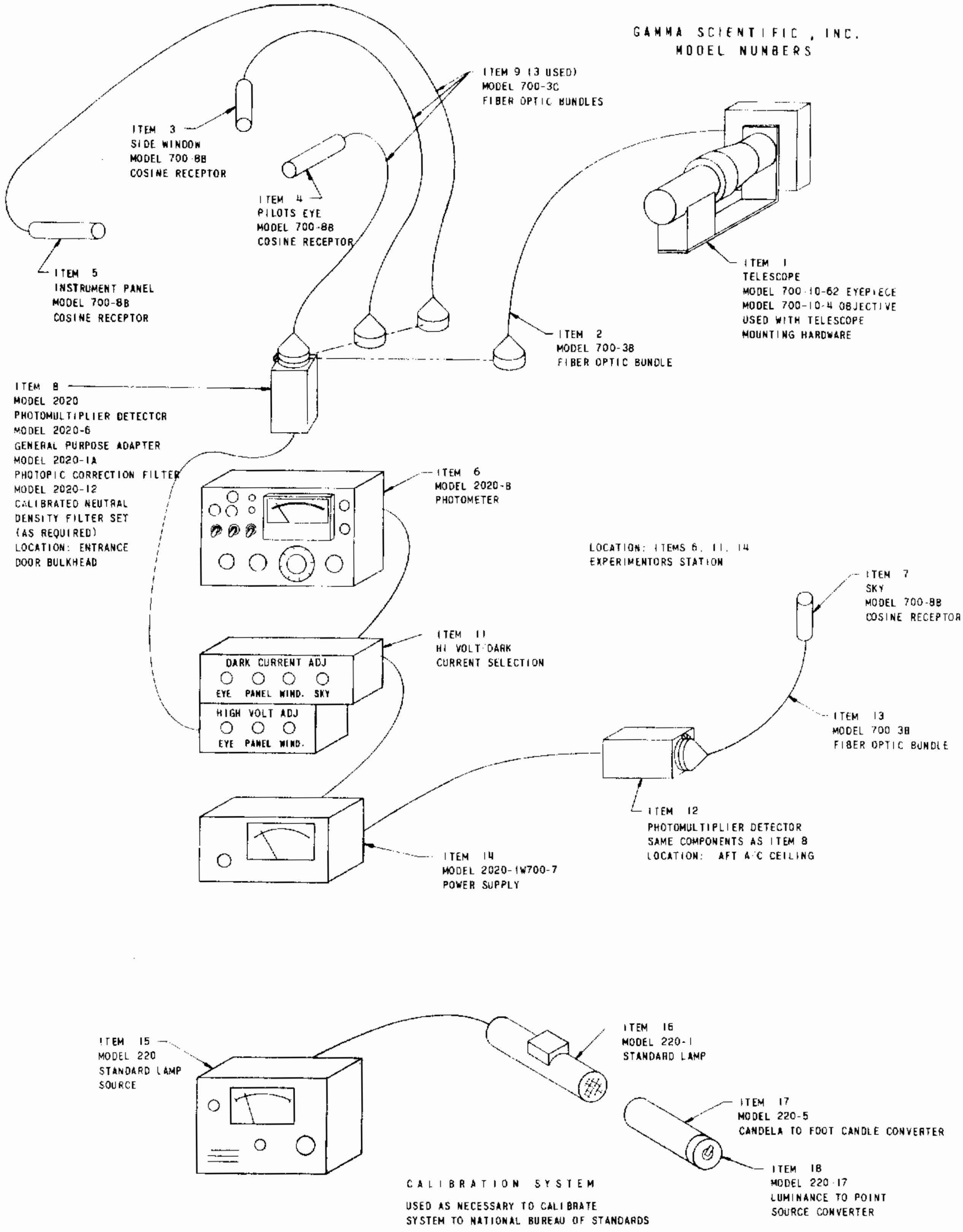

FIGURE 5. T-39 LIGHT MEASURING SYSTEM

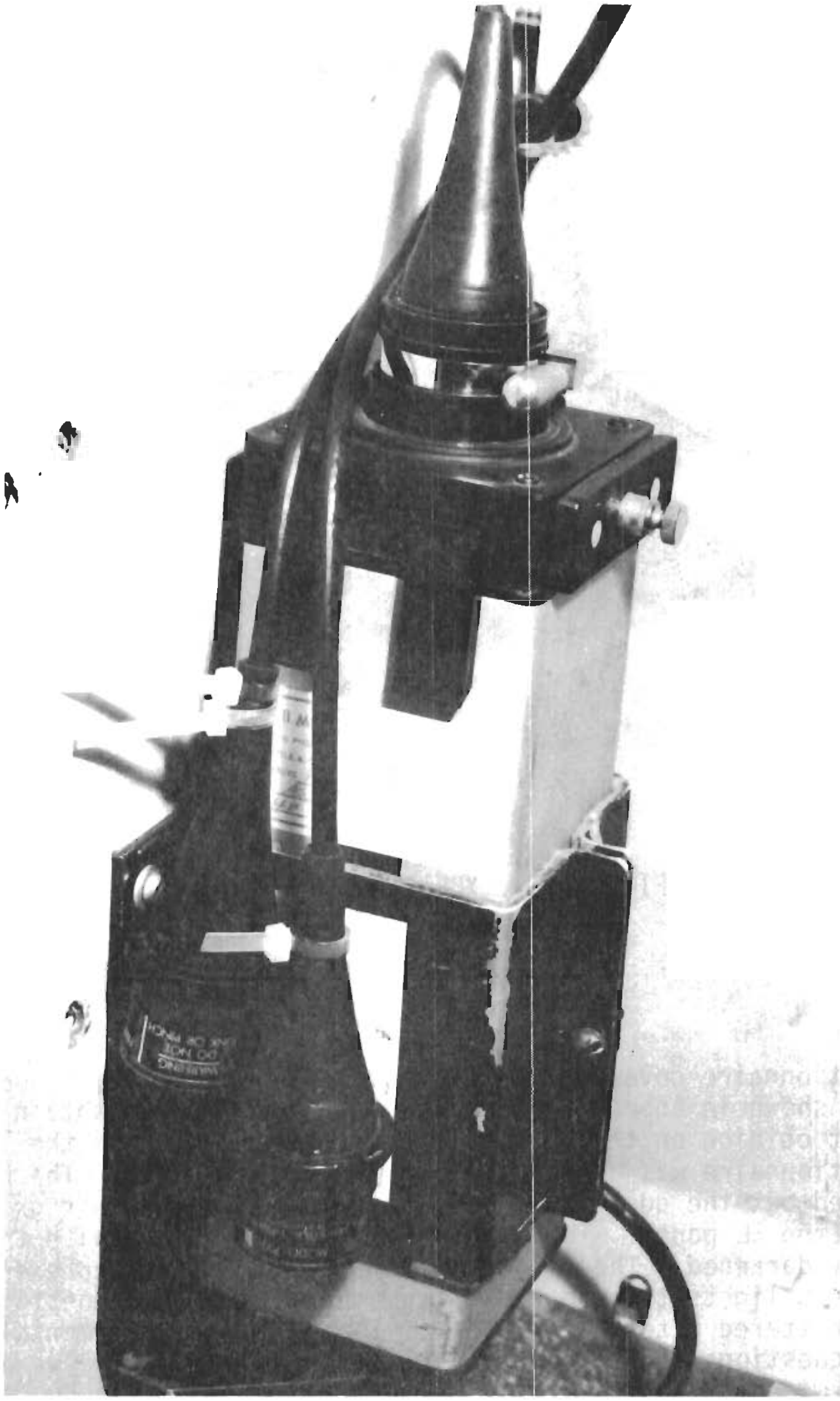

FIGURE 6. PHOTOMETER PHOTOMULTIPLIER HEAD LOCATED BEHIND THE PILOT'S SEAT ON BULKHEAD

FIGURE 7. EXPERIMENTER'S CONSOLE

questionnaire covering the EL lighting system. This EL questionnaire, also shown in Appendix A, page 84, was designed to obtain detailed pilot opinion on the EL lighting system installed in the T-39. This questionnaire was administered to each pilot twice. The pilots first filled out the questionnaire after they received their ground checkout with the EL panel. The ground checkout took place with the cockpit fully darkened. The pilots adjusted all displays and exercised the cockpit lights through their full range. The same questionnaire was administered after the pilots completed their experimental flight(s). The questions and the ratings in the EL questionnaire were used to determine: 1) what, if any, bias existed toward the EL lighting prior to flight, and 2) the effects of flight experience with the EL lighting on pilot opinion.

A detailed mission briefing was given during the orientation session. Three different types of missions were flown. The Experiment I mission consisted of a series of box patterns flown at high altitude in a restricted area. Only radio navigation was used and no out-of-the cockpit visual tasks were imposed. A high/low cross-country profile was flown in Experiment II. Out-of-the-cockpit visual tasks included in the low altitude portion of the profile included checkpoint identification using radio aids and the "see and be seen" requirement for avoiding low altitude aircraft under VFR conditions. A simulated low-level penetration and weapons delivery mission was flown in Experiment III. A low level oil burner route was flown at an altitude of 1000 feet above the ground. Out-of-the-cockpit visual task loading was increased by requiring low level checkpoint identification without the use of radio aids. Complete details of these missions are contained in the mission portion of the individual sections on each experiment.

A review of the mission briefing was given just prior to each flight using the briefing form shown in Appendix A, page 86. The pilots were instructed to use their cockpit light in any manner they chose, the only constraints being that they were to maintain the brightness of the forward instrument panel "at the minimum level for safe flight", and the forward panel flood lights were to be left off except for emergencies. The latter constraint was necessary to obtain accurate brightness measures of the individual displays.

A thorough post-flight debriefing was conducted after completion of each flight. Using the debriefing questionnaire shown in Appendix A, page 87, the experimenter verbally presented the questions to the subject pilot and wrote down his answers. The verbal question and answer method was selected to provide the experimenter freedom to dig deeply into those areas where problems might exist and to uncover the specific reasons behind simple yes and no answers. This method also encouraged the subject pilots to not only point out problems with the lighting system but to propose solutions to these problems.

Crew Responsibilities

A crew of five participated in each experimental flight. The crew consisted of a safety pilot, a subject pilot, an experimenter and two equipment technicians.

Safety Pilot - A safety pilot sat in the co-pilot seat on every experimental flight. The safety pilots were all highly qualified Air Force test pilots and T-39 instructor pilots. The safety pilot filled out and signed the clearance and was primarily responsible for the safe conduct of the experimental flight. He also obtained the weather briefing prior to the flight and was responsible for the final go, no-go decision based on the weather and experimental flight restrictions. The safety pilot also conducted a short briefing for all crew members covering those items for which he, as aircraft commander, was responsible. In the event of an equipment malfunction or an in-flight emergency, the safety pilot was responsible for assuming control of the aircraft until the emergency was terminated. If at any time during the flight the weather or any other factor interfered with the safe conduct of the flight, it was the safety pilot's prerogative to abort the mission.

Subject Pilot - The subject pilots were selected by the FTFB Test Director, from a pool of Air Force test pilots at WPAFB. During the experimental missions the subject pilots flew in the left seat normally occupied by the pilot in command. They were permitted to request the safety pilot to change radio frequencies, tune the radio navigation aids, and make appropriate radio calls. However, the subject pilots were responsible for their own navigation throughout the mission.

Experimenter - Prior to each flight, the experimenter briefed the safety pilot and subject pilot. Before taxiing out for take-off, he checked out his instrument console and the in-flight recording equipment using the checklist shown in Appendix A, page 90. The experimenter recorded the required data throughout the flight. After the completion of each flight, the experimenter debriefed the subject pilot and recorded the pilot's answers to the questions in the post-flight questionnaire.

Equipment Technician - Two equipment technicians participated in each flight. One technician was primarily responsible for the onboard data recording equipment. The other technician performed manual switching of various equipment and assisted the experimenter as required. One of the two technicians was also qualified to trouble-shoot and perform in-flight maintenance on all experimental equipment.

Calibration Procedures

In order to assure accurate, reliable data, written procedures were followed and all equipment was calibrated at regularly established intervals. Calibration times for the equipment were as follows:

EL Lighting - Voltage brightness calibrations for each of the thirteen controls of the EL lighting were made with the cockpit in total darkness prior to the start of each experiment, at monthly intervals during an experiment, and at the conclusion of each experiment (Appendix F).

Peripheral Lighting - Voltage brightness calibrations were made for the console, overhead, and pedestal lighting. They were obtained immediately before data collection began and again when data collection was completed for each of the three experiments.

Photometer - Using a standard lamp source, each of the four cosine receptors was calibrated prior to each data collection flight (Appendix E, pages 111 through 114).

Visacorder - Prior to each data collection flight, the Visacorder channel calibrations were checked against established calibration limits.

Data Collection

Both subjective and objective data were collected during each experiment. The basic procedures for collecting these data were the same for all experiments.

The forms for collecting the subjective data have been previously discussed in the Experimental Procedures section and appear in the Appendices. In general, these data consist of information on the background of the subject pilots and the pilots' opinions of standard aircraft lighting and a critique of the EL display lighting used in the study. These data were used to describe the pilot population, and amplify and extend the objective data.

Objective data for all experiments included the brightness levels of the pilot's displays, the brightness of peripheral cockpit lights, external ambient illumination levels, and normal acceleration levels (G's). These data were recorded in-flight as voltages on the Visacorder. The voltages were manually read from the Visacorder chart and converted through use of a computer program into the appropriate light measurements. These data were then tabulated, analyzed and graphed. Individual brightness measurements were made of the following displays:

1) Airspeed
2) ADI (Altitude Direction Indicator)
3) HSI (Horizontal Situation Indicator)
4) Altimeter
5) Rate-of-Climb
6) Engine Legends
7) Engine Indices
8) Clock Numbers
9) Clock Panel
10) Oxygen Pressure
11) Oxygen Panel
12) Radio Call Panel
13) Course Select Panel

To record the full range of ambient illumination, filters were placed in the photomultiplier heads during daylight ambient conditions. The photogalvanometer was equipped with a variable sensitivity selector with a range of 3.0 ft. candles to 1 X 10^{-5} ft. candles to cover all normal night ambient illumination levels. Brightness settings from the displays and ambient illumination reading from the cosine receptors were all recorded as voltage outputs on the Visacorder. The data was "packaged" as voltage outputs from display groupings. Approximately 1.5 minutes were required to manipulate the switches on the experimenter's console and sample all the data outputs.

III

EXPERIMENT I

III. 1 SUBJECTS

Five USAF test pilots participated as subjects in Experiment I. The pilots were all graduates of the USAF Test Pilot School and ranged in age from 31 to 44; the average age was 35. Their average total flight time was 4575 hours which included 416 hours combat time and 884 hours night time. The subject pilots all had experience in a wide variety of both single and multi-engine aircraft and averaged 11 years as rated pilots.

III. 2 MISSION

The Experiment I mission originated at Wright-Patterson Air Force Base (WPAFB) and was approximately 2.5 hours in duration. Takeoff times were scheduled for 20 minutes prior to official sunset. The mission profile for Experiment I is depicted in Figure 8.

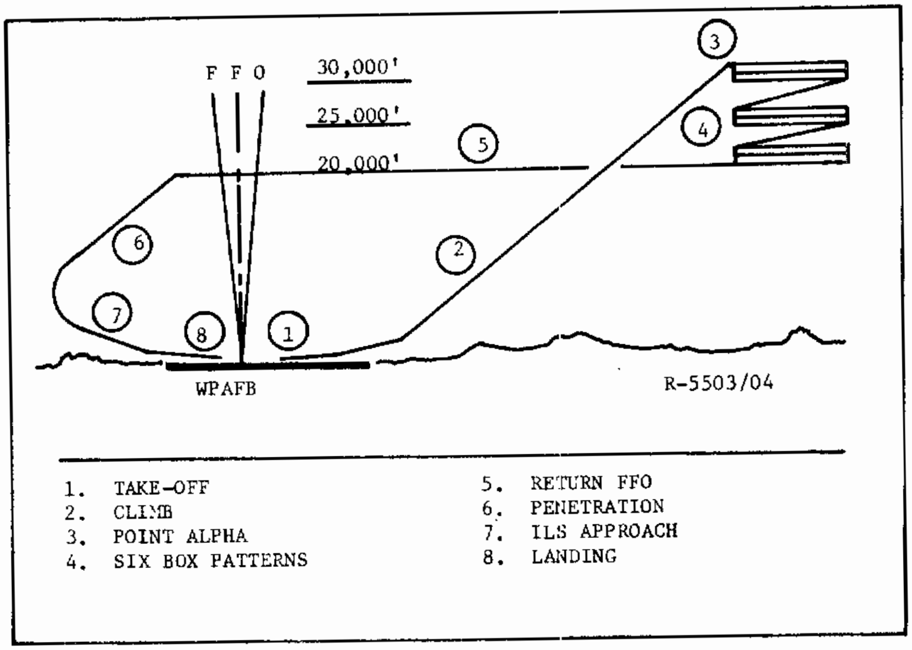

FIGURE 8. EXPERIMENT I MISSION PROFILE

After takeoff the aircraft was radar vectored to the restricted area (R-55004/03) adjacent to WPAFB. Upon entering the restricted area, the pilot climbed to 30,000 feet and intercepted the 162° radial of the Patterson TACAN (FFO). The pilot adjusted an abbreviated holding pattern to cross the 34 nautical mile fix of the 162° radial within ±10 seconds of official sunset. A series of six box patterns were then flown from point to point TACAN fixes. The headings, radials, and distances used in the box pattern are shown in Figure 9. Two box patterns were flown at 30,000 ft., followed by a descent to 25,000 ft. Two more patterns were then flown and a second descent made to 20,000 ft. The final two patterns were completed

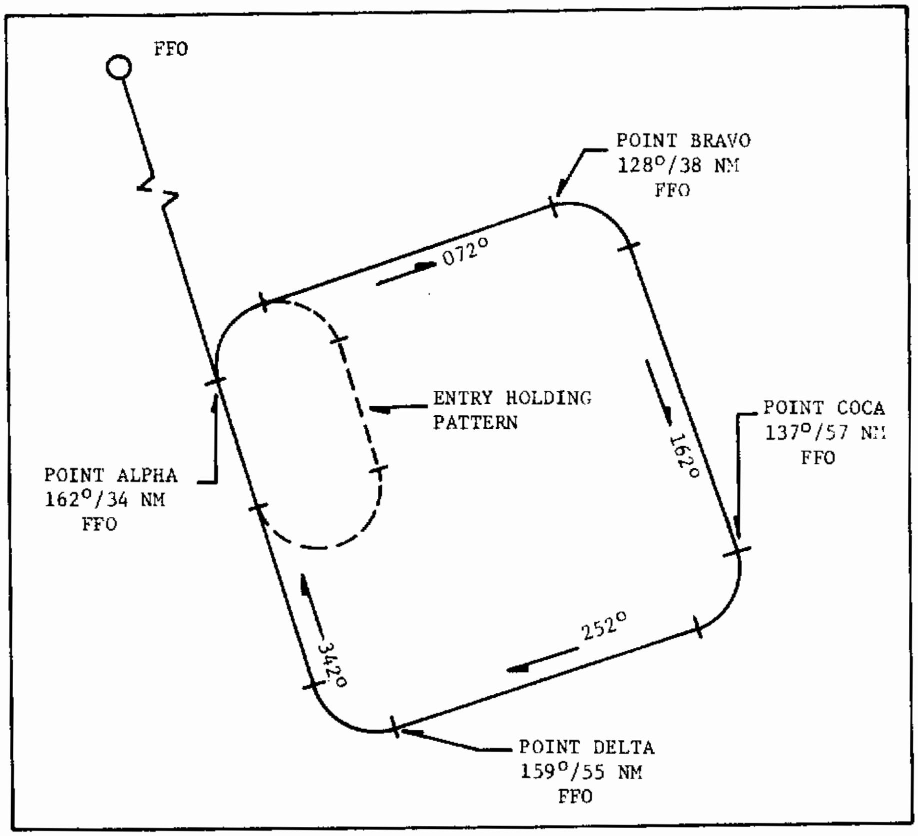

FIGURE 9. EXPERIMENT I BOX PATTERN

at 20,000 feet. Airspeed was varied at the different altitudes to maintain patterns which were approximately 16 minutes in duration. The box arrangement effectively cancelled any wind effects. After completion of all six patterns, the pilot flew to the approach fix at FFO and made a TACAN penetration and ILS approach followed by a full stop landing at WPAFB.

III. 3 PROCEDURES

In addition to the general procedures outlined in Section II, the following procedures were used in this experiment.

The subject pilots each participated in three data flights. This procedure was initiated to determine the extent of inter-subject variability from one flight to another. During the orientation briefing, the pilots were provided a mission card which contained the flight sequence (Appendix B, page 92), a flight course card depicting the box pattern, TACAN radials and distances similar to Figure 9, and a mission profile card similar to Figure 8. A debriefing was conducted by the experimenter after the completion of each flight. After each pilot's final flight, he completed the EL questionnaire for the second time. Photometric and display brightness voltages were recorded by the experimenter at selected points throughout the mission (see the experimenter's data sheet Appendix B, page 93).

III. 4 EXPERIMENTAL DESIGN

The independent variables for Experiment I were the ambient levels of illumination measured at the pilot's eye and directly above the aircraft. The dependent variables were the illumination measures taken from twelve pilot controlled rheostats. Five pilots flew the mission three times each to enhance the reliability and stability of the data.

III. 5 DATA ANALYSIS

For purposes of data analysis, graphs were drawn of the pilot's display brightness settings as a function of mission time. Photometric measures of the ambient illumination at the pilot's eye and directly above the aircraft were also plotted in a similar manner. Correlations were then performed to determine the influence of the ambient illumination on the pilot's display brightness settings. Pearson product moment correlation coefficients (R) were computed using the method described by Hays (Ref. 12). Significance levels were based on the correlation coefficient values table in Edwards (Ref. 13).

III. 6 RESULTS

PHOTOMETRIC DATA

The ambient illumination photometric data was averaged over all pilots and all flights. Figure 10 is a graph of the ambient illumination recorded from two of the cosine receptors, one located near the pilot's eye and the other located in front of the vertical stabilizer, pointing at the sky directly above the aircraft. The data points plotted in Figure 10 included measurements at points Bravo and Delta in each of the six patterns, when passing through 10,000 ft. in the let-down, and at two miles from the runway on the final approach.

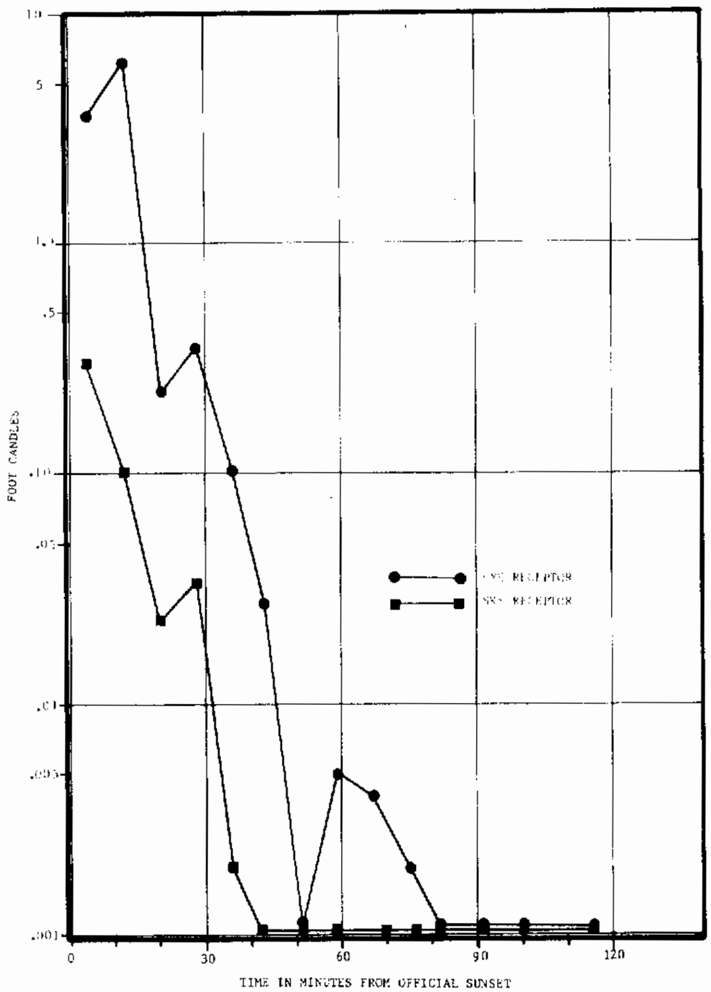

FIGURE 10. AMBIENT ILLUMINATION AS A FUNCTION OF TIME AFTER OFFICIAL SUNSET

During the first hour of the flight, the illumination at the pilot's eye was consistently higher at point Delta. This was due to the orientation of the box pattern. The aircraft was flying away from the setting sun on the Alpha to Bravo leg and toward the setting sun on the Coca to Delta leg. The effect of sun position was not as pronounced on the cosine receptor pointed at the sky except for a short time period about 30 minutes after official sunset. The sun position at this time was such that atmospheric dispersion may have caused the sky illumination to momentarily increase. The position of the cosine receptor in front of the aircraft vertical stabilizer may also have influenced this momentary rise.

Smoothed curves of the ambient illumination are shown in Figure 11.

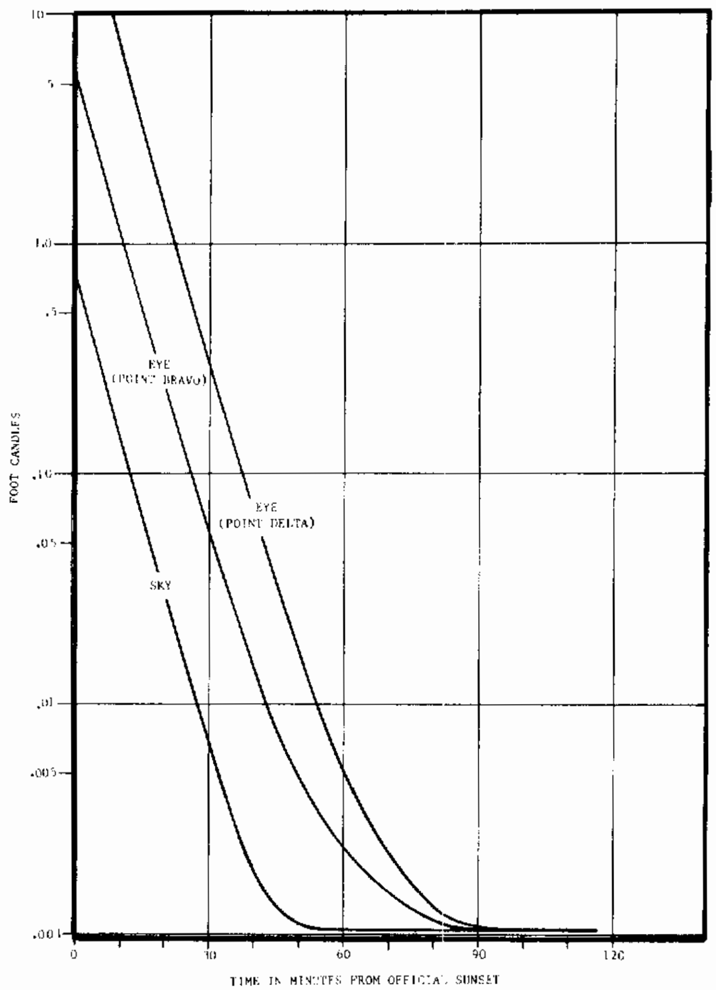

FIGURE 11. AVERAGE AMBIENT ILLUMINATION INTO AND AWAY FROM THE SUN AND DIRECTLY ABOVE THE AIRCRAFT AS A FUNCTION OF TIME AFTER OFFICIAL SUNSET

The eye position data is plotted as two curves, one showing illumination encountered when flying into the sun and the other when flying away from the sun. The sky illumination curve has also been smoothed. The time period shown in the figure is from official sunset until approximately 2 hours after official sunset.

The differential of the two eye receptor curves was insignificant (less than .003 ft. candle) after one hour of flight. This was the time at which the final descent was made to 20,000 ft. further decreasing the sun angle in relation to the aircraft position and resulted in the two curves overlapping.

DISPLAY ILLUMINATION DATA

The display brightness settings selected during each pilot's three flights were averaged for the data analysis.

Graphs were plotted for each of the 12 displays showing the brightness selections (the means of each pilot's three flights) as a function of mission time. Figure 12, showing the HSI data, is representative of these graphs. The remaining 11 display brightness graphs are shown in Appendix B, pages 94 through 99.

Figure 12 contains two additional means; a grand mean for all five pilots and a mean for four pilots excluding Pilot C. Although explicit instructions were given to all pilots to maintain the display brightness settings "at the minimum level for safe flight", Pilot C used extremely high brightness settings throughout all his flights. During the debriefings, Pilot C stated that he felt there was no reason to maintain dark adaptation for looking out of the cockpit at night. This position was shared by approximately 10% of the pilots who responded to the cockpit lighting questionnaire in an earlier study (Milligan, Ref. 2) and answered "no" to the question "During a VFR night flight do you adjust your cockpit lights to maintain maximum out-of-the-cockpit visibility?" When answering this same question, Pilot C qualified his negative answer by stating, "I never fly VFR at night". Pilot C made almost no light adjustments after the first few minutes of the flight. Therefore, inclusion of his data in the means would merely add a constant to the computation of the brightness setting means and artifically raise the baseline data being sought. It was therefore decided to exclude Pilot C's data from the display brightness means. However, the graphs in Appendix B, pages 94 through 99 , all contain a plot of Pilot C's data to indicate the total range of display illumination selected by the pilots. The average light levels selected by the pilots to illuminate the EL-emitting displays are shown in Figure 13. Only two rheostats were available for the five displays in the engine/fuel group, one for the indices and one for the legends. The graphs for these two rheostats therefore represent the average brightness for these five displays. The pilots rapidly dimmed the EL-emitting displays during the first thirty minutes of the flight and dimmed these displays very little during the final hour of the flight. After ninety minutes of flight the relationship between these three light sources was quite stable. At this time the engine display indices were illuminated at .025 ft. lamberts. The clock numbers were almost three times brighter at .065 ft. lamberts and the engine display legends at .450 ft. lamberts were 18 times brighter than the indices on these same displays.

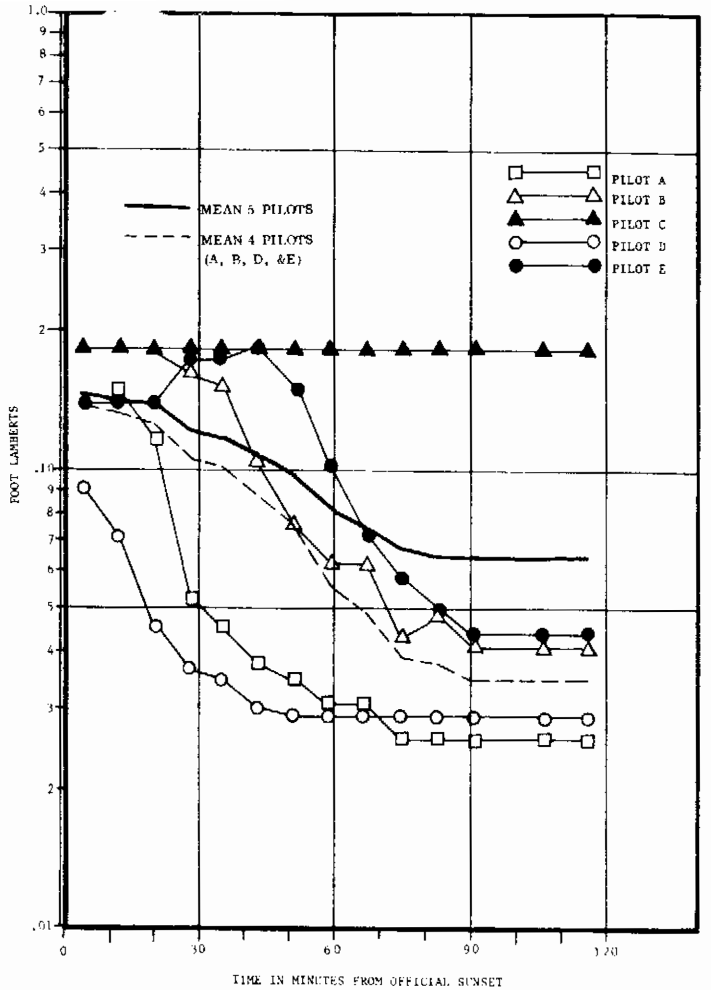

FIGURE 12. ILLUMINATION LEVELS SELECTED FOR THE HSI AS A FUNCTION OF TIME AFTER OFFICIAL SUNSET

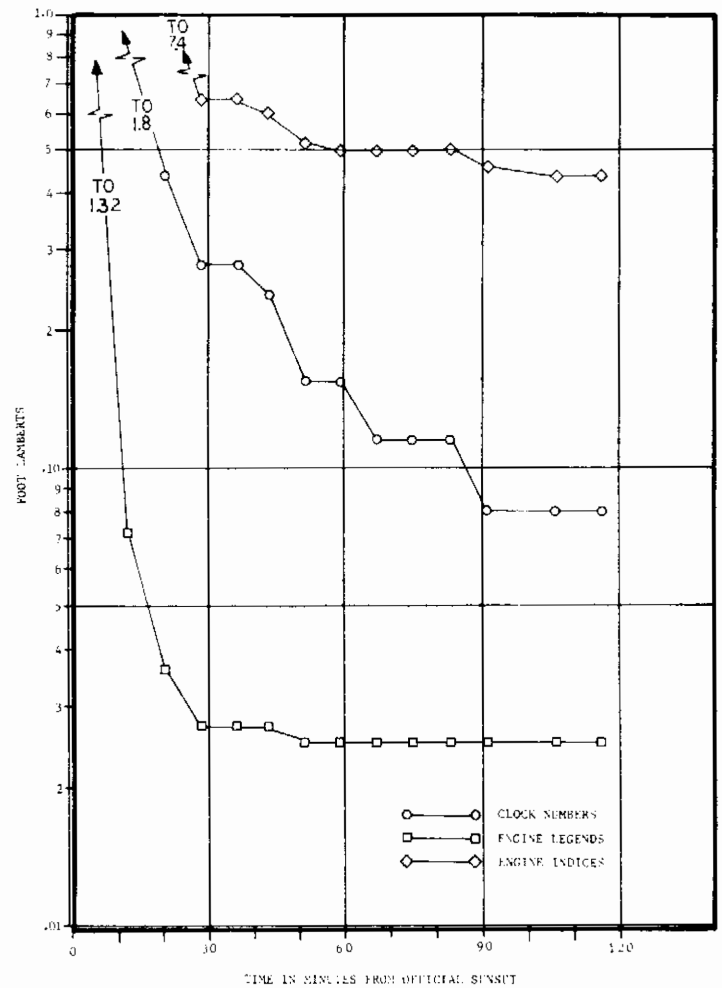

FIGURE 13. AVERAGE ILLUMINATION USED FOR EL-EMITTING DISPLAYS AS A FUNCTION OF TIME AFTER OFFICIAL SUNSET

The brightness levels of the four panel displays, which were illuminated with EL-transmitted light, are shown in Figure 14. The dimming pattern for these displays was similar to the EL-emitting displays. Rapid dimming was evident during the first hour after sunset and

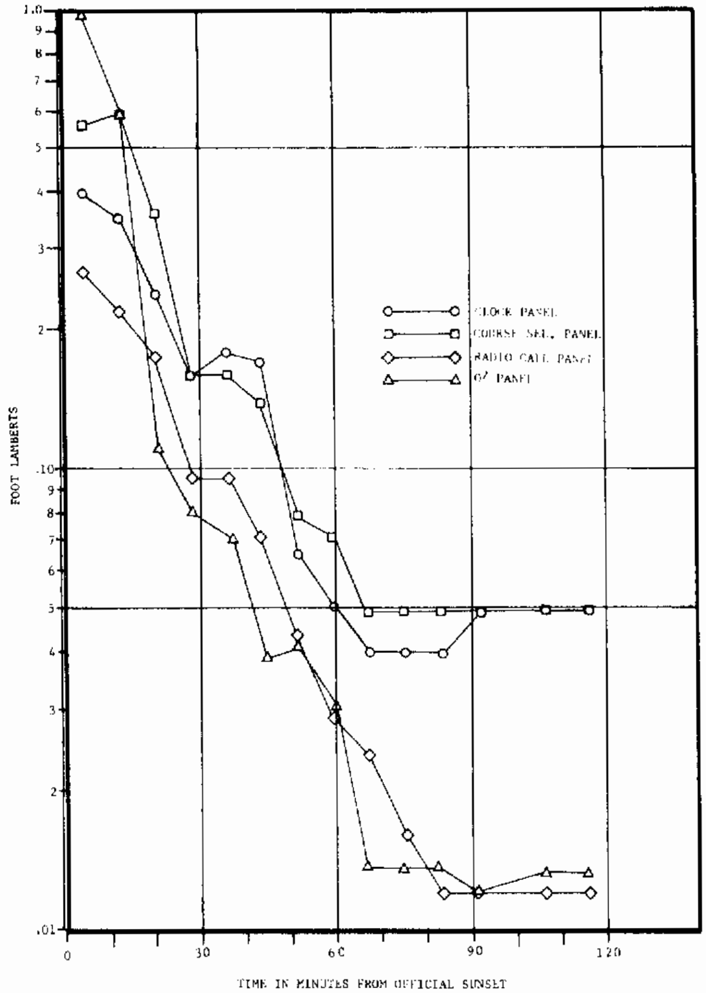

FIGURE 14. AVERAGE ILLUMINATION USED FOR EL-TRANSMITTING DISPLAYS AS A FUNCTION OF TIME AFTER OFFICIAL SUNSET

few changes were made during the final hour of the flight. A distinct break may be noted in the dimming of these displays one hour after sunset. The Radio Call and Oxygen panels were grouped together at an extremely low light level (approximately .015 ft. lamberts). The Course Select and Clock panels were also grouped but at a much higher illumination level (approximately .050 ft. lamberts).

The various light levels used with the five flight instruments are graphed in Figure 15. With the exception of the HSI, the brightness settings of these displays were grouped in fairly close proximity. At the individual data collection points the differences in the brightness settings among the ADI, Airspeed, Rate-of-Climb, and Altimeter ranged from .06 to only .01 ft. lamberts of illumination.

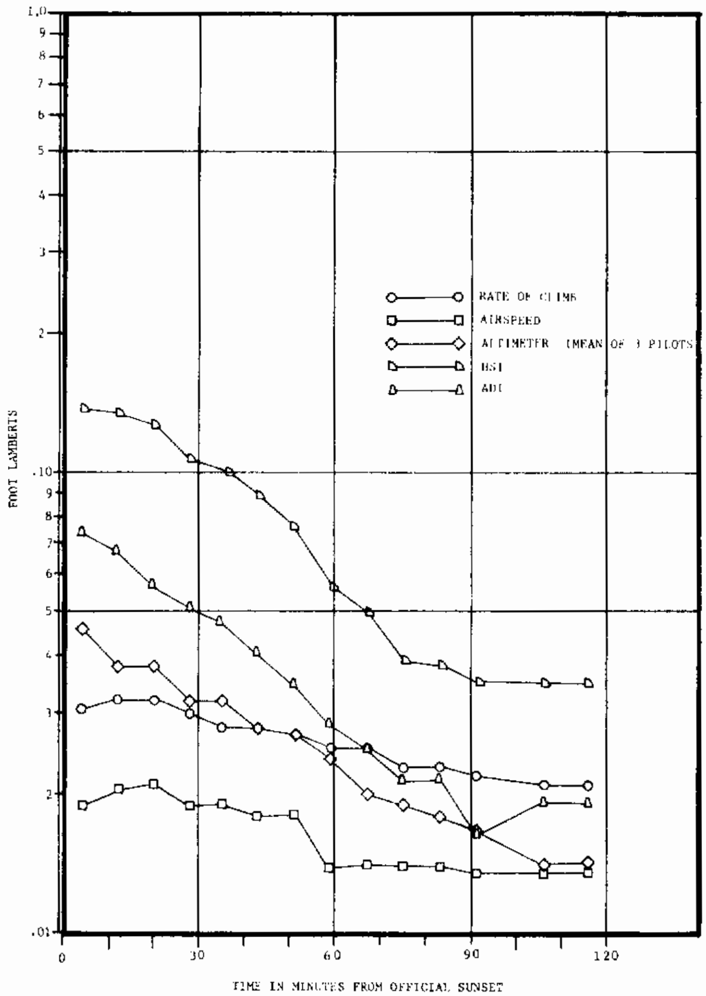

FIGURE 15. AVERAGE ILLUMINATION USED FOR EL-REFLECTING DISPLAYS AS A FUNCTION OF TIME AFTER OFFICIAL SUNSET

Throughout the flight the brightness of the Airspeed indicator was consistently lower than the other flight instruments, while the HSI was the most highly illuminated of the five primary flight instruments.

The ranges and means of the illumination used for each of the twelve displays were tabulated as a function of 30-minute flight intervals. This data, shown in Table I, was based on the means of four pilots (Pilot C's data was omitted for previously explained reasons). The Altimeter data was based on three pilots (B, D & E) due to early installation difficulties with the EL-illuminated altimeter. The displays were grouped according to the type of EL light used to illuminate the displays. The first three displays used EL-emitted light, the next four used EL-transmitted light and the last five were illuminated using EL-reflected light. A grand mean was computed for each display group starting at official sunset and for three subsequent 30-minute intervals.

TABLE I. RANGES AND MEANS OF DISPLAY ILLUMINATION USED AT THIRTY-MINUTE FLIGHT INTERVALS (FT. LAMBERTS)

TYPE OF EL LIGHT	DISPLAY	OFFICIAL SUNSET			SUNSET + 30 MIN.			SUNSET + 60 MIN.			SUNSET + 90 MIN.		
		RANGE LOW	RANGE HIGH	MEAN	RANGE LOW	RANGE HIGH	MEAN	RANGE LOW	RANGE HIGH	MEAN	RANGE LOW	RANGE HIGH	MEAN
EMITTED	ENG. LEGEND	.030	5.625	2.365	.003	.190	.033	.003	.190	.027	.003	.190	.026
EMITTED	CLOCK NOS.	.300	6.500	2.760	.100	.900	.280	.100	.300	.160	.001	.900	.080
EMITTED	ENG. INDICES	1.480	20.800	9.962	.100	4.300	.946	.045	1.480	.488	.045	1.480	.459
EMITTED	GRAND MEAN			5.029			.420			.225			.168
TRANSMITTED	CLOCK PANEL	.080	.560	.330	.010	.560	.160	.010	.130	.050	.010	.090	.050
TRANSMITTED	O^2 PANEL	.000	1.505	1.018	.000	.250	.078	.000	.250	.045	.000	.050	.015
TRANSMITTED	COURSE SEL.	.050	1.170	.560	.010	1.170	.160	.001	.330	.064	.001	.110	.049
TRANSMITTED	RADIO CALL	.130	.350	.290	.001	.350	.092	.001	.120	.029	.001	.040	.012
TRANSMITTED	GRAND MEAN			.549			.122			.047			.031
REFLECTED	ADI	.066	.076	.075	.070	.076	.049	.020	.054	.025	.002	.052	.018
REFLECTED	HSI	.067	.181	.129	.045	.182	.106	.015	.134	.056	.015	.064	.035
REFLECTED	AIRSPEED	.011	.021	.020	.014	.021	.019	.005	.021	.014	.003	.021	.013
REFLECTED	ALTIMETER	.037	.048	.046	.011	.048	.032	.004	.048	.024	.004	.037	.017
REFLECTED	RATE OF CLIMB	.027	.032	.031	.012	.032	.028	.013	.032	.025	.007	.032	.022
REFLECTED	GRAND MEAN			.060			.047			.029			.021

Using the mean brightness settings at official sunset as an arbitrary 100% base, the percent of this baseline light used was computed at 30-minute intervals for the time period extending 1.5 hours after sunset (see Table II). This time period was selected because the pilots made the majority of their light reductions during this time. As shown in Table II the pilots dimmed both the EL-emitting (engine and clock) and EL-transmitted light displays (panels) in approximately the same manner. The EL-reflected light displays (flight instruments) were dimmed much less than the other types of displays in comparison to the amount of light used at sunset.

TABLE II. PERCENT OF LIGHT USED AFTER OFFICIAL SUNSET

TYPE OF DISPLAYS	TIME PERIOD SUNSET(SS)	SS+30 MIN	SS+60 MIN	SS+90 MIN.
EMITTED LIGHT	100%	8.4%	4.6%	3.8%
TRANSMITTED LIGHT	100%	13.0%	5.4%	3.3%
REFLECTED LIGHT	100%	78.0%	48.0%	35.0%

CORRELATION OF PHOTOMETRIC AND DISPLAY ILLUMINATION DATA

The mean brightness settings for all displays were correlated with the mean of the photometric data taken from the cosine receptors which sensed illumination at the pilot's eye and the sky directly above the aircraft. A Pearson product moment correlation coefficient (R) was computed for each of the twelve displays under both ambient illumination conditions. The .01 level was used to test for significance. An R of .612 is required to show a positive correlation which is statistically different from zero at the .01 level of significance. Table III contains the correlation coefficients for each display.

TABLE III. CORRELATION COEFFICIENTS OF DISPLAYS AND AMBIENT ILLUMINATION MEASURES

DISPLAY	EYE (R) COEFFICIENT	SKY (R) COEFFICIENT
1. ADI	.81	.75
2. HSI	.76	.69
3. ALTIMETER	.71	.72
4. AIRSPEED	.72	.38**
5. RATE OF CLIMB	.51*	.48*
6. CLOCK PANEL	.89	.82
7. O^2 PANEL	.92	.95
8. COURSE SEL. PANEL	.94	.79
9. RADIO CALL PANEL	.88	.85
10. CLOCK NUMBERS	.86	.96
11. ENGINE INDICES	.79	.97
12. ENGINE LEGENDS	.62	.93

ALL COEFFICIENTS SIGNIFICANT AT .01 LEVEL EXCEPT:

*SIGNIFICANT AT .05 LEVEL
** NONSIGNIFICANT

As shown in Table III there were consistently high correlations between the display brightness settings and the eye and sky ambient illumination. The only exceptions to this finding were the Airspeed and Rate-of-Climb displays.

A second finding was that almost all display brightness settings correlated higher with the ambient illumination measured at the eye position receptor than at the sky receptor. The major exception to this finding was the light settings for the three EL-emitting displays. EL-emitting engine indices, engine legends and the clock numbers all had a higher coefficient when correlated with the sky receptor data.

PILOT OPINION

EL Questionnaire Results

The first item on the EL questionnaire consisted of a list of the panel displays which were to be rated on readability under night conditions. The ratings were scaled from one (1) the highest, to seven (7), the lowest. The means of the pilots' ratings are presented in Figure 16. In their preflight evaluation, the pilots rated the Engine Instruments, Clock, ADI and HSI as being more readable than the Vertical Speed Indicator, Altimeter, and Airspeed Indicator. Six of the

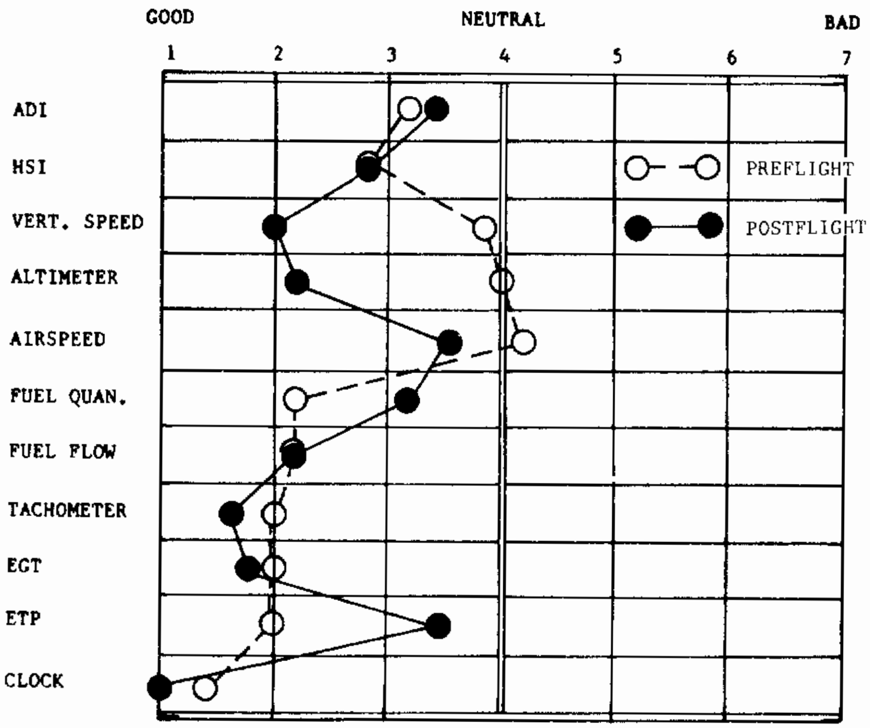

FIGURE 16. COMPARISON OF PRE AND POST-FLIGHT PILOT RATINGS OF EL-DISPLAY READABILITY

eleven ratings improved as a result of the flight experience, two remained the same and three decreased. Two of the three decreased ratings involved the EL-emitting Fuel Quantity and Exhaust Total Pressure displays. Both these displays suffered a gradual reduction of light intensity within the displays due to failure of the display pressure seal. Because all five EL-emitting displays were ganged on two rheostats, the lower light level of the two degraded displays made reading them difficult when the other EL-emitting displays were properly adjusted.

The pilots also rated the T-39 EL instrument lighting in comparison to conventional incandescent cockpit lighting. Figure 17 shows the results of the pre-and post-flight evaluations using ten paired adjectives to describe the lighting. All ratings fell to the left or "good" side of the scale. The pilots' ratings of the EL lighting improved on almost all scales as a result of their flight experience. The only exception to this trend was on the "precise-crude" scale.

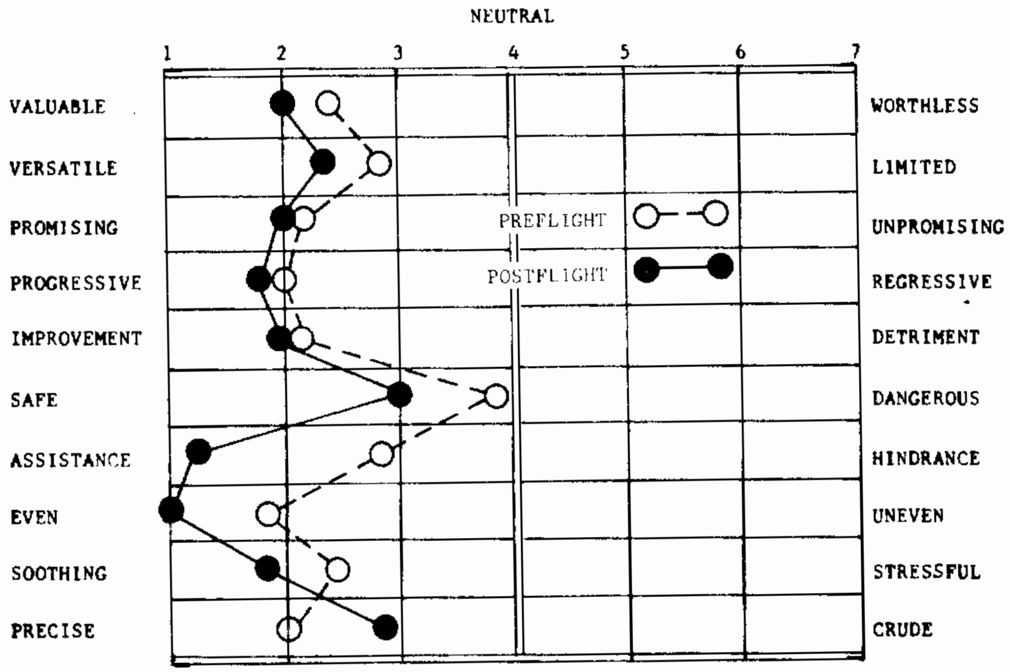

FIGURE 17. PRE- AND POST-FLIGHT PILOT RATINGS OF ELECTROLUMINESCENT LIGHTING COMPARED TO CONVENTIONAL INCANDESCENT COCKPIT LIGHTING

The pilots were all familiar with both edge-lit and light-reflecting displays. However, since none of them had previous experience with light emitting displays, a series of eight paired adjective questions on the EL-emitting displays (engine instruments and clock) were included in the EL questionnaire.

When rating the vertical "tape" presentation for the engine parameters on an assistance-hindrance scale, the pilots' mean post-flight rating showed a marked improvement over the preflight rating (2.4 vs 3.6).

The green color of the EL-emitting displays was generally accepted by the pilots. In fact, the rating of the green display lighting increased slightly on the post-flight questionnaire with the mean rating improving from 2.1 to 2.0. Ratings of the individual features of the EL digital clock also improved as a result of the flight experience. Ratings of the clock for all flight phases on a good-bad scale improved from 2.2 to 1.8 on the assistance-hindrance scale. The clock numbers and format were rated on a clear-confusing scale and the rating improved from 1.8 to 1.0 towards the clear side of the scale. Rapid changing of the seconds numerals was rated fairly low to neutral (3.6) on the assistance-hindrance scale during the pre-flight evaluation; however, this rating improved to 2.6 on the post-flight ratings. On the pre-flight evaluation, the pilots gave a rating of 2.4 to the inclusion of a conventional clock in addition to the EL digital clock. This rating decreased following their flights (2.8) indicating that the EL clock was sufficient by itself and, in the pilots' opinion, inclusion of a conventional clock would not necessarily improve performance.

Debriefing Results

A summary of the five pilots' debriefing comments on the individual displays is as follows:

ADI - One pilot did not like the blue-brown color of the attitude ball. He preferred a black-white or gray-white coloring. The other pilots found the color format satisfactory. Two pilots stated that there was insufficient definition of the horizon line on the attitude ball and that a wider horizon line was needed. Two pilots also stated that light reflections on the blue upper portion of the ball caused a hot spot of light when the rest of the display was illuminated at a comfortable intensity.

HSI - Four of the five pilots stated that the digital readouts for the Course Select and DME were poorly illuminated on the HSI. As a result, these pilots stated they maintained a higher light level on the HSI than they would have preferred in order to see the digital portions of the display.

ALTIMETER - The EL Altimeter pilot opinion data was based on four pilots due to the late arrival of the EL altimeter which required the first pilot to use a conventional red illuminated altimeter. All pilots reported the EL Altimeter lacked sufficient brightness during twilight conditions. Also, the Kollsman window digital readout on the Altimeter was reported as difficult to read when the rest of the display face was properly illuminated. During the experimental flights, the altimeter setting was adjusted prior to take-off and again before starting the penetration for landing. The pilots stated that when the Altimeter was satisfactorily dimmed for reading the altitude they still had to lean forward to see the Kollsman window numbers when adjusting the altimeter setting.

AIRSPEED AND VERTICAL SPEED - Both the Airspeed and Vertical Speed displays received the same critical comments. Four pilots stated both these displays had insufficient illumination. However, this criticism was limited to the twilight portion of the mission (shortly after sunset and prior to the sky becoming quite dark). One pilot complained of insufficient light on these displays throughout the entire mission even under extremely dark conditions.

ENGINE INSTRUMENTS - The RPM and Exhaust Gas Temperature displays were both considered satisfactory even in bright sunlight. The only exception was the Exhaust Total Pressure display which, due to internal failure, was quite dim at the end of the experiment. The primary criticisms of the engine displays were not with the amount of display lighting but with the layout of the displays. The comments of the pilots indicated that the numbers on the scales were too small. Two pilots stated that a slight increase in number size would enhance display readability. The distance between the vertical "tape" readouts was reported to be too large and two of the pilots stated that they had difficulty equalizing the indications on the two engines due to the distance between the "tapes". They suggested that either the distance between the "tapes" be reduced or that the scale marking be made continuous between the "tapes".

FUEL DISPLAYS - The comments on the Fuel Flow and Fuel Quantity indicators were similar to those made about the engine instruments. The Fuel Quantity Indicator was well illuminated throughout all ambient conditions and (at the beginning of the experiment) the Fuel Flow was also satisfactory. However, some deterioration over a period of time occurred in the Fuel Flow lighting due to internal failure. Three of the pilots recommended an expanded scale for the Fuel Flow indicator. The Fuel Flow indicator had a conventional scale with equal graduations from zero to 4,000 lb/hr of fuel flow. However, in the normal cruise range, the fuel flow is usually between 1,500 and 1,000 lb/hr and the pilots stated they would like the low portion of the scale to be expanded to facilitate more accurate reading of the flow rates in the normal cruise mode.

EL CLOCK - The pilots were high in their praise of the EL clock. It was the highest rated of any of the displays. The EL digital readouts for both normal time and elapsed time were easily read, and the digital format was judged to be more effective than the hands on a conventional clock. The primary complaint concerned the operation of the switches necessary to set and operate the clock. All pilots found the clock setting switch layout confusing and stated that a simpler switch layout with setting buttons below the appropriate digit would be more satisfactory.

SUBPANELS - The subpanels illuminated with EL edge lighting were all considered to be well illuminated. The pilots reported they were not too "interested" in the information on these panels and turned them quite low. One pilot turned the oxygen panel off during his flights because it "unbalanced the instrument panel". The only discrepancy noted in the panel lighting was the lack of illumination on the switches. The Radio Call, Course Select, and Oxygen subpanels all contained either toggle or rotary switches. All pilots stated that it was difficult to determine the positions of these switches due to a lack of switch illumination. The small oxygen flow indicator on the oxygen panel was also criticized by two pilots as being too small and difficult to read.

In addition to the pilots' comments on the individual EL-illuminated displays, the following general information was obtained during the debriefing:

None of the pilots reported any eye fatigue or general fatigue due to the mission. Neither did they report having any trouble focusing on the displays. None of the pilots experienced any floating illusions or "black hole" effects when flying with the EL-illuminated displays. All five pilots stated that none of the displays degraded their night vision and the white lighting of the flight displays was "highly satisfactory". The pilots also found the green lighting in the EL-emitting displays "acceptable" but stated white light would be "just as good".

There were no reports of glare or reflections on the instrument faces from the cockpit lights. Two pilots reported reflections on the forward windscreen and left window. In one case, the pilot reported the reflections were caused by a console light which he forgot to dim. The other pilot reported the dimming control box containing the EL light control rheostats caused some reflections on the windscreen.

During the debriefing the pilots were all asked how they adjusted the display illumination on the forward instrument panel. A summary of methods used by the pilots is as follows:

Pilot A - Attempted to maintain an "even" light level across all displays with the exception of the engine instruments and clock which he adjusted "slightly lower".

Pilot B - Divided the displays into three categories and adjusted the flight instruments highest, the engine instruments and clock slightly lower, and the subpanels "fairly dim".

Pilot C - Adjusted all displays to the same brightness level with the exception of the Airspeed, Altimeter and Rate-of-Climb indicator which he turned full up and still failed to get them as bright as he desired.

Pilot D - Divided the displays into five categories with the brightest to the dimmest as follows: 1) ADI and HSI, 2) Altimeter, Airspeed, and Vertical Speed, 3) engine and fuel instruments, 4) subpanels, and 5) clock.

Pilot E - Adjusted his lights into three categories in a manner similar to Pilot B.

When asked how they would arrange the lighting controls if no constraints were imposed, four of the five pilots stated they would like to have individual display rheostats or light trim knobs on each display. In addition, they recommended a single main rheostat which would allow quick simultaneous adjustment of all displays. The fifth pilot recommended five rheostats grouped as described in Pilot D's comments, above.

III. 7 DISCUSSION OF RESULTS

The correlations of the photometric and display illumination data showed that the pilots dimmed their cockpit lights in almost direct proportion to the decrease in ambient illumination (Table III, page 27). The differences in the correlations for the sky and eye position receptors indicate that the pilots were influenced by not only the outside ambient illumination but also by the cockpit lights themselves. According to the pilots' statements the wide range of display illumination settings (Figure12, page 23) was influenced by not only the ambient light conditions but also by the priority individual pilots placed on being able to see outside the aircraft at night.

If a cockpit lighting system is to perform its function properly the lighting system must be compatible with the full range of light adjustment behaviors exhibited by the different pilots. Lighting system specifications and design criteria should be keyed not only to the average display illumination used by the pilots but to the entire range of display illumination used by different pilots. Based on these assumptions and the experimental data, when using lunar white light an illumination range of 1.0 to .01 ft. lamberts should be sufficient from daylight to approximately 2 hours after sunset for displays illuminated by either EL-transmitted or EL-reflected light.

The subject pilots reported no difficulties adjusting the brightness of the displays which contained EL-emitting light sources. According to the pilots, the brightness range of the clock numbers and engine displays was sufficient for all ambient conditions encountered throughout the mission including the bright sunlight encountered at altitude prior to sunset.

The rate at which the displays were dimmed throughout the mission was equivalent for all emitting light sources; however, the levels of illumination used for the individual display elements differed widely. As a result, the illumination requirements for EL-emitting displays are not as straightforward as the other two types of EL illumination.

The only major disagreement between pilot performance and pilot opinion was found in the data for the EL-emitting displays. The pilots reported they set all EL-emitting light sources at approximately the same brightness. However, the data showed the numbers on the EL clock were three times brighter than the engine display legends and the "tape" indices were 18 times brighter than the legends on the same engine displays. This data indicates that brightness judgments between EL-emitting light sources may be influenced by a psychophysical factor or factors which cause measurable differences in brightness matching. One factor, which possibly influenced this psychophysical disparity, is display element size. The stroke width of the numbers on the clock and engine legends and the width of the engine "tape" indices were all measured. Table IV compares stroke width of the clock and engine display symbology with the brightness settings of these same display elements during the final 30 minutes of the flight. As stroke width increased in size, display element brightness also increased. These increases were not proportionate but the general trend indicates that stroke width of the symbology may be an influencing variable. Further research will be necessary to determine the specific variables which influence brightness matching of elements within and between EL-emitting displays.

TABLE IV. COMPARISON OF EL-EMITTING DISPLAY BRIGHTNESS AND SYMBOLOGY STROKE WIDTH

	ENGINE LEGENDS	CLOCK NOS.	ENGINE INDICES
STROKE WIDTH(INCHES)	.030	.038	.140
BRIGHTNESS (FT.L)	.026	.080	.459

In this experiment, the basic problem of configuring the display illumination across an instrument panel was virtually eliminated by using individual dimming controls for the displays. Although the dimming control box was not in the most comfortable location, the ability to individually adjust the displays was well received by the pilots. This capability also contributed to the high post-flight pilot ratings of the EL displays on both the "assistance" and "even" scales (Figure 17, page 29). In an operational situation, one or two master rheostats will be necessary for rapid dimming of primary instrument groups or for the entire instrument panel. However, the ability to adjust or "trim" the lighting for each display should be provided in the cockpit lighting system.

Despite occasional display lighting discrepancies the pilot opinion ratings indicated that the EL lighting was highly acceptable and, in general, there was close agreement between pilot performance and pilot opinion data. Explanations of the pilots' lighting adjustment behavior were often found in their post-flight debriefing statements and the opinions they expressed through the EL questionnaire ratings.

The illumination levels of all but two displays correlated positively with the ambient illumination. Only the Airspeed and Rate-of-Climb illumination levels failed to correlate at the selected .01 level of significance. According to the pilot's comments, these two displays, and to some extent the Altimeter, were not sufficiently illuminated during the earlytwilight portion of the mission. All five pilots agreed that a brighter light source would enhance the readability of these displays during twilight conditions. The low correlation coefficients of the Airspeed and Rate-of-Climb are therefore attributed to insufficient display lighting during the early portion of each flight.

The difference in the light levels used for the various EL-trans-illuminated panels (Figure 14, page 24) was also explained by the pilots' comments. Two pilots stated that they used very low light settings for the Oxygen and Radio Call panels because these panels contained very little "useful information". One pilot reported he turned the Oxygen panel completely off because its location made the instrument panel appear "unbalanced". As a result, the Oxygen and Radio Call panels had the lowest light levels of any of the displays.

All of the post-flight adjective pair ratings of the EL lighting improved with the exception of the rating on the "precise-crude" scale (Figure 17, page 29). According to the pilots, this decreased rating was due to insufficient illumination on the digital readout portions of the HSI and Altimeter. There is a digital display design problem, illustrated in Woodson and Conover (Ref. 14), which causes poor legibility of mechanical digital readouts. If set too far forward, the cutout or "window" for the digital readout drum causes a shadow across the face of the display. Four of the five pilots stated that difficulty in reading the small digital readouts on the HSI forced them to fly with the HSI more brightly illuminated than they desired. This may explain the high illumination of the HSI as compared to the other displays illuminated with EL-reflected light (see Figure 15, page 25). The digital readouts for the Kollsman dial setting on the altimeter were also reported as difficult to read. However, the pilots stated that they set the overall altimeter lighting at a comfortable level and because the altimeter setting information was seldom needed, they merely leaned forward to read the Kollsman digits when this information was required. Woodson's solution to the digital readout illumination problem is to move the cutout back and increase the size of the digital readouts thus reducing the shadow.

Based on the data gathered in this experiment, a brightness range of 20.0 to .01 ft. lamberts for EL-emitting displays should be sufficient during ambient conditions ranging from bright sunlight until two hours after sunset. However, when designing future EL-emitting displays, it may be necessary to take into consideration variables such as display element size. If size or the stroke width of the symbology is a controlling variable for apparent brightness judgments, the voltages driving EL-emitting display elements may have to be "tailored" to compensate for psychophysical differences in apparent brightness.

IV.

EXPERIMENT II

IV. 1 SUBJECTS

Twenty-eight USAF test pilots were selected at random by the FTFB Test Director to participate as subjects in Experiment II. The pilots all had flight test experience. They ranged in age from 28 to 48; their average age was 36. Table V contains a breakdown of the pilots' flying experience.

TABLE V. EXPERIMENT II SUBJECT PILOTS' FLIGHT EXPERIENCE (ALL FLYING TIME IN HOURS)

		YEARS RATED	TOTAL FLYING TIME	COMBAT TIME	NIGHT TIME	NO. OF ILS APPROACHES
Mean		12	4,250	277	675	185
Range	Low	6	2,400	0	165	60
	High	28	14,000	640	1750	700

IV. 2 MISSION

The mission flown in Experiment II was approximately 2.1 hours in duration. Takeoff times were adjusted to obtain the desired ambient conditions and were scheduled no earlier than 1.5 hours after official sunset. The mission profile consisted of a takeoff and climb, a high altitude cruise, a straight-in letdown and ILS approach to an interim airfield, a low altitude cruise, and an ILS approach and full stop landing. Figure 18 is a diagram of the mission route which originated at WPAFB. The high altitude cruise was flown from Falmouth VOR (FLM) east to the Bellair TACAN (AIR), then north toward the Chardon TACAN (CXR). An interim letdown and ILS approach was accomplished on a westerly heading straight-in from CXR to the ILS final approach to runway 28 at Cleveland Hopkins airport. The final approach was flown over the brightly illuminated northeast section of the city of Cleveland. Upon reaching the published ILS minimums, a missed approach and climb to 4000 ft. was initiated toward Cleveland TACAN (CLE). The low altitude cruise went from CLE west to Waterville TACAN (VWV), then southerly toward the Rosewood TACAN (ROD). From ROD the pilots were radar vectored to intercept the Patterson low altitude approach fix (FFO 140/11). They then flew the published low altitude circling approach to the ILS final and landed.

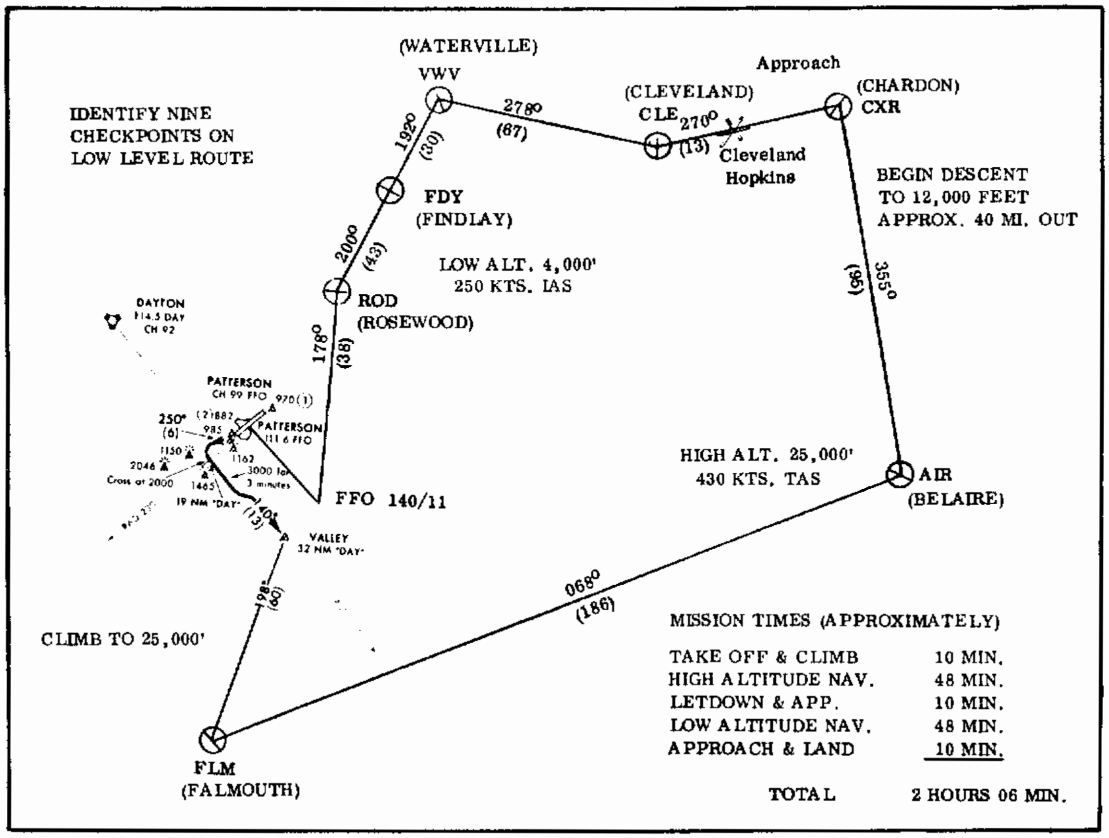

FIGURE 18. EXPERIMENT II MISSION ROUTE

IV. 3 PROCEDURES

The general procedures described in Section II were followed in Experiment II with the following additions:

Each subject pilot flew a single data collection mission. The mission portion of the orientation briefing included a complete description of the route to be flown and the specific altitudes and airspeeds to be used. The pilots were provided a study kit containing a mission card which outlined the mission (Appendix C, page 100), a route diagram similar to Figure 18, and a knee map covering the low level portion of the mission. A typical section of the low level map is shown in Appendix C, page 101. Additional mission aids in the study kit included an AF Form 70 Pilot's Flight Plan (Appendix C, page 102), and a card containing a list of the low level checkpoints (Appendix C, page 103). Photometric and display brightness data were recorded at all points shown on the experimenter's data sheet in Appendix C, page 104.

IV. 4 EQUIPMENT CHANGES

Data collection problems encountered in Experiment I dictated a need for equipment changes prior to beginning Experiment II. The cosine receptor which sensed the light directly above the aircraft (referred to as the "sky" receptor) was originally mounted 2 inches below the outside skin of the aircraft. The cutout for the receptor limited the view angle at which the receptor viewed the sky to approximately 60 degrees. When the moon was low on the horizon, the sky receptor output did not indicate the contribution of the moon to the total sky ambient. Because the amount of moonlight was an important variable in Experiments II and III, the sky receptor was raised to permit 180° coverage of the sky above the aircraft and provided more accurate sensing of the different levels of ambient illumination.

The limited light available for illuminating the Airspeed, Altimeter, and Rate-of-Climb indicators was supplemented by increasing the size of the EL light "wedges". This increased the upper limit at which the pilots could illuminate these displays. The Exhaust Total Pressure and Fuel Flow gages both deteriorated slightly and were replaced with spare displays. Recalibrations were accomplished on all displays and receptors prior to beginning the second experiment.

IV. 5 EXPERIMENTAL DESIGN

A between-group experimental design was used in this experiment. The dependent variable was the pilot's display brightness selection. The three independent variables included ambient illumination (four levels); mission segments (seven levels); and display types (thirteen levels).

The four levels of ambient illumination were: 1) high ambient conditions, defined as 3/4 to full moon; 2) medium ambient, defined as 1/4 to 1/2 moon; 3) low ambient, defined as starlight only; and 4) low ambient, no peripheral cockpit lights. This last ambient illumination level was flown with starlight only and the pilots were briefed to turn off all console, pedestal, and overhead cabin lights and use only the forward instrument panel illumination throughout the mission. On all other missions the pilots were free to use the peripheral lights as they desired. A total of 28 pilots participated in the experiment. They were divided into four groups of seven pilots with one group flying each of the four ambient conditions.

The seven mission segments were: (1) take-off and climb, (2) high altitude I, (3) high altitude II, (4) letdown, approach, and missed approach at Cleveland, (5) low altitude I, (6) low altitude II, and (7) approach and landing at WPAFB. The high and low altitude cruise portions of the mission were each divided into two segments. The first 20 minutes of each cruise portion were designated Segment I and the last 20 minutes were designated Segment II. The cruise portions of the mission were divided in this manner to determine what, if any, effects the previous segments of the flight had on the lighting requirements at high and low altitude.

The thirteen display types comprising the independent variables are listed in Section II under Data Collection.

IV. 6 DATA ANALYSIS

An analysis of variance of the pilots' display illumination settingswas performed using a 4 (ambient light conditions) x 7 (mission segments) x 13 (displays) matrix. For convenience of analysis, the thirteen displays were grouped into three categories. These categories consisted of those displays using (1) EL-emitted light, (2) EL-transmitted light and (3) EL-reflected light.

Two types of mean difference tests were used. For significant main effects the Scheffe' test was used at the .10 level of significance as recommended by Scheffe' in Edwards (Ref.13). Significant interactions containing large numbers of means were examined using Dunn's multiple comparison procedures which employed the Bonfronni "T" as shown in Kirk (Ref. 15). The latter test was used to maintain the selected .05 significance level across large numbers of means. Appropriate graphs were drawn for each display group.

IV. 7 RESULTS

QUANTITATIVE ANALYSIS

A summary of the analysis of variance of the pilot's display illumination settings is shown in Table VI.

TABLE VI. ANALYSIS OF VARIANCE OF DISPLAY ILLUMINATION

SOURCE	df	MEAN SQUARE	F-RATIO	LEVEL OF SIGNIFICANCE
AMBIENT CONDITIONS (A)	3	.4372	2.7847	-
FLIGHT SEGMENTS (F)	6	.0945	2.2881	.01
DISPLAY TYPES (D)	12	.9658	6.1752	.05
AF	18	.0357	0.8644	-
AD	36	.1562	0.9987	-
FD	72	.0456	1.3103	.05
AFD	216	.0348	0.9063	-

The analysis of variance indicates that the flight segments and display types both had a significant main effect on display brightness. However, these effects were somewhat attenuated by a significant flight segment by display interaction. No significant display illumination differences were found which could be attributed to the change in ambient light caused by various moon conditions. The mean sky illumination from each group of seven flights ranged across mission segments and ambient conditions from 4.6×10^{-4} to $.23 \times 10^{-4}$ foot candles. The mean illumination at the pilot's eye ranged from 3.4×10^{-4} to $.53 \times 10^{-4}$ foot candles. Comparisons were made of display illumination and ambient illumination by mission segment. All levels of both eye and sky ambient illumination were cross-compared with the mean display brightness of the EL-emitting, EL-reflecting, and EL-transmitting displays and the overall display means. The resulting Pearson product-moment coefficients showed no significant correlations between display brightness and ambient illumination (.05 level of significance).

The low ambient conditions (no moon - starlight only) were flown by two groups of pilots. One group was permitted to use the peripheral cockpit lights while the second group was instructed not to use the overhead panel, console, and pedestal lights. These peripheral lights were edge-lit using red incandescent light. The results of the analysis of variance showed these lights had no significant effect on the pilots' illumination selection for the forward instrument panel displays.

The mean ambient illumination levels recorded from the "eye" and "sky" photoreceptors for each ambient condition and mission segment are shown in Appendix C, page 105.

Average brightness settings for the three display categories and the grand mean for all displays are graphed as a function of mission segments in Figure 19. The grand mean for all displays shows the pilots made small reductions in display brightness during both cruise portions of the flight. The slight increase in the mean display illumination during the approach to Cleveland was due to increased illumination settings of the EL-transmitting and EL-reflecting displays. A larger increase in mean display brightness is also evident during the final approach and landing. This latter increase was due to increased illumination settings of the EL-emitting and EL-reflecting displays. The Sheffe' test showed a significant difference in illumination between the first mission segment (take-off and climb) and the sixth mission segment (second-half of the low level). Due to the wide variability among pilots no other main effect differences were found between mission segments.

The mean illumination for each of the thirteen displays is shown in Table VII.

The Scheffé test showed only the engine indices to be significantly brighter than any other displays. In addition, the Scheffe' test indicated the engine indices were significantly brighter than seven

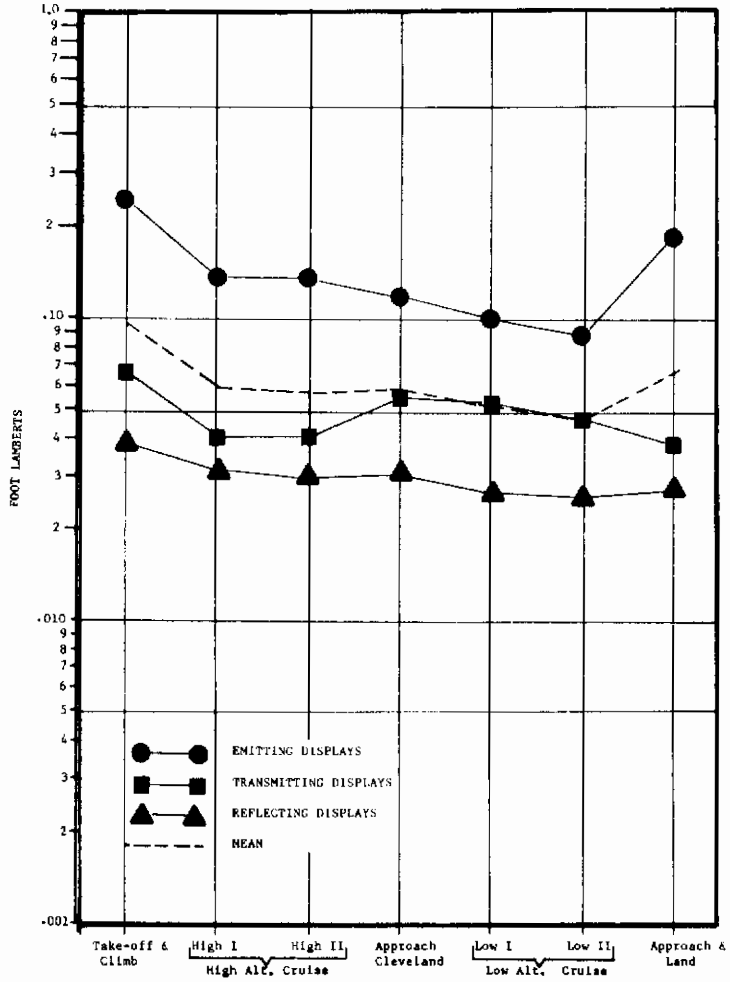

FIGURE 19. AVERAGE DISPLAY ILLUMINATION AS A FUNCTION OF MISSION SEGMENTS

TABLE VII. MEAN DISPLAY ILLUMINATION (ALL MISSION SEGMENTS)

EL-EMITTED LIGHT		EL-TRANSMITTED LIGHT		EL-REFLECTED LIGHT	
DISPLAY	MEAN FT. L.	DISPLAY	MEAN FT. L.	DISPLAY	MEAN FT. L.
ENGINE LEGENDS	.025**	RADIO CALL PANEL	.071	HSI	.050
				O^2 PRESSURE	.047
CLOCK NUMBERS	.133	CLOCK PANEL	.061	AIRSPEED	.024**
ENGINE INDICES	.269*	O^2 PANEL	.030**	VERTICAL SPEED	.020**
		COURSE SEL. PANEL	.028**	ALTIMETER	.017**
				ADI	.018**

* Significant at the .10 level.
**Significantly dimmer than the engine indices at the .10 level.

of the remaining twelve displays as shown in Table VII.

Due to the large number of means involved, a Bonfronni "T" test was performed on the 91 mission segment by display interactions. All means were tested at the .05 level of significance. For convenience, the thirteen displays were grouped by the type of EL light used for illumination and these three groups were graphed separately. Figure 20 contains plots of the illumination settings of the three EL-emitting light sources. The "T" test showed no significant illumination differences among the engine display indices across mission segments. However, the illumination levels of the engine display indices were significantly brighter than the

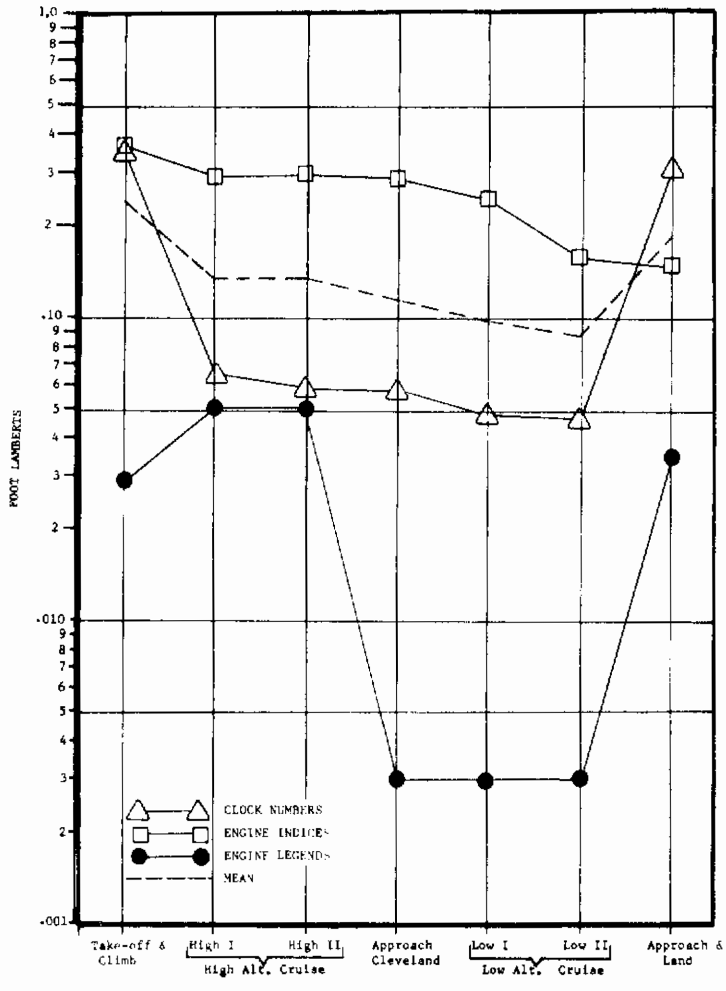

FIGURE 20. AVERAGE ILLUMINATION USED FOR EL-EMITTING DISPLAYS AS A FUNCTION OF MISSION SEGMENTS

engine display legends throughout all segments of the mission. With the exception of the first and last mission segments the illumination levels of the engine display indices were significantly brighter than the clock numbers. The clock numbers, in turn, were significantly brighter than the engine display legends during the same mission segments. However, there were no statistically significant differences between the illumination levels of the engine legends and clock numbers during the middle mission segments.

Plots of the illumination settings of the four EL-transilluminated subpanels are shown in Figure 21. All subpanels were dimmed during the high altitude cruise and, with the exception of the clock panel, all were brightened during the approach to Cleveland. The illumination of both the Radio Call and Course Select panels was increased again during the beginning of the low level route. The

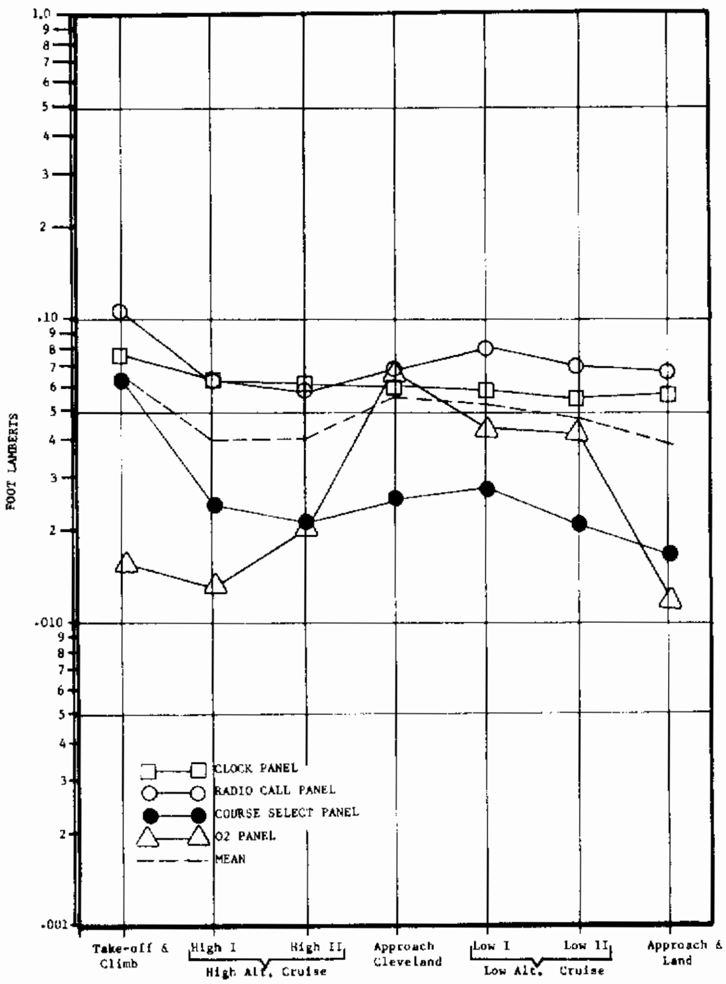

FIGURE 21. AVERAGE DISPLAY ILLUMINATION USED FOR EL-TRANSMITTING DISPLAYS AS A FUNCTION OF MISSION SEGMENT

illumination of all subpanels decreased during the last segment of the low level cruise and, with the exception of the Clock panel, continued to decrease for the approach and landing. The "T" test revealed no significant differences between the illumination levels of the EL-transmitting subpanels as a function of mission segment. However, during all mission segments the brightness of all the EL-transmitting subpanels was significantly lower than the brightness of the engine indices (Figure 20) during the first three mission segments. The O^2 panel illumination during the first two and the last mission segments and the Course Select panel illumination during the last mission segment were significantly lower than the lowest illumination level (seventh mission segment) used for the engine display indices.

The EL-reflecting displays consisted of the five primary flight instruments and the small O^2 Pressure indicator. The plots in Figure 22 reveal an extremely small range of illumination settings

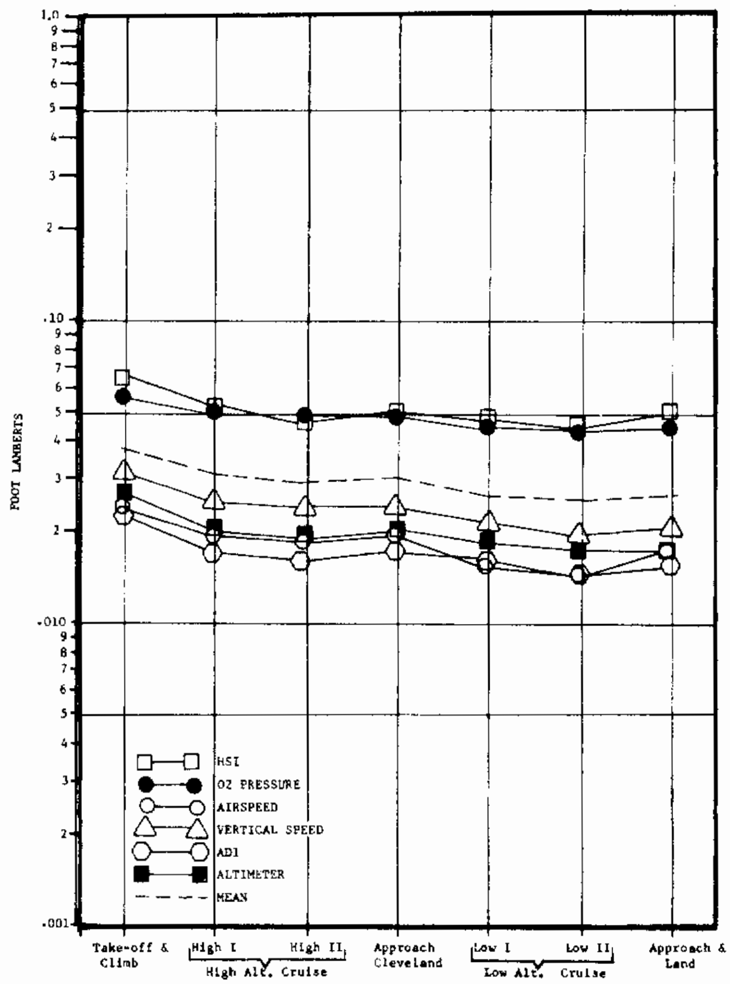

FIGURE 22. AVERAGE ILLUMINATION USED FOR EL-REFLECTING DISPLAYS AS A FUNCTION OF MISSION SEGMENTS

among these displays. In addition the dimming pattern for these displays was highly consistent throughout all mission segments. All EL-reflecting displays were continuously dimmed during the take-off, climb and high altitude cruise. A slight increase in illumination was evident during the approach at Cleveland. Illumination was again decreased during both segments of the low level cruise and then increased for the final approach at Wright-Patterson. There were no significant illumination differences as a function of mission segments within any of the EL-reflecting displays nor were there any significant illumination differences between the six displays. However, a significant illumination difference was noted between the engine display indices (Figure 20) and all six of the EL-reflecting displays. During the first five mission segments the illumination settings of the engine display indices were significantly brighter than the settings of the EL-reflecting displays.

As shown in Figure 22, the HSI and 0^2 Pressure indicator were consistently brighter than the other four EL-reflecting displays. With the exception of the illumination required during the first flight segment, the Airspeed, Vertical Speed, ADI, and Altimeter were all significantly dimmer than the illumination used for engine display indices on the final mission segment (Figure 22). However, the HSI and 0^2 Pressure illumination settings were not significantly lower than this particular illumination level. This indicates a real illumination difference between these two displays and the remaining four EL-reflecting instruments.

PILOT OPINION

EL-Questionnaire Results

All subject pilots rated the eleven EL-illuminated displays both before and after the experimental flight. Figure 23 depicts the mean ratings of all 28 pilots on a seven point readability scale which varied from good to bad. In general, all displays were rated on the good side of the scale. The ratings clustered into two general groups. The EL-reflecting flight instrument ratings clustered between ratings of 2.5 to 2.9 and the EL-emitting engine and fuel displays clustered between 1.9 and 2.2. There was very little difference between the pre- and post-flight ratings of the flight instruments. The Vertical Speed and Airspeed ratings improved slightly while the remaining three flight displays received slightly lower post-flight ratings. All EL-emitting displays with the exception of the clock had slightly lower post-flight ratings. The clock had the highest rating of any display on both the pre- and post-flight ratings.

Despite the lower post-flight ratings of individual displays, the pilots' opinion of the EL lighting as compared to conventional displays improved considerably. This overall acceptance of EL-

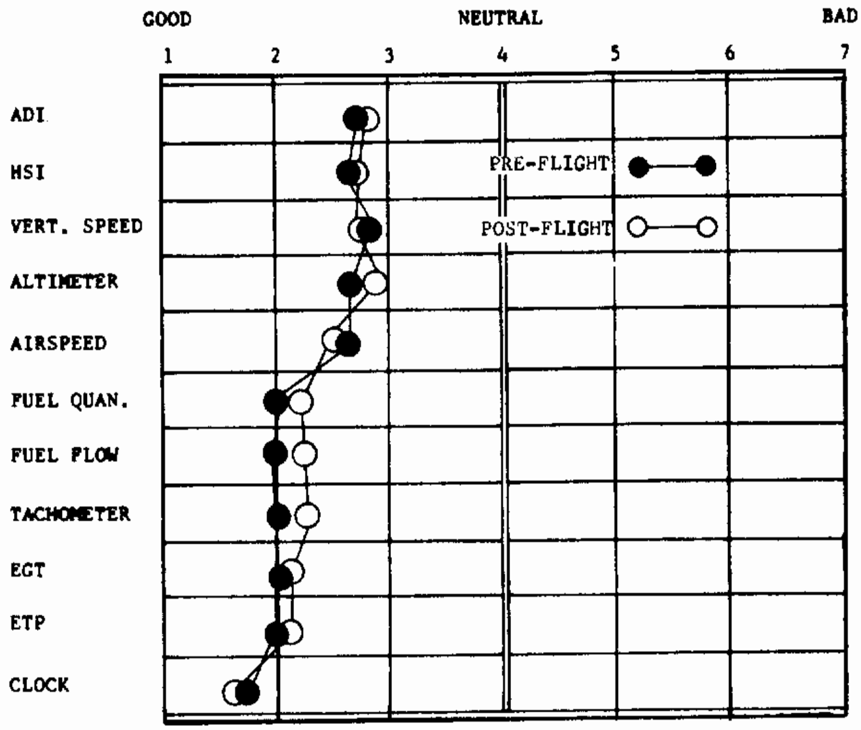

FIGURE 23. MEAN PRE- AND POST-FLIGHT RATINGS OF DISPLAY READABILITY

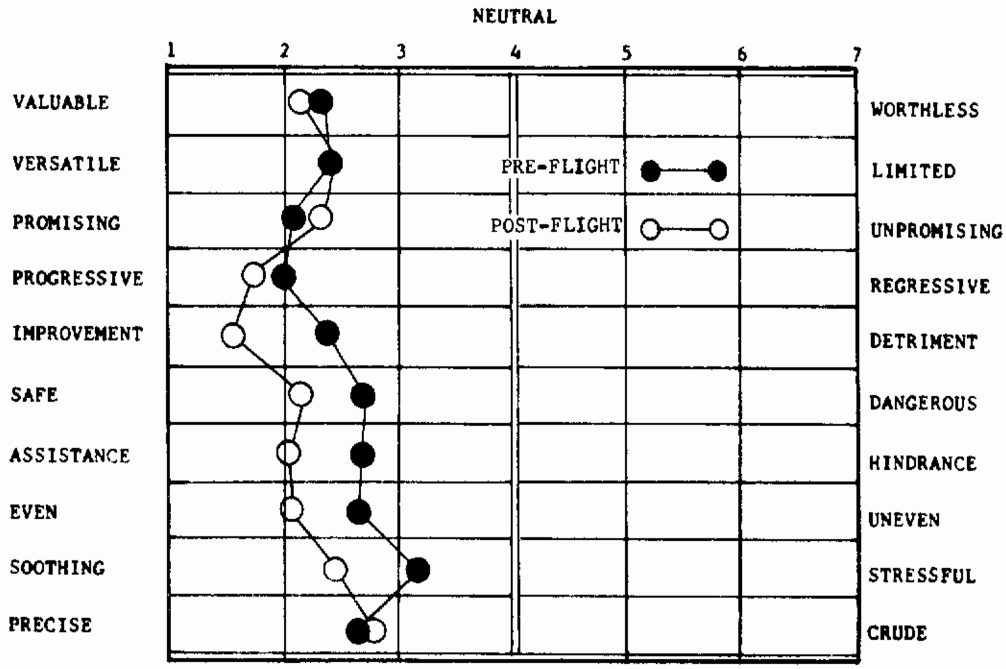

FIGURE 24. MEAN PRE- AND POST-FLIGHT RATINGS OF EL-LIGHTING COMPARED TO CONVENTIONAL INCANDESCENT COCKPIT LIGHTING

lighting is illustrated in Figure 24 by the pre- and post-flight ratings of ten paired adjectives used to compare the EL lighting with conventional incandescent lighting. Ratings on all but three word pairs increased as a result of the flight experience. The two highest rated words were "progressive" and "improvement". These were closely followed by high ratings on "assistance" and "even".

Pre- and post-flight ratings on a series of eight scales (Appendix A, page 85) used to evaluate the EL-emitting displays (engine displays and clock) were examined to determine if specific features of the EL-emitting displays were acceptable to the pilots. The pre-flight rating (2.25) of the tape format for the engine and fuel displays on an assistance-hindrance scale showed a slight degradation as a result of the flight experience (2.57). The rating of the green color of these displays also decreased on a good-bad scale from a pre-flight rating of 2.64 to a post-flight rating of 3.14.

The green EL-light was more acceptable on the clock where the pre-flight rating of 2.86 improved as a result of the flight to 2.75. Ratings of other clock features such as the general format, elapsed time, rapid changing of the seconds numerals and general usefulness all improved on the post-flight ratings. The pilots were fairly neutral in their ratings of whether a conventional dial clock should be used in addition to the digital EL-clock.

Only six pilots objected to the green color used for the EL-emitting displays. These six pilots stated they would have preferred white lighting for the EL-emitting displays.

Debriefing Results

The pilots were asked if they encountered any difficulties with the cockpit lights during the various mission segments. Five of the 28 pilots had specific complaints during the take-off and approach mission segments. Fourteen complaints were recorded during the high and low altitude cruise segments. All display lighting difficulties encountered were discussed in detail during the critique of the individual displays. A summary of the pilots comments on the design and illumination of the individual displays is as follows:

ADI - Nine of the pilots reported difficulties with the ADI. Four pilots reported the small black pitch lines lacked contrast on the blue field and were difficult to see. Three pilots stated the horizon line, formed by the intersection of the blue and brown fields, was difficult to use in controlling pitch attitude. Three pilots reported the blue field was too bright and had "hot spots" when the rest of the display was adjusted to a comfortable level. One pilot stated the dot between the symbolic aircraft wings was too small.

HSI - Thirteen pilots stated that the digital readouts on the HSI for Course and DME were too small. These pilots all reported they used a higher illumination level than they would have preferred in order to see the small digits.

ALTIMETER - The Altimeter was a conventional three needle type with a rotating Kollsman dial barometric setting. Twelve pilots reported the Kollsman dial was difficult to see when the rest of the instrument face was properly illuminated.

AIRSPEED AND VERTICAL SPEED - There were no specific discrepancies noted by any of the pilots concerning the illumination of these two displays. A general criticism of the Airspeed, Vertical Speed, and Altimeter was made by four subject pilots. These four pilots stated that they would have preferred brighter illumination of these displays expecially at take-off and prior to the time their eyes become well adapted to the darkness.

O^2 PRESSURE INDICATOR - Twelve pilots stated the small size of the O^2 Pressure Indicator made it difficult to read.

ENGINE INSTRUMENTS AND FUEL DISPLAYS - With the exception of comments by three pilots who were not impressed with the vertical format there were no major illumination discrepancies reported for the engine instruments. Five pilots stated that the light segments which made up the index "tape" were too "coarse". Two of these pilots reported the step inputs to the tape made it difficult to adjust the power settings.

EL-CLOCK - The digital format of the clock was highly praised ("A great clock") by the pilots. There were no complaints about the illumination except for the fact that the setting switches were not illuminated; the layout of these switches was not considered satisfactory by six of the pilots.

SUBPANELS - The illumination of the legends on the subpanels was considered quite satisfactory by all of the pilots. However, the lack of illumination on the subpanel switches was considered a deficiency by ten pilots.

PERIPHERAL LIGHTING - The only peripheral light source to receive major criticism was the C-4 lamp used to illuminate the letdown plates and low level map. The following list of discrepancies was noted concerning the adjustable red or white illumination of the C-4 lamp:

1. Caused glare on instrument faces (2 pilots)
2. Caused glare on windows (12 pilots)
3. Difficult to use (10 pilots)
4. White light cannot be dimmed enough (4 pilots)
5. White too bright, red not good for map reading (3 pilots)
6. Hard on dark adaptation (5 pilots)

Except for the C-4 lamp, no other lights in the cockpit were reported to cause reflections or to have a deleterious effect on night vision. Six pilots stated they would have preferred white lights in place of the green EL-emitting displays, three pilots stated they "liked" the green color, the remainder of the pilots were neutral.

Only three pilots attempted to set all cockpit lights at the same intensity. The remaining pilots configured the displays into 3 to 5 groups and adjusted some groups brighter than others. In general, the pilots reported they grouped the five primary flight instruments and adjusted them to a "comfortable level". The engine and fuel displays were reported as being used at a slightly lower illumination except for take-off and landing. The subpanels were reported as being maintained at a "dim" level and three pilots reported they turned off one or more of the subpanels during the flight.

Arrangement of light control rheostats was discussed with the pilots during the debriefing. Eight pilots stated they would like to have individual adjustments for each display plus a single master rheostat for quick adjustments of the entire forward instrument panel. The remaining pilots recommended from 3 to 7 rheostats for adjusting selected groups of displays.

IV. 8 DISCUSSION OF RESULTS

The experimental data showed that when flying both high and low altitude navigation missions using radio aids, the average display illumination used by the pilots as a function of the mission segments ranged from .095 to .045 ft. lamberts. For green EL-emitting displays the mean illumination ranged from .250 to .085 ft. lamberts; for white EL-transmitting displays the range was .065 to .037 ft. lamberts; and for white EL-reflecting displays the range was .038 to .025 ft. lamberts.

The most important finding in this experiment was that the mission segments and the type of display were the controlling variables which determined display illumination rather than the amount of ambient light. The data analysis indicated that the amount of ambient light available during a night mission, ranging from full moon to starlight, and the use of console,pedestal, and overhead panel lights, had no significant influence on the pilots' lighting requirements.

The amount of light used during the take-off and climb portion of the mission was significantly greater than that used during subsequent mission segments. Due to the wide variability among pilots, there were no significant differences during the later mission segments but the data trends indicate a definite dimming pattern was used by the pilots. These trends are best illustrated by the mean of the EL-reflecting displays shown in Figure 22.

Although there were no large excursions in display illumination, the general trends showed gradual dimming of the flight displays during both the high and low altitude cruise portions of the mission. In addition, display brightness was increased for the straight-in approach to Cleveland over the brightly illuminated city background and a similar increase was noted during the circling approach over a somewhat lower illuminated background when landing at WPAFB. Also, when flying the low level route, the pilots used a lower display illumination setting than when flying the high altitude portion of the mission where no out-of-the-cockpit visual information was required.

The significant difference in display illumination during take-off and climb was primarily influenced by the pilots' dark adaptation requirements. The pilots left a brightly illuminated briefing room and went directly to the aircraft. Pre-flight, start, and taxi required 15 to 20 minutes and most of the pilots used the bright overhead cabin lights during their starting procedures. From the time taxi clearance was received to the completion of the level-off approximately 30 minutes elapsed. This time period is equivalent to the mean time usually required for dark adaptation.

In addition to the influence of mission segments on lighting requirements, the type of display also had a significant influence on the brightness settings used by the pilots. This significant display difference was due primarily to the EL-emitting displays and the engine and fuel display indices in particular. Despite the fact that the pilots attempted to match the brightness of the legends and indices on the vertical displays, the overall means for the entire mission showed the indices to be 10 times brighter than the legends (.269 vs. .025 ft. lamberts). This supports the results found in Experiment I and indicates that brightness matching of EL-emitting symbology may be influenced by presently undefined psychophysical factors. The fact that the EL-emitting displays were illuminated with green light while all other displays were white-lit may also have influenced the high illumination settings of these displays. However, due to the brightness variability among the emitting displays, no definite conclusions can be drawn at this time. The pilot opinion data indicated that the digital read-outs on the HSI and the small size of the O^2 Pressure Indicator made both of these displays difficult to read and forced the pilots to use a higher illumination level than they desired. This opinion was supported by the data (Figure 22, page 45) which showed that both these displays were used at a consistently higher illumination level than the other EL-reflecting displays.

There were twelve complaints concerning the Kollsman dial reading on the altimeter. However, because the Kollsman dial information did not require constant cross-checking during the mission the pilots did not increase the illumination on this display beyond that required to read the large numbers on the dial face.

Pilot opinion data indicated that the EL-lighting was highly acceptable. Although the single flight experience had little positive influence on the ratings of the individual displays, the overall rating of the EL lighting increased considerably. Individual ratings indicated the pilots felt the EL lighting was "progressive" and a definite "improvement" over conventional incandescent cockpit lighting.

V.

EXPERIMENT III

V. 1 SUBJECTS

Eighteen of the 28 pilots who flew in Experiment II were selected by the FTFB Test Director to fulfill the subject pilot requirements of Experiment III. In the interest of flying safety, only pilots who had low altitude navigational experience of one type or another, were chosen. Most had low altitude, high speed fighter experience. Thus, the 18 subject pilots who participated in Experiment III were highly qualified to fly in the night low altitude navigation and weapons delivery environment and were also familiar with the prototype EL displays. Table VIII details the flight experience of the selected group of pilots.

TABLE VIII. EXPERIMENT III SUBJECT PILOTS' FLIGHT EXPERIENCE

		YEARS RATED	TOTAL FLYING TIME	COMBAT TIME	NIGHT TIME	NO. OF ILS APPROACHES
Mean		12	4,125	307	644	180
Range	High	26	14,000	640	1750	700
	Low	6	2,400	65	150	60

V. 2 MISSION

The Experiment III mission was a simulated low altitude night penetration and weapons delivery mission. The mission originated at WPAFB and was approximately 1.8 hours in duration. Two flights were scheduled each night. The first flight began approximately 1.5 hours after sunset and the second flight was scheduled for three hours later. Takeoff times were occasionally adjusted to obtain the desired ambient illumination conditions.

A diagram of the mission route is shown in Figure 25. The mission route consisted of a takeoff from WPAFB and a climb to 5000 ft. A direct route was flown from WPAFB to the Lockbourne Low Level Route No. 2 initial point. The low level route was flown to a bridge south of Camp Atterbury, Indiana. At this point, a climb was made to 8000 ft. The target was located between the airways south of Columbus, Indiana and consisted of a large group of lights on the ground. After reaching the target area, the pilot made a series of four 30-degree dive bombing passes. Upon completing the bombing runs, the pilot climbed to 17,500 ft. and flew a direct route to the high altitude approach fix at WPAFB. He then made a standard jet penetration, ILS approach and full stop landing.

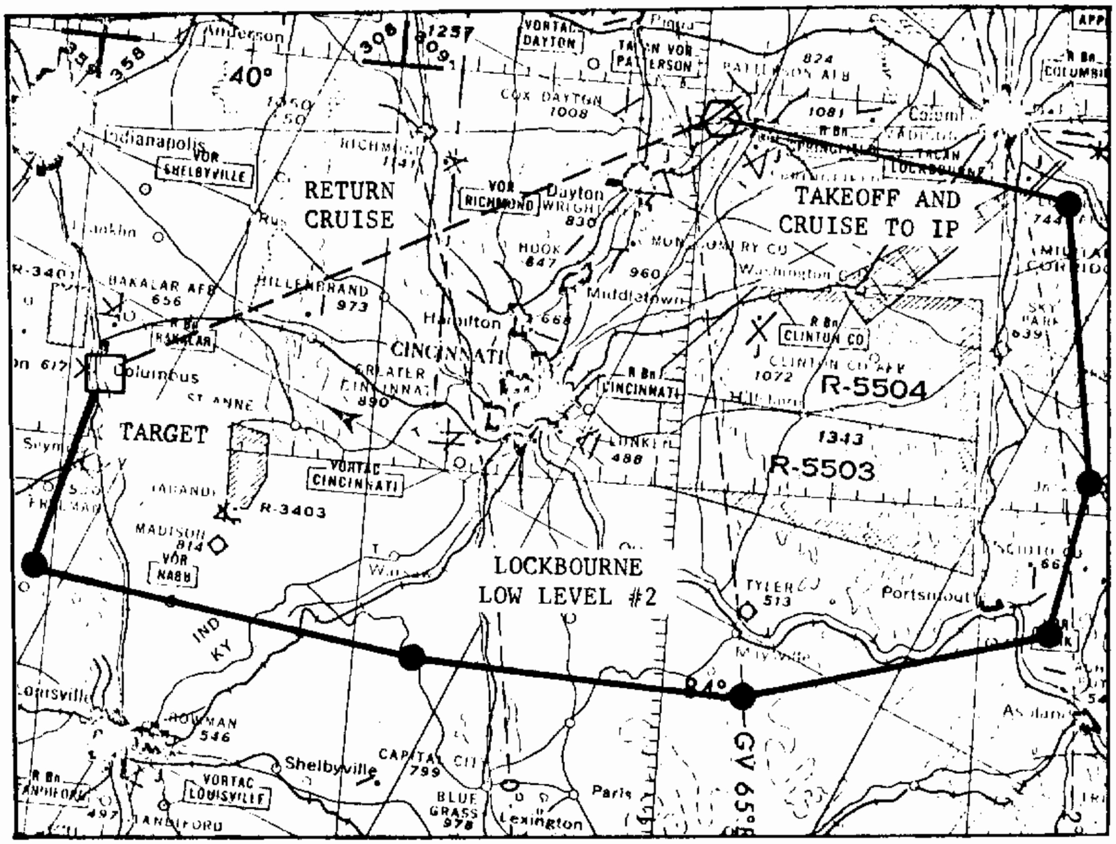

FIGURE 25. EXPERIMENT III MISSION ROUTE

V. 3 PROCEDURES

The following additions to the procedures outlined in Section II were used in Experiment III. Each of the 18 subject pilots flew a single mission. The pilots were provided 1) a mission card, 2) an AF Form 70, Pilots' Flight Plan, (Appendix D, pages 106-107 3) route diagram similar to Figure 25, and 4) a knee map, a portion of which is reproduced on Page 108 Appendix D. The experimenter recorded photometric and display brightness data at the times shown on the experimenter's data sheet in Appendix D, page 109.

V. 4 EQUIPMENT CHANGES

The only equipment change made prior to beginning Experiment III was the inclusion of an experimental kneeboard for use in place of the C-4 lamp. The kneeboard, shown in Figure 26, was developed by Plumly Flight Products, Inc., Fort Worth,Texas. It included a polarized transparent front plate which distributed illumination

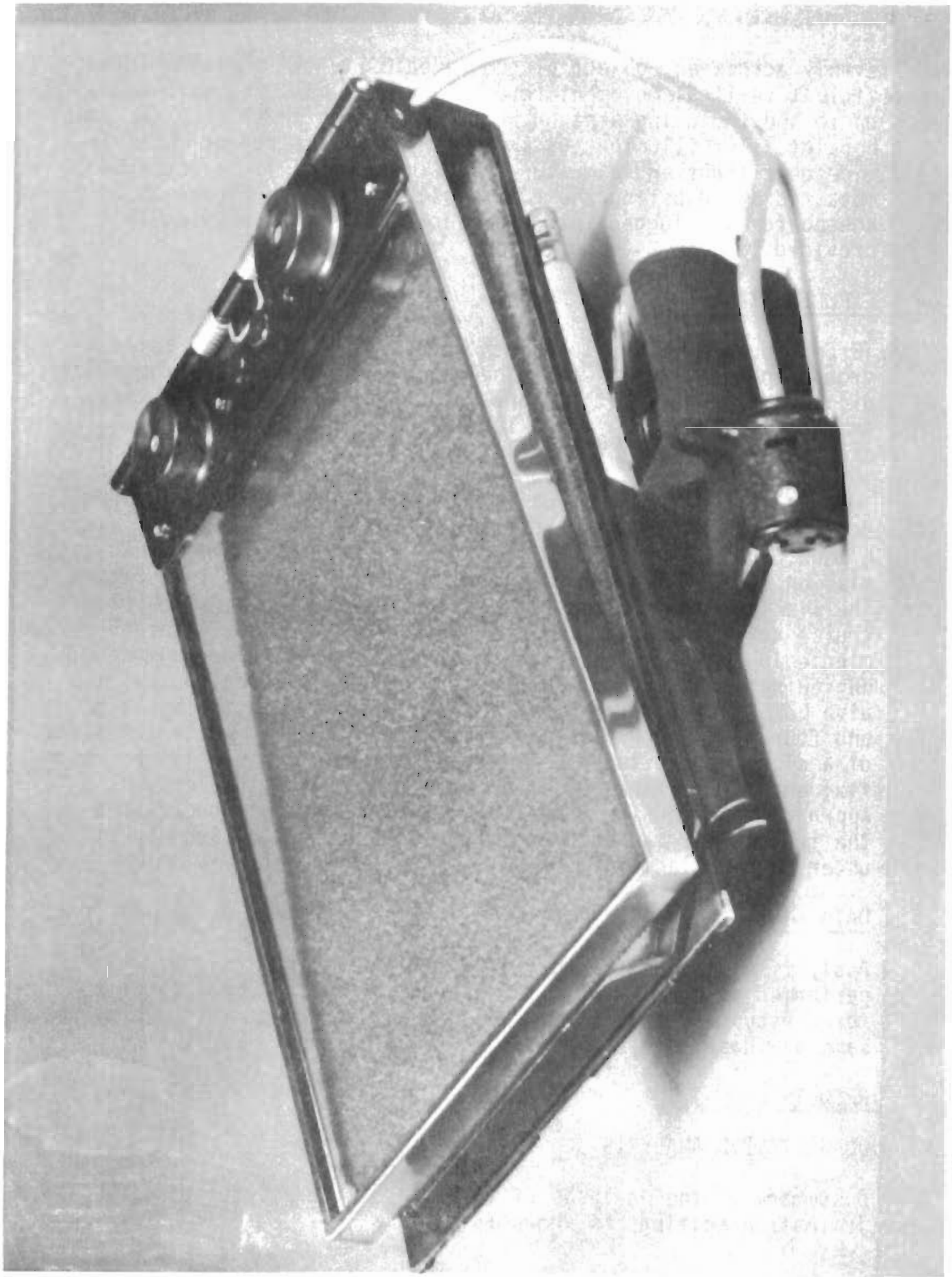

FIGURE 26. EXPERIMENTAL KNEEBOARD USED IN EXPERIMENT III

evenly across any object placed beneath it. This plate had sufficient vertical movement to easily accept maps and various papers up to and including a standard one-half inch thick terminal area booklet. The illumination source was variable red or white incandescent light and a mixture of both types of light could be obtained by adjusting the two rheostats shown in Figure 26. The kneeboard was plugged into the electrical socket previously provided for the C4-Lamp.

V. 5 EXPERIMENTAL DESIGN

Three groups of six pilots each were used in the basic between-group experimental design. The dependent variable was the pilot's display brightness setting and the independent variables were: ambient illumination (three levels), mission segments (seven levels), and display types (thirteen levels).

The three levels of ambient illumination were: 1) high ambient, defined as 3/4 to full moon, 2) medium ambient, defined as ¼ to ½ moon, and 3) low ambient, defined as starlight only. The seven mission segments were each approximately 15 minutes in duration. The mission segments consisted of: 1) the takeoff, climb, and cruise to the low level initial point; 2), 3), and 4) the 45 minute low level route, which was divided into three segments, a beginning, middle, and end, each 15 minutes in duration; 5) the dive bombing segment, which included the approach to the target and four high angle passes; 6) the return cruise, which consisted of a climb to altitude and a direct route to the initial approach fix; and 7) the final mission segment including the letdown, approach, and landing. The thirteen display types comprising the independent variables are listed on page 15 of Section II under Data Collection.

V. 6 DATA ANALYSIS

Analysis of the Experiment III display illumination data was performed using a 3 X 7 X 13 analysis of variance matrix with three groups of six pilots each. Mean difference tests were the same as those used in Experiment II (Section IV, page 38.)

V. 7 RESULTS

QUANTITATIVE ANALYSIS

A summary of the analysis of variance of the pilots' display illumination settings is shown in Table IX.

TABLE IX. ANALYSIS OF VARIANCE OF DISPLAY ILLUMINATION

SOURCE	df	MEAN SQUARE	F	LEVEL OF SIGNIFICANCE
AMBIENT CONDITIONS (A)	2	.0410	.0532	-
FLIGHT SEGMENTS (F)	6	.6136	5.1347	.01
DISPLAY TYPES (D)	12	4.8470	13.2867	.01
AF	12	.1404	1.1749	-
AD	24	.0475	.1302	-
FD	72	.2132	2.7333	.01
AFD	144	.0634	.8128	-

Significant main effects were found for both the flight segments and display types. These effects were attenuated somewhat by a significant flight segment by display type interaction. No significant main effects were attributable to the ambient illumination conditions.

The mean sky illumination from each group of six flights across mission segments and ambient conditions ranged from 4.0 X 10^{-4} to .22 X 10^{-4} foot candles. The mean illumination at the pilots' eyes ranged from 3.0 X 10^{-4} to .31 X 10^{-4} foot candles. Comparisons were made of display illumination and ambient illumination by mission segments. All levels of both eye and sky ambient illumination were cross-compared with the mean display brightness of the EL-emitting, EL-reflecting, and EL-transmitting displays and the overall display means. The resulting Pearson product moment coefficient showed no significant correlations between display brightness and ambient illumination. The mean ambient illumination levels as recorded from the "eye" and "sky" photoreceptors for each ambient condition and mission segment are shown in Appendix D, page 110.

Figure 27 shows the mean brightness setting for each of three groups of displays and an overall mean for all displays as a function of mission segments. All display types followed the same general pattern during the first three mission segments with gradually decreasing illumination. The illumination of the EL-emitting displays was continually dimmed throughout the mission while that of the EL-transmitting displays showed slight increases during the fourth and last mission segments. The EL-reflecting displays, which consisted primarily of the basic flight instruments, decreased in illumination throughout the first five mission segments and then increased during the final two segments. The Scheffe' test indicated that the mean display illumination during the first mission segment was significantly greater (.10 level of significance) than the illumination used during the third and the seventh mission segments. The difference in the amount of light used during the first and second mission segments was not significant.

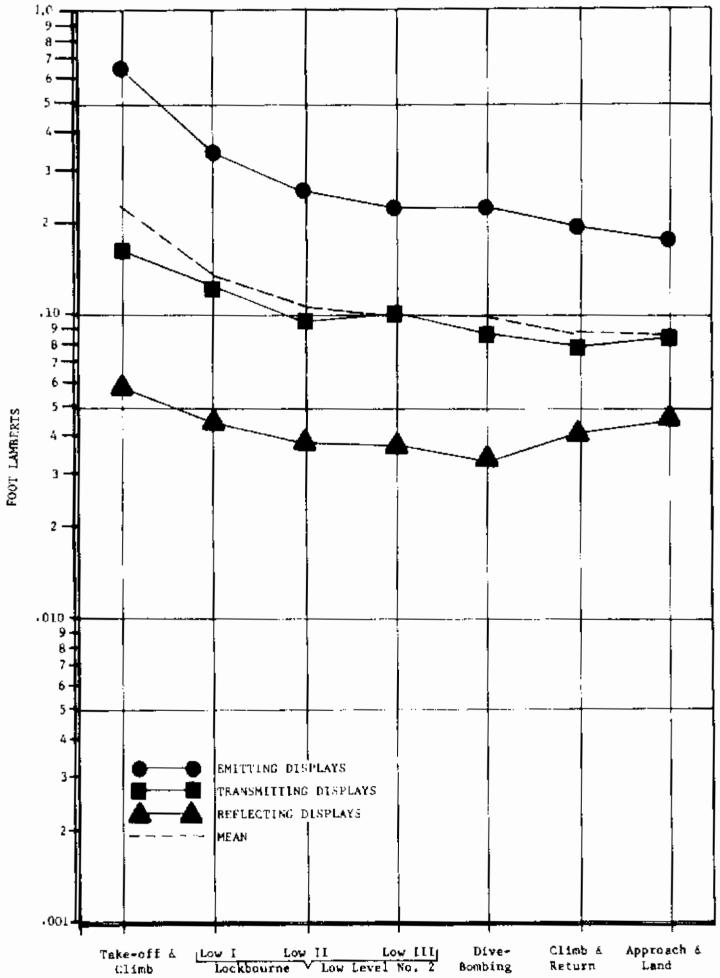

FIGURE 27. AVERAGE DISPLAY ILLUMINATION AS A FUNCTION OF FLIGHT SEGMENTS

The mean illumination levels for each of the thirteen displays across all mission segments are shown in Table X.

TABLE X. MEAN DISPLAY ILLUMINATION (ALL MISSION SEGMENTS)

EL-EMITTED LIGHT		EL-TRANSMITTED LIGHT		EL-REFLECTED LIGHT	
DISPLAY	MEAN FT. L.	DISPLAY	MEAN FT. L.	DISPLAY	MEAN FT. L.
ENGINE LEGENDS	.003	RADIO CALL PANEL	.134	O^2 PRESSURE	.061
CLOCK NUMBERS	.745*	CLOCK PANEL	.201	HSI	.056
ENGINE INDICES	.146	O^2 PANEL	.032	AIRSPEED	.036
		COURSE SEL. PANEL	.052	ADI	.038
				ALTIMETER	.033
				VERTICAL SPEED	.028

*SIGNIFICANT AT THE .10 LEVEL

The Scheffe' test indicated that the EL-emitting clock numbers were significantly brighter than all other displays.

The"T"tests on the ninety-one mission segment by display type means revealed that in addition to the clock numbers, during specific mission segments the engine indices (Figure 28) and clock panel (Figure 29) were also significantly brighter than other displays (.05 level of significance). Figure 28 contains plots of the three EL-emitting light sources. The clock number illumination used during the first mission segment was significantly brighter than that used in all other mission segments (.05 level). The clock number illumination used when starting the low level cruise (second mission segment) was significantly brighter than the illumination used during the return cruise and recovery at the home base (last two mission segments). In addition, during the first mission segment, the illumination of the engine indices was significantly brighter than the illumination used for the engine legends throughout the entire flight. As shown in Figure 28, the engine legends were maintained at an illumination level lower than any other EL-emitting light source.

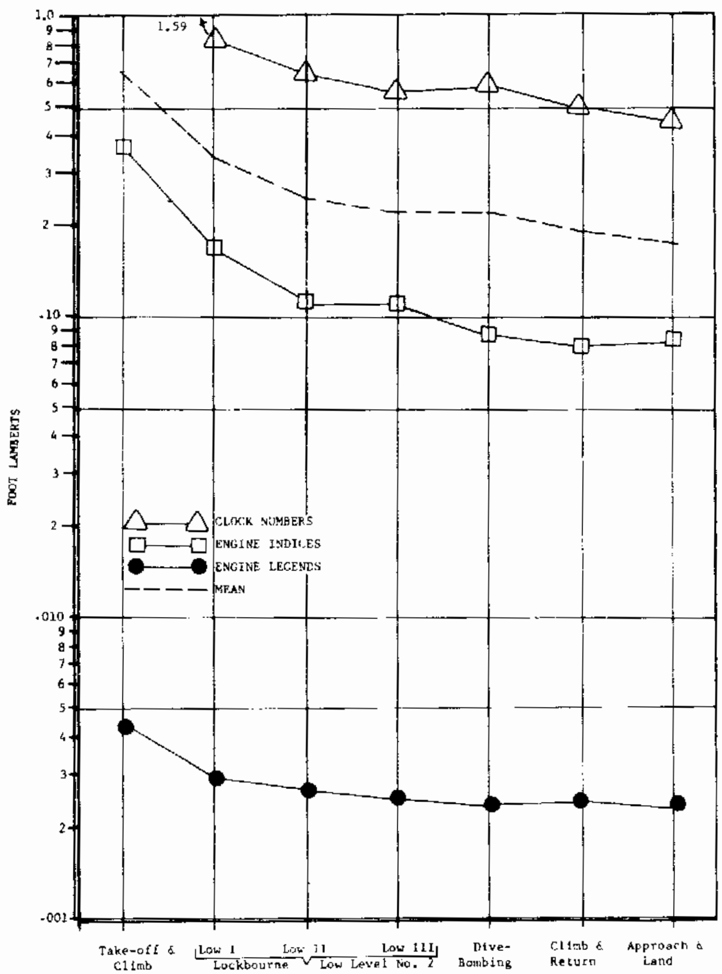

FIGURE 28. AVERAGE ILLUMINATION USED FOR EL-EMITTING DISPLAYS AS A FUNCTION OF FLIGHT SEGMENTS

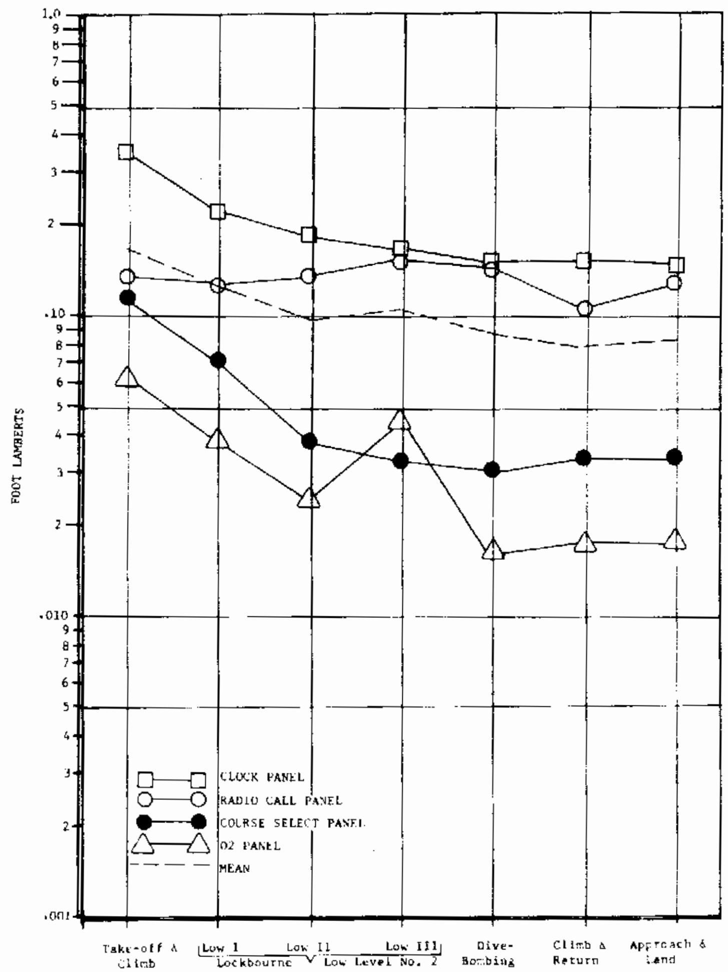

FIGURE 29. AVERAGE ILLUMINATION USED FOR EL-TRANSMITTING DISPLAYS AS A FUNCTION OF FLIGHT SEGMENTS

The illumination levels of the subpanels, which made up the EL-transmitting display group, are graphed as a function of mission segments in Figure 29. The mean comparison "T" tests showed the first segment illumination of the clock panel to be significantly brighter than the six lowest illumination means for the other EL-transmitting displays (.05 level). These means include the illumination of the Course Select panel during the fourth and fifth segments and the O^2 panel illumination recorded during the 3rd, 5th, 6th, and 7th mission segments. The EL-reflecting display illumination means were closely grouped between mission segments and across the six displays as shown in Figure 30. The HSI and O^2 Pressure Indicator were both set at higher illumination levels than any other EL-reflecting display across all mission segments.

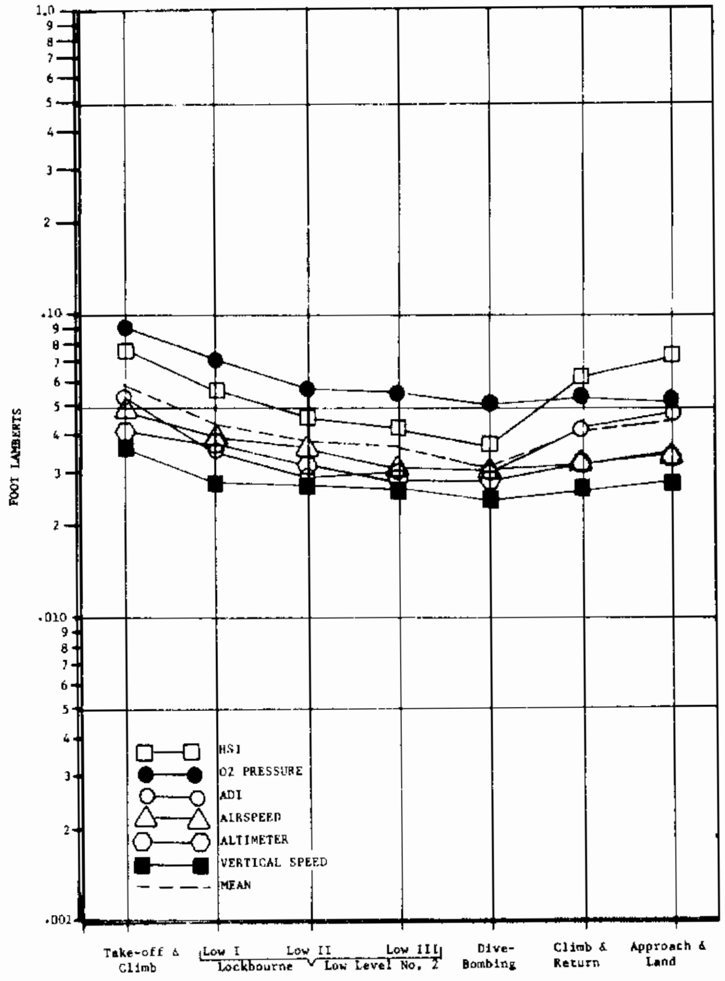

FIGURE 30. AVERAGE ILLUMINATION USED FOR EL-REFLECTING DISPLAYS AS A FUNCTION OF FLIGHT SEGMENTS

This difference proved to be significant when comparing the illumination of the EL-reflecting displays to the illumination of the clock panel. The "T" test showed the first segment illumination of the clock panel (.354 foot lamberts) was significantly brighter than any displays which required .0365 foot lamberts or less of illumination. The illumination of the Vertical Speed throughout all mission segments was below this level as was the airspeed and altimeter illumination in five mission segments and the ADI illumination in five mission segments. The illumination levels of the HSI and O^2 Pressure Indicator were consistently above .0365 foot lamberts throughout all mission segments; thus indicating a real illumination difference between these displays and the remaining four EL-reflecting displays.

PILOT OPINION

EL-Questionnaire Results

Because the eighteen subject pilots had all participated in Experiment II, their pre-flight ratings of the display readability and EL-lighting were taken from the Experiment II data and compared to the post-flight ratings from both Experiments II and III. Figure 31 depicts the mean display readability ratings before Experiment II and after flying Experiment II and III missions. In general,

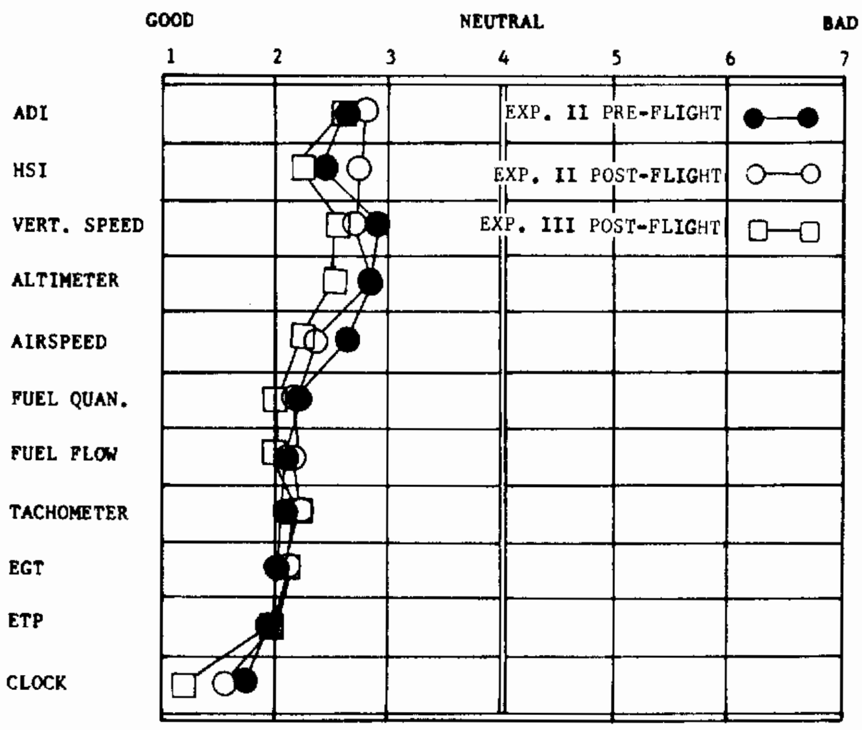

FIGURE 31. MEAN PRE- AND POST-FLIGHT RATINGS OF DISPLAY READABILITY

the pilots post-flight ratings improved from Experiment II to Experiment III for all displays with the ratings of the EL-reflecting flight instruments showing slightly more improvement than the ratings of the EL-emitting displays.

General improvement was also found from the Experiment II to the Experiment III post-flight ratings of the EL-illuminated displays compared to conventional incandescent display lighting (see Figure 32). Ratings on all but one adjective pair improved. Large improvement was shown for such words as "promising" and "versatile."

A series of eight paired adjective scales (see Appendix A, page 85. was used to examine specific features of the EL-emitting displays. The pilots' Experiment III post-flight ratings of the green color of the EL-emitting displays improved over the Experiment II post-flight ratings for both the clock and engine displays. Only two

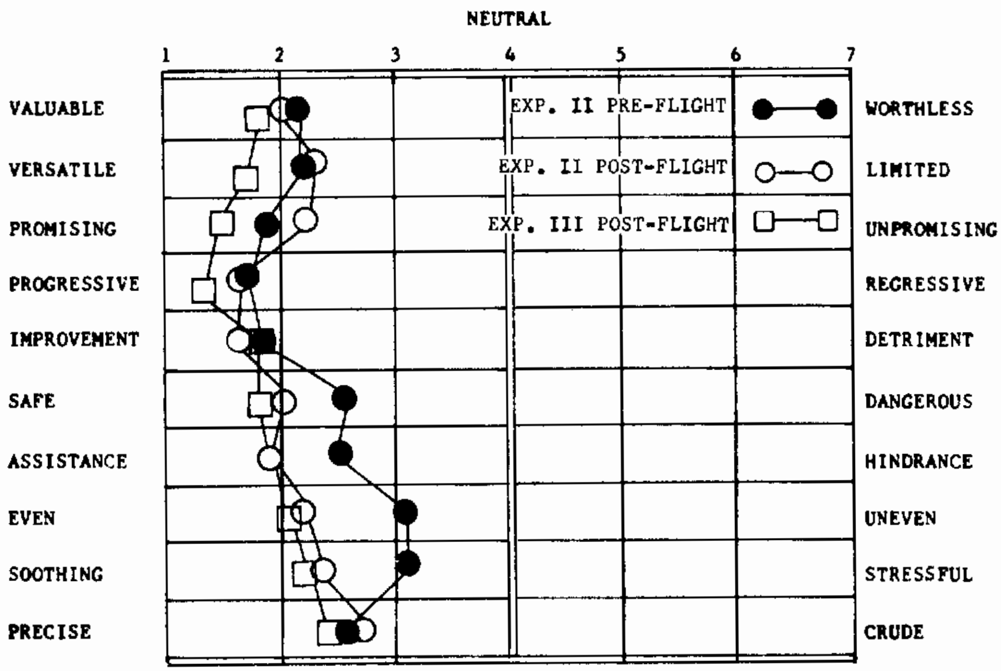

FIGURE 32. MEAN PRE- AND POST-FLIGHT RATINGS OF EL-LIGHTING COMPARED TO CONVENTIONAL INCANDESCENT COCKPIT LIGHTING

pilots expressed a preference for other than green illumination; both of these pilots stated they preferred white light. The Experiment III post-flight EL-clock ratings improved almost a full point over the Experiment II pre-flight ratings of usefulness, clarity of format, elapsed time presentation, and rapid changing of the seconds numerals. The pilots indicated a neutral attitude (pre-flight rating 4.05, post-flight 4.10) toward inclusion of a standard dial clock in addition to the EL digital clock.

De-Briefing Results

Of the eighteen pilots only four stated they had difficulties with the cockpit lights during specific mission segments. One pilot reported insufficient illumination on the Altimeter, Airspeed, and Rate-of-Climb throughout the mission. Three pilots each reported difficulties with the lighting during the low level cruise, the letdown and the approach. In addition, there were specific criticisms by several other pilots of the ADI, HSI, the Subpanels, and the kneeboard. These pilots stated the individual display illumination problems did not have a significant influence on successful completion of the mission but they felt appropriate corrective action should be taken. A summary of all pilots' comments on the design and illumination of the individual displays is as follows:

ADI - Seven pilots reported the following difficulties with the ADI:

1) Uneven illumination between the center and sides of the ball (5 pilots).
2) Did not like the blue and brown colors (3 pilots).
3) Small pitch lines on the ball were hard to see (3 pilots).
4) Horizon line inadequate (2 pilots).

HSI - Eight pilots reported the digital readouts for course and DME were poorly illuminated when the rest of the display was adjusted comfortably.

ALTIMETER - Nine pilots reported the Kollsman dial was difficult to illuminate properly when the face of the Altimeter was comfortably illuminated.

AIRSPEED AND VERTICAL SPEED - Three pilots stated that brighter illumination was required for these two displays and for the Altimeter during the early portion of the mission. One of these pilots requested brighter illumination for these three displays throughout the mission.

ENGINE INSTRUMENTS AND FUEL DISPLAYS - The only complaint from two pilots was that the step segments making up the display indices were too large.

EL CLOCK - The pilots were highly enthusiastic over the EL Clock. Several pilots described it as "excellent for the low level mission."

SUBPANELS - Lack of illumination on the subpanel switches was the only discrepancy noted by six of the pilots.

KNEEBOARD - Seven pilots were pleased with the illumination of the experimental kneeboard. They stated it was a great improvement over the lighting used for the standard Air Force issue kneeboard. Many of the other pilots also stated that the experimental kneeboard was well illuminated but they also noted some discrepancies. The list of discrepancies and the pilots recommendations are as follows:

1. Illuminated area did not cover the entire low level map (7 pilots).

   Recommendation: Make the map smaller so it will fit under the illuminated front plate.

2. Too much manipulation required to adjust objects being viewed under the illuminated front plate (5 pilots).

   Recommendation: Use a roller device and moving map or use a gooseneck console lamp or plug the C-4 lamp into top of kneeboard.

3. Too much head movement required to look at map (4 pilots).

   Recommendation: Place map or letdown plates in a holder on the instrument panel similar to method used in C-141.

4. Kneeboard interfered with control wheel movement (2 pilots).

   Recommendation: Same as 3 above.

5. Light from kneeboard reflected on windows and windscreen (5 pilots).

   Recommendation: Turn off kneeboard light when not in use (On-off switch for kneeboard should be in a convenient place such as the stick or throttle).

All pilots used white light to illuminate the kneeboard with the exception of two pilots who used a pink mixture of red and white light. The majority of the pilots stated that white light was necessary to discriminate the colors used on the map.

In addition to the comments on the individual displays and the kneeboard, the following general information was obtained during the debriefing: Two pilots stated they preferred white lights for the EL-emitting displays, the remaining pilots found the green color satisfactory. With the exception of the kneeboard, no other cockpit lights were reported to cause reflections or glare on the display faces or the cockpit windows.

Configuration of the forward instrument panel illumination varied among pilots. However, the following general arrangement was reported most frequently: The five primary flight instruments were grouped together. The ADI and HSI were set at an illumination level equal to or slightly higher than the Airspeed, Altimeter, and Vertical Speed. The EL-emitting displays (clock and engine instruments) were turned down after take-off with the clock "fairly high" and the engine displays at a "low" illumination level. The subpanels were adjusted to a "dim" illumination level. Two pilots reported they turned the oxygen panel off at some time during the mission.

Ten pilots preferred individual rheostats for adjusting the illumination of each display. However, they also recommended a master rheostat for quick illumination changes of the entire forward panel. Several of these pilots recommended that the individual display rheostats be placed in close proximity to the displays they controlled (i.e., on the display bezel). The remaining eight pilots recommended from 3 to 5 rheostats be used for selected groups of displays. The three groups most often recommended for common illumination were: 1) flight displays; 2) engine displays; and 3) subpanels.

V. 8 DISCUSSION OF RESULTS

The experimental data showed that when flying a night low altitude navigation and weapons delivery mission the average illumination for all displays across all mission segments ranged from .230 to .087 foot lamberts. The brightest display group was the EL-emitting displays. The illumination of these displays ranged across mission segments from .650 to .175 ft. lamberts. The EL-transmitting displays ranged from .165 to .078 ft. lamberts and the EL-reflecting displays from .058 to .036 ft. lamberts.

The pilots consistently dimmed their displays while flying the first four mission segments, which included the takeoff and the low level route. During this portion of the mission, the pilots consistently referred to their kneemap. The light plate on the kneeboard presented a large illuminated area which may have influenced pilot dark adaptation. To provide good out-of-the-cockpit vision while maneuvering in the dive bombing pattern the majority of the pilots turned off their kneeboard light and dimmed their basic flight instruments, especially the HSI and ADI. After completing the dive bombing runs the pilots increased the illumination of the basic flight instruments for the return cruise, letdown and landing.

Of the three independent variables, only the mission segments and display types had any significant effect on the pilot's display brightness selections. Ambient illumination conditions ranging from full moon to starlight did not significantly influence the pilots' display illumination settings.

The take-off portion of the mission proved to be the only segment requiring significantly higher illumination. This high illumination was undoubtedly influenced by the lack of pilot dark adaptation prior to beginning the flight.

The EL-clock was the most brightly illuminated display throughout the mission. This is understandable considering the importance of time during a low level mission. Without the use of radio aids, the night environment made it quite difficult to visually locate the low level checkpoints and the pilots had to depend on dead reckoning for navigation. Dead reckoning requires close adherence to time, speed, and heading. The importance of time was underscored by the fact that during the low level cruise many of the pilots were unable to locate all the checkpoints and were forced to make one or more turns based strictly on time.

The difference in the illumination of the legends and indices on the EL-emitting engine and fuel display was even more pronounced than in previous experiments. This disparity is best illustrated by the grand means of these two light sources. The small engine legends had a mean illumination of only .00279 ft. lamberts while the large indices or "moving tape" portion on the same displays had a mean illumination level of .14619 ft. lamberts. Despite this disparity the pilots reported they had attempted to match the brightness of these two portions of the engine displays symbology. The psychophysical factors influencing EL brightness matching should be subject to further research in order to properly control the illumination of future EL-emitting displays.

As in previous experiments, there was general agreement between the pilot opinion and pilot performance. The O^2 Pressure Indicator, which the pilots criticized as being too small, and the HSI, which contained poorly illuminated digital readouts, were both illuminated at a consistently brighter level compared to the remaining four flight displays. Three pilots complained of insufficient illumination for the Altimeter, Vertical Speed, and Airspeed indicator. However, the small variation in illumination between the five primary flight displays indicates that the majority of the pilots preferred a fairly consistent brightness level among these displays. This finding was further reinforced by the pilots' statements that the five primary flight displays could easily share a common rheostat, but an individual rheostat for trimming the illumination of each display would be highly desirable.

VI

CROSS COMPARISON OF EXPERIMENTAL RESULTS

VI. 1 DISCUSSION AND CONCLUSIONS

AMBIENT ILLUMINATION

The ambient illumination data collected during the three in-flight experiments reflected the weather conditions under which the missions were flown. All missions requiring high and medium ambient illumination were flown under VFR weather conditions with the sky cover ranging from clear to scattered clouds. VFR conditions were also planned for those missions which required low ambient conditions. However, in order to complete the data collection in a reasonable time, some of these missions were flown under IFR weather conditons with overcast skies.

As might be expected, the normal weather conditions in Southern Ohio had a pronounced influence on the ambient illumination measures. The haze layer associated with this geographical area is usually located between the ground and approximately 6,000 feet and its altitude and density varies from night to night. In recording the photometric data, it was noticed that the haze layer provided a ground illumination backscatter effect which caused the sky receptor to show increased illumination when flying at low altitude over a highly illuminated ground environment. This backscatter decreased as a function of altitude and on clear nights with little haze the effect was much less pronounced.

Prior to the sky becoming completely darkened, the Experiment I photometric data showed that the illumination recorded from the eye receptor was higher than that recorded from the sky receptor. This was due primarily to the bright horizon where the sun was setting. One and a half hours after sunset the two receptors showed comparable ambient readings. The data from Experiments II and III, which began well after sunset, showed little difference between eye and sky photometric readings (See Appendix C, page 105 and Appendix D, page 110). In general, when high ambient conditions (full to 3/4 moon) were flown, the sky ambient was brighter than the ambient at the pilot's eye. Under medium to low ambient conditions (1/2 moon to starlight), the illumination recorded at the pilot's eye was equal to or higher than the sky illumination. These findings are attenuated by the fact that the T-39 test aircraft had a transport type roof over the cockpit. The influence of high ambient night illumination on the illumination recorded by a receptor near the pilot's eye might possibly be different in a fighter type aircraft equipped with a clear bubble canopy. The combined results of the three experiments indicate that night ambient illumination (external to the aircraft) had little influence on the brightness settings of the pilot's displays once this illumination fell below .001 foot candles. In Experiment I, a significant correlation was found between ambient illumination and display brightness; however, the average sky ambient illumination directly above the aircraft ranged from .5 foot candles at sunset to less than .001 foot candles one and half hours after sunset. In Experiments II and III, the flights all began 1.5 hours after sunset and the average sky ambient ranged from .00046 foot candles down to .00002 foot candles. These extremely low levels of illumination had no significant influence on display brightness settings as shown by the correlations and analyses of variance performed in Experiments II and III.

Although the test aircraft was not equipped with a clear fighter type canopy, the levels of night illumination recorded above the test aircraft even under full moon conditions were not sufficiently bright to influence the pilot's display illumination settings. Therefore, the resulting display illumination data may be applied to all types of aircraft.

In Experiment II the low ambient illumination missions were flown by two groups of pilots. One group was permitted to use the standard red incandescent peripheral panel lights, which consisted of the console, pedestal, and overhead panel integral lights, and the console flood lights. The second group was instructed to leave these lights off. The analysis of variance indicated there were no significant differences in the forward panel display illumination between these two groups.

The illumination produced by the peripheral lights was measured by mounting a cosine receptor on a tripod 36 inches from the panels. The receptor was aimed at three areas of each panel and the resulting voltage-brightness measurements were then averaged. The in-flight data from both Experiments II and III showed that the panel integral light illumination, used by the pilots, ranged from 2.8×10^{-3} to 1.5×10^{-4} foot lamberts. Only 14 of the 21 pilots in Experiment II who were permitted to use the console flood lights chose to do so. The illumination used by these pilots ranged from 8×10^{-3} to 1×10^{-4} foot lamberts. The mean illumination used for all peripheral panel lighting was approximately .003 foot lamberts. The contribution of this small amount of light to the cockpit ambient illumination failed to influence the pilots' display brightness settings.

ILLUMINATION REQUIREMENTS FOR EL-DISPLAYS

Accurate information display is essential to safe flight. Therefore, a display illumination range which will satisfy the illumination requirements of only the fifth through ninty-fifth percentile group of pilots is not acceptable. To be acceptable display illumination ranges must satisfy the illumination requirements of <u>all</u> Air Force pilots. To assure that this requirement was met a <u>careful</u> examination was made of the entire range of display illumination used by each pilot in all three experiments.

The display illumination ranges recommended as a result of Experiment I were verified by the results of both Experiments II and III. The lower limit of illumination which was recommended for all three types of EL displays in Experiment I was .01 ft. lamberts. With the exception of the illumination of the EL-emitting engine display legends no displays exceeded this lower limit during any of the experiments. Examination of the illumination ranges used by the individual pilots in all three experiments showed that displays incorporating EL-reflecting and EL-transmitted light will require a maximum of 1.0 foot lamberts of illumination. This upper limit will be sufficient to meet the needs of all pilots whenever the ambient sky illumination falls below 10 foot candles.

When the sky ambient illumination is above 10 foot candles, there is sufficient light to read the standard cockpit displays without the aid of artificial illumination.

EL-emitting displays such as the engine displays and clock used in these experiments are unique in that they must be artificially illuminated even under daytime ambient illumination conditions because the EL-light elements themselves produce the display information. The only opportunity to investigate the daytime illumination requirements for the EL-emitting displays was during the take-off and climb segment of Experiment I. Based on this limited in-flight data and the pilots' comments, approximately 20.0 foot lamberts should be sufficient daytime illumination, assuming high contrast EL-emitting displays are located beneath an appropriate instrument panel glare shield which minimizes their exposure to direct sunlight.

Based on the data of Experiment I, the recommended lower illumination limit for EL-emitting displays was .01 foot lamberts. This lower limit was occasionally exceeded in all three experiments when individual pilots selected extremely low illumination settings (i.e., less than .005 ft. lamberts) for the engine display legends. However, these low illumination settings were influenced by an unplanned brightness matching task which the pilots performed. The EL-emitting engine displays were equipped with two rheostats for separately adjusting the legends and indices on these displays. This switch arrangement was set up for the convenience of wiring and to eliminate the need for individual rheostats for each of the five vertical displays. However, the inclusion of independent rheostats for control of these two portions of the engine displays gave the pilots the opportunity to match the brightness of the small legends and the large indexes or "tape" portions of the displays. Unlike the basic flight displays, which were closely matched in illumination (see Figures 15, 22 and 29), large illumination differences were found throughout all experiments between the engine display legends and indices (see Figures 13, 20 and 28). These differences were so large in comparison to the other displays that a complete recheck was made of the display wiring, data recording equipment and calibration procedures to be sure the data were not in error. The data from all three experiments proved to be correct and showed that the engine indices were set at an illumination level one to two orders of magnitude brighter than that used for the engine legends. In Experiments I and II, the EL-emitting clock numbers were set at an illumination level in between that recorded for the engine legends and indices. This appeared to indicate that the size of the EL-emitting area might possibly have influenced the pilots' brightness matching behavior. A comparison of light-emitting element size and illumination indicated that as the emitting elements became larger more light was required to produce the same apparent brightness. However, in Experiment III, the high illumination of the clock numbers, which was attributed to the high priority need for this information, prevented the element size/illumination relationship from being consistent across all three experiments.

A recently published study by Reynolds (Ref. 16) contains a graph of EL-display brightness required for legibility as a function of letter height. Based on these data, numbers the size of those used on the engine display legends should have required approximately .01 foot lamberts of luminance for threshold legibility. However, as previously pointed out, the engine legend illumination levels selected by some of the pilots were far less than .01 foot lamberts. Despite this low illumination, no complaints of poor engine legend legibility were reported by any of the pilots during the debriefings. It should be noted that Reynolds was investigating legibility of letters and not EL brightness matching. Therefore, the results of the three experiments described in this report do not necessarily contradict his findings. Further investigations will be required to determine what psychophysical processes control brightness matching of EL-emitting displays.

FACTORS INFLUENCING DISPLAY ILLUMINATION REQUIREMENTS

The Experiment I mission was a high altitude instrument flight which was flown from sunset until the sky was quite dark and the pilot's primary flight information sources were the in-cockpit displays. The Experiment II mission was begun well after sunset. The early portion of this mission repeated the high altitude flight task while later mission segments included out-of-cockpit low altitude visual tasks. During these latter mission segments, the pilot was required to locate checkpoints using both a knee map and a radio navigation aids (VOR and TACAN). The Experiment III mission increased the out-of-cockpit visual task loading and mission success was heavily dependent on: 1) the pilot's ability to locate checkpoints using only dead reckoning and a knee map, and 2) the ability of the pilot to maintain spatial orientation while flying the dive bombing pattern.

The Experiment I data showed a significant correlation between the twilight sky ambient illumination and the pilots' display illumination settings. In Experiments II and III, the results consistently showed that both the mission segment and the type of display had a significant influence on the pilots' display brightness settings. The display illumination required during the early mission segments of Experiments II and III was primarily influenced by the pilots' exposure to the high illumination in the briefing room and to lights on the flight line. Approximately thirty minutes after they began to taxi out for takeoff the pilots had adapted to the night cockpit illumination. Once the pilots were dark adapted, the experimental data indicated that display brightness settings were influenced by three factors:

1. The type of information the pilot required for successful completion of the mission. (In-cockpit displays or out-of-cockpit checkpoints, terrain, etc.).

2. The priority the pilot placed on specific types of information.

3. The effects of artificial illumination on display legibility.

The mission segments of each experiment were keyed to the in or out-of-cockpit information requirements. At high altitude under radar control the pilots are freed from most out-of-cockpit information requirements. The primary information required for successful completion of a high altitude mission segment is provided by the basic flight instruments (ADI, HSI, Airspeed, Altimeter, and Vertical Speed). Extremely close correspondence was evident between the basic flight instrument illumination used by the pilots during the latter high altitude portion of Experiment I (90 minutes after sunset) and the high altitude segments of Experiment II. (Compare Table I, page 26 and Figure 22, page 45).

During the low altitude segment of Experiment II, the pilots decreased the illumination of the basic flight instruments and concentrated on the out-of-cockpit checkpoint identification task (this decrease was not statistically significant but the trends were consistent). In Experiment II the pilots were permitted to use radio aids to assist them in locating checkpoints. This reduced the need for dead reckoning and the requirement for close attention to the knee map. The basic flight instrument illumination used during the Experiment III low level mission segments was slightly higher than that used in the low level mission segments of Experiment II. There are several reasons for this difference. Because they were denied the use of radio aids the pilots placed greater priority on dead reckoning and use of the knee map. This required close attention to elapsed mission time and the course shown on the knee map. The extremely high illumination used for the clock attests to the priority the pilots placed on time and the experimental kneeboard used for map reading in Experiment III presented a much larger illuminated area than was created by the C-4 lamp in Experiment II. The combination of these factors may have reduced the pilots' dark adaptation and could account for the display illumination differences between Experiment II and III low level mission segments. This assumption is supported by the fact that after completion of the low level route the pilots turned off their kneeboard light and turned down the basic flight displays illumination during the dive bombing maneuver. By reducing the overall cockpit illumination the pilots sought to maximize their dark adaptation and use all available external cues for maintaining their spatial orientation while in the weapons delivery pattern.

The design of the displays themselves also influenced the amount of illumination used by the pilots. The consistent high illumination of the HSI, compared to the other basic flight instruments, was directly attributed to the poorly illuminated digital readouts incorporated in this display. The high illumination of the small O_2 Pressure indicator recorded in Experiments II and III indicated that poor legibility due to small size also forces the pilot to use higher than desired illumination.

The priority which the pilots placed on specific information interacted with display design in influencing the selection of display illumination. This was illustrated throughout all three experiments by the numerous complaints concerning the inadequate illumination on the small Kollsman dial of the Altimeter. Despite the poor illumination of this portion of the display, the pilots maintained the altimeter at a "comfortable" low illumination level. They did this because, in their judgment, the Kollsman dial setting was not critical until a landing approach was begun. At this time they merely leaned forward to view the Kollsman dial while setting the altimeter.

Illumination of the forward instrument subpanels reflected the priority the pilots placed on their usefulness. Those subpanels which were judged less critical to the mission were maintained at a very dim illumination setting and sometimes turned completely off. Another example of the pilot's lighting priority assignment was evident in Experiment III where the increased illumination of the clock numbers was accompanied by a matching increase in the Clock Panel illumination which resulted in the Clock Panel being the most brightly illuminated subpanel.

The pilot opinion data have shown that electroluminescent light is highly acceptable to USAF pilots as the primary source of night illumination for cockpit displays. However, conversion to EL light is not a panacea which will cure all the problems associated with cockpit lighting. When flying with EL-illuminated displays, the vast majority of the pilots were not concerned with the type or color of the light, but with the adjustment of the illumination, its distribution across an individual display, and the interaction of display design and illumination which, in some cases, caused a decrease in display legibility.

The results of these three experiments indicate that cockpit lighting in a military aircraft is not a simple matter of selecting a particular type of cockpit light. On the other hand, the results have shown rather conclusively that all information sources within the cockpit must be designed with detailed attention directed toward their night illumination. In addition, all cockpit lights must be systematically integrated so the total illumination to which the pilot is exposed is compatible with the mission requirements. Finally, the pilots must be provided sufficient controls with which they can easily adjust the cockpit lights to meet their individual requirements.

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APPENDIX A
QUESTIONNAIRES AND CHECKLISTS

PILOT'S BACKGROUND QUESTIONNAIRE

NAME ____________ RANK ____________ SERIAL NO. ____________

AGE ____________ PILOT RATING ____________ YEARS RATED ____________

UNIT ____________ BASE ____________ DUTY PHONE ____________

Please complete the following using best estimates: DATE ____________

Type Flying Time	Hours	Aircraft Flown*	
		Type	Night Hours
Student Pilot			
Co-Pilot		1.	
First Pilot		2.	
Command Pilot		3.	
A/C Commander		4.	
Total Flight Time		5.	
Combat Day		6.	
Combat Night		7.	
Total Combat		8.	
Night VFR		9.	
Night WX		10.	
Total Night		11.	
Number ILS Appraoches		12.	

* List only aircraft in which you have been checked out and have a minimum of 25 hours flying time.

Hours Flight Time	Jet	Recip.	Turbo	Helio
Single Engine				
Two Engine				
More Than 2 Engines				

1. Have you graduated from a test pilot school? Yes ____ No ____ What School? ____________ What Year? ____________

2. Has your primary duty ever included test pilot work? Yes ____ No ____ How many hours do you have as a test pilot? ____________ What programs have you participated in? ____________

3. Have you ever flown an aircraft or simulator with experimental displays? Yes ____ No ____ What program? ____________ What displays? ____________

FIGURE 33. PILOT'S BACKGROUND QUESTIONNAIRE

SUBJECT	TIME (MINUTES)
1. INTRODUCTION TO FLIGHT TEST PROGRAM	5
(A) PROGRAM OBJECTIVES AND BACKGROUND (B) OVERVIEW OF PROGRAM	
2. INTRODUCTION TO ELECTROLUMINESCENCE	10
3. EXPERIMENTAL MISSION	15
(A) OBJECTIVES (B) MISSION ROUTE (C) PILOT TASKS (D) DATA COLLECTION (E) MISSION PROCEDURES	
4. COCKPIT CHECKOUT AND PRACTICE BY SUBJECTS	20
(A) LIGHT DIMMING CONTROL LOCATIONS (B) DIMMING PROCEDURES (C) PANEL EVALUATION (D) QUESTIONS AND ANSWERS	
5. ADMINISTRATION OF T-39 QUESTIONNAIRE	5
6. SCHEDULING	
(A) FLIGHT SCHEDULE (B) BRIEFING TIMES	
7. FINAL QUESTION AND ANSWER PERIOD	5
TOTAL TIME	1 HOUR

FIGURE 34. AGENDUM FOR PILOT ORIENTATION BRIEFING

EL COCKPIT LIGHTING QUESTIONNAIRE

NAME ______________________________
DATE ______________________________

You have had an opportunity to see the EL Displays installed in the T-39. Based on that experience, answer the following questions.

I. Check the appropriate block to indicate your evaluation of the <u>readability</u> of the following T-39 EL illuminated instruments under <u>nighttime illumination</u>.

	GOOD			NEUTRAL			BAD
1. ADI							
2. HSI							
3. VERTICAL SPEED							
4. ALTIMETER							
5. AIRSPEED							
6. FUEL QUANTITY							
7. FUEL FLOW							
8. TACHOMETER							
9. EGT							
10. EXHAUST PRESS.							
11. CLOCK							

II. Use the following list of paired adjectives to evaluate the T-39 EL instrument lighting <u>as compared to conventional incandescent cockpit lighting</u>.

				NEUTRAL				
Valuable								Worthless
Versatile								Limited
Promising								Unpromising
Progressive								Regressive
Improvement								Detriment
Safe								Dangerous
Assistance								Hindrance
Even								Uneven
Soothing								Stressful
Precise								Crude

FIGURE 35. EL COCKPIT LIGHTING QUESTIONNAIRE

III. Evaluate the following items on the scales provided.

Engine Instruments

1. The tape presentation for balancing engine parameters.

Assistance			Neutral			Hindrance

2. Green color of engine scales.

Good			Neutral			Bad

3. Is there any other color you would prefer? Yes _____ No _____
   What color? _____________

EL Clock

1. Use of clock for all flight phases.

Good			Neutral			Bad

2. Lapsed time feature of the EL clock.

Assistance			Neutral			Hindrance

3. EL clock numbers and format.

Clear			Neutral			Confusing

4. Rapid changing of "seconds" numerals on the EL clock

Assistance			Neutral			Hindrance

5. Use of standard dial clock in conjunction with EL clock.

Improvement			Neutral			Detriment

6. Green color of numbers.

Good			Neutral			Bad

7. Is there any other color you would prefer? Yes _____ No _____
   What color? _____________

FIGURE 35. EL COCKPIT LIGHTING QUESTIONNAIRE (CON'T)

BRIEFING GUIDE (ALL MISSIONS)

1. Personal Equipment
   (a) Use of Flashlight
   (b) Use of Kneeboard
   (c) Use of C-4 light

2. Mission Cards and Maps

3. Checklist
   (a) Pilot
   (b) Experimenter

4. Flight Profile
   (a) Weather Restrictions
   (b) Altitudes and Airspeeds
   (c) Mission Route

5. Radio Calls
   (a) Procedures
   (b) Experimenter to Pilot

6. Light Adjustment Procedures
   (a) Start & Taxi
   (b) Take-off
   (c) In-Flight

7. Instrument Lighting Restrictions

8. Shutdown Procedures

9. Debriefing

FIGURE 36. EXPERIMENTER'S BRIEFING GUIDE

DEBRIEFING QUESTIONNAIRE
(To Be Filled Out by the Experimenter)

Did you encounter any difficulties with the cockpit lights during any of the following portions of the flight?

	YES	NO	COMMENTS
1. TAKE-OFF			
2. CLIMB			
3. CRUISE			
4. CRUISE (LOW)*			
5. WEAPONS***			
6. PENETRATION			
7. APPROACH			
8. MISSED APPROACH**			
9. LANDING			

Did you have any difficulty adjusting the light levels for any of the following instruments? Refer to panel Photo.

	YES	NO	COMMENTS
10. A/S			
11. ADI			
12. HSI			
13. R/C			
14. ALT.			
15. CRS. SEL.			
16. RADIO CALL			
17. ENG. SCALES			
18. ENG. NOS.			
19. CLOCK NOS.			
20. CLOCK PANEL			
21. O^2 IND.			
22. O^2 PANEL			

* Experiment II and III only
** Experiment II only
*** Experiment III only

FIGURE 37. DEBRIEFING QUESTIONNAIRE

Were any of the following instruments unevenly illuminated?

	YES	NO	COMMENTS
23. A/S			
24. ADI & HSI			
25. R/C			
26. ALT.			
27. ENG.			
28. FUEL			
29. CLOCK			

Did you turn any displays off? Did you group any of the displays by lighting them higher or lower than others?

	GROUP	HIGH	LOW	OFF	COMMENTS
30. A/S					
31. ADI					
32. HSI					
33. R/C					
34. ALT.					
35. CRS. SEL.					
36. RADIO CALL					
37. ENG. SCALES					
38. ENG. PANEL					
39. CLOCK NOS.					
40. CLOCK PANEL					
41. O^2 IND.					
42. O^2 PANEL					

43. If you could design the lighting, what displays would you group on separate rheostats?

44. Were there stray light emissions from any of the displays? What displays? Did this light degrade instrument readability?

FIGURE 37. DEBRIEFING QUESTIONNAIRE (CON'T)

45. Were there reflections on any of the instrument faces from any of the cockpit lights? What instruments? Which lights caused the reflections?

46. Was the background of the displays sufficiently illuminated to prevent a floating illusion of the display markings?

47. Were there reflections on any of the aircraft windows from the cockpit lights? Which windows? What lights caused the reflections?

48. Did any of the cockpit lights degrade your night vision? How much? Which lights?

49. Did you notice any color shift as you brightened or dimmed the cockpit lights? What lights shifted?

50. Did you have any eye fatigue during the flight

51. Any trouble focusing on the displays?

52. Did you have to stare at any of the instruments to read them?

53. Were you tired at the end of the mission?

54.* How many of the checkpoints did you see?

55.* Did you consider the checkpoints difficult to locate?

56.* Did you have any trouble using the low level map?

57.* Was the cockpit C-4 lamp (kneeboard) sufficient for map reading?

58.* Do you have any suggestions for improvement of map reading at night?

Any other items you would like to discuss or comment on?

Thank you.

* Experiment II and III only

FIGURE 37. DEBRIEFING QUESTIONNAIRE (CON'T)

EXPERIMENTER'S CHECKLIST

EXTERIOR INSPECTION

1. Check windows, clean where cosine receptors are mounted

INTERIOR CHECK

Cabin

1. Check shutters on fore and aft photo multipliers - IN

2. Recorder Paper Supply - CHECK

BEFORE STARTING ENGINES

Experimenter's Panel

1. Read photomultiplier upper shutter lever - CLOSED (INBOARD)
2. Photometer record switch - OFF
3. Recorder channel select - OFF
4. Experimenter's panel position select switches - OFF
5. LIS master switch - OFF
6. FI, Panels, and EIS master switches - OFF
   rheostats - OFF

AFTER ENGINES START

1. FI, Panels, and EIS master switches - ON
   rheostats - FULL ON

PHOTOMETER - MAIN PANEL POWER SUPPLY

1. Remote program - ON
2. Power switch - ON
3. Batt. output function switch - BATT (meter 100 V $\pm$ 2)
4. A Button (black) - DEPRESS (meter above replace batt. line)
5. B Button (red) - DEPRESS (meter above replace batt. line)

PHOTOMETER - SIDE PANEL POWER SUPPLY

1. Power switch - ON
2. Top black button - DEPRESS (check meter 100 V $\pm$ 2)
3. Top and bottom black buttons - DEPRESS TOGETHER (meter above replace batt. line)
4. Top black button and red button - DEPRESS TOGETHER (meter above replace batt. line)
5. Function switch - OPERATE (meter 21 volts)

FIGURE 38. EXPERIMENTER'S CHECKLIST

BEFORE TAXI

1. Photomultiplier filters - CHECK
2. Side shutters both photomultipliers - OUT (on as required)
3. Rear photomultiplier upper shutter lever - OPEN (outboard)
4. Scale factor - CHECK
5. Photometer function switch - H.V. (rotate photocell select switch, check for voltage drop on each position)
6. Photometer function switch - OPERATE
7. Visicorder - ON
8. Channel select switch - ZERO POSITION (0)
9. Recorder channel switch - ON
10. Recorder output for each photocell - CHECK

BEFORE TAKEOFF

1. Recorder channel switch - CHANNEL 1
2. Left position switch - OFF
3. Right position switch - PED INT (check recorder output)
4. Recorder channel switch - CHANNEL 2
5. Right position switch - EIS SCALES (check recorder output)
6. Right position switch - OFF
7. Recorder channel switch - CHANNEL 3
8. Left position switch - CLOCK PANEL (check recorder output)
9. Recorder channel switch - CHANNEL 4
10. Left position switch - ADI (check recorder output)
11. All recording switches - CHECK FOR TAKEOFF

BEFORE ENGINE SHUT DOWN

1. LIS, FIL, Panels, & EIS master switches - OFF

SHUT DOWN

1. Rear photomultiplier upper shutter - CLOSED (inboard)
2. All experimenters panel switches - OFF
3. Photometer switches - OFF
4. Recorder - OFF
5. Side shutters both photomultipliers - IN
6. Recorder paper - REMOVE

FIGURE 38. EXPERIMENTER'S CHECKLIST (CON'T)

APPENDIX B
EXPERIMENT I FORMS AND DATA

MISSION CARD
EXPERIMENT I

1. TAKE-OFF WRIGHT-PATTERSON AFB
2. OBTAIN CLEARANCE TO R-5504/03
3. CLIMB TO FL 300
4. CROSS POINT ALPHA AT OFFICIAL SUNSET
5. FLY SIX BOX PATTERNS
6. POINT DELTA DIRECT FFO INITIAL APPROACH FIX
7. TACAN PENETRATION TO WPAFB
8. ILS, FULL STOP

FIGURE 39. EXPERIMENT I MISSION CARD

Date________________

Mission No.________________ Subject Pilot________________

Safety Pilot________________ Experimenter________________

Event	Time	Instrument Record		Ambient Record											
		0 1 2 3 4	Monitor	Eye			Panel			Window			Sky		
				F	S	M	F	S	M	F	S	M	F	S	M
T.O.															
15K															
A1															
B1															
C1															
D1															
A2															
B2															
C2															
D2															
A3															
B3															
C3															
D3															
A4															
B4															
C4															
D4															
A5															
B5															
C5															
D5															
A6															
B6															
C6															
D6															
HC															
10K															
GO															
2 OUT															

Remarks T.O. WX. ________________ MOON ________________

30K WX. ________________

LAND WX. ________________

FIGURE 40. EXPERIMENT I EXPERIMENTER'S DATA SHEET

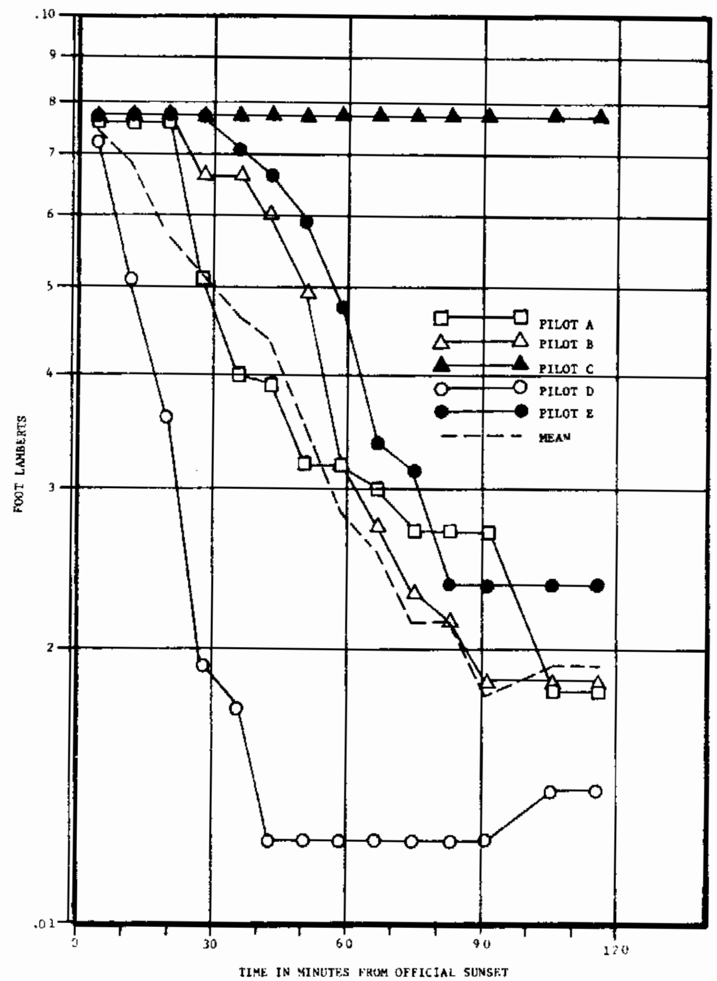


FIGURE 41. ILLUMINATION LEVELS SELECTED FOR THE ADI AS A FUNCTION OF TIME AFTER OFFICIAL SUNSET

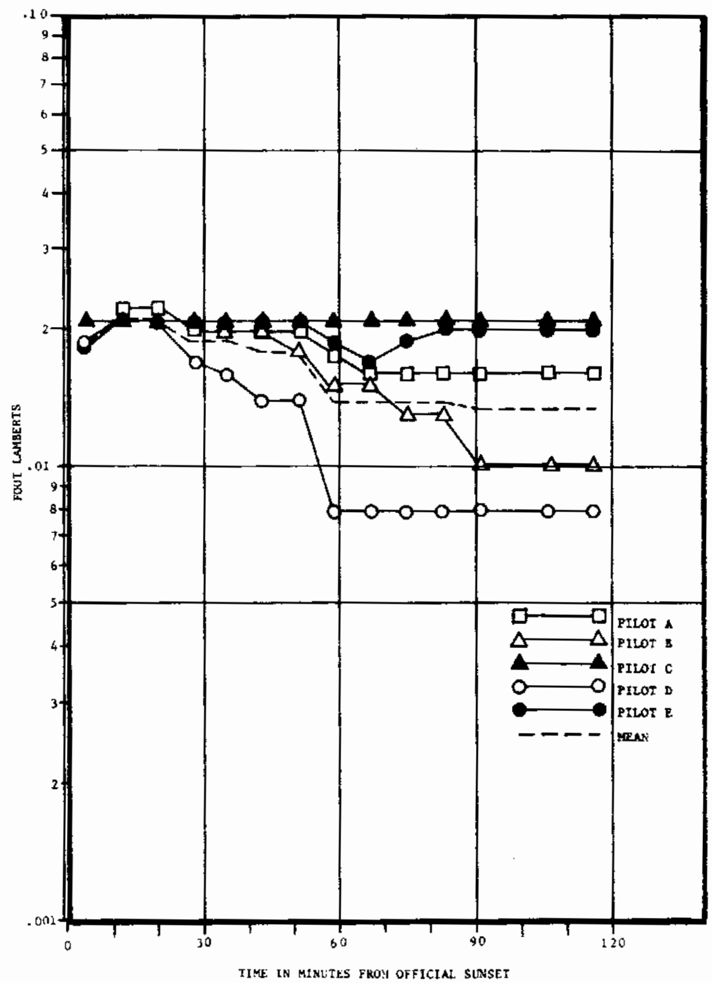


FIGURE 42. ILLUMINATION LEVELS SELECTED FOR THE AIRSPEED INDICATOR AS A FUNCTION OF TIME AFTER OFFICIAL SUNSET

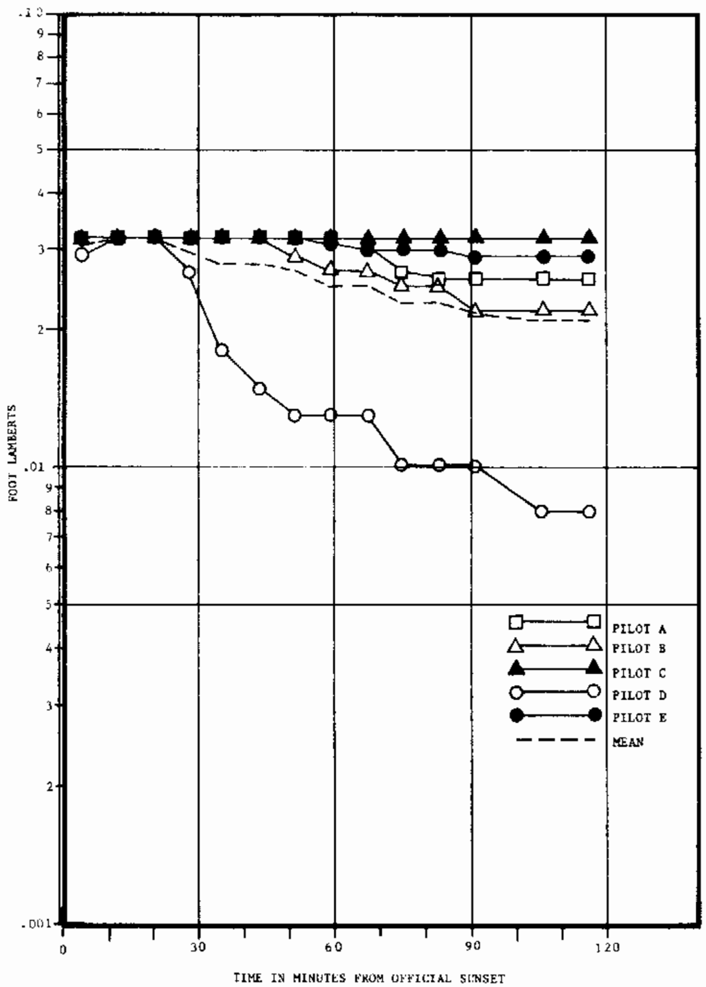


FIGURE 43. ILLUMINATION LEVELS SELECTED FOR THE VERTICAL SPEED AS A FUNCTION OF TIME AFTER OFFICIAL SUNSET

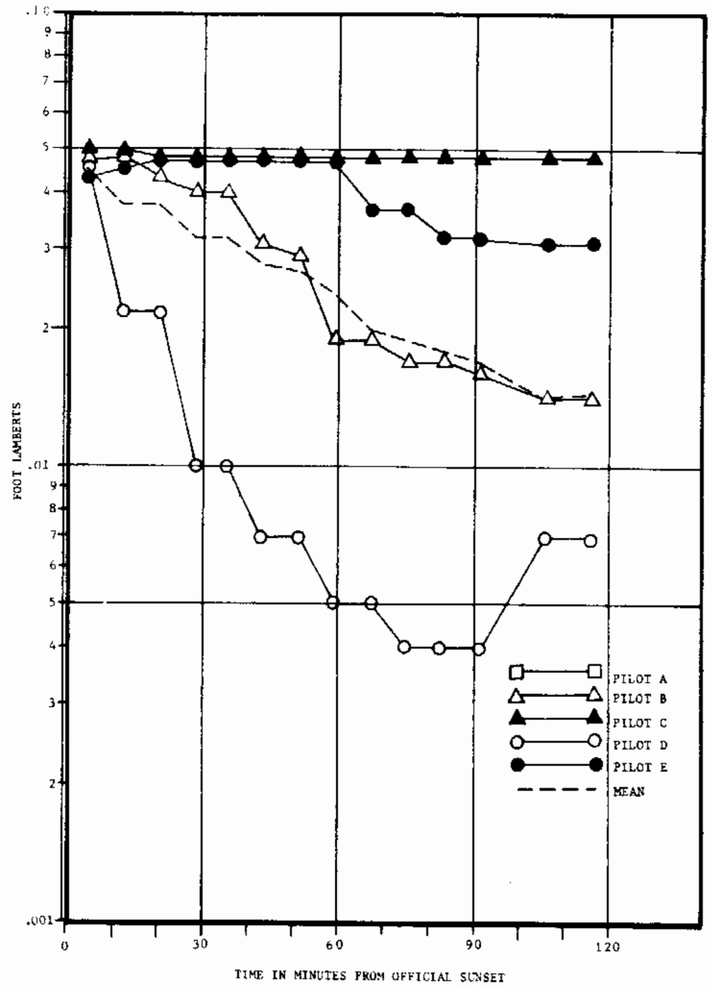


FIGURE 44. ILLUMINATION LEVELS SELECTED FOR THE ALTIMETER AS A FUNCTION OF TIME AFTER OFFICIAL SUNSET

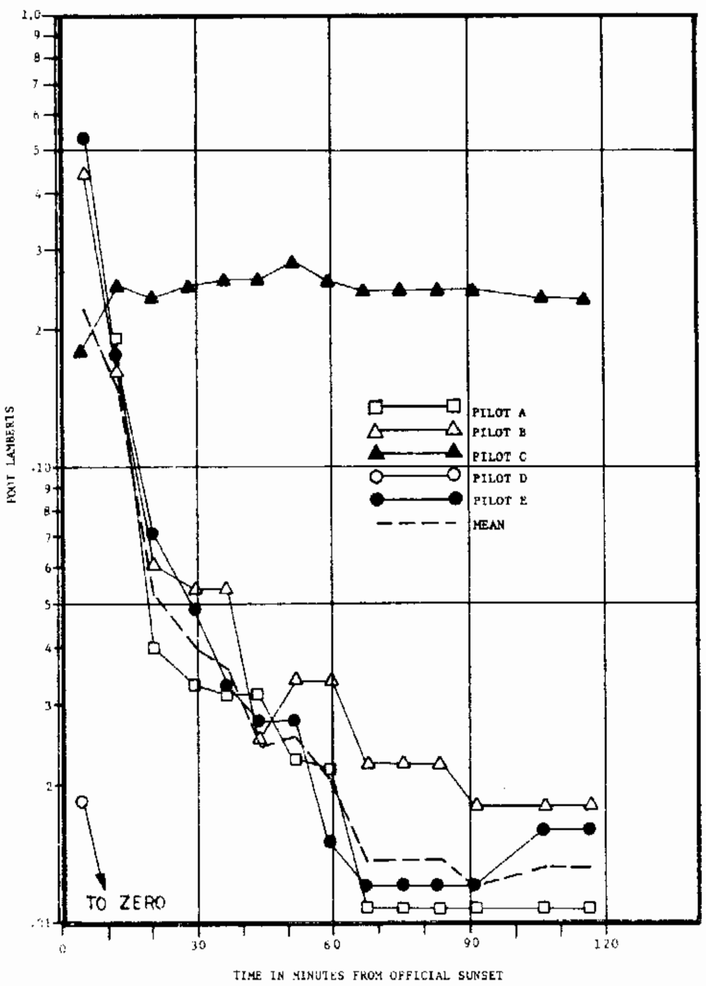


FIGURE 45. ILLUMINATION LEVELS SELECTED FOR THE O^2 PANEL AS A FUNCTION OF TIME AFTER OFFICIAL SUNSET

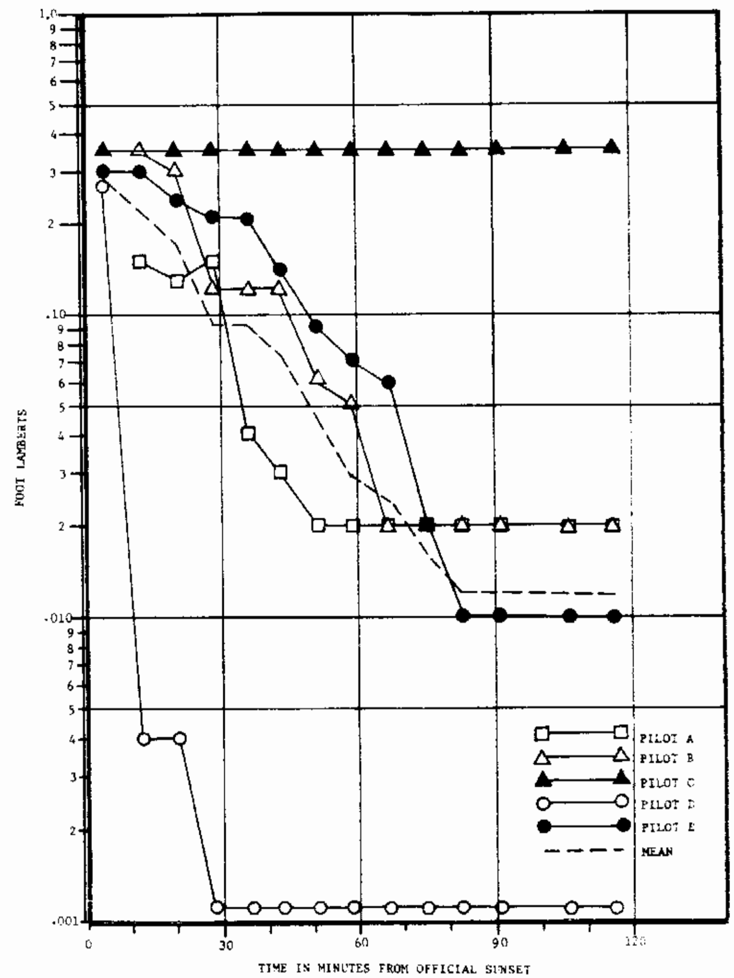


FIGURE 46. ILLUMINATION LEVELS SELECTED FOR THE RADIO CALL PANEL FUNCTION OF TIME AFTER OFFICIAL SUNSET

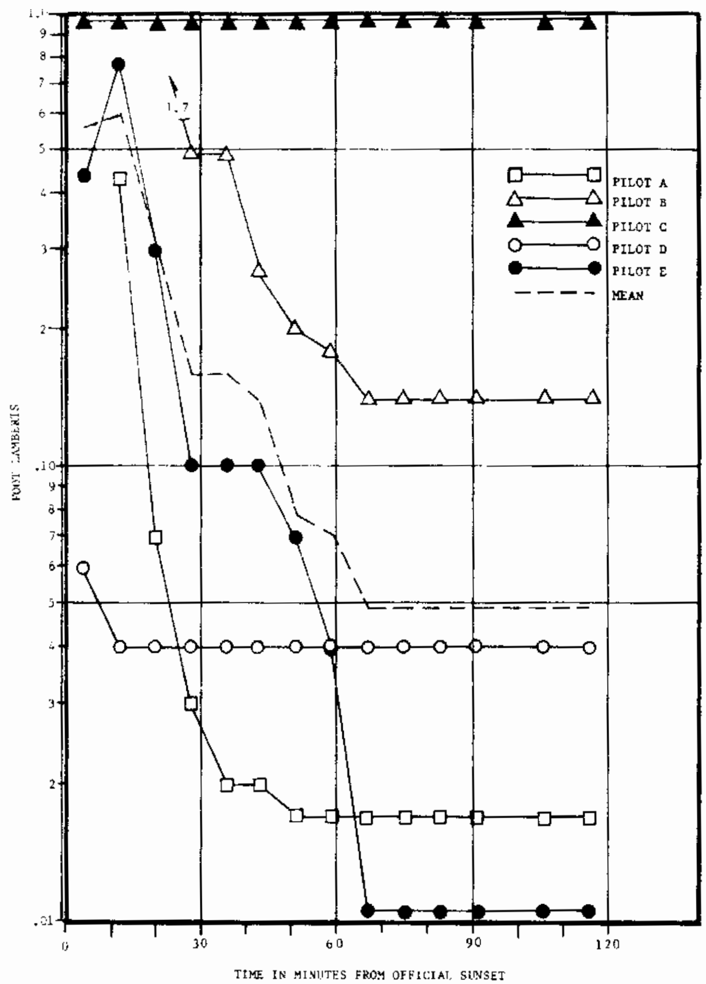


FIGURE 47. ILLUMINATION LEVELS SELECTED FOR THE COURSE SELECT PANEL AS A FUNCTION OF TIME AFTER OFFICIAL SUNSET

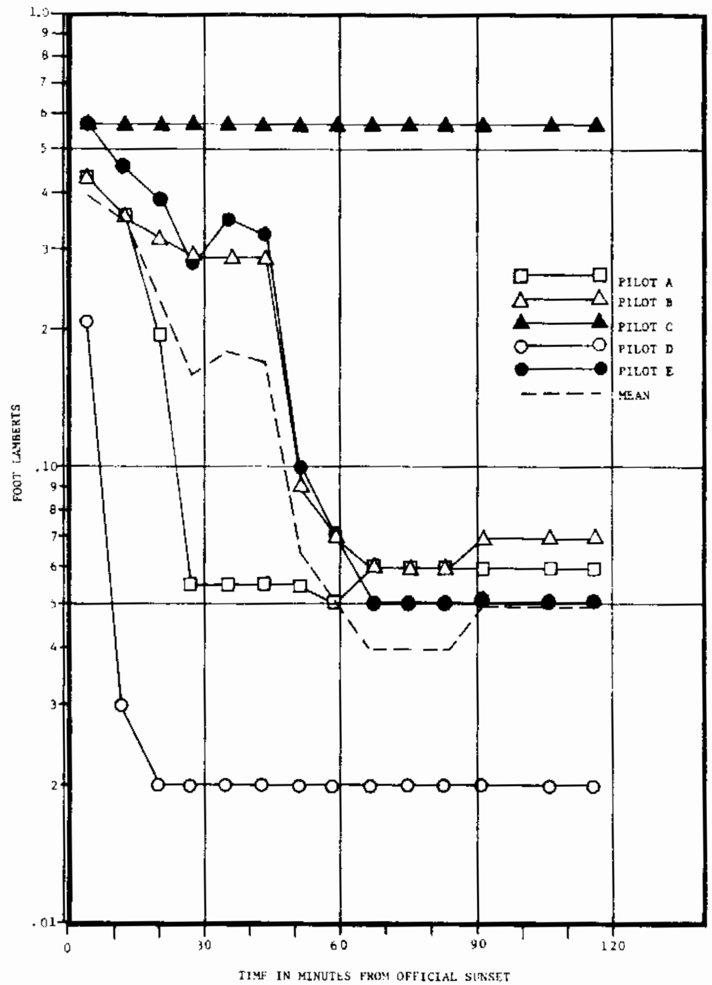


FIGURE 48. ILLUMINATION LEVELS SELECTED FOR THE CLOCK PANEL AS A FUNCTION OF TIME AFTER OFFICIAL SUNSET

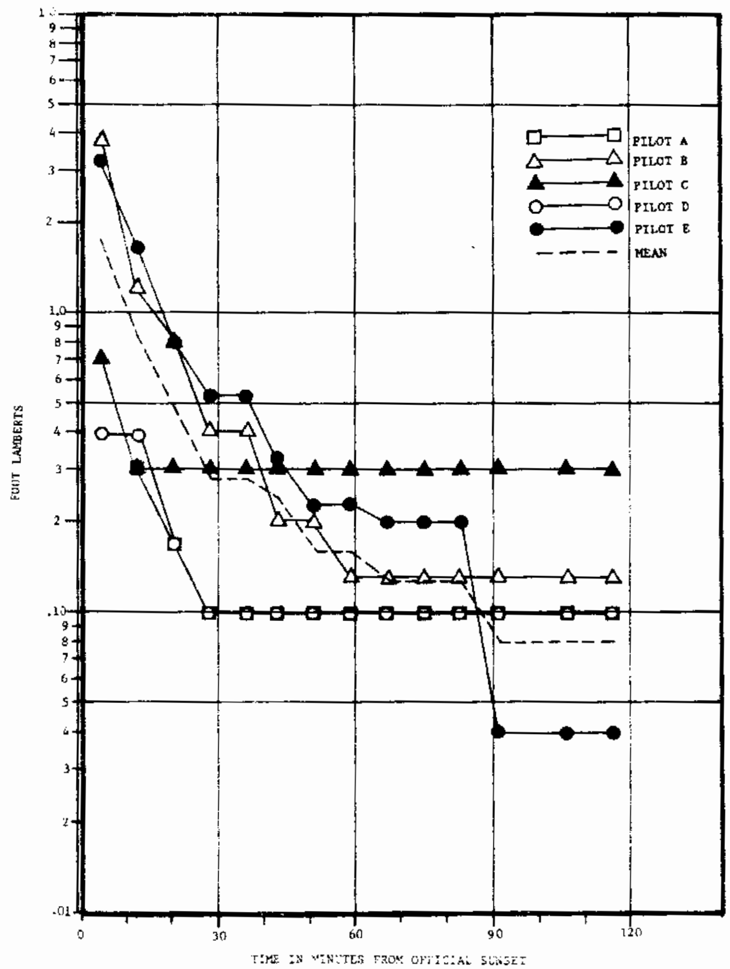


FIGURE 49. ILLUMINATION LEVELS SELECTED FOR THE CLOCK NUMBERS AS A FUNCTION OF TIME AFTER OFFICIAL SUNSET

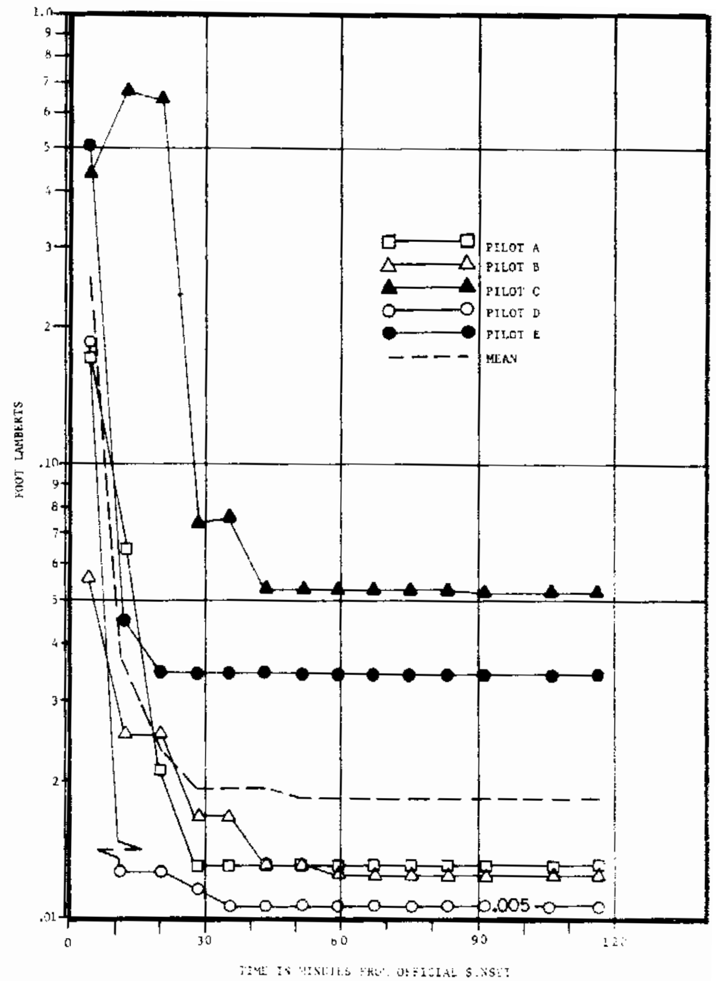


FIGURE 50. ILLUMINATION LEVELS SELECTED FOR THE ENGINE LEGENDS AS A FUNCTION OF TIME AFTER OFFICIAL SUNSET

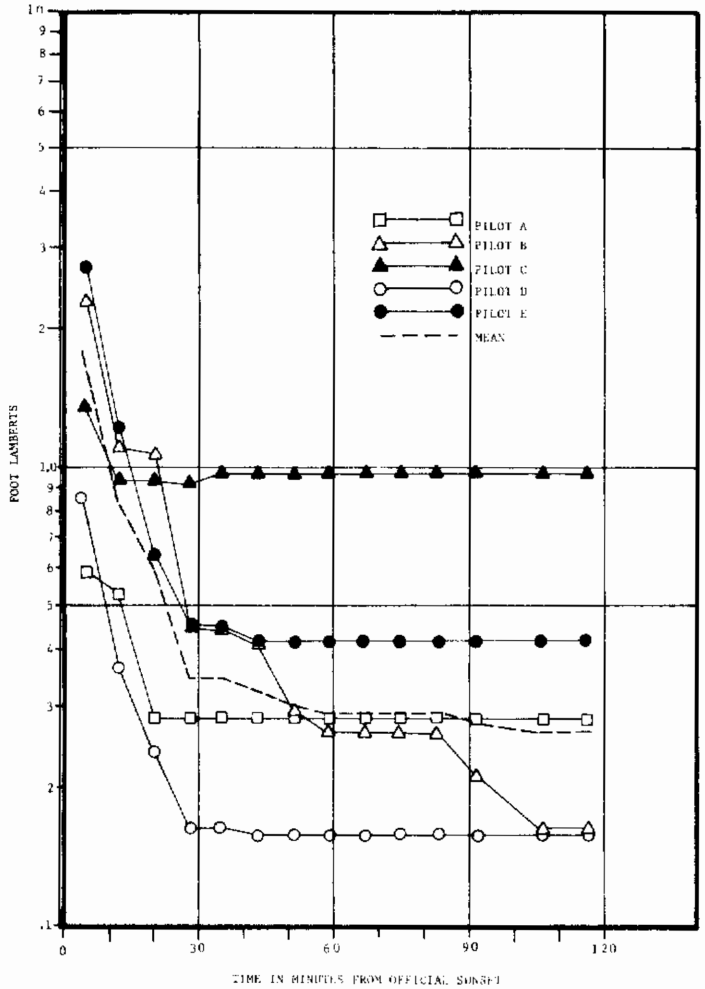


FIGURE 51. ILLUMINATION LEVELS SELECTED FOR THE ENGINE INDICES AS A FUNCTION OF TIME AFTER OFFICIAL SUNSET.

APPENDIX C
EXPERIMENT II FORMS AND DATA

MISSION CARD
EXPERIMENT II

1. TAKE-OFF PATTERSON AFB
2. RADAR VECTORS FLM, CLIMB TO FL 250
3. FLM DIRECT AIR
4. AIR DIRECT CXR
5. 40 SOUTH CXR DESCEND TO 12,000
6. RADAR VECTORS, PENETRATION, ILS, TO RW 28 CLEVELAND HOPKINS AIRPORT
7. MISSED APPROACH, CLIMB TO 4000 FEET DIRECT CLE
8. CLE V6 VWV
9. VWV V47 FOY
10. FDY V47 ROD
11. ROD DIRECT FFO 140/11
12. LOW ALTITUDE APPROACH, ILS, FULL STOP WPAFB

FIGURE 52. EXPERIMENT II MISSION CARD

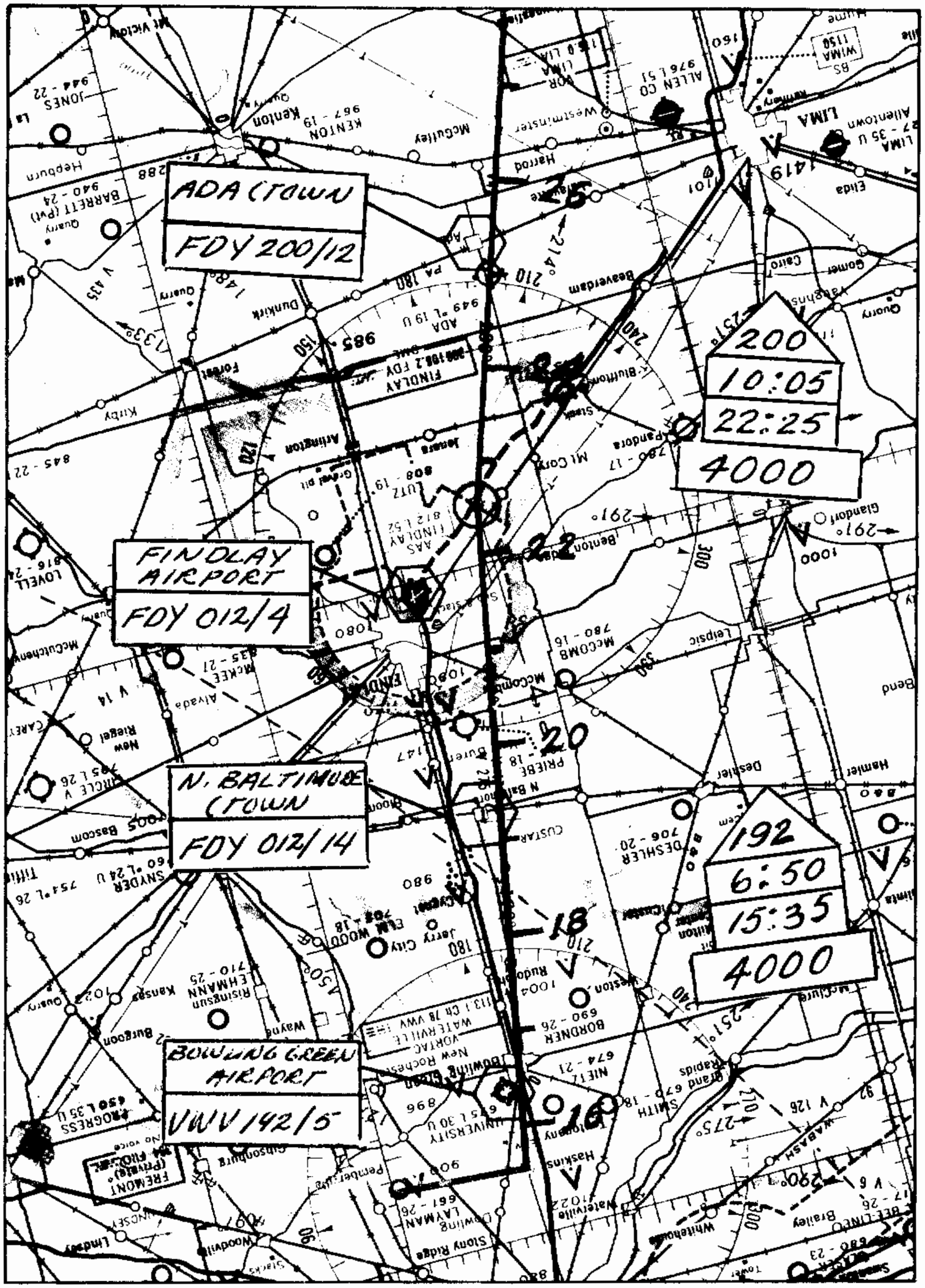


FIGURE 53. EXPERIMENT II LOW LEVEL MAP SECTION

PILOT'S FLIGHT PLAN AND FLIGHT LOG

ARTC FREQ				

AIRCRAFT IDENT	TAKE-OFF TIME	TOTAL DISTANCE	TOTAL ETE	TOTAL AMT FUEL
T-39A 610649		578	1 + 55	6800

FIX	ROUTE	IDENT / FREQ	IDENT / FREQ	MAG CRS	DISTANCE / REMAIN	GROUND SPEED	ETE / REMAIN	ETA / ATA	LEG / REMAIN	ACTUAL FUEL REMAIN
	V-1	FLM			73		16		800	
FLM		117.0			505		1+39		6000	
	D	AIR	AIR	062	186		28		800	
		117.1	118	068	319	430	1+11		5200	
	D	CXR	CXR		95		14		400	
CXR		112.7	74	355	224	430	57		4800	
	DELAY FOR IFR APPROACH									
	RV	CLE	CLE		46		16		400	
CLE		113.6	83		178	260	41		4400	
	V6	VWV	VWV		76		15		700	
VWV		113.1	78	278	111	260	26		3700	
	V47	FDY	FDY		30		7		300	
FDY		108.2	19	192	81	260	19		3400	
	V47	ROD	ROD		42		10		460	
ROD		117.5	122	200	38	260	9		2940	
FFO	D		FFO		38		9		400	
140/11			99	178	0	260	0		2540	

AF FORM MAY 66 70 REPLACES AF FORM 21A, JAN 63, WHICH WILL BE USED UNTIL STOCK IS EXHAUSTED.

FIGURE 54. EXPERIMENT II PILOTS' FLIGHT PLAN AND FLIGHT LOG

LOW LEVEL ROUTE
CLE-V6-WVW
WVW-V47-FDY
FDY-V47-ROD

CHECKPOINTS

1.	CLE 278/17	HURON RIVER
2.	VWV 096/25	SANDUSKY RIVER
3.	VWV 096/8	PEMBERVILLE
4.	VWV 192/5	B. G. AIRPORT
5.	FDY 012/14	N. BALTIMORE
6.	FDY 012/4	FINDLAY AIRPORT
7.	FDY 200/12	ADA (TOWN)
8.	ROD 019/13	LAKE-LAKEVIEW
9.	ROD	QUINCEY

RADIO CALLS

1. TAKEOFF
2. CROSSING FALMOUGH (FLM)
3. CROSSING BELLAIR (AIR)
4. CROSSING CHARDON (CXR)
5. CROSSING CLEVELAND (CLE)
6. CROSSING WATERVILLE (VWV)
7. CROSSING FINDLAY (FDY)
8. CROSSING ROSEWOOD (ROD)
9. STARTING APPROACH (FFO 140/11)

FIGURE 55. EXPERIMENT II LOW LEVEL CHECKPOINTS AND RADIO CALLS

Date______________

Mission No.____________________ Subject Pilot____________________

Safety Pilot____________________ Experimenter____________________

Event	Time	Instrument Record 0 1 2 3 4	Monitor	Ambient Record Eye F	Eye S	Eye M	Panel F	Panel S	Panel M	Window F	Window S	Window M	Sky F	Sky S	Sky M
T.O.															
+5															
+10															
FLM															
+10															
+20															
AIR															
+10															
CXR															
GD															
MA															
CLE															
+10															
WVW															
FDY															
ROD															
FFO															
GD															
2 OUT															
		CHECKPOINTS													
	1	Huron R.													
	2	Sandusky R.													
	3	Pemberville													
	4	B. G. Apt.													
	5	N.Baltimore													
	6	Find. Apt.													
	7	Ada													
	8	Lake													
	9	Quincey													

Remarks T.O. WX ____________ MOON ____________

HIGH ALT. WX. ____________

LOW ALT. WX. ____________

LND. WX. ____________

FIGURE 56. EXPERIMENT II, EXPERIMENTER'S DATA SHEET

TABLE XI
EXPERIMENT II
AMBIENT ILLUMINATION AT THE PILOT'S EYE
($X10^{-4}$ FOOT CANDLES)

MISSION SEGMENT	AMBIENT CONDITIONS* FULL - 3/4 MOON	1/2 - 1/4 MOON	STARLIGHT + CONSOLE LIGHTS	STARLIGHT ONLY	MEAN ALL AMBIENTS
TAKEOFF & CLIMB	2.28	0.86	0.92	0.81	1.22
HIGH CRUISE I	2.12	0.60	0.55	0.57	0.96
HIGH CRUISE II	1.95	0.69	0.63	0.57	0.96
APPROACH (CLE)	3.40	2.24	2.16	1.97	2.44
LOW CRUISE I	2.44	1.65	1.29	0.86	1.56
LOW CRUISE II	2.00	0.70	0.58	0.53	0.95
APPROACH & LAND	2.94	1.67	1.51	1.20	1.83
MEAN ALL SEGMENTS	2.45	1.20	1.09	0.93	1.42 GRAND MEAN

*MEAN OF SEVEN FLIGHTS

TABLE XII
EXPERIMENT II
SKY AMBIENT ILLUMINATION MEASURED ABOVE THE AIRCRAFT
($X10^{-4}$ FOOT CANDLES)

MISSION SEGMENT	AMBIENT CONDITIONS* FULL - 3/4 MOON	1/2 - 1/4 MOON	STARLIGHT + CONSOLE LIGHTS	STARLIGHT ONLY	MEAN ALL AMBIENTS
TAKE-OFF & CLIMB	3.08	1.45	1.24	1.29	1.77
HIGH CRUISE I	4.63	0.64	0.51	0.41	1.56
HIGH CRUISE II	4.27	0.56	0.27	0.18	1.32
APPROACH (CLE)	8.61	1.81	1.07	0.72	3.05
LOW CRUISE I	3.48	0.62	0.40	0.38	1.22
LOW CRUISE II	4.07	0.57	0.23	0.25	1.28
APPROACH & LAND	3.70	1.75	1.27	1.29	2.00
MEAN ALL SEGMENTS	4.55	1.06	0.71	0.66	1.74 GRAND MEAN

*MEAN OF SEVEN FLIGHTS

APPENDIX D
EXPERIMENT III FORMS AND DATA

MISSION CARD
EXPERIMENT III

1. TAKE-OFF WRIGHT-PATTERSON AFB
2. FLY VFR DIRECT TO LCK, 5000 FEET
3. ENTER LOCKBOURNE LOW LEVEL NO. 2
4. FLY L.L.L. NO. 2 TO BONO
5. CLIMB 8000' DIRECT TO TARGET 045°/45 NM
6. PERFORM FOUR SIMULATED WEAPON DELIVERIES (10 MINUTES)
7. CLIMB 17,500' DIRECT FFO
8. TACAN PENETRATION, ILS, FULL STOP WRIGHT-PATTERSON AFB

FIGURE 57. EXPERIMENT III MISSION CARD

PILOT'S FLIGHT PLAN AND FLIGHT LOG				
ARTC FREQ	TOW HOUSE	340.8	383.7	
	IND CENT	@ SHB	319.8	124.4
AIRCRAFT IDENT	TAKE-OFF TIME	TOTAL DISTANCE	TOTAL ETE	TOTAL AMT FUEL
		419	1 + 37	6800

FIX (ROUTE)	IDENT / FREQ	Rad / Dme	MAG CRS	DISTANCE / REMAIN	GROUND SPEED	ETE / Total	ETA / ATA	LEG / REMAIN	ACTUAL FUEL REMAIN
	LCK	170		60		+15		800	
1P	69	17	109	359		+15		6000	
				30		+06		250	
LAKE			169	329		+21		5720	
				22		+04		200	
PLANT			181	307		+25		5550	
	YRK			53		+11		450	
RR	113.4		263	254		+36		5100	
	FLM			60		+12		550	
DAM	117.0		267	194		+48		4550	
	ABB			66		+13		600	
BEND	113.5		285	128		1+01		3950	
				28		+06		250	
XROADS			045	100		1+07		3700	
FFO				100		+30		1700	
270/09			068	0		1+37		2000	
	112.0								
SHB	57								

AF FORM 70 MAY 66 REPLACES AF FORM 21A, JAN 63, WHICH WILL BE USED UNTIL STOCK IS EXHAUSTED.

FIGURE 58. EXPERIMENT III PILOT'S FLIGHT PLAN AND FLIGHT LOG

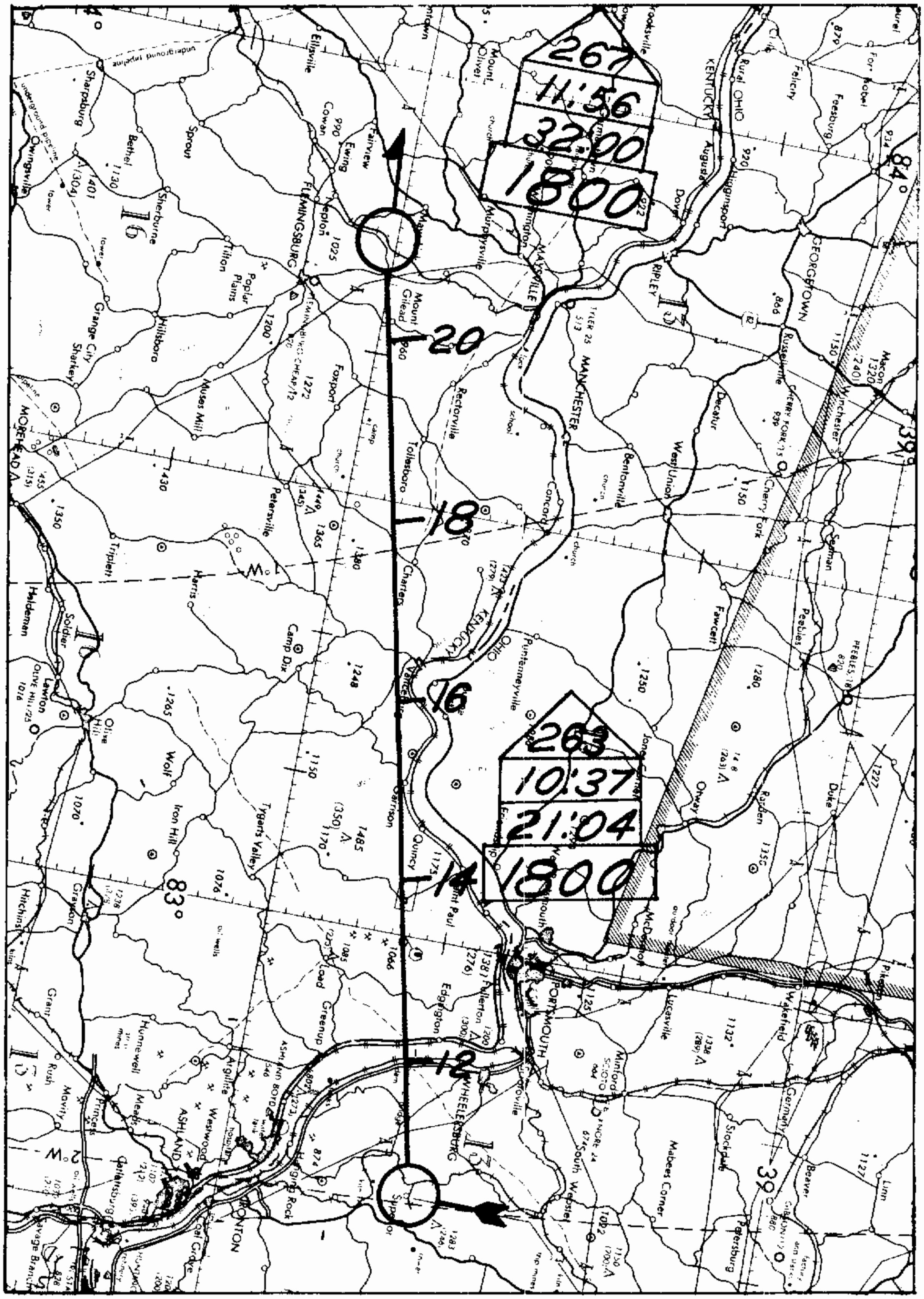


FIGURE 59. EXPERIMENT III LOW LEVEL MAP SECTION

Date ____________________

Mission No. ____________________ Subject Pilot ____________________

Safety Pilot ____________________ Experimenter ____________________

Event	Time	Instrument Record		Ambient Record											
		0 1 2 3 4	Monitor	Eye			Panel			Window			Sky		
				F	S	M	F	S	M	F	S	M	F	S	M
T.O.															
+5															
+10															
IP															
+5		Lake 6:00													
+10		Plant 10:27													
+15															
+20		RR 21:04													
+25															
+30															
+35		Dam 32:00													
+40															
+45		River 45:14													
+50		Tgt 50:47													
P-1															
P-2															
P-3															
P-4															
+5															
+10															
HC															
GD															
2 OUT															

Remarks

T.O. WX. ____________________ MOON ____________________

LL WX. ____________________

TGT WX. ____________________

LND WX. ____________________

FIGURE 60. EXPERIMENT III EXPERIMENTER'S DATA SHEET

TABLE XIII
EXPERIMENT III
AMBIENT ILLUMINATION AT PILOT'S EYE
($X10^{-4}$ FOOT CANDLES)

MISSION SEGMENT	AMBIENT CONDITIONS* FULL - 3/4 MOON	1/2 - 1/4 MOON	STARLIGHT ONLY	MEAN ALL AMBIENTS
TAKE-OFF TO IP	3.07	1.28	0.99	1.78
LOW LEVEL I	1.61	0.71	0.65	0.99
LOW LEVEL II	0.96	0.73	0.58	0.75
LOW LEVEL III	1.35	0.61	0.60	0.85
DIVE BOMBING	1.52	0.52	0.31	0.78
RETURN CRUISE	1.73	0.71	0.49	0.97
LET DOWN & LAND	2.53	2.45	1.70	2.22
MEAN ALL SEGMENTS	1.82	1.00	0.76	1.19 GRAND MEAN

*MEAN OF SIX FLIGHTS

TABLE XIV
EXPERIMENT III
SKY AMBIENT ILLUMINATION MEASURED ABOVE THE AIRCRAFT
($X10^{-4}$ FOOT CANDLES)

MISSION SEGMENT	AMBIENT CONDITIONS* FULL - 3/4 MOON	1/2 - 1/4 MOON	STARLIGHT ONLY	MEAN ALL AMBIENTS
TAKE-OFF TO IP	2.32	1.53	1.61	1.82
LOW LEVEL I	3.25	0.42	0.58	1.42
LOW LEVEL II	3.61	0.63	0.22	1.48
LOW LEVEL III	3.35	1.75	1.22	2.10
DIVE BOMBING	4.04	0.73	0.68	1.81
RETURN CRUISE	2.66	0.77	0.43	1.28
LET DOWN & LAND	3.21	1.07	1.52	2.14
MEAN ALL SEGMENTS	3.21	1.08	0.89	1.72 GRAND MEAN

*MEAN OF SIX FLIGHTS

APPENDIX E
PHOTOMETERIC CALIBRATION PROCEDURES

Forward Photomultiplier and Receptor Calibration

1. Remove the three miniature cosine receptors from their locations leaving the fiber optics bundles attached.
2. Set up the standard lamp source with the 1 x 10^{-2} foot candle adapter and the standard length cosine adapter tube in place.
3. Place one (e.g. window) miniature cosine receptor in position on the photomultiplier.
4. Assure that the correct fiber optics bundle is in place on the photomultiplier tube.
5. Close the photomultiplier tube shutter.
6. Select the "window" position on the photometer four position selector switch.
7. Turn on the photometer power supplies.
8. Check the battery condition of both photometer power supplies.
9. Allow the photomultiplier to stabilize for approximately 5 minutes.
10. Place the photometer "internal/remote" switch in the "remote" position.
11. Place the recorder output switch in the "meter" position.
12. Zero the sensitivity by switching the scale selector switch to the least sensitive scale and zeroing the needle with the zero set know.
13. Zero the dark current by moving the scale selector switch to the most sensitive position and zeroing the pointer with the #3 dark current potentiometer (under table at right).
14. Open the shutter on the front photomultiplier assembly.
15. Turn on and adjust the standard lamp with the 1 x 10^{-2} foot candle adapter in place on the lamp and the window miniature cosine receptor in place on the adapter assembly.
16. Select the .01 scale on the photometer and adjust the meter swing to read 1 on that scale utilizing the #3 high voltage potentiometer.

17. Repeat steps 12 and 13.

18. You are now calibrated for the scale range selected.

19. Switch the photometer to the read high voltage position and record the voltage being applied to the photomultiplier tube. Note that the voltage scale is on top and approximately 2X the 0-120 scale.

20. Repeat the procedure for the remaining two cosine receptors being careful not to damage them when inserting them into the foot candle adapter tube assembly.

    Note: Dark current stability is a function of the high voltage applied to the tube. If the high voltage goes above approximately 1150 volts, it will be impossible to stabilize the dark current.

Aft Photomultiplier and Receptor Calibration

1. Set up the standard lamp source with the 1 x 10^{-2} foot candle adapter and the standard length cosine adapter tube in place.

2. Position items of Step 1 over sky cosine receptor and tape as necessary to exclude ambient light.

3. Open fuselage sextent shutter.

4. Close the photomultiplier tube shutter.

5. Select the "sky" position on the photometer four position selector switch.

6. Turn on the photometer power supplies.

7. Check the battery condition of both power supplies.

8. Allow the photomultiplier to stabilize for approximately 5 minutes.

9. Place the internal/remote switch in the "remote" position.

10. Place the recorder output switch in the meter position.

11. Zero the sensitivity by switching the scale select switch to the least sensitive scale and zeroing the needle with the zero set knob.

12. Zero the dark current by moving the scale select switch to the most sensitive position and zeroing the pointer with the #4 dark current potentiometer (under table at right).

13. Open the shutter on the aft photomultiplier assembly.

14. Turn on and adjust the standard lamp.

15. Select the .01 scale on the photometer and adjust the meter swing to read .9 on that scale utilizing the aft photomultiplier power supply high voltage adjustment.

16. Repeat steps 11 and 12.

17. You are now calibrated for the scale range selected.

18. Record the high voltage being applied to the photomultiplier.

    Note: Dark current stability is a function of the high voltage applied to the tube. If the high voltage goes above approximately 1150 volts, it will be impossible to stabilize the dark current.

Instructions For Use of Calibrated Filter Set

These filters are useful in extending the range of light measurable without recalibration.

1. These filters do not affect the calibration of the photometer. They do reduce the amount of light reaching the photomultiplier tube by a known factor.

2. To use the filters:

    a. Insert one (e.g., 1.0N) in the photomultiplier.

    b. You will now read approximately 1/10 of the light flux on the receptor. (The exact value is 0.107).

    c. If the meter with its scaling shows 10 foot candles, there are actually 107 foot candles being applied to the cosine receptor.

    d. If you had started with the 1.5N filter, the actual light value would have been 330 foot candles.

3. Calibrated Neutral Density Filter Set, Model 2020-12 characteristics are tabled below:

Filter	Transmissibility	Opacity
0.5N	0.292	3. 4:1
1.0N	0.107	9.34:1
1.5N	0.033	30. 3:1
2.0N	0.0091	109. 0:1
2.5N	0.0035	285 :1
3.0N	0.0011	909 :1
3.5N	0.00036	2777 :1
4.0N	0.00013	7692 :1
0.0N	1.00	1:1

APPENDIX F
INSTRUMENT BRIGHTNESS CALIBRATION

Aircraft Instrument Brightness Setup and Calibration

1. Install telescope and telescope mounting hardware in aircraft cockpit.

2. Remove the front photomultiplier assembly from the compartment wall and lay it on the glare shield where it can be reached by the fiber optics bundle from the telescope.

3. Place blackout curtain over cockpit windows and tape as necessary to prevent ambient light from entering cockpit area; also place blackout curtain over entrance doorway and tape as necessary.

4. When calibrating or making lighting measurements, the blackout curtains on the cockpit bulkhead and passenger bulkhead should be closed.

5. Insert the spare fiber optics bundle in the front photomultiplier tube assembly and in the scanning eyepiece receptable of the telescope.

6. Select 6 inch (±2 inches) focal distance (telescope focal point to panel instrument surface being measured) and focus telescope.

   Note: 1. Do not refocus after focal distance has been selected.

   2. Maintain this focal distance for all measurements.

7. Make certain the shutter is closed on the front photomultiplier.

8. Set up the standard lamp and source with the 1.05 foot lambert screen in place in front of the lamp. Turn standard lamp source on.

9. Select the internal position on the photometer internal/remote switch.

10. Turn on the photometer power supply.

11. Check the battery condition of both power supplies.

12. Set the high voltage for about 1100 volts.

13. Allow the tube to stabilize for approximately 5 minutes before continuing.

14. Zero the voltage sensitivity by switching the photometer scale select switch to the least sensitive scale and zeroing the needle with the zero set knob.

15. Zero the dark current by moving the scale select switch to the most sensitive position and zeroing the meter pointer with the photometer dark current potentiometer.

16. Place the telescope the standard selected focal distance away from the standard lamp (See step 6), and adjust the standard lamp source voltage for a null indication on its meter.

17. Open the shutter on the front photomultiplier assembly.

18. Select the 1 foot lambert scale on the photometer scale selector switch.

19. Adjust the photometer needle to read 21 on the 0 - 120 scale with the high voltage adjust potentiometer.

    Note: This results in a multiplier of 5 which must be applied to all readings.

20. It is desirable to recheck and rezero both dark current and sensitivity after this step and then to repeat the calibration since a change in high voltage will affect both sensitivity and dark current.

21. The photometer is now calibrated for reading foot candles (X5) on the scale range selected.

22. It is possible that zero and dark current will drift during extended periods of photometer use. A zero drift of 2 - 3 scale divisions and dark current drift of perhaps 10 scale divisions is normal during extended use periods. These should be checked frequently with the photomultiplier shutter closed and rezeroed as necessary. This will not change the calibration of the equipment.

Aircraft Instrument Brightness Measurements

A. RPM, EGT, ETP, Fuel Flow, Fuel Quantities and Clock

1. After calibration position the telescope in front of the desired instrument at the selected focal distance determined in step 6 of Setup and Calibration.

2. The selected instrument lighting excitation voltage is applied by placing the associated toggle switch on the experimenter's panel to the ON position.

3. Lighting excitation voltage to the selected instrument is adjusted by rotating the associated dimming control on the experimenter's panel, and is monitored by the digital voltmeter when its selector switch is rotated to the selected instrument's position.

4. Turn the selected instrument's lighting voltage adjustment pot on the experimenter's panel full clockwise (maximum voltage).

5. Scan the illuminated area to be measured with the telescope and select the point having the brightest intensity, as displayed on the photometer.

   Notes: 1. The pilot's dimming pot for the selected instrument should be full clockwise or in its maximum position - located on the pilot's dimming panel.

   2. The points or areas to be measured for each instrument are described on the prepared voltage/brightness forms.

6. Complete the voltage/brightness form for the selected instrument. Note any deviations or alterations.

7. For brightness measurements which exceed the maximum range of the photometer (0 - 15 foot lamberts as calibrated), use the 0.5N calibrated filter and insert it in the forward photomultiplier. This will extend the range to 51 foot lamberts, or make the multiplier X17 (X5 from calibration and X3.4 from filter). Note on voltage/brightness form when filter is used. Reference "Instructions for Use of the Special Calibrated Filter Set."

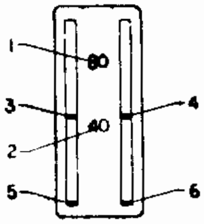
ENGINE VERTICAL SCALES

RPM

DATE ______

PLACE ______

SIGNED ______



BRIGHTNESS

READ POSITION	LAMP EXITATION (VOLTS)									
	100	90	80	70	60	50	40	30	20	10
1										
2										
3										
4										
5										
6										

1. 8ℓ IN "80"
2. 4ℓ IN "40"
3. 46 PERCENTILE SEGMENT, #1
4. 46 PERCENTILE SEGMENT, #2
5. BOTTOM SEGMENT, #1
6. BOTTOM SEGMENT, #2

FIGURE 61. RPM VOLTAGE/BRIGHTNESS FORM

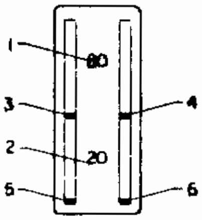
ENGINE VERTICAL SCALES

EGT

DATE ______

PLACE ______

SIGNED ______

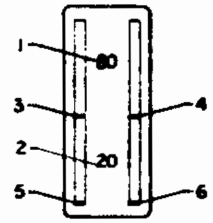


BRIGHTNESS

READ POSITION	LAMP EXITATION (VOLTS)									
	100	90	80	70	60	50	40	30	20	10
1										
2										
3										
4										
5										
6										

1. 8ℓ IN "80"
2. 2ℓ IN "20"
3. 46 PERCENTILE SEGMENT, #1
4. 46 PERCENTILE SEGMENT, #2
5. BOTTOM SEGMENT, #1
6. BOTTOM SEGMENT, #2

FIGURE 62. EGT VOLTAGE/BRIGHTNESS FORM



ENGINE VERTICAL SCALES

ETP

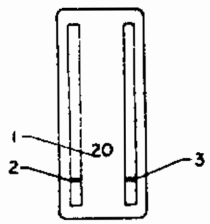
DATE ____________
PLACE ____________
SIGNED ____________

BRIGHTNESS

READ POSITION	LAMP EXITATION (VOLTS) 100	90	80	70	60	50	40	30	20	10
1										
2										
3										
4										
5										
6										

1. 8 IN "80"
2. 2 IN "20"
3. 46 PERCENTILE SEGMENT, #1
4. 46 PERCENTILE SEGMENT, #2
5. BOTTOM SEGMENT, #1
6. BOTTOM SEGMENT, #2

FIGURE 63. ETP VOLTAGE/BRIGHTNESS FORM



ENGINE VERTICAL SCALES

FUEL FLOW

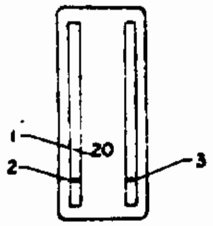
DATE ____________
PLACE ____________
SIGNED ____________

BRIGHTNESS

READ POSITION	LAMP EXITATION (VOLTS) 100	90	80	70	60	50	40	30	20	10
1										
2										
3										

1. 2 IN "20"
2. 10 PERCENTILE SEGMENT, #1
3. 10 PERCENTILE SEGMENT, #2

FIGURE 64. FUEL FLOW VOLTAGE/BRIGHTNESS FORM



ENGINE VERTICAL SCALES

FUEL QUANTITY

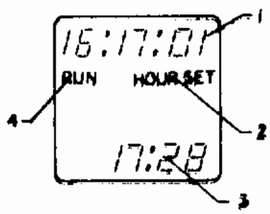
DATE __________
PLACE __________
SIGNED __________

BRIGHTNESS

READ POSITION	LAMP EXITATION (VOLTS)									
	100	90	80	70	60	50	40	30	20	10
1										
2										
3										

1. 2 IN "20"
2. 10 PERCENTILE SEGMENT, #1
3. 10 PERCENTILE SEGMENT, #2

FIGURE 65. FUEL QUANTITY VOLTAGE/BRIGHTNESS FORM



CLOCK

DATE __________
PLACE __________
SIGNED __________

BRIGHTNESS

READ POSITION	LAMP EXITATION (VOLTS)										
	130	120	110	100	90	80	70	60	50	40	30
1											
2											
3											
4											

1.
2. R
3. 2
4. R

FIGURE 66. CLOCK VOLTAGE/BRIGHTNESS FORM

B. ADI, HSI, Rate of Climb, Altimeter, Airspeed, Course Select Panel, Antenna/Oxygen Panel, O_2 Gauge, Radio Call Panel.

1. Remove above instruments and panels from aircraft and transport to the Instrument Lighting Lab. in Building 16, Area B, Wright-Patterson AFB.

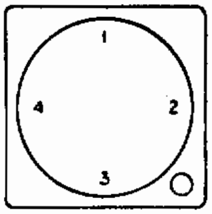
2. Apply the lighting voltage per the table below utilizing (1) Model OSC-1-45/5KC ± 1% oscillator as the EL power source (California Industries Corporation/Aiken Industries, Incorporated - Behlman Division) and (2) Model 326 voltmeter to monitor the lighting voltage (Weston).

EL LIGHTING PIN DESIGNATIONS

PANEL OR INSTRUMENT	PIN NO. HOT	COM.	PLUG DESIGN	MAX. OPERATING VOLTAGE
HSI	HH	AA	XP909	220 - 400 ∿
ADI	L	M	XP908	220 - 400 ∿
Rate/Climb	2	3	XP918	220 - 400 ∿
Altimeter	2	3	XP919	220 - 400 ∿
IAS	1	3	XP929	220 - 400 ∿
0^2 Ind.	F	A	XP915	220 - 400 ∿
Course Select	C	D	XP920	110 - 400 ∿
Radio Call	C	D	XP917	110 - 400 ∿
UHF/OXY	C	D	XP914	110 - 400 ∿

3. Perform brightness measurements utilizing Photo Research Corporation, Spectra Brightness Spot Meter and Spectra Power Supply.

4. Complete the voltage/brightness form for each instrument or panel. Note any deviations or alterations.



ADI

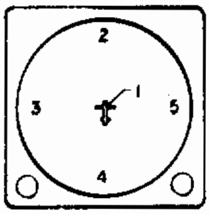
DATE ______
PLACE ______
SIGNED ______

BRIGHTNESS

READ POSITION	LAMP EXITATION (VOLTS)							
	200	175	150	125	100	75	50	25
1								
2								
3								
4								

1. FLAG ______
2. PITCH REF LINE ______
3. BANK INDEX ______
4. PITCH REF LINE ______

FIGURE 67. ADI VOLTAGE/BRIGHTNESS FORM



HSI

DATE ______
PLACE ______
SIGNED ______

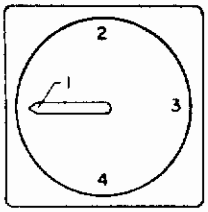
BRIGHTNESS

READ POSITION	LAMP EXITATION (VOLTS)							
	225	200	175	150	125	100	75	50
1								
2								
3								
4								
5								

1. ______
2. ______
3. ______
4. ______
5. ______

(2–5) SET HDG PTR TO POS SHOWN

FIGURE 68. HSI VOLTAGE/BRIGHTNESS FORM



RATE OF CLIMB

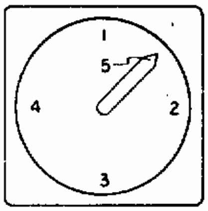
DATE ____________
PLACE ____________
SIGNED ____________

BRIGHTNESS

READ POSITION	LAMP EXITATION (VOLTS)							
	200	175	150	125	100	75	50	25
1								
2								
3								
4								

1. POINTER
2. 2
3. 6
4. 2

FIGURE 69. RATE OF CLIMB VOLTAGE/BRIGHTNESS FORM



ALTIMETER

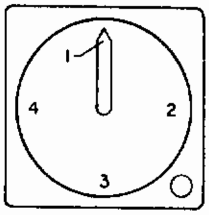
DATE ____________
PLACE ____________
SIGNED ____________

BRIGHTNESS

READ POSITION	LAMP EXITATION (VOLTS)							
	200	175	150	125	100	75	50	25
1								
2								
3								
4								
5								

1. 0
2. 2
3. 5
4. 7
5. POINTER

FIGURE 70. ALTIMETER VOLTAGE/BRIGHTNESS FORM



AIRSPEED

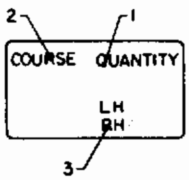
DATE ____________
PLACE ____________
SIGNED ____________

BRIGHTNESS

READ POSITION	LAMP EXITATION (VOLTS)								
	225	200	175	150	125	100	75	50	25
1									
2									
3									
4									

1. POINTER ____________
2. 2 ____________
3. 4 ____________
4. 5 ____________

FIGURE 71. AIRSPEED VOLTAGE/BRIGHTNESS FORM



COURSE SELECT

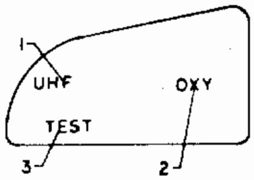
DATE ____________
PLACE ____________
SIGNED ____________

BRIGHTNESS

READ POSITION	LAMP EXITATION (VOLTS)									
	110	100	90	80	70	60	50	40	30	20
1										
2										
3										

1. Q ____________
2. R ____________
3. R ____________

FIGURE 72. COURSE SELECT PANEL VOLTAGE/BRIGHTNESS FORM



ANTENNA/OXYGEN

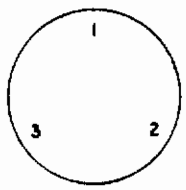
DATE ________
PLACE ________
SIGNED ________

BRIGHTNESS

READ POSITION	LAMP EXITATION (VOLTS)									
	110	100	90	80	70	60	50	40	30	20
1										
2										
3										

1. F ________
2. X ________
3. E ________

FIGURE 73. ANTENNA/OXYGEN PANEL VOLTAGE/BRIGHTNESS FORM



O_2 GAUGE
(ON ANT OXY PANEL)

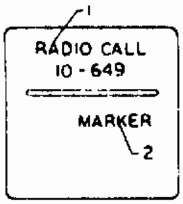
DATE ________
PLACE ________
SIGNED ________

BRIGHTNESS

READ POSITION	LAMP EXITATION (VOLTS)							
	225	200	175	150	125	100	75	50
1								
2								
3								

1. 2 IN "25" ________
2. 5 IN "5" ________
3. 5 IN "15" ________

FIGURE 74. O_2 GAUGE VOLTAGE/BRIGHTNESS FORM



RADIO CALL

DATE ____________
PLACE ____________
SIGNED ____________

BRIGHTNESS

READ POSITION	LAMP EXITATION (VOLTS)									
	100	90	80	70	60	50	40	30	20	10
1										
2										

1. AR ____________
2. K ____________

FIGURE 75. RADIO CALL VOLTAGE/BRIGHTNESS FORM

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13. ABSTRACT

This report describes an experimental program designed to obtain baseline cockpit illumination data using three types of electroluminescent display lighting. A series of three in-flight experiments was flown in a T-39 aircraft by highly experienced USAF pilots. The mission profiles were designed to simulate different types of operational flights by progressively increasing the external visual task loading on the pilot. Both objective measurements and pilot opinion data were obtained on display illumination under external ambient illumination ranging from twilight to night no-moon conditions. Photometric data collected during the flights showed that the pilots' display lighting requirements were influenced by the outside ambient illumination only when this illumination exceeded .001 foot candles. When the night ambient fell below this level, display illumination was primarily influenced by: 1) the pilots' pre-flight dark adaptation; 2) the type of information required for successful mission completion and the priority the pilots placed on the information available; and 3) the effects of cockpit lighting on display legibility. The experimental results showed that a range of 1.0 to .01 foot lamberts is sufficient for night illumination of displays incorporating either EL-transmitting or EL-reflecting illumination. EL-emitting displays, which must be illuminated under both daylight and night ambient conditions, will require an illumination range of approximately 20.0 to .01 foot lamberts. The effects of mission requirements and display design on cockpit lighting are discussed. Conclusions and recommendations for cockpit lighting based on pilot performance and pilot opinion are also presented.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Cockpit Lighting						
Cockpit Lighting Requirements						
Electroluminescent Lighting						
Electroluminescent Displays						
Solid State Displays						
Cockpit Illumination						
Display Illumination						

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