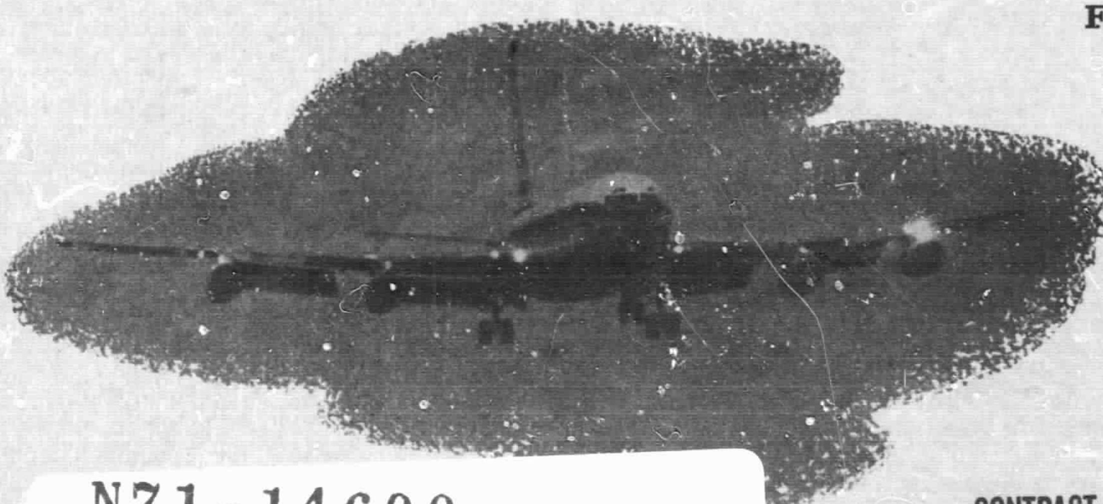
CR 73495
AVAILABLE TO THE PUBLIC

TR386-70-01(U)

IMPROVED DISPLAY SUPPORT FOR FLIGHT MANAGEMENT DURING LOW VISIBILITY APPROACH AND LANDING: A Simulator Evaluation of an ILS-independent Runway Perspective Display

Final Report



CONTRACT NO. NAS2-5851

NOVEMBER 1970

PREPARED FOR

MAN-MACHINE INTEGRATION BRANCH

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

AMES RESEARCH CENTER

MOFFETT FIELD, CALIFORNIA

PREPARED BY:

serendipity, inc.

Palo Alto, California

02

IMPROVED DISPLAY SUPPORT FOR FLIGHT MANAGEMENT DURING LOW VISIBILITY APPROACH AND LANDING

A Simulator Evaluation of an ILS-independent Runway Perspective Display

Walter B. Gartner
Kenneth M. Baldwin

October 1970

Prepared under Contract NAS2-5851 By

SERENDIPITY, INC.

Palo Alto, California

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWARD

The simulation research project documented in this report was conducted as a collaborative effort between Serendipity, Inc., and the Man-Machine Integration Branch at Ames Research Center. Guidance and support in all phases of the study were provided by Mr. Charles C. Kubokawa, Technical Monitor for the project. Other technical personnel at Ames also made significant contributions to the project. In particular we wish to acknowledge the efforts of Mr. Darrell Igelmund in preparing the programmed flight profiles and of Mr. Dave McCann of the Simulation Experiments Branch in modifying the simulator cab to accommodate the experimental display units.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

IMPROVED DISPLAY SUPPORT FOR FLIGHT MANAGEMENT DURING LOW VISIBILITY APPROACH AND LANDING

A Simulator Evaluation of an ILS-independent Runway Perspective Display

W. B. Gartner and K. M. Baldwin
Serendipity, Inc.

SUMMARY

Command pilots of jet transport aircraft will require improved flight situation displays for accurate monitoring and assessment of the aircraft's position and movements relative to the runway during an approach under Category II visibility conditions (less than 2400 feet runway visual range). In this study, a preliminary evaluation of an ILS-independent, pictorial runway perspective display concept was conducted to determine the improvement which might be realized in the accuracy of flight management task performance when pilot judgments are made by reference to this experimental display rather than to conventional attitude-director indicators.

Six senior airline pilots flew a total of 180 simulated Category II approach and landing sequences using three different displays as the basis for approach assessment tasks. The three alternate display concepts were designed to provide increasing levels of directness

in representing the flight situation parameters relevant to the flight management task. Pilot judgments made by reference to the experimental runway perspective display were expected to be significantly more accurate than the same judgments made by the same pilots using conventional Category II instrumentation.

The results of the study indicate that flight management task performance would be more accurate and consistent when pilot judgments are made by reference to the experimental display. The clearest improvement recorded was for the assessment of flight path alignment (i. e, the lateral displacement of the aircraft from the extended runway centerline) as the aircraft approached the 100-foot decision height. During debriefing sessions pilots expressed a clear preference for the runway perspective display and stated that they would feel confident in attempting an approach under actual Category II conditions using this display to monitor the flight situation.

INTRODUCTION

The simulation research project documented in this report is the second empirical study in an ongoing research program concerned with the effectiveness and reliability of flight management task performance during low visibility approach and landing operations in civil jet transport aircraft. The broad objectives of this program are to determine the extent to which the judgmental and decision making activities of the pilots in command of these aircraft are supported by flight deck instrumentation and operating procedures projected for Category II and III certified systems and, where deficiencies are disclosed, to identify and evaluate improved means for implementing the flight management function. Both anayltic and empirical investigations have been carried out in pursuing these objectives.

In the initial simulator study (ref. 1), the investigation was focused on the pilot's ability to judge his approach to the authorized 100-foot minimum decision altitude for Category II operations, using only the conventional flight instrumentation adopted by most major airlines to satisfy FAA certification requirements. Very briefly, this baseline system is typified by an advanced, 5-inch attitude/flight director indicator, incorporating expanded localizer and glide slope deviation display elements (see description, p. 13), and augmented by approach progress indicators and a radio altimeter. Standard flight instruments (airspeed, barometric altimeter, vertical velocity, etc.) complete this baseline configuration. The results of the first simulator study supported the contention developed in earlier analytic work (ref. 2) that this baseline instrumentation would not satisfy requirements for accurate monitoring and assessment of the approach to Category II minimums.

In the present study the focus is shifted toward an evaluation of display improvements which might correct the inadequacies of conventional instrumentation. Following current trends in avionic developments toward ILS-independent runway imaging systems (ref. 3) and the continuing expression of pilot preferences for more "natural" and "real world" oriented displays for approach monitoring and assessment (refs. 4 and 5), the present study examines the potential application of such display concepts to the flight management problem. An ILS-independent pictorial runway perspective display, based on relative position data obtained from microwave transmitters installed on the runway and in the approach area, was evaluated for this application. This display concept was already being investigated at the Ames Research Center as a sole source of information available to pilots for carrying out a manually controlled approach and landing at airports not equipped with ILS (ref. 6). In addition to the convenience of its availability for the present study, this concept offered the advantages of representing various levels of display aiding for flight management and of representing the desired attributes of a more effective and acceptable display for low visibility operations. These attributes are:

1. A more direct representation of the key flight situation parameters considered necessary for the approach assessment task;
2. An integrated and coherent presentation of the dynamic flight situation, readily interpreted by pilots using the same perceptual skills and expectancies as those acquired in many hours of flight by visual reference;

3. Independent of current landing aids and guidance systems and connected more directly and accurately to real world objects and kinematics;
4. Selective integration of additional display elements which are useful for increasing the precision of pilot judgments or for providing essential quantitative information (e. g., airspeed, rate-of-sink).

The aim of the simulator study was to determine the contribution, if any, that displays of this kind could make to more accurate and reliable pilot assessments of an approach to Category II minimums. Simulator run series were designed to contrast the performance of highly qualified airline pilots using two different versions of the pictorial runway perspective display concept and the baseline instrumentation cited earlier as alternative bases for making approach success judgments. Following a brief discussion of the need for improved display support for flight management and a more complete description of the alternative display concepts evaluated in this study, a more explicit statement of the hypotheses tested and the experimental plan adopted is given and the results obtained are presented and discussed.

The Need for Improved Display Support

The specific role of the pilot-in-command during low visibility approach and landing operations continues to be the subject of much concern and considerable difference of opinion. It can be argued that system development efforts directed toward reducing visiblity requirements for approach and landing have been concentrated almost exclusively on achieving flight control objectives without relying on direct pilot participation. The pilot's role is thus seen as changing from directly controlling the flight path of the aircraft to one of "monitoring" the performance of automatic flight control systems (AFCS) and/or of serving as overall "systems manager." This emphasis on increased reliance on automatics is based, in part, on an early recognition of the fact that the quality of information available to the pilot under low visibility conditions, from both flight instruments and external visual reference, would be inadequate for safe and consistent performance of the manual flight control task.

Without significant improvements in the quality of available information, however, it is not immediately clear how the command pilot is going to perform effectively as an approach manager. In view of the known deficiencies in information availability and display characteristics, specific questions regarding the degree of "authority" the pilot can and should exercise over the automatic equipment remain unanswered and there is little agreement on how and when the pilot should be allowed to enter the control loop to abort a landing maneuver or to achieve more precise control of the aircraft's flight path. Earlier analysis (ref. 2) clearly indicates that effective flight management will impose even more stringent demands on aircraft display systems than flight control by instrument reference. The latter capability might be achieved by further refinements to flight director indicators and the addition of such display elements as flight path angle, absolute altitude, and augmented vertical velocity (ref. 7).

The general point of the foregoing discussion is that the shift in the pilot's role from aircraft controller to flight manager is expected to intensify and expand the need for improved flight deck display systems. In this research program, the position taken is that command responsibility must be retained by the pilot and that his role as monitor/manager cannot be construed, as it appears to be in some system development concepts, as one of AFCS mode selection and the monitoring of equipment operating status. The command pilot must be able to continuously assess the ongoing flight situation in such a way that he is ahead of the airplane and can anticipate critical events. Moreover, he must be able to exercise control authority over the AFCS on the basis of these assessments and to take corrective action at any point in the approach, landing maneuver, or roll out on the runway. The critical resource underlying these performance capabilities is the information the pilot is able to extract from his flight instruments and external visual reference. And evidence is accumulating that neither of these sources will provide information of the required quality in the Category II and III operating environment.

A full elaboration of the command pilot's information requirements and the specific deficiencies of projected Category II instrumentation and external visual cues is beyond the scope of this discussion; the interested reader is referred to earlier analyses (ref. 2). Experimental data obtained in the initial simulator study confirmed the general conclusion of this analysis, namely, that conventional Category II instrumentation would not enable the pilot to make timely and accurate assessments of the ongoing flight situation (ref. 1). Operationally significant errors in judging height above touchdown, the alignment of the aircraft's flight path with the extended runway centerline, and the aircraft's tracking tendencies occurred on more than a third of the simulated approach sequences and pilot judgments were highly variable. The aim of the present simulator study was to develop and evaluate a display concept designed to correct some of these deficiencies in display support for flight management.

Description of the Experimental Display

The basic display concept adopted for evaluation is illustrated in Figure 1a. This display is an early version of the simulated pictorial landing display under investigation at Ames at the time this study was initiated. It should be clear that it was a display concept that was adopted for evaluation in the present study and not a particular ground-based sensor and/or airborne signal processing and display system. Study results and discussion are thus intended to be applicable to a wide range of independent landing monitors and pictorial attitude-director display systems.

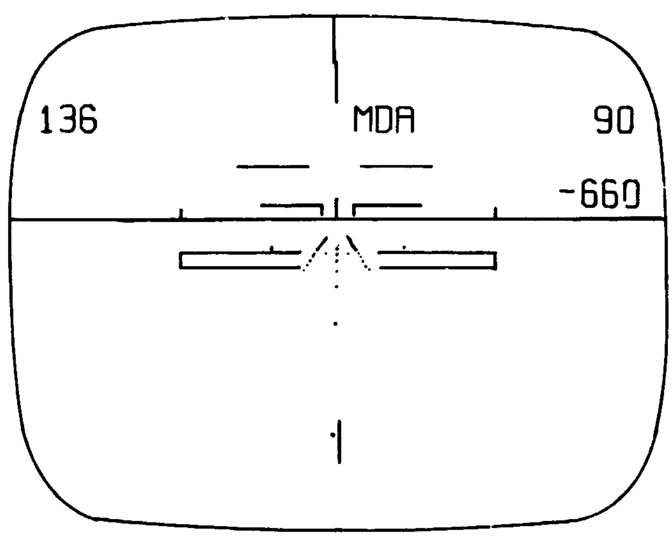


Figure 1a. Line Drawing of the Basic Runway Perspective Display.

The display was generated by the SEL 840 digital computer system using computer graphics techniques. A 40 x 40 degree field of view is depicted and the central display element is a dotted runway image programmed to move in correct perspective relationship to the pilot's line of sight. A 525 line closed-circuit TV system was used to transfer the display from the CRT at the computer to an 8-inch monitor tube mounted on the pilot's instrument panel (see Figures 4 and 6). Pilot and/or autopilot control actions fed back from the simulator cab produced corresponding changes in the relationship of the runway image and horizon line to the fixed aircraft symbol and reference marks in order to represent changes in aircraft attitude and position relative to the runway. Display elements of the basic perspective display are identified in Figure 1b.

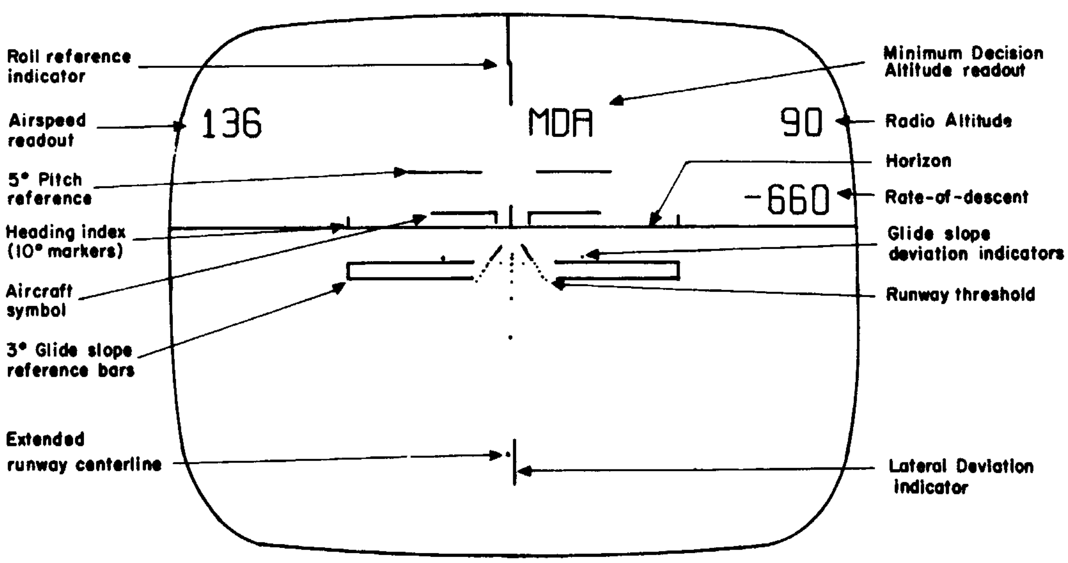


Figure 1b. Identification of Display Elements for the Basic Runway Perspective Display.

The heading index, centered on the horizon line, is set to the runway heading and moves laterally relative to the aircraft symbol (always fixed in the center of the display field) as the aircraft's magnetic heading deviates from the pre-selected value. Digital readouts of airspeed, radio altitude, and rate-of-descent are always available in the indicated positions. The MDA symbol appears when radio altitude reaches a pre-set value representing an elevation of 100 feet above the runway, taking differences in terrain elevation approaching the runway into consideration. Dots on either side of the runway centerline indicate the intersection of the glide slope with the runway (1000 feet from the threshold) and glide slope deviation is indicated by the alignment of these dots with the 3 degree glide slope bar and by the number of dots appearing outside the runway edges (i.e., two dots for "on", three for "high", and one dot for "low"). Localizer deviation, per se, is not represented. The extended runway centerline flows past the lateral deviation indicator (a fixed reference symbol aligned with the center of the aircraft symbol and perpendicular to the horizon) to indicate cross-track position.

Certain modifications to this basic runway perspective display were considered necessary in order to provide more direct support to the pilot for the flight management task. The modified display is illustrated in Figure 2a and is the primary display evaluated in the study. It is clear that this version was derived from the basic display concept and only minor changes were necessary to incorporate the desired features for flight management. The principal change to the basic display was the addition of a "500-foot decision bar." This display element is located 500 feet in front of the runway threshold and may be interpreted as a projection of this threshold. It is also apparent that both the threshold and the 500-foot bar have been given greater definition by adding more dots. Since a conventional 150-foot wide runway is depicted, these dots are on 25-foot centers and provide an immediate basis for judging flight path alignment and aircraft tracking tendencies. The location of this "decision bar" at the 500-foot point brings the fixed lateral deviation indicator to a position alongside the reference dots as the aircraft approaches the 100-foot decision height. The extended runway centerline is also better defined in this revised display. Dots are spaced at 100-foot intervals rather than the 500-foot intervals on the basic display.

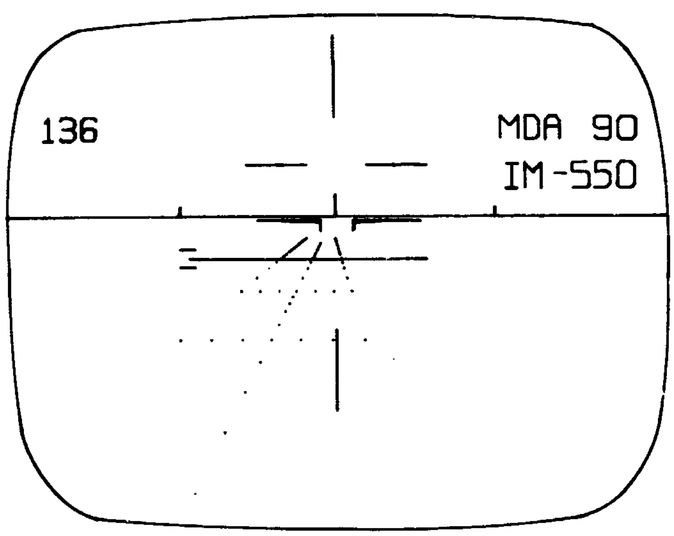


Figure 2a. Line Drawing of the Experimental Runway Perspective Display.

Modified elements of the experimental runway perspective display are identified in Figure 2b. Digital readouts of airspeed, radio altitude, and vertical velocity are unchanged. The MDA symbol was moved to the right, closer to the radio altitude readout, and additional readouts were added to indicate marker beacon passage. A modified glide slope deviation indicator was also adopted in order to reduce clutter and to examine the feasibility and acceptance of a pictorial glide slope display. An "on glide slope" condition is represented by a straight line through the glide slope-runway intersection, as shown in Figure 2b. Deviation from the

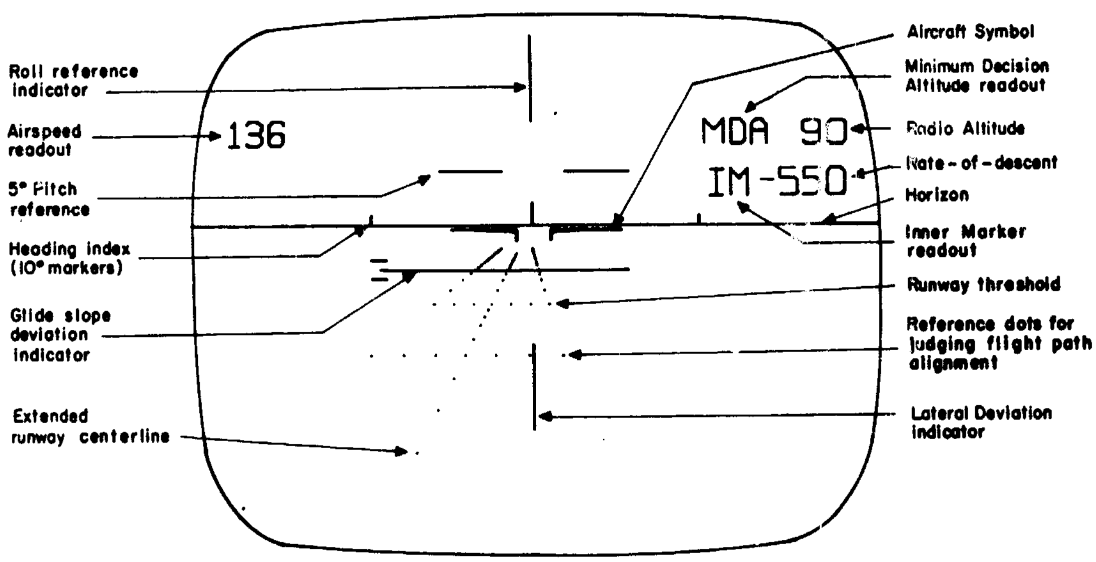
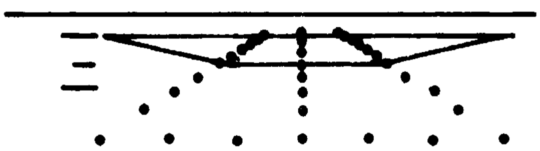
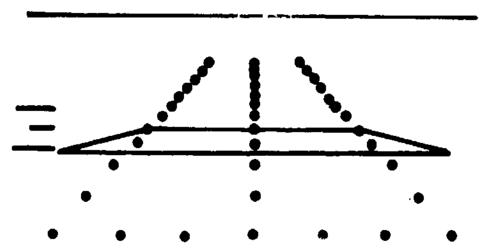


Figure 2b. Identification of Display Elements of the Experimental Runway Perspective Display.

glide slope is indicated by the displacement of this line above or below the runway intersect line. This displacement forms a pictorial view of the glide slope which appears to be hinged at the runway and to extend out toward the approaching aircraft. One-dot displacements above and below the glide slope are illustrated below:



Aircraft is one dot below glide slope



Aircraft is one dot above glide slope

The more important kinematic features of this display concept, i. e., the way the display elements move relative to each other to represent the dynamic flight situation, cannot be clearly conveyed in this static presentation. As the aircraft descends toward the decision height situation depicted in Figures 1 and 2, the digital readouts are changing, the display field behind the fixed aircraft symbol and reference marks moves to reflect any changes in aircraft attitude, and the dotted runway image grows in size and moves in correct perspective relationship to the pilot's line of sight. It should also be noted that no flight director elements (i. e., pitch and roll steering commands) are represented in the pictorial runway perspective displays. In this study, the display concept was evaluated for flight management support only; pilots did not attempt to hand-fly the simulator by reference to this display.

For the evaluation, pilots performed specified flight management taks using both conventional Category II flight instrumentation and the pictorial displays just described. Conventional instrumentation was represented by the Collins FD-109 Integrated Flight Director System, as it was in the first simulator study. For the reader's convenience, the principal flight situation display elements provided by this system are identified in Figure 3 in a line drawing of the FD-109 Flight Director Indicator. All display elements were functional except the qualitative airspeed indicator on the right side of the instrument and the "GO AROUND" (GA) indicator at the top left. The rising runway symbol moved laterally to indicate localizer deviation but did not move vertically to indicate absolute (radio) altitude.

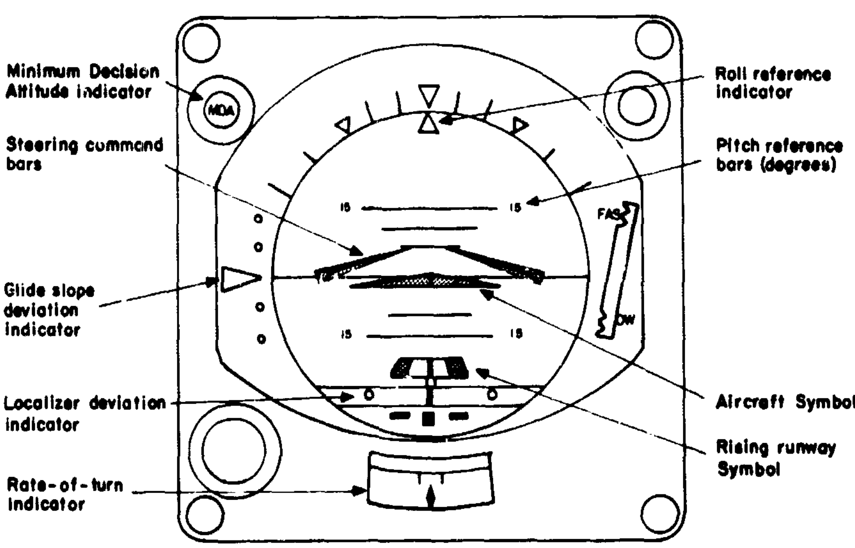


Figure 3. Identification of Display Elements for the Collins FD-109 Flight Director Indicator.

EXPERIMENTAL METHOD

Simulation research project 2 (SRP-2) was designed to determine the improvement which might be realized in the accuracy of flight management task performance when pilot judgments are made by reference to the experimental runway perspective display (ERPD) just described rather than to conventional attitude-director indicators (ADI). Conventional instrumentation provides both computed (e. g., flight director) and raw (e. g., glide slope/ localizer deviation) ILS-derived flight situation data in an integrated semi-pictorial and symbolic form. The ERPD provides a more direct, pictorial representation of key elements of the external visual field (e. g., the runway image), rather than derived quantities from the ILS deviation signals. The principal experimental variable examined in SRP-2 may thus be understood as the level of directness in representing the flight situation parameters relevant to the flight management task.

Three levels of this experimental variable are embodied in the alternative display modes which were contrasted in SRP-2. Conventional instrumentation, typified by the FD-109 Flight Director Indicator, represents the first and lowest level of directness. The basic runway perspective display (BRPD) provides a more direct representation of the aircraft's position relative to the runway, but does not include display elements which are specifically designed as an aid to flight management. The BRPD represents an intermediate level of directness. Since specific display features were incorporated into the ERPD to provide a more direct and precise representation of the flight situation assessed by the pilot (i. e., flight path alignment and tracking as the aircraft approaches the 100-foot DH), this display mode represents the third and highest level of the experimental variable.

Simulated approach and landing sequences were designed to obtain data on the accuracy of flight management tasks performed by highly qualified airline pilots using each of these display modes. An experimental design was developed to test the general hypothesis that the level of directness represented in the display would have a significant effect on the accuracy and consistency of pilot judgments. More specifically, pilot judgments made by reference to the ERPD were expected to be significantly more accurate than the same judgments made by the same pilots using conventional instrumentation (FD-109). The BRPD was included in the experiment to assess the value of the specific aiding designed into the ERPD, i. e., to determine whether the pictorial, perspective format alone would produce a significant improvement in flight management task performance.

A secondary objective of the study was to determine the effect of the variation in display support provided for the approach assessment task on the outcome of the subsequent landing maneuver. Under Category II conditions, the landing maneuver is executed by external visual reference after the pilot goes "head up" at the DH and the displays are not intended to be used for this phase of the approach and landing sequence. However, it was considered reasonable to assume that the more direct display would provide the pilot with a clearer orientation to the flight situation during the transition to the landing and thereby enhance the effectiveness of his initial control actions, especially when the lateral offset and/or tracking situation at the DH was marginally acceptable. The experimental design is fully described in Appendix A.

Simulation Facility and Experimental Conditions

SRP-2 was conducted in the Man-Machine Integration Branch (MMIB) simulation laboratory at Ames Research Center. This facility has been described in an earlier report (ref. 1). An overview of the equipment set-up established for the present study is given in Figure 4. In addition to re-programming the diode function generators (DFGs) used for controlling the aircraft's flight path during the approach, the principal modifications to the set-up used for the initial study were the modification to the instrumentation provided in the simulator cab, the use of the SEL-816 Display Generator to produce the CRT displays, and the closed circuit TV system used to transfer the CRT picture to the video monitor mounted in the simulator cab. These facility modifications and the conditions represented in the present study are outlined below.

Approach and Landing Sequence

The simulated approach and landing sequence adopted as the operational context for SRP-2 was again a Category II approach to Dulles International Airport. In the present study, only one visibility condition was represented: a runway visual range (RVR) of 1600 feet. Simulator runs were initiated just inside the Outer Marker, with the aircraft essentially on the localizer course and glide slope, and the sequence ended shortly after the touchdown and roll-out on the runway. Variations in terrain elevation approaching the runway were represented in the simulation using the three terrain profiles developed for the first study. No wind conditions were simulated.

It should also be noted that the engine thrust indicators used in the initial study were replaced with engined pressure ratio (EPR) indicators in SRP-2.

Generation of the Experimental Display

The display generation program for the pictorial displays was based on a mathematical perspective model for calculating the rotations of the runway image about aircraft-referenced azimuth, pitch, and roll axes and relating these rotations to the pilot's viewing axis. These calculations (performed by the SEL 840 digital computer) determined the x-y coordinates for generating line segments and dots on the cathode ray tube (CRT) utilizing the SEL 816 Computer Graphics System.

Separate perspective display programs were developed for the ERPD and the BRPD by modifying an existing program currently being used with light aircraft dynamics in other display evaluation studies being conducted at Ames (ref. 6). Modifications to this program were necessary in order to change the source of flight situation measures from calculations of light aircraft dynamics to those derived from the calculation of DC-8 aircraft dynamics by the AD-256 analog computer, and to add the display features illustrated in Figures 1 and 2. The basic perspective model adapted to the display generation program has been described in reference 12. Additional calculation required to incorporate the pictorial glide slope deviation indicator in the ERPD is described in Appendix D to this report.

RESULTS AND DISCUSSION

Data obtained in this simulator study were processed to derive three basic indicators of the improvement in flight management task performance which might be realized if the experimental pictorial runway perspective display concept were adopted for Category II operations. The primary concern of this experiment was the contribution this display concept could make to the effectiveness of command pilot assessments of the approach to Category II minimums and, accordingly, the corresponding criterion measures were the accuracy and consistency of pilot estimates of specified flight situation parameters. A less direct measure of the potential improvement in display support to the pilot was derived from data on landing performance following the approach assessment by instrument reference. The third indicator was based on pilot acceptance attitudes and preferences expressed in the debriefing sessions.

This section presents the contrast in display support provided by the experimental runway perspective display (ERPD) with that provided by both conventional instrumentation (FD-109) and a more basic version of the pictorial display (BRPD). The format adopted for this presentation of study results is a series of statements summarizing the general experimental findings. Following each statement, raw and processed data which support these assertions or provide amplifying information are presented and discussed.

Statement 1: Flight management task performance was clearly more accurate and more consistent when pilot judgments were made by reference to the ERPD.

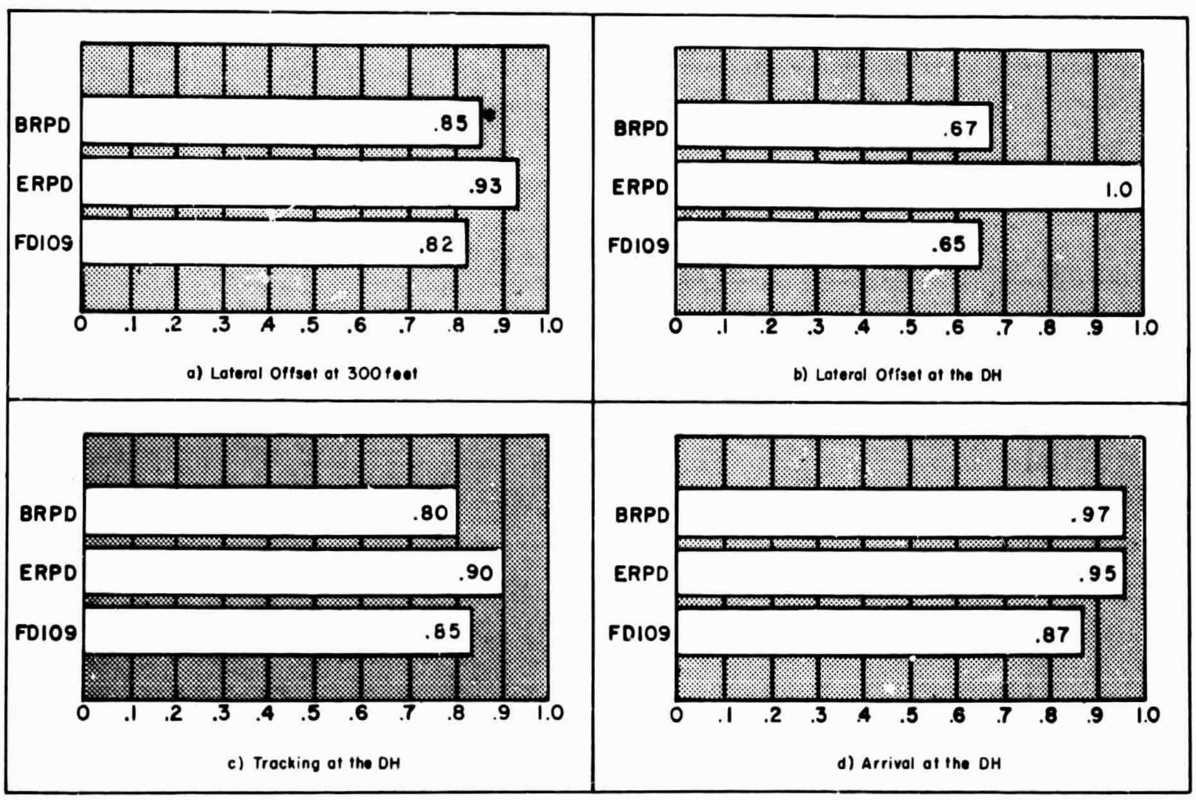
An overview of the accuracy of pilot estimates of flight path alignment, aircraft tracking tendencies, and arrival at the 100-foot decision height (DH) is presented in Table 1. The cell entries in this table are the total number of errors in specified pilot judgments (errors are defined in the Experimental Design section, p. A-9 of Appendix A) which were observed for each pilot on the ten approach sequences flown using each of the alternate displays. Total error counts at the bottom of each column thus indicate the accuracy of pilot judgments on sixty simulated approach sequences under each of the three display conditions. A more complete record of the data obtained in this experiment is provided in Appendix C which gives the recorded flight situation parameters and error counts for each pilot on each simulation sequence.

The clearest improvement in flight management task performance using the ERPD is evident for pilot judgments of flight path alignment, i. e., the lateral displacement of the aircraft from the extended runway centerline. At 300 feet, pilots made twice as many errors in this judgment using the basic version of the pictorial display (BRPD) and almost three times as many errors using the conventional instrumentation (FD-109). This trend toward more accurate pilot judgments using the ERPD is much more obvious when the flight path alignment estimates were made at the critical 100-foot decision height (DH). At this point in the approach, no errors in estimating lateral offset were made by any of the six pilots on the sixty simulated approach sequences. When either the BRPD or the FD-109 was used as the basis for these judgments, errors occurred on about one third of these attempts. Similar trends were observed in the error counts for pilot judgments of the aircraft's tracking tendencies and of its arrival at the 100-foot DH, but the contrast among displays here is not as clear.

Table 1. Number of Errors in Pilot Judgement on Each Component of the Approach Assessment Task.

PILOT	Lateral Offset at 300'			Lateral Offset at the DH			Tracking at the DH			Arrival at the DH		
	BRPD	ERPD	FDI09	BRPD	ERPD	FDI09	BRPD	ERPD	FDI09	BRPD	ERPD	FDI09
1	2	0	4	3	0	5	2	1	3	0	0	5
2	2	1	1	3	0	4	0	0	0	0	0	1
3	2	0	0	5	0	0	3	1	0	0	0	0
4	1	2	2	6	0	5	5	1	1	2	0	0
5	1	1	2	2	0	5	2	2	3	0	0	0
6	1	0	2	1	0	2	0	1	2	0	3	2
TOTAL	9	4	11	20	0	21	12	6	9	2	3	8

In Figure 7, the error counts given in Table 1 are transformed into a simple "accuracy index" to further illustrate the contrast in flight management task performance when the alternative display concepts are considered. As indicated, the accuracy index is the ratio of correct judgments to the total number of judgments attempted (n=60) and is expressed as a proportion. The relative accuracy of pilot judgments using the different displays is shown on the bar graphs for each component of the flight management task. The accuracy indices given in these bar graphs may also be construed as the probability of a correct judgment when the designated display concept is used. Further clarification of these comparisons and the statistical evaluation of the improvement in pilot performance is given in subsequent statements.



* These numbers are the proportion of correct pilot responses (n = 60)

Figure 7. Accuracy of Specified Components of the Approach Assessment Task when Alternate Display Modes are Used.

Statement 2: Pilot estimates of lateral offset at 300 feet tend to be more accurate and consistent when the ERPD is used.

The error counts tabulated in Table 1 show that lateral offset estimates made by reference to the ERPD were consistently more accurate than those made using either the BRPD or the FD-109. At this point in the approach, the reference dots for judging flight path alignment are in view but not yet in correspondence with the fixed aircraft reference mark (see Figure 2 for illustration of these display elements). The data suggest that this display feature provides some additional support for the lateral offset judgment even when the aircraft is as far out as the Middle Marker. Two of the pilots noted this in the debriefing sessions and recommended that additional "decision bars" be located earlier in the approach, e. g., at ranges of 1000 and 1500 feet from the runway as well as at 500 feet.

The differences in the accuracy of pilot estimates of lateral offset at 300 feet are not statistically significant. Analysis of variance, using a square-root transformation of the number of correct judgments as the criterion measure, did not reach significance at the .05 level. The square-root transformation was used to correct for unequal variances in criterion data for the different display conditions (see ref. 8, p. 218). As a further check, a non-parametric analysis (Friedman test, see ref. 8, p. 136) was carried out using a simple rank ordering of accuracy counts and again the .05 significance level was not attained. The obtained data do not support the hypothesis that the alternative display concepts have a differential effect on this element of the approach success judgment.

Statement 3: At the 100-foot decision height, pilots made no errors in estimating lateral offset by reference to the ERPD -- a significant degradation in the accuracy of these pilot estimates occurred when either the FD-109 or the BRPD was used by the same pilots.

This finding is already clear from the data given in Table 1 and is here supported by the statistical analysis. Using the number of correct estimates as the criterion measure and rearranging the data in accordance with a single factor design with repeated measures (ref. 8, p. 105), the analysis of variance test was significant at better than the .01 level. A summary of this analysis is presented in Table 2.

Table 2. Analysis of Variance for the Effect of Display Support Mode on the Accuracy of Lateral Offset Estimates at the DH

Source of Variation	Sum of Squares	df	Mean Square	F
Between Pilots	12.28	5		
Within Pilots	73.33	12		
Display Mode	46.78	2	23.39	8.79*
Residual	26.55	10	2.66	
Total	85.61	17		

*$F_{.99}(2,10) = 7.56$

The experimental display concept represented by the ERPD was, of course, deliberately designed to support the pilot in this key element of the approach success judgment. In addition to providing empirical validation of this display concept, the data obtained also support the contention developed in earlier analytic studies (ref. 2) that significant degradation of flight management task performance could be anticipated when excessive information processing demands are imposed on the pilot in command. This analysis argued for a more direct representation of the critical flight situation parameters under assessment by the pilot and this was the guiding principle in developing the ERPD as an improved aid to flight management.

Specific contrasts between alternative display concepts were examined using Dunnett's **t** statistic for separately comparing the ERPD and BRPD with the FD-109 control condition (ref. 8, p. 89). This test is based on the differences in the accuracy indices reported in Figure 7 for the comparisons of interest. The accuracy index for the ERPD was found to be significantly higher than both the FD-109 [$t = 3.72$, $t_{.99}(10) = 3.11$] and the BRPD ($t = 3.55$) at the .01 level of significance. The contrast between the BRPD and FD-109 accuracy indices was not significant ($t < 1$).

Statement 4: No significant differences in the accuracy of pilot judgments of aircraft tracking tendencies were apparent in the contrast between displays, but a weak trend in favor of the ERPD was noted.

The error counts presented in Table 1 indicate that tracking judgments were consistently more accurate when they were made by reference to the ERPD, but the overall differences are not statistically significant. It is interesting to note the pilot estimates of aircraft tracking by reference to the FD-109 instrumentation were considerably more accurate in this study than in the initial simulation study (ref. 1) under similar conditions. In the first study errors in tracking

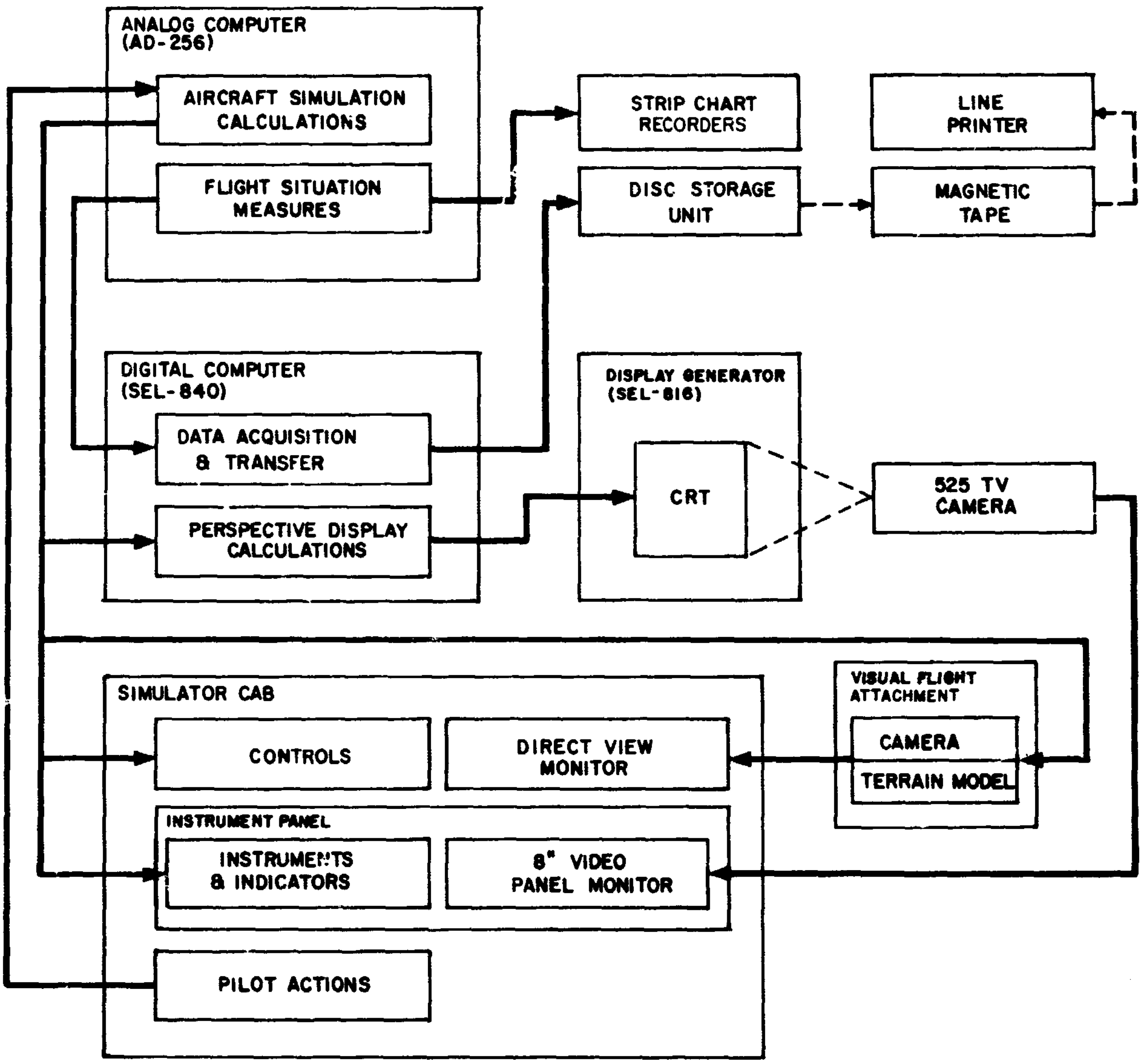


Figure 4. Simulation Facility Configuration

A fully-coupled automatic flight control mode was simulated on all approach sequences in SRP-2. Since the basic experimental task was an assessment of the aircraft's position relative to the runway as it approached the 100-foot decision height, the aircraft's flight path during the approach was a controlled variable in the experiment. Ten different flight profiles were programmed on DFG's to generate the desired variations in lateral offset and tracking tendencies in the decision region and to assure that the same flight situations were being judged under each of the three display mode conditions. The ten profiles used in the study are illustrated in Figure 5.

Instrument Panel Modifications

Pilot-subjects carried out assigned flight management tasks from the left seat of the MMIB simulator cab. Flight instrumentation and controls provided at the pilot's station were basically the same as the first study with the important addition of provisions for representing the alternative experimental display conditions. A new instrument panel was installed to accommodate the 8-inch video monitor and incorporated an adapter panel to simplify the set up of alternative display conditions. The new panel is illustrated in Figure 6.

The display condition illustrated in Figure 6 is the ERPD; conversion to the BRPD was accomplished by loading a different display generation program into the SEL 840 computer. In order to set up the FD-109 condition, the adapter panel shown in Figure 6 was removed and replaced with a second panel with the FD-109 Flight Director Indicator installed in the center. A minor rearrangement of the basic flight instruments around the adapter panel was necessary, as shown, but the basic configuration remained the same.

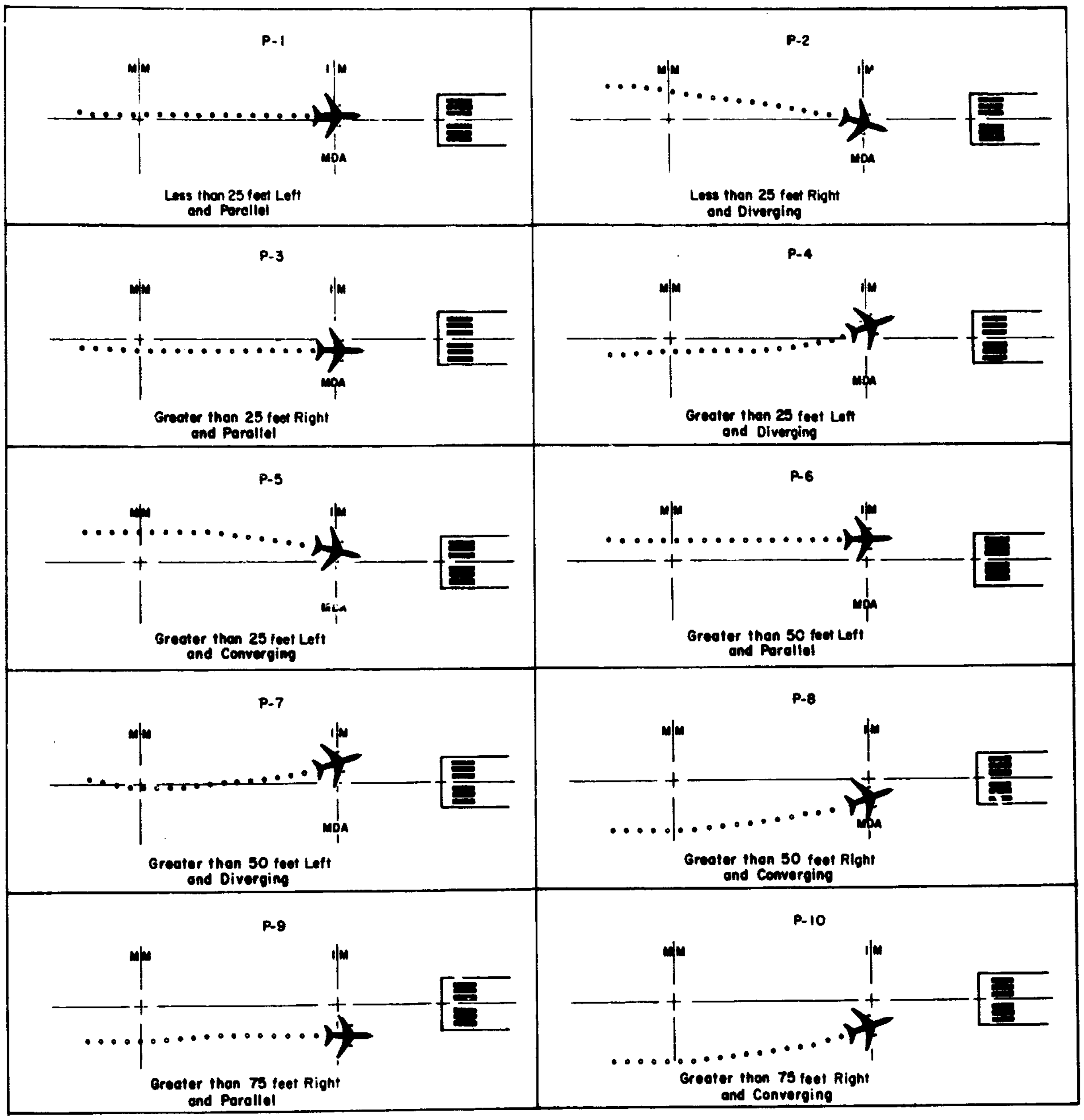


Figure 5. Programmed Flight Path Alignment and Tracking Profiles.

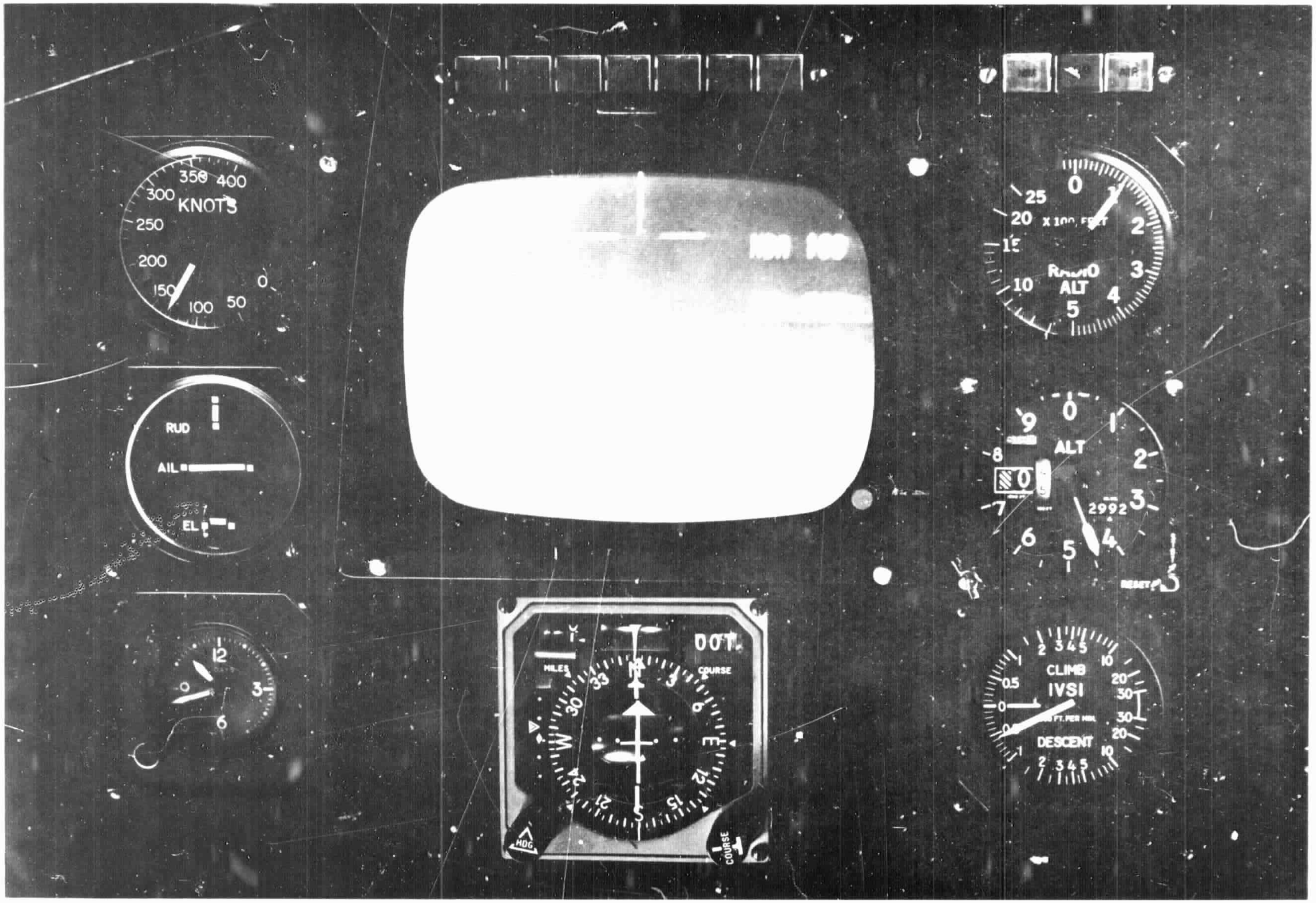


Figure 6. Instrument Panel Layout with the 8-inch Video Monitor Installed on the Adapter Panel.

judgments occurred on almost half (47%) of the simulated approach sequences; in this study only 15% of these tracking judgments were incorrect. The principal differences in the conditions under which data were obtained in the two studies were in the procedures adopted for judging and reporting lateral offset (see Appendix A). The simplification of the pilot's task in the present study may have contributed to the improved performance.

It is also of interest to note that error counts for tracking estimates made by reference to the BRPD were somewhat higher than the ERPD count. Since the data indicate that the concurrent lateral offset estimates were more difficult using either the BRPD or the FD-109, perhaps the demands of this task element degraded performance on the tracking judgments. If this argument were accepted, the potential contribution of the ERPD concept could be construed as facilitating the overall approach assessment task as well as increasing the accuracy of specific task elements, e. g., the lateral offset estimate.

Statement 5: Pilot estimates of arrival at the minimum decision altitude (MDA) tended to be more accurate when either version of the perspective display was used.

Figure 7 indicates that pilot errors in estimating arrival at the MDA were negligible for all display conditions but there is some indication of improved accuracy when either the BRPD or the ERPD is contrasted with the FD-109. The reported differences in error counts for the alternative display conditions (Table 1) are not statistically significant. Arrival at the pre-selected MDA is represented directly on all three display modes -- by illumination of the MDA light on the FD-109 Flight Director Indicator and by the appearance of the MDA symbol on the CRT displays. Since the task demands are the same, no significant differences in the accuracy of pilot responses were expected.

The somewhat less accurate judgments made by reference to the FD-109 could again be attributed to the greater demands of the concurrent lateral offset judgment, but this argument is weakened by the absence of any similar effect when the BRPD data are considered. Table 5 indicates that concurrent lateral offset judgments using the BRPD are at the same level of difficulty as those made using the FD-109 and MDA estimates did not seem to be affected. This observation suggests that more accurate judgments using the perspective displays may be attributed to the large MDA readouts available on the CRT displays and/or to their more optimum location within the pilot's primary visual scan area.

Statement 6: The displays used to assess approach success do not differentially affect the outcome of the landing maneuver.

Immediately following their assessment of the aircraft's flight situation at the 100-foot DH, pilots were instructed to assume manual control and complete the landing maneuver by reference to simulated external visual cues. The approach assessments were made strictly by instrument reference, using one of the alternative display modes evaluated in this study, and the subsequent landings were made strictly by visual reference. It should be clear, then, that the outcome of the landing attempts does not constitute any sort of evaluation of the three display concepts as an aid to the pilot in the flight control task of landing the aircraft. The general rationale for examining landing performance data following assessments by reference to the different displays is that any differential effect might suggest that the display mode associated with better landings provided the pilot with a clearer and more accurate orientation to the flight situation as he assumed manual control and would thus contribute to the effectiveness of his initial control actions.

No differential effects of this sort were noted in this experiment. Summary data on landing outcomes (i. e., touchdown performance data) following specified flight situations at the 100-foot DH are presented in Table 3. Data from 178 landing attempts (on two approaches the pilot elected to abort prior to touchdown) are presented in subsets defined by the display mode used for the approach assessment task. The touchdown positions and aircraft velocities reported here may be contrasted with the defining characteristics of a successful landing adopted in the initial simulator study:

1. Lateral displacement from the runway centerline (mean values are reported as $\overline{Y}$ in Table 3) should be within ± 27 feet.

2. Touchdown along the runway should occur within the first 2500 feet from the runway threshold (mean touchdown positions are reported as $\overline{X}$ in Table 3; at the threshold X = 0 feet.)

3. Vertical velocity at touchdown ($\dot{h}$) should be 6 feet/sec. or less.

4. Cross-track velocity at touchdown ($\dot{y}$) should be 8 feet/sec. or less.

Since the assessment of landing outcomes was not a primary concern of the present study, the experiment was not designed to allow a systematic statistical test of the effects of display mode or flight situation at the DH or touchdown performance. However, the touchdown data associated with the various combinations of these conditions in Table 3 can be examined for any consistent trends. For example, a cursory scan of the first touchdown position column indicates that mean touchdown positions along the runway were all

Table 3. Touchdown Data for Various Flight Path Alignment Situations at the DH Arranged by Display Mode

Flight Situation		Display Mode	Touchdown Position (ft.)				Velocities (ft./sec.)			
Lateral Offset	Tracking Vector		Along Runway		Lateral		Vertical		Cross-track	
			$\bar{X}$	sd X	$\bar{Y}$	sd Y	$\bar{\dot{h}}$	sd $\dot{h}$	$\bar{\dot{Y}}$	sd $\dot{Y}$
Within ± 50 ft. of Runway Centerline (n = 81)	Diverging (n = 25)	BRPD	1394.	227.	34.6	13.2	9.5	4.5	6.7	6.3
		ERPD	1598.	365.	17.2	20.7	10.5	5.6	5.8	4.2
		FD-109	1673.	476.	22.5	10.8	6.8	3.3	8.0	5.8
	Converging /Parallel (n = 56)	BRPD	1458.	321.	18.9	14.9	12.1	4.5	4.2	6.4
		ERPD	1464.	411.	19.6	13.8	12.6	5.6	2.6	2.8
		FD-109	1519.	329.	21.8	11.7	9.4	4.8	3.2	2.7
More than 50 ft. from Runway Centerline (n = 97)	Diverging (n = 27)	BRPD	1426.	308.	47.8	21.5	10.5	4.5	6.8	5.4
		ERPD	1285.	304.	39.7	15.1	12.7	4.8	8.0	3.5
		FD-109	1532.	373.	36.2	23.9	7.2	4.2	10.3	5.2
	Converging /Parallel (n = 70)	BRPD	1453.	326.	43.5	25.9	11.3	4.2	7.2	5.0
		ERPD	1467.	455.	40.2	24.9	13.0	6.2	5.9	4.6
		FD-109	1532.	421.	33.3	23.5	9.6	4.6	8.0	5.2

within the 2500-foot touchdown zone and that both the means and the standard deviations (sd X) were about the same under all of the conditions distinguished. Within specified DH conditions, there is also no indication that lateral displacement and touchdown velocities were consistently lower for any particular display mode, particularly in view of the reported variability in each of these parameters.

It is of some interest to note that all of the mean lateral displacements exceeded the 27-foot criterion value for landings attempted from DH offset positions greater than 50 feet. At one standard deviation (sd Y), this criterion value was also exceeded for landings attempted from DH offset positions within 50 feet of the centerline, but lateral displacements were within the ± 45-foot limits on useful runway width defined in earlier studies (ref. 1). The touchdown data in Table 3 are consistent with the results obtained in the first study and provide additional support for the contention that manually controlled landing maneuvers under Category II visibility conditions will not satisfy established touchdown displacement criteria and that additional display aiding will be required for this flight control task.

Statement 7: Expressed pilot preferences and acceptance attitudes were unanimously in favor of the ERPD.

During a debriefing session following their experience in the simulator with all three display concepts, pilots were asked to express their opinions regarding the pictorial situation display as an aid to flight management during actual Category II approach and landing operations. A debriefing questionniare (see Appendix B) was used to structure the discussion and the most direct expression of pilot preferences and acceptance attitudes were obtained in reponse to items 6 and 7.

In response to item 6, all six pilots stated that they felt that the pictorial situation display (ERPD) would provide significantly better support to them than conventional instrumentation (FD-109) for judging the success of a Category II approach. Pilots understood that this item referred to display characteristics such as ease of interpretation, symbology used to represent flight situation parameters, relevance to flight management task, etc. In response to item 7, the six pilots were also unanimous in stating that they would feel more confident of their assessment of the aircraft's position relative to the runway when these assessments were made by reference to the pictorial display.

Pilot responses to items 8 and 9 of the debriefing questionnaire provided further indications of their positive acceptance of the ERPD display concept. Responding to item 8, all of the pilots indicated that they would feel confident in attempting an approach under actual Category II visibility conditions using this display to monitor the flight situation and they specified 1600 feet RVR or lower as the visibility conditions they would accept. In reponse to item 9, pilots also expressed confidence in conventional instrumentation (FD-109) for monitoring a Category II approach, but in two instances better visibility conditions were specified, i.e., 2400 feet RVR rather than 1600.

Unsolicited pilot comments during familiarization training on the ERPD and while completing the experimental run series also indicated positive acceptance of this display concept. Some negative reactions were expressed with respect to the glide slope deviation symbol and to the absence of flight director display elements, but acceptance of the pictorial format and of the direct correspondence of the runway perspective display to the actual relative position and movement of the runway was very positive. Suggested improvements to the ERPD included the following:

1. Extend the runway centerline dots farther out into the approach area and add reference dots for juding lateral offset earlier in the approach, e.g., at 1000 feet, 1500 feet, and even as far out as the Middle Marker.

2. Add flight director elements, particularly for pitch commands.

3. Re-design glide slope deviation symbol to facilitate interpretation and avoid confusion with flight director displays.

CONCLUDING REMARKS

The results of this study indicate that the experimental runway perspective display (ERPD) would provide significantly better support to pilots for monitoring and assessing an approach under Category II visibility conditions than the conventional instrumentation represented by an advanced design attitude-director indicator (ADI). It also seems clear that the pictorial runway perspective display would enhance pilot confidence in his judgments of the flight situation and contribute to positive acceptance of low visibility landing systems and operational procedures. Additional research directed toward the refinement of the experimental display and to extending its application to terminal area maneuvering and to monitoring landings under Category III visibility condtions (700 feet RVR and lower) is strongly recommended. Applications to unconventional approach operations, such as the steep approach for noise abatement, slow speed decelerating approaches characteristic of V/STOL aircraft, and space shuttle vehicle recovery operations should also be investigated.

Data obtained in this study show that the concept of providing a more direct representation of the flight situation parameters assessed by the pilot within a more natural, "real world" oriented format can significantly improve the accuracy and ease of pilot judgments. Estimates of flight path alignment with the runway as the aircraft approached the authorized Category II decision height were the most directly aided element of the approach assessment task and pilots made no errors in this judgment on 180 simulated approach sequences. When either the conventional ADI or the more basic runway perspective display (no direct aiding for the lateral offset estimate) was used, a significant degradation in the accuracy of pilot judgments occurred. Contrasts between the three displays on other components of the approach assessment which were not so directly aided show similar trends in favor of the ERPD, but the differences were not as marked.

The display concept evaluated in this experiment is only a very preliminary version of a pictorial display format that might be developed to support the pilot in all aspects of the low visibility landing problem. Emphasis was placed on the requirement for more direct aiding of the flight management function and the important requirements of integrating display features for the flight control task were not considered. A synthesis of display requirements for both the control of the aircraft (or direct monitoring of automatic control system operation) and the monitoring and assessment of the effectiveness of flight control (i. e., the actual position and movement of the aircraft relative to the intended touchdown point on the runway) will be necessary in the further refinement of the ERPD.

Two observations are pertinent here. One is that the flight management requirements imposed on the pilot are sometimes minimized, even by pilots, and display concepts are accepted which would delimit the pilot's role to one of "null monitoring". This orientation derives from a preoccupation with the requirements of the flight control task and habitual reliance on command type displays such as the flight director steering bars and on qualitative ILS deviation indicators. For monitoring purposes this orientation would lead to acceptance of null positions as indications that flight control objectives were being satisfied. The basic problem with this orientation is briefly illustrated by the fact that even when the pilot (or autopilot) succeeds in tracking the localizer to well within the $\pm$ 25 microampere tolerances established by the FAA (ref. 9) the aircraft can arrive at the 100-foot DH with excessive lateral offset.

Considering just the effects of localizer signal characteristics which remain within ICAO limits, Litchford (ref. 10) has shown that lateral offsets at the DH can be as high as 55 feet on a 3 sigma basis (82 feet in the worst case) and it is important to note that this situation can occur with the flight director and localizer deviation indicators maintaining a null position. When allowable flight control errors are considered the 3 sigma lateral offset situation increases to 104 feet. As one pilot put it:

> There must be a secondary system entirely independent of the primary approach system to have true redundancy and to have true safety. The pilot must have complete confidence that he is committing his aircraft to a safe landing or he will never even start an approach. If that landing is to be made without visual reference -- or very limited reference -- some method of cross-reference is absolutely necessary between two entirely independent systems with totally different sources of information and, if possible, different display methods in the cockpit. (ref. 11)

The second observation is that a preoccupation with just the flight management requirements can be equally one-sided and fall short of doing the whole job. Action decisions taken on the basis of pilot judgments will, in many instances, entail the assumption of manual control by the pilot and displays optimized for assessing the ongoing flight situation might not be suitable for the smooth conversion to manual control. Refinements to the ERPD investigated in future analytic and simulation studies must consider the interacting requirements of situation monitoring and flight control.

REFERENCES

1. Gartner, W. B.: A Simulator Study of Flight Management Task Performance During Low Visibility Approach and Landing Using Baseline Category II Flight Instrumentation, NASA CR 73478, December, 1969.

2. Gartner, W. B. and Shoemaker, R. G.: Study of Flight Management Requirements During SST Low Visibility Approach and Landing Operations, Final Summary Report, NASA CR 73243, June, 1968.

3. "New Instrumentation Concepts -- Part I," Aviation Week and Space Technology, March 23, 1970.

4. Beck, R. H.: The Revival of the "One Man Band", ALPA All Weather Flying Committee, 1967.

5. DeCelles, J. L.: The Fail-Safe Landing, A Report of the ALPA All-Weather Flying Committee, paper presented at ALPA's 17th Air Safety Forum, July, 1970.

6. Wempe, T. and Palmer, E.: Pilot Performance with a Simulated Pictorial Landing Display Including Different Conditions of Resolution and Update Rate, unpublished paper, NASA Ames Research Center.

7. Control-Display Pilot Factors Program. Instrument Evaluation Project NR. 62-1B, sponsored by FAA, Randolph AFB, Texas, September 1966.

8. Winer, B. J.: Statistical Principles in Experimental Design, McGraw-Hill Book Company, Inc., New York, 1962.

9. Federal Aviation Agency: Criteria for Approval of Category II Landing Weather Minima, FAA Advisory Circular AC 120-20, June 6, 1966.

10. Litchford, G. B.: Analysis of Cumulative Errors Associated with Category II and III Operations with Requirements for Additional Research, NASA CR 1188, 1968.

11. Halaby, N.E.: All-Weather Operations -- Progress and Challenges, Astronautics and Aeronautics, May 1968.

12. Greatorex, F.S., Jr., and Cohen, Dan: Producing Dynamic Perspective Views for Vehicle Simulation, Data Processing Magazine, April 1968.

APPENDIX A
EXPERIMENTAL DESIGN AND PROCEDURES

Experimental Design

The basic experimental design for evaluating the effects of the three display concepts on flight management task performance was a single factor experiment with repeated measures (ref. 8, p. 105). This design required that all pilot-subjects perform the same assigned flight management tasks by reference to each of the three alternate displays on an equal number of simulated approach and landing sequences. The overall plan of the experiment is schematized in Table A-1.

Table A-1. Experimental Design

PILOT	Display Condition by Run Series		
	1st	2nd	3rd
1	FD109	ERPD	BRPD
2	FD109	BRPD	ERPD
3	FD109	BRPD	ERPD
4	BRPD	ERPD	FD109
5	ERPD	BRPD	FD109
6	ERPD	BRPD	FD109

In accordance with this plan, each of the six pilots completed three 10-run series under each display condition. Flight management task performance data were thus obtained on a total of 180 simulator runs; 60 runs using each of the different displays. Table A-1 also shows the order in which each pilot was exposed to the display conditions. This counterbalancing of the order in which the three display modes were used was adopted to preclude any systematic bias in the data due to pilot fatigue or learning effects which might have operated over the three run series. Pilot and simulator facility scheduling constraints did not allow for a completely counterbalanced design, i.e., FD-109 instrumentation could be used on the first run series or the last, but there was not enough time to allow for a conversion from the CRT display to the FD-109 and then back to the CRT during a scheduled experimental session.

Each run series was comprised of 10 approach and landing sequences incorporating the same patterns of variations in flight profile and terrain elevation. This pattern is given in Table A-2 and was defined by randomizing the order in which the ten programmed profiles were used and by associating the different terrain profiles with each of the major profile variations.

Table A-2. Definition of Run Series Used for All Display Conditions

Run Number	Programmed Flight Profile	Programmed Terrain Profile
1	P-1	TP-1 (level)
2	P-2	TP-3 (15' high at IM)
3	P-6	TP-2 (40' low at IM)
4	P-10	TP-1
5	P-5	TP-1
6	P-8	TP-2
7	P-9	TP-3
8	P-3	TP-3
9	P-7	TP-1
10	P-4	TP-2

Prior to each experimental run series, pilots were given display and simulator familiarization training and then completed a practice run series to learn the experimental task and the procedure for reporting their judgments of the flight situation. The first three sequences were flown without performing the experimental task for simulator familiarization and landing practice. The practice series consisted of 6 runs on which pilots performed assigned flight management tasks by reference to the display mode scheduled for the subsequent experimental run series.

Pilot Subjects

Six senior airline pilots, currently active as line pilots with Pan American World Airways, served as subjects for this study. A seventh Pan Am pilot participated in the checkout of the simulation equipment and experimental procedure prior to the scheduling of the experimental run series. All of the participating pilots were individually qualified for Category II operations and were currently flying as Captains on Boeing 707/720 aircraft. Total airline flying experience averaged 5,835 hours of jet transport time for these six pilots (plus an average of over 12,000 hours in propeller driven aircraft) and an average of 11 years command pilot experience. The average age for the six pilots was 50 years.

Procedure

Each of the six pilots completed the scheduled run series on the three display concepts in two sessions. At the beginning of the first session a standardized orientation was given to each pilot in the form of a booklet outlining the purpose of the study, the characteristics of the simulation equipment, and the procedures to be followed. This booklet and the form used to record pilot background data is reproduced in Attachment 1. The experimenter was present during the orientation session to provide amplifying comments and/or to answer questions.

The pilot orientation material reproduced in Attachment 1 provides an outline of the operating procedures followed in the simulator. Following a quick scan of this material, the pilot and experimenter (E) proceeded to the simulator cab for more specific training on the display to be used in the first scheduled run series. Simulator operation was explained by E and each element of the flight situation display was explained to the pilot. E then initiated a demonstration run to illustrate display dynamics and the procedures to be followed in executing each approach and landing sequence. Pilots were then seated and flew 3 runs to get the feel of the simulator and to practice the manually controlled landing maneuver.

The basic experimental task assigned to the pilots is outlined in Attachment 1 to this Appendix. After the pilots completed the simulator familiarization runs, E reviewed this procedure and the display to be used and the pilots were allowed to fly 6 practice runs, making the specified approach assessments and reporting their estimates to E. Pilots were not given specific instructions on <u>how</u> to interpret the flight situation displays to make the specified approach assessments. Display elements and features were simply described and pilots were instructed to use their own experience and judgment in deriving the information they required.

After a short break, the scheduled experimental run series were completed in accordance with the design described earlier. When the FD-109 instrumentation was used first, the 10-run series was completed and the pilot returned the next day to complete additional practice and experimental run series on the CRT displays.

When CRT displays were scheduled first, experimental series on both versions were completed on the first day and the pilot returned the following day to do the FD-109 series. Debriefing sessions were conducted after all experimental runs were completed to allow the pilots to comment on their experiences with the different displays and to obtain opinion and attitude data. The questionnaire used to guide this debriefing discussion is reproduced as Appendix B to this report.

Data Recording and Analysis

On each simulator run during the experimental series E recorded pilot reports of lateral offset at 300 feet and lateral offset and tracking at the DH as they were given. After each run, E relayed these reports via an intercom system to an operator in the simulation laboratory where they were entered into the SEL 840 computer using an ASR-33 teletype terminal. Two strip chart recorders were also used during the run series to record key flight situation parameters and events on each run. These continuously recorded parameters and reference events are identified in Table A-3.

Fourteen of the data items listed in Table A-3 were monitored by the SEL 840 computer via analog-to-digital converter channels. A data acquisition program was used to control the sampling of values for selected flight situation parameters at key points in the approach and landing sequence and to transfer these data to disc storage. Data channels monitored by the SEL 840 system and the scaling factors used in the analog to digital conversion are presented in Table A-4.

Table A-3. Flight Situation Data and Events Recorded on Strip Chart Recorders

a. Recorder #1

TRACE	PARAMETER	DESIGNATOR	DYNAMIC RANGE	RESOLUTION	
Margin	Timing	----	----	----	
1	Horizontal Distance	X	a) 48000' to 8000' b) 8000' to -2000'	a) 800' b) 200'	*
2	Lateral Offset	Y	0 ± 100'	4'	
3	Height above Touchdown	Z	a) 1600' to 400' b) 400' to 0'	a) 24' b) 8'	*
4	Localizer Deviation	D_l	0 ± 150 μamps (± 2 dots)	6 μamps	
5	Glide slope Deviation	D_g	0 ± 150 μamps (± 2 dots)	6 μamps	
6	Not Used	----	-------	-----	
7	Touchdown Relay	TD	Event Marker	-----	
8	AFCS Disengage Control	AD	Pilot Response	-----	

* Requires Scale Change

b. Recorder #2

TRACE	PARAMETER	DESIGNATOR	DYNAMIC RANGE	RESOLUTION	
Margin	Timing	----	----	----	
1	Cross-Track Velocity	$\dot{Y}$	±25 fps	1 fps	
2	Heading	ψ	±25 degrees	1 degree	
3	Pitch Attitude	θ	±25 degrees	1 degree	
4	Roll Attitude	ϕ	±50 degrees	2 degrees	
5	Absolute Altitude	h_a	0' to 250'	5'	*
6	Vertical Velocity	$\dot{h}$	±25 fps	1 fps	
7	AD-256 Operate Control	OP	Event Marker	-----	
8	AFCS Disengage Control	AD	Pilot Response	-----	

* Record not required above 250 feet

Table A-4. Flight Situation Parameters and Events Monitored by the SEL 840 Computer System.

ADC Ch.	Parameter	Designator	Scaling Information
18	Glide slope Deviation	GDV	4.5 degrees/volt
19	Lateral Velocity	$\dot{Y}$	10 feet/sec/volt
20	Radio Altitude	RA	20 feet/volt
21	AC-256 Operate	OPR	Operate = -6 volts
23	AFCS Engage/Disengage	AD	Engaged = -6 volts
24	Airspeed	UO	6.075 knots/volt
25	Vertical Velocity	$\dot{h}$	10 feet/sec/volt
26	Roll Angle	ϕ	.03773 radians/volt
27	Pitch Angle	θ	.00228 radians/volt
28	Heading	ψ	.0303 radians/volt
29	Touchdown Relay	SWIT	Touchdown = -6.volts
30	Horizontal Distance	X	295 feet/volt
31	Height above Touchdown	Z	20.4 feet/volt
32	Lateral Offset	Y	60.8 feet/volt

At the end of each run series, a second data treatment program was used to transfer run data from disc storage to magnetic tape, calculate errors in pilot judgments, and print out a summary data sheet for designated practice and experimental run series on the line printer. The data content and format of the summary data print out is illustrated in the sample printout for one run reproduced in Figure A-1. Additional printouts were generated by the computer for each run in the series.

```
TIME: 10:43:45
RUN NØ:    3                              SUBJECT:    3
PRØFILE:    6                             TERRAIN:    2

          X          Z         Y         HD        YD
 MM    3577.       194.      -58.        9.         .
500    5903.       299.      -56.       10.         .
 IM    1229.        83.      -58.        9.        1.
MDA    1578.        99.      -58.       10.         .
 AD    1686.       104.      -58.       10.         .
 TD    -352.        13.      -10.        8.        4.

PREDICTIØN:      ALIGNMENT:       TRACKING:
    3                -3                0

 ØE     RE     AE     TE     DHE    YOE    XOE    HDOE
 0      0      0      0      0      0      0      1
```

Figure A-1. Sample Computer Printout of Flight Situation Data and Error Counts.

Data elements above the matrix in this printout identify the time the run was initiated, the run number, the programmed flight profile, the subject, and the programmed terrain profile. Data elements in the cells of the matrix are the values of flight situation parameters identified by coded designators heading each column sampled at the points identified by the coded designators for each row. Designated parameters are identified in Table A-4 (HD and YD are $\dot{h}$ and $\dot{y}$) and the sampling points are as follows:

MM	=	Middle Marker
300	=	300 feet above the runway
IM	=	Inner Marker
MDA	=	Minimum Decision Altitude
AD	=	AFCS disengage
TD	=	Touchdown

Coded entries below the matrix indiate the pilot estimates entered on the ASR-33 for lateral offset at 300 feet (PREDICTION), lateral offset at AFCS disengage (ALIGNMENT), and aircraft tracking (TRACKING). The final line of data elements in the computer print out are the error counts for five types of errors which could have occurred on designated elements of the approach assessment task and on three "errors" in the outcome of the landing maneuver. Criterion measures for evaluating the three display concepts were derived from these error counts and are discussed in the next section. A brief definition of each error type is given below.

ØE = Offset error at 300 feet -- pilot reports of lateral offset at 300 feet were compared with Y at 300 feet and errors were counted in accordance with the following logic:

An error was counted when pilot reported: . . .	and Y at 300 ft. was:
"RIGHT ON"	$> \pm$ 30 ft.
"More than 25"	$< \pm$ 20 ft. or $> \pm$ 55 ft.
"More than 50"	$< \pm$45 ft. or $> \pm$ 80 ft.
"More than 75"	$< \pm$70 ft.

RE = Reversal error -- pilot reports of lateral offset included an indication of the direction of the aircraft's displacement from the extended runway centerline, e.g. "right" or "left"... RE errors were counted whenever the pilot misjudged this direction.

AE = Alignment error -- pilot reports of lateral offset at AD were compared with Y at AD; error counts were based on the logic given above for ØE errors.

TE = Tracking error -- pilot reports of aircraft tracking tendencies were compared with value of YD($\dot{y}$) at AD and errors were counted in accordance with the following logic:

An error was counted when pilot reported: . . .	. and YD at AD was:
Parallel	> 4 fps
Converging	> 1 fps away from runway C/L
Diverging	> 1 fps toward runway C/L

DHE = Decision height error -- pilots were instructed to disengage AFCS (AD) when they were confident that the aircraft was at 100 feet above the runway; errors were counted when Z (height above touchdown) at AD was < 88 feet or > 112 feet, i. e., a correct judgment of arrival at the MDA was indicated by AD occurring within $\pm$ 12 feet of the DH.

YOE = Lateral displacement error at touchdown -- an "error" (excessive lateral displacement from the runway centerline) was counted when Y at touchdown was greater than $\pm$ 27 feet.

XOE = Longitidinal displacement error at touchdown -- an "error" was counted whenever touchdown occurred outside a touchdown zone defined by the first 2500 feet down the runway from the threshold, i. e., when X at touchdown exceeded either + 1000 or - 1500 feet (X = 0 at the glide slope intersection with the runway at 1000 feet from the threshold).

HDOE = Excessive rate-of-sink at touchdown -- an error was counted whenever $\dot{h}$ at touchdown was greater than 6 feet per second.

ATTACHMENT 1
PILOT ORIENTATION BOOKLET

ORIENTATION

The Man-Machine Integration Branch here at the NASA Ames Research Center is engaged in a broad program of research concerned with flight crew factors in the operation of commercial jet transport aircraft. The study you have been asked to participate in today is being carried out by Serendipity, Inc., under contract to Ames and is one of a series of simulation research porjects designed to examine the duties and responsibilities of the pilot-in-command during Category II approach and landing operation. Your participation in this project will help us obtain data which are more relevant to actual flight operations and will promote acceptance of study results by the aviation community.

The specific purpose of the current simulation study is to evaluate an ILS-independent, pictorial approach situation display as an aid to command pilots for judging an approach to Category II minimum decision altitudes. The experimental display is a computer-generated graphic representation of a runway which will move in correct perspective relationship to the aircraft during the approach. Certain display features have been added to enable command pilots to make more precise judgments of flight path alignment with the runway and of aircraft tracking tendencies in the decision region.

It should be clearly understood that the study is not intended, in any sense, to evaluate the quality of your judgmental or decision making abilities as an individual pilot. Your job will be to serve as the command pilot in the simulation and to bring to bear your experience and knowledge of low visibility approach operations to our evaluation of three different display concepts. Using these displays, you will be asked to make certain assessments of the aircraft's flight path during the approach and then to complete the landing maneuver by visual reference under simulated Category II visibility conditions. Data taken on each simulation run will be used to determine the accuracy and timeliness of the assessments and decisions you are asked to make. As noted above, the analysis of these data is designed to evaluate the experimental displays in terms of the information made available to you as the basis for your judgments. Your performance of the experimental tasks will be interpreted as reflecting the quality of the displays rather than of your individual skills and abilities.

The material presented in this booklet is intended to provide you with an overview of what to expect during the rest of the session, to briefly identify the simulated equipment and operating conditions, and to outline the tasks you will perform as a subject in this experiment. If you would like to know more about the aims of the study, we will be happy to discuss your interests with you after the completion of the experiment. The availability of your experience, skills, and knowledge is an important element in the success of our investigation and we appreciate your contribution of time and effort. We would like to thank you for participating in this report.

BACKGROUND DATA

Before proceeding to the more specific orientation material, please complete the brief Background Data Sheet attached to this booklet. The information requested is of interest only to the project staff and will be used in subsequent interpretations of study results. You will not be identified by name in the publication of study results and data records for designated individuals will not be released to outside agencies or individuals. This also applies to any comments you may make during the course of the day or to opinions you will be asked to express during the briefing session following the completion of the simulator run series.

BACKGROUND DATA SHEET

Subject No.________

Date________________

1. Name:____
(This entry is optional)

2. Airline:____

3. Current aircraft type ratings:_________________________
(Please underline type currently flown, if more than one type cited)

4. Crew position: Captain__________First Officer__________

5. Additional flight and/or ground duties:________________
(e.g., Check pilot, training, safety chairman, etc.)

6. Approximate total airline flying hours: Jet_____Prop_____

7. Age:__________

8. Years pilot experience: Command:______Flight Officer____

9. Approximate total military flying hours:________________

10. Principal military aircraft type (check one):

Transport______________ Bomber______________

Fighter ______________ Other ______________

11. Please indicate the extent to which you are familiar with Category II operating requirements and equipment developments: (Circle as many as are applicable.)

a. Have completed formal Category II classroom and simulator/flight training program with my airline

b. Have flown Category II qualification check ride with FAA designated Company Check Pilot.

c. Have personally participated as research pilot or consultant in development projects concerned with all-weather landing systems.

d. Have participated in actual approach and landing under Category II conditions (i.e. reporting ceiling lower than 200' and/or RVR lower than 2600')

12. What are the lowest minimums to which you are currently certified?

    RVR__________ Ceiling (if applicable)__________

13. What type of flight director/attitude indicator is in the aircraft you usually fly? (e.g. Collins FD-109 system, Sperry HZ-4, etc.)

14. Is the aircraft you typically fly equipped with Radio Altimeters?_________________

    Does the system include an audio warning tone?_________

15. Have you ever flown aircraft equipped with automatic throttle control?_________________

16. With the quipment you usually fly, what are the lowest minimums you feel confident and comfortable with?

    RVR__________ Ceiling__________

17. Have you ever been a subject in a flight simulation research study before?__________ If so, please give approximate date and briefly indicate type of study.

FLIGHT SEQUENCE AND EQUIPMENT REPRESENTED IN THE SIMULATION

The operational context represented in the simulator runs is an ILS approach under 1600 feet RVR conditions to runway 1R at Dulles International Airport. Each run in the simulator will represent the execution of a flight sequence beginning with the aircraft at approximately four nautical miles from the runway, stabilized on the localizer course, and descending to the authorized 100-foot minimum decision altitude (MDA). This sequence ends with the aircraft on the runway decelerating to a nominal turn-off speed. A copy of the current Jeppesen Approach Chart for Dulles will be provided by the Experimenter.

Aircraft response characteristics and flight control system dynamics represented in the simulation are those of the DC-8 airplane. The crew compartment is a conventional transport-type cab mounted on a stationary raised platform (no motion cues are provided). You will occupy the Captain's seat and function as the pilot-in-command on all runs. In contrast to the training simulators you have flown, our research simulator will probably appear to be somewhat austere. No attempt has been made to reproduce the flight deck configuration for any particular aircraft type and a full complement of instrumentation and controls is not provided. The instrumentation and controls which will be available to you for the first experimental run series are identified in Figure C-1.*

Detailed familiarization with these instruments and controls will be given at the simulator; however, the equipment characteristics outlined below should be noted and if you have any general questions, we will attempt to resolve them at this time.

1. Primary flight situation and command information is provided by an experimental electronic display (see Figure C-2)* on some runs and by the Collins FD-109 Integrated Flight System on others. The principal features of the FD-109 System are illustrated in a booklet provided by the Experimenter. The electronic display is based on an ILS-independent microwave system and provides situation information only, i.e., no flight director steering commands are provided. The characteristics of this display will be demonstrated and discussed in the simulator.

2. The FD-109 system is used to represent conventional Category II instrumentation based on ILS guidance signals. An important feature of the FD-109 system is the expanded localizer deviation display element located on the attitude-director indicator. Note that a full, one-dot deflection on this expanded scale represents the same 75 micro-amp localizer deviation signal as that available on a smaller scale on the conventional horizontal situation indicator (PDI). At the decision point, this one-dot deflection will represent a lateral offset of about 190 feet.

3. A fully coupled flight control mode will be simulated on all runs. The automatic flight control system (AFCS) is programmed to track the ILS glide slope and localizer, and is deliberately designed to generate various flight path offset conditions to represent the test situations you will be asked to judge. There are no gimmicks, malfunctions, or highly unusual flight situations in the test series.

* Photographs of the instrument panel and controls in the simulator cab were shown to the pilots at this time.

4. An autothrottle function is also simulated. This feature will be used on all runs and will maintain an approach airspeed of 135 knots to within ± 5 knots automatically. It should be noted, however, that in the simulator this will not be accomplished by automatic positioning of the throttle levers.

5. The simulator is also equipped with a Visual Flight Attachment which will provide you with a color TV projection of the runway and its surrounds. Since Category II conditions will be represented (1600'RVR), an "in-cloud" condition will be simulated until the aircraft is sufficiently close to the approach lights and/or runway for visual cues to fade-in.

OPERATING PROCEDURE

Your role in the simulation sequence, as already indicated, will be to act as pilot-in-command and to carry out designated flight management tasks. We are primarily interested in your ongoing assessment of the success of the approach to the 100-foot decision height (DH). At specified points in the sequence you will indicate the outcome of judgments you make regarding the aircraft's lateral offset from the assigned approach course and its tracking vector (i.e., alignment of the aircraft's flight path with the approach course.) On every run, regardless of the aircraft's offset position at the DH, when you determine that you are precisely at the 100-foot DH, you will disengage the AFCS and execute the landing maneuver under manual control.

The general procedure you will follow on each run is outlined below. You will be exercised in carrying out this procedure in the simulator prior to performing the experimental series. An Experimenter (E) will be present in the cab to monitor and coordinate the simulation sequence on each run. At the start of each run, the simulator will be set to the appropriate initial position and you will initiate the run when E indicates that everything is ready.

1. Set up and / or check flight deck for initial approach conditions:

   a) Gear down.

   b) Flaps set to 30°. (drop flaps to 50° passing Outer Marker.)

   c) Set airspeed bug to 135 kts.

   d) Set AFCS to AUTO control.

   e) Engage autothrottle function (A/T control to ON) and select command airspeed.

   f) Position throttles for disconnect (this is a simulator-peculiar item, throttles should be set for an EPR setting of about 2.0.

   g) Set Radio Altimeter reference bug to appropriate decision height (DH) value. E will identify the approach terrain profile for the designated run. One of three alternate terrain profiles will be specified:

      (1) "Level-95" - this is the actual terrain profile at Dulles, 95' is the Radio Altitude specified on the appraoch chart for the glide slope height at the 100' DH (Inner Marker).

      (2) "Low-140' " - this is the first variation and represents a drop in terrain elevation to 40' below the runway elevation, the Radio Altitude cited on the Approach Chart for this profile would thus be 140'.

      (3) "High-85' " - this variation represents rising terrain to a relative altitude of +15', published Radio Altitude would therefore be 85'.

   h) Trim aircraft for initial approach (or for AFCS disconnect).

2. E will indicate readiness to start the run. Acknowledge by placing simulator in OPERATE mode, using the control on the center pedestal.

3. Simulation will now go dynamic. Monitor flight instruments and assess aircraft position throughout the approach.
4. Approaching the Middle Marker, at about 300 feet, report your estimate of the aircraft's lateral offset position and tracking tendencies (specific reporting procedures will be covered later).
5. Fifty feet above the bug setting on the Radio Altimeter an auditory alert tone will sound in your headset. At the onset of this tone, carefully estimate the aircraft's cross-track position (lateral displacement from the extended runway center line) and its tracking vector (drift) as the aircraft approaches the DH and prepare to report this estimate to E. On every run you will

use a strict "head down" procedure in assessing the approach to the DH. As a matter of discipline, you must stay on instruments until you judge the aircraft to be at the 100-foot DH. When you are confident that you are at the DH, you must disengage the AFCS (see item 6 below), assume manual control and attempt to carry out the landing maneuver by external visual reference.

On arrival at the 100' DH give your best estimate of the aircraft's cross-track position and then report the aircraft's tracking vector. The specific reporting procedure*will be explained later and you will have an opportunity to practice until the sequence is familiar and easy to execute.

6. As indicated above, when you are confident that the aircraft is at precisely 100 feet above the runway (i.e., at the DH), depress and release the AFCS DISENGAGE (AD) button on the left horn of the control wheel. Both the AFCS and the autothrottle will be disengaged when the AD button is depressed and you will immediately assume full manual control. Remember, the AD button is also used to indicate your judgment of arrival at the DH; do not hit the AD button to disengage the AFCS earlier (or later) in the approach.
7. Execution of the landing maneuver should be accomplished by external visual reference with cross-checking of flight

* This procedure is outlined in Attachment 2 to this Appendix.

instruments at your discretion. Your goal, of course, is to correct your alignment with the runway, if necessary, and achieve an acceptably soft touchdown on the runway within the 3000-foot touchdown zone. To stay within established touchdown limits, you should attempt to land within ± 27 feet of the runway center line and at a point along the runway where you would see at least the last four bars of the touchdown zone lights. We would like you to attempt the landing on every approach, even when you feel that your offset or tracking situation at the DH would be unacceptable in actual flight situations. However, do not use control techniques that you would not use under actual Category II approach conditions, i.e., do not use excessive roll rates or bank angles and do not accept an excessively hard landing in order to touchdown within the limits just cited. Remember, this exercise is not a test of your flight control skills or of your ability to salvage a bad approach. Touchdown performance will be interpreted as an indication of how well the displays under consideration supported you in judging your approach. We are also interested in seeing the outcome of landing attempts from various offset conditions at the DH. If at any time after initiating the landing attempt you feel that a safe touchdown on the runway cannot be accomplished without excessive maneuvering, initiate a go-around and/or terminate the simulation sequence by depressing the I.C. control located on the center pedestal.

At some point during the roll out, E will reposition the simulator for the next run in the scheduled series by depressing the I.C. button. The general procedure just outlined will then be repeated for the next scheduled run. If you have any questions regarding the procedures just outlined, please ask the experimenter for further clarification.

ATTACHMENT 2

PROCEDURE FOR REPORTING FLIGHT PATH SITUATION ALIGNMENT AND TRACKING TENDENCIES

1. As the aircraft approaches the runway, monitor the flight instruments and concurrently judge the aircraft's height above the runway, its position relative to the extended runway centerline, and its tracking tendencies relative to this approach course.

2. At 300 feet, report your best estimate of the aircraft's lateral offset position and tracking using the statements outlined below. At the DH, your report of lateral offset and tracking must be coordinated with your judgment of arrival at the 100-foot MDA and the transition to manual control in the following manner:

   a) When you are confident that the aircraft has arrived at the pre-determined minimum decision altitude (MDA), depress the AD button. Remember to consider terrain elevation.

   b) Report your judgment of the aircraft's cross-track position at the time you depressed the AD button, using one of four possible statements:

      1. If you judge the aircraft to be within 25 feet (left or right) of the extended runway centerline, say "RIGHT ON."

      2. If you judge it to be offset more than 25 feet but less than 50, say "MORE THAN 25 LEFT (RIGHT)."

      3. If you judge it to be offset more than 50 feet but less than 75, say "MORE THAN 50 LEFT (RIGHT)."

      4. If you judge the aircraft to be offset more than 75 feet, say "WAY OUT" or "MORE THAN 75 LEFT (RIGHT)."

   c) Immediately following the lateral offset judgment add your judgment of the aircraft's tracking tendencies, using one of three possible statements:

      1. If you judge the aircraft to be maintaining its position relative to the approach course (extended runway centerline), say "TRACKING PARALLEL."

      2. If you judge the aircraft to be moving toward the runway from some lateral offset position, say "TRACK CONVERGING."

      3. If you judge the aircraft to be moving away from the runway, in either direction, say "TRACK DIVERGING."

APPENDIX B

PILOT DEBRIEFING QUESTIONNAIRE AND SUMMARY OF PILOT RESPONSES

The attached debriefing questionnaire was used to structure a discussion of pilot acceptance attitudes toward the experimental display concept and to record pilot reactions to the procedures followed, the flight management task they were asked to perform, the simulation equipment, or any other comments on their participation in the study. Summary statements of pilot responses to the questionnaire items are presented in the space following each item.

PILOT DEBRIEFING QUESTIONNAIRE

Based on your experience in carrying out the flight management activities during the simulation exercise, we would like you to comment on certain aspects of the procedures employed, the simulation equipment, and your reactions to the task we asked you to perform. In addition, we would like to solicit your opinion regarding the pictorial situation display as an aid to flight management during actual approach and landing operations under Category II conditions. Please note any impressions you have in response to the following questions. Feel free to include any negative or critical comments that may occur to you without attempting to be fair or reasonable or strictly relevant to the question asked.

1. Did you consider the study orientation and simulator familiarization you received to be adequate preparation for the tasks you were asked to perform? If not, what additional information or familiarization exercise do you think would have been helpful?

Pilot #1: "...needed explanation of the glide slope presentation... what it is telling you."

Pilot #2: Yes. Requested clarification of turn indicator on FD-109 -- confused with expanded localizer display element.

Pilot #3: Yes.

Pilot #4: Yes.

Pilot #5: "...found the pictorial display difficult to get used to..." Suggested more practice on display for manual flight control prior to evaluation runs.

Pilot #6: Yes. Felt that additional familiarization training might have blurred distinctions among display concepts evaluated.

2. Was the procedure used to report your judgments of the flight situation awkward or limiting in any way?

All six pilots said no.

3. How confident do you feel about the accuracy of your judgments of the aircraft's arrival at the MDA?

a. They were highly accuracte (i.e., within about 12 feet) ______.

b. They were close enough (i.e., within about 25 feet) ______.

c. I was somewhat uncertain about them. ______.

d. I was highly uncertain - wouldn't rely on them. ______.

Pilot #1: a

Pilot #2: a

Pilot #3: a

Pilot #4: a

Pilot #5: b (commented that CRT display more accurate)

Pilot #6: b (commented that ERPD display more accurate)

4. How confident do you feel about the accuracy of your estimates of cross-track position at the MDA?

   a. Highly confident (i.e. just about all of them were correct) ________.

   b. Confident (i.e. most of them were correct) ________.

   c. Somewhat uncertain (i.e. not sure how many were correct) ________.

   d. Highly uncertain (i.e. wouldn't rely on them) ________.

   Pilot #1: a ("...unless drifting fast.")

   Pilot #2: b

   Pilot #3: a

   Pilot #4: a

   Pilot #5: a

   Pilot #6: c

5. Where do you think the lateral offset limits at the decision height should be set for routing Category II operation?

   Pilot #1: 75 ft. (outer limit)

   Pilot #2: 50 ft. and parallel or $>$50 ft. and converging ("...always go around if $>$75 ft.")

   Pilot #3: 75 ft.

   Pilot #4: 50 ft.

   Pilot #5: 50 ft. -- maximum

   Pilot #6: About 50 ft.

6. Do you feel that the pictorial situation display would provide significantly better support to you in accurately judging the success of a Category II approach than a conventional attitude-director indicator (such as the FD-109)?

Pilot #1: Yes

Pilot #2: Yes -- ERPD preferred over BRPD

Pilot #3: Yes

Pilot #4: "Yes -- with some modifications -- such as a flight director, at least for glide path information."

Pilot #5: Yes

Pilot #6: Yes

7. Would you feel more confident about your assessments of the aircraft's position relative to the runway using the pictorial display?

Pilot #1: Yes

Pilot #2: Yes -- FD-109 information seen as "too qualitative...ERPD gives quantitative offset information." Said ERPD provided better orientation to control action required at AFCS disengage.

Pilot #3: Yes

Pilot #4: Yes

Pilot #5: Yes

Pilot #6: Yes

8. With a pictorial situation display like the more complete version you used in the simulator, would you feel confident in attempting an approach under actual visibility conditions of:

2400 feet RVR? __________

1600 feet RVR? __________

Lower? __________

Pilot #1: No response -- would need experience with this display.

Pilot #2: Lower (1200 ft.)

Pilot #3: Lower

Pilot #4: 1600 ft. RVR

Pilot #5: 1600 ft. RVR

Pilot #6: 1600 ft. RVR - possibly 1200 ft. with more practice

9. What minimums would you feel confident with using the FD-109 (or similar instrumentation)?

2400 feet RVR? __________

1600 feet RVR? __________

Lower? __________

Pilot #1: 2400 ft. RVR

Pilot #2: Lower (1200 ft.)

Pilot #3: Lower (1200 ft.)

Pilot #4: 1600 ft. RVR

Pilot #5: 2400 ft. RVR - probably 1600 ft. with more practice

Pilot #6: 2400 ft. RVR

10. What additions or changes to the pictorial display would you like to see that would make the instrument more useful or acceptable for Category II approach operations?

Pilot #1: Delete pitch symbol (aircraft symbol confused with flight director)

Pilot #2: Provide additional decision bars for earlier assessment of lateral offset. Revise GS deviation symbol for easier interpretation. Add marker for center of aircraft symbol.

Pilot #3: None

Pilot #4: Delete MM readout -- add pitch command -- revise GS deviation element, especially on BRPD.

Pilot #5: Introduce color to improve readability for pitch and roll.

Pilot #6: Add flight director ("fly to") elements.

11. Were there any peculiarities of the flight simulator or the procedures you were asked to follow which made your behavior in the simulator differ from how you would conduct an actual Category II approach?

Pilot #1: Use of pitch display (aircraft symbol)

Pilot #2: Rate-of-descent decreases when AFCS disengaged in simulator -- not like aircraft where transition is smooth, i.e., no change in $\dot{h}$

Pilot #3: No

Pilot #4: Not really -- simulator too sensitive in yaw -- needs yaw damper

Pilot #5: No -- more complete approach sequence would be better, e.g., add localizer capture maneuver

Pilot #6: Only standard attitude toward simulators as not an actual approach

12. Briefly state your attitude toward the use of flight simulators for research, i.e., do you feel that data obtained from simulation studies are valid and applicable to actual flight situations?

Pilot #1: "...found much useful data from the simulator."

Pilot #2: "...good simulation... reproduced transition to visual very well."

Pilot #3: "Very much so."

Pilot #4: "In most cases, however the phase from 50' or 75' to touchdown is somewhat different (in aircraft)."

Pilot #5: Yes.

Pilot #6: "Very much so. There is nothing like experience, and simulators provide this... comparisons of displays can only be done where situations can be exactly duplicated."

13. Do you think your time was well spent in participating in this study? (Please feel free to offer any negative or critical comments regarding your experience as a subject or the issues raised in the study.)

Pilot #1: "Yes. A very interesting experience."

Pilot #2: "Yes -- good practice, very interesting."

Pilot #3: "Yes. I think more of this work, i.e., pilot participating in actual research, should be accomplished."

Pilot #4: "Yes. I think using pilots who are going to use this equipment is a very good idea."

Pilot #5: Yes.

Pilot #6: "Yes... you can't evaluate unless you compare, and I welcomed this opportunity to see new or different displays."

APPENDIX C

COMPLETE RECORD OF EXPERIMENTAL DATA

The data records presented in this appendix provide a tabulation of the recorded values of flight situation parameters at key points in the approach sequence and the error counts taken for the principal types of errors in pilot judgments. Designated flight situation parameters are identified below and error types are defined in Appendix A, page A-9.

Y300 = Lateral offset at 300 feet above runway (ft.)
ZAD = Height above runway when AFCS was disengaged (ft.)
YAD = Lateral offset when AFCS was disengaged (ft.)
YDAD = Rate of lateral offset when AFCS was disengaged (ft/sec.)
XTD = Distance from runway threshold at touchdown (ft.)
YTD = Displacement from runway centerline at touchdown (ft. -- sign indicates direction, i.e., — means left)
HDTD = Vertical velocity at touchdown (ft/sec.)
YDTD = Lateral velocity at touchdown (ft/sec.)

Experimental Data Record -- Pilot Number 1

Display Condition	Run No.	Recorded Values of Flight Situation Parameters								No. of Errors by Type			
		Y300	ZAD	YAD	YDAD	XTD	YTD	HDTD	YDTD	OE	AE	TE	DHE
BRPD	1	-6	102	-6	0	1525	-12	6	0	0	0	0	0
	2	115	102	63	-7	1320	31	8	2	0	0	0	0
	3	37	101	95	-2	1359	40	6	2	1	1	1	0
	4	131	101	95	-2	1835	54	8	-9	0	0	1	0
	5	-64	105	-15	9	1197	17	7	-2	1	1	0	0
	6	-61	105	24	5	1190	37	6	-1	0	0	0	0
	7	-65	107	-64	0	1777	5	5	11	0	0	0	0
	8	95	106	95	1	981	70	6	-14	0	0	1	0
	9	48	106	-37	-3	1363	-25	10	12	0	1	0	0
	10	-3	105	57	3	1338	37	4	-11	0	0	0	0
ERPD	1	-10	105	-9	0	1867	2	6	0	0	0	0	0
	2	112	104	64	-7	1399	15	5	-6	0	0	0	0
	3	58	103	47	0	2170	30	2	-11	0	0	0	0
	4	126	104	91	-2	1644	46	5	-11	0	0	1	0
	5	-81	104	-25	11	1370	2	9	-5	0	0	0	0
	6	-52	104	27		1680	-6	3	6	0	0	0	0
	7	-63	106	-61	0	2033	-8	8	15	0	0	0	0
	8	97	106	95	1	1673	38	4	-4	0	0	1	0
	9	55	105	-31	-3	1482	-7	5	0	0	0	0	0
	10	14	105	63	3	1327	34	3	-11	0	0	0	0
FD-109	1	-10	93	-9	0	1889	-10	4	2	0	0	0	0
	2	115	105	64	-9	1320	20	7	0	1	1	0	0
	3	37	86	37	0	1943	40	6	0	1	1	1	1
	4	123	81	94	1	1881	84	7	10	0	1	1	1
	5	-94	92	-24	10	2000	-2	2	-10	0	0	0	0
	6	-71	82	28	3	2350	11	6	17	0	0	0	1
	7	-67	112	-64	0	1399	-42	2	-7	1	1	1	0
	8	100	80	78	-1	2300	24	5	-18	0	0	0	1
	9	52	100	-40	-4	2000	20	3	2	0	1	0	0
	10	68	75	125	3	----	--	-	-	1	0	0	1

Experimental Data Record -- Pilot Number 2

Display Condition	Run No.	Recorded Values of Flight Situation Parameters								No. of Errors by Type			
		Y300	ZAD	YAD	YDAD	XTD	YTD	HDTD	YDTD	OE	AE	TE	DHE
BRPD	1	0	96	-3	0	1601	14	14	1	0	0	0	0
	2	-61	102	36	5	1406	28	13	-13	1	1	0	0
	3	-53	105	-55	0	1680	9	15	14	0	0	0	0
	4	134	103	94	-5	1680	30	14	-16	0	0	0	0
	5	-85	97	-31	9	2126	5	17	-27	0	1	0	0
	6	122	110	74	-9	1856	16	16	-6	0	0	0	0
	7	98	103	97	0	2155	-32	19	0	0	0	0	0
	8	34	104	33	0	2162	58	13	6	0	1	0	0
	9	18	103	78	3	2119	23	17	-14	1	0	0	0
	10	49	104	-47	-5	1874	23	11	17	0	0	0	0
ERPD	1	2	102	-2	0	1676	10	18	1	0	0	0	0
	2	-56	105	36	5	1932	8	20	-8	0	0	0	0
	3	-49	103	-52	0	2270	16	13	2	0	0	0	0
	4	132	101	92	-4	2141	31	15	-17	0	0	0	0
	5	-68	90	-10	8	1867	24	15	-3	0	0	0	0
	6	120	106	10	-10	1889	19	15	2	0	0	0	0
	7	92	106	91	0	2155	11	21	4	0	0	0	0
	8	37	104	35	0	1795	21	18	-5	1	0	0	0
	9	6	99	75	3	1705	48	13	-14	0	0	0	0
	10	51	106	-44	-6	1705	-2	15	10	0	0	0	0
FD-109	1	-6	94	-7	0	1539	19	14	1	0	0	0	0
	2	-68	102	31	5	2047	40	4	13	0	0	0	0
	3	-52	99	-55	0	2190	-12	13	8	0	1	0	0
	4	78	101	22	-5	1096	20	13	0	0	0	0	0
	5	-87	91	-25	9	1572	23	15	-3	0	1	0	0
	6	114	104	66	-11	1140	13	16	0	0	1	0	0
	7	94	102	93	0	1190	49	14	-18	0	0	0	0
	8	31	71	32	0	1925	30	15	-3	0	1	0	1
	9	10	92	77	2	2130	54	6	15	0	0	1	0
	10	46	103	-52	-5	1719	7	12	2	1	0	0	0

Experimental Data Record -- Pilot Number 3

Display Condition	Run No.	Recorded Values of Flight Situation Parameters								No. of Errors by Type			
		Y300	ZAD	YAD	YDAD	XTD	YTD	HDTD	YDTD	OE	AE	TE	DHE
BRPD	1	-7	89	-8	0	1208	-7	11	0	0	0	0	1
	2	-64	91	39	4	1521	46	5	-4	1	1	1	0
	3	-56	104	-58	0	1352	-10	8	4	0	0	0	0
	4	142	94	98	-4	1330	66	8	-9	0	0	1	0
	5	-75	94	-18	9	1438	8	7	0	0	1	1	0
	6	128	97	69	-9	1410	27	6	-3	0	1	0	0
	7	98	104	97	0	1183	69	9	-10	0	0	0	0
	8	45	102	42	0	1197	37	11	-4	0	1	0	0
	9	13	95	80	2	1330	76	8	-8	0	0	1	0
	10	57	99	-41	-5	1204	-12	8	10	1	1	0	0
ERPD	1	-6	95	-7	1	2115	23	8	6	0	0	0	C
	2	-54	93	43	4	1997	0	10	-11	0	0	0	0
	3	-58	99	-58	0	1644	-1	8	5	0	0	0	0
	4	136	95	92	-4	1651	78	9	-6	0	0	1	0
	5	-81	95	-25	10	1932	39	8	0	0	0	0	0
	6	122	104	70	-10	1860	15	7	4	0	0	0	0
	7	95	101	95	1	1575	76	9	-12	0	0	0	0
	8	45	92	42	0	1586	45	9	-1	0	0	0	0
	.9	12	95	80	2	1644	30	9	-14	0	0	0	0
	10	60	99	-41	-7	1853	15	9	8	0	0	0	0
FD-109	1	-11	94	-10	0	1701	18	3	6	0	0	0	0
	2	-65	102	28	5	1204	25	9	-7	0	0	0	0
	3	-49	101	-52	0	1377	2	5	12	0	0	0	0
	4	126	92	83	-4	1366	54	9	-9	0	0	0	0
	5	-70	94	-18	8	1273	20	6	1	0	0	0	0
	6	100	99	57	-10	1190	11	8	3	0	0	0	0
	7	91	102	91	0	1168	54	12	-12	0	0	0	0
	8	49	103	40	0	1147	31	6	-3	0	0	0	0
	9	0	99	69	0	1363	52	4	-11	0	0	0	0
	10	60	100	-35	-5	1622	33	5	11	0	0	0	0

Experimental Data Record -- Pilot Number 4

Display Condition	Run No.	Recorded Values of Flight Situation Parameters								No. of Errors by Type			
		Y300	ZAD	YAD	YDAD	XTD	YTD	HDTD	YDTD	OE	AE	TE	DHE
BRPD	1	-6	92	-8	1	1700	0	18	12	0	0	0	0
	2	-76	96	22	5	1500	46	13	0	0	0	0	0
	3	-52	76	-60	0	2000	-80	11	-3	0	1	0	1
	4	100	100	94	-5	1460	68	16	-8	0	1	1	0
	5	-76	100	-32	9	1640	23	13	5	0	1	1	0
	6	100	100	63	-10	1440	-8	16	-12	0	1	1	0
	7	94	122	92	11	1400	90	15	-2	0	1	0	1
	8	30	102	30	0	1460	22	15	-5	0	0	1	0
	9	4	100	75	5	1460	73	15	-1	0	0	0	0
	10	44	104	-51	-5	1305	-68	4	1	1	1	1	0
ERPD	1	-13	103	-13	1	1089	-8	13	1	0	0	0	0
	2	-59	98	37	4	1006	49	14	0	1	0	0	0
	3	-68	100	-66	0	1179	-69	9	-1	1	0	0	0
	4	132	103	94	-5	1230	82	13	0	0	0	0	0
	5	-84	105	-38	9	1064	23	8	4	0	0	0	0
	6	103	105	60	-10	1276	-33	9	-9	0	0	0	0
	7	86	106	87	0	974	81	11	-5	0	0	1	0
	8	27	101	28	0	1006	30	13	0	0	0	0	0
	9	-4	105	66	4	1662	55	11	-3	0	0	0	0
	10	46	104	-50	5	1136	-58	9	5	0	0	0	0
FD-109	1	-10	96	-10	0	1410	-12	12	-1	0	0	0	0
	2	-64	102	32	5	1521	8	11	-10	1	1	0	0
	3	-53	98	-59	0	1503	-49	18	7	1	1	0	0
	4	132	94	89	-4	1640	72	15	-5	0	0	0	0
	5	-85	95	-28	9	1657	23	9	-5	0	0	0	0
	6	116	99	61	-10	1493	-12	9	0	0	1	0	0
	7	86	103	88	0	1766	30	1	-14	0	0	1	0
	8	36	102	34	0	1507	25	13	-4	0	1	0	0
	9	-1	95	75	2	1485	54	7	-8	0	0	0	0
	10	46	98	-52	-4	1903	-3	6	19	0	1	0	0

Experimental Data Record -- Pilot Number 5

Display Condition	Run No.	Recorded Values of Flight Situation Parameters								No. of Errors by Type			
		Y300	ZAD	YAD	YDAD	XTD	YTD	HDTD	YDTD	OE	AE	TE	DHE
BRPD	1	-10	95	-10	1	1194	0	10	3	0	0	0	0
	2	-70	103	27	5	1363	51	3	2	0	0	1	0
	3	-67	101	-61	-1	1035	-31	12	12	0	0	0	0
	4	129	96	9	-4	1647	68	12	-4	0	0	0	0
	5	-87	95	-32	9	1183	25	8	4	0	0	0	0
	6	106	100	56	-10	1651	23	8	-1	0	1	0	0
	7	84	103	86	1	1215	61	5	-5	1	1	0	0
	8	29	99	30	0	1705	27	10	-3	0	0	0	0
	9	-1	96	71	3	1701	43	11	0	0	0	0	0
	10	45	100	-53	-4	1125	-15	13	4	0	0	0	1
ERPD	1	-13	95	-12	1	1244	3	12	1	1	0	1	0
	2	-71	101	25	5	1132	51	8	-4	0	0	0	0
	3	-64	97	-62	0	1550	-21	10	9	0	0	0	0
	4	128	96	86	-4	1086	53	16	0	0	0	1	0
	5	-89	93	-32	9	1118	11	10	0	0	0	0	0
	6	110	101	63	-10	1082	44	15	-1	0	0	0	0
	7	89	102	89	1	1190	61	13	1	0	0	0	0
	8	31	103	31	1	992	43	15	1	0	0	0	0
	9	-6	97	65	3	1060	61	11	-7	0	0	0	0
	10	45	97	-52	-5	1010	-16	16	1	0	0	1	0
FD-109	1	-13	95	-13	1	2033	37	19	7	1	1	0	0
	2	-69	104	28	5	1766	17	5	0	1	0	0	0
	3	-61	100	-61	0	1733	5	8	9	0	1	1	0
	4	125	94	85	-4	1889	42	5	-6	0	0	0	0
	5	-84	96	-29	10	1691	46	5	5	0	1	0	0
	6	109	101	63	-11	1925	25	10	8	0	1	0	0
	7	86	102	87	0	2137	-9	8	0	0	0	1	0
	8	25	103	28	0	1248	33	5	1	0	0	0	0
	9	-4	96	71	2	1615	37	2	-7	0	0	1	0
	10	48	102	-50	-4	1514	6	3	15	0	1	1	0

Experimental Data Record -- Pilot Number 6

Display Condition	Run No.	Recorded Values of Flight Situation Parameters								No. of Errors by Type			
		Y300	ZAD	YAD	YDAD	XTD	YTD	HDTD	YDTD	OE	AE	TE	DHE
BRPD	1	-12	95	-12	1	1482	-10	16	0	0	0	0	0
	2	-70	101	31	5	1122	44	17	-2	0	0	0	0
	3	-73	92	-70	0	1147	-68	15	0	0	0	0	0
	4	134	96	89	-4	1104	58	17	-10	0	0	0	0
	5	-53	92	1	8	1017	13	21	-1	0	0	0	0
	6	112	99	55	-10	967	20	14	5	0	0	0	0
	7	104	102	102	0	1258	52	10	-15	0	0	0	0
	8	20	101	23	0	1093	23	16	-2	0	0	0	0
	9	-9	94	67	3	1244	53	10	-12	0	1	0	0
	10	31	94	-62	-4	1212	-43	13	11	1	0	0	0
ERPD	1	-15	94	-13	0	1305	-16	21	-2	0	0	1	0
	2	-28	113	48	4	834	21	23	4	0	0	0	1
	3	-78	66	-72	0	1759	-56	23	7	0	0	0	1
	4	129	94	88	-4	1075	58	20	-9	0	0	0	0
	5	-102	93	-35	8	1046	-6	22	4	0	0	0	0
	6	115	96	55	-11	1010	28	20	-5	0	0	0	0
	7	80	148	82	0	488	46	26	-10	0	0	0	1
	8	25	101	27	0	1104	18	20	-3	0	0	0	0
	9	-15	94	61	3	1042	36	20	-7	0	0	0	0
	10	47	90	-58	-3	981	-20	23	10	0	0	0	0
FD-109	1	0	95	-4	0	1046	5	8	3	0	0	0	0
	2	-67	101	28	5	877	26	12	-4	0	0	0	0
	3	-39	100	-40	0	1017	-15	10	9	0	1	1	0
	4	147	97	104	-3	--	--	--	--	0	0	1	0
	5	-81	75	-9	8	1377	-15	11	-2	1	1	0	1
	6	109	99	58	-10	830	36	16	2	0	0	0	0
	7	99	101	98	0	996	61	11	-11	0	0	0	0
	8	25	123	26	1	1017	8	15	7	0	0	0	1
	9	-3	92	71	3	1183	57	12	-8	0	0	0	0
	10	42	100	-54	-5	877	-56	13	8	1	0	0	0

APPENDIX D

CALCULATIONS REQUIRED TO ADD A PICTORIAL GLIDE SLOPE DEVIATION INDICATOR TO THE EXPERIMENTAL RUNWAY PERSPECTIVE DISPLAY

In generating the glide slope indicator for the Experimental Runway Perspective Display three contributing factors were taken into consideration:

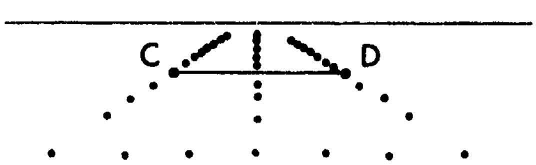
(1) Current X-Y coordinate points of the glide slope intersect (GSX)

(2) Effect of glide slope deviation signal on the display element

(3) Effect of roll angle on the geometry of the display element

GLIDE SLOPE INTERSECT COORDINATES

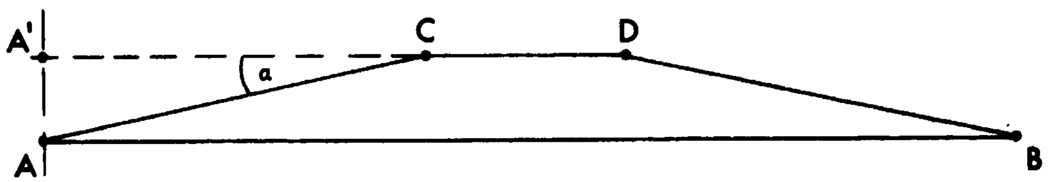
The two runway edge dots corresponding to a location 1000 feet down the runway were selected as end points of a line forming the base of the display element. For any given flight situation the X-Y coordinate locations for the two dots, shown below as points C and D, were available from the subroutine generating the runway perspective display.



EFFECT OF GLIDE SLOPE DEVIATION SIGNAL

The glide slope indicator at a zero (no deviation) condition was represented by two lines extending 100 raster units to either side of the runway (CA and DB).

To calculate the coordinates of points A and B as a result of a deviation input, the angle α was assigned a value of 22.5 degrees per 0.5 degrees (2 dots) of deviation. For simplification the horizontal (X) component (A'C) was assigned a value of 100 units for all cases. Therefore, the vertical (Y) component was the only unknown to be calculated for any deviation input.



Given an input of 0.5 degree (2 dot) deviation, the following calculations are performed:

$$A'A = \text{Tan}\,\alpha \times A'C$$
$$A'A = \text{Tan}\,22.5^{\circ} \times A'C$$
$$A'A = .4142 \times 100$$
$$A'A = 41.42 \text{ (vertical units for a 2 dot input)}$$

Then the solution of the relationship :

$$\frac{A'A}{41.42} = \frac{\text{GS deviation (degrees)} \times 4.5}{22.5}$$

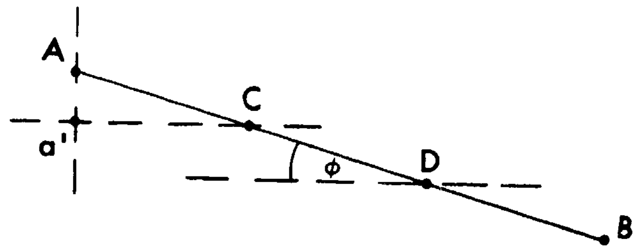
$$A'A = 41.42 \times \left(\frac{\text{GS deviation} \times 4.5}{22.5} \right)$$

produces a value of A'A (vertical component in relation to point C) for any value of glide slope deviation. This value (converted to an integer) may be combined with the Y value of points C and D to produce the vertical locations of points A and B.

Note: The glide slope deviation input for the example shown was a negative (above) value.

THE EFFECT OF ROLL ANGLE

To prevent misleading distortion of the glide slope deviation indicator due to roll inputs to the perspective display, a correction factor was calculated and combined with the coordinates for points C and D. In the following example a zero glide slope deviation was assumed for clarity.



To find the horizontal (X) component due to the effects of roll (a'C) we recall the value of AC as being 100 units. Therefore, the calculation :

$$\text{Cos } \phi = \frac{a'C}{100}$$

$$a'C = \text{Cos } \phi \times 100$$

produces a value of a'C for any roll angle (ϕ). This value when subtracted from the X value of point C produces the adjusted X value of A as a of roll, and conversely added to the X value of point D to arrive at the new X value for point B.

The value of a'A was similarly calculated using the formula;

$$\text{Sin } \phi = \frac{a'A}{100}$$

$$a'A = \text{Sin } \phi \times 100$$

and subtracting the value obtained from the Y value of point C and adding to the Y value of point D. In the example shown the roll angle (left wing down) is a negative value.

COMBINING INDIVIDUAL VALUES

As previously stated, the X-Y coordinates for the two points (C and D) defining the base (GSX) are supplied in the calculations of the runway perspective. The following equations combine these coordinate points with the correction factors reflecting the effects of glide slope deviation and roll angle to produce the coordinates for the third and fourth points (A and B).

$$A(X) = C(X) - a'C$$
$$A(Y) = C(Y) - a'A + A'A$$
$$B(X) = D(X) + a'C$$
$$B(Y) = D(Y) + a'A + A'A$$

When the points defining the indicator element have been obtained the indicator is displayed as four line segments connecting the points.

To avoid distracting from other elements of the overall display the glide slope indicator was limited to a maximum deflection of 2 dots.