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PILOT SIMULATOR PERFORMANCE WITH STANDARD AND VERTICAL READING PRIMARY FLIGHT INSTRUMENTS

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FOREWORD

Work covered by this report was initiated under contract by the Aero Medical Laboratory, Engineering Psychology Branch, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio. The original research upon which this report is based was completed at the Instrumentation Research Section, Flight Control Laboratory, WADC, under Air Force Contract No. AF 33(616)-5472 to The Martin Company, entitled: "Human Engineering Support to the Air Force Flight Control and Flight Display Integration Program." Mr. J. H. Kearns (WCLCD) is Air Force Project Engineer. Captain R. H. DiVall (WCLDPPS) is Air Force Task Scientist. F. A. Muckler is Principal Investigator for The Martin Company.

The active support of Mr. R. R. Davis (WCLCDR, Chief, Instrumentation Research Section) is gratefully acknowledged. The scoring equipment was designed and built by Mr. R. D. Monroe (Link Aviation, Incorporated). 1/Lt. J. A. Bodine (WCLCDR) was responsible for the EA computer facility. Mr. Monroe was task equipment engineer and was responsible for the successful operation of the YF-102 flight simulator. Appreciation is particularly extended to these individuals.

ABSTRACT

Pilot performance in a flight simulator was objectively measured with 30 Air Force jet qualified pilots using standard and vertical reading primary flight instruments. During the completion of a simulated mission profile, five flight parameters were selectively sampled and scored: heading, altitude, mach, vertical rate, and airspeed.

Comparing the standard and vertical instruments, the following results were obtained:

1. Heading performance with the standard reading side instruments was superior to the vertical instruments.
2. Altitude performance was found to be significantly better with the standard reading instrument.
3. Mach performance was significantly better with the vertical reading instrument.
4. Vertical rate performance indicated no significant differences between standard and vertical reading instruments.
5. Airspeed performance indicated no significant difference between standard and vertical reading instruments.

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SUMMARY AND CONCLUSIONS

The past ten years have seen a radical shift in the basic principles of the display of flight information. For the first time, integrated flight instrument panels are being developed in terms of the whole panel instead of piecemeal by single instruments (see Wright, 1956). One of the immediate results of whole panel development has been the use of new instrument types. The most singular example of this has been the shift from circular scales to straight scales. However, these changes have been of such fundamental magnitude that concern has been expressed over the capability of the pilot to perform proficiently on the new display systems. Coincident with the development of the whole panel technique has come a new sophistication about the methodology of test and evaluation of pilot-instrument systems. Previous methods evaluated performance on just one type of or a single instrument, usually stressing "good" performance on that particular instrument not recognizing the possibility of performance degradation on other related flight parameters. In reality, the pilot's task involves a time-sampling process across several instruments displaying many different flight parameters, and the objective measurement of pilot performance should take this fact into account.

The primary purpose of this study is to demonstrate objective measurement of pilot simulator performance in the whole panel context where several flight parameters are selected and scored simultaneously. A second objective of this study is to objectively measure pilot simulator performance on several flight parameters while using either standard circular flight instruments or straight scale vertical reading instruments to fly a simulated complex flight profile.

A standardized flight profile was flown by 30 Air Force jet qualified pilots in a YF-102 Link flight simulator using two instrument panel configurations. One display system utilized the vertical reading scales of the USAF Phase II Integrated Instrument Panel, and the other used the circular scales of the standard reading flight instruments most common in aircraft today. Pilot performance on heading, altitude, mach, vertical rate, and airspeed control was measured by means of electronic scoring equipment which provided an error term that was reduced to a root-mean-square (RMS) score. The data were subjected to thorough statistical analysis.

Results indicated that (1) heading performance with the standard reading side instruments was superior to that with the vertical reading side instruments, (2) performance on the standard reading altimeter was superior to performance on the vertical reading altimeter, (3) mach performance was superior on the vertical reading mach indicator, and (4) vertical rate and airspeed performance showed no differences between instrument configurations. Separate analyses for those subjects with and without previous vertical instrument experience did not alter these findings.

In essence, performance on the vertical reading instruments for mach, vertical rate, and airspeed was found to be equivalent to or better than performance on the standard reading instruments for the same flight parameters. Consequently, it may be concluded that no degradation in performance would be expected on a shift from standard to vertical reading instruments for the flight parameters of mach, vertical rate, and airspeed with scale factors comparable to those used in this study. Such a shift would then allow for satisfactory addition of command information markers and reduce the scale length limitations existent on circular dials. Altimeter performance results suggest that further experimentation is required to produce a vertical moving-tape scale that will promote performance at least equivalent to that on the standard reading instrument. Suggested experimental scalar designs for non-linear scales, combination of non-linear scales, combination of linear and non-linear scales, and combination of linear scales are nearing the human factors evaluation stage. Because heading performance was measured on the same indicator with different side instruments, no direct performance comparison was possible. However, interpretation of the results indicates that prior experience with vertical reading instruments seems to allow more time for heading monitoring aside from primary pitch control under the conditions of this experiment.

The need for further human factors research in the area of flight information display techniques is most urgent. The early "fog-flying" days of Doolittle's time are gone; today's ultra-high performance aircraft require precision flight control over fantastically expanded flight envelopes, and there is every reason to assume that the aircraft and space vehicles of tomorrow may make even more extreme demands on the pilot. The development of optimum displays both from the standpoint of the man and the mechanism is imperative. It is probable that the success of such a development program will rest upon the use of sophisticated objective measuring techniques in every step of development from initial instrument design, through flight simulator research, and most important of all in inflight test and evaluation.

INTRODUCTION

Background of Instrument Development

Man has been engaged in the development of airborne equipment for the measurement and display of flight information since the very beginning of manned flight. Nicklas (1958) has noted that:

> "The history of aeronautical instruments began a few years after the invention of the free balloon in 1783. At this time, the mercurial barometer was adopted for measuring altitudes. In 1845, the aneroid barometer replaced the mercurial type because of its lighter weight and greater convenience, even though it was less accurate. Sometime later, the aneroid was scaled in feet of pressure altitude replacing the inches of mercury scale."

Since man was ascending towards the heavens, it would appear only natural that he would be interested in knowing how high he had risen. The horizontal distance traveled was also important, and as Nicklas (1958) points out, the Wright Brothers used a Richard anemometer to measure the length of their flights. In later years, the anemometer was used to determine airspeed. Initially, however, most pilots were dependent on the force of the wind in their faces to judge airspeed.

Once heavier-than-air flying machines could maintain flight for any period of time, pilots began seeking devices to forewarn them of impending malfunctions. An oil pressure gauge and a visible fuel line were the first to appear. As manned flight rose to greater heights, the interest in instrumentation turned to indicating straight and level flight, speed, and direction. Thus began man's search for better methods of displaying the necessary information to maintain flight first under contact conditions, then during the "fog-flying" days, and more recently under all-weather conditions.

Early attempts at providing information to the pilot were hampered by the inability of designers and builders to get the indicator in the cockpit. The instrumentation was placed at or near the source of the sensing mechanism. As better means of transmitting information to the cockpit were devised, the number of instruments on the "board" began to increase, usually with little or no thought as to how necessary or how often the new instruments were to be used.

Attempts at Instrument and Panel Integration

Nicklas (1958) points out that instrument integration, the technique of displaying several pieces of related flight information on one scale, was lacking in the early years of aviation. However, efforts toward panel integration were made. Doolittle made a notable contribution in this direction by suggesting that instruments should be arranged in line vertically and horizontally so that pointers across instruments would align or could be adjusted to align for any given flight condition. By so doing, the deviation of any pointer from this alignment would be immediately apparent to the pilot and corrective action could be taken. Doolittle's main objective was simplification, through which he sought to relieve the pilot of all unnecessary interpretation.

New Whole Panel Concepts.

Wright (1956) has very adequately summarized the status of flight instrumentation which has existed since shortly after the conclusion of World War II, with the following words:

> "When the situation is analyzed, it is seen that there ... (has been) ... actually no systematic method for design of the instrument panel. The need for various parameters to control flight is recognized and these parameters are measured and presented with some type of display. However, each of these instruments is a completely independent, unrelated entity, often conflicting with its neighbor on the panel. The panel as a whole presents the pilot with a lot of unrelated and abstract information. He must continually scan the ever changing values of each individual instrument and perform a continuous series of mental calculations to convert their readings into usable information which can be used for the control of the aircraft.
>
> "Instruments have been actually becoming a limiting factor in the capabilities of weapon systems. Specific features which have caused trouble are the excessive number of instruments, more than could actually be put on the panel, their small sizes, the clutter of the dials, and the cluttered appearance of the panel in general. Various attempts have been made to improve the situation, by combining one or more instruments into one case and reducing the size of the instruments. However, none of these have been really successful in alleviating the unsatisfactory conditions. The major difficulty has been

that the full potential has been realized in the individual development and use of instruments, and a new approach is required to provide really effective instrumentation for high performance aircraft."

The need for a new concept in instrumentation development was becoming increasingly more obvious. The "sacred six" or "eight" arrangement was difficult to maintain because of the large numbers of instruments "required" on the panels, the limited space available, and the lack of an overall concept for instrument panel arrangement and design. The instrument panel could no longer be treated with the attitude, "it's got to go on somewhere". Rather, it should be considered as a visual communications system, with information presented in a related, readable and interpretable form instead of as independent bits of abstract information. Improvements must be pursued on a "whole panel" basis instead of on an individual instrument basis.

Wright (1956) speaks of the "whole panel" concept with the following words:

"An instrument panel designed under the whole panel concept is one designed on the basis of the total visual communication requirement, wherein each individual element has been designed in terms of its environment and its contribution to the whole. The design of the display of each individual instrument on such a panel is made from considerations of the intelligence that it is to transmit along with that transmitted by all other instruments to be used with it, the display of this intelligence by these instruments, and the way these instruments are arranged in relation to each other. It is the philosphy of the design of the individual instruments so that a visual communications system will result."

Application of the Whole Panel Concept

The concrete application of the whole panel concept to the design of integrated instrument panels had led to a number of major changes in the basic principles of the display of primary flight information. One of the most apparent examples of this fact is the shift from circular dials to straight scales; the USAF Phase II Panel (Svimonoff, 1958) is a specific illustration of the extensive use of vertical straight scales in place of circular dials.

In actual fact, straight scales had been used early in the history of flight instrument development in at least one specific case. Nicklas (1958) reports that during the period of 1923-1924, the D. H. airplane P-302 appeared with an instrument board that included vertical scale instruments for pitch, airspeed, RPM, and engine gauges. The Pioneer Flight Indicator, which gave the pilot a more direct indication of pitch attitude, variation from being level in bank, and correct rudder-aileron application, represents one of the earlier instances of combining several instruments within a single case. In 1925, the Pioneer instrument board appeared with a vertical scale rate of climb instrument added to the previous array of vertical scale instruments. In general, from the midtwenties to the midthirties, a number of vertical scale instruments appeared. Then followed a reversion to the circular scales which lasted until the midfifties when the present return trend to the vertical scales was initiated.

However, a change in display design concept must assume that the pilot is able to use the new instrument technique more effectively than the previous method. To demonstrate that this is in fact the case, there are a number of evaluatior techniques possible. One line of evaluation is experimental investigation from the human factors point of view. This type of evaluation may be illustrated by examples of instrument display investigations and particularly the study of altimeter displays.

Instrument Display Investigations

Static Studies of Altimeter Displays

As Muckler (1959) points out, "The development of altimeter display techniques ... was not based, for the first thirty years at least, on experimental investigations of optimum display principles from the pilot's point of view. Like most cockpit instruments, the display techniques were usually selected on the basis of individual judgment and modified on the basis of field experience". It became evident by the late 1940's, that the display of altitude information was not optimum from the pilot's point of view and the need for investigation to provide improvements was increasingly obvious.

Grether (1947) was the first to investigate experimentally the presentation of altitude information. He compared a variety of altimeter configurations by a paper and pencil technique from which he recorded errors of interpretation as well as interpretation time. The displays included the conventional three-pointer altimeter, combinations of a counter and a pointer, a counter alone, and also two configurations of moving-tape vertical displays. After considering the various uses of altitude information, he recommended a combination of a sensitive pointer and counter as offering the most promise. The vertical displays compared quite favorably with the counter-pointer displays under his experimental conditions, and were much superior to the standard three-pointer altimeter.

The Simon studies (Simon, et.al., 1956; Simon and Roscoe, 1956) report several investigations of altitude information display techniques. These studies also used a paper and pencil technique in which the pilot subjects were required to make flight decisions on the basis of information that was presented on drawings of the various displays. In general, their findings indicated that performance was superior on the integrated vertical linear-scale display over several methods of circular display. No change in the results was recorded between two levels of pilot experience among the subject groups.

Use of Flight Simulators for Objective Measurement

Early investigations of information presentation to the pilot were limited to static legibility tests. Little had been done to compare pilot performance in the simulated inflight situation where the instruments are used as a continuous tracking display. Recently, however, Mengelkoch and Houston (1958a, 1958b, 1958c) have published three studies investigating pilot performance with various altimeter displays while flying a profile in a Link C-8 Instrument Trainer.

In the first study (1958a), twenty experienced instrument qualified pilots flew a series of maneuvers in the trainer using the standard three-pointer altimeter and an experimental vertical moving-tape linear scale altimeter. Performance on the three-pointer altimeter was found to be superior to performance on the moving-tape altimeter, although the magnitude of the performance differences was small. The authors considered the differences not to be operationally significant.

In the second study (1958b), 14 pilots from the group used in the first study were given additional practice on the vertical moving-tape altimeter. The results again indicated that performance on the three-pointer altimeter was superior to performance on the vertical moving-tape altimeter. Performance on both altimeters was increased, but the difference in performance between displays remained approximately the same. It was concluded that further additional practice would not serve to reduce the difference in performance, and that the effects of an expanded scale should be investigated.

The third study (1958c) was designed to determine the effects on performance of an expanded scale on the moving-tape display when compared to performance on the standard three-pointer altimeter. The scale was expanded from 1.5 inches per thousand feet (used in the first two studies) to 2.375 inches per thousand feet. Two groups of experienced instrument qualified pilots (10 from the original group and 12 with no previous experience on vertical reading instruments) flew the same simulated flight maneuvers used in the earlier studies on each altimeter display. The results showed that performance on the vertical reading moving-tape altimeter with a scale factor of 2.375" per 1000' was essentially equivalent to performance on the three-pointer altimeter. The need for further evaluation in a high performance jet simulator was expressed.

Muckler (1959) comments on the work of Mengelkoch and Houston, stating that "The results of this series of studies would not have been predicted on the basis of the static legibility investigations ... (previously mentioned). However, the final experiment ... (Mengelkoch and Houston, 1958c)... would seem to indicate that superiority of instrument type in the tracking situation is a matter of detailed scalar design and not of basic instrument type".

Objectives of the Present Study

Past experimental investigations have usually dealt with just one type of instrument -- measuring performance in some fashion on a single flight parameter. In reality, the pilot "flys" several instruments at one time. His task is complex, requiring the interpretation and integration of information from many sources. Consequently, pilot performance measurement should take into account the entire informational context and sample performance from the whole panel concept.

The present study is offered as an example of a methodology for accomplishing this basic need in present-day man-machine performance measurement and evaluation. It is not intended to replace the methods previously discussed, but is rather an extension in a more sophisticated manner to the whole panel context.

Specifically, the present study was designed to accomplish three objectives:

1. To measure pilot performance simultaneously on several flight parameters on a simulated flight task.

2. To compare pilot performance measures on two different display principles: Standard reading round dial displays and vertical reading moving-tape displays.

3. To provide a standardized technique for the evaluation of pilot performance under varying simulated flight conditions of instrumentation, dress, and environment.

EXPERIMENTAL METHOD

Apparatus

YF-102 Flight Simulator.

The YF-102 Link flight simulator, located in the Instrumentation Research Section, Flight Control Laboratory, Wright Air Development Center, Dayton, Ohio, was used as the experimental apparatus. This simulator is an electronic analog computer which was designed to solve the flight equations of the YF-102 aircraft. For purposes of this study, the flight equations were altered to produce a highly sensitive, moderately high performance flight simulator representative of no particular present day aircraft. The simulator was capable of speeds up to mach 1.2, altitudes up to 50,000 feet, and vertical speeds up to 40,000 feet per minute. Flight simulation is presented by continuously changing flight display indications in response to pilot control actions. The simulator does not have motion.

Instrument conditions were simulated by covering the canopy and windscreen with grey paper. The canopy was closed for each flight. The instrument panel was lighted by a fluorescent lamp located in the top of the canopy in such a manner so as to give good lighting over the entire panel and forward half of the cockpit. The cockpit was air conditioned for the subjects' comfort. An intercom system was used that provided clear communications between the experimenter and the subject.

A full set of repeater instruments was available to the experimenter for monitoring performance and to provide the proper cues to commence scoring at various places in the profile. In addition, a "freeze" or hold switch was available which made it possible to freeze the simulator in any flight condition.

Flight Instrumentation.

Two instrument configurations were used. One consisted essentially of vertical reading, moving-tape, primary flight instruments and the other of standard reading round primary flight instruments.

Vertical Reading Instruments. The vertical reading panel made use of the Air Force Phase II Integrated Instruments

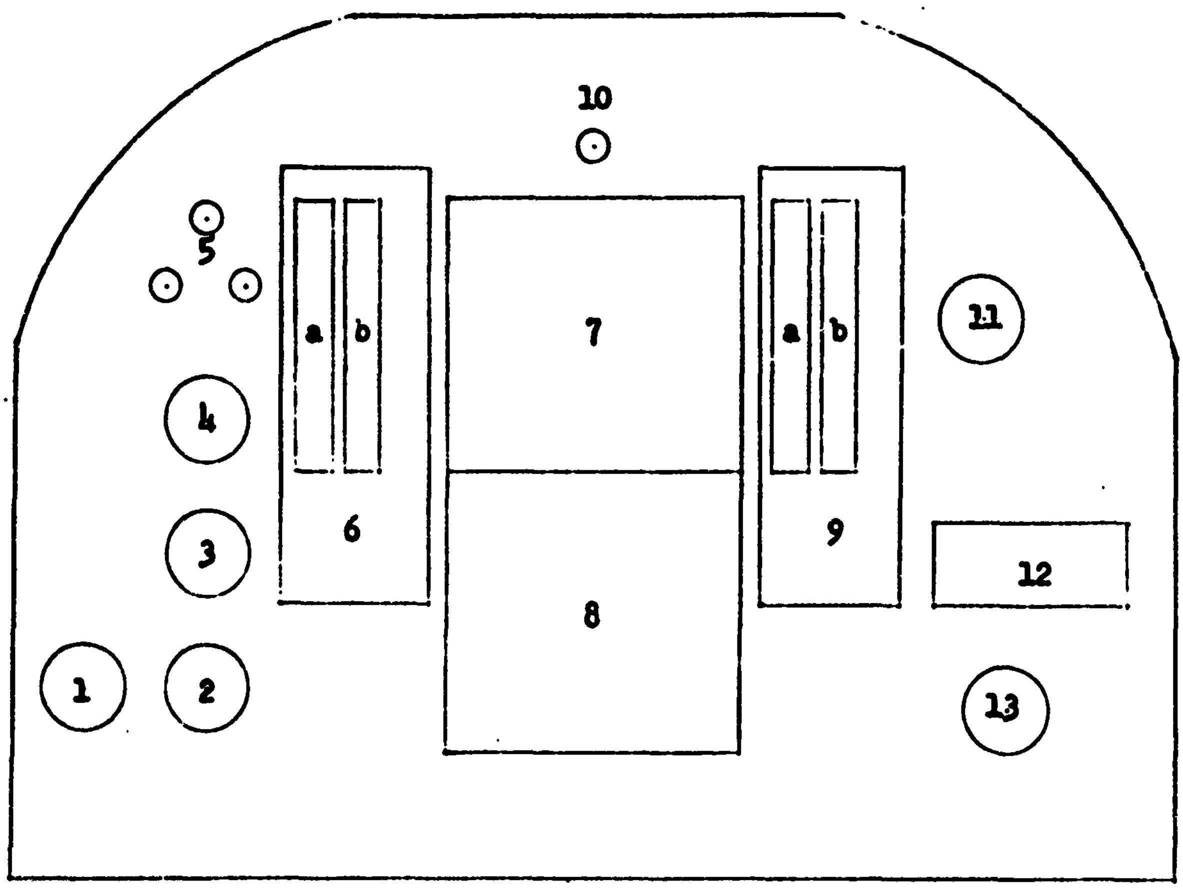
(Svimonoff, 1958, p.x) and is shown in Figure 1. However, only selected features of these instruments were utilized. The following modifications were made to produce the desired effect:

1. The Attitude Director Indicator was used to present only pitch and bank information. The glide slope displacement pointer, bank director needle, and pitch director needle were not operative. Essentially, it operated as a conventional attitude instrument with additional features such as a two-tone sphere with pitch degree and ground reference markings on a five inch display.

2. The Horizontal Situation Indicator was used to present only heading information. It is a five inch instrument which employs a moving card with a stationary index to display heading information. The bearing pointer, command heading, course arrow and deviation bar, to-from indicator, and mode windows were inoperative. The digital readouts for course and distance were masked off, and the subject was instructed not to operate the Course Select Knob or the Manual Select Knob for command heading.

3. The airspeed-mach indicator had the angle of attack tape and the digital readouts for command mach and airspeed masked off. The command markers for both mach and airspeed were slewed to the extreme top of the instrument and remained there during the entire flight. Subjects were instructed not to operate the command marker slewing switches. The airspeed moving tape was numbered at 50 knot intervals with markings for every 10 knots of airspeed. The mach moving tape was numbered at every .1 mach with markings for every .01 mach.

4. The altitude-rate of climb indicator had the vertical planning scale, target altitude digital readout, and the command altitude digital readout masked off. The altitude command marker was slewed to the extreme bottom of the scale and remained there for the entire flight. Barometric setting was placed at 29.92. Subjects were instructed not to operate the command marker slewing switch or the barometric set knob. The altimeter moving tape was numbered at every 1000 foot level with small markings for every 100 feet and a somewhat larger marking for the 500 foot levels. The rate of climb presentation was not altered. This instrument is capable



Legend

1. Fuel flow gauge
2. Fuel quantity gauge
3. Tailpipe temperature gauge
4. Percent RPM gauge
5. Landing gear indicator
6. Vertical reading airspeed-mach indicator
    a. Mach scale
    b. Airspeed scale
7. Attitude Director Indicator
8. Horizontal Situation Indicator
9. Vertical reading altimeter-rate of climb indicator
    a. Rate of climb scale
    b. Altimeter scale
10. Station marker light
11. Turn and bank indicator
12. Penetration placard
13. Speed brake indicator

Figure 1. Modified Air Force Phase II Integrated Instrument Panel Installed in YF-102 Simulator.

of displaying vertical rate changes up to 40,000 feet per minute, and is near instantaneous in its presentation.

Standard Reading Instruments. The standard reading panel, shown in Figure 2, utilized the Attitude Director Indicator and the Horizontal Situation Indicator previously mentioned.

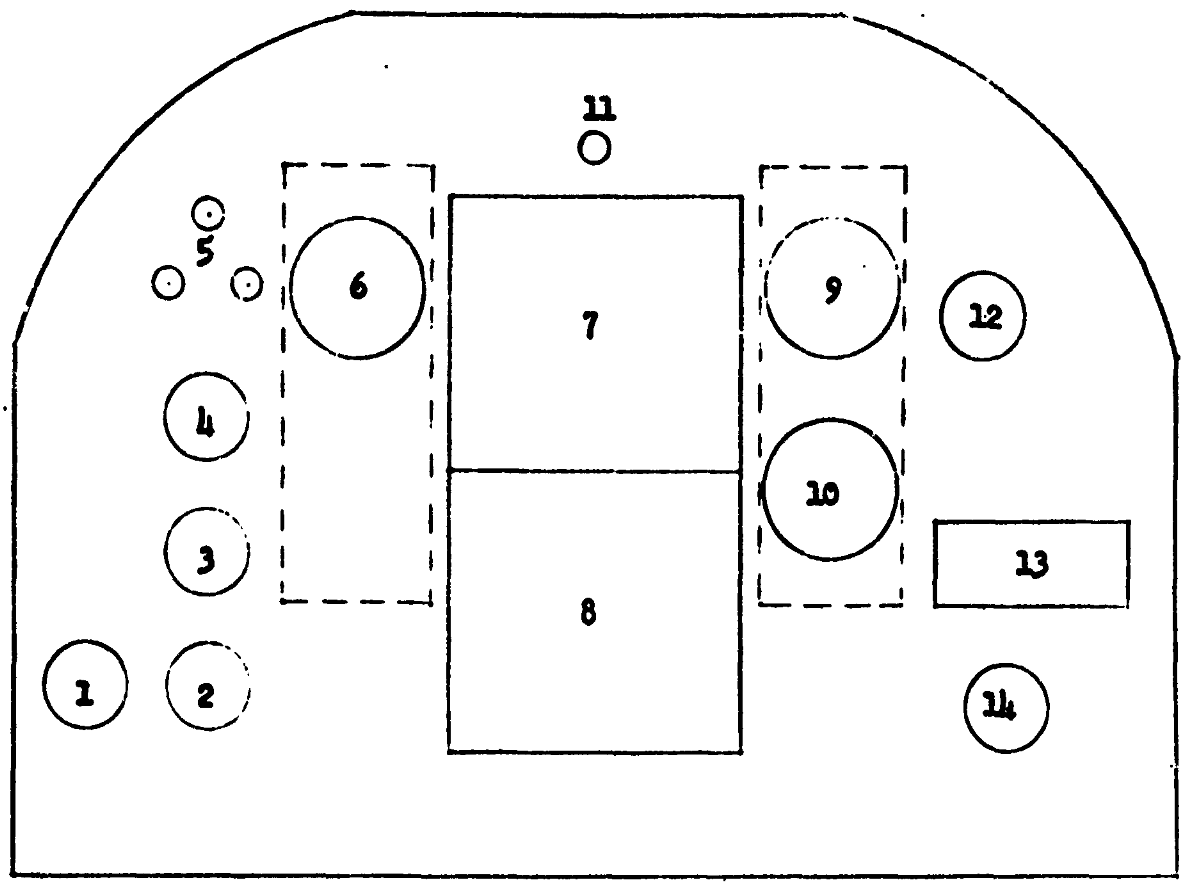
The ME-1 round type airspeed-mach indicator was used in place of the vertical reading instrument. This instrument uses a single moving pointer against a stationary airspeed scale and a rotating mach scale. The set index mark was placed at the low end of the scale and the subjects were instructed not to adjust the knob. The instrument was mounted in a face plate fitted to cover the hole used to mount the vertical reading airspeed-mach instrument.

The vertical reading altimeter-rate of climb instrument was replaced by separate round type altitude and rate of climb instruments. A three-pointer altimeter (MA-1) without low altitude cross hatch warning was utilized. Barometric setting was set at 29.92 and subjects were instructed not to adjust the setting knob. The conventional 6,000 feet-per-minute rate of climb instrument (MS 23049-1) was used. This instrument has a 7-12 second lag in its presentation. Both instruments were mounted in a face plate fitted to cover the hole used to mount the vertical reading altimeter-rate of climb instrument.

Additional Common Instrumentation. Several instruments and indicators were common to both panel configurations. They were the percent RPM gauge, speed brake indicator, landing gear indicator, and station marker light (used to show passage of the high and low stations). A turn and bank indicator, tail pipe temperature gauge, and fuel flow gauge were also visible, but monitoring of these instruments was not required during any part of the flight profile.

Subjects

Because of the nature of the experimental task and the variables being investigated, it was determined that the subject population should be highly trained experienced pilots qualified in jet aircraft. Accordingly, the following minimum requirements were set up: (1) Air Force jet qualified pilot, (2) must have had at least 50 hours in the last six months, and



Legend

1. Fuel flow gauge
2. Fuel quantity gauge
3. Tailpipe temperature gauge
4. Percent RPM gauge
5. Landing gear indicator
6. ME-1 airspeed-mach indicator
7. Attitude Director Indicator
8. Horizontal Situation Indicator
9. MA-1 standard reading altimeter
10. MS 28049-1 standard rate of climb indicator
11. Station marker light
12. Turn and bank indicator
13. Penetration placard
14. Speed brake indicator

Figure 2. Modified Standard Reading Instrument Panel Installed in YF-102 Simulator.

TABLE 1

SUBJECT EXPERIENCE DATA

Subj. No.	Rank	Age	Inst. Card	Vert. Sim.	Inst. Air	Exp. Total	Jet Sim. Hours	Instrument Time	Jet Hours	Last 6 Months	Total Hours
1	Capt	33	Green		4	4	40	450	2300	150	3100
2	Capt	32	Green			-	30	500	2500	200	10100
3	Capt	32	White			-	16	200	450	60	1800
4	Capt	34	Green	6	50	56	60	200	1900	250	3300
5	1/Lt	27	White			-	50	200	1800	150	2400
6	Major	43	White			-	5	500	1100	50	5200
7	Capt	33	White			-	50	300	1400	50	1900
8	Major	37	Green			-	30	500	200	70	4350
9	Capt	33	Green		5	5	100	500	3400	175	6500
10	Major	34	Green		15	15	60	550	2100	140	4000
11	Major	37	Green		35	35	50	400	1800	110	3100
12	Capt	33	Green		8	8	15	250	2000	150	3100
13	Capt	30	Green			-	65	300	2500	120	2900
14	Capt	31	White			-	48	125	1200	60	1730
15	Major	34	Green			-	100	350	1800	100	3300
16	Major	35	Green			-	20	350	2600	100	3500
17	Major	34	Green			-	50	300	2500	150	4300
18	Col	39	Green			-	20	300	800	60	3700
19	Capt	30	Green		4	4	45	200	2200	150	2500
20	Major	37	Green	1		1	1	875	80	200	8500
21	Capt	39	Green			-	50	350	800	60	3900
22	Col	39	Green			-	25	600	600	50	5700
23	Major	40	Green	2		2	10	300	200	60	11000
24	1/Lt	29	Green			-	130	250	1800	100	2100
25	Major	36	Green		5	5	50	450	2000	100	3500
26	Capt	35	Green		2	2	56	305	600	50	2500
27	Capt	28	White	1		1	200	400	1100	100	1750
28	Capt	34	Green		2	2	35	250	1850	120	4175
29	Capt	29	Green			-	30	300	2500	200	3500
30	Major	33	Green			-	25	550	500	200	3700
Mean		34.0		0.8	10.0	10.8	48.9	370.2	1552.7	117.8	4003.7

(3) must be instrument qualified. Thirty Air Force pilots stationed at Wright-Patterson Air Force Base were used as subjects. All participation was voluntary. Subjects were given Form 5 credit for two hours of jet simulator time. The flight qualifications of the subjects are shown in Table 1.

Sixteen of the subjects were attached to Fighter Branch, Directorate of Flight and All-Weather Test, Wright Air Development Center and the remaining fourteen were recruited from other sources on the base. As Table 1 shows, the subjects varied in rank from 1/Lt. to Colonel, had a mean age of 34 years, all had instrument cards, 13 had previous vertical instrument experience ranging from 1 to 56 hours with a mean of 10.8 hours, had a mean of 48.9 hours of jet simulator time, had a mean of 370.2 hours of instrument time, had a mean of 1552.7 hours of jet time, had a mean of 117.8 hours in the last six months, and had a mean of 4003.7 hours total time.

Eight pre-experimental subjects were used to evaluate the flight task and the scoring system, and to provide practice for the experimenter.

Subject's Task

A flight task was designed to encompass many of the common flight procedures that are typical of military jet aircraft flights. The flight task, shown in Figure 3, involves the following maneuvers: Take-off and climb to 40,000 feet at mach .85 (15,000-20,000 fpm), level off at 40,000 feet, 180 degree level turn to the left, 180 degree level turn to the right, straight and level flight at 40,000 feet, fast rate letdown holding mach 1.0 (15,000-20,000 fpm), level-off at 20,000 feet, jet penetration maintaining 4000 fpm vertical rate, level-off at 2300 feet, and a low approach at 1300 feet. Instructions were given before each maneuver or groups of maneuvers over the intercom system. All instructions were read verbatim from typewritten cards. These instructions are reproduced in Appendix A.

Subjects were not briefed on the flight task and no indications of performance level were given. It took approximately 35 minutes to complete the flight task.

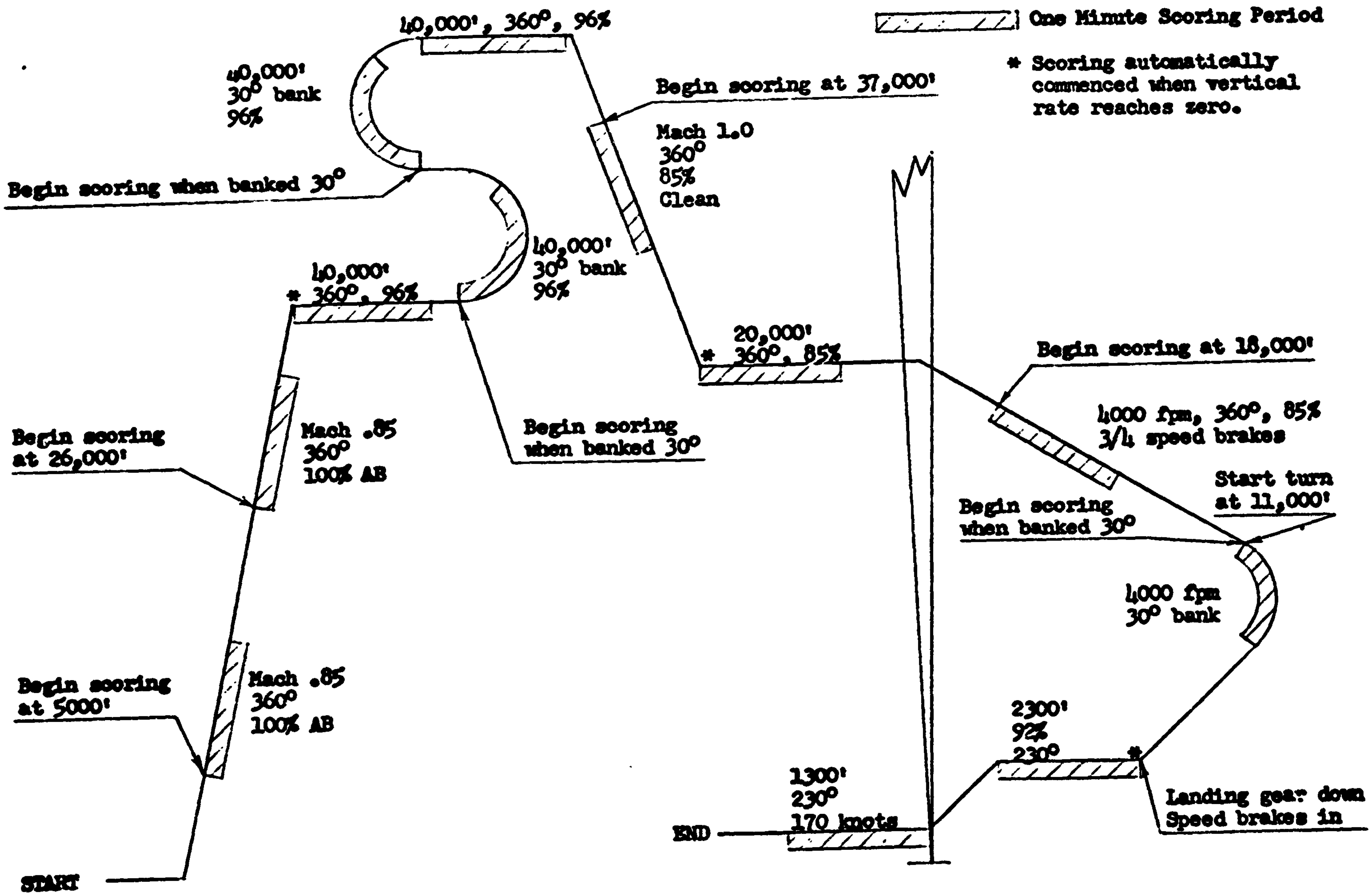


Figure 3. FLIGHT TASK

Scoring Equipment

Since the YF-102 flight simulator is an electronic analog computer, it is possible to measure electrical potentials at various points in the system that would be directly proportional to the flight equation values of the different flight parameters. It is also possible to set up reference values in terms of electrical potentials that would correspond to a level of desired performance. The difference in the two potentials would then describe the error in performance for the selected flight parameter. Apparatus was installed to measure these errors for the flight parameters of heading, altitude, mach, vertical rate, and airspeed. The error voltage was squared and integrated with time for a period of one minute for each scoring period through the use of an EA computer. The resultant error term was read-out on a digital voltmeter on the experimenter's scoring panel, shown in Figure 4. Square root extraction then provided an error roct mean square (RMS) score.

Table 2 presents the selected parameters that were scored during each maneuver. As the table shows, a total of 22 data points were obtained for each flight. These error scores were recorded on a scoring sheet that was designed to assist the experimenter in proper scoring procedure and ease of measurement recording. It is reproduced in Appendix B. Every effort was made to insure consistently precise scoring procedures for each flight. A standardized procedure was established and followed explicitly. It is described in Appendix C.

Two modes of scoring were available. When the Master Scoring switch was placed in the "Man" setting, the scoring period began immediately upon depressing the "Start" button. With the Master Scoring switch in the "Auto" position, depression of the "Start" button armed the system to begin scoring when the rate of vertical movement reached exactly zero. This mode was used primarily to score level-offs. In both modes, the scoring period consisted of an automatically-timed one minute interval.

Equipment limitations made it necessary to limit the area about the index of desired performance (IDP) that could be scored. The size of the available area that was utilized was regulated by the results of pre-experimental testing. The following scoring limits were set up as being compatible with subject capabilities. Errors of performance larger than their respective

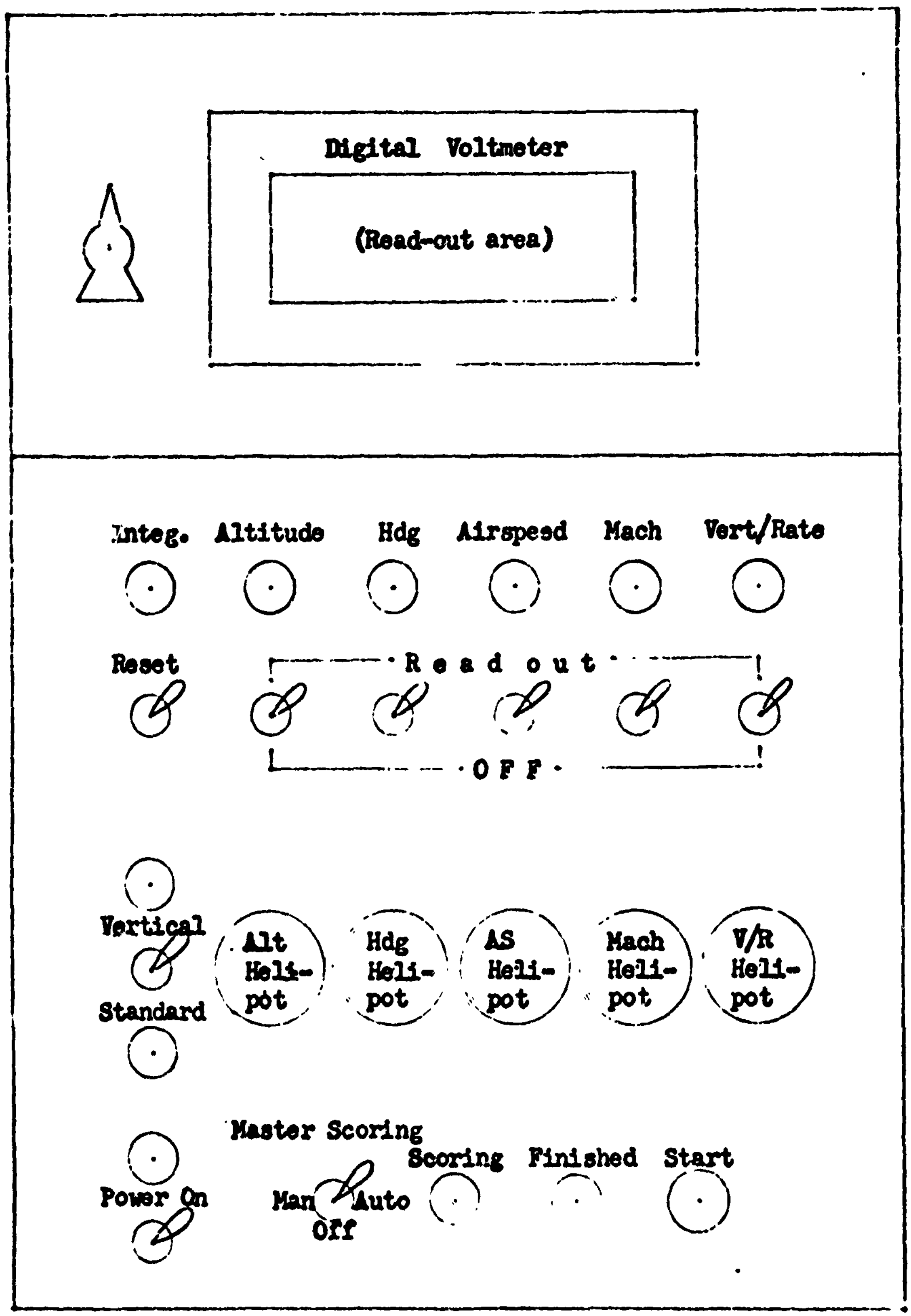


Figure 4. Experimenter's Scoring Panel

TABLE 2

Flight parameters scored during each maneuver of the flight task.

Man. No.	Maneuver	Altitude	Heading	Mach	Vert Rate	Airspeed
1a	Climb at .85 mach		x	x		
1b	Climb at .85 mach		x	x		
2	Level-off at 40,000'	x	x			
3	180° left turn	x				
4	180° right turn	x				
5	Straight & level	x	x			
6	Fast rate letdown		x	x		
7	Level-off at 20,000'	x	x			
8	Outbound penetration		x		x	
9	Penetration turn				x	
10	Level-off at 2300'	x	x			
11	Low approach	x	x			x
	Total times scored	7	9	3	2	1

limits were treated as maximum limit errors.

Heading	± 10 degrees
Altitude	± 800 feet
Vertical Rate	± 2,000 feet per minute
Mach	± .12 mach
Airspeed	± 30 knots

The parameters of vertical rate and airspeed were scored at just one value for the IDP, 4000 fpm down and 170 knots respectively. The reference voltages for these parameters were set up within the computer racks of the YF-102. The parameters of heading, altitude, and mach were scored at more than one value for the IDP, however, so the capability was provided for adjusting reference voltages from the experimenter's panel. Precise adjustment was made possible through the use of 10 turn 100K reference helipots.

Experimental Procedure

All subjects performed the flight task once while using each panel configuration. Order of presentation of the two panels was counter-balanced: 15 subjects started on the standard panel and ended on the vertical reading panel, and 15 subjects started on the vertical reading panel and ended on the standard panel. This procedure was necessary to counteract any bias due to learning effect.

Each flight on either panel was preceded by a cockpit check and a 10 minute practice session. Details are presented in Appendix D.

An optimum time of three days between flights on the two panel configurations was selected as being most suitable from the standpoint of mechanization problems of changing instruments, re-calibrating the scoring equipment, and not allowing too much time to pass between flights. The achieved time intervals between flights were as follows: 73.3 hours for all 30 subjects, 71.9 hours for the 15 subjects who started on the standard instruments first, and 74.7 hours for the 15 subjects who started on the vertical reading instruments first.

RESULTS

The significance of differences in pilot performance while using standard reading primary flight instruments as compared to performance while using vertical reading primary flight instruments was tested by the analysis of variance technique for a treatment x treatment x subjects without replication design as described in Lindquist (1953) for the flight parameters of heading, altitude, mach, and vertical rate. Differences in performance for the parameter of airspeed were tested for significance by the *t* test method as described in Edwards (1950). Because some of the pilots had previous vertical reading instrument experience, it was deemed necessary to insure that simple experience differences did not account for the primary performance differences between instruments. Accordingly, separate analyses were completed for the experienced and non-experienced groups, as well as all subjects combined. *

Heading Control

Tables 3, 4, and 5 summarize the analyses as applied to performance differences for the flight parameters of heading. In the case of this parameter, the heading display remained constant while the side instruments of mach, airspeed, altitude and vertical rate were changed from standard to vertical reading. Table 3 shows the results for all 30 subjects. Table 4 shows the results for the 13 subjects who had previous vertical reading instrument experience, and Table 5 shows the results for the 17 remaining subjects who had no previous experience with vertical reading instruments. Inspection of the table indicates a significant between instruments difference with varying levels of significance on all three analyses.

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* Summary tables containing the mean RMS error scores by maneuvers for experienced, non-experienced, and all subjects on standard and vertical reading instrument performance are presented in Appendix E.

These differences were all in favor of better heading control while using the standard reading side instruments. Between maneuvers differences all proved significant at the .001 level, but since no effort was made to equate the difficulty of the maneuvers, a significant difference would be expected. Likewise, the significant between subjects differences shown in all three tables would be expected. Significant interaction effects appear in all three tables.

Table 3

Analysis of variance results for heading performance with standard versus vertical reading side flight instruments for all subjects. N=30.

Source of variation	Sum of Squares	df	Mean Square	F
Panels	13.782	1	13.782	13.088***
Maneuvers	110.631	8	13.829	13.133***
Subjects	155.311	29	5.356	5.086***
I x M	8.756	8	1.094	1.039
I x S	50.926	29	1.756	1.668*
M x S	352.327	232	1.519	1.443**
I x M x S	244.396	232	1.053	
Total	936.129	539		

*** .1% Sig.
** 1% Sig.
* 5% Sig.

Table 4

Analysis of variance results for heading performance with standard versus vertical reading side flight instruments for 13 subjects with vertical instrument experience.

Source of variation	Sum of Squares	df	Mean Square	F
Panels	4.040	1	4.040	4.040*
Maneuvers	69.090	8	8.636	8.636***
Subjects	44.767	12	3.731	3.731***
I x M	9.243	8	1.155	1.155
I x S	20.041	12	1.670	1.670
M x S	143.712	96	1.497	1.497*
I x M x S	95.973	96	1.000	
Total	386.866	233		

*** .1% Sig.
* 5% Sig.

Table 5

Analysis of variance results for heading performance with standard versus vertical reading side flight instruments for 17 subjects with no vertical instrument experience.

Source of variation	Sum of Squares	df	Mean Square	F
Panels	10.074	1	10.074	9.285**
Maneuvers	48.515	8	6.064	5.589***
Subjects	110.487	16	6.905	6.364***
I x M	9.118	8	1.140	1.051
I x S	30.553	16	1.910	1.760*
M x S	201.641	128	1.575	1.452*
I x M x S	138.818	128	1.085	
Total	549.206	305		

*** .1% Sig.
** 1% Sig.
* 5% Sig.

Altitude Control

Tables 6, 7, and 8 summarize the results of the analyses as applied to performance differences for the flight parameter of altitude. Table 6 presents the results for all 30 subjects, while Table 7 presents the results for the 13 subjects who had previous vertical instrument experience and Table 8 presents the results for the remaining 17 subjects who had no previous experience with vertical reading instruments. All three tables indicate a significant between instruments difference at the .001 level. In each case, the difference indicated better pilot performance while using the standard reading altimeter. The between maneuvers differences are shown to be significant at the .001 level for all three analyses, as are the between subjects differences. Again, these differences would be expected to be significant. Several significant interaction effects are also noted in all three tables.

Table 6

Analysis of variance results for altitude performance on standard versus vertical reading flight instruments for all subjects. N=30.

Source of variation	Sum of Squares	df	Mean Square	F
Instruments	112.474	1	112.474	88.210***
Maneuvers	160.372	6	26.729	20.964***
Subjects	230.573	29	7.951	6.236***
I x M	51.989	6	8.665	6.796***
I x S	37.255	29	1.285	1.008
M x S	360.174	174	2.070	1.624**
I x M x S	221.890	174	1.275	
Total	1174.727	419		

*** .1% Sig.
** 1% Sig.

Table 7

Analysis of variance results for altitude performance on standard versus vertical reading flight instruments for 13 subjects with vertical instrument experience.

Source of variation	Sum of Squares	df	Mean Square	F
Instruments	46.836	1	46.836	30.552***
Maneuvers	54.040	6	9.007	5.875***
Subjects	148.412	12	12.368	8.068***
I x M	22.296	6	3.716	2.424*
I x S	24.327	12	2.027	1.322
M x S	226.658	72	3.148	2.053**
I x M x S	110.381	72	1.533	
Total	632.950	181		

*** .1% Sig.
** 1% Sig.
* 5% Sig.

Table 8

Analysis of variance results for altitude performance on standard versus vertical reading flight instruments for 17 subjects with no vertical instrument experience.

Source of variation	Sum of Squares	df	Mean Square	F
Instruments	65.673	1	65.673	59.272***
Maneuvers	113.033	6	18.839	17.003***
Subjects	78.551	16	4.909	4.431***
I x M	34.795	6	5.799	5.234***
I x S	12.893	16	.806	--
M x S	126.815	96	1.321	1.192
I x M x S	106.407	96	1.108	
Total	538.167	237		

***.1% Sig.

Mach Control

Tables 9, 10, and 11 summarize the results of the analyses as applied to performance differences for the flight parameter of mach. Table 9 presents the results for all 30 subjects, while Table 10 presents the results for the 13 subjects who had previous vertical instrument experience and Table 11 presents the results for the remaining 17 subjects who had no previous experience with vertical reading instruments. A significant between instruments difference at the .001 level is indicated on all three tables. In all three cases, this difference favored better mach performance while using the vertical reading instrument. A significant between maneuvers effect at the .001 level will again be noted for each analysis. Between subjects differences are significant at the .01 level for all three analyses. Further inspection will indicate several interaction effects significant at the .01 level.

Table 9

Analysis of variance results for mach performance on standard versus vertical reading flight instruments for all subjects. N=30.

Source of variation	Sum of Squares	df	Mean Square	F
Instruments	69.311	1	69.311	78.495***
Maneuvers	198.380	2	99.190	112.333***
Subjects	87.416	29	3.014	3.413***
I x M	20.917	2	10.459	11.845***
I x S	16.357	29	.564	- -
M x S	103.040	58	1.777	2.012**
I x M x S	51.215	58	.883	
Total	546.636	179		

*** .1% Sig.
** 1% Sig.

Table 10

Analysis of variance results for mach performance on standard versus vertical reading flight instruments for 13 subjects with vertical instrument experience.

Source of variation	Sum of Squares	df	Mean Square	F
Instruments	30.162	1	30.162	44.817***
Maneuvers	84.776	2	42.388	62.984***
Subjects	33.654	12	2.805	4.168**
I x M	17.520	2	8.760	13.016***
I x S	7.638	12	.637	- -
M x S	22.116	24	.922	1.370
I x M x S	16.153	24	.673	
Total	212.019	77		

*** .1% Sig.
** 1% Sig.

Table 11

Analysis of variance results for mach performance on standard versus vertical reading flight instruments for 17 subjects with no vertical instrument experience.

Source of variation	Sum of Squares	df	Mean Square	F
Instruments	39.149	1	39.149	38.761***
Maneuvers	115.096	2	57.548	56.978***
Subjects	53.094	16	3.318	3.285**
I x M	6.152	2	3.076	3.046
I x S	8.719	16	.545	- -
M x S	79.432	32	2.482	2.457**
I x M x S	32.307	32	1.010	
Total	333.949	101		

*** .1% Sig.
** 1% Sig.

Vertical Rate Control

Tables 12, 13, and 14 summarize the results of the analyses as applied to performance differences for the flight parameter of vertical rate. Table 12 presents the results for all 30 subjects, while Table 13 presents the results for the 13 subjects who had previous vertical instrument experience and Table 14 presents the results for the remaining 17 subjects who had no previous experience with vertical instruments. Inspection of these tables reveals that no significant differences were found in performance on standard versus vertical reading presentation of vertical rate flight information. With just two maneuvers involved, the tables also indicate that between maneuvers differences were not significant. Between subjects differences proved significant at the .01 level or better. The instruments by subjects interaction effect for all 30 subjects was significant at the .05 level.

Table 12

Analysis of variance results for vertical rate performance on standard versus vertical reading flight instruments for all subjects. N=30.

Source of variation	Sum of Squares	df	Mean Square	F
Instruments	.010	1	.010	- -
Maneuvers	2.303	1	2.303	2.490
Subjects	147.502	29	5.086	5.498***
I x M	3.421	1	3.421	3.698
I x S	54.485	29	1.879	2.031*
M x S	29.913	29	1.031	1.115
I x M x S	26.826	29	.925	
Total	264.460	119		

*** .1% Sig.
* 5% Sig.

Table 13

Analysis of variance results for vertical rate performance on standard versus vertical reading flight instruments for 13 subjects with vertical instrument experience.

Source of variation	Sum of Squares	df	Mean Square	F
Instruments	.915	1	.915	- -
Maneuvers	.710	1	.710	- -
Subjects	69.593	12	5.799	5.828**
I x M	3.998	1	3.998	4.018
I x S	29.973	12	2.498	2.511
M x S	14.463	12	1.205	1.211
I x M x S	11.937	12	.995	
Total	131.589	51		** 1% Sig.

Table 14

Analysis of variance results for vertical rate performance on standard versus vertical reading flight instruments for 17 subjects with no vertical instrument experience.

Source of variation	Sum of Squares	df	Mean Square	F
Instruments	.693	1	.693	- -
Maneuvers	1.637	1	1.637	1.886
Subjects	77.886	16	4.868	5.608***
I x M	.427	1	.427	- -
I x S	22.914	16	1.432	1.650
M x S	15.406	16	.963	1.109
I x M x S	13.885	16	.868	
Total	132.848	67		*** .1% Sig.

Airspeed Control

Table 15 summarizes the t test analyses of the RMS error differences for the flight parameter of airspeed. As the table indicates, no significant difference in performance between the standard and vertical reading airspeed indicator was found for all 30 subjects, or for the experienced and non-experienced groups. These analyses covered just one maneuver, the low approach at 1300 feet while maintaining a heading of 230 degrees and an airspeed of 170 knots.

Table 15

Results of t tests on differences in mean airspeed RMS error on standard and vertical reading flight instruments.

Subject Group	t	df	Sig.
13 Experienced Subjects	.926	24	NS
17 Non-Experienced Subjects	.881	32	NS
All 30 Subjects	1.301	58	NS

Individual Maneuver by Flight Parameter Analysis

To further test the significance of differences in the RMS error scores by maneuvers for the flight parameters of heading, altitude, mach, and vertical rate between standard and vertical reading instruments, individual *t* tests were computed for each maneuver by parameter for all 30 subjects. The results of these tests are summarized in Tables 16, 17, 18, and 19. In general, these tables substantiate fully the results of the analyses of variance performed on the data. The individual tables are reviewed below.

Heading Maneuver Performance

Table 16 presents the results of the individual maneuver *t* tests on heading performance. It should again be remembered that the heading instrument remained the same while the side instruments were changed from standard to vertical reading. The table shows that after submitting the differences in RMS error scores for each maneuver to the *t* test, only one maneuver, the level-off at 2300 feet, proved significant at the .05 level in favor of performance with the standard reading side instruments. However, when the cumulative effect of RMS error scores for all maneuvers was subjected to a *t* test for the differences in performance, a significant difference at the .01 level in favor of performance with the standard reading side instruments was recorded. This is in agreement with the results of the analysis of variance previously reported.

Table 16

Results of t tests on differences in mean heading RMS errors with standard and vertical reading side flight instruments for all subjects. N=30.

Man. No.	Mean on Standard	Mean on Vertical	Mean Diff.	df	t	Sig.
1a	2.590	3.251	.661	58	1.211	NS
1b	1.711	1.725	.014	58	.052	NS
2	1.889	2.169	.280	58	.956	NS
5	1.354	1.472	.118	58	.605	NS
6	1.157	1.286	.129	58	.721	NS
7	1.826	1.882	.056	58	.176	NS
8	1.485	1.792	.307	58	1.158	NS
10	1.342	2.020	.678	58	2.201	.05
11	1.536	2.167	.631	58	1.743	NS
All	1.654	1.974	.320	538	2.832	.01

Altimeter Maneuver Performance

Table 17 shows that altimeter performance was significantly better at the .01 level in favor of the standard reading altimeter for all maneuvers except one. On this maneuver, the level-off at 20,000 feet, no statistically significant difference in performance between instruments was found.

Table 17

Results of t tests on differences in mean altitude RMS errors on standard and vertical reading flight instruments for all subjects. N=30.

Man. No.	Mean on Standard	Mean on Vertical	Mean Diff.	df	t	Sig.
2	2.072	3.864	1.792	58	3.507	.01
3	1.108	2.433	1.325	58	3.451	.01
4	1.385	2.715	1.330	58	3.205	.01
5	.634	2.184	1.550	58	4.669	.01
7	2.248	1.743	.505	58	1.336	NS
10	1.067	2.072	1.005	58	3.655	.01
11	.426	1.173	.747	58	2.884	.01

Mach Maneuver Performance.

Table 18 indicates that mach performance on the vertical reading instrument was significantly better at the .01 level than performance on the standard reading instrument for all three maneuvers involving specific mach number control.

Table 18

Results of *t* tests on differences in mean mach RMS errors on standard and vertical reading flight instruments for all subjects. N=30.

Man. No.	Mean on Standard	Mean on Vertical	Mean Diff.	df	*t*	Sig.
1a	4.863	2.671	2.192	58	5.412	.01
1b	2.458	1.554	.904	58	2.852	.01
6	1.577	.950	.627	58	3.503	.01

Vertical Rate Maneuver Performance

Table 19 indicates no differences in performance on either maneuver involving vertical rate control on standard or vertical reading instruments. A small difference in alternate directions was recorded, but as Table 19 shows, these differences were statistically insignificant.

Table 19

Results of *t* tests on differences in mean vertical rate RMS errors on standard and vertical reading flight instruments for all subjects. N=30.

Man. No.	Mean on Standard	Mean on Vertical	Mean Diff.	df	*t*	Sig.
8	3.755	4.074	.319	58	.780	NS
9	3.815	3.460	.355	58	.983	NS

Experienced vs Non-Experienced Performance on Vertical Reading Instruments

To test the differences in performance of experienced versus non-experienced pilots on vertical reading flight instruments, it was necessary to ferret out those experienced and non-experienced subjects who had performed on the instrument configurations in the same order of presentation. It was found that 8 experienced and 7 non-experienced subjects had flown the vertical reading instrument configuration first. The distribution of subjects who had flown the vertical reading instrument configuration last was less balanced, 5 experienced and 10 non-experienced, because no attempt was made to control the order of appearance of the subjects. The RMS error scores for the group who performed on the vertical reading instruments first were compared by t tests for the flight parameters of heading and altitude. The results are summarized in Tables 20 and 21. These tables indicate that there were no significant differences in performance on heading and altitude control on any of the maneuvers while using the vertical reading instruments between the selected experienced and non-experienced subject groups.

Table 20

Results of t tests on differences in mean heading performance with the vertical reading side instruments for the experienced and non-experienced subjects who performed on the vertical reading instruments first.

Maneuver Number	Experienced Mean N=8	Non-Experienced Mean N=7	Mean Diff.	df	t	Sig.
1a	2.935	3.001	.066	13	.075	NS
1b	1.749	1.240	.509	13	1.454	NS
2	1.957	2.660	.703	13	1.031	NS
5	1.268	1.754	.486	13	1.459	NS
6	.998	1.198	.200	13	.461	NS
7	1.637	1.987	.350	13	.504	NS
8	1.941	1.775	.166	13	.324	NS
10	1.299	2.830	1.531	13	1.879	NS
11	2.496	2.111	.385	13	.379	NS

Table 21

Results of t tests on differences in mean performance on the vertical reading altimeter for the experienced and non-experienced subjects who performed on the vertical reading instruments first.

Maneuver Number	Experienced Mean N= 8	Non-Experienced Mean N=7	Mean Diff.	df	t	Sig.
2	3.490	3.526	.036	13	.040	NS
3	2.590	1.937	.653	13	.594	NS
4	1.953	2.789	.836	13	1.201	NS
5	1.670	.899	.771	13	1.637	NS
7	1.876	2.045	.169	13	.202	NS
10	1.988	2.028	.040	13	.112	NS
11	1.358	1.093	.265	13	.311	NS

Altimeter Reading Errors

Throughout the flight task, the experimenter maintained a vigilant look-out for evidence of altimeter reading errors on both altimeter displays. No altimeter reading errors were detected at any point throughout the profile under either display configuration.

A specific scoring point was set up on the scoring sheet to record the altitude at which the penetration turn was commenced. All penetration turns were initiated within ± 200 feet of the instructed altitude for either altimeter. This is considered to be within the performance criteria limits that most pilots set for themselves, and is not regarded as any kind of reading error.

DISCUSSION OF RESULTS

This study represents one of the first attempts to measure and evaluate pilot simulator performance on the whole panel basis. It has been common practice to evaluate performance on one type of instrument, usually with the major emphasis on "good" performance being assigned to that particular instrument. In reality, "good" performance must come as a result of proper reading and interpretation of several flight instruments. To remove one, or possibly two, instruments from the panel and direct investigation towards performance on them, is not looking at the entire informational context of the pilot's task. Provision should be made to record performance on all instruments contributing to the display of information required by the pilot to maintain the desired flight path. The present study was designed to accomplish this objective.

Why Vertical Instruments

The need for a shift to vertical reading instruments was necessitated by a number of reasons, among which are the following:

1. Not enough room for scale length on the circular dials.

2. No feasible method available for displaying command information.

3. In the case of the three pointer altimeter, the inherent interpretation error characteristic.

However, as previously stated, such a shift in display principle must assume a corresponding shift of equal or better pilot performance to the new instrument display technique. Unless this is accomplished, anything else gained by the change would be offset by degradation in performance.

The present study has examined differences in pilot simulator performance on two flight parameter display principles only. These principles are circular dials versus vertical moving-tapes. It is not a comparison of the Air Force Phase II Panel and the round standard reading instruments. The Phase

II instruments provided a convenient vehicle from which to obtain vertical reading moving-tape displays of flight parameter information. Conclusions can only be extracted from the results in terms of these display principles. Any extrapolation to the Phase II Panel must be viewed with full cognizance that the Phase II Panel adds still a third display principle — that of the use of command indices. It can logically be assumed that the addition of command markers should improve performance, but this is an assumption which can be tested experimentally and suggests another pilot performance measurement study, comparing performance on vertical reading instruments with and without command information.

Interpretation of the Findings

Reviewing the results, it was indicated that heading performance was superior while using the standard reading side instruments, altitude performance was superior while using the standard reading altimeter, mach performance was superior while using the vertical reading mach indicator, and vertical rate and airspeed performance showed no differences between instrument configurations. Separate analyses for those subjects with and without vertical instrument experience did not change the results of the overall analyses.

Mach, Vertical Rate, and Airspeed

In the light of the previous discussion, the results of the present study may be interpreted in this manner. Performance on the vertical reading instruments for mach, vertical rate, and airspeed was found to be essentially equivalent to or better than performance on the standard reading instruments for the same flight parameters. As a result, it may be concluded that no degradation in performance may be expected on a shift from standard to vertical reading instruments for the flight parameters of mach, vertical rate, and airspeed with scale factors comparable to those used in this study. Such a shift would only involve a change to vertical moving-tape displays without command markers. However, by making the change to vertical reading displays, it is then possible to overcome the scale length limitations of circular dials and to make the addition of commandindices. As previously suggested, a logical assumption would call for the expectation of better performance with the command markers added to the vertical display. Human factors experimentation could test this assumption.

Altitude

Altitude performance results present a somewhat different picture. The results indicated that performance on the standard three-pointer altimeter was superior to that obtained on the vertical reading altimeter. From previous work by Mengelkoch and Houston (1958a, 1958b, 1958c), these performance differences can probably be attributed to a large extent to the problem of scalar design. The scale factor in the vertical reading altimeter (2" per 1000') is not conducive to equivalent performance with that on the standard reading instrument. Again, the prior work of Mengelkoch and Houston suggest the direction of change to be used in an attempt to produce equivalent performance on the two types of altitude display principles. An expansion of the linear scale factor on the vertical moving-tape is suggested. Recently, other proposals for increasing the sensitivity of altitude moving-tape presentations have been suggested by Gainer (1959a). These include the introduction of non-linear scales, combinations of non-linear scales, combinations of linear and non-linear scales, and combinations of linear scales. Experimental evaluation of these scales has been recommended (Gainer, 1959b) and is scheduled for early completion. It is anticipated that the results of the forthcoming studies will produce an altitude moving-tape scale that will promote performance at least equivalent to that obtained on the three-pointer altimeter. Once this point has been reached, the shift to a vertical reading altimeter will be justified. In addition to no performance degradation, the capability of command marker presentation and the virtual elimination of interpretation errors will make the vertical reading altimeter a valuable asset to modern-day aviation.

Heading

Heading performance was recorded on nine maneuvers, each somewhat different from the other. It will be recalled that the heading instrument itself was not changed for the two different panel configurations. Along with the Attitude Director Indicator, it remained the same while the side instruments for mach, airspeed, altitude, and vertical rate were alternated. A highly significant difference at the .001 level was shown to favor performance with the standard reading side instruments for all 30 subjects. The difference in performance for the 17 subjects with no previous vertical instrument experience was significant at the .01 level in favor of performance with the standard reading side instruments. The level of significance for the difference in performance for the 13 subjects with previous vertical instrument experience dropped to the .05 level, still in favor of performance with the standard reading side instruments. It is tempting to interpret these results as indicating that previous experience with vertical reading instruments does not influence performance on heading control. If the .05 level of significance is acceptable, it might be concluded that previous experience had no effect on heading performance, and that heading control remained superior for the panel configuration with the standard reading side instruments, regardless of any previous experience with vertical reading instruments. From the strictly statistical approach, it is necessary that the .05 level of significance be accepted on the basis of pre-experimental decision. However, from the operational viewpoint, there appears to be some indication that prior experience with vertical reading instruments seemed to allow more time for heading monitoring aside from primary pitch control under the conditions of this experiment.

Since performance on the Horizontal Situation Indicator was not compared to that of any other heading indicator, this discussion is purely speculative. The heading indicator was used primarily as a control instrument to indicate the effect that changing of the side instruments might have on heading performance. Although not statistically supported, as previously stated, this procedure provided the only indication that experience level (on vertical reading instruments) may have some effect on initial performance.

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TECHNICAL APPENDICES

APPENDIX A

Flight Instructions

The following flight instructions were read verbatim from typewritten cards prior to the indicated maneuver.

Introductory Statement

How do you read me?
Roger, I read you loud and clear.
All flight instructions will have a definite starting command such as "Begin NOW".
Please do not initiate any maneuver prior to receiving this command.
You need not acknowledge any further instructions, however, feel free to request a repeat.
Your call will be "Air Force 59".

Take-off, Climb-out, and Level-off at 40,000'

Air Force 59
You are cleared to take-off and climb on a heading of zero degrees.
Use 100% with afterburner for the climb.
Stay below 3000' until you reach mach .80 and then set up and maintain a climbing mach of .85.
Level off at 40,000', 96% without afterburner, and maintain 40,000' and a heading of zero degrees until further advised.
I repeat: (repeat the instructions).
Begin your take-off NOW.

180° Turn to the Left

Air Force 59
You are to make a 180 degree LEVEL TURN TO THE LEFT.
Maintain 40,000', use a 30 degree bank and your present power setting of 96% without afterburner.
Begin your turn NOW.

180° Turn to the Right

Air Force 59
You are to make a 180 degree LEVEL TURN TO THE RIGHT.
Maintain 40,000 feet, use a 30 degree bank and your present power setting of 96% without afterburner.
Begin your turn NOW.

Straight and Level Flight

Air Force 59
Maintain 40,000 feet, heading zero degrees, and 96% until further advised.

Fast Rate Descent to 20,000'

Air Force 59
You are cleared to descend to and maintain 20,000 feet.
Use 85% and maintain mach 1.0 during the descent.
Leave the power at 85% after leveling off at 20,000 feet.
Hold yourheading of zero degrees throughout the maneuver.
I repeat: (repeat the instruction).
Begin NOW.

Jet Penetration

Air Force 59
You are now apprcaching the range station and are cleared for a penetration.
Refer to the placard.
After passing the high station, extend 3/4 speed brakes and set up a 4000 foot per minute rate of descent.
Leave the power at 85%. Begin a right penetration turn at 11,000 feet using a 30 degree bank. Inbound heading is 230 degrees. Level off at 2300 feet, advance power to 92%, drop the landing gear, pull in the speed brakes, and maintain 2300 feet and a heading of 230 degrees.
I repeat: (repeat the instruction).
Standby for the high station.

Low Approach

Air Force 59
You are now four miles out and are cleared to descend to

and maintain 1300 feet, heading 230 degrees, 170 knots.
After passing the low station, extend particular effort to maintain 1300 feet, 230 degrees, and 170 knots until further advised.
Begin your descent NOW.

Flight Termination

Air Force 59
That completes the flight.
The simulator is frozen.
Canopy is coming up. (Open the canopy).

APPENDIX B

Scoring Sheet

NAME ______________________ SUBJECT NO. ______ CONDITION ______

Rank/Job ______ Time last 6 months ______ Total Time ______

Age ______ Jet Simul. Time ______ Instrument Time ______

Date ______ White/Green/CAA Inst. Card Jet Time ______

Previous vertical instrument experience: Yes ☐ No ☐ Hours ______

(1) CLIMB TO 40,000' (5,000') Mach (.85) ☐ Heading (360°) ☐	(26,000') Mach (.85) ☐ Heading (360°) ☐	(2) LEVEL OFF 40,000' Altitude (40,000') ☐ Heading (360°) ☐
(3) 180° LEFT TURN Altitude (40,000') ☐	(4) 180° RIGHT TURN Altitude (40,000') ☐	(5) S & L 40,000' Altitude (40,000') ☐ Heading (360°) ☐
(6) FAST RATE DESCENT Mach (1.0) ☐ Heading (360°) ☐	(7) LEVEL OFF 20,000' Altitude (20,000') ☐ Heading (360°) ☐	(8) OUTBOUND PENETRA. (18,000') Vert/Rate (4000 fpm) ☐ Heading (360°) ☐
(9) PENETRATION TURN Vert/Rate (4000 fpm) ☐ Turn Alt. (11,000') ☐	(10) LEVEL OFF 2300' Altitude (2300') ☐ Heading (230°) ☐	(11) LOW APPROACH 1300' Altitude (1300') ☐ Heading (230°) ☐ Airspeed (170 knots) ☐

APPENDIX C

Scoring Procedures

The following scoring procedures were observed for all experimental runs. The numbers correspond to the scoring maneuvers on the scoring sheet.

(1) Take-off and Climb to 40,000 Feet

Master Scoring switch on "Man" (Manual).
Push "Start" button (begin scoring) at 5000 feet.
Score mach at .85.
Score heading at zero degrees.
Readout error scores.
Reset integrators.

Master Scoring switch on "Man".
Push "Start" button (begin scoring) at 26,000 feet,
Score mach at .85.
Score heading at zero degrees.
Readout error scores.
Reset integrators.

(2) Level-off at 40,000 Feet

Master Scoring switch on "Auto" (Automatic)
Push "Start" button (system is now armed to begin scoring automatically when vertical rate reaches zero) at 39,200 feet.
Score altitude at 40,000 feet.
Score heading at zero degrees.
Readout error scores.
Reset integrators.

(3) 180 Degree Level Turn to the Left

Master Scoring switch on "Man".
Push "Start" button (begin scoring) when bank reaches 30 degrees..
Score altitude at 40,000 feet.
Readout error score.
Reset integrators.

(4) 180 Degree Level Turn to the Right

Master Scoring switch on "Man".
Push "Start" button (begin scoring) when bank reaches 30 degrees.
Score altitude at 40,000 feet.
Readout error score.
Reset integrators.

(5) Straight and Level Flight

Master Scoring switch on "Man".
Start timer clock when finished with voice instruction.
Push "Start" button (begin scoring) when 30 seconds have elapsed.
Score altitude at 40,000 feet.
Score heading at zero degrees.
Readout error scores.
Reset integrators.

(6) Fast Rate Let-down

Master Scoring switch on "Man".
Push "Start" button (begin scoring) at 37,000 feet.
Score mach at 1.0.
Score heading at zero degrees.
Readout error scores.
Reset integrators.

(7) Level-off at 20,000 Feet

Master Scoring switch on "Auto".
Push "Start" button at 20,800 feet (system now armed to begin scoring when vertical rate reaches zero).
Score altitude at 20,000 feet.
Score heading at zero degrees.
Readout error scores.
Reset integrators.

(8) Outbound Penetration

Master Scoring switch on "Man".
Push "Start" button (begin scoring) at 18,000 feet.
Score vertical rate at 4000 feet per minute.
Score heading at zero degrees.

Readout error scores.
Reset integrators.

(9) Penetration Turn

Master Scoring switch on "Man".
Record altitude when bank (turn) is commenced.
Push "Start" button (begin scoring) when bank reaches 30 degrees.
Score vertical rate at 4000 feet per minute.
Readout error score.
Reset integrators.

(10) Level-off at 2300 Feet.

Master Scoring switch on "Auto".
Push "Start" button at 3100 feet (system now armed to begin scoring automatically when vertical rate reaches zero.)
Score altitude at 2300 feet.
Score heading at 230 degrees
Readout error scores.
Reset integrators.

(11) Low Approach at 1300 Feet

Master Scoring switch on "Man".
Start timer clock when vertical rate reaches zero when within 200 feet of 1300 feet altitude.
Turn on station marker light at end of 30 seconds.
Push "Start" button (begin scoring) and turn off station marker light at end of 5 seconds.
Score altitude at 1300 feet.
Score heading at 230 degrees.
Score airspeed at 170 knots.
Readout error scores.
Reset integrators.

APPENDIX D

Cockpit Check

Prior to each flight in the YF-102 Link flight simulator, the subject was given a thorough cockpit check covering all the controls, switches, and instruments that would be used by him during the experimental run. After the subject had entered the cockpit, he was asked to make himself comfortable by adjusting the rudder pedals and the seat. The following checklist was then used to complete the check:

Throttle Control

1. Normal use.
2. Afterburner operation.
3. Speed brake switch and operation.
4. Mike button.

Landing Gear

1. Handle operation.
2. Indication.

Instrument Panel

1. Attitude Director Indicator. (Operation and interpretation of display).
2. Horizontal Situation Indicator. (Operation and interpretation of display).
3. Airspeed-Mach Indicator. (Operation and interpretation of display).
4. Altimeter-Rate of Climb Indicator. (Operation and interpretation of display).
5. Percent RPM indicator. (Operation and interpretation of display).
6. Station marker light.
7. Speed brake indicator.
8. Penetration card.

Control Stick

1. Sensitivity of control action.
2. Trim control (pitch trim slow, necessary to hold longer).
3. Mike button (alternate).
4. Pilot assist button (caution against using).

Canopy Operation

1. Switch location and operation.
2. Panel light location.

Any Questions

Headset and Lip Mike

1. Flight instructions will be given over the intercom.
2. Put headset on and get it adjusted.

Refer to Practice Session Instructions

Practice Session

A ten minute practice session was given to each subject before each flight in the simulator. The following instructions were read to the subjects vertabim. At times it was necessary to supplement the instructions with additional comments, if the subject had difficulty in handling the trainer during the take-off.

1. OK, we are now ready for a practice session. I will close the canopy and instruct you through a take-off from the perch here. (Close the canopy, making sure the canopy rails are clear).

2. The engine is now at idle RPM.

3. I want you to advance the throttle full forward. As the RPM nears 100%, kick in the afterburner by moving

the throttle outboard.

4. OK, we're in afterburner operation; when the airspeed reaches 150 knots, begin rotating the nose to about 10 degrees pitch up. Once airborne, as indicated by the altimeter, it will be necessary to apply forward stick pressure and trim to keep the nose from shooting up rather abruptly.

5. OK, you're airborne, raise the landing gear.

6. Keep the pitch up angle at 5 degrees or less and stay below 3000' until mach .80 is reached. As you pass through mach .80 then increase the pitch up angle and set up a climbing mach of .85.

7. OK, you're passing through mach .80, increase the pitch up angle slightly and set up a climbing mach of .85.

8. You will now have 10 minutes to practice climbs, turns, level flight, descents, and speed brake operation.

9. Request you stay below 20,000'.

10. It's all yours.

At this point the time was noted for purposes of starting the 10 minute practice period. During the practice session, the station marker light was turned on and the subject was asked to signal when he had the light adjusted to a desired brightness. The light was then turned off. Just prior to the completion of nine minutes practice, the subject was informed that there was one minute remaining in the practice session and it was suggested that he start down toward ground level. When the ten minutes were up, the simulator was put in the "freeze" position and the canopy was opened. The experimenter then put the simulator back in normal operation and flew it to ground level. The subject was asked if he had any questions about the operation of the simulator or the instruments. After answering any questions, the experimenter went through the following checklist to insure proper and identical starting points for each flight:

1. Ground level (zero feet altitude).
2. Zero degrees heading.
3. Idle RPM.
4. Landing gear down.

5. Speed brakes in.
6. Pilot assist off.
7. Damper on manual.
8. Any questions.

The canopy was then closed and the experimenter went to the experimenter's control panel to begin the flight task instructions.

APPENDIX E

Table 22

Mean Heading RMS Errors

Maneuver Number	Experienced		Non-Experienced		All Subjects	
	Standard	Vertical	Standard	Vertical	Standard	Vertical
1a	2.632	3.707	2.558	2.903	2.590	3.251
1b	1.591	1.742	1.802	1.712	1.711	1.725
2	1.897	1.967	1.883	2.324	1.889	2.169
5	1.487	1.399	1.253	1.52[illegible]	1.354	1.472
6	1.091	1.199	1.207	1.351	1.157	1.286
7	1.875	1.698	1.788	2.02[illegible]	1.826	1.882
8	1.347	1.839	1.590	1.756	1.485	1.792
10	1.487	1.468	1.231	2.442	1.342	2.020
11	1.632	2.384	1.462	2.001	1.536	2.167

Table 23

Mean Altitude RMS Errors

Maneuver Number	Experienced		Non-Experienced		All Subjects	
	Standard	Vertical	Standard	Vertical	Standard	Vertical
2	2.280	3.621	1.912	4.050	2.072	3.864
3	1.174	2.679	1.056	2.245	1.108	2.433
4	1.409	2.439	1.368	2.926	1.385	2.715
5	.818	2.535	.493	1.915	.634	2.184
7	2.306	1.713	2.203	1.766	2.248	1.743
10	1.336	2.406	.861	1.817	1.067	2.072
11	.429	1.462	.424	.951	.426	1.173

Table 24

Mean Mach RMS Errors

Maneuver Number	Experienced		Non-Experienced		All Subjects	
	Standard	Vertical	Standard	Vertical	Standard	Vertical
1a	4.903	2.373	4.832	2.898	4.863	2.671
1b	2.547	1.618	2.390	1.505	2.458	1.554
6	1.243	.970	1.833	.934	1.577	.950

Table 25

Mean Vertical Rate RMS Errors

Maneuver Number	Experienced		Non-Experienced		All Subjects	
	Standard	Vertical	Standard	Vertical	Standard	Vertical
8	3.511	4.306	3.941	3.897	3.755	4.074
9	3.850	3.500	3.789	3.429	3.815	3.460

Table 26

Mean Airspeed RMS Errors

Maneuver Number	Experienced		Non-Experienced		All Subjects	
	Standard	Vertical	Standard	Vertical	Standard	Vertical
11	1.290	1.895	1.638	2.084	1.487	2.002