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13. ABSTRACT

The human reliability data (Data Store, An Index of Electronic Equipment Operability) derived by the American Institute for Research was used to select, modify, or construct 11 indicators and controls. These indicators and controls were assembled into two panels representing the best and worst reliability figures that could be utilized. To produce realistic operational panels, little reliability difference could be made in the dimensions. The panel equipment, through a Tally tape reader, was operated to simulate an aircraft flight profile from take-off to level-off. A checklist was devised varying response control indicator relationships. Trained subjects performed discrete actions in response to indications of airspeed, altitude, and vertical velocity. Their response was recorded and observed. To minimize equipment variability for higher reliability tasks, redundant error recording and interpretation was performed.

In addition to equipment reliability consideration, many tangential errors (such as proximity and similarity) appeared that would affect validation and analysis. A new error (called response error) was tabulated for a pilot study performed on the equipment. Relative validation of the data was accomplished.

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A SYSTEM FOR VALIDATING HUMAN RELIABILITY DATA

THESIS

Edward Low
Major USAF

Details of illustrations in
this document may be better
studied on microfiche

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A SYSTEM FOR VALIDATING HUMAN RELIABILITY DATA

THESIS

Presented to the Faculty of the School of Engineering of
The Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

By
Edward Low
Major USAF
Graduate Reliability Engineering
December 1971

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Preface

This thesis has been an attempt to expand the overall techniques for quantification and validation of human reliability data. It was only a beginning, but one with colossal potential. It was a complete thesis, preceding from theory through design and building of equipment, designing an experiment, testing subjects, tabulating the results, and then analyzing them. It confirmed the hypothesis that testing can well become more a function of the testor than the subject. Many error factors emerged that should not be ignored in serious studies of complete systems. The response error developed here might be a very useful tool for future analysis. With extreme reliability measurement, redundancy is necessary to control the reliability of complex testing equipment.

I am indebted to Dr. Donald Topmiller of the Aeromedical Laboratory for giving me this interesting and challenging thesis topic. The expectations of Dr. Donald Norris imbued me with a sense of depth and prespective for an enormous project. Mrs. Sara Munger, a developer of the data, gave me useful guidance. In any low-cost project manpower becomes paramount and from the Human Resources Laboratory Instrument Branch with which I worked, John Ferguson helped me find the off-the-shelf equipment and Noel Schwartz somehow translated ideas into electrical devices and put this conglomerate mass of wires and relays together.

I thank Prof. Moore for this continued interest and support for me and my class and Doris Brown's late hours of typing.

Edward Low

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Abstract

The human reliability data (Data Store, An Index of Electronic Equipment Operability) derived by the American Institute for Research was used to select, modify, or construct 11 indicators and controls. These indicators and controls were assembled into two panels representing the best and worst reliability figures that could be utilized. To produce realistic operational panels, little reliability difference could be made in the dimensions. The panel equipment, through a Tally tape reader, was operated to simulate an aircraft flight profile from take-off to level-off. A checklist was devised varying response control indicator relationships. Trained subjects performed discrete actions in response to indications of airspeed, altitude, and vertical velocity. Their response was recorded and observed. To minimize equipment variability for higher reliability tasks, redundant error recording and interpretation was performed.

In addition to equipment reliability considerations, many tangential errors (such as proximity and similarity) appeared that would affect validation and analysis. A near error (called response error) was tabulated for a pilot study performed on the equipment. Relative validation of the data was accomplished.

A SYSTEM FOR VALIDATING
HUMAN RELIABILITY DATA

I. INTRODUCTION

Purpose

The purpose of this thesis has been to devise a system for validating human reliability data. This involved the design, construction, and test of an apparatus which presented an operation using indicators and controls of varying dimensions and measuring the reliability of the operators. The roots of this thesis lie in the development of the quantification of human performance.

Background

Machines that man operates are merely extensions of his abilities; yet for a very long time his function was not considered a part of the machine output. The performance parameters of the man-machine system evaluated were only those of the machine. The reliability of a system was generally defined in terms of the probability of system operation without equipment breakdown. With the advent of high reliability missiles and electronic equipment, the human factor entered a recognition phase. Shapero (Ref 20) pointed out that 20-53% of missile malfunction reports investigated were classified as human-initiated.

Another phase of human element assessment might be called the qualitative phase. Extensive research produced a large number of texts and research reports which helped engineers design equipment for man's use. This qualitative data gave dimensions and equipment characteristics for optimum human performance. Yet a need existed to quantify the human role if the total mission effectiveness was to be determined.

Quantification

Irwin (Ref 7) outlined several approaches to the quantification of human performance.

1. Analysis of field experience.
2. Extrapolation from experimental literature.
3. Conducting special studies in simulated environment.
4. Conducting special studies in operational environment, and
5. Judging and rating reliability.

Basic to all these methods is a reduction of a mission down to a specific task analysis.

The first major work in this area was done by the American Institute for Research (AIR). They began with an extensive literature search. Through manipulation of the data and their own judgement they produced reliability figures for various dimensions of simple indicators and controls and put them into a collection called Data Store.

Rook (Ref 17) analyzed error data for 23,000 production defects detected in assembly operations of electronic equipment. He developed a classification scheme and a quantitative model for evaluating the contribution of human error to the degradation of product quality. Swain (Ref 21) extended Rook's work to military applications and used the Data Store. His method was called Technique for Human Error Rate Prediction (THERP). He used a probability tree to cover all possible consequences of operator action.

A computer extension of this methodology was developed by Miller (Ref 11). He oriented his approach around the operator of U.S. Army Signals Corps field equipment. Called Tactical Data Entry System (TACDEN), it was basically a typewriter type of keyboard for entry of data, a magnetic drum for storage and a cathode-ray tube which showed the information the operator was supplying the system.

AIR Data Store

The Data Store of AIR (an Index of Electronic Equipment Operability) was the basic building block for many approaches. The basic unit of evaluation for the index was a specific step or action. This step was subdivided into three aspects: (1) inputs(stimuli to the senses), (2) mediating processes (thinking, evaluating), and (3) outputs or responses (motor activities). Equipment behavior components were identified that were likely to affect each aspect of behavior (Table I). The authors of the Data Store recognized a paucity of categories, mediating process and a need for materials in this area.

These individual components were then broken down into parameters and then into dimensions which were discrete categories or intervals (Table II).

Table I

List of Input, Mediating Process, and Output Components

Inputs	Mediating Process	Outputs
Circular Scales	Identification/Recognition	Cable Connections
Counters	Manipulation	Cranks
Labeling		Disconnecting
Lights		Joysticks
Linear Scales		Knobs
Non-Speech		Levers
Scopes		Object Positioning
Semi-Circular Scales		Pushbuttons
Speech		Rotary Selectors
		Speech
		Toggle Switches
		Writing

(From Ref 17:11)

Table II

Counter Parameters and Dimensions

1. Size (length)
   - a. 1"
   - b. 1-2"
   - c. 3" and up
2. Numbers of drums (or digits)
   - a. 1-3
   - b. 4-5
   - c. 7 and up
3. Style
   - a. Quantitative reading
   - b. Qualitative reading

(From Ref 15:4)

Unfortunately, the Experimental data was very difficult to quantify and large gaps existed. Here they interpolated and extrapolated from related studies, used their judgement, or made "quick and dirty" studies. As can be seen, some gaps still existed. For the second parameter in Table II, number of drums, the quantity 6 is omitted because they did not want to overinterpret the data.

Over a variety of equipments and missions the range of operator reliabilities was 85 to 90%. This was interpreted to mean that 10-15% of the time an operator error would fail or seriously degrade mission effectiveness. Since no field tests for reliability for individual task steps or behavior components were available, they derived their own. Using their mean unreliability figure of 0.13 (10-15%), they divided it by the mean number of steps in a mission. For 26 different equipments the average number of steps was 50, so their mean unreliability per step was

$$\frac{0.13}{50} = 0.0026$$

This means that in 10,000 operations of this step, operator error would fail or seriously degrade a mission, 26 times. This step unreliability was then compared to mean unreliability per experimental trial studied. The experimental mean value was 0.31935. Assuming a trial was equivalent to a step, the ratio of the ratio of the two numbers gave a conversion factor to multiply times the experimental unreliability.

$$\frac{0.0026}{0.31935} = 0.008145$$

The product of laboratory unreliability and the conversion factor gave an unreliability or error rate for a dimension. For example, if a counter 1 inch long gave a lab reliability of 0.8773, its unreliability would be 0.1227 (1-0.8773). The Data Store unreliability or estimate of field error rate for that dimension would be

$$(0.1227) \times (0.001845) = 0.001$$

giving a reliability of 0.999. Table III shows a portion of a page from the Data Store Index which begins with this reliability for the first dimension.

Table III

Counter Dimensional Reliability

Reliability	Parameter & Dimension
	1. Size (length)
.9990	a. 1"
.9998	b. 1-2"
.9995	c. 3" and up
	2. Number of drums (or digits)
.9997	a. 1-3
.9993	b. 4-5
.9985	c. 7 and up
	3. Style
.9995	a. Continuously rotating
.9997	b. Unit jumps
	4. Use
.9999	a. Quantitative read
.9990	b. Qualitative read
	5. Numeral legibility
.9999	a. Clear and concise
.9994	b. Potentially ambiguous

(From Ref 15:4)

Another element, response time, listed in the Data Store, is not evaluated in this study.

The purpose of the data was to evaluate equipment by identifying design features which would degrade operator performance and providing guidance concerning selection and training of operators for evaluated equipment.

Some Limitations

The definition of error will be covered more fully when the results of the test are examined. The AIR definition, "seriously degrade", seemed to be an individual judgement item. The conversion factor tied the resultant reliability figures to general field reliability and possibly, totally irrelevant or inadequate laboratory data. Validation and adjustment of the data was made on a narrow group of equipment with insufficient reliability data to make any statistical analysis. Nonetheless, the use of the data by the developers of other methods confirmed a general "in the ball park" validity. Since this data still remains as the primary bank of information, a continuation of this thesis project could contribute significantly toward human performance evaluation.

System Development

To construct a system which would validate the data, an apparatus was constructed with two panels having the same type of component displays and controls. One panel contained components with dimensions as closely approximating those in the data that gave the highest reliability and the other with dimensions similar to those having the worst reliability. The components and other equipment were all off-the-shelf or experimental equipment not currently in use. Since some of the equipment was experimental, it was not completely predictable and most of it was modified to perform in a manner not originally intended. The panel was programmed to simulate an aircraft sequence from take-off to level-off in order to get a maximum number of logical uses of the components.

II. EQUIPMENT DESIGN

The system had two main groups of equipment. The display and control group consisted of the equipment with which the subjects were associated. It included two panels of displays and controls and the platform and the throttle it housed. The driving equipment included all the other apparatus for operating the experiment and recording operator responses. More technical description of the operation of the indicators and controls is included in the equipment section. The panels are shown in Figures 1 and 2. The resulting equipment design was a function of individual equipment dimensions, availability, adaptability to the experiment, possible control, and panel layout. Schematics for the various equipment circuitry is included in the Appendix.

Indicators and Controls

It was possible to use five types of indicators on each panel: scales that were semi-circular, circular, and linear; a counter and a light. The controls used were a knob, a rotary selector, a toggle switch, a push button, and levers. Sketches were drawn of the best and worst case for the parameters in the Data Store Index. From these sketches, the search began for the indicator and control components. It was obvious that many parameters and categories were not appropriate to an aircraft instrument application.

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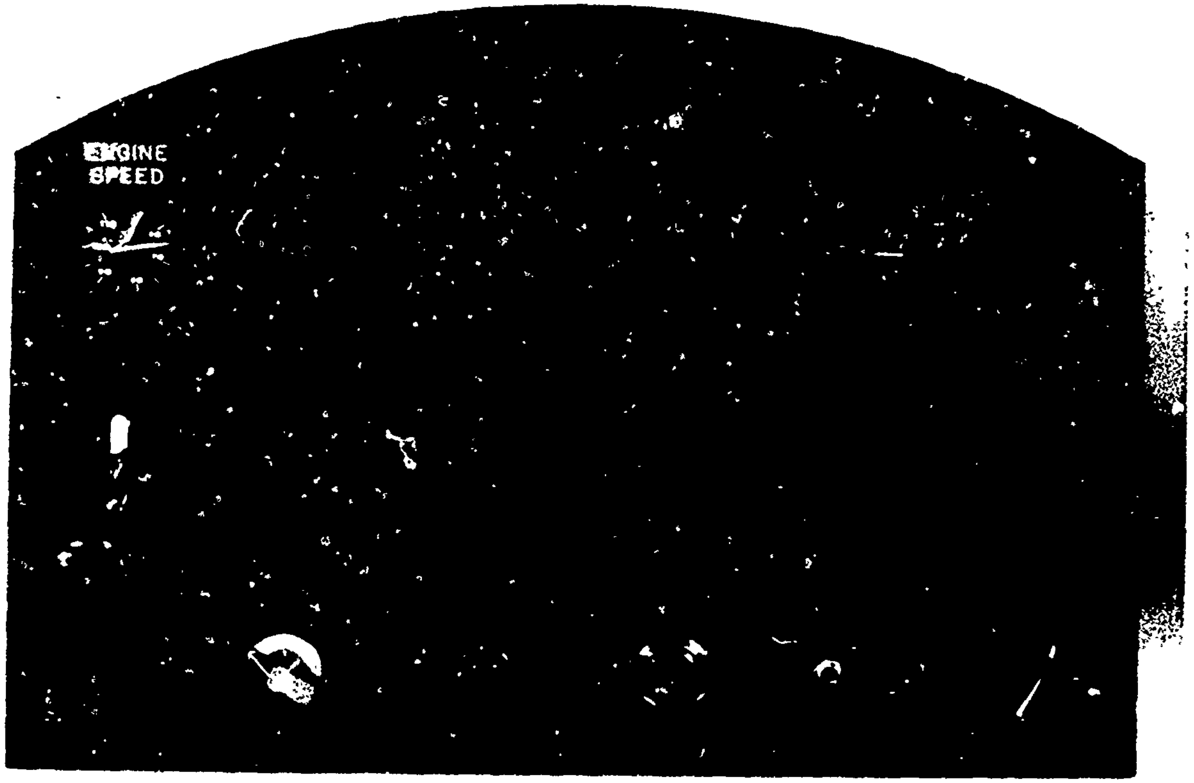

Fig. 1
Panel 1, Best Case

Fig. 2
Panel 2, Worst Case

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In the Data Store Index there are an average of nine parameters for each indicator and control. Generally less than six of these parameters could be used. For each parameter there are three or four values for each parameter. Quite often the extreme values were difficult to use. For example, a semi-circular scale most naturally could be used for aircraft rate of climb or descent (vertical velocity). The parameter, scale arc length (number of degrees included by scope face) has the categories 25°, 50-100° and 200°. The lowest category, 25°, did not seem to allow for presentation of several vertical velocities and graduations between them so only two categories were used. The number of graduations still had to be reduced to make the worst case indicator legible. For the parameter, scale interval spacing (distance between graduation marks), the reliability figure actually turned out better for the worst case. The only useful ammeter that could be found that fit the 50-100° category had a pointer radius in the same range as the best case so this parameter could not be differentiated. Normal aircraft vertical velocity indicators could not be used because their variable graduation spacing did not lend itself to the index. Similar problems were encountered differentiating among the other instruments. New faces had to be made for the circular engine speed indicators. Again, for legibility, the smaller instrument had to have fewer graduations and a better reliability for that parameter.

The vertical scale used for altitude was an experimental model. Two identical instruments were used. To create a worst case, the presentation area was reduced and the number of graduations was increased. Counters worked out best for airspeed. A fourth digit on the largest (best case) counter was taped to keep the reliability at least equal to the worst case. A light served to indicate if the brakes were set.

Levers were used for the throttle and gear handles. A push button served as a brake button and a rotary selector acted as a flap position control. Another type of rotary selector, a knob, was wing position control. The Index used the knob in conjunction with a separate display but for simplicity this was omitted. A three-position toggle switch, spring loaded to the center position, functioned as a nose position control. This control was created to give the operator a discrete elevation control. The normal aircraft control wheel or stick would present a continuous control function which would have been difficult to evaluate. For this reason and experiment complexity, a heading control was not used.

Placement on Panel

The controls and displays were located on the panels in the most functional manner possible. The panels are 21 inches wide and 12 inches high at the side, with the top curving up to 15 inches in height at the center. A row of indicators was centered on a horizontal line 10-1/2 inches up from the bottom of the panel. This located them just below eye level, 28 inches from the eyes of an average male subject seated in the planned position at the console. Since the zero position of the vertical velocity was at the nine o'clock position, it was placed on the right side of the panel. To balance the panel, the circular scale was put on the left. The vertical linear scale was centered on the panel to use the maximum panel height and the airspeed indicator was on the left of it. Another horizontal line, 2 inches up from the bottom of the panel, contained most of the controls and the brake light. This placement put them closer to the hands of the subjects. Since both the knob and rotary selector were similar in operation, they were placed on opposite sides of the panel. The brake light and button were symmetrically below the altitude indicator. To balance the number of controls and manipulations, the toggle switch was placed on the right side of the panel. The gear lever was placed to the extreme left of the panel so when it was in the up or down position it would not shield any instruments or controls. It was also above the line of other controls so it would always extend well above the bottom of the panel and away from the throttle, which was also on the left side. One throttle was used with both panels. It is shown in Figure 3. It moved fore and aft in a control box which was clamped to the chair of the subject. It was placed on the left side to locate it on the same side as the engine speed indicator it controlled. All adjacent controls had a least 1-1/2 inch clearance between moving surfaces. All controls and displays were labeled in 1/4 inch letters with names most appropriate to what they showed or did. Several labels were arbitrary. Wing position was not the generally used term for wing sweep, yet it seemed to be an easier understood description for the actual function of the control.

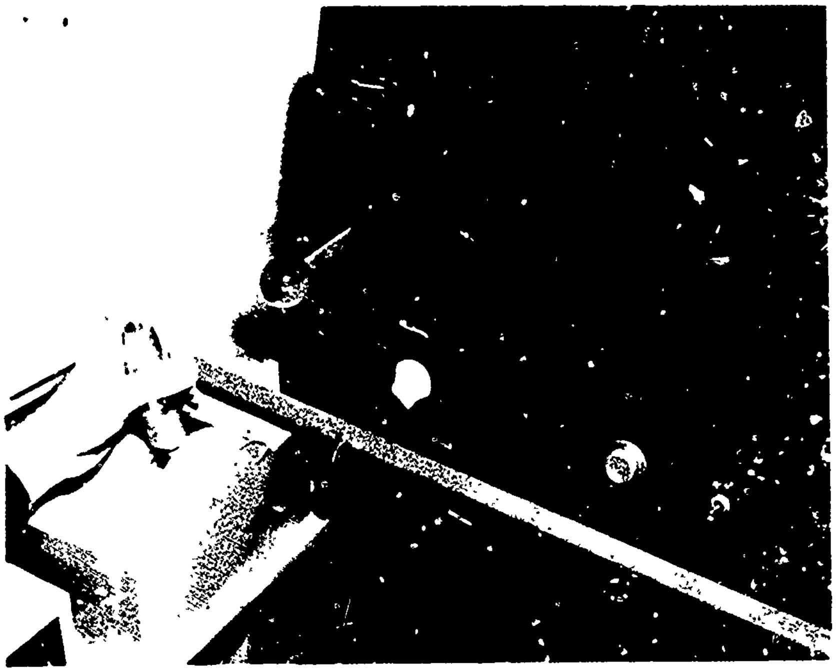

Fig. 3
Throttle for Both Panels

Driving Equipment

The other equipment included a Tally tape reader, three Hunter IIIC timers, a control chassis, a white noise generator, an Esterline-Angus recorder, and the associated wiring and electronic equipment. The tape reader, with the control chassis and timers on top of it, is shown in Figure 4. Wiring diagrams for the equipment are included in the Appendix.

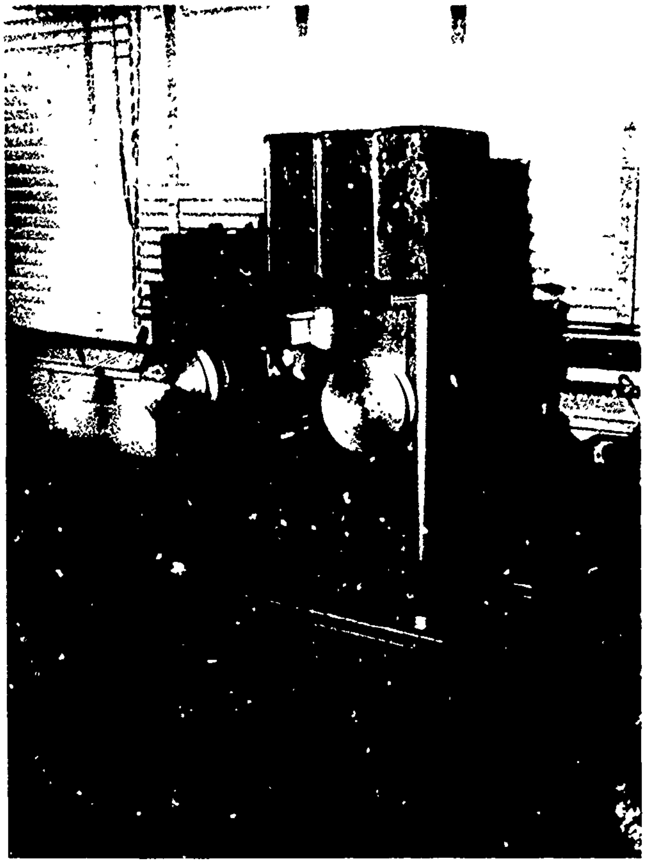

Fig. 4
Tape Reader, Chassis,
and Timers

All the panel indicators except engine speed were programmed from the Tally reader. The Tally read eight channels of punched paper tape (as shown in Figure 4). Within the Tally console were two relay trees whose outputs controlled relays in the control chassis. These control chassis relays operated the various panel instruments. Both panels were driven by the same circuitry except for the airspeed counters.

The airspeed of Panel 2 (worst case) was a 3-digit impulse counter driven from a relaxation oscillator using a unijunction transistor. According to tape code, the pulse counter could be stepped at two rates or stopped. These rates could be adjusted by potentiometers on the chassis, allowing actuations from zero to 20 pulses per second. This allowed airspeed to increase well beyond normal human discrimination of the last digit. The counter had a push button reset to zero. The other airspeed counter was geared to an Electro-Craft motor. The motor had its own control unit which had a relay placed inside it to allow two-speed control from the control chassis. Two additional potentiometers also permitted individual control of the increase in counter reading. Since the indication on the counter was over 200 after the run and it had to be reset to zero for the next run, the motor control was switched to the reverse position and the Hunter timer (which is labeled No. 1 in Figure 3 and in the Appendix schematic) was connected to allow runback to zero for the selected time interval. The speed control of the motor was used to allow a faster reset rate than the two and four units-per-second rates set in the control chassis for the experimental runs.

The moving tape of the altitude indicators was controlled from a 400-cycle synchro generator. This synchro, on the control chassis, was positioned in steps by a modified stepping switch. The switch stepped one position every time an altitude code appeared on the punched programmer tape. The reset timer, mentioned earlier, was connected to the reset coil of the stepping switch, so that altitude could be reset to zero.

The climb meter was essentially a milliameter, connected through one of three rheostats to 28 volts d-c or disconnected for a zero rate. The programming tape codes selected one of four relays, which in turn selected one of three rheostats for the three climb rates or no rheostat for zero climb. The more sensitive meter on Panel 2 had a rheostat shunt to adjust it to the same sensitivity as the other vertical velocity indicator. With this arrangement, the three rheostats on the control chassis were used to adjust the indicator on Panel 1, and the indicator on Panel 2 could then be corrected with its own rheostat in back of the panel.

The throttle was coupled to a rotary selector switch and a synchro generator. The selector switch routed 28 volt d-c to the appropriate channels of the Esterline-Angus recorder. The synchro generator fed throttle position information to a synchro repeater of the engine speed indicator on the panel.

Wing position, flap position, gear and nose position controls functioned only to a route 28 volts to the various channels of the Esterline-Angus for recording.

The tape reader could also be used to interrogate various control positions during a program. The appropriate code resulted in a blip on the Esterline channel corresponding to the proper position of the throttle or flap controls if the control was <u>not</u> in the correct position. No mark would be made when the control was in the correct position and the Esterline pen properly displaced. This feature was not used in the experiment because during the final debugging period, spurious signals actuated instruments erroneously when the interrogation codes ran through the reader.

The speed at which the Tally read the signals was regulated by a pair of Hunter timers (labeled No. 2 and No. 3). The sum of the two timer settings was the cycle period. The most convenient cycle period for the tapes was one second so each timer was set at a 0.5-sec interval. These timers applied power to the relay trees at the appropriate time of the read cycle and moved the tape through the reader.

III. THE DESIGN OF THE EXPERIMENT

The experiment was designed to obtain a maximum number of output manipulations by four trained operators. A take-off sequence was selected because it would give more control actuations in a short time and appear more realistic for discrete indications and a pre-determined program. By using a low altitude level-off, a basic checklist was developed with 17 realistically spaced control actions tied to various indicator displays.

Timing was developed through a variety of runs with a group of trained psychologists and subjects. The objective was to condense the sequence into the shortest time in which a trained subject could read the checklist, observe the display, and perform the action wihtout being rushed or required to wait too long for the next indication. The timing turned out to be comparable to the flight sequence of a high speed aircraft.

Flight Profile

The flight profile used is shown in Figure 5. The base (abscissa) is time in seconds from brake release. The ordinate axis is marked in units of airspeed (knots)on the left side and altitude (feet)on the right. Airspeed built up at an increasing rate for the first 25 seconds, then more slowly as an aircraft would until take-off at 40 seconds. At this time vertical velocity jumped to 1000 feet per minute (FPM) and altitude began to increase. Airspeed and altitude increased

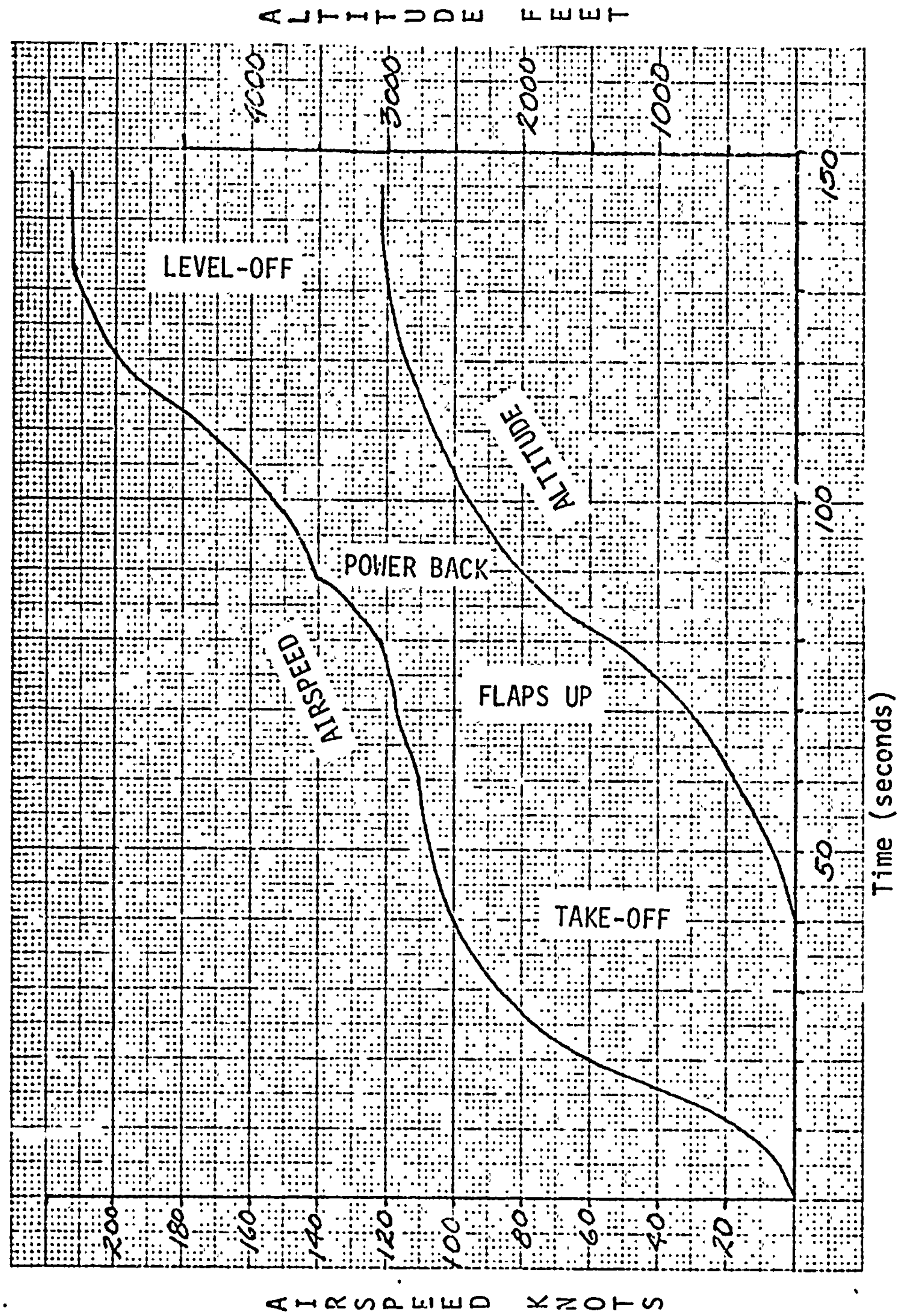

Fig. 5
Simulated Flight Profile

in an undulating path as they would for various aircraft power and pitch changes until level-off at 3100 feet and approximately 212 knots, 2 minutes 12 seconds after break release.

Varying aircraft performance would allow for many realistic flight paths. For variation in the experiment, two alternate sequences were randomly included. One started out with a higher airspeed and lower vertical velocity or climb rate typical of an aircraft nose-low altitude. The other sequence simulated a nose-high climb with lower airspeed and higher vertical velocity initially. Both sequences end up at the same standard level-off.

The checklist used in the experimental runs is shown in Table IV. It and the profile were carefully arranged to provide uniformly spaced actions throughout the run. The checklist gave an action to be performed on a control for various indicator displays. Indicator-control pairs were varied as much as possible. The link analysis in Figure 6 shows how the diversified pairing of the indicators and controls is used. The average indicator and control use was 3.1 times per run.

The students used the checklist during the runs. The first checklist action, pushing the brake button, started the sequence on the tape reader. Their final level-off setting left the controls at the initial start of take-off roll configuration.

Procedure

Four male students from the University of Dayton were used for the pilot study of the experiment. The coordinator at the University

Table IV

Checklist

The actions are to be performed after obtaining the proper indication. The indications will always appear. Complete each action in the numbered order, even though the succeeding indication might appear earlier. Your objective should be to perform the actions accurately without falling behind the sequence of indications.

	Indication		Action
1.	BRAKE LIGHT	-	BRAKE BUTTON
2.	AIRSPEED INCREASE	-	ENGINE SPEED, 100 PER CENT
3.	AIRSPEED, 75 KNOTS	-	NOSE UP
4.	AIRSPEED, 90 K	-	ENGINE SPEED, 110%
5.	VERTICAL VELOCITY, 1000 FPM	-	NOSE UP
6.	ALTITUDE, 300 FT	-	GEAR UP
7.	ALTITUDE, 550 FT	-	BRAKE BUTTON
8.	VERTICAL VELOCITY, 2000 FPM	-	FLAPS, 30 DEGREES
9.	AIRSPEED, 120 K	-	FLAPS, 0°
10.	ALTITUDE, 1700 FT	-	ENGINE SPEED, 100%
11.	AIRSPEED, 145 K	-	WING POSITION, 40°
12.	ALTITUDE, 2550 FT	-	WING POSITION, 60°
13.	ALTITUDE, 2800 FT	-	NOSE DOWN
14.	VERTICAL VELOCITY, 1000 FPM	-	ENGINE SPEED, 80%
15.	AIRSPEED, 195 K	-	GEAR DOWN
16.	ALTITUDE, 3100 FT	-	FLAPS, 60°
17.	VERTICAL VELOCITY, 0	-	WING POSITIONS, 20°

LINK ANALYSIS – CENTER POINT OF DISPLAY AND CONTROL

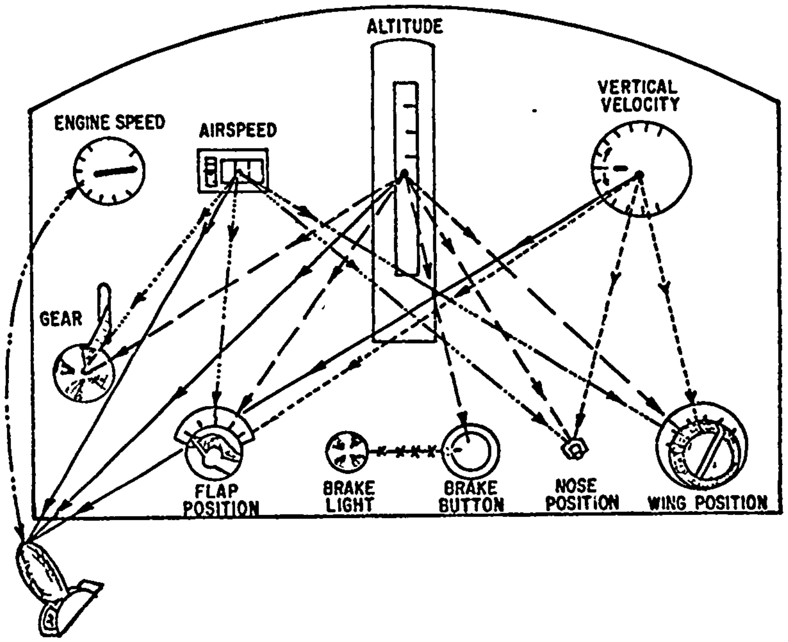

Fig. 6
Link Analysis

of Dayton were used for the pilot study of the experiment. The coordinator at the University was asked to get students without flight experience, if possible. They spent three hours training one week on one panel and 6 one-hour sessions testing the next two weeks. Two subjects tested on the panel on which they had trained, two switched to the other panel. The third week all four students switched panels.

Table V

Panel Usage

	Panel		
	Training	Test	
Subject	Week 1	Week 2	Week 3
1	1	1	2
2	1	2	1
3	2	2	1
4	2	1	2

First week - Two subjects at a time were taken the first day to avoid duplication and increase learning by observing another perform. They were given a short instruction sheet (Appendix B) which explained that they were being used in an experiment to measure human performance. They filled out a questionnaire (Appendix C) which gave scheduling and location information. They were also questioned about flight or tracking experience. After being scheduled for the remaining activity, they were shown the two panels. Logical relationships and analogies between the equipment and aircraft indicators and controls were presented. The subjects were encouraged to ask questions throughout the training.

The subjects than sat in front of the panel and went through the checklist, manipulating each control in the instructed fashion as the observer explained each indication that would be observed. It was emphasized that each action had to be performed in order before looking for the next indication. The subjects also observed the other parties being instructed.

The observer made the first "live" run to demonstrate the flow of indications. This run took 6 minutes 15 seconds from brake release until the last indication, which was zero vertical velocity (sequence 21 or S20, Appendix D). The run, averaging 19 seconds between checklist indications, had three 20-30 second periods without indicator changes which could be used for subject questions. The tape reader could be stopped for any length of time, if necessary. Each subject then performed and observed this run.

At this point the subjects were given a short coffee break. While they chatted they were handed an outline of the panel and parts and asked to name the indicators and controls. Each subject then returned to the panel, performed and observed a 4 minute 10 second run and several 3 minute 10 second runs. The average time between required actions had been reduced down to 15 and 12 seconds. After their first demonstration run the subjects wore ear phones and heard random noise which was checked before, after, and intermittently during the runs. The random noise was kept well below any uncomfortable level yet covered a frequency range and volume sufficient to block out almost all outside noise.

When the subjects came back two days later for their individual training hour, they performed runs until they had completed a total of six 3-minute runs and three 2-minute 12-second runs similar to the actual test run.

Second week - At the first session of the second week each subject was given each one of the three tests. After completing the training, one man on each panel switched to the panel on which he had not trained. The subjects completed as many runs as possible the first day and 45 runs for the week.

Third week - All four subjects switched panels for the last 45 runs this week. This gave each subject at least 14 training runs on one panel and 45 test runs on each panel. After the final run was completed each subject was questioned briefly about his impressions and ideas about the experiment and the purpose of the experiment was explained.

IV. EQUIPMENT OPERATION

Within the limitations of laboratory voltage and equipment operation, every effort was made to precisely control the system. This was done to produce uniform subject presentations and most accurate possible recording of their responses.

Laboratory Power

Unexpected variation in the line voltage to the equipment hampered system operation. The apparatus was set up on the third floor of an Aeromedical Laboratory at Wright-Patterson Air Force Base. This building was one of four drawing power from a feeder station. In all of the buildings, variable experimental activity was conducted. In the basement of this building there was a test altitude chamber. When the last of three vacuum pumps for the chamber was activated, a voltage drop of several volts was created in the building. According to power and maintenance personnel for the area, the third floor of this building had one of the most variable voltages. Intermittent observations showed a variation in voltage from 114-v to 125-v ac. During the last day of runs a microcorder tape was made which is shown in Figure 7.

The instrument was dampened and did not show large temporary voltage changes. Various afternoon times are shown along the voltage line which is indexed at 115-v and 125-v. Arrows show unusual breaks. Several of these breaks drop to 115-volts shortly before and after

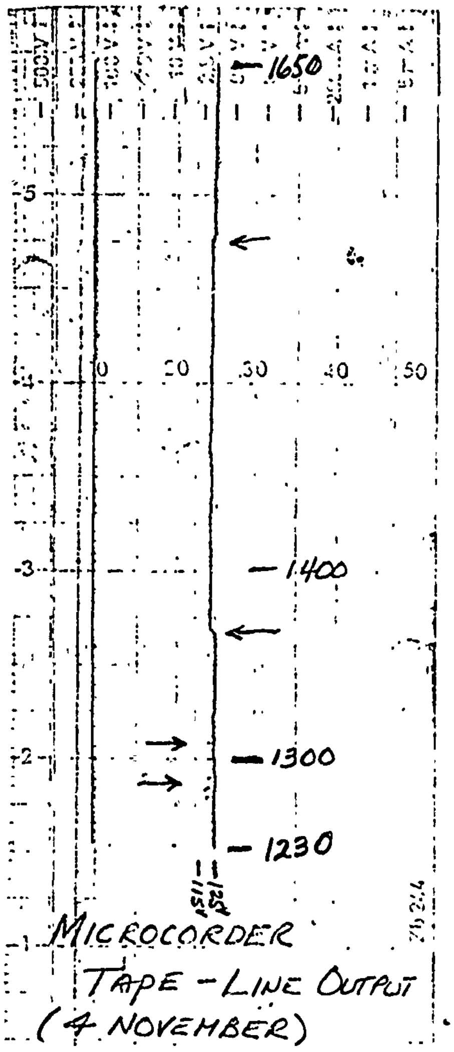

Fig. 7
Equipment Line Voltage Input

1300. It could be expected that a large amount of equipment would be turned on right after the lunch hour. The minimum consistent voltage was reached in mid-afternoon and built up again as building equipment was turned off late in the day. This presented a problem for exact input voltage into the system. Sola constant voltage transformers were used with the most important equipment to minimize the problem.

Airspeed

The airspeed on Panel 1 seemed to present the most problems. The counter was geared to an Electro-Craft motor unit which appeared to have a warm-up effect on airspeed. The final test run sequences had approximately the same smount of run time and were programmed to end up at the same end airspeed, so the final counter reading was used as an index of the operation of the airspeec circuitry. It was found that this final airspeed would gradually build and peak after 6-10 runs. Airspeed checks with precise variable outputs did show that the airspeed output was also a function of line voltage. Isolating other factors, a drop from 128-v to 116-v produced a rise in final counter reading of 10 units. Below 111v the readings dropped again.

About the time the test runs were to begin it was discovered that the Hunter timers which controlled the basic system pulse were also probably heavy contributors to the variation. Timer variations could have been related to the times between runs, times between actuations, the actuation period, equipment variation (±5% for 117 ±6 volts), and input voltages.

A test run sequence took 2 minutes 12 seconds with approximately 80 seconds of airspeed motor run time. Then, 1-2 minutes of reset time which included around 11 seconds of fast airspeed runback. Even if a warm-up pattern was made it had to run until just before the subject started because as little as 5 minutes cooling would result in the same increasing output.

The final hook-up procedure had both timers and the airspeed control plugged into the Sola transformer. All equipment was put on warm-up for approximately one hour before subject time. Two runs were also made shortly before expected subject time to eliminate an initial low outcome. Figure 8 shows bar graphs of the distribution of termination airspeeds for the first five days. Table VI shows some statistics of these distributions. Included is range, mean, mode, secondary mode and number of runs.

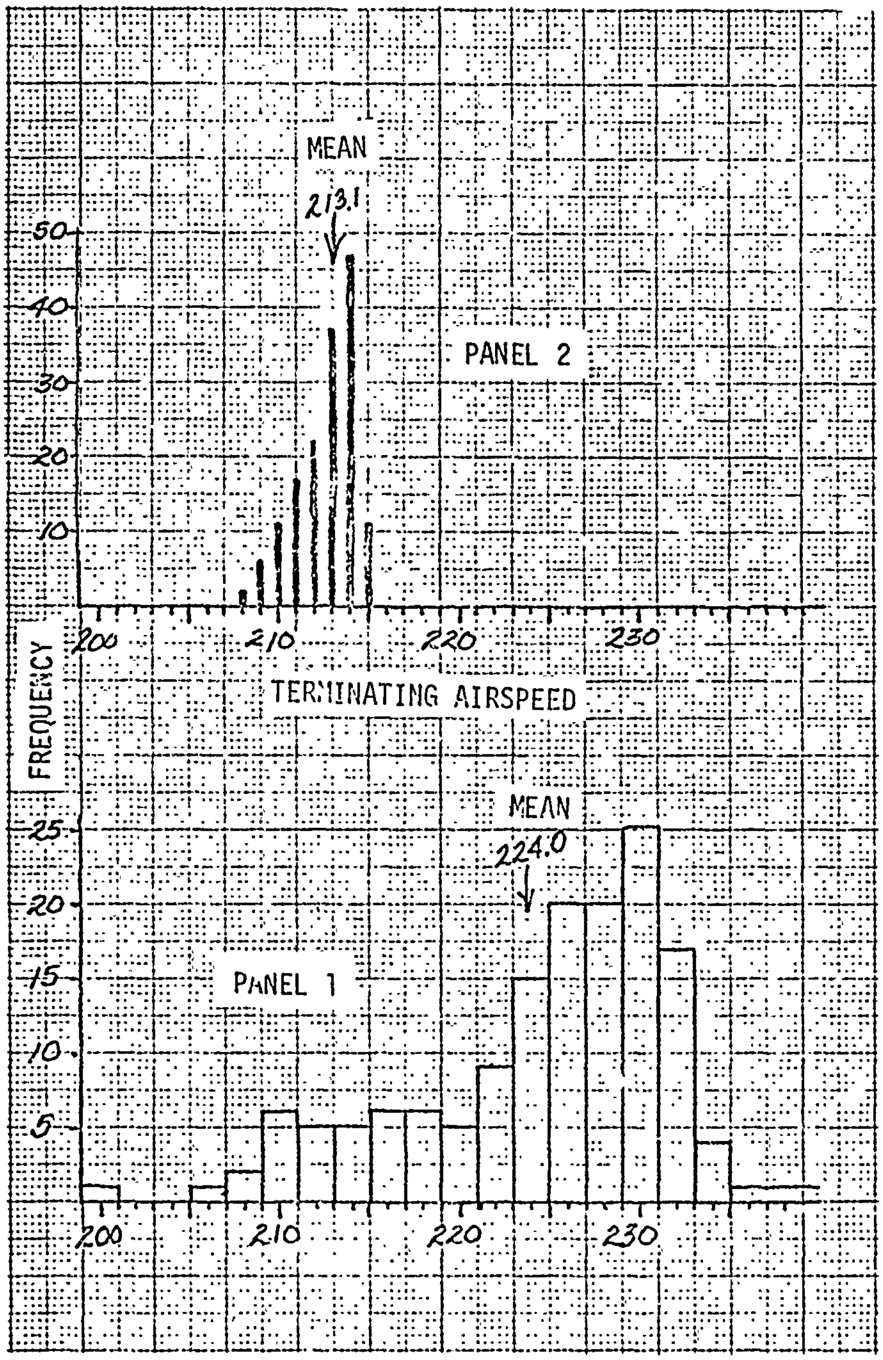

Fig. 8
Termination Airspeeds

Table VI

Termination Air Speed Statistics

Day	1	2	3	4	5	6	
Lowest	223.5	213.5	200.5	211.5	222	203	
Highest	233.5	232.5	225.5	236	231.5	222.5	
Mean	228.8	226.4	215.6	226.3	227.5	214.3	
Mode	229-231	231-3	209-211	231-3	225-227 227-229	---	Panel 1
Secondary Mode	225-227	227-9	219-221	225-227 227-229 229-231	---	---	
No of Runs	25	32	33	30	30	30	
Lowest	210	208	209	209	210	210	
Highest	212	214	215	215	215	214*	
Mean	211.2	212.0	214.3	213.0	213.5	212.7 214.2*	
Mode	211	213	214	213 214	214 213	213	Panel 2
Secondary Mode	212	214	213	---	215	214	
No of Runs	18	33	39	30	30	30	

*214.2 average includes 3 runs ending at 228

Several alternate hook-ups were tried the last day and a variac was used by itself to test control and also attempt to bring the average run times of all subjects closer together. Interestingly enough, although the range of end speeds (as indicators, generally, of speed relationships to other instruments throughout the run) was larger than desired, the average end speed seen by all four subjects varied by only three units. This means that the average time at which a subject saw a specific airspeed during the runs varied less than 2 seconds. This would indicate that for a larger number of runs, if each subject ran at different times of the day, the distributions for all subjects would probably be equivalent.

It would be suggested for future experiments that the variac be hooked in the line after the Sola transformer. Because of the low output voltage of the Sola, this would give some variable control over airspeed. To eliminate the warm-up range of output, several sequences could be run just before the subject started (with the 400 cycle power turned off to cut out altimeter actuation). If this could not be done, the variac could be set low and gradually turned up as the system warmed up. Runs could also be scheduled to avoid general building turn-on and turn-off activity.

The airspeed of Panel 2 shows less effect of voltage variation and would require little attention. One unexplanable variation should be avoided. When the timers were plugged into the variac (which only allows some control, not constant voltage) the final counter readings jumped to 228, a rise of approximately 15 units. No variation of the variac could regulate this output so they had to be plugged into the line voltage or the Sola transformer.

Altimeter

The altimeters were experimental instruments and no wiring diagrams could be found on-base, with the distributor, or at the factory. Guess work was involved determining the wiring, so complete control was sometimes questionable. The synchros in the instrument were geared to drive the movable tape through its entire 11,500 foot range. The fine synchro made approximately 17 revolutions to one revolution of the gross synchro (schematic in Appendix).

Originally the altitude was programmed to go to 5000 feet. When the reset timer was actuated, the step switch driving the synchro generator would spring back to the zero position. The instrument gross synchro had been switched on and attempted to follow back to the nearest zero position. At the completion of the reset timing, the fine synchro was re-activated and returned to the nearest zero position. With repeated use, the gross synchro seemed to return to large negative values or to a position that upset the fine synchro when it took over an it would not go completely to its original zero point or would go beyond to one complete revolution and indicate 6500 feet. This condition could not be resolved in the short time before subjects were to be run so the gross synchro was disconnected and the program sequence was re-written to keep the fine synchro in a range (less than 180 degrees of movement or 3300 feet of altitude) that would allow it to return to the zero point after each run. There remained some variation in the altitude indications but the checklist was organized to avoid ambiguous readings. The subjects were required to note a specified altitude plus or minus 50 feet before making control actuations.

The stepping switch increased altitude approximately 280 feet in each incremental step. The variation in the instrument seemed to be caused by a spring in the instrument which opposed the movement and/or an uneven torque sometimes caused by a slight shift in phase of the 400-cycle input voltage.

V. TEST RESULTS AND ANALYSIS

The experiment was designed as a pilot study for further system testing. It was important to define and analyze errors, not only to determine reliability but to design the equipment and the test. The following discussion might aid later, more sophisticated testing.

Error Definition

The basic error definition in AIR material, an action that would degrade the system, seemed too narrow. Of the many definitions, one of the more acceptable (Ref 16 and Ref 15) was:

1. Perform required action incorrectly
2. Perform required action out of sequence
3. Perform non-required action
4. Failure to perform required action.

An interview with Mrs. Sarah Munger, AIR research scientist, (Ref 26) convinced the author that "near" errors could have significant effects, give more data, and should be recorded. So, any incorrect response (with some modification) was recorded and classified as either actuation or response error. An actuation error was a definite indicator misreading or incorrect control movement by the subject (slightly modified by later discussion). A "near" or response error was a start toward the wrong control. With this consideration and for a back-up of the recording system, all subject runs were observed.

An observer sheet was developed which reduced the distraction from subject operation of the panel.

Observation Sheet

The observation sheet (see Appendix A) was a 8 x 10-1/2 inch General Purpose Data Sheet, with extra columns added. The correct action and indication for each step are on the left side of the sheet. As an aid to the observer, the action he is watching is also repeated on the right side of the sheet. Two columns for each of the five controls and a comments column spread from left to right. One of the two columns is marked A for actuation errors, the other column is marked R for response error. The observer checks the block for the incorrect control action made (response or actuation) on the correct response-indication line. Display errors could be recorded by circling the indication.

A sheet was used for each run. The starting time and ending airspeed counter readings were recorded for equipment evaluation. After the testing, the checked blocks were compared with the Esterline-Angus recording and tabulations made for the various component errors.

Error Amplification

Further amplification of errors was necessary for system components. The subject sometimes moved the throttle through the correct position. If he immediately moved it back to the correct position, it was not counted as an error. The average subject took about 1-1/2 to 2 seconds to glance from the throttle or any place on the panel, observe an incorrect engine speed and change it. If he appeared to do more than this action or take longer (depending on the movement rate of the subject) he was credited with an error. Movement in the wrong direction was considered an error.

For both actuation and response errors it was helpful to understand the mannerisms of the subjects. The movement rate for subjects varied. One man normally took longer to glance around or move a dial and if the 1-1/2 to 2 second rule was rigidly maintained, some of his normal rate actions would have been considered as actuation errors. Conversely, a faster acting man might be committing a response error if he left the control incorrectly positioned longer than he normally would take to observe the incorrect indication.

One subject always placed his hand on the next control to be actuated long before the necessary indication. Observing one of the other subjects, the occasional time he reached out to manipulate a control, it appeared he was making a response error.

Other Error Effects

Unfortunately, many errors appeared which could not be specifically attributed to indicator or control characteristics nor eliminated by experiment design. A checklist was used because of the number of experiment steps and allowable training. Twice a subject omitted a step. These omissions might be attributed more properly to the checklist or the pacing of events in the sequence. The checklist was constructed to give a logical progression of events but some did not appear as realistic as desired. One uncomfortable action for the subjects required putting the Nose Position up when the vertical velocity read 1000 feet per minute (FPM). One subject said he always wanted to do something else at altitude 1700 feet, rather than pull power back to 100%.

The proximity of one control to another was a significant factor, especially with the gear and throttle levers. It was intended to have the subject seated with his eyes 25-28 inches from the panel, horizontally in line with the top row of indicators. This arrangement located the edge of the throttle 12 inches from the gear lever at the closest position. Spacing between the wall and the chair in the stall in which the subject worked was limited and he consequently tended to move forward to a position 6 inches closer. This reduced the eye-to-panel distance and throttle-gear separation. This gear-throttle proximity error seemed a more important factor than their dimensions. This proximity error showed up for all controls. The flap and wing sweep were placed on opposite sides of the panel to minimize errors due to their similarity of shape and movement but this also was significant. Several times an improper control movement at one point caused subject confusion with possible response and actuation errors when the next use of that control was required.

Recording and Observer Errors

Also present were equipment and observer errors. The observer monitored equipment and watched subjects for over four hours every day, trying to record and interpret their errors, while also considering equipment operation. He also reset and tested the equipment and recorded its operation. No doubt fatigue played a role, especially later in the day. To complete runs as fast as possible, the subjects were started on succeeding runs as soon as the observer could get back to his seat. There were slight observer distractions as the runs started and these and the time delay for close concentration might have caused him to miss errors early in the sequence. He also might have missed indicators of proper control movement. These were as clicks into detents or the absence of clicks as controls were actuated properly. All these little possibilities became signi when unexpected Esterline-Angus recording errors and its reduced reliability appeared.

On the last six runs of the testing, when the gear was to be lowered at a 195 knot airspeed, the recorder showed an error. It indicated that the gear was taken out of the up position but never went to the down position. The subject was not rushed on these particular runs, in a situation when he might have slapped at the control and would not have completely activated the control. The observer was sure that the subject had completely moved the gear lever in most of these cases and was not developing an error habit. Also the Esterline-Angus several other times exhibited what was determined to be group erroneous signals. For five, almost consecutive runs, the recorder showed no blip at Wing Position 60° when required, thus indicating a position between the 40° and 60° detents. This should have meant that the subject left the selector at 50°. On the next step when the subject brought the control to 20°, the recorder showed a blip at 60°, as though the control had gone through that position. Since 60° was a limit position and the subject would not go through it going to 20°, for this series of runs it was judged there was no subject error. Efforts to duplicate this situation and Esterline-Angus error indications were unsuccessful.

The tabulation of errors is shown in Table VII. It is broken down by day for each panel and subject. Each block of the [illegible] section shows the actuation plus response error totals for each panel, subject, day, and test. Table VIII gives the corresponding number of runs made for each subject and day. Subject tardiness, equipment problems and the 12 training runs given the first day prevented an equal distribution of runs the first week and any comparison of daily errors should consider this.

Subjects 2 and 3 trained on Panel 1. For the first week subjects 3 and 4 ran Panel 1. They rotated panels the second week. There were 12 training runs the first test day on the panels on which the subjects were to begin the test. For subjects 2 and 4, these 12 runs were their only runs on the particular test panel, before the test began. Subjects 1 and 3 got to train and practice on the panels they began the test.

The results did show fewer errors on Panel 1, substantiating the general design preference, although this was hardly adequate validation

Table VII

Test Errors

	Day	1	2	3	4	5	6	Totals
Panel	1	2+1	0	1+3	2+6	0+6	0+9	5+25
	2	0+8	4+12	6+10	2+0	2+1	0+2	14+33
SUBJECT	1	0+5	2+3	4+6	1+5	0+4	0+7	7+30
	2	0+3	2+9	2+4	1+1	0+2	0+2	5+21
	3	2+0	0	1+2	2+0	1+1	0+2	6+5
	4	0+1	0	0+1	0	1+0	0	1+2

*First number is Actuation Error
Second number is Response Error
2+1 means two Actuation Errors
and one Response Error

Table VIII

Test Runs

	Day	1	2	3	4	5	6	Totals
Panel	1	25	32	33	30	30	30	180
	2	18	33	39	30	30	30	180
SUBJECT	1	9	16	20	15	15	15	90
	2	9	17	19	15	15	15	90
	3	10	17	18	15	15	15	90
	4	15	15	15	15	15	15	90
Runs Totals		43	65	72	60	60	60	360
		+12 Training						

Total errors did decrease the second week and observations of the subjects and interviews with them later confirmed that learning was still taking place. Unexpectedly,the best performer had to shift panels for testing and the worst performer remained on the same panel he had trained.

Effect of Non-Subject Errors

Unfortunately malfunctions of control, display and recording equipment were numerous enough to seriously degrade test results if there was not considerable redundancy in error observation. This probability led to the early decision to observe every run, manually record errors, spot-check and monitor equipment, and carefully interpret Esterline recorder readings. This error analysis resulted in an error tree (Figure 9, for Panel 1).

To be counted as an error, a correct action had to be incorrectly recorded, interpreted, and observed; or, an error had to be correctly recorded, interpreted, and observed. Of course there was a great deal of interplay, especially between interpretation and observer detection but simply, line RsQrQiQo represented incorrectly determined errors, line QsRrRiRo represented properly determined errors. Analysis of the recorder before and during the tests indicated it had an accuracy of 0.999 (20 errors in more than 18,000 movements). Psychology literature continually emphasized observer accuracy of 0.85 (although I dispute this low figure) and events during use of the Esterline-Angus pointed to an interpretation accuracy of 0.95. Using these numbers and analysis,

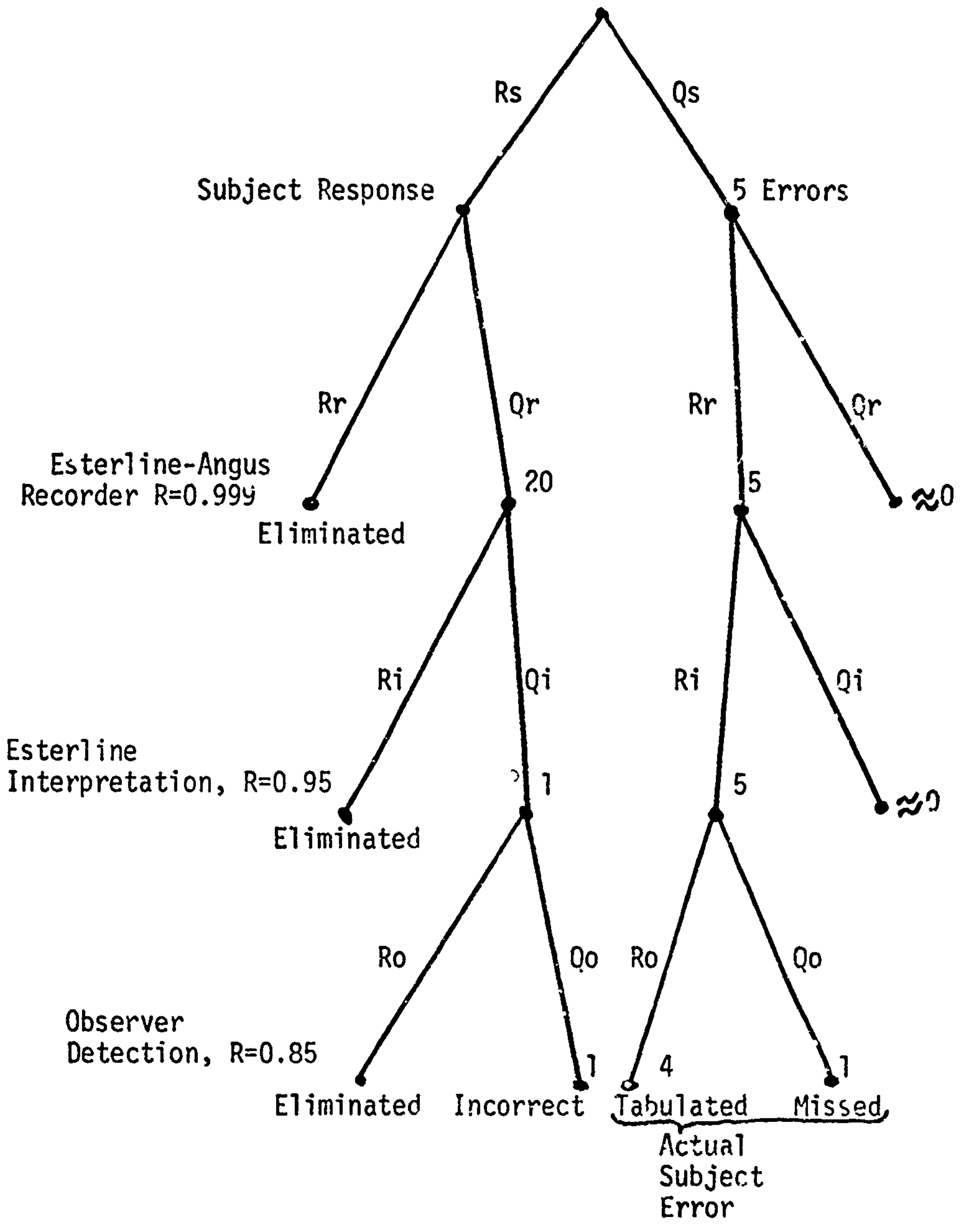

Fig. 9
Error Analysis Tree

the 20 indicated errors on the recorder were reduced to one actual recorder error which matched the one error missed by all the redundancy. This is approximate logic, used only to verify the magnitude of error determination, not substantiate exact numbers.

Panel Analysis

Table IX shows a conversion of reliabilities (from the Data Store Index) to errors for 10,000 uses. For each step of the checklist, the indicator and control pair is listed plus the errors for 10,000 uses and a resultant reliability for the pair. This reliability includes an identification-discrimination effect which is approximately two errors per 10,000 uses. Interestingly enough, the product of these three high reliability numbers is closely related to the sum of errors per 10,000 uses. The product is almost equal to the ratio of 10,000 minus the sum, over 10,000.

As the AIR Data Store indicates, most errors could be expected from the gear and throttle levers; the experimental results agreed. If the data for a lever (as it does for some components) contained a parameter for proximity and/or similarity of controls it would be possible to evaluate this effect.

According to the Data Store, the most numerous display errors could be attributed to the semi-circular scale, vertical velocity. The qualitative manner in which this was used (asking the subject to read whole 1000's of feet within ±200 feet) seemed to reduce this error.

Table IX

Panel Analysis - AIR Data

		Panel 1			Panel 2		
	Indicator-Control Pair	Errors		Reliability	Errors		Reliability
1	Light & Brake Button	9+8*	=	.9981	13+10	=	.9975
2	Airspeed & Throttle Lever	82+14	=	.9902	82+20	=	.9896
3	Airspeed & Nose Position	15+14	=	.9969	17+20	=	.9961
4	Airspeed & Throttle Lever	82+14	=	.9902	82+20	=	.9896
5	Vertical Velocity & Nose Position	15+149	=	.9834	17+152	=	.9829
6	Altitude & Gear Lever	174+58	=	.9766	179+86	=	.9734
7	Altitude & Brake Button	9+58	=	.9931	13+86	=	.9899
8	Vertical Velocity & Flap Control	21+145	=	.9828	44+154	=	.9802
9	Airspeed & Flap Control	21+13	=	.9964	44+20	=	.9936
10	Altitude & Throttle Lever	82+58	=	.9859	82+86	=	.9831
11	Airspeed & Wing Sweep	14+14	=	.9970	19+20	=	.9959
12	Altitude & Wing Sweep	14+58	=	.9926	19+86	=	.9893
13	Altitude & Nose Position	15+58	=	.9925	17+86	=	.9895
14	Vertical Velocity & Throttle Lever	82+149	=	.9768	82+152	=	.9765
15	Airspeed & Gear Lever	174+14	=	.9810	179+20	=	.9799
16	Altitude & Flap Control	21+58	=	.9919	44+86	=	.9866
17	Vertical Velocity & Wing Sweep	14+149	=	.9835	19+152	=	.9827
	Panel Reliability			.8251			.7970

*The numbers represent the expected errors for 10,000 uses for each component. Hence, 9 errors could be expected using the light, 8 for the brake button and 2 for discrimination, yielding a combined reliability of 0.9981.

A table of actuation error rates for the system components is shown. Components are listed in the center and Data Store prediction and experimental results for actuation errors are listed. All actuation errors with Panel 1 were with the throttle. For Panel 2, errors were made with all the controls, except the brake button. Since the air-speed was a component of throttle, it was not evaluated per se. Probably a more accurate analysis would give more weight to response errors and consequently a closer approximation to the Data Store values.

Table X

Comparison of Data Store and System Component Reliability

Panel 1		Component	Panel 2	
Data Store	Experiment		Data Store	Experiment
.9986	1.0000	Counter	.9980	1.0000
.9992	1.0000	Light	.9990	1.0000
.9942	1.0000	Linear Scale	.9914	1.0000
.9851	1.0000	Semi-circular	.9848	1.0000
.9986	1.0000	Knob	.9981	.9926
.9918	.9907	Throttle	.9918	.9907
.9826	1.0000	Gear	.9821	.9926
.9991	1.0000	Brake Button	.9987	1.0000
.9979	1.0000	Rotary Selector	.9956	.9975
.9985	1.0000	Toggle Switch	.9983	.9926

Subject Debriefing

The subjects were questioned after the experiment. They agreed that the throttle and gear proximity and wing position and flap control similarity were prime error effectors. The altimeter was the most difficult to read yet its indication jumps drew their attention. They felt the training was adequate.

When asked about the specific purpose of the panel, most felt it was to test the equipment, panel design or readability. One man gussed that the purpose was to determine subject response to different controls, timing, and errors.

VI. CONCLUSION

A system was designed, built and operated to validate human reliability data. A great number of variables appeared in the design and operation of the equipment. These variables were eliminated, avoided, controlled or reduced to the point they had minimal effect on the evaluation of subject performance. Equipment operating instructions in Appendix B would maintain the best equipment performance obtained during the study. The experimental results would be imporved considerably in an area with more constant voltage and with the recommended equipment improvements.

The subject comments and their performance indicate that the pacing and timing evolved for the runs were good. Their overall performance improved only slightly during the testing and their comments indicate that the pre-test training was adequate

The redundancy used to determine actual errors proved to be the most valuable foresight. Further studies might film the subject from an angle which would allow subsequent recheck of his movements. This would eliminate observer error and allow for permanent records which could be analyzed in any desirable manner. This would be particularly fruitful for problems that occur after testing had begun and the procedure could not be altered.

The relative validity of the AIR Data Store Index and some of the instruments, indicators and combinations were confirmed for the two panels. The system could serve as a broad base for further research on the parameters of individual indicators and controls. Simple tasks could be performed by masking or removing many of the indicators or controls. This would allow a larger number of short runs for statistical analysis of individual units and combinations. Using the panels as a breadboard, variations in dimensions and instruments could be studies. Pacing could be varied and the reaction times correlated.

Population averages and variances of error could be obtained. With the data collected, different mathematical models could be derived to predict reliability. Basic human error rate data could be generated.

The variables of equipment operation could be carefully analyzed and the test equipment and results improved. The various error effects would be a fruitful study area to improve methods and validation. Particularly useful might be the response errors as defined and measured in this study.

Quantification of human reliability data is a young and fertile field. Hopefully, this study has added to the enrichment of that area.

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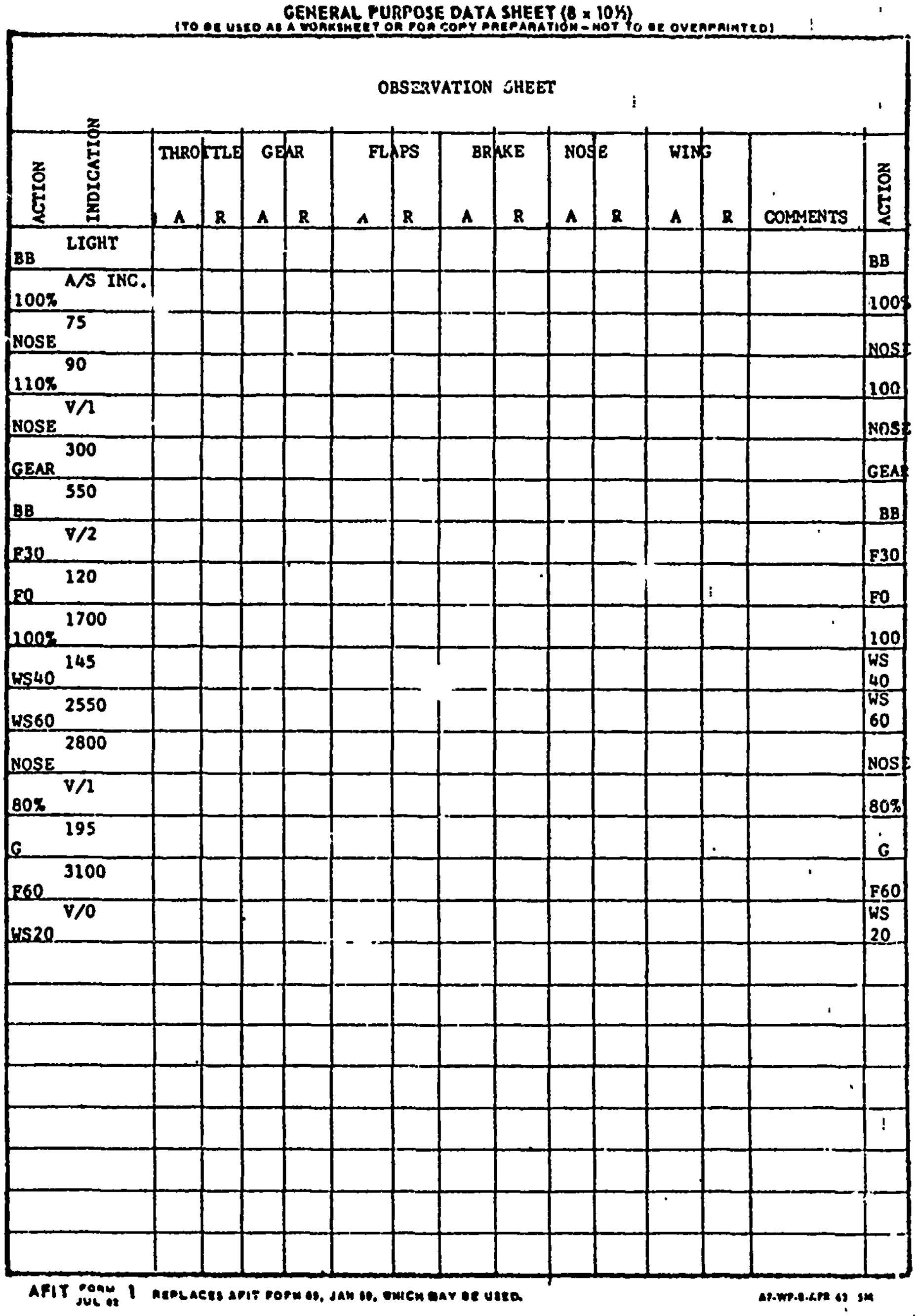
Appendix A

Observation Sheet



GENERAL PURPOSE DATA SHEET (8 x 10½)
(TO BE USED AS A WORKSHEET OR FOR COPY PREPARATION – NOT TO BE OVERPRINTED)

OBSERVATION SHEET

ACTION	INDICATION	THROTTLE A	THROTTLE R	GEAR A	GEAR R	FLAPS A	FLAPS R	BRAKE A	BRAKE R	NOSE A	NOSE R	WING A	WING R	COMMENTS	ACTION
BB	LIGHT														BB
100%	A/S INC.														100%
NOSE	75														NOSE
110%	90														100
NOSE	V/1														NOSE
GEAR	300														GEAR
BB	550														BB
F30	V/2														F30
F0	120														F0
100%	1700														100
WS40	145														WS 40
WS60	2550														WS 60
NOSE	2800														NOSE
80%	V/1														80%
G	195														G
F60	3100														F60
WS20	V/0														WS 20

AFIT FORM JUL 62 1 REPLACES AFIT FORM 60, JAN 59, WHICH MAY BE USED. AF-WP-B-APR 63 5M

Fig. 10
Observation Sheet

Appendix B

Instructions

You are being used in an experiment to measure human performance. Following a checklist, you will observe indicators and operate controls on two panels which resemble an airplace cockpit panel. These panels each have the same locations. The dimensions and other parameters of these indicators and controls vary for the panels.

You will be trained to operate a panel in a manner similar to an aircraft sequence from take-off to level-off. First you will be given a brief description of the equipment and the general relationships to actual aircraft equipment. The checklist will then be explained and you will operate the controls. The observer will make a slow demonstration run and you will perform the same run. After training and practice runs, you will perform experimantal runs.

This first period will last two hours (with a short break) and the succeeding five periods, one hour each. Questions will be answered anytime during your training. Please complete the questionnaire and arrange for the next appointment before proceeding to the experimental booth.

Fig. 11
Subject Instructions

Appendix C

General Information

NAME: ____________________________

AGE: ______________________________

PHONE NO: ________________________

BEST TIMES TO CALL: ________________

OTHER TIME DEFINITELY AVAILABLE: ________________________

WILL YOU NEED TRANSPORTATION? ____________________________

HAVE YOU PARTICIPATED IN ANY TRACKING STUDIES? __________

HOW MANY HOURS (APPROX.)? __________________________________

WHAT FLIGHT EXPERIENCE DO YOU HAVE? ________________________________

____

____

Fig. 12
Subject General Information

Appendix D

Typical Tape Sequence

Table XI
Sequence 24(S24)

Relay Action gives indicator being activated. A/S, Airspeed.S/0, S/1, S/2 are the airspeed motor speeds of 0, 2 KT/Sec, 4 KT/Sec. V/0, V/1, V/2 are vertical velocity indications of 0, 1000 FPM, 2000 FPM. A-1, A-2, . . . are altimeter actuations in increments of 280 ft. Checklist Action shows required action by operator.

Time (Sec)	Relay Action	A/S	Checklist Action
1	S/1		Brake Button
2	S/0	2	
3	S/2		100%
19	S/0	66	
20	S/2		Nose Up
24	S/0	82	
25	S/1		
27	S/0	86	
28	S/1		100%
32	S/0	94	
34	S/1		
37	S/0	100	
39	S/1		
42	S/0	106	
44	V/1		Nose Up
45	S/1		
47	S/0	110	
49	S/1		
50	S/0	112	
54	A-1		Gear Up
57	S/1		
58	S/0	114	
62	A-2		Brake Button
66	V/2		Flaps 30°
68	S/1		
71	A-3		Flaps 0
73	S/0	124	
76	A-4		100%
78	S/0	130	
79	S/1		
82	A-5		
83	S/0	138	
84	S/1		
85	V/3		
86	S/0	142	
88	A-6		100%
89	S/1		Wing Sweep 40°
91	S/0	146	
92	S/1		
93	A-7		
94	S/0	150	
96	S/1		
97	A-8		
98	S/0	154	
99	S/2		
103	S/0	170	
104	A-9		Wing Sweep 60°
105	S/1		
107	S/0	174	
109	S/2		
110	S/0	178	Nose Down
111	A-10		
112	S/2		
113	V/2		
115	S/0	190	
117	V/1		80%
118	S/1		
121	S/0	196	Gear Down
123	S/1		
128	S/0	206	
129	A-11		Flaps 30°
130	S/1		
131	S/0	208	
132	V/0		Wing Sweep 20°
133	S/1		
135	S/0	212	

Appendix E

Equipment Operating Instructions

To give the most useful information on operating the equipment and to help avoid or minimize several minor complications, the following checklist might be used until the observer is familiar with the equipment operation.

One hour before subject run time (warm-up)

1. Plug motor speed control and Timers 2 and 3 power into Sola transformer (most critical sources to control).
2. Plug in Esterline-Angus, Timer 1 (2 plugs), Tally reader, and Control Chassis into 115v a-c (5 connections to 115v).
3. Plug Sola transformer into 115v a-c. (Be sure Timer 1 is plugged in before motor control is on or airspeed will begin to run if Panel 1 is connected.) (1 connection to 115v a-c)
4. Plug 400 cycle connection into wall outlet.

Fifteen minutes before subject run time

5. Start 400 cycle generator

Restart Sequence

1. Hunter Timer #2 Interval, ON
2. Esterline-Angus Recorder, OFF
3. Airspeed, Reset
4. Timing, Set
5. Hunter #3, ON
6. Tape, Check
7. Airspeed, Run
8. Hunter #2, ON
9. Esterline-Angus, ON
10. Panel Airspeed Counter, Recheck

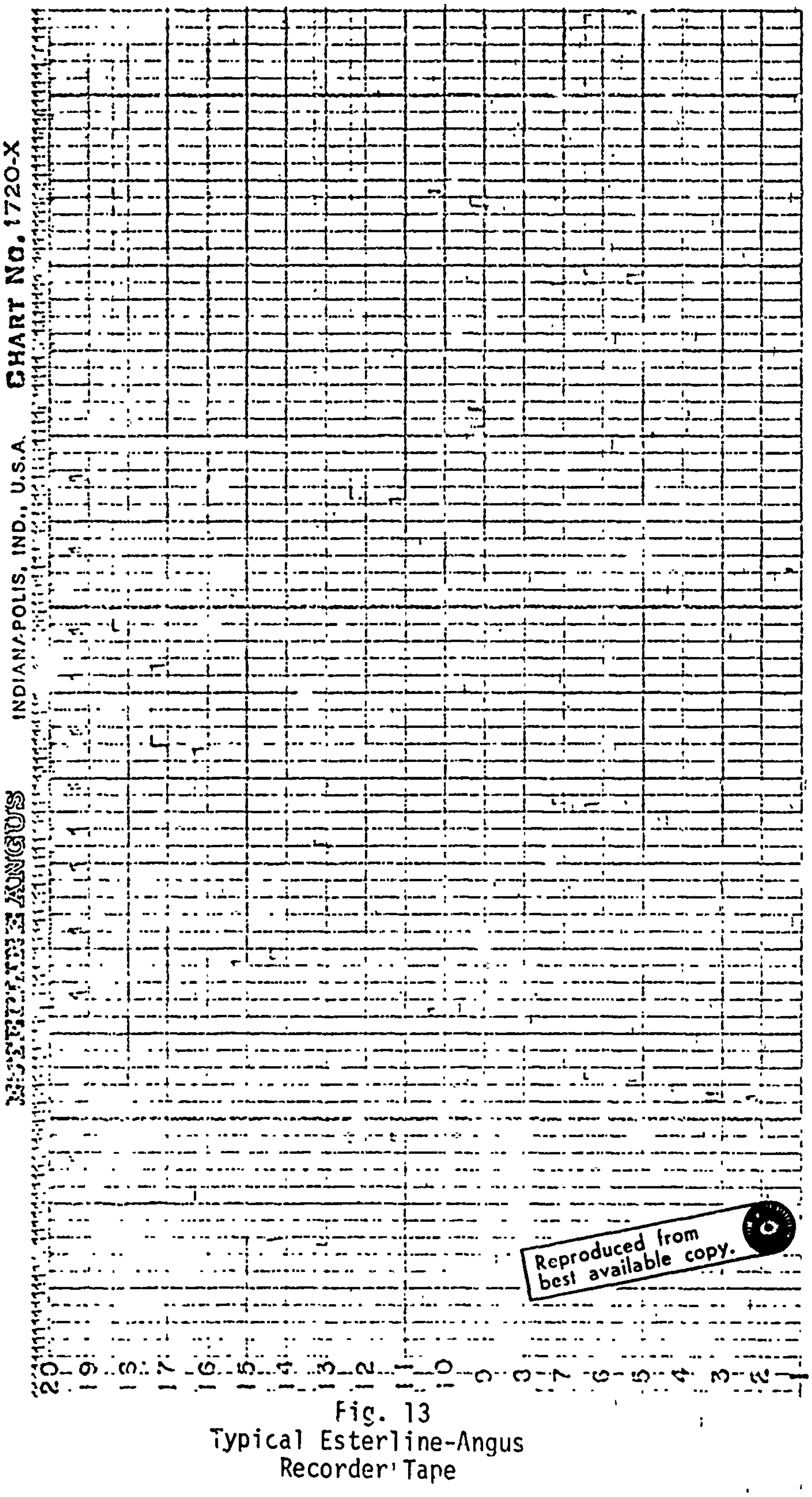
Appendix F

Recording Equipment

Table XII

Esterline-Angus Channel Functions

Channel	Function
1	Brake
2	Throttle Idle
3	~ 73%
4	~ 80%
5	90%
6	100%
7	110%
8	---
9	Nose Up
10	Nose Down
11	Gear Down
12	Gear Up
13	Wing Sweep 20°
14	Wing Sweep 40°
15	Wing Sweep 60°
16	Flaps 0°
17	Flaps 30°
18	Flaps 60°
19	Altitude Reference
20	Time Reference (Sec)



Reproduced from best available copy.

Fig. 13
Typical Esterline-Angus
Recorder Tape

Appendix G

Component Electrical Diagrams

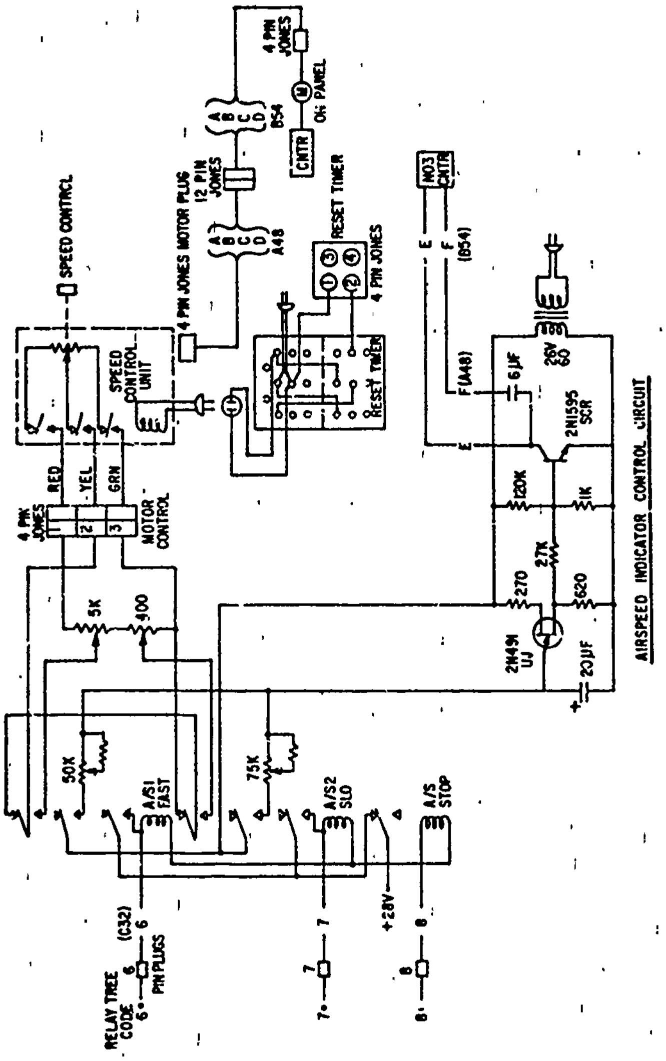


Fig. 14
Airspeed Indicator Circuit

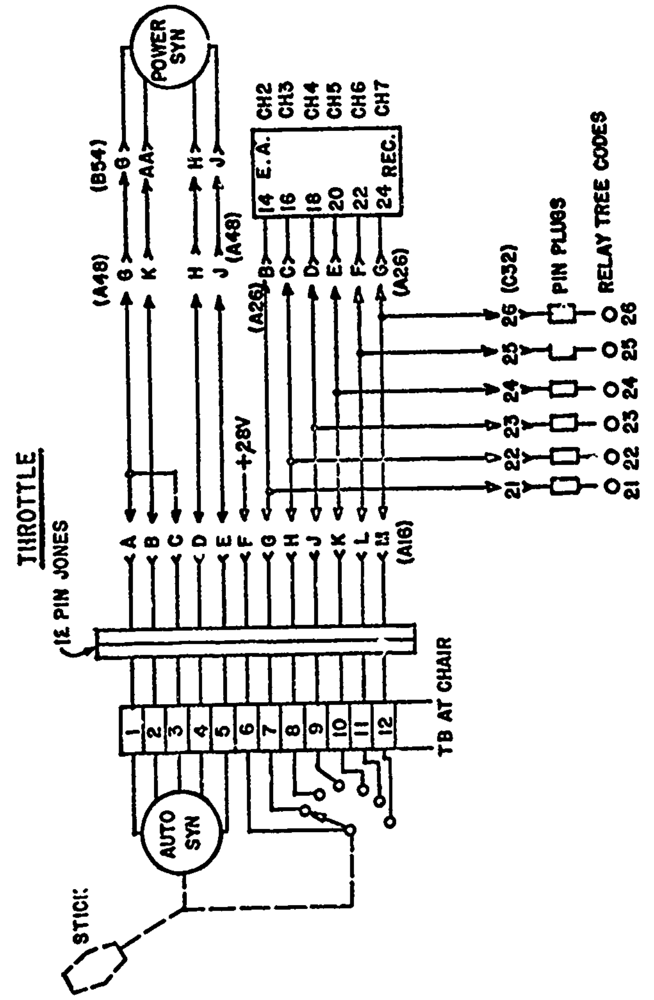


Fig. 15
Throttle Circuit

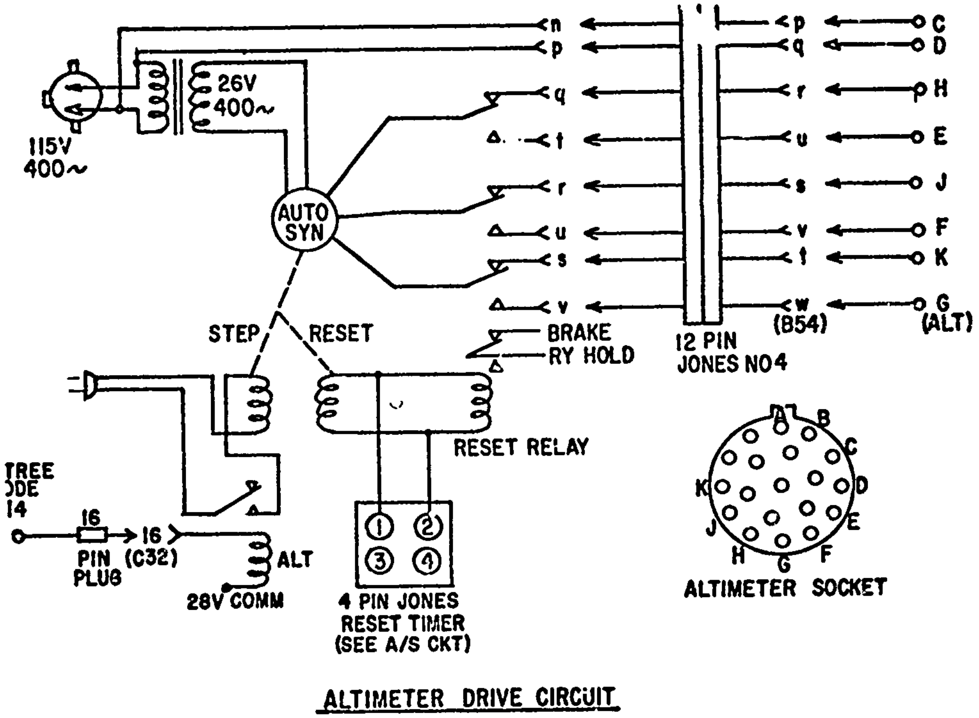


Fig. 16
Altimeter Dirve Circuit

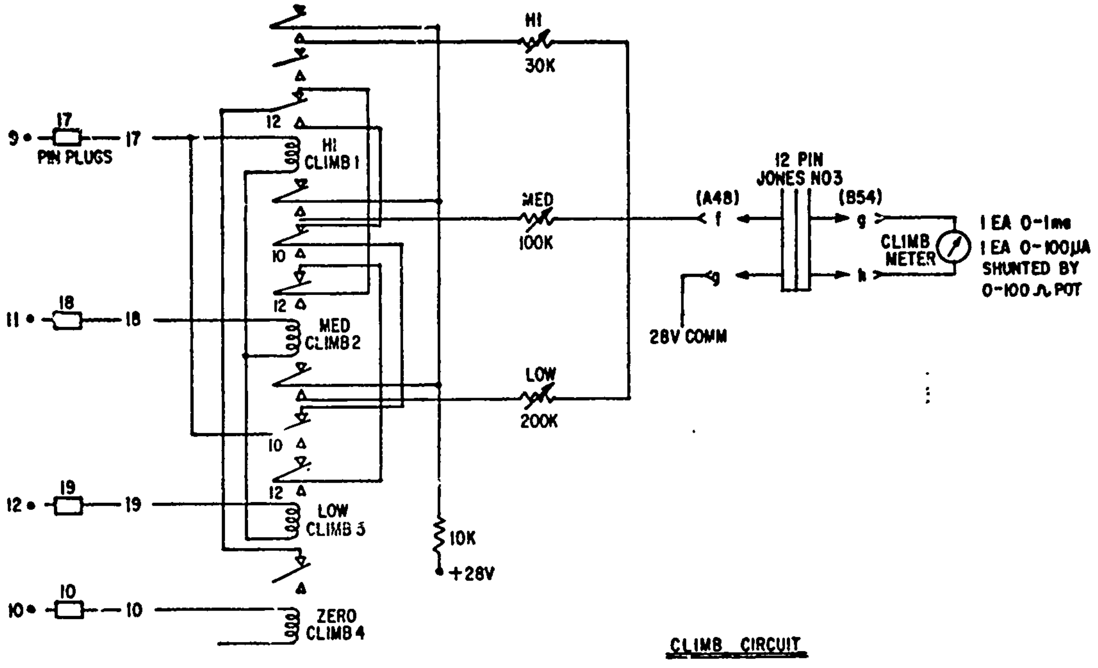


Fig. 17
Climb Circuit

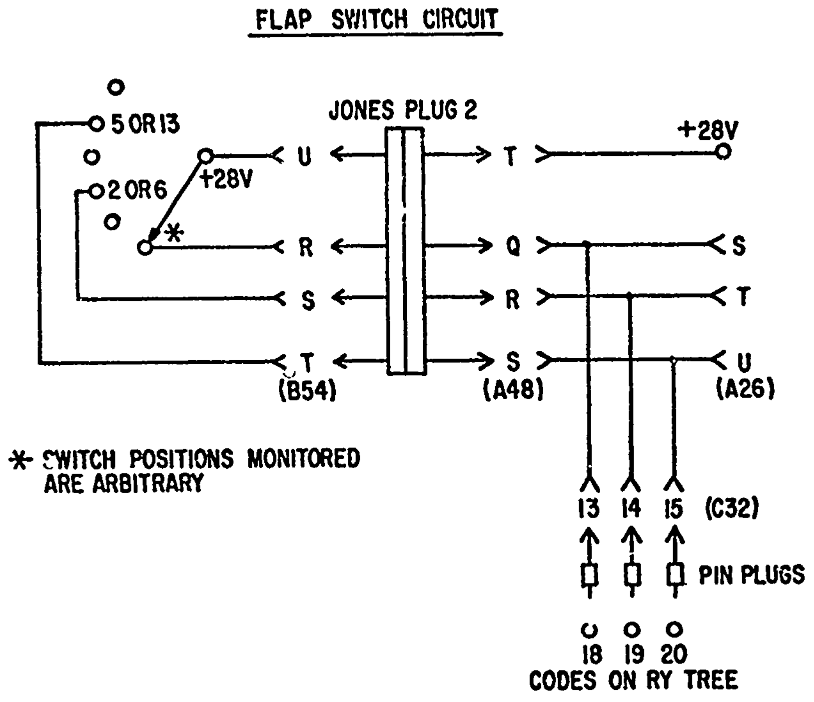


Fig. 18
Flap Switch Circuit

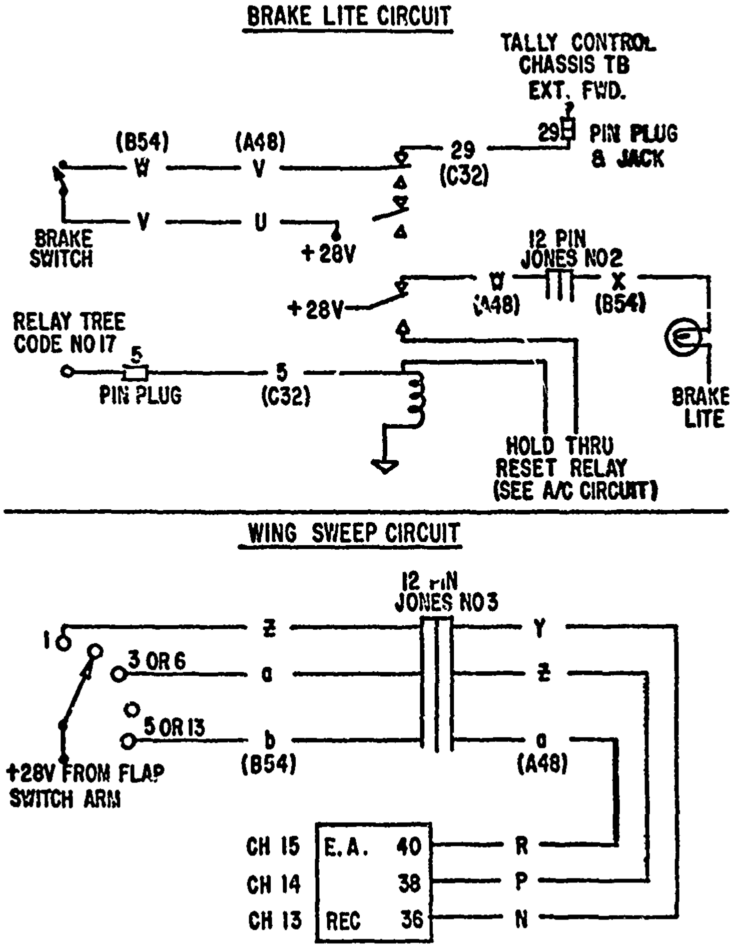


Fig. 19
Brake Lite and
Wing Sweep Circuits

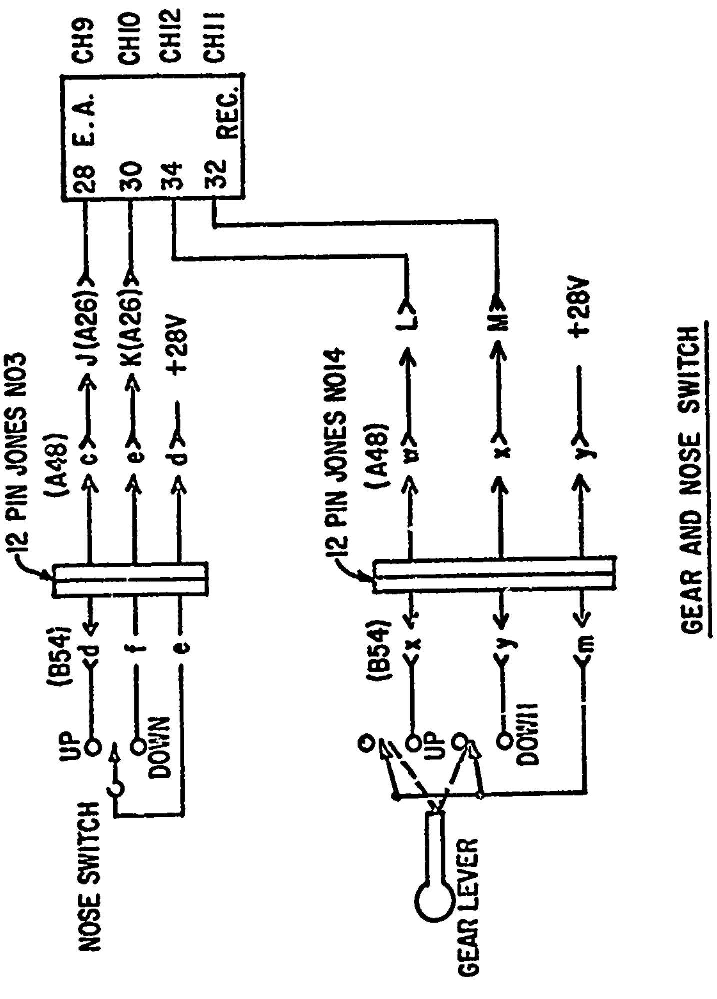


Fig. 20
Gear and Nose Switch

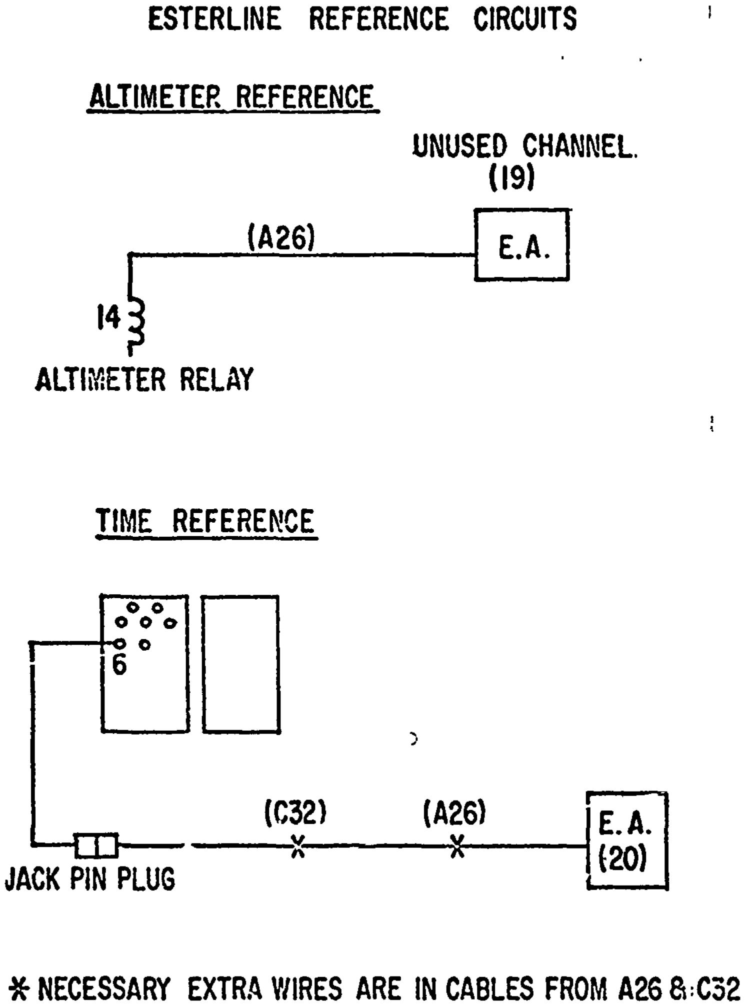


Fig. 21
Esterline Reference
Circuits

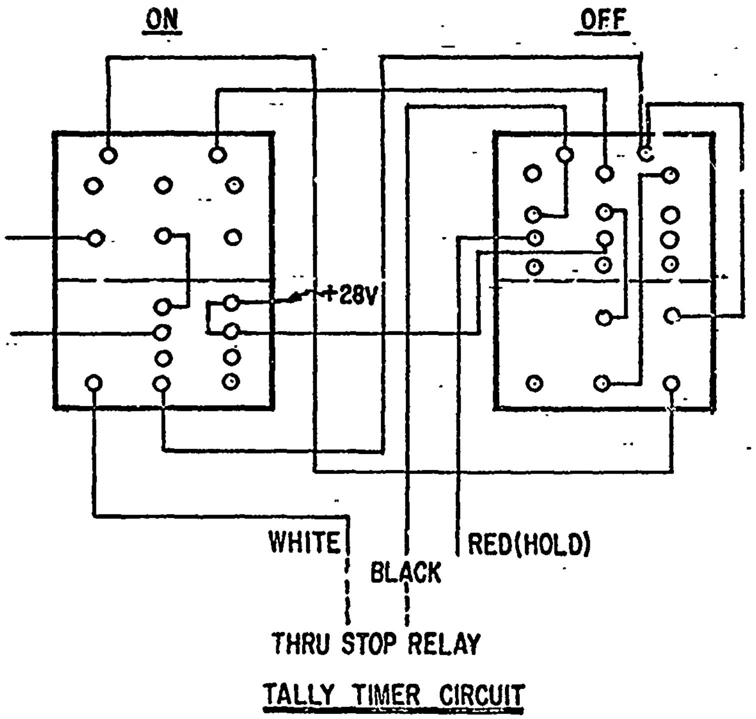


Fig. 22
Tally Timer Circuit

VITA

Edward Low was born on 11 July 1933 in Marysville, Ohio. He graduated from Marysville High School in 1951 and the United States Naval Academy in 1955. Commissioned in the USAF, he received his Pilot Wings in August 1956 and a Navigator-Bombardier rating in March 1957. He flew as a co-pilot and aircraft commander in the B-47 at Lockbourne Air Force Base, Ohio until his entry into the Air Force Institute of Technology in 1965.

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This thesis was typed by Mrs. Doris G. Brown