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AN EVALUATION OF B-1B PILOT PERFORMANCE DURING SIMULATED INSTRUMENT APPROACHES WITH AND WITHOUT STATUS INFORMATION

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FOR THE COMMANDER

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The majority of aircraft incidents occur during the approach to landing phase of flight. Little research has been conducted that evaluates the efficiency of the instrument display format used by the pilots for the approach to landing. This research examined the effects of two Instrument Landing System display formats on the tracking performance of pilots in a B-1B simulator under varying crosswind and starting conditions. One display contained flight director command steering supplemented with raw glideslope and localizer data; the other display was the same minus the raw data. This research was based on the hypothesis that superior tracking performance would result with flight director and raw glideslope and localizer data on the Instrument Landing System display. The independent variables were: display types, initial starting point, and wind. The dependent variables were: glideslope deviation, localizer deviation, airspeed, roll rate variability, pitch rate variability, and altitude Above Ground Level. Twelve qualified B-1 pilots served as subjects in this simulation study, each subject flew a total of 16 Instrument Landing System approaches after practice. The two types of Instrument Landing System formats were evaluated under two wind conditions that began with two starting positions.

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The results of this experiment indicate that the Instrument Landing System display without raw data was tracked more accurately by the subjects for localizer deviation. However, better glideslope tracking performance was observed with the display containing command and raw data. Of the dependent variables analyzed, glideslope and localizer deviation were the only variables effected by the display type.

Preface

This report describes the results obtained when B-1B pilots were provided with a flight director with and without status information during simulated instrument approached. The results are believed to be generalizable to a variety of other aircraft.

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INTRODUCTION

BACKGROUND

Aircraft accidents are infrequent occurrences but when they do occur they result in loss of life. Pilots are usually implicated as a causal factor in half of these accidents (Boeing, 1985). Of the percentage of accidents that do occur, over 55% happen during the approach and landing phases of flight (Boeing,1985). The present research shall examine pilot performance during an approach-to-landing task with two different instrument landing system displays. To aide the reader in understanding the problem of conducting an approach-to-landing without visual reference, a brief historical overview of aircraft instrument design and integration is provided. This is followed by a brief overview of the Instrument Landing System, aircraft flight director, and models of pilot control strategy. Finally, background on the B-1B flight station and Instrument Landing System displays, used as the research vehicle in this study, is provided and the specific research hypothesis identified.

Aircraft navigation by reference to radio wave steering information has existed since the 1930's. The equipment of that era consisted of an aircraft receiver that conveyed steering information to the pilots by use of Morse code provided in their headsets (Wiener & Nagel,1988). During the 1940's and 1950's, as technology progressed, more precise instrumentation replaced the Morse code based Adcock range (Cooper, 1991). New navigation systems provided both auditory and visual guidance information to the pilot for both enroute and terminal portions of flight. The primary navigation instrument, called a Course Deviation Indicator, informed the pilot if he was on centerline or left/right of the navigation beam.

Until the Fitts, Jones, and Milton (1949) studies of instrument scanning, aircraft manufacturers placed instruments where space was available. The results of Fitts *et al*. changed the way instruments were arranged in civilian and military aircraft. The standard layout that was found to be effective in reducing pilot workload is called the "Sacred Six" or "T" instrument layout (Ercoline, 1985).

One of the findings by Fitts *et al*. was that certain instruments are viewed more frequently than others. Fitts *et al*. proposed that if they could combine frequently used instruments into one, they would improve pilot performance and also save critical instrument space. One of the first instrument integrations was the combination of the Course Deviation Indicator also known as a Cross Pointer and the Directional Gyro resulting in the creation of the Horizontal Situation Indicator. Illustrated in Figure 1 is the original eight instruments used in the Fitts, *et al*. study. The basic six instruments and their placement are the two rows of three instruments. They are: Airspeed, Directional Gyro, Gyro Horizon, Altimeter, Turn and Bank and Vertical Speed indicators.

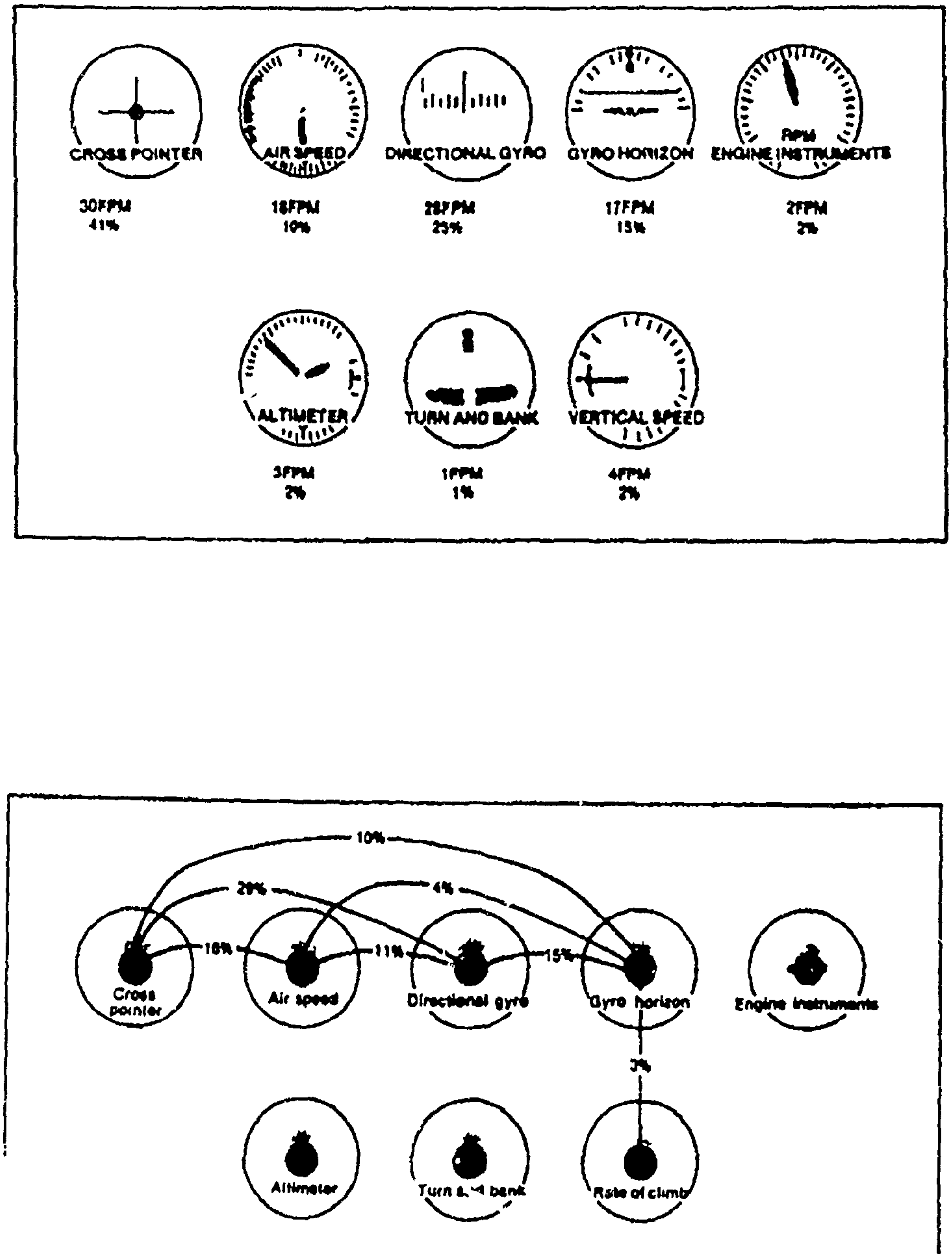


Figure 1. COCKPIT LAYOUT OF INSTRUMENTS USED By Fitts *et al*. (1949)

Aircraft instruments that are used for instrument flight today are: 1) the Airspeed Indicator, 2) the Directional Gyro or Horizontal Situation Indicator, 3) Attitude Indicator also known as the Gyro Horizon, 4) the Altimeter, 5) the Turn and Bank Indicator, and 6) the

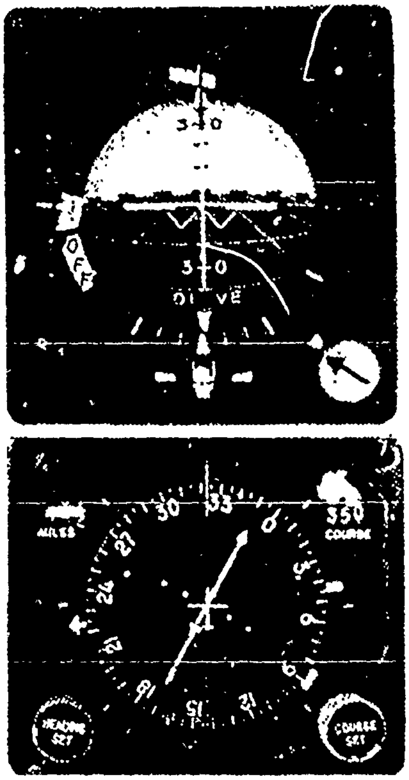
Vertical Velocity Indicator.

Airspeed information is combined with timing information on a landing approach and is used as a cross check of position during the approach. A specific airspeed is also used as a target setting during the approach depending on the gross weight of the aircraft. The Horizontal Situation Indicator or Directional Gyro/Course Deviation Indicator combination provides the pilot with the present heading, direct of turn, and steering information. Gyro horizon or aircraft attitude information informs the pilot of the aircraft attitude in both pitch and roll axes. Altimeter information provides the corrected absolute reference for the starting and decision points during an approach-to-landing. The Turn and Bank Indicator provides a confirmation of the direction the aircraft is turning and if the aircraft is flying in a coordinated manner. Vertical velocity information informs the pilot of his rate of climb or descent.

It was noted by Fitts et al. that during instrument approaches, pilots spent considerable time scanning both the Course Deviation Indicator and the Directional Gyro. Both of these instruments were combined into one instrument, called the Horizontal Situation Indicator (Williams & Roscoe,1949), which resulted in pilots spending less time scanning and hence seemingly lowering pilot workload. The Horizontal Situation Indicator and the Attitude Direction Indicator are juxtaposed so as to keep the critical information in foveal vision. According to Kelley (1968) and Roscoe (1968) this instrument placement improved the ability of the pilot to notice and respond to velocity changes on a display. Control of a multi-axis vehicle, such as an airplane, using an Attitude Direction Indicator is more natural (aircraft direction of movement is the same direction as the control input) using the integrated displays. As aircraft continued to become larger and heavier, pilot workload increased due to larger aircraft inertia forces and corresponding slower control system response characteristics. Small deviations if not corrected immediately result in large excursions from the desired flight path. Recovery back to the correct flight path would require a large control input resulting in a degraded overall system performance with the possibility of causing pilot-induced-oscillations. Complicating the problem of slow system response was that the pilot was responsible for integrating all instrument information and then deciding on the correct course of action to maintain flight path. The standard instrument layout does not directly inform the pilot of a deviation from the flight path. Once the deviation has been detected, the pilot acts as a rate controller and must estimate the correction required. However for large aircraft, a time delay is resident in the system response before it reacts to a control input.

The time it takes a pilot to integrate information across displays, coupled with a control response lag, is the principal reason that the aircraft flight director was invented. The flight director consists of a computer that receives signals from aircraft navigation and performance instruments and displays an optimized steering path for the human pilot or autopilot to follow. The flight director was designed to minimize flight path deviations and reduce pilot workload. The flight director computer can detect small deviations almost immediately and provide a steering correction for the pilot to follow thus reducing his integration burden and reducing the likelihood of pilot-induced-oscillation. The piloting task is then reduced to a twodimensional tracking task. The purpose of this study centers around the information provided by the flight director with and without raw steering information. Of interest is how a pilot might use this information during an approach-to-landing task.

The integration of the flight director occurred shortly after the analog computer was miniaturized to fit in fighter sized aircraft (Birmingham & Taylor, 1954). The flight director design was a spin-off of research being performed by the U. S. Air Force on fighter aircraft and on submarines by Birmingham and Taylor (1954) for the U. S. Navy. Typically, the steering information provided by the flight director is presented on the Attitude Direction Indicator as a steering cross representing steering commands for pitch and roll axes. The flight director receives the navigational information from the Instrument Landing System located adjacent to the runway. The steering information provided by the Instrument Landing System consists of two steering beams representing localizer and glideslope. Localizer and glideslope steering information is presented in an unfiltered, raw form on the Horizontal Situation Indicator and in a filtered form on the steering cross of the Attitude Direction Indicator. Figure 2 illustrates the typical representation of the Attitude Direction Indicator with steering cross and the Horizontal Situation Indicator with raw glideslope and localizer data.



FLIGHT DIRECTOR SYSTEM

Figure 2.Typical Flight Director, the top figure is an Attitude Direction Indicator with steering cross, the bottom figure is the Horizontal Situation Indicator

For a more complete understanding of the flight director and the associated use of raw data, examination of the key elements of an Instrument Landing System are in order. A typical Instrument Landing System must include instrumentation that provides precise steering to the runway environment and precise steering down the Glideslope beam that provides the vertical steering cues to the pilot. As can be seen in Figure 3, the Instrument Landing System provides a narrow steering beam for lateral runway alignment of approximately five degrees. This beam represents the localizer and is aligned within a few degrees of the runway. Vertical guidance is provided by a very narrow glideslope beam of approximately one and four tenths of a degree. The aircraft receives the steering information from the Instrument Landing System and depending upon how the aircraft is equipped, can represent the steering information on either a Course Deviation Indicator, a Horizontal Situation Indicator, or a flight director equipped with an Attitude Direction Indicator and Horizontal Situation Indicator. The pilot's task is the same, independent of the method of Instrument Landing System presentation. The piloting task is to keep the steering needles in the center of the display which represents for all displays the center of the steering beams.

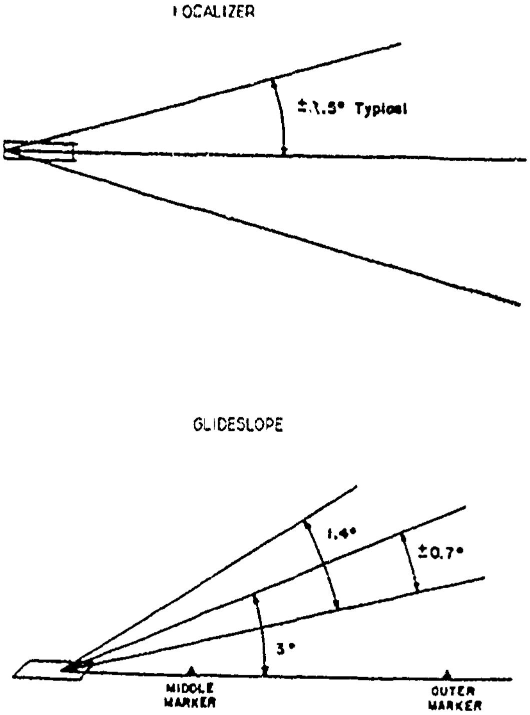


Figure 3. ILS BEAM WIDTHS, top figure is Localizer, bottom figure is Glideslope.

THE INSTRUMENT LANDING SYSTEM

An Instrument Landing System must provide distance or positional information from the runway threshold. These distances or positions must be identified and correspond with key elements of this system such as Decision Height or Glideslope Intercept Point. Decision Height is usually defined as an altitude of 200 feet above Mean Sea Level which corresponds to approximately one-half mile from the end of the runway. Decision Height serves as the point where the pilot must decide to either land the aircraft or conduct a missed approach if the runway or airport environment is not visible. The Glideslope Intercept Point is located at the beginning of the approach and is the point that the aircraft begins descending based on vertical steering cues provided by the glideslope beam. Both Decision Height and Glideslope Intercept Point can be represented by either a fixed location marker or by Distance Measuring Equipment, measured in nautical miles. Fixed markers, known as marker beacons, are represented in a flight station by an annunciator of flashing lights and an aurally provided Morse code identifier in a pilot headset or aircraft speaker. Distance Measuring Equipment, shown in Figure 4, is displayed as a digital readout on a Horizontal Situation Display or may be a separate instrument. Distance Measuring Equipment provides distance in nautical miles from a known reference point.

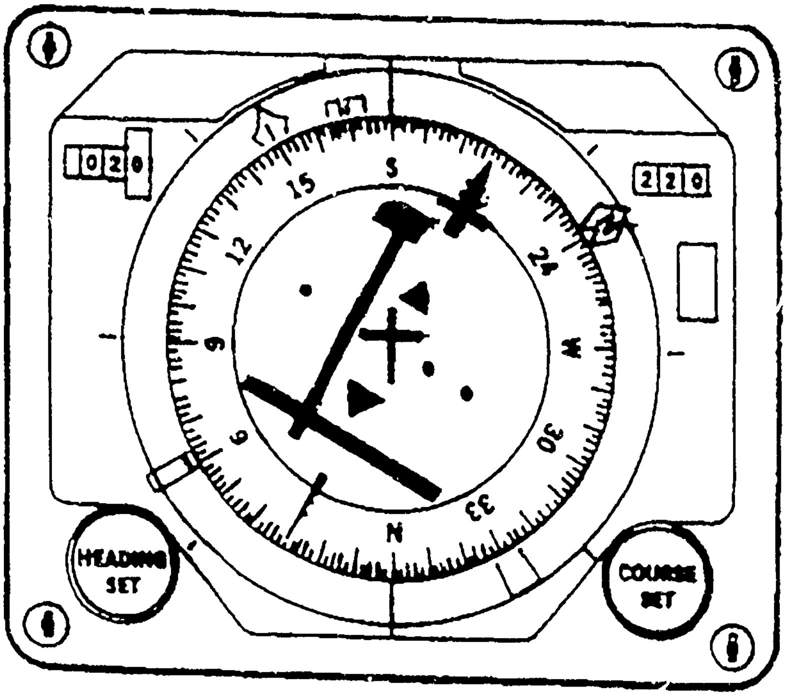


Figure 4. DISTANCE MEASURING EQUIPMENT, Horizontal Situation Indicator with a distance of 2.0 nautical miles shown in the upper left corner

The basic instrumentation convention for both military and civilian aircraft today has changed little since the 1950's. The implementation of the Cathode Ray Tube into the flight station occurred in 1968 when Sobocinski (1968) successfully integrated a working prototype of a Horizontal Situation Indicator into a flight test aircraft. The availability of the Cathode Ray Tube has released the aircraft engineer and designer from employing designs that were required due to limitations of an electromechanical instrument. Primary flight information such as that provided by an Attitude Direction Indicator or steering information provided by the Horizontal Situation Indicator could now be displayed in any manner that the designer wishes. This unbounded design option offered challenges to designer, researcher and pilot alike. Questions concerning the method of presenting data to pilots now had greater significance. Previous research questions that attempted to determine what should move on a display, where it should be located and when should it move (Berube, 1981) will require reevaluation as new Cathode Ray Tube displays replace their electromechanical predecessors in all class and categories of aircraft. Cathode Ray Tube display research on aircraft predictor displays has been successfully transitioned and implemented into Boeing 757 and 767 cockpits (Jensen, 1981; Grunwald, 1981; and Palmer, Jago, & DuBord, 1981). Other researchers (Aretz, 1988, 1989; Harwood, 1989; Wickens, Aretz & Harwood, 1989) have examined Head Down Displays in the context of situational awareness and pilot's internal frame of reference. Implementation of newer display designs into civilian and military aircraft will be difficult. Airline owners are very conservative and are not willing to implement newer technology unless that technology is better and of lower cost than that presently in service. Pilots also are not likely to receive this new technology in a positive light until issues such as transfer of training are addressed.

B-1B FLIGHT STATION DISPLAY FORMATS

The B-1B is capable of executing Instrument Landing System approaches in almost any weather. The B-1B Instrument Landing System displays used by the pilots to fly these approaches have required redesign due to poor representation of critical data presented on the Vertical Situation Display. The first B-1B Instrument Landing System display was a transformed version of the one used on the Space Shuttle. Rockwell International, prime contractor of both the Space Shuttle and the B-1B, employed the same Instrument Landing System display used by the Space Shuttle into the B-1B aircraft. Aircraft differences and operational environment dissimilarities resulted in poor user acceptance of the Space Shuttle Instrument Landing System box. The Space Shuttle Instrument Landing System display required the pilot to fly the flight director steering cross into the center of a box representing the center of the Instrument Landing System (see Figure 5). The redesigned display uses fixed dots to represent glideslope and localizer position and is similar to the Instrument Landing System that is in current Air Force aircraft.

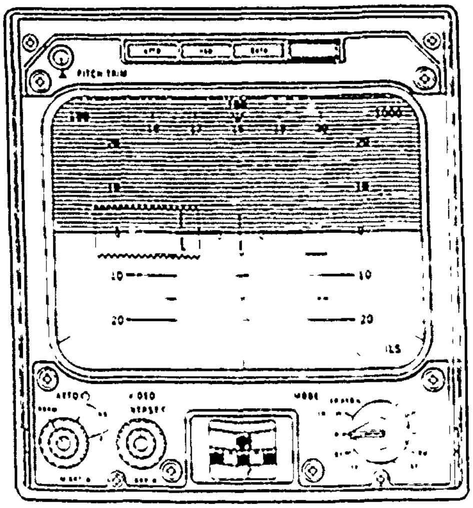


Figure 5. B-1B INSTRUMENT LANDING SYSTEM DISPLAY

The B-1B flight station was designed as a conventional cockpit except for a Cathode Ray Tube display located directly in front of each pilot. The Cathode Ray Tube displays primary flight information and is called a Vertical Situation Display. The B-1B aircraft, as presently configured, provides the Instrument Landing System navigational information to each pilot through the Vertical Situation Display (Reynolds, Purvis, & Marshak, 1990). Primary flight navigation information such as: attitude, airspeed, altitude, heading and steering information is provided on this display. The B-1B Vertical Situation Display can be considered an integral, object display. An integral object display according to Wickens (1984) provides the most compatible means of providing the supervisor (in our application, pilot) with an overall representation. The small airplane symbol on the B-1B Vertical Situation Display remains fixed in the center of the display relative to the world around it. Sky/ground shading and movement of pitch and roll axes are represented to the pilot from an inside the aircraft perspective looking outside. The representation of the glideslope and localizer beams and locations during an instrument approach to landing are represented by the dots and cursor combination on the Vertical Situation Display.

One of the many design requirements for this aircraft was that it be capable of precision approaches using earth referenced navigational sources such as an Instrument Landing System provides. The B-1B presents attitude information on the Vertical Situation Display with a fixed aircraft symbol and a moving horizon, thus the display is aircraft-referenced. The B-1B displays airspeed information to the pilot on the Vertical Situation Display in either indicated, true, or ground-referenced (see Appendix A). Indicated airspeed is used for an approach-to-landing. Altitude information is provided in either an absolute term, Above Ground Level or referenced to a sea level datum called Mean Sea Level. Heading information is the direction the aircraft is traveling with either an earth reference to true or magnetic North.

The B-1B flight station Vertical Situation Display as seen in

Figure 6 is unique. It is the only aircraft known to integrate both an Attitude Direction Indicator and Horizontal Situation Indicator information on the same Head Down Display.

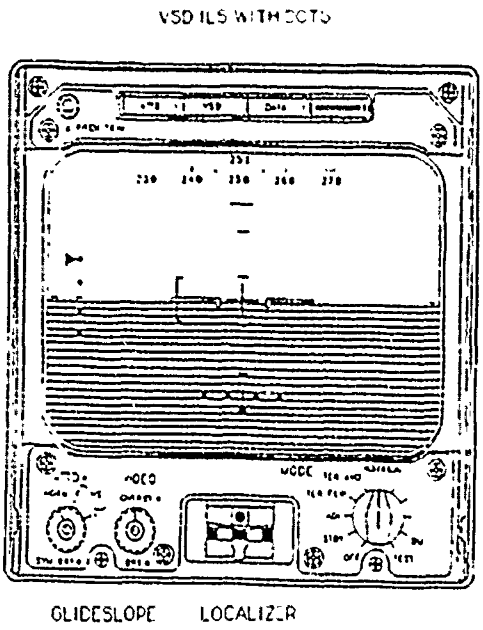


Figure 6. VERTICAL SITUATION DISPLAY

FLIGHT DIRECTOR DESIGN

Until the B-1B bomber became operational, all flight directors contained both flight director steering information and raw glideslope and localizer information. Electromechanical system designs dictated that if the primary steering information was not available due to either a component failure or indicator malfunction, flight crews could fly the approach-to-landing, albeit less precisely with the raw data display.

The B-1B flight station Vertical Situation Display Instrument Landing System was originally designed without any raw glideslope or localizer data; only flight director steering information was provided. Recently the B-1B flight station Vertical Situation Display formats, used for the display of both navigation and status information were redesigned to incorporate raw glideslope and localizer information (Purvis, Green, St. John, Reynolds, & Lovering, 1988). Aircraft that contain multiple Cathode Ray Tube systems are typically called Electronic Flight Instrument System aircraft. However, unlike the B-1B, previous commercial and military Electronic Flight Instrument System displays have not changed in orientation or color from that of their older analog counterparts, an electronic Attitude Direction Indicator looks like an electromechanical Attitude Direction Indicator. All currently produced Electronic Flight Instrument System displays provide the same Horizontal Situation Indicator layout with raw glideslope and localizer information although that information is no longer required by the FAA to be on the display.

B-1B pilots are presented with steering commands that must first be integrated by the flight director computer before they are presented on the Vertical Situation Display. As can be seen in Figure 7, the flight director control panel must be in one of the active flight director modes before any steering commands are provided to the Vertical Situation Display. When the flight director panel is in the off position (see Figure 7), the steering bars are removed (stowed) and no steering information is presented.

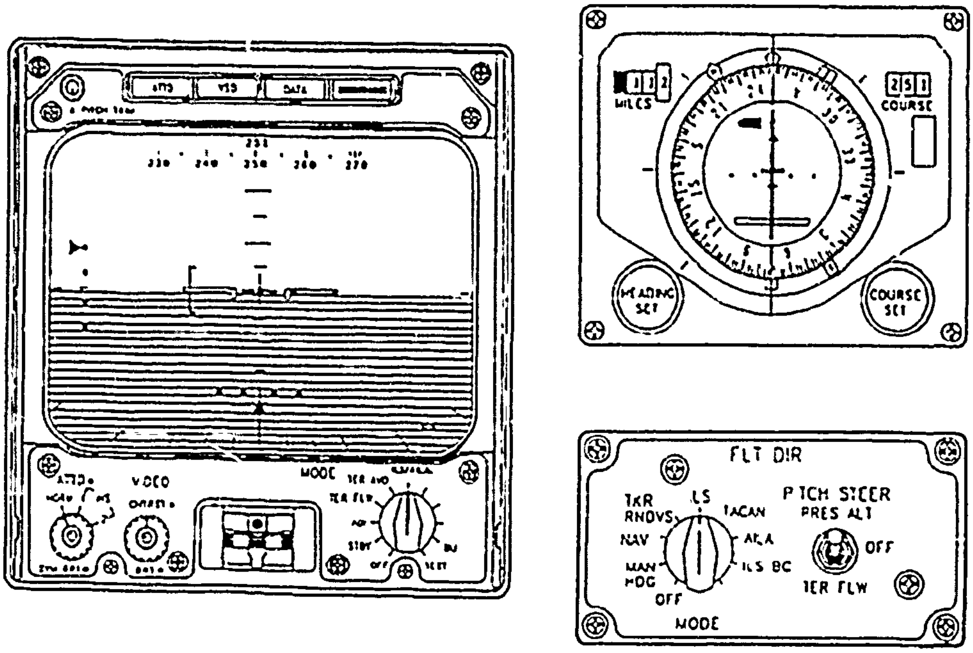


Figure 7. VERTICAL SITUATION DISPLAY WITH FLIGHT DIRECTOR

The B-1B flight director provides steering information to the pilot in the shape of a steering cross. The flight director steering cross only provides steering information during the Instrument Landing System approach. The raw glideslope and localizer data presented on the Vertical Situation Display in dot form, reinforce or confirm the flight director steering commands. Typically a flight instrumentation system provides this raw data in the event that a mechanical failure disables the flight director. However digital display systems typically require all data to be input into the flight director system before display presentation. This makes the raw data display redundant if used as a back-up to the flight director. If a flight director component or Vertical Situation Display fails, no partial degraded capability exists and whatever backup analog, electromechanical instrument is available becomes the only means of presenting navigation information.

The Vertical Situation Display presents raw glideslope and localizer information as a series of fixed dots that represent the beamwidth of the guidance signals. Figure 8 depicts this display. The glideslope dots (arrow A) are located on the left side of the screen and the localizer dots (arrow A) are located on the bottom of the screen. The moving triangular symbol represents the center of that beam and the dots are fixed.

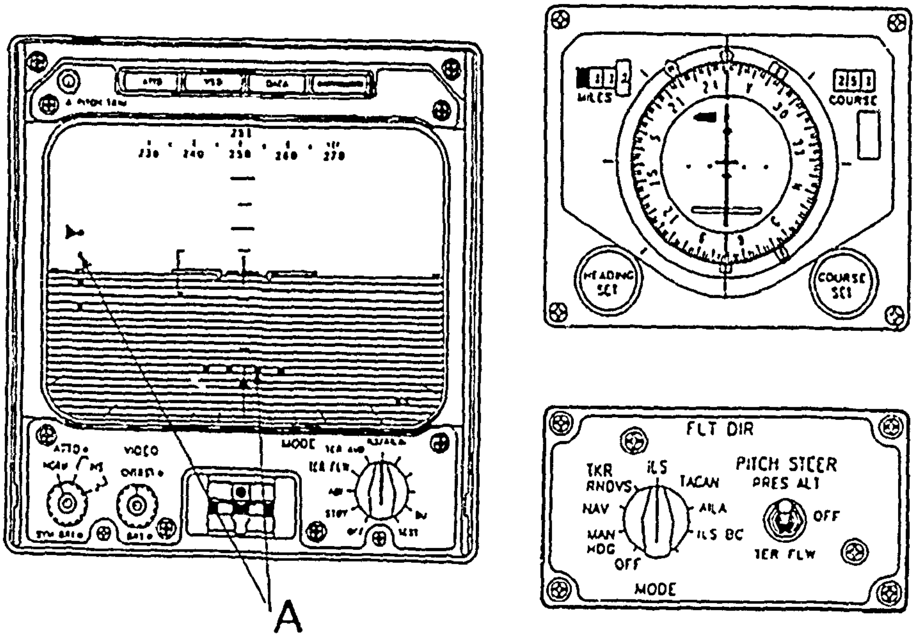


Figure 8. VERTICAL SITUATION DISPLAY WITH RAW GLIDESLOPE AND LOCALIZER DOTS

Illustrated in Figure 9, arrow A points to the location of the Horizontal Situation Indicator. Notice that it is located well below the Vertical Situation Display, arrow C. The B-1B Horizontal Situation Indicator provides only lateral steering information, no glideslope information is provided. The Horizontal Situation Indicator serves as a partial electromechanical back-up to the Vertical Situation Display. The Vertical Situation Display is considered the primary navigational instrument for instrument flight. The Horizontal Situation Indicator backup would be suitable for only non-precision approaches due to the lack of vertical guidance information.

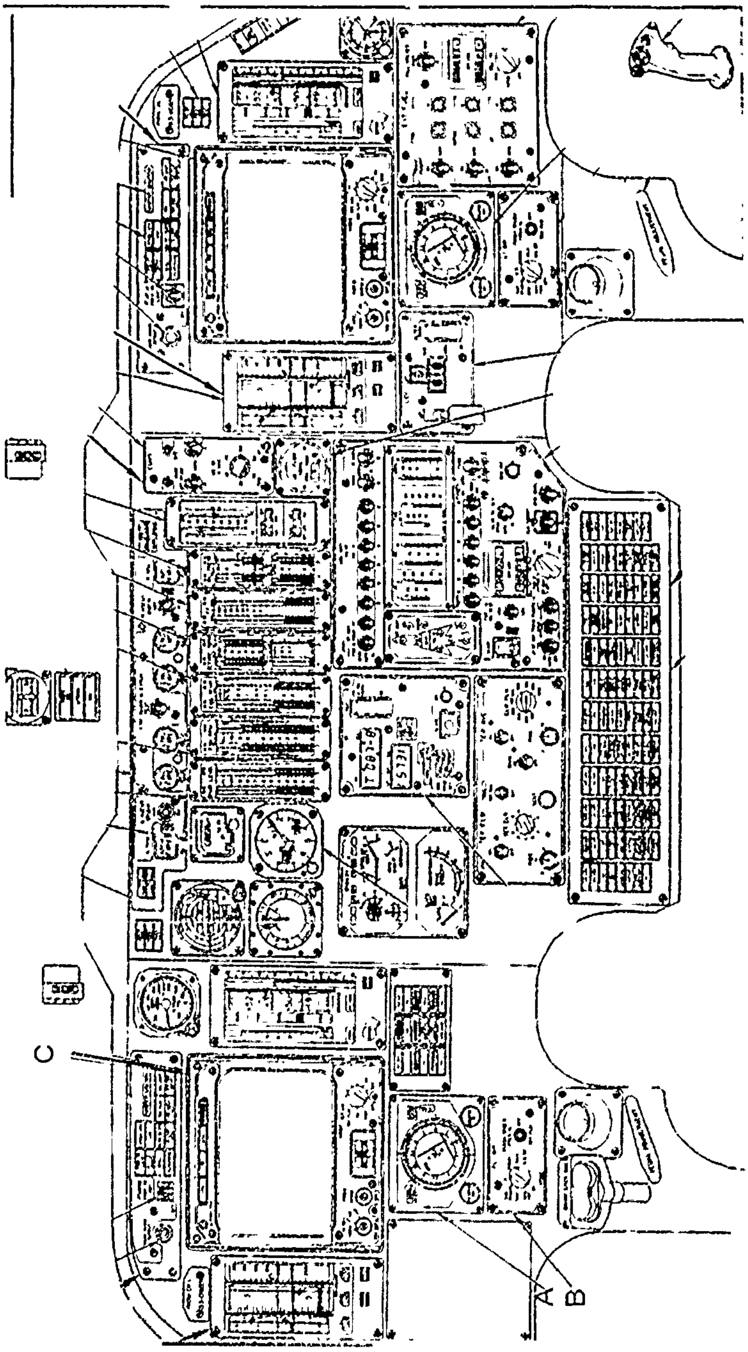
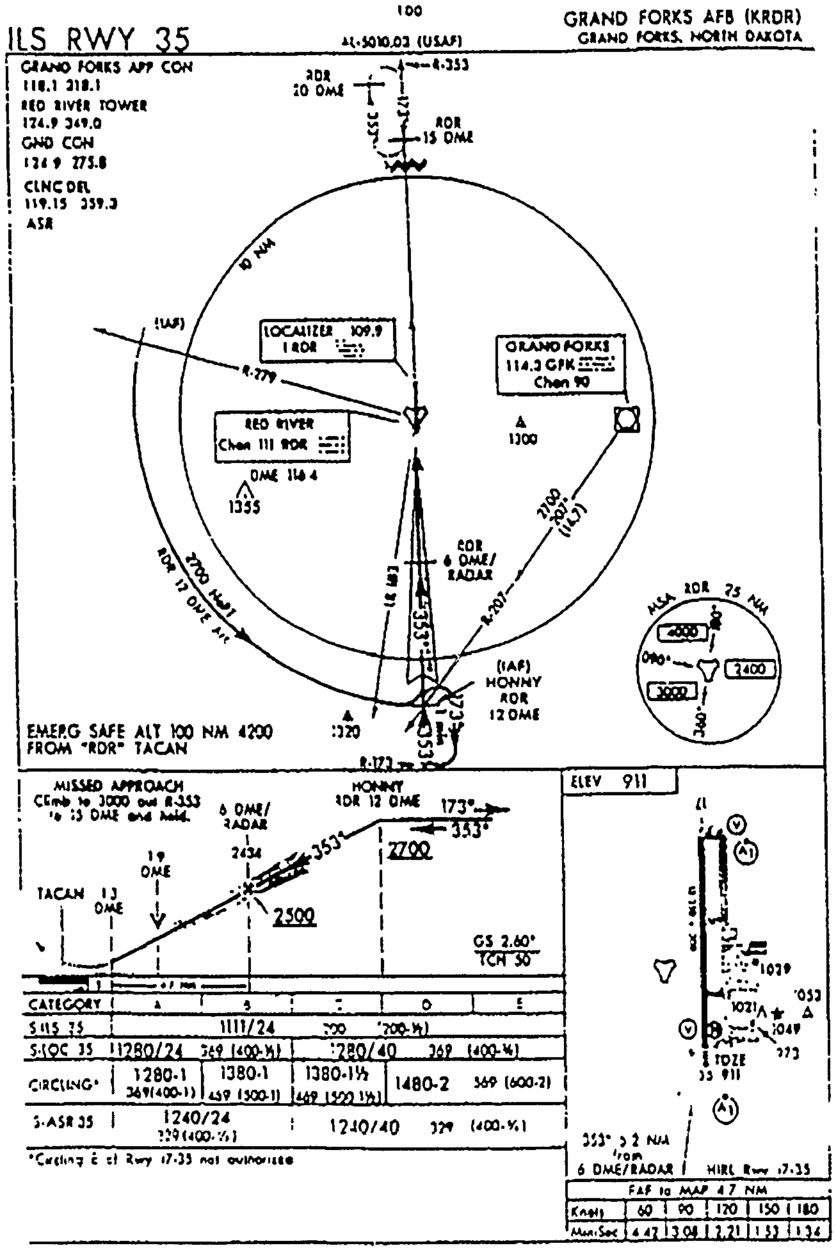


Figure 9. B-1B FLIGHT STATION

The B-1B is provided with both Distance Measuring Equipment and marker beacons as sources of information. The design philosophy was to provide the pilot with a known location from which he could maintain situational awareness during an approach-to-landing. If for example, the Instrument Landing System glideslope beam fails during the approach, the pilot must revert to a non-precision approach and rely upon the marker beacons and Distance Measuring Equipment to provide both timing and positional information. A non-precision approach requires a different technique than that used for a precision Instrument Landing System. However both precision and non-precision approaches will demand the same level of concentration from the pilot. The pilot must be able to predict what the state of the aircraft is and where the runway environment will be. The paper tool that the pilot uses to visualize the approach-to-landing is called an approach plate. The approach plate is also used as an aid for prediction and is provided in a plan and profile view of topography surrounding the airfield. A typical Instrument Landing System approach plate is seen in Figure 10. Both plan and profile views of the Instrument Landing System are shown to scale unless otherwise noted.



CATEGORY	A	B	C	D	E
S-ILS 35	1111/24		200 (200-½)		
S-LOC 35	1280/24 369 (400-½)		1280/40 369 (400-¾)		
CIRCLING*	1280-1 369 (400-1)	1380-1 469 (500-1)	1380-1½ 469 (500-1½)	1480-2 569 (600-2)	
S-ASR 35	1240/24 329 (400-½)		1240/40 329 (400-¾)		

*Circling E of Rwy 17-35 not authorized

FAF to MAP 4.7 NM					
Knots	60	90	120	150	180
Min:Sec	4:42	3:08	2:21	1:53	1:34

Figure 10. INSTRUMENT APPROACH PLATE

Every Instrument Landing System approach is both similar and unique. Each Instrument Landing System has a localizer and glideslope beam that become narrower the closer the aircraft is to the landing threshold. Each Instrument Landing System consists of a gradual descent of approximately 3 degrees to a minimum altitude, the Decision Height.

However variables such as wind velocity and direction, Glide Slope Intercept Point, glideslope angle of descent, direction/distance of localizer intercept, surrounding topography, and levels of other air traffic are always unique. The B-1B steering cross represents command guidance inputs provided by the flight director computer. The Instrument Landing System display provided on the Vertical Situation Display is of the pursuit type, with the input or steering cross separated from the output or aircraft present position.

The Vertical Situation Display has a fixed aircraft symbol and a moving flight director cross. The pilot steers the aircraft symbol in the direction of the steering cross to reduce the error between input and output. The principal advantage of separating input and output signals (Garg, 1988) is that the pilot is better able to monitor the error differential and anticipate his or her input. Another purported strength of this display is that it permits more accurate tracking except when frequencies are very low Kelley (1968).

STATUS AND COMMAND INFORMATION

The design of aircraft navigation displays basically falls into two categories, those that are designed as status displays and those that are designed as command or "quickened" displays.

A status display is one that informs the human operator how the controlled element is responding. Status displays do not provide the pilot information on how to control the system. The pilot must first scan and interpret this information then act to control or modify the system state. For most aircraft, status information is represented by round dial instruments that indicate airspeed, altitude, attitude, vertical velocity, heading, bank angle, glideslope and localizer. The

B-1B Vertical Situation Display however, displays airspeed, attitude, heading, glideslope and localizer information in one central location. The B-1B Vertical Situation Display dot representation of glideslope and localizer presents the pilot with the actual electronic beamwidths and the current aircraft location relative to those beamwidths. Status information provides an indication of how the overall system is performing. The glideslope and localizer dots provides this overall system check during the approach-to-landing task.

A command display differs from a status display in that it informs the operator how the aircraft is to be controlled and provides no information as to the current aircraft state. Aircraft flight directors are the most common form of command displays. The pilot flying an approach to landing task with the aid of a flight director has only to steer the aircraft in the direction that the flight director indicates for a successful outcome. Only tracking skill is required, no pilot interpretation is necessary. Command displays require operators to receive very little training before being able to use the display (Kelley, 1968). For a more in depth review of command and status display types see Kelley (1968) or Poulton (1974).

Our interest is in determining which display provides better performance on an approach-to-landing task, a command display or a command plus status display. According to Kelley (1968) and Garg (1988), the advantage of providing the actual error (status information) with command steering information is that better true performance will result, with less root mean square error. The results of flight simulation work performed by Garg (1988) indicate that augmenting command information with status information improved the performance (reduced root mean square error) of pilots for levels of display quickening between 0.032 and 0.373 cm/deg-sec.

A pilot flying an Instrument Landing System approach is concentrating on correcting deviations from glideslope and localizer centerline which, according to control behavior models proposed by Kelley (1968), Poulton (1974) and Rasmussen (1981), are inner-loop activities. Inner-loop activities are those activities that are necessary for maintenance of a control system. Kelley (1968) has described this as part of a hierarchical control loop process with the foundation being the inner-loop control process. In aviation, pitch controls vertical attitude, vertical attitude controls vertical displacement from flight path. Pitch and roll control are considered inner-loop processes or as stated by Kelley (1968), zero-order control loops. A zero-order control loop is the lowest control order in Kelley's (1968) hierarchy. Three control orders are possible, zero-order, first-order, and second-order. A first-order control process such as vertical attitude determines the second-order control process of vertical displacement from flight path. An inner-loop control process can be a zero, first, or second order system. Usually zero or first order systems are selected as inner-loop control processes. Poulton (1974) has demonstrated that the human is best suited to tracking position (zero order) or velocity (first order) systems and poorly suited to tracking acceleration (second order) systems.

Outer-loop activities are considered by Poulton (1974) and Kelley (1968) to be the output of the inner-loop activities. Outer-loop activities can be first or second order control processes. A pilot flying an Instrument Landing System approach is typically provided with an assigned heading that is maintained until intercepting the localizer course. The inner-loop control process (zero order) of banking the aircraft will change the outer-loop control process (first order) of aircraft heading. However once the aircraft is established on the localizer beam, aircraft flight path becomes the outer-loop activity which is dependent upon aircraft heading. Control of glideslope and localizer are outer-loop activities. Kelley (1968) considers this linear ordering of control loop activities to be consistent with the pilots internal model for the variable under control. Instrument student pilots are provided with this hierarchical model for roll and pitch. As their training progresses they understand the cause and effect of their control inputs. Once these control loop activities are well practiced, the lower order control loops become automatic (Rasmussen, 1981). Additional attentional capacity is then made available to the pilot for monitoring and control of higher order (outer-loop) control activities. Rasmussen's (1981) model of operator performance agrees with Kelley (1968) and Poulton (1974). However instead of a linear ordering of control loop hierarchy as proposed by Kelley (1968), Rasmussen's methodology is distinguished by three levels of operator behavior: skill-based behavior, rule-based behavior, and knowledge-based behavior. These three levels focus on the behavior of the human and not whether the human is tracking a zero, first, or second order control system. Rasmussen's model assumes that the order of the control system is properly suited to the capabilities of the human operator and that decisions can be made at any of the three behavior levels. Skilled-based behavior is defined as highly practiced, inner-loop, automatic, nearly effortless behavior and is characteristic of manual control. Rule-based behavior is defined as a series of rules taught to an operator (i.e.instrument student) that may eventually transition to skill-based behavior. Rule-based behavior is the closest approximation to the outer-loop decision processing strategy proposed by Kelley (1968), and Poulton (1974).

The human operator can be considered an adaptive controller (Kelley, 1968); control is maintained in the face of change. Adaptive, as used by Kelley (1968), is synonymous with the classical control theory term of optimal control (Kleinman, Baron, & Levison, 1970). Optimal control can only be achieved if there is a comparison between the present state and optimal state. The optimal control model is a human operator model that provides a differential weighting schema for the variables manipulated by the model. The optimal in optimal control refers to the strategy that a human operator would use in minimizing control errors by adjusting control gains and weightings depending upon the situation.

Optimal control modeling has been successfully applied to the modeling of aircraft flight directors in approach to landing tasks (Kleinman et al., 1970). The B-1B Vertical Situation Display flight director steering cross is considered a command or "quickened" display. This display does not directly tell the pilot what is happening to the system under control, but simply what to do. The inner-loop functions have been computed for the pilot freeing additional attentional capacity for flying the flight director or attending to other cockpit tasks. This is contrasted with raw glideslope and localizer data (outer-loop) which depicts the actual location of the aircraft in relation to the Instrument Landing System. The pilot must mentally compare the flight director steering inputs (command information) against the raw glideslope and localizer data (status information) as a system check of flight director performance. Disagreement between the flight director and the raw glideslope and localizer steering cues is sufficient reason to abort the approach to landing.

Crosscheck of raw data compared with flight director steering inputs is an instrument flying technique that all Air Force pilots are instructed to perform during approach-to-landing. The continuous input of status information (outer-loop) allows the pilot to integrate information and decide on a specific course of action. Status information (outer-loop) is provided to the pilot at a hierarchical level that is compatible with the level at which the decision making process occurs. The decision to continue or abort an approach to landing is not made based on inner-loop information but on outer-loop information. A human model of operator performance presented by Banbridge (1981) and Kelley (1968) suggest that the operator would use a different mental model as he moved from inner to outer-loop control. Optimal control theory modeling (Kleinman *et. al.*, 1970) supports this theory of mental model changes with changes in hierarchy by manipulating the control strategy and weighting of information being input to the model. The pilot's perception of how well the display is functioning effects the confidence that the pilot has in the display. This effects the outcome of an approach to landing in cases that weather is at minimum visibility and ceiling. Subjective dependent measures such as a post-trial questionnaires and the Subjective Workload Dominance Technique (SWORD) should compliment the performance dependent measures collected in this study.

The present study shall try to quantify the impact of status information gain on pilot performance during an approach-to-landing flying task. Part of the problem with flying an approach-to-landing task is that the pilot has no display or true indication of his actual flight path. Deviation from desired flight path can only be observed indirectly by noting the difference between glideslope or localizer position error or flight director steering inputs. Better root mean square tracking performance with command plus status information would indicate that the pilot is benefiting from this additional status information. Presentation of status information (outer-loop) at a hierarchical level compatible with pilot decision making (outer-loop) should reduce the root mean square error if the pilot is able to benefit from this information. The pilot's goal in flying an Instrument Landing System approach is to minimize error on both glideslope and localizer axes thus assuring that the aircraft will be properly positioned for the landing.

POSITIONAL INFORMATION

Aircraft positional information relative to other aircraft and the ground while conducting a navigation task, is considered a requirement by pilots. Pilots are willing to accept higher workload during a flying task if they receive positional information beneficial to them (Hughes, Hassoun, Ward, & Rueb, 1990). The pilot conducting an Instrument Landing System approach is always concerned with the aircraft's position during the approach. Critical locations such as the Glideslope Intercept Point and Decision Height are confirmed by the pilot at a much higher frequency than other sectors of the approach, due to the consequences of being off course. For example, the pilot approaching the Glideslope Intercept Point would be alternating frames of reference between outside-in (to visualize the distance and direction from Glideslope Intercept Point) and inside-out (to maintain correct heading, altitude and airspeed). The goal at this point is one of knowing how many nautical miles from the Glideslope Intercept Point the aircraft is, what the assigned altitude is and what altitude the Glideslope Intercept Point should be, and what compensation is needed to counteract the effects of crosswind. Any deviation from these parameters requires a decision to be made by the pilot as to what system changes are required to reduce the deviations to acceptable levels. While on the glideslope, the pilot continues to change frames of reference typically viewing flight director data inside-out while viewing other information such as the distance in nautical miles the aircraft is from Decision Height or touchdown as outside-in. Frame of reference changes occurs continuously during an approach to landing in instrument conditions. Unlike visual flight conditions where the pilot is easily able to determine his position by looking out the window, during instrument flight the pilot must rely on the instruments inside the cockpit for positional information. Crosswind has its greatest effect during the approach to landing phase of flight, wind direction and velocity change constantly as altitude and aircraft heading change.

One unfortunate aspect of most flight directors is that they were designed as an inside-out instrument. However conceptualization of the aircraft's position requires outside-in perspective of the world. Information such as: where am I, where should I be, and where am I going, can not be obtained from the flight director. The Attitude Direction Indicator is typically represented as inside-out display, the pilot is sitting in the aircraft looking out. The aircraft icon on the Attitude Direction Indicator is fixed and the horizon moves around the icon. An outside-in display provides a perspective of being external to the aircraft looking in. The aircraft flight director steering cross does not provide that external perspective, and conversely provides the perspective of inside-out, moment-to-moment information to the pilot. The Horizontal Situation Indicator, marker beacons, Distance Measuring Equipment, and compass locators all attempt to provide the pilot with the positional information that is lacking in a more centralized display form. The Horizontal Situation Indicator provides the lateral cue as to left/right while the other cues inform the pilot of where horizontally the aircraft is located, the altimeter provides the vertical or height cue. Subjective pilot comments and performance data observed in simulators (Wickens 1984) and aircraft suggest that pilots switch states from outside-in to inside-out perspective and then back again. This may account for the reported occurrence of pilots who have been observed misinterpreting the Attitude Direction Indicator and inputting an incorrect control input (Roscoe; 1968, 1980, Wickens, *et al*., 198[illegible],.

Pilot control reversals have been attributed to lack of a stable frame of reference (Wickens, 1984) available to pilots. If the pilot is visualizing information from an outside-in perspective (glideslope and localizer dots) and acting on information presented in an inside-out perspective (Attitude Direction Indicator), incorrect pilot control inputs could result. Aircraft positional information in relation to other aircraft as well as navigation aides (Smith, Ellis, & Lee, 1984) has been reported as critical to pilots. There appears to be limited information that addresses the issue of positional information in an aircraft navigational context. The use of dots in this study to represent glideslope and localizer positional information may not be the most optimal method of providing the outside-in perspective. However, this method is the typical representation of glideslope and localizer information that is provided to almost all civilian and military aircraft flying today. The dot representation of glideslope and localizer data help to bound the area that the aircraft should be within during an instrument approach. The location of the dot cursor, the rate of cursor movement and the direction of travel are available sources of information to the pilot during an instrument approach. Outside-in information provided by the dots is only related to the beamwidths of the localizer and glideslope.

The purpose of this research effort was to evaluate how pilots use the information content of two modified navigation formats displayed on the B-1B Vertical Situation Display during simulated approach-to-landings with and without crosswind conditions. The effects of command and status plus command information were provided to the pilots for evaluation.

One hypothesis is proposed for this study. The hypothesis posits that the addition of glideslope and localizer raw data (status information) to the flight director (command display) will be confirmatory and reinforce the flying strategy of the pilot. Pilot performance using raw data and flight director information will be better (less root mean square error) than with only the flight director. Outer-loop information provided by the glideslope and localizer dots will provide trend and position information that is not available from the flight director.

SECTION 2

METHODS

SUBJECTS

Twelve proficient and alert-qualified United Stated Air Force B-1B pilots served as subjects for this study. The subjects were male and had a mean of 1153 flying hours (range= 367 to 4800 hrs) in a variety of different aircraft and were instrument certified in the B-1B aircraft. All subjects regularly flew the Engineering Research Simulator for pilot proficiency as well as the B-1B Weapon Systems Trainer and the aircraft.

APPARATUS

A fixed-base B-1B Engineering Research Simulator located at Grand Forks Air Force Base, North Dakota, was used to evaluate pilot performance with two Instrument Landing System displays. The simulator had neither an out-the-window visual system nor motion base, but it fully modeled the displays and controls, flight and instrument characteristics of the B-1B bomber (Purvis, Reynolds, & Marshak, 1990). Each pilot flew a total of 16 (8 Dot and 8 No dot) simulated Instrument Landing System approaches to Grand Forks AFB ILS runway 35. The initial conditions of the simulator at the beginning of each trial were: (a) The aircraft was configured for an approach to landing, (b) the proper approach airspeed and angle of attack were set for the approach, (c) the landing gear, flaps and slats were down and locked, and (d) engine power was appropriately adjusted for the approach.

EXPERIMENTAL DESIGN

A 2 X 2 X 2 repeated-measures factorial design was used. The three factors were: Display type (dots showing glideslope and localizer raw data vs. no dots), wind condition (winds on or off), and approach initialization point (8 vs. 18NM). The raw data display had five fixed dots along the left side (vertically) of the Vertical Situation Display representing glideslope beam orientation. Five fixed dots were centered (horizontally) along the bottom of the Vertical Situation Display, representing localizer beam orientation. A moving symbol (triangle), adjacent to the dots, represented the centerline of the steering beam. The wind was either active at a 45 degree angle of intercept to the localizer at a velocity of 24 knots diminishing to 10 knots at decision height or it was not active. A complete wind model is provided in Appendix B. Wind was provided because it significantly determined the difficulty level of the approach and increased realism. The initial approach condition, as seen in Figure 11, was either 8 nautical miles from touchdown at an angle of 20 degrees to the localizer beam or 18 nautical miles at a 55 degree angle to the localizer beam. The shorter approach was considered the more difficult of the two approach conditions because the aircraft would intercept the glideslope and localizer almost immediately upon simulator release.

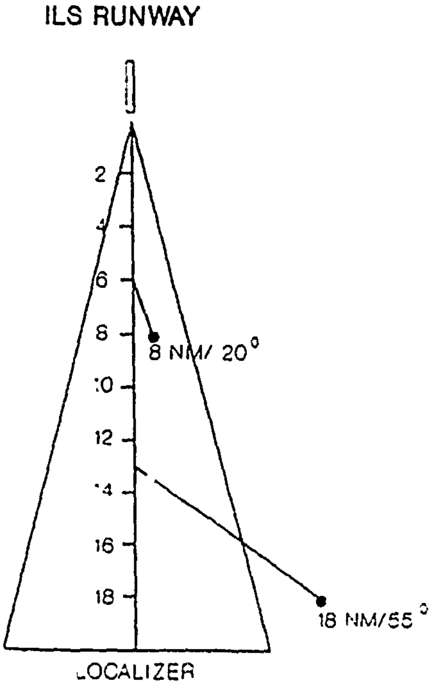
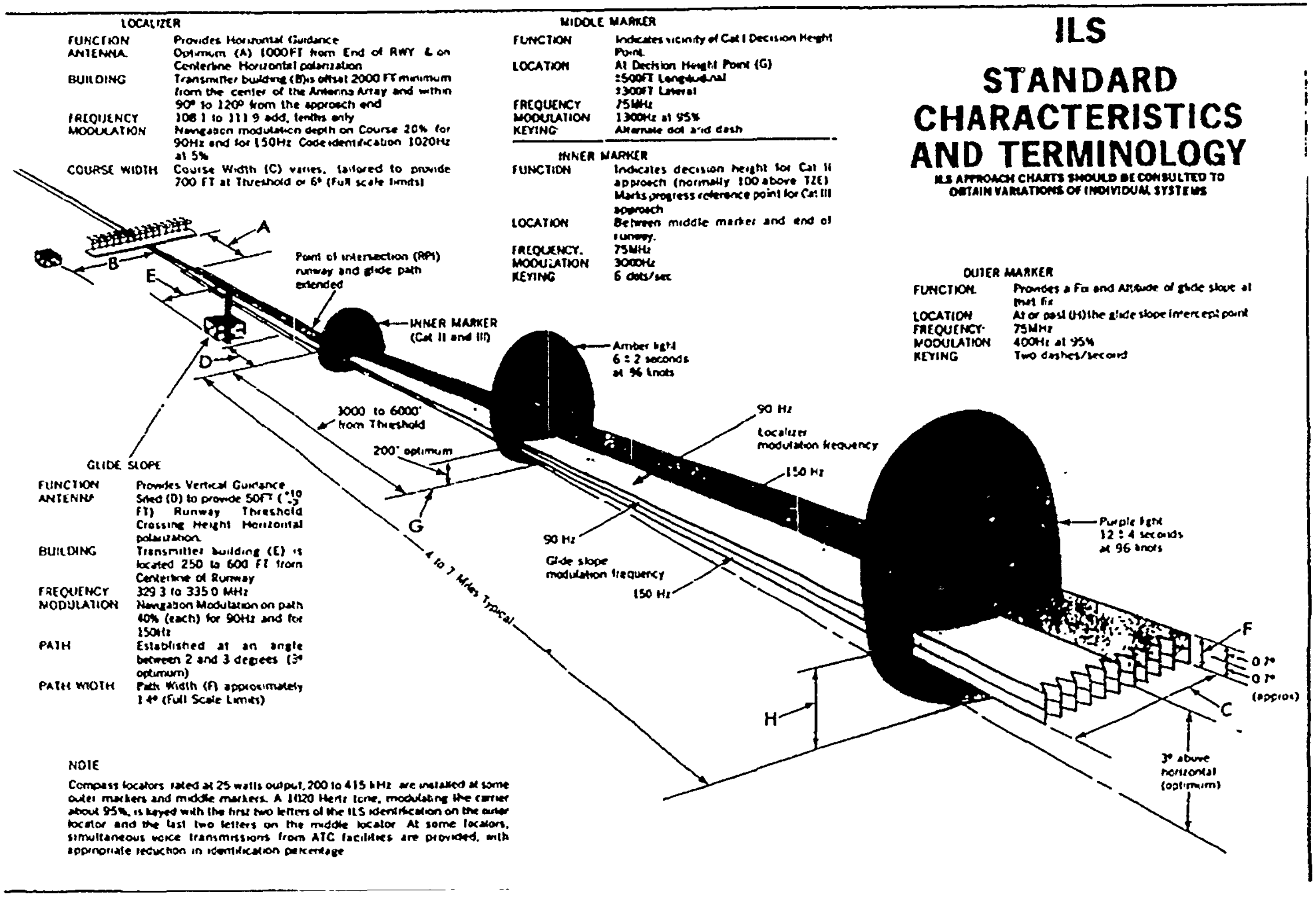


Figure 11. Initial Starting Conditions

Localizer intercept angle and distance also directly affect approach difficulty. Steep angles of localizer intercept make for a more difficult approach due to the likelihood of overshooting the localizer. Short approach distances before glideslope intercept also increase the approach difficulty due to the limited amount of time available before capturing the glideslope.

Six simulator dependent variables were collected in this study. These variables were: 1) glideslope deviation, 2) localizer deviation, 3) lateral alignment at decision height, 4) deviation from target airspeed (in knots), 5) Roll rate variability and 6) Pitch rate variability. An expanded explanation of each dependent variable is provided in Appendix A. Prior research (Roscoe, 1968; Inderbitzen, Miller, & Wiener, 1989) has found that these dependent variables were the most sensitive of the available flight parameters. Five subjective dependent measures were collected in this study. These measures were: 1) a confidence index (collected before each subject flew the simulator), 2) SWORD, 3 & 4) a short questionnaire administered following each block of trials, and 5) a nine question comparative questionnaire administered following test completion. SWORD is a subjective workload technique that requests a subject's estimation of workload experienced utilizing one system as compared to another system, employing the same or similar tasks. SWORD is a paired-comparison technique (Vidulich, Ward & Schueren 1991) and the pilots compare each of the pairs formed by the 8 experimental conditions used. The response scale is composed of two scales with nine levels of dominance that can favor either task. SWORD data is next converted into a judgment matrix which is normalized and as such has a range of between zero and one. The calculation of SWORD ratings is obtained from this matrix.

The Instrument Landing System as seen in Figure 12 becomes progressively narrower as you travel closer to the beam origin. In this study, the degree of displacement from the centerline of the glideslope and localizer beams during the approach was measured. Greater variability was expected during the initial capture of the localizer. These data were collected for trend information but no analyses were performed until the aircraft was established on the localizer beam. As the aircraft approaches the origin of the localizer beam, beamwidth (in feet) is decreased due to its proximity. A tighter tolerance was expected to be applied here due to the consequences of being off axis on either glideslope or localizer. Air Force Manual (AFM) 51-37 provides guidance as to what tolerance is acceptable before the pilot is required to execute a missed approach. Specified tolerance is one dot low or two dots high on glideslope or full scale deflection of the localizer display needle.



ILS

STANDARD CHARACTERISTICS AND TERMINOLOGY

ILS APPROACH CHARTS SHOULD BE CONSULTED TO OBTAIN VARIATIONS OF INDIVIDUAL SYSTEMS

LOCALIZER

FUNCTION	Provides Horizontal Guidance
ANTENNA	Optimum (A) 1000FT from End of RWY & on Centerline Horizontal polarization
BUILDING	Transmitter building (B) is offset 2000 FT minimum from the center of the Antenna Array and within 90° to 120° from the approach end
FREQUENCY	108.1 to 111.9 odd, tenths only
MODULATION	Navigation modulation depth on Course 20% for 90Hz and for 150Hz Code identification 1020Hz at 5%
COURSE WIDTH	Course Width (C) varies, tailored to provide 700 FT at Threshold or 6° (Full scale limits)

MIDDLE MARKER

FUNCTION	Indicates vicinity of Cat I Decision Height Point.
LOCATION	At Decision Height Point (G) ±500FT Longitudinal ±300FT Lateral
FREQUENCY	75MHz
MODULATION	1300Hz at 95%
KEYING	Alternate dot and dash

INNER MARKER

FUNCTION	Indicates decision height for Cat II approach (normally 100 above TZE) Marks progress reference point for Cat III approach
LOCATION	Between middle marker and end of runway.
FREQUENCY.	75MHz
MODULATION	3000Hz
KEYING	6 dots/sec

OUTER MARKER

FUNCTION.	Provides a Fix and Altitude of glide slope at that fix
LOCATION	At or past (H) the glide slope intercept point
FREQUENCY·	75MHz
MODULATION	400Hz at 95%
KEYING	Two dashes/second

GLIDE SLOPE

FUNCTION	Provides Vertical Guidance
ANTENNA	Sited (D) to provide 50FT $(^{+10}_{-5}$ FT) Runway Threshold Crossing Height Horizontal polarization.
BUILDING	Transmitter building (E) is located 250 to 600 FT from Centerline of Runway
FREQUENCY	329.3 to 335.0 MHz
MODULATION	Navigation Modulation on path 40% (each) for 90Hz and for 150Hz
PATH	Established at an angle between 2 and 3 degrees (3° optimum)
PATH WIDTH	Path Width (F) approximately 1.4° (Full Scale Limits)

NOTE

Compass locators rated at 25 watts output, 200 to 415 kHz are installed at some outer markers and middle markers. A 1020 Hertz tone, modulating the carrier about 95%, is keyed with the first two letters of the ILS identification on the outer locator and the last two letters on the middle locator. At some locators, simultaneous voice transmissions from ATC facilities are provided, with appropriate reduction in identification percentage

Figure 12. Instrument Landing System, from AFM 55-37 (1986)

PROCEDURE

Briefing Phase Each pilot received a briefing prior to flying the simulator for display evaluation. The briefing consisted of a description of the changes made to the existing B-1B Instrument Landing System display during which he also was given a handout illustrating the changes. The purpose of the study was explained and he was told the approximate amount of time required for his participation. Next a facility orientation and safety briefing was conducted followed by the signing of a standard Armstrong Laboratories consent form. A copy of the Armstrong Laboratory consent form is provided in Appendix C. After signing the consent form the pilot filled out a short confidence questionnaire.

The pilots were instructed to perform the simulated Instrument Landing System approaches as precisely as possible. Emphasis was placed on attention to beam alignment, roll/pitch rates and maintenance of target airspeed.

Testing Phase The pilot was free to ask any questions prior to the start of testing. The Horizontal Situation Indicator was covered so that only Distance Measuring Equipment information was exposed. This was done to eliminate any source of raw dot information except for that provided on the Vertical Situation Display.

Normally all pilots are required to fly the simulator at least once per month to maintain their instrument proficiency. Nonetheless, all pilots had to fly two practice Instrument Landing System trials before the beginning of each block of 8 trials. A short break was provided then testing resumed with two practice trials followed by 8 test trials. The two conditions tested, display with raw data in dot form or no raw data, were separated into two blocks of 8 trials. Once a subject started a block, all trials were either dot or no dot conditions. Blocks were counterbalanced across subjects. Twelve random patterns of 16 treatment conditions (2 replications of the 8 experimental cells) were implemented for this study. The 12 testing orders were randomly assigned to subjects. Orders were determined so that each wind and distance condition occur equally often. The four possible conditions occurred equally often in each set of four trials. Wind was presented in ABBA or BAAB order while distance was presented in AABB or BABA order. The testing order for each pilot is given in Appendix D.

The experimenters informed the pilot prior to the beginning of each trial what the initial conditions were, but not whether wind was or was not present. After the pilot completed two practice trials, the data collection trials began. Each simulator trial was expected to last between three to six minutes, depending upon the initial starting point. The simulator required approximately one minute to be reset. A new trial was then initiated upon the pilot's release command. After completing all trials in one block, the pilot was given a short break during which he was asked to complete a short questionnaire that requested his opinion on the display he had just flown. Once the questionnaire was completed, the pilot re-entered the simulator and the retesting began on the second block of eight trials. The pilot was again provided with two practice trials before the actual testing started. Upon completion of the second block of trials, the pilot was requested to complete the same questionnaire that was administered after the first block of trials. Once this short questionnaire was completed,

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and decision height was reached at approximately 0.5 nautical mile from the runway threshold. Six dependent variables were analyzed, but only four variables were statistically significant. The four dependent measures were: localizer deviation, glideslope deviation, pitch rate variability, and roll rate variability. Root mean square error was analyzed by measuring the deviation (absolute) from the mean or referenced position. Airspeed and altitude were not sensitive dependent measures and are not reported.

Localizer Deviation The addition of dots on the display showing raw status information increased the mean root mean square error made on localizer performance, $F(1,10) = 5.45$, $p < .05$. Without dots on the display, the root mean square localizer error was 0.020 degrees, but this increased to 0.028 degrees when the dots were added. Thus, the redesigned display decreased performance. As Table 1 shows, the nearer starting distance (8NM) also produced larger localizer error than the farther starting distance did, $F(1,10) = 24.35$, $p < .001$. Mean root mean square localizer error was 0.031 degrees for the nearer condition compared to 0.017 degrees for the farther condition. Greater localizer error was an expected result for the shorter approach starting point and confirmed the original intent of increasing task difficulty. Wind condition was also important for localizer performance. As Table 1 shows, mean localizer root mean square error increased from 0.017 degrees without wind to 0.031 degrees when wind was present, $F(1,10) = 26.99$, $p < .001$.

TABLE 1. Localizer Root Mean square Error

LOCALIZER RMSE (degrees)

	WIND ON		WIND OFF		
	8 NM	18 NM	8 NM	18 NM	MEAN
DOTS ON	.055	.019	.021	.018	.028
DOTS OFF	.031	.017	.016	.014	.020

As Figure 13 shows, performance with the wind on and near starting distance was poorer (0.043 degrees) than it was for the 18 nautical mile experimental condition (0.018 degrees) for either wind condition. The wind X approach interaction was statistically significant, F(1,10) = 25.9, p <.001. With no crosswind, performance was similar for 18 nautical miles (0.018 degrees) and for 8 nautical miles (0.016 degrees).

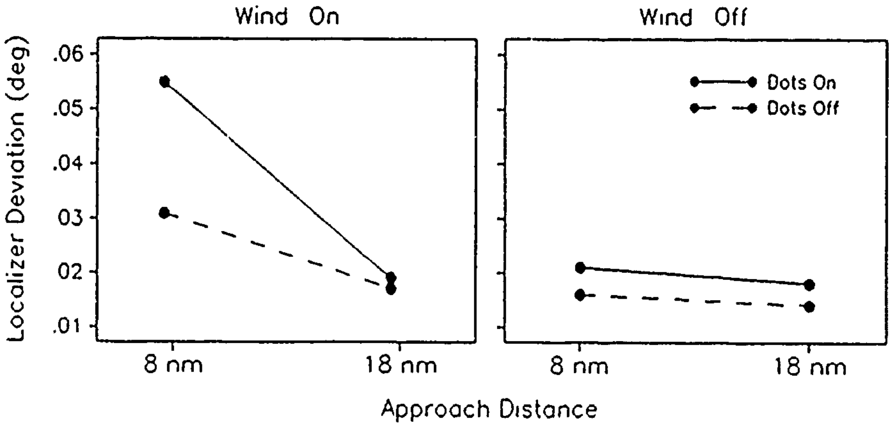


FIGURE 13. Localizer Deviation for All Conditions

The dot X approach and dot X wind interactions were not statistically significant, F(1,10) = 4.58, p >.05 and F(1,10) < 1.0, p >.05, respectively. Figure 13 shows the interaction of dots X approach X wind for the dependent variable localizer. This interaction was not found to be statistically significant, F(1,10) = 4.27, p >.05. The complete ANOVA table can be found in Appendix G.

Glideslope Deviation Unlike the localizer deviation, mean root mean square error for the glideslope deviation was higher for the no dots display compared with the dots display, F(1,10) =6.08, p < .05. As Table 2 shows, mean root mean square glideslope deviation was 0.070 degrees when the display without dots was used. Adding dots to the axes decreased deviation by 0.010 degrees. Mean glideslope deviation was also higher for the wind on condition (0.069 degrees) than for the wind off condition (0.061 degrees), F(1,10) = 9.12, p < .01. Neither the effect of approach, F(1,10) <1.0, p >.05, nor the interaction of wind X approach, F(1,10) = 1.74, p >.05 were statistically significant. The interactions of dots X approach, F(1,10) <1.0, p >.05 and dots X wind, F(1,10) <1.0, p >.05 were not statistically significant. The interaction of dots X approach X wind was not statistically significant, F(1,10) = 1.01, p >.05.

TABLE 2. Glideslope Root Mean square Across All Conditions

GLIDE SLOPE RMSE (degrees)

	WIND ON		WIND OFF		
	8 NM	18 NM	8 NM	18 NM	MEAN
DOTS ON	.068	.059	.058	.054	.060
DOTS OFF	.079	.071	.059	.071	.070

Pitch Rate Variability Pitch rate variability differences were not significant for the dots on compared to dots off conditions, $F(1,10) < 1.0$, $p > .05$. Pitch rate variability was about the same (0.200 degrees) for the 8NM starting point and the 18NM starting point (0.207 degrees); this difference was not statistically significant, $F(1,10) = 2.93$, $p > .05$. Application of a crosswind produced greater pitch rate variability (0.210 degrees) compared to a wind off condition (0.197 degrees). This difference was statistically significant, $F(1,10) = 12.22$, $p < .01$. The interaction of dots X approach, $F(1,10) < 1.0$, $p > .05$, dots X wind, $F(1,10) < 1.0$, $p > .05$ and dots X approach X wind, $F(1,10) = 4.87$, $p > .05$, were not statistically significant. The interaction of winds X approach was significant, $F(1,10) = 8.76$, $p < .05$. With 8NM approaches, pitch rate variability was reduced when pilots flew without wind (0.188 degrees) compared to the wind on condition (0.212 degrees). In contrast, when pilots started their approach 18NM out, there was only a 0.002 degrees difference (0.208-0.206) in pitch rate variability with the wind on and wind off conditions.

Figure 14 shows pitch rate means with all independent variables. Although Figure 14 suggests that a three way interaction may be present, the interaction of dots X approach X wind was close, $p = .0518$ but did not attain the 0.05 level of confidence.

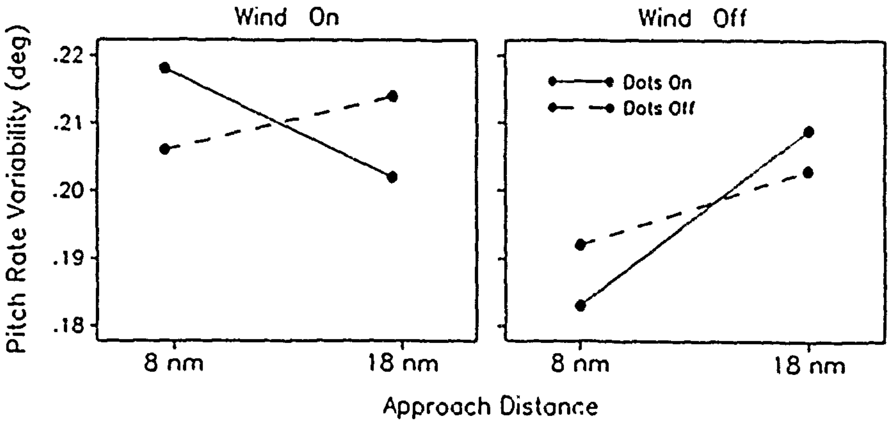


Figure 14. Pitch Rate Variability with All Conditions

Roll Rate Variability Roll rate variability was not significantly affected by dots on or dots off conditions, F(1,10) =2.22, p >.05. The interaction of dots X approach, F(1,10) <1.0, p >.05, dots X wind, F(1,10) <1.0, p >.05, and dots X approach X wind, F(1,10) <1.0, p >.05, were not significant for roll rate variability. However, pilots had greater roll rate variability for the shorter starting position of 8 nautical miles, (0.202 degrees) than the 18 nautical miles starting position, (0.172 degrees), F(1,10) = 104.21, p < .001. Table 3 shows mean roll rate variability for all experimental conditions.

Table 3. Roll Rate Variability with All Conditions

ROLL RMSE (degrees)

	WIND ON		WIND OFF		
	8NM	18NM	8NM	18NM	MEAN
DOTS ON	.224	.169	.196	.185	.193
DOTS OFF	.204	.159	.183	.177	.181
MEAN	.214	.164	.190	.181	

The interaction of wind X approach was also significant for roll rate variability, $F(1,10) = 18.03$, $p < .01$. Pilot performance flying the shorter, 8 nautical miles, starting condition with wind on produced the greatest variability. The mean was 0.214 degrees compared to mean of 0.190 for the same condition with wind off, a difference of 0.024 degrees. At an 18 nautical miles starting condition, wind did not increase variability, or if anything decreased variability by 0.017 degrees. The interaction of wind X approach was expected and confirm the intent of increasing task difficulty for the shorter approach and wind on conditions. Unexpectedly only approach produced a significant main effect; wind did not. No other main effects or interactions were statistically significant. The complete ANOVA table can be found in Appendix G.

SUBJECTIVE DATA

Table 4 presents the SWORD mean ratings. The data were analyzed using a 2 X 2 X 2 repeated-measures ANOVA with display type (dots or no dots), wind (on or off), and approach (8 or 18 nautical miles) as factors.

TABLE 4. SWORD Means Across All Conditions

SWORD MEAN RATINGS

WIND	ON		OFF		MEAN
APPROACH	8NM	18NM	8NM	18NM	
DOTS ON	.1936	.1105	.1321	.0845	.1302
DOTS OFF	.1727	.0883	.1417	.0767	1199
MEAN	.1832	.0994	.1369	.0806	.1250
GRAND MEAN	.1413		.1088		

Pilots did not find the two display types to be different, the dots on display mean was 0.130 while the no dots display was 0.010 smaller, F(1,10) <1.0, p >.05. However, pilots reported that the 8 nautical miles starting point had produced higher workload. Starting point was found to be significant, F(1,10) = 23.29, p < .001. The mean was 0.160 for 8 nautical miles compared to 0.090 for the 18 nautical miles. Workload was also reported as being higher for the wind on condition. Wind was found to be significant F(1,10) = 9.14, p <.05. The mean was 0.141 for winds on compared to 0.109 for the no wind condition. Interaction of starting point X wind was significant, F(1,10) = 6.12, p <.05. Pilots reported higher workload, mean of 0.183, for the wind on condition at the 8 nautical miles, than for the 18 nautical miles wind off starting point, mean of 0.081. Workload was also reported as being higher for the wind off condition at the 8 nautical miles starting point, mean of 0.137, compared to the wind on, 18 nautical miles starting point, mean of 0.099. Figure 15 illustrates that the highest pilot workload rating was provided for the short approach condition with wind. The next highest level of pilot workload was reported for the short approach with no wind. The longer, 18 nautical miles approaches received the lowest workload ratings with the 18 nautical miles wind off condition receiving the lowest rating. The short approach condition with wind on was expected to produce higher workload ratings and the lowest workload rating was expected to be the 18 nautical miles condition with no wind present. SWORD rating agree with the general trend that higher workload is produced with short approaches and wind on. SWORD ratings for longer approaches are in general agreement with most of the performance data. No other main effects or interactions were statistically significant. The complete ANOVA table can be found in Appendix G.

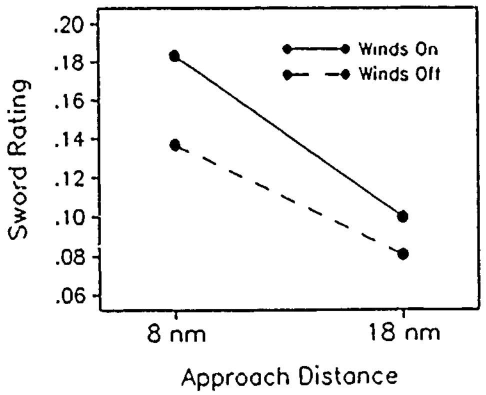


FIGURE 15. SWORD Ratings, Approach X Wind

Post-Trial Questionnaire At the completion of each of the two block trials, a short questionnaire was administered. The following paragraphs briefly summarize the subject's response to the questionnaires.

The first three questions requested pilot likes/dislikes and situational awareness importance during an Instrument Landing System approach. Six of the twelve subjects liked the ability to concentrate on only the flight director and use other non Cathode Ray Tube instruments for the crosscheck. However the reduction of crosscheck workload for the no dot display came at the expense of lack of perceived situational awareness which was considered important by all pilots.

Question 4 asked the subjects to rate their workload based on a scale that ranged from low to high. Pilots' ratings indicated stated that their workload was about the same with both displays, dots mean of 7.81 compared to the no dots mean of 7.36. Question 4 provided the opportunity to conduct a t-test on the two rated display types of dots and no dots. No difference between display types was reported by pilots, $t(10) = 0.339$, $p > .05$.

Question 5 and 6 solicited the subjects opinion if they would fly this display to decision height and what improvements to this display could they suggest. Nine pilots stated they would fly this display to decision height without raw data as long as everything else appeared normal. One pilot said he would not and two others said it was conditional since it would be uncomfortable. No pilot was willing to fly the no dot display below decision height without positional information. Improvements suggested by 8 pilots would be the incorporation of the raw data (dots) into the operational display. Two other pilots stated they would like better flight director damping and one pilot requested a separate warning light for decision height rather than radar altimeter setting of 200 feet AGL.

No Dot Post-Trial Questionnaire . An additional questionnaire was provided after both displays had been flown by the subjects. Subjects were requested to rate overall aspects of the no dot display on a scale from (5)- excellent to (1)- poor.

Table 5 provides a listing of questions one through seven and an averaged response to those questions by the pilots. In general pilots reported that the Instrument Landing System display was easy to see and understand, easy to track and anticipate localizer and glideslope steering. However situational awareness was rated only slightly better than fair.

TABLE 5. Pilot Rating of the No Dots Display

Question Number	Rating
1 Ease of use from IP to localizer	4.33
2 Ease of use from localizer cap to DH	4.75
3 Anticipation and capture of glideslope	4.00
4 Ease of use tracking the localizer	3.92
5 Maintain situational awareness	2.75
6 Size of symbology on the display	3.92
7 Display update rate	4.25

Questions 8 and 9 requested pilot workload based on a low to high scale. Question 8 asked pilots to rate the workload from initial starting point to localizer capture using a scale of (very low)- (low)- (moderate)- (high). Pilots rating are as follows: 1 rating of very low, 5 ratings of low, 5 ratings of moderate, and 1 rating of high. Question 9 asked pilots to rate their workload on the same scale from localizer capture to DH. Pilots ratings are as follows: 1 rating of very low, 8 ratings of low, 2 ratings of moderate, and 1 rating of high workload.

SECTION 4

DISCUSSION and CONCLUSIONS

The hypothesis tested in this study was that a performance would deteriorate when pilots were presented with Instrument Landing System data that did not contain raw glideslope and localizer information. The original expectation was that pilot performance would be better for the status and command condition as compared to the command condition alone. This hypothesis was not supported and does not agree with Garg's (1988) research. Garg suggested that status information should improve the performance of a command display because the status information indicated true system error. The raw glideslope and localizer data was presented on the Instrument Landing System display in dot form; all other presentations of Instrument Landing System data did not contain dots.

Significant main effects were found for display type dots compared with no dots. The localizer data provided less root mean square error with no dots, while the glideslope data provided less root mean square error with dots. Pilots were asked to provide their best performance for both of the display types (dots and no dots) that were presented to them. Three possible performance outcomes are possible: 1 no difference in pilot performance when dots were added, 2 better performance as pilots used the trend information provided by the addition of the dots, and 3 worse performance if pilots followed the dots data and disregarded the flight director display. The results do not support any of these strategies as being successful for superior performance.

The magnitude of the error differences were small for both localizer and glideslope. This difference translated to less than two feet for both axes at decision height. B-1B aircraft land on runway that are 300 feet wide: Therefore, a difference of only two feet is not considered important for this application. Other applications that require greater landing precision could benefit from attaining superior performance. Greater localizer error with the dots on condition coupled with decreasing glideslope error data imply that attentional sharing may be occurring. All pilots commented that they would not fly an Instrument Landing System approach in real instrument conditions below decision height, with the flight director without some indication of situational/positional information. The status information (dots display) provides a confidence indication that the flight director is operating properly but at a cost of an increase in localizer deviation. This confidence could decide the difference between completing an approach to landing or executing a missed approach when weather is at minimum visibility and ceiling at decision height. Pilots may have been comparing the trend information that the dots were providing to flight director steering inputs. The difference in the error for the localizer compared to glideslope is surprising. The beamwidth for the localizer is 5.0 degrees while the beamwidth for the glideslope is only 1.4 degrees. This is approximately a 3:1 ratio in sensitivity for the same dot deflection. Clearly, if the pilots were attending to the glideslope and localizer beams equally than the error difference would be expected to be the same proportionality as the sensitivity of the dots. The differences between glideslope and localizer root mean square are small for the display independent variable. In fact, a review of Tables 1 and

2 show that the localizer while three times wider than the glideslope had consistently lower root mean square. Greater attention appears to be expended on the localizer axis than was expended on the glideslope axis as evidenced by the differences in root mean square error compared to beamwidth sensitivities.

For the B-1B flight director with no dots display, greater attention may have been available to track the flight director steering inputs. This explanation is plausible as pilots reported no workload difference with fewer distractions when no raw data was present. However equivalent workload without the raw data display does not agree with results reported by Garg (1988) and was not an expected result of this study. Garg's assumption that workload should be lower with the addition of status information is based on a survey done by Weirwille and Connor (1983). Weirwille and Connor stated that pilot perception of workload correlated directly with root mean square activity. The root mean square activity that Weirwille and Connor were referring to was not root mean square error reduction but that of stick activity from the human operator.

The localizer performance results for the dots display were unexpected. The original hypothesis predicted that the pilot would use the raw data to confirm the indications provided by the flight director steering cross. Had the pilot relied exclusively on dots data, overshoots would have been the observed as the B-1B aircraft inertia does not permit perfect performance when flying dots only. The pilot models that were suggested for interpreting the Instrument Landing System display do not appear to adequately account for the time delays that are incurred for both the mental information integration of the raw dots data and the longer response time resident in a large aircraft. A time-sharing, pilot mental model, that allocates attention primarily to the flight director with limited attention allocated for trend monitoring, provided by the dots data, should be implemented into an Instrument Landing System task and evaluated. This time-sharing was a strategy that was reportedly used by most pilots in this study.

There are major differences in experimental apparatus between the study performed by Garg (1988) and the Instrument Landing System study reported herein. These experimental differences may account for the reported performance differences. The Garg (1988) study used a personal computer based simulator with a Cathode Ray Tube representing the display and the flight controls provided by a simple two-axis joy stick. Of considerable importance was that in Garg's experiment only longitudinal information was provided as an experimental manipulation and this axis was tracked with and without the addition of status information. The three subjects used in Garg's experiment were pilots of varying experience levels. The Instrument Landing System study however used a high fidelity flight simulator with 12 highly experienced pilots trained to fly the simulator. The vehicle dynamics of the B-1B simulator, control loading system and display system were faithful replications of the real aircraft. B-1B pilots were required to track both longitudinal and lateral axes during the Instrument Landing System approach. The experimental differences between these two studies are of great enough magnitude to produce different results.

When asked which display was easier to use, pilots commented that the flight director with no dot data was easier. However all pilots stated that they would not fly a flight director only approach in a real

B-1B unless there was positional data available in some form. Pilots appear willing to accept greater deviation from Instrument Landing System centerline and greater workload for the added confidence that positional awareness provides. This result agrees with Hughes et al.(1990) finding on situational awareness in air to air engagements.

Subject four was removed from the analysis because his performance using the status and command display was over five standard deviations from the means of the other subjects. If subject four's performance could be extrapolated to the pilot population as a whole then we would expect eight and one-half percent of the pilot population would have difficulty flying an integrated status and command display. Subject four's performance on the command only display was in the same range as that of the other subjects. All subjects were provided with the same instructions and all subjects appeared to comply with these instructions. However a conclusion can be reached that subject four decided to fly the status and command display in difference to the instructions provided. This disregard of experimenter instructions has been observed by the author during the conduct of other piloting experiments Purvis et al. (1988). Based on this information, subject four has been treated as an outlier and it is believed that he does not and is not representative of the pilot population as a whole.

Poor pilot acceptance of the flight director only display is a paradox. Pilots seem willing to accept higher workload and lower or equal levels of performance as a trade-off for positional or situational information they feel is an essential element of the Instrument Landing System display.

The results of this research project does not support the hypothesis that performance will be improved and workload will be reduced with the addition of status information to a command display. It is possible that the independent variables and measures that were collected and analyzed for this study were not sensitive to true differences between the two display types. The independent variables were selected based on previous research on this topic. Had the experimental set-up focused on a more lengthy and difficult approach to the Instrument Landing System, and one that required much higher levels of positional awareness by the pilot, the results may have been different.

Recommendations based on the results of this study support retention of status information with flight director command steering information. Aircraft conducting an instrument approach to landing without the generous 300 feet wide by 12,500 feet long runways, could benefit from the greater precision offered by the addition of the dots display. This recommendation to retain dots is based solely on the subjective opinion of the pilots. Performance and SWORD data do not show a clear trend of one display superior to another. Status information as presented in dot form on the Vertical Situation Display does not translate situational context well. Translation of aircraft position requires the pilot to mentally transform information presented to him in plan and profile views from his approach plate to a dot display orientation. However newer jet aircraft avionics are breaking away from the tradition of the dot display and are presenting aircraft position on an Instrument Landing System in the same plan and profile views as that of the instrument approach plate.

APPENDIX A. Definition of Dependent Variables

1.) Glideslope deviation . This is defined as the aircraft deviation from the center of the GS beam. This can be measured in either distance from centerline or degrees from centerline. This study will be measuring deviation in degrees from centerline.

* GS RMS $=1/n\sqrt{}\Sigma(X-T)**2$ T = target value

2.) Localizer deviation . This is defined as the aircraft deviation from the center of the LOC beam. This can be measured in either distance or degrees from centerline. This study will use degrees from centerline.

* LOC RMS $=1/n\sqrt{}\Sigma(X-T)**2$ T = target value

3.) Altitude Above Ground Level (AGL) is the altitude above the ground that the aircraft is in feet at a sampling rate of 16 hertz correlated with latitude and longitude position.

AGL = NUMBER OF SAMPLES PER SECOND / 16 HERTZ

4.) Knots Indicated Airspeed (KIAS). This is a measure of airspeed deviation from target or ideal. The VSD provides an indicator of target airspeed and indications of too fast or slow. This is measured in KIAS. For example, if the target airspeed was 167 KIAS and the pilot flew 180 KIAS then the reported difference is 13 KIAS.

KIAS = MEAN AND STANDARD DEVIATION / NUMBER OF APPROACHES

5.) Roll rate . This is the rate of rotation about the longitudinal axis of the aircraft. Roll is a first order measure and as such is usually measured in degrees per second or radians per second. This study measured roll rate in degrees per second.

* ROLL RATE RMS $= 1/n\sqrt{}\Sigma(X-X)**2$

APPENDIX A. CON'T

6.) *Pitch rate* . Pitch rate is the rate of rotation about the lateral axis of the aircraft. This is usually measured in degrees per second as it too is a first order system. Pitch rate was measured in degrees per second.

* PITCH RATE RMS = $1/n\sqrt{\sum}(X-X)**2$

* $X1, X2, X3, \ldots Xn$ = a sample of discrete scores
n = number of samples

$|X-Xi|$ = deviation (absolute) from the mean

Airspeed Definitions

Ground speed is defined as the speed of the aircraft over the ground.

Indicated airspeed is defined as the airspeed value obtained independent of wind effects. This airspeed is usually read directly from the airspeed indicator.

True airspeed is defined as the airspeed that is obtained when effects of temperature, barometric pressure and altitude are accounted for.

A *knot* is defined as a measure of distance traveled over time. One knot equals 1.15 miles per hour.

APPENDIX B. Wind Model for B-1B Simulation

```
      REAL*4 R_WIND_VEL_CURR

      REAL*4 K_WIND_VEL_INIT, K_WIND_HDG

      REAL*4 K_ALT_INIT, K_ALT_FINAL, K_WIND_VEL_FINA

      PARAMETER (K_ALT_INIT = 3275.)

      PARAMETER (K_ALT_FINAL = 200.)

      PARAMETER (K_WIND_VEL_INIT = 40.)    COMMENTS: THIS IS THE VELOCITY AT
3275 FEET

      PARAMETER (K_WIND_VEL_FINAL = 15.)    COMMENTS: THIS THE VELOCITY AT THE
END OF THE RUN (APPROXIMATELY 200 FEET)

      PARAMETER (K_WIND_HDG = 45/57.29578)  : THERE ARE 57.29578 DEGREES PER
RADIAN  COMMENTS: THIS IS THE WIND DIRECTION


      IF (WINDS_On) THEN

      R_WIND_VEL_CURR= K_WIND_VEL_INIT - ((K_ALT_INIT-
ALTITUDE_AGL)*(K_WIND_INIT - K_WIND_VEL_FINAL) / (K_ALT_INIT K_ALT_FINAL))


      IOF_NORTH_STEADY_WIND = R_WIND_VEL_CURR * COS(K_WIND_HDG)

      IOF_EAST_STEADY_WIND =R_WIND_VEL_CURR * SIN(K_WIND_HDG)

      ELSE


      IOF_NORTH_STEADY_WIND =0.

      IOF_EAST_STEADY_WIND =0.ENDIF

      RETURN

      END
```

APPENDIX C: Armstrong Lab Consent Form

B 1B ILS VSD EVALUATION
Protocol No. 90-09
INFORMATION PROTECTED BY THE PRIVACY ACT OF 1974
CONSENT FORM Initials _____

Title: B-1B Instrument Landing System Evaluation (718410)

OVERVIEW

1. The Instrument Landing System Evaluation is set up to collect pilot performance data during routine Instrument Landing System (ILS) approaches using: a) the flight director computer (FDC) steering commands and b) FDC steering commands with raw glideslope and localizer information. The purpose of the evaluation is to determine if there is any significant pilot performance difference between making an ILS approach with FDC control laws with and without the indication of raw localizer and glideslope information. The duration of the ILS evaluation will be one week and each subject will be asked to participate for one session lasting about four hours.

2. Each subject will be asked to fly twenty ILS approaches in the B-1B Engineering Research Simulator (ERS).

3. The subject may experience fatigue due to the length of the study, approximately four hours, and the number of ILS approaches required for the study.

4. Participation in this study will afford the subjects an opportunity to see firsthand the proposed changes to the B-1B ILS display and also give them an opportunity to make comments about the design.

5. The subjects will be advised of the two different ILS display configurations so they will be able to complete the evaluation questionnaire.

PLEASE CAREFULLY READ AND FILL IN THE FOLLOWING SECTION

6. I, ________________________, am participating because I want to. The decision to participate in this research study is completely voluntary on my part. No one has coerced or intimidated me into participating in this program.________________________________ has adequately answered any and all questions I have asked about this study, my participation, and

the procedures involved, which are set forth above, which I have read. I understand that the Principal Investigator or his designee will be available to answer any questions concerning procedures throughout this study. I understand that if significant new findings develop during the course of this research which relate to my decision to continue participation, I will be informed. I further understand I may withdraw this consent at any time and discontinue further participation in this study without prejudice to my entitlements. I also understand that the Medical Consultant for this study may terminate my participation in this study if he feels this is to be in my best interest. I may be required to undergo certain further examinations, if in the opinion of the Medical Consultant, such examinations are necessary for my health or well being.

7. I have considered and accept the unlikely but theoretical possibility as follows:

a) If physical exams and or monitoring of physiological parameters related to this experiment are conducted, it is possible for an unknown physical defect to come to light which might result in physical disqualification from flight or other special duty.

b) If physical injury were to occur it could result in physical disqualification from flight or other special duty.

8. I understand that my entitlement to medical care or compensation in the event of injury are governed by federal laws and regulations, and that if I desire further information I may contact the Principal Investigator.

I understand that I will not be paid for my participation in this experiment.

I understand that my participation in this study may be photographed, filmed or audio/video taped. I consent to the use of these media for training purposes and understand that any release of records of my participation in this study may only be disclosed according to federal law, including the Federal Privacy Act, 5 U.S.C 552a, and its implementing regulations. This means personal information will not be released to an unauthorized source without my permission.

APPENDIX C CON'T

I FULLY UNDERSTAND THAT I AM MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. MY SIGNATURE INDICATES THAT I HAVE DECIDED TO

PARTICIPATE, HAVING READ THE INFORMATION PROVIDED ABOVE.

Volunteer Signature SSAN Date Time

Witness Signature Date Time

INFORMATION PROTECTED BY THE PRIVACY ACT OF 1974

Authority 10 U.S.C. 8012, Secretary of the Air Force; powers and duties; delegation by; implemented by DOI 12-1. Office Locator

Purpose is to request consent for participation in approved medical research studies. Disclosure is voluntary.
Routine Use Information May be disclosed for any of the blanket routine uses published by the Air Force and reprinted in AFR 12-35 and in Federal Register 52 FR 16431.

APPENDIX D. Order of Testing

B-1 Display Evaluation

Order of Testing Wind and Approach Conditions

			Trial							
Group A	Subj	Block	1	2	3	4	5	6	7	8
Dot	1		ON8	OFF8	OFF18	ON18	OFF18	ON8	ON18	OFF8
	2		ON18	OFF18	OFF8	ON8	OFF8	ON18	ON8	OFF18
	3	1	OFF8	ON18	ON8	OFF18	ON8	OFF8	OFF18	ON18
	4		OFF18	ON8	ON18	OFF8	ON18	OFF18	OFF8	ON8
	5		ON8	ON18	OFF8	OFF18	OFF8	ON8	OFF18	ON18
	6		OFF18	OFF8	ON18	ON8	ON18	OFF18	ON8	OFF8
No Dot	1		ON18	OFF18	OFF8	ON8	OFF8	ON18	ON8	OFF18
	2		ON8	OFF8	OFF18	ON18	OFF18	ON8	ON18	OFF8
	3	2	OFF18	ON8	ON18	OFF8	ON18	OFF18	OFF8	ON8
	4		OFF8	ON18	ON8	OFF18	ON8	OFF8	OFF18	ON18
	5		OFF18	OFF8	ON18	ON8	ON18	OFF18	ON8	OFF8
	6		ON8	ON18	OFF8	OFF18	OFF8	ON8	OFF18	ON18
Group B	7		ON18	OFF8	OFF18	ON8	OFF18	ON18	ON8	OFF8
No Dot	8		OFF18	ON18	ON8	OFF8	ON18	OFF8	OFF18	ON8
	9	1	OFF8	ON8	ON18	OFF18	ON8	OFF18	OFF8	ON18
	10		ON8	OFF18	OFF8	ON18	OFF8	ON8	ON18	OFF18
	11		ON18	ON8	OFF8	OFF18	OFF8	ON18	OFF18	ON8
	12		OFF8	OFF18	ON18	ON8	ON18	OFF18	ON8	OFF18
Dot	7		ON8	OFF18	OFF8	ON18	OFF8	ON8	ON18	OFF18
	8		OFF8	ON8	ON18	OFF18	ON8	OFF18	OFF8	ON18
	9	2	OFF18	ON18	ON8	OFF8	ON18	OFF8	OFF18	ON8
	10		ON18	OFF8	OFF18	ON8	OFF18	ON18	ON8	OFF8
	11		OFF18	OFF8	ON8	ON18	ON8	OFF18	ON18	OFF8
	12		ON8	ON18	OFF18	OFF8	OFF18	ON8	OFF8	ON18

Entries report wind and approach condition. For example, ON8 refers to WIND ON and an approach distance of 8NM.

APPENDIX E. Questionnaire

B-1B ILS VSD EVALUATION QUESTIONNAIRE

THE PURPOSE OF THIS QUESTIONNAIRE IS TO OBTAIN YOUR OPINION ABOUT THE ILS DISPLAY WITHOUT RAW GS AND LOC DOTS.

1. HOW EASY WAS THE DISPLAY TO USE FROM THE INITIALIZATION POINT TO ESTABLISHED ON THE LOCALIZER?

5 - EXCELLENT - IT WAS EASY TO USE AND WAS CLEARLY UNDERSTOOD.
4 - GOOD - IT WAS FAIRLY EASY TO USE AND FAIRLY EASY TO UNDERSTAND.
3 - ADEQUATE - FOR MOST ALL TASKS.
2 - SOME DIFFICULTY USING THE DISPLAY.
1 - POOR - HAD MAJOR PROBLEMS USING THE DISPLAY.

2. HOW EASY WAS THE DISPLAY TO USE FROM LOCALIZER CAPTURE TO DECISION HEIGHT (DH)?

5 - EXCELLENT, IT WAS EASY TO USE AND WAS CLEARLY UNDERSTOOD.
4 - GOOD - IT WAS FAIRLY EASY TO USE AND FAIRLY EASY TO UNDERSTAND.
3 - ADEQUATE - FOR MOST ALL TASKS.
2 - SOME DIFFICULTY USING THE DISPLAY.
1 - POOR - HAD MAJOR PROBLEMS USING THE DISPLAY.

3. HOW EASY WAS THE DISPLAY TO USE FOR ANTICIPATING AND CAPTURING THE GS?

5 - EXCELLENT, IT WAS EASY TO USE AND WAS CLEARLY UNDERSTOOD.
4 - GOOD - IT WAS FAIRLY EASY TO USE AND FAIRLY EASY TO UNDERSTAND.
3 - ADEQUATE - FOR MOST ALL TASKS.
2 - SOME DIFFICULTY USING THE DISPLAY.
1 - POOR - HAD MAJOR PROBLEMS USING THE DISPLAY.

4. HOW EASY OVERALL WAS THE DISPLAY TO USE FOR ANTICIPATING AND TRACKING THE LOCALIZER?

5 - EXCELLENT, IT WAS EASY TO USE AND WAS CLEARLY UNDERSTOOD.
4 - GOOD - IT WAS FAIRLY EASY TO USE AND FAIRLY EASY TO UNDERSTAND.
3 - ADEQUATE - FOR MOST ALL TASKS.
2 - SOME DIFFICULTY USING THE DISPLAY.
1 - POOR - HAD MAJOR PROBLEMS USING THE DISPLAY.

5. HOW WELL WERE YOU ABLE TO MAINTAIN SITUATIONAL AWARENESS?

5 - EXCELLENT, IT WAS EASY TO USE AND WAS CLEARLY UNDERSTOOD.
4 - GOOD - IT WAS FAIRLY EASY TO USE AND FAIRLY EASY TO UNDERSTAND.
3 - ADEQUATE - FOR MOST ALL TASKS.
2 - SOME DIFFICULTY USING THE DISPLAY.
1 - POOR - HAD MAJOR PROBLEMS USING THE DISPLAY.

APPENDIX E. Continued

6. RATE THE SIZE OF THE SYMBOLOGY USED ON THE DISPLAY.

   5 - EXCELLENT, IT WAS EASY TO USE AND WAS CLEARLY UNDERSTOOD.
   4 - GOOD - IT WAS FAIRLY EASY TO USE AND FAIRLY EASY TO UNDERSTAND.
   3 - ADEQUATE - FOR MOST ALL TASKS.
   2 - SOME DIFFICULTY USING THE DISPLAY.
   1 - POOR - HAD MAJOR PROBLEMS USING THE DISPLAY.

7. IS THE UPDATE RATE ADEQUATE FOR FLYING AN ILS?

   5 - EXCELLENT, IT WAS EASY TO USE AND WAS CLEARLY UNDERSTOOD.
   4 - GOOD - IT WAS FAIRLY EASY TO USE AND FAIRLY EASY TO UNDERSTAND.
   3 - ADEQUATE - FOR MOST ALL TASKS.
   2 - SOME DIFFICULTY USING THE DISPLAY.
   1 - POOR - HAD MAJOR PROBLEMS USING THE DISPLAY.

8. RATE YOUR WORKLOAD FROM THE INITIALIZATION POINT TO LOC CAPTURE

VERY LOW   LOW   MODERATE   HIGH   VERY HIGH

9. RATE YOUR WORKLOAD FROM LOCALIZER CAPTURE TO DH.

VERY LOW   LOW   MODERATE   HIGH   VERY HIGH

APPENDIX E. Continued Comparative Questionnaire

Questionnaire to be administered after each trial block

1. Now that you have flown this display, what do like and dislike about it and why?

2. Was this display useful for situational awareness?

3. Is situational awareness important on an ILS approach?

4. Rate your workload using this display. Mark an X that is closest to your workload during the ILS approach.

Low---------Medium---------High

5. Would you fly this display to DH? Disregard AFM 51-37 guidance for this question.

6. What do you suggest to improve this display and why?

APPENDIX F. Subject Four Analysis

MEAN OF THE 11 REMAINING SUBJECTS, AFTER DROPPING SUBJECT 4= -3.6824

MEAN OF SUBJECT 4= - 0.6554

S = STANDARD DEVIATION OF THE 11 SUBJECTS (WITHOUT SUBJECT 4)=0.5769

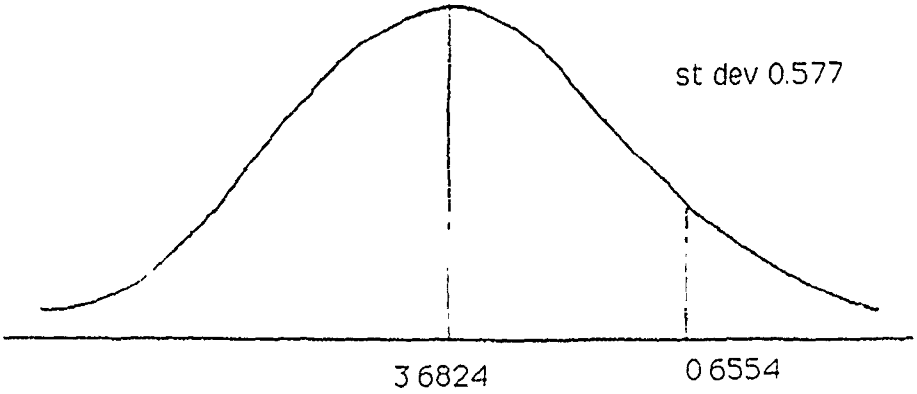
WE WANT TO KNOW HOW MANY st.devs. AWAY FROM THE REMAINING 11 SUBJECTS' MEAN IS THE MEAN OF SUBJECT 4.

i.e.| -3.6842 -(- 0.6554) | = k * (0.5769)

WHAT IS k ?

k=3.0288/0.5769
=5.25

HENCE MEAN OF SUBJECT 4 IS 5.25 ST.DEV. AWAY FROM THE MEAN OF THE REMAINING 11 SUBJECTS.



SUBJECT 4 (MEANS)

DOTS	WIND	APPROACH	LOC	GS	PITCH RATE	ROLL RATE
ON	ON	8 NM	1.19746	.16894	.29597	.34102
		18 NM	.45802	.23817	.26224	.21889
	OFF	8 NM	.36427	.21717	.28440	.25122
		18 NM	.41215	.23062	.25996	.18491

APPENDIX F. CON'T.

DOTS	WIND	APPROACH	LOC	GS	PITCH RATE	ROLL RATE
OFF	ON	8 NM	.04428	.07155	.22791	.39071
		18 NM	.02389	.08708	.23936	.45286
	OFF	8 NM	.02335	.07792	.25406	.36823
		18 NM	.02032	.07836	.19903	.40851

APPENDIX G. ANALYSIS OF VARIANCE

REPEATED MEASURES ANALYSIS OF VARIANCE RESULTS

ALL TESTS HAVE 1,11 DEGREES OF FREEDOM

WITHOUT GROUP AND WITH SUBJECT 4

LOCALIZER RMSE (degrees)

SOURCE	SUM OF SQUARES	F VALUE	P VALUE
DOTS	6.759486	4.37	0.0606
WINDS	5.893286	32.46	0.0001*
APPROACH	5.380230	28.40	0.0002*
DOTS*WINDS	0.030625	0.25	0.6242
DOTS*APPROACH	0.295430	4.86	0.0497*
WINDS*APPROACH	2.816386	31.86	0.0001*
DOTS*WINDS*APPROACH	0.317634	5.43	0.0399*

GLIDE SLOPE RMSE (degrees)

SOURCE	SUM OF SQUARES	F VALUE	P VALUE
DOTS	0.047619	0.12	0.7334
WINDS	0.357517	8.57	0.0138*
APPROACH	0.005113	0.05	0.8239
DOTS*WINDS	0.015782	0.27	0.6152
DOTS*APPROACH	0.109031	0.82	0.3852
WINDS*APPROACH	0.120420	1.20	0.2970
DOTS*WINDS*APPROACH	0.061394	1.03	0.3328

ROLL RATE RMSE (degrees)

SOURCE	SUM OF SQUARES	F VALUE	P VALUE
DOTS	0.000068	0.01	0.9180
WINDS	0.001319	1.93	0.1926
APPROACH	0.019893	112.38	0.0001*
DOTS*WINDS	0.000244	0.61	0.4507
DOTS*APPROACH	0.002199	1.73	0.2158
WINDS*APPROACH	0.009222	18.60	0.0012*
DOTS*WINDS*APPROACH	0.000198	0.87	0.3709

* = level of confidence 0.05

APPENDIX G. CON'T.

REPEATED MEASURES ANALYSIS OF VARIANCE RESULTS

ALL TESTS HAVE 1,11 DEGREES OF FREEDOM

WITHOUT GROUP AND WITH SUBJECT 4

PITCH RATE RMSE (degrees)

SOURCE	SUM OF SQUARES	F VALUE	P VALUE
DOTS	0.000245	0.18	0.6783
WINDS	0.004000	13.21	0.0039*
APPROACH	0.000497	0.92	0.3576
DOTS*WINDS	0.000009	0.04	0.8374
DOTS*APPROACH	0.000118	0.32	0.5855
WINDS*APPROACH	0.001953	4.99	0.0472*
DOTS*WINDS*APPROACH	0.002755	6.54	0.0266*

* = level of confidence 0.05

APPENDIX G. CON'T.

REPEATED MEASURES ANALYSIS OF VARIANCE RESULTS

ALL TESTS HAVE 1,10 DEGREES OF FREEDOM

WITHOUT GROUP AND WITHOUT SUBJECT 4

LOCALIZER RMSE (degrees)

SOURCE	SUM OF SQUARES	F VALUE	P VALUE
DOTS	2.072777	5.45	0.0418*
WINDS	5.390935	26.99	0.0004*
APPROACH	5.053018	24.35	0.0006*
DOTS*WINDS	0.019151	0.15	0.7108
DOTS*APPROACH	0.301817	4.58	0.0580
WINDS*APPROACH	2.497021	25.91	0.0005*
DOTS*WINDS*APPROACH	0.273144	4.27	0.0658

GLIDE SLOPE RMSE (degrees)

SOURCE	SUM OF SQUARES	F VALUE	P VALUE
DOTS	0.548117	6.08	0.0334*
WINDS	0.389549	9.12	0.0129*
APPROACH	0.029666	0.31	0.5893
DOTS*WINDS	0.006587	0.10	0.7531
DOTS*APPROACH	0.122586	0.84	0.3799
WINDS*APPROACH	0.176515	1.74	0.2161
DOTS*WINDS*APPROACH	0.065837	1.01	0.3392

* = level of confidence 0.05

APPENDIX G. CON'T.

REPEATED MEASURES ANALYSIS OF VARIANCE RESULTS

ALL TESTS HAVE 1,10 DEGREES OF FREEDOM

WITHOUT GROUP AND WITHOUT SUBJECT 4

ROLL RATE RMSE (degrees)

SOURCE	SUM OF SQUARES	F VALUE	P VALUE
DOTS	0.003358	2.22	0.1672
WINDS	0.000310	0.78	0.3990
APPROACH	0.019084	104.21	0.0001*
DOTS*WINDS	0.000105	0.25	0.6249
DOTS*APPROACH	0.000323	0.61	0.4540
WINDS*APPROACH	0.009347	18.03	0.0017*
DOTS*WINDS*APPROACH	0.000041	0.22	0.6518

PITCH RATE RMSE (degrees)

SOURCE	SUM OF SQUARES	F VALUE	P VALUE
DOTS	0.000009	0.01	0.9278
WINDS	0.003978	12.22	0.0058*
APPROACH	0.001166	2.93	0.1175
DOTS*WINDS	0.000010	0.04	0.8365
DOTS*APPROACH	0.000096	0.23	0.6394
WINDS*APPROACH	0.002730	8.76	0.0143*
DOTS*WINDS*APPROACH	0.002185	4.87	0.0518

* = level of confidence 0.05

APPENDIX G. CON'T.

REPEATED MEASURES ANALYSIS OF VARIANCE RESULTS

ALL TESTS HAVE 1,10 DEGREES OF FREEDOM

WITHOUT GROUP AND WITHOUT SUBJECT 4

SWORD RATINGS

SOURCE	SUM OF SQUARES	F VALUE	P VALUE
DOTS	0.002332	0.09	0.7716
WINDS	0.023270	9.14	0.0128*
APPROACH	0.108010	23.29	0.0007*
DOTS*WINDS	0.002784	1.86	0.2028
DOTS*APPROACH	0.000478	0.11	0.7484
WINDS*APPROACH	0.004159	6.12	0.0329*
DOTS*WINDS*APPROACH	0.000356	0.76	0.4024

* = level of confidence 0.05

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