NASA Contractor Report 4176

An Evaluation of Flight Path Formats Head-Up and Head-Down

George A. Sexton, Laura E. Moody,
Jo Anne Evans, and Kenneth E. Williams

CONTRACT NAS1-18029
SEPTEMBER 1988

NASA

NASA Contractor Report 4176

An Evaluation of Flight Path Formats Head-Up and Head-Down

George A. Sexton, Laura E. Moody,
Jo Anne Evans, and Kenneth E. Williams
Lockheed Aeronautical Systems Company
Georgia Division
Marietta, Georgia

Prepared for
Langley Research Center
under Contract NAS1-18029

National Aeronautics
and Space Administration

Scientific and Technical
Information Division

1988

FOREWORD

This report describes the integration of flight path display formats into head-down and head-up electronic displays, and a comparison of pilot performance using them to fly precision instrument approaches in an advanced concepts research simulator. The work reported was performed by the Georgia Division of the Lockheed Aeronautical Systems Company (formerly Lockheed-Georgia Company) for the National Aeronautics and Space Administration (NASA) Langley Research Center at Hampton, Virginia. The project was funded by NASA under Contract Number NAS1-18029, Task 02. This report is also identified as LG87ER0154 for Lockheed internal control purposes.

Guidance for the program was provided by George G. Steinmetz, NASA-Langley Technical Monitor and Cary R. Spitzer, NASA-Langley Technical Representative of the Contracting Officer. George A. Sexton directed the Lockheed effort, which was performed as part of a continuing preliminary design investigation of new aircraft concepts by the Georgia Division Aeronautical Systems Development Department, Charles F. Klusmann, Manager. Other Lockheed contributors were H. Kyle Collins, Jo Anne Evans, Teresa L. Mann, Bernie Miron, Laura E. Moody and Kenneth E. Williams.

SUMMARY

Pilot performance was tested while flying precision approaches in a generic, next-generation transport aircraft simulator using flight path primary flight display (PFD) formats. One was a head-down format; the second was a head-up format. Both objective and subjective data were collected. The ten subjects (airline pilots) unanimously preferred flying the head-up display (HUD) format over that presented head-down for a number of reasons, with ease of transition to outside visual scene and the more expanded scaling permitting more precise flying being the major factors stated. Although trends can be detected in favor of the HUD, objective data shows little significant difference in pilot performance between the two. The magnitude of deviations from the vertical and horizontal profile and in indicated airspeed were always less using the HUD, but performance on either was acceptable within the tolerances defined. While there may have been other contributing causes, the smaller deviations with the HUD are attributed mainly to its larger scale presentation (better resolution of information). All of the pilots also indicated that they strongly preferred flying flight path PFD formats, either head-down or head-up, over attitude PFD formats found in current aircraft. Additionally, the majority of the pilots had a strong preference for the side-stick controller over the control wheel and column in current aircraft.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (cont'd)

SYMBOLS AND ABBREVIATIONS

Symbols

h_{rad}	Radar Altitude
$K_{\_}$	Scheduled Gain
q_c	Compressible Dynamic Pressure
S	Laplace variable
γ	Flight Path Angle
δ_{A_L}	Left Aileron Deflection
δ_{A_R}	Right Aileron Deflection
$\delta_{A_{TOT}}$	Total Aileron Deflection
δ_E	Elevator Deflection
δ_F	Flap Deflection
δ_{HS}	Horizontal Stabilizer Deflection
δ_{SLAT}	Slat Deflection
δ_{SP}	Spoiler Deflection
δ_{STAB}	Stabilizer Deflection
θ_{FB}	Theta Feedback Signal
θ_{FC}	Theta Flight Control Signal
θ_I	Theta Integral Signal
θ_P	Theta Proportional Signal

Abbreviations

AFCS	Automatic Flight Control System
AGL	Above Ground Level
ANOVA	Analysis of Variance Test
A/P	Autopilot
ATT	Attitude
BMDP	Biomedical Data Package
CAP	Capture
CB	Circuit Breaker
CMD	Command
CRT	Cathode Ray Tube
CRZ	Cruise
CSS	Control-Stick Steering
EGT	Exhaust Gas Temperature
EOS	Experimenter/Observer Station
EPR	Engine Pressure Ratio
EXT	Extend
FD	Flight Director
FDI	Flight Dynamics Incorporated
FF	Fuel Flow
FPA	Flight Path Angle
FPM	Feet-Per-Minute
GCP	Guidance and Control Panel
GRD	Ground
HCSSLD	Horizontal Control-Stick Steering Level Detector
HGS	Head-Up Guidance System
HNAV	Horizontal Navigation
HUD	Head-Up Display
IAS	Indicated Airspeed
ILS	Instrument Landing System
INGRES	Relational database developed by Relational Technology, Inc.
I/O	Input/Output
kt(s)	Knot(s)
LE	Leading Edge
LED	Light Emitting Diode
mi	Mile
MM	Middle Marker
Nav	Navigation (display)
ND	Aircraft Nose Down
NL	Aircraft Nose Left
NR	Aircraft Nose Right
NU	Aircraft Nose Up
OM	Outer Marker
PFD	Primary Flight Display
PVV	Potential Velocity Vector
PWR	Power
RA	Radar Altitude
RET	Retract
rms	Root-Mean-Square
RVR	Runway Visual Range
SAS	Stability Augmentation System
s.d.	Standard Deviation

Abbreviations (cont'd)

s.d.	Standard Deviation
SPD	Speed
STAB	Stabilizer
SW(s)	Switch(es)
TE	Trailing Edge
TRK	Track
TSRV	Transport Systems Research Vehicle
VCSSLD	Vertical Control-Stick Steering Level Detector
VV	Velocity Vector

INTRODUCTION

Considerable research has been conducted at NASA to develop a system to provide pilots with instantaneous inertial flight path information. This work was performed primarily in the Transport Systems Research Vehicle (TSRV) (formerly TCV) flight simulator and 737 airborne flight simulation aircraft. A flight path primary flight display format for monochromatic electronic displays was developed, along with the information necessary to properly drive the symbols. The goal was to provide the pilot with information and control for precisely manually flying the aircraft during approach and landing in very low visibility conditions. This work, documented in several of the referenced reports, has successfully achieved its goal in flight simulation (but flight path head-down formats have not yet been incorporated into operational aircraft).

Meanwhile, considerable research has also been conducted within NASA to provide pilots with similar type of flight path information on a head-up display. This work, documented in referenced reports, has also been very successful. One manufacturer of head-up displays, Flight Dynamics Incorporated (FDI), adapted much of this NASA work for use on transport aircraft. A lengthy development and flight test program, completed in 1985, culminated in FAA certification of the FDI HUD on Boeing 727 aircraft for manual landing to Category IIIa weather minima (0 ceiling and 700 feet runway visual range).

The Advanced Concepts Simulators, described later in this report, are ideal research facilities to examine control and display issues concerning future aircraft. Since monochromatic head-up displays and full color electronic head-down displays are now being installed in commercial transport aircraft, it is desirable to determine if there is a significant difference in pilot performance between using a flight path PFD on a full color head-down display or a flight path PFD on a monochromatic head-up display. Research of this type can be used to further determine the value of flight path PFD formats, head-up or head-down, and to make recommendations concerning them.

In order to evaluate flight path formats in a realistic operating environment, a flight simulation experiment was conducted. Two flight path formats were used for this study. A highly modified version of the Langley concept was used on the head-down display. It differed in that (1) airspeed, altitude and vertical velocity data were integrated with flight path data, thus reducing the size of the flight path symbology being displayed; (2) the airspeed and altitude were presented on small round dial formats; (3) flight director guidance was added in some cases; and (4) this study incorporated color cathode ray tubes (CRTs) as opposed to NASA's research which used mostly monochromatic CRTs. On the head-up display, although the NASA concept for flight path PFD was used, the formats in this study differed in that (1) the symbolic runway symbol was changed slightly and it was presented at greater distances from the runway; (2) additional flare symbology was incorporated; and (3) wing flap alerting messages were added.

DESCRIPTION OF SIMULATOR

The Advanced Concepts Simulators are similar research facilities located at NASA Langley, NASA Ames and Lockheed Aeronautical Systems Company (LASC) - Georgia Division. They are used to examine issues pertaining to future aircraft safety, operations, crew systems design and human factors. The work reported here was performed in the LASC - Georgia Division facility, which is the only one that has head-up displays installed. With that exception, the flight stations in all simulators are identical. Only those portions of this fixed base, two-pilot flight station simulator used during this experiment are discussed here. A more complete description of the Pilot's Desk Flight Station, shown in Figure 1, is provided in Appendix A.

For this study, head-down information was displayed to the pilots on 13" diagonal color CRTs located on the main instrument panel. The PFD format and navigation display format were duplicated on CRT number 1 and 5 as shown in Figure 2. CRT number 2 and 4 were also duplicates and displayed engine power and instrument approach information formats. A static format was presented on CRT number 3 for the sake of appearance, but was not used for the study.

Head-up information was presented to the pilots on a holographic combiner of an overhead mounted display system. Stroke written primary flight symbology was presented on this monochromatic display.

A Rediffusion SP2 computer generated imagery visual system was used to generate out-the-window scenes for the two front windows. It has the capability to provide daylight, dusk, or night scenes and any combination of cloud and visibility conditions. This study was conducted using daylight conditions, three different ceilings and visibilities, and two different wind conditions, described later in the section on experimental design. A view of the runway during the landing flare is shown in Figure 3.

Side-stick controllers, located on the outboard side of each pilot's position, were used to provide pitch and roll inputs for the flying task. Travel was limited to seven degrees in each direction. The stick grip, shown in Figure 4, contained a 4-way pitch and roll trim switch operated by the pilot's thumb. Rudder pedals provided inputs for yaw control.

The guidance and control panel (GCP), located on the glareshield, was used to select the flight control modes (manual or control-stick steering (CSS)), appropriate horizontal and vertical steering modes for the flight segment, and the referenced indicated airspeed (IAS) and flight path angle (FPA). The reference IAS switch armed the IAS deviation symbols, and the reference FPA thumbwheel permitted the pilot to move the reference FPA symbol to the appropriate place on the head-up and head-down primary flight display formats.

The study actually used only two of the many possible GCP configurations. When flying the manual flight control mode (stability augmentation only), the flight director was defaulted "ON" and the autopilot was left "OFF". The glideslope were armed ("ARM"). Values for the initial track and the desired ILS final approach course were entered via default through the reset process. This setup is shown in Figure 5. The lower portion of the HNAV and VNAV legends automatically changed from "ARM" to "ON" when the localizer was captured and again when the glideslope was captured. All flight, autopilot, and auto-throttle modes were also annunciated on the head-down PFD.

The second GCP setup called for the CSS mode of the autopilot to be engaged. For this mode the autopilot bat-handle was raised to the mid-position, eliminating the horizontal and vertical options for the autopilot, and thus the flight director guidance. This setup is shown in Figure 6. The autothrottle remained OFF throughout the experiment, but the indicated airspeed command monitor option was enabled, permitting referenced indicated airspeed and airspeed error to be properly displayed on the head-up and head-down primary flight displays.

The simulation employs a standard six degree of freedom aircraft with a standard flight control system for a transport aircraft in terms of control surfaces and functions. The airplane modeled for this study was a generic "paper" transport aircraft with low wings, T-tail, and twin fanjet engines. The aerodynamics were developed to give responses typical of a subsonic transport. All systems provided reasonable performance for a transport type aircraft and were not made to duplicate the actual performance of any existing aircraft.

The simulation also included a complete propulsion system model and flight controls model as needed. Additionally, all necessary communications and navigation models were incorporated. For this study a wind model was used which generated constant winds with selected speed and direction.

A Sanders Graphics 7 stroke display system was used as the Experimenter/Observer Station (EOS). This station shown in Figure 7, was located inside the simulator house aft of the first officer's seat, and served a variety of functions. Data collection software was developed as part of this system, and during the trials, collection was started and stopped from this station. Twenty-four reset cases, developed for the experiment, were selected through the EOS. Each reset case included one of several weather, wind and cockpit configuration conditions; however, many different combinations were selected during the pilot training. The EOS also provides capability for the experimenter to monitor the performance of many simulated aircraft systems such as flight control systems and surfaces, propulsion, landing gear, aerodynamics, and ground dynamics.

Display Formats Used in the Study

The flight path PFD formats, which were presented head-down and head-up for this study, provided the pilots with all of the information required to fly the flight profile. Several other formats were presented to provide additional navigation, propulsion, and instrument approach procedure information. Detailed descriptions of the symbols on the head-down and head-up PFD, which were the primary focus of the study, and the navigation MAP format, which was available at all times to provide the pilots with additional situation awareness, have been included as part of Figures 8, 9, and 10.

The head-up and head-down PFD formats present information unique to that found in most aircraft. This unique feature is the presentation of velocity vector (VV) or flight path (FP) data. While formatted differently, they both provide the pilot with the capability to instantaneously determine the vertical path of the aircraft relative to the horizon and the glideslope, and, on final approach, the horizontal path relative to the localizer and the symbolic runway. Additionally, potential flight path or flight path acceleration symbology provides instantaneous information on whether the present engine power is adequate to maintain, increase, or decrease the indicated airspeed with a given flight path. The combination of these two, flight path and potential flight path, data reduces the amount of interpretation of information required over that presented on typical attitude PFD formats.

For purposes of clarity and consistency in this study, the term "flight path" is used in describing that parameter on both the head-up and head-down displays. The term "velocity vector" has been used in describing the same parameter in conjunction with most of the previous head-down display work at NASA-Langley.

Head-down primary flight display format - The head-down primary flight display format, illustrated in Figure 8, integrates information on the aircraft's flight path, potential flight path, pitch and roll attitude, airspeed, barometric and radar altitude, vertical velocity, localizer and glideslope deviation, flight director guidance, track angle error, symbolic runway, and landing flare. It also includes other ancilliary data, such as annunciation of flight control/flight director modes, altimeter settings, and reference steerpoint altitudes. This format is a rather large modification of a flight path PFD format developed in NASA's TSRV simulator. The modifications include integration of airspeed, altitude, and vertical velocity data; reducing the size/scaling of flight path data; integration of flight director guidance in some cases; and presenting the information on a color CRT rather than monochromatic.

Head-up primary flight display format - The head-up primary flight display format, illustrated in Figure 9, depicts information on the aircraft's flight path, potential flight path, pitch and roll attitudes, airspeed, barometric and radar altitude, vertical velocity, heading, track, distance-to-go, localizer and glideslope deviation, flight director guidance, symbolic runway, and landing flare. It also includes annunciations of outer marker, middle marker, inner marker, decision height, and mode of operation. This is a modification of a flight path PFD format originally developed within NASA and adapted by Flight Dynamics, Incorporated. It has been incorporated into transport aircraft where it has received FAA certification for landing in category IIIa weather minima. The modifications made for this study include greatly increasing the amount of time that the symbolic runway is displayed (from a range of 300' radar altitude (RA) to 50' RA, to a range of 5 miles to 50' RA); addition of a flare bar symbol and a flare message symbol; addition of wing flap alerting messages; and addition of runway ends and centerline.

Figure 9 includes an explanation of each symbol and the algorithms used. The descriptions of the various HUD symbols point out similarities and differences between symbols on this display and those on the head-down PFD format, shown earlier in Figure 8, and the navigation MAP format, shown in later in Figure 10. In those descriptions, the term "HDD" is used to designate the head-down PFD format, and the term "MAP" is used to designate the navigation MAP format. The following is a summary of the differences between the two PFD formats.

- o The pitch and track scaling is different between the two displays, permitting smaller deviations in those parameters to be noticeable on the HUD than the HDD.
- o Airspeed, altitude, and vertical velocity values available only digitally on the HUD are available on analog symbology (sometimes redundantly) on the HDD display.
- o Relative movement of symbols, i.e., which ones move and which are static, is different between the two displays. On the HDD the flight path symbol remains centered ("burned-on"), while on the HUD, the aircraft attitude symbol remains centered.

In addition, the HUD format is only presented head-up, while the HDD format is only presented head-down. This allowed the pilots to view the outside visual scene through the HUD format for part or all of each trial (depending on visibility conditions), but it was necessary for them to take their eyes from the HDD format and look through the windshield to see the outside world when using the head-down display. Because these factors could not be accounted for in the experimental design, additional steps were taken in the analysis to determine the potential impact of some of these differences on the results.

<u>Navigation Display Format</u> - The navigation MAP format, shown in Figure 10, depicts the intended route of flight in relation to the "Own-Aircraft" symbol. Other major features include: a position predictor for 20, 40 and 60 seconds from the present time, track scale and digital readout of track, heading, range markers, wind direction and velocity, and digital readouts of time and distance to the next steerpoint, direct and desired course to the next steerpoint, true airspeed, and ground speed. Additionally, the navigation mode, and the condition of true or magnetic heading are annunciated. Overlays for airfields, obstacles, navigation aids, and map range markers can be shown or removed with declutter switches located on the desk top. The map range scale can also be changed with desk top switches.

<u>Engine Power/Status and Approach Chart Formats</u> - Engine parameters are available in either bar graphs, as shown in the upper portion of Figure 11, or digital form, as shown in the lower portion of that figure, to be displayed simultaneously or individually by selecting the appropriate touch panel switches. These formats include integral limit indicators (bars divided along their length) for engine pressure ratio (EPR), exhaust gas temperature (EGT), RPM, and fuel flow (FF); instantaneous throttle position; and digital values, color-coded to show systems health. In addition to the digital status format, the lower portion of this display may be used to present a variety of instrument approach procedure formats, such as the vertical approach profile shown in Figure 12. Other options available through touch panel switches include horizontal profile, standard arrival route, standard instrument departure, terminal control area, airfield diagram, and airfield taxiways and ramps.

RESEARCH METHODOLOGY

Figure 13 shows the experimental design for this study. The experimental conditions were:

- o Steering (between subjects factor)
  - control-stick steering (CCS)
  - manual
- o Ceiling and Visibility (within subjects factor)
  - 5000 feet and 10 miles
  - 200 feet and 1/2 statute mile
  - 0 feet and 1200 feet runway visual range (RVR)
- o Wind Direction and Velocity (within subjects factor)
  - 090 degrees at 10 knots
  - 135 degrees at 21 knots
- o Display Format and Location (within subjects factor)
  - head-down
  - head-up

The experimental design was a mixed model, with steering as a between subjects factor and the rest as within subjects factors, resulting in a 2 (between) by 3 by 2 by 2 (within) design. The subjects were divided into two steering condition groups (CSS and manual).

The dependent variables were:

- o Deviation from Referenced/Commanded
  - horizontal profile (course or localizer)
  - vertical profile (altitude or glideslope)
  - indicated airspeed
  - flight path angle
  - track angle error
- o Touchdown Footprint
  - lateral (x-track) dispersion
  - longitudinal (along-track) deviation
  - sink rate
  - heading

Data Collection Procedure

The flight profile, shown in Figure 14, started at 9.3 miles from touchdown and consisted of level flight on a 45 degree intercept angle to the ILS localizer course, level flight on the localizer until glideslope interception, then glideslope and localizer to flare and landing. The referenced indicated airspeed was 150 knots until glideslope interception. At that point, the pilot reset the referenced IAS to 130 knots and reduced power to maintain that speed until flare. Pilots slowed the aircraft to approximately 120 knots for touchdown. The landing gear remained extended throughout the experiment. Wing flaps were in the approach position on each trial until glideslope interception, where the pilot extended them to the landing position. After touchdown and initial rollout, the simulator was reset to the initial position and conditions for the next trial. Prior to starting each trial, the guidance and control panel was configured for the appropriate flight control mode, and the aircraft and propulsion system were automatically trimmed for the given condition.

Ten airline pilots with a range of experience in a variety of aircraft, as shown in Figure 15, were selected as test subjects. They each participated for approximately 12 hours--4 hours on 3 separate days, a training day and 2 data collection days. On the first day they were briefed on the program, trained on the operation of the simulator systems, and received enough practice flying to become proficient. The practice flying consisted of familiarization maneuvers, followed by flying several profiles with frequent "flight freezes" to discuss the situation and the symbology. The pilots then practiced flying a profile, which terminated in an ILS approach and landing, under various ceiling, visibility and wind conditions. All training trials were conducted using the steering mode assigned to that subject. Training continued until the individual pilots felt proficient and were observed to be proficient by a research pilot who conducted all the training.

On the two data collection days, each subject received several training trials (until proficiency was observed and felt), followed by 24 test trials. The test trials were flown in two groups of twelve with a break in between. All trials on one day were conducted using the head-up display, as shown in Figure 16, and all the trials on the alternate day used the head-down display, with the order counterbalanced across subjects. Wind and ceiling/visibility conditions were assigned randomly within subjects and display conditions. The primary flight display format on the head-down display was covered from the pilot's view while data was being collected using the head-up display, as shown in Figure 17. The navigation display format was always available. Figures 18 through 23 are a photo sequence of the head-down PFD and MAP display formats as they appeared to the pilots during the flight profile. During this sequence the pilot was flying in the manual flight control mode with flight director guidance and a 10 knot headwind on final approach. Figures 24 through 27 show a sequence from the outer-marker to flare using the same formats. In this sequence, the pilot was flying in CSS flight control mode without flight director guidance, and was experiencing a crosswind. Figures 28 through 33 are a photo sequence of the head-up PFD format during the flight profile. During this sequence the pilot was flying in manual flight control mode with flight director guidance cue and a 10 knot headwind on final approach. Figures 34 through 38 show a HUD sequence from the outer marker to flare flying in CSS flight control mode without guidance cue and with crosswind.

In order to provide consistency, the same experimenter provided all training and briefings, controlled the experiment during data collection, and observed all flight segments from the inside experimenter's/observer's station. This experimenter was an experienced transport aircraft pilot who was intimately familiar with the simulated aircraft systems. This experience and knowledge was extremely helpful in maintaining a professional rapport with the subject pilots and in communicating with them on design rationale, flying procedures, and subjective findings. During data collection flights the experimenter changed the various conditions according to the scripted experimental design, started and stopped the data collections, and ensured proper simulated aircraft configuration for each trial.

Subjective comments, made during the flight segments and during debriefing sessions, were noted. After completion of all flying, the subject pilots each completed a questionnaire, results of which are included in Appendix C.

Data Reduction

Data reduction was accomplished in three steps. In the first step, raw data from the simulator's SEL computer was converted to ASCII code and saved to tape. Each tape held data from twelve consecutive trials (one data collecting session), as well as a header specifying the type, location, and size of each frame or data point on the tape.

The second step in the data collection procedure involved loading the raw data from the tape to the VAX 8600. This was accomplished through a program which reduced the data and set up two separate files. The data from the approach phase of each trial were reduced to one data point per second and stored in a file named T1SMPL.IN. These included the control inputs, airspeed deviation, deviations from the glideslope and track, and the altitude and vertical velocity deviations. The touchdown footprint, consisting of the touchdown time, the x and y distance from the target touchdown point, the sink rate, and the touchdown heading for each trial, was stored in a file named T1RUN.IN. Also stored in this file were the values assigned to the independent variables for each run. The two files thus created were loaded directly into the INGRES data base.

Once stored in the INGRES data base, the data could be examined for errors, manipulated as needed, and reported or graphed using a variety of formats. This data handling process, shown graphically in Figure 39, provided a powerful tool for preprocessing the data.

The third and final step in the data reduction procedure involved the creation of a data file for use with the BMDP statistical package. An application package was developed using INGRES application tools which enabled the researchers to interactively select the dependent variables to be studied, specific bands over which data were to be reduced, and the statistics to be generated for each variable. Reduction bands could be selected by distance from target touchdown point, time since the start of the simulation, or aircraft altitude. The choice of statistics to be generated for each variable included the mean, variance, Root-Mean-Square (rms) value, minimum, maximum, and sum-total.

For this study, the dependent variables, previously listed, were chosen for analysis. RMS values were generated for each variable for four bands in the flight profile, as well as at decision height for each trial. In addition, the touchdown footprint data were generated for each trial. These were written to a data file in a format directly readable by the BMDP software.

Data Analysis

Data from all four bands in the flight profile, as well as the touchdown footprint, were analyzed using the BMDP 2V Analysis of Variance (ANOVA) with Repeated Measures. The ANOVA results throughout the profile were examined, then because of the voluminous amount of data collected, three critical segments of the approach, shown in Figure 40, were selected for closer evaluation. These were the segment from the outer marker (OM) to the middle marker (MM), a band spanning 200 feet along-track before and after decision height (DH), and the touchdown footprint. Because the manual and CSS flight control modes were not developed to the same extent at the time of the study, the data from the two control modes were analyzed separately with no factor of steering appearing in the analysis. In addition, lost data from one subject resulted in the manual steering mode analysis containing data from only four subjects.

To examine the effects of the differences in the two displays, several more in-depth examinations of the data from the three segments described earlier were performed. The mean values of several dependent variables were graphed as a function of wind, display format, and visibility, and were examined for trends. Differences in performance under the lowest visibility condition (0'ceiling/1200' RVR) were examined over the band from the outer marker to the middle marker to determine if there was a difference in performance between the two formats when the advantage of the outside visual scene was removed. In addition, differences in performance between the two formats were examined as the distance to touchdown decreased to determine the effect of scale on the differences in the two formats.

As a final measure of "practical" significance, margin of safety or tolerance values based upon the judgement of an experienced pilot, were set for various parameters at decision height and at touchdown. These are listed in Table 1. Mean plus one standard deviation (s.d.) values outside this tolerance were deemed to constitute a "practically" significant effect. Trends in these effects will be noted and discussed in the following sections.

RESULTS

The results of this study are divided into two sections, Performance dealing with objective data and Questionnaires and Comments dealing with subjective data.

Performance

Significant results of the ANOVA for the three critical bands are provided in Appendix B and summarized in Figure 41. An examination of results of the ANOVA for all bands revealed several significant interaction effects throughout the flight profile for both steering modes (See Figure 41). These may be primarily due to individual differences in flying technique among the subject pilots. In addition, although the pilots were instructed to fly a precision approach, they were also instructed to land using their "normal airline pilot flare and touchdown techniques" rather than attempting to "spot land" the aircraft. Since they were landing on a long runway, the pilots frequently eased the aircraft down (rolled it on) for "passenger comfort." Thus, the landing footprint was larger than it would have been had they been briefed to use test pilot procedures. These instructions tended to enhance, rather than minimize, individual differences. Consequently, it is possible only to talk in terms of trends in the data when discussing many of the results.

Graphs of the data and charts of the mean plus one standard deviation values for the performance parameters of interest are shown in Figures 42 - 54. Each parameter was plotted as a function of the wind, format, and visibility conditions.

From Figure 41, it can be seen that display format has a statistically significant main effect on several parameters in the outer band (outer marker to middle marker) in both control modes. These parameters are cross-track deviation, flight path angle deviation, and track angle error. The graphs of the data (Figures 44, 49, 51) show the head-down display format resulting in a greater deviation than the head-up format, primarily in the 200'/0.5 mile and 0'/1200'RVR visibility conditions. The deviation scores are not, however, unusually large overall for the distance over which they were averaged and the distance from the touchdown point. In addition, the results at decision height, which will be detailed for each parameter, indicate that the differences in performance between the formats at this distance is primarily a function of the difference in scale.

Airspeed deviation - At decision height, there are no statistically significant main effects of any independent variable in either steering mode. There is a format by visibility interaction and a wind by visibility interaction in the manual mode. This can been seen in Figure 43a, especially in performance with the head-up format in the 21 knot crosswind and the head-down format in the same wind condition.

No trends can be found in the data from the manual or CSS steering mode as shown in the graphs of Figure 43, nor in the tolerance table of Figure 43c. From this figure, it can be seen that all mean values are within tolerance. Mean + 1 s.d. values tend to exceed tolerance in the CSS mode in the 5000'/10 mile and 200'/0.5 mile visibility conditions, while in the manual mode, mean + 1 s.d. values tend to go out of tolerance as visiblity degrades from the 5000'/10 mile condition.

X-Track deviation - At decision height, there are no statistically significant main or interaction effects of any parameter in either control mode. The graphs in Figure 45 illustrate a tendency in the manual mode for the head-up format to result in slightly smaller deviation scores than the head-down format. However, at most, this difference is less than 15 feet.

It should be noted that the differences in deviation scores between the two formats has decreased markedly from the OM to MM band, indicating an effect of differences in display scaling.

From a practical point of view, the chart of Figure 45c shows all mean and mean + 1 s.d. values to be within or close to tolerance in the CSS control mode. In the manual control mode, all mean and mean + 1 s.d. values are within tolerance with the head-up format, but tend to exceed tolerance as visibility degrades with the head-down format.

At touchdown, there is a statistically significant effect of format and wind, as well as format by wind interaction, in the manual mode. However, all mean and mean + 1 s.d. values are within tolerance, so there is no "practically" significant effect. (See Figure 46)

Glideslope deviation - There is a statistical main effect of visibility in the glideslope deviation parameter in the manual control mode at decision height. This is evidenced by a sharp increase in the 200'/0.5 mile condition over the other two visibility conditions and a tendency for mean + 1 s.d. values to be out of tolerance under this visibility condition. (See Figure 48). This also occurs in the CSS mode. No suitable explanation can be found for this effect, which occurs throughout the data. There is also a tendency for the mean + 1 s.d. values of the glideslope deviation in the CSS mode to be out of tolerance under the 200'/0.5 mile and the 0'/1200'RVR visibility conditions regardless of format or wind.

Flight Path Angle deviation - In the manual control mode, there is a statistically significant visibility effect, as well as an effect of the format by wind by visibility interaction. From the graph in Figure 50a, this effect is seen as an increase in deviation from desired flight path angle under the 21 knot crosswind, head-down format condition overall, as well as a greater deviation for the head-down format condition in the 0'/1200'RVR visibility condition.

From a practical standpoint, all mean and mean + 1 s.d. values in the 5000'/10 mile visibility condition are within the 1 degree tolerance. However, as visibility degrades, mean + 1 s.d. values tend to exceed tolerance regardless of wind or format. (See Figure 50c).

There are no effects of any parameter on flight path angle deviation in the control-stick steering mode and all mean and mean + 1 s.d. values are within tolerance.

Runway longitudinal dispersion - There are statistically significant format by wind and format by wind by visibility interactions in the runway longitudinal dispersion the manual control mode. In this control mode, the longitudinal dispersion, in general, shows no effect of wind or format in the 5000'/10 mile or 200'/0.5 mile visibility conditions, except for a notably higher mean dispersion in the 135/21kt wind condition flying the head-down format. (See Figure 53). In the 0'/1200' RVR condition, the head-down format tends to result in a greater dispersion than the head-up format. In the CSS control mode, there is no effect of format in the 5000'/10 mile visibility condition, but as visibility degrades, there is a slight tendency for the the head-down format to result in greater dispersions. It is not reasonable to discuss these results in terms of tolerances because of the impact of individual flying technique on flare and landing procedures.

Sink rate at touchdown - In the manual control mode, mean + 1 s.d. values for the sink rate at touchdown are generally out of tolerance for both formats. In addition, mean values tend to exceed tolerance with the head-down format as visibility degrades below the 5000'/10 mile condition. In the CSS control mode, there is a tendency for mean sink rate values to be lower with the head-up format and mean plus one standard deviation values exceed tolerance with the head-down format as visibility degrades. (See Figure 54).

Heading at touchdown - For both control modes, mean heading at touchdown is out of tolerance in the 135/21kt wind condition regardless of visibility or format. This is at least partially due to the fact that there was no aural or motion cue to inform the pilot when he was on the ground. In the absence of such cues, pilots were often unsure of whether they had touched down or were still a few feet above the runway. (See Figure 52).

Subjective Ratings And Comments

The ten airline pilot subjects volunteered their personal time to participate in this study. Their primary goal was to enhance future flight stations and crew systems by providing their expertise during the early conception and design. This very honorable motivation must be considered when reviewing their comments and responses to the questionnaire which are included in Appendix C. The summary of subjective ratings and comments contained in this section are also influenced by verbal remarks and observations obtained during flying sessions and debriefings. The pilots were very enthused about flying the advanced concepts simulator and they expressed satisfaction with the experiment. The two most emphatic comments from virtually all of the subjects were that: (1) they liked to fly using flight path (or velocity vector) information for reference, either head-down or head-up, as opposed to present day "attitude" information, and (2) they liked flying head-up versus head-down.

<u>Interpretability of the HUD Format</u> - The pilots rated the interpretability (i.e., their ability to know the aircraft's situation by looking at the data displayed) of the head-up display formats as good with flight director guidance and excellent without it. The overall comments were highly favorable, however, some suggestions for improvement were made. The most frequent suggestions were (1) improve the presentation of the course deviation indicator data, particularly prior to course intercept, (2) leave the perspective runway displayed until after touchdown rather than removing it at 50 feet AGL, (3) connect the localizer and glideslope symbols into a "plus" sign rather than having them move independently, and (4) make the glideslope symbol more distinctive from other horizontal lines.

<u>Adequacy of Information on the HUD Format</u> - The pilots indicated that all information required to complete the flying task was available on the HUD. They did, however, suggest improvements including (1) remove some of the information (no consensus) because too much was presented, and (2) improve course intercept information by making it less confusing and by providing a better alert of initial movement of the CDI pointer during course capture.

<u>Interpretability of HDD Format</u> - The pilots rated the interpretability of the head-down format as good, both with and without flight director guidance. The most frequent suggestions for improvement were (1) change the flight director symbol from a filled ball to an unfilled circle so that the symbolic runway can be seen through it, (2) enlarge the airspeed and altimeter symbols, and (3) extend the localizer and glideslope deviation pointers to cross the center of the display.

<u>Adequacy of Information on the HDD Format</u> - The pilots indicated that all information required to complete the flying task was available on the HDD. Some suggestions were made that too much data (unspecified) was presented, and that a roll scale added at the bottom of the PFD would be helpful.

<u>Preferred Method of Display</u> - The pilots unanimously preferred flying with the head-up display over the head-down display for the approach and landing task, while some felt that the HDD would be preferrable while enroute. The principal reasons stated for preferring the HUD included (1) not needing to transition from instruments to outside visual scene during low visibility approaches, and (2) more expanded scaling permitting more precise positioning of the aircraft relative to desired profile.

Effect of Wind and Visibility on Control Mode - Overall, the subjects did not feel that wind condition or visibility had any effect on the ease of flying the simulator in either control mode. In the manual mode, the median ratings were excellent under best case conditions and good under worst case. In the CSS mode, median ratings were good under best case conditions and excellent under worst case. As a general comment the subjects felt that the manual mode was to sensitive in both axes making precise control of the aircraft difficult near the runway. Figure 55 shows the results of the subjective rating scales.

Effect of Wind and Visibility on Workload - Wind and visibility had little effect on workload when flying head-up or head-down. The median workload ratings were moderately low when using the HUD and moderate when using the HDD for both control modes and in worst case wind and visibility conditions.

Opinion of Using HUD for Instrument Approaches - The subject pilots were highly enthused about using the HUD for flying instrument approaches. Not needing to transition from head-down to head-up for landing was thought to be a great advantage. They also projected the advantage of head-up flying with flight path information into airfields with few or no navigation aids.

Opinion of Side-Stick Controller Versus Control Wheel - The majority of the subjects had a strong preference for the side stick over the control wheel because of comfort of use, and unrestricted view of the instrument panel. The opinion was not unanimous, however, with some pilots preferring the control wheel and one suggestion of a center stick. There was also concern for ensuring the reliability of fly-by-wire systems.

Opinion of Flight Path Format Versus Attitude Format - The subject pilots expressed an overwhelming preference for flight path formats over the standard attitude formats that they are using in current aircraft. They adapted very quickly and immediately liked the philosophy of "seeing where the aircraft was going" rather than interpolating from attitude information. This agrees with a well-established principal that subjects perform better when the amount of data that they are required to interpret is reduced.

Opinion of the Experiment - In general, the subjects were highly complementary of the simulator and the way the experiment was conducted. Without exception, they requested the opportunity to participate in future simulations. They also expressed the opinion that such studies are necessary and helpful to the aviation industry.

CONCLUSIONS

Objective performance data did not establish a significant difference between the head-down and head-up display. However, the differences in performance, although small and often not of "practical" significance, favored the head-up display, especially as visibility degraded from the 5000'/10 mile condition. To what degree this difference is due to format, difference in scale resolution, the need not to transition between the outside visual scene and the head-down instrument panel, or a combination of these factors is a topic for future investigations.

Subjective data was much more clear-cut. The pilots much preferred the head-up display over the head-down display, and there was an overwhelming preference expressed by the subject pilots for the flight path primary flight display formats over conventional attitude PFD formats. Additionally, the control-stick steering mode received better comments than the manual steering mode, although a direct comparison was not made. This was expected because the CSS mode had been developed a little more fully than the manual mode.

An ancillary conclusion is that one of the most significant accomplishments resulting from this study was the completion of a facility suitably equipped for the investigation and evaluation of both head-up and head-down display formats and other advanced crew systems for transport aircraft in a dynamic environment. The completion of this facility, along with the supporting display development, data reduction, and data analysis software, provides a powerful tool for advanced flight station design.

RECOMMENDATIONS

The accuracy provided by both head-down and head-up or flight path displays for manually flying approaches and landings, along with the pilots' enthusiasm for using these types of data, indicate that further action should be taken to incorporate this information into transport aircraft flight stations. While flight path data are starting to be used on some transport aircraft head-up displays, aircraft owners, operators, and pilots are generally oblivious to its existence, possible applications and apparent advantages. It is recommended that head-down displays of flight path data be validated to the same degree as it has been for head-up displays, i.e., FAA certification to Category IIIa landing minima. Additionally, it should be determined whether the HDD and HUD formats need to be identical. For example, if the pilot were required to transition from the HUD to the head-down display due to HUD failure while manually flying a very low visibility approach, would performance be degraded to a degree that is critical or at all? Continued research to provide answers to these questions and others pertinent to certification of future airlifters is recommended.

APPENDIX A

DESCRIPTION OF THE SIMULATOR

The research facility used in this study in one of three nearly-identical full-mission flight simulators developed jointly by NASA-Langley Research Center, NASA-Ames Center and LASC - Georgia. The facilities are used to research issues affecting current and future transport aircraft crew systems. The cockpit, which contains a full complement of advanced controls and displays, is called the Pilot's Desk Flight Station. The simulation is driven by two host computers, Gould SEL 32/8750 and VAX 11/780, which are integrated with several other avionic components, as shown in Figure A-1.

The Pilot's Desk Flight Station, shown earlier in Figure 1, is a unique design that more resembles an operator's console than today's cockpit. It became feasible because of the use of fly-by-wire/light flight and thrust control systems, without mechanical redundancy, which eliminates the requirement for large and cumbersome columns, control wheels or center sticks, and mechanical throttle levers. This, in turn, permits more efficient use of the space presently occupied by those controls. Thus, the desk-top design was conceived, with small side-stick controllers and other controls/displays located much more conveniently for pilots' reach and vision. Only small, easily accessible center-pedestal and overhead consoles are required.

Within the next few years, advances in display technology will make possible the use of large, high-resolution, color, flat-panel displays. These are emulated by five vertically oriented 13-inch diagonal, color, cathode ray tubes mounted side-by-side on the main instrument panel, as well as two monochromatic, flat-panel displays on the desk top. The center three CRTs and the two flat-panel displays have touch-sensitive panels over their faces to provide pilot control of systems. Each pilot also has a head-up display on which primary flight information is presented, giving the pilot capability to simultaneously see the symbology and view the outside world.

Some other unique features of the design are: automatic loading of navigation and other operational data into the aircraft computers; performance management for most efficient/economical operation, integrated with a four-dimensional navigation system and the automatic flight control system; advanced air traffic control systems including Mode S data link of traffic and weather information, clearances, and collision avoidance; integrated control of communications, navigation systems, and transponders; a hard-copy printer for pilot selectable information; and a voice command and response system for announcing advisories, cautions and warnings, accessing/call-up of information, entering information into on-board computers, and controlling a limited number of systems.

The flight simulators are designed to provide full-mission simulation capability by placing the pilots in a realistic operating environment, where they interface with the outside world, air traffic control, and all functional aircraft systems while performing typical (or a-typical) flight profiles.

Aircraft - A generic transport aircraft was formulated and sized based upon projected user needs for 1995, and a forecasted technology cutoff date of 1990. The aircraft modeled for this simulation study shown in Figure A-2, had the following characteristics:

- o Twin engine - 29,566 pounds thrust each
- o Tee tail
- o Low wing
- o Max gross weight - 223,740 pounds
- o Payload - 60,000 pounds at 2.5g
- o Capacity - 200 passengers
- o Speed - 0.78 Mach
- o Range - 2500 nautical miles
- o Fly-by-wire/light
- o Negative static margin
- o Supercritical wing
- o Active flight controls
- o Two-pilot flight station crew

Location of Components - The main instrument panel contains five multifunction electronic displays (three with touch panel overlays) upon which the majority of information for the pilot is presented, and much of it is controlled. Outboard of the multifunction displays on each side is a digital clock and a CRT master brightness control. Additionally, there is a turn and slip indicator on the left-hand side.

The desk top contains the nosewheel steering controls, side-stick controllers, control/display units, integrated comm/nav system, navigation mode and display selection, throttles, parking brake, rudder pedal adjust, coffee cup holders, and ash trays.

The controls for the automatic flight control system (AFCS), autothrottle engage, altitude alerting systems, barometric pressure and radar altimeter set knobs, and the master caution and warning lights are located on the glareshield.

The overhead console contains controls for the fire control system, engine start, flight control system, head-up displays, interior and exterior lights, landing gear, brake system, oxygen system, cockpit voice recorder, auxiliary power unit, adverse weather system, and emergency circuit breakers. Additionally it has displays for wing flap position and fuel quantity.

The center pedestal contains controls for the alternate trim system, wing flaps, global positioning system, weather radar, printer, data transfer module, and emergency landing gear release. It also contains controls for resetting and freezing the flight simulation.

The side pedestals contain oxygen regulators, smoke and oxygen mask storage, microphone and headset jacks, a drawer for storing papers, and a chart and map storage area.

Head-Down Displays - The front panel contains five multifunction displays. They are identical 13-inch diagonal, stroke/raster, high resolution, shadow-mask color CRTs. They are mounted on the front instrument panel side-by-side, long dimension in the vertical plane. Each of the five head-down displays is driven by an Adage RDS 3000 raster display system with full color outputs being presented on five Conrac monitors. The three center CRTs have

Elographics touchpanel overlays which can be used to call up various displays and to change simulation variables. The control logic is tailored to the format being displayed. The display system correlates the grid coordinate of the pilot's finger with the display and, through program logic, determines the action required (e.g., check-off checklist item, send a discrete signal to a switch/valve control, call up a new display, etc). The signal is then sent to the appropriate system processor for action.

All formats required for a full mission simulation have been developed. The primary flight and navigation display formats present all of the information (and more) typically found in the standard "T" on the pilots' instrument panels. The primary flight display (PFD) format is directly above the navigation display format located on the #1 and #5 displays on the captain's and first officer's centerlines. The information on the the PFD and Nav display includes airspeed, altitude, attitude, flight path, and other symbology required to fly the aircraft and provide situational awareness. Secondary information is displayed inboard from the primary flight display, much the same as with all modern transport aircraft where engine instruments and caution and warning annunciations typically occupy the center instrument panel. Switches enable the pilots to move information formats between displays.

Head-Up Displays - The flight station contains two Flight Dynamics, Inc. Model 1000 HGS (Head-up Guidance System) head-up displays (HUDs); one for the captain and one for the first officer. Each system has an overhead unit which projects stroke information onto a holographic combiner. The information on the combiner is focused at optical infinity and overlays the outside visual scene. The HUDs are driven by an Interactive Machines Inc. IMI455D stroke symbol generator, an easily programmable system for developing and testing stroke symbology. Primary flight information is presented on the HUD, which permits the pilots to fly the aircraft precisely without referring to the information displayed on the main instrument panel, and while viewing the outside world. The field of view displayed on the combiner is 24 degrees vertically and 30 degrees horizontally. From the design eye point, (12 inches aft of the combiner), the 24 x 30 degree field of view approximates the size and shape of the left or right front windows of a transport aircraft. HUD symbology varies, depending upon the mode selected on the HUD control on the overhead control panel.

Side-Stick Controller - When flying other than in autopilot command mode, pilot inputs to the pitch and roll axes of the flight control system are made through side-stick controllers, shown earlier in Figure 4, mounted on the desk top outboard of each pilot position. The equivalent position of the interconnected sticks is transmitted by the McFadden feel system to the simulation software through the simulator I/O mechanization. For pitch control, the stick is restricted to seven degrees forward and seven degrees aft movement. For roll control, the stick movement is seven degrees to each side. Each stick has a "coolie hat" thumb switch to command pitch and roll trim inputs. In the control stick steering mode, which is mechanized through the autopilot system, the pitch trim switch can be used to increment the flight path angle without moving the stick. Switches for emergency pitch trim disconnect, emergency autopilot disengagement, voice command, and communication radio microphones are also located on each controller.

Guidance and Control Panel - The Guidance and Control Panel (GCP) is an interactive control and display device located on the center of the glareshield for easy access by either pilot. The primary function of the GCP shown earlier in Figures 5 and 6, is to communicate pilot commands to the AFCS and to annunciate those commands to the pilot. The GCP contains 24 0.75 inch square push switches each with 2 rows of software programmable light emitting diode (LED) legends. These switches are used to select the phase of flight, the vertical and horizontal guidance modes, and the referenced indicated air speed. The switches are treated as momentary discrete inputs even though their activation is transmitted through the I/O as a message. The programmable upper and lower legends are also transmitted through the I/O as messages. The GCP also contains several knobs to set values for referenced IAS, track, course, reference flight path angle, and decision height. These switches, which are true discretes, are connected to infinite turn pots and are used to change analog commanded values for the various referenced terms. The pilot also uses the GCP to engage or disengage the autopilot, flight director and autothrottle. A detailed description of the GCP including switching logic is given in "ACFS Simulator Software Requirements - Automatic Flight Control System", Report ACFS-C358-019-Revision B.

Flight Control System - The aircraft was modeled as having a standard flight control system for a transport aircraft in terms of control surfaces and functions. All controls were designed as fly-by-wire systems without the need for hydraulics and mechanical linkages from the control inputs to the actuators. Primary flight control is provided through pilot inputs through the stick and pedals to the elevator, rudder, ailerons and spoilers. The spoilers are used both as lift dumping devices and as roll aids when deflected asymmetrically. Figure A-3 shows a general layout of the flight controls on the aircraft. Secondary control for low speed performance is provided by leading edge slats and trailing edge flaps. Standard pitch, roll and yaw trim systems are programmed in the simulation. Pitch trim used a stabilizer control surface. Roll trim was provided through aileron offset, and yaw trim through rudder offset. Schematics of the manual flight controls are shown in Figures A-4 through A-11. The aircraft is equipped with a full-time stability augmentation system (SAS) for smoother flight and control response. Control laws for these systems are shown in Figures A-12 through A-14.

The flight controls system includes an autopilot/flight director model which enables either manual flight guided by the flight director, control-stick steering flight through the autopilot, or fully automatic flight using command modes of the autopilot. Control laws for the flight director common innerloop mechanization for both the pitch and roll (vertical and horizontal) axes are shown in Figure A-15. Control laws for the outerloop flight director signals for the modes used in the experiment are shown in Figures A-16 through A-20. Figure A-16 shows the flare mode, which is automatically engaged at a radar altitude of 50 feet when in the ILS glideslope mode. The other half of the tests were conducted using the velocity vector control-stick steering mode of the autopilot. Control laws for the roll or horizontal axis are shown in Figure A-21. Figure A-22 shows the control laws for the pitch or vertical axis.

ORIGINAL PAGE IS
OF POOR QUALITY

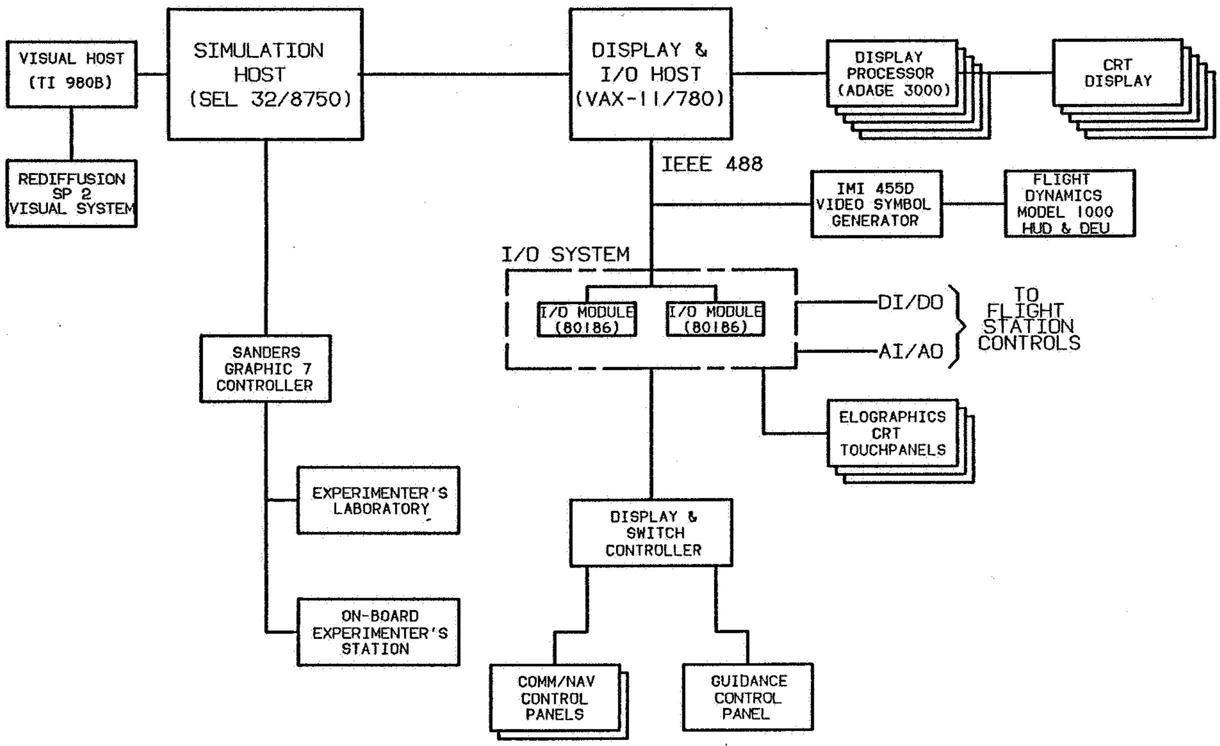


Figure A-1. Simulator System Used in Format Evaluation Study

Figure A-2. A Generic Transport Aircraft was Modeled for Simulation

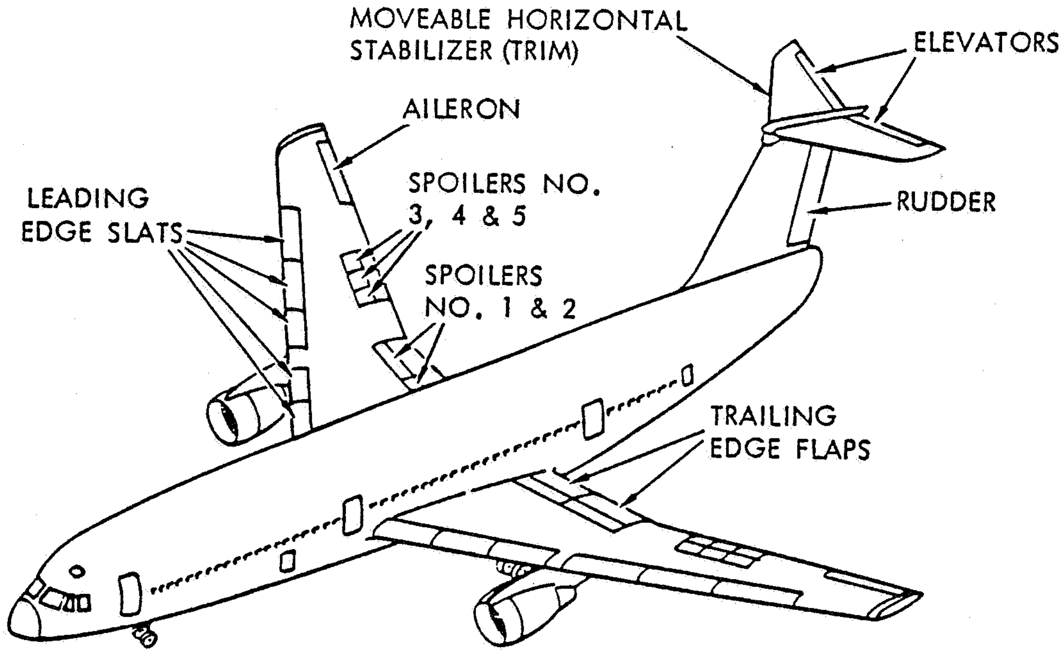


Figure A-3. Simulated Aircraft Control Surfaces

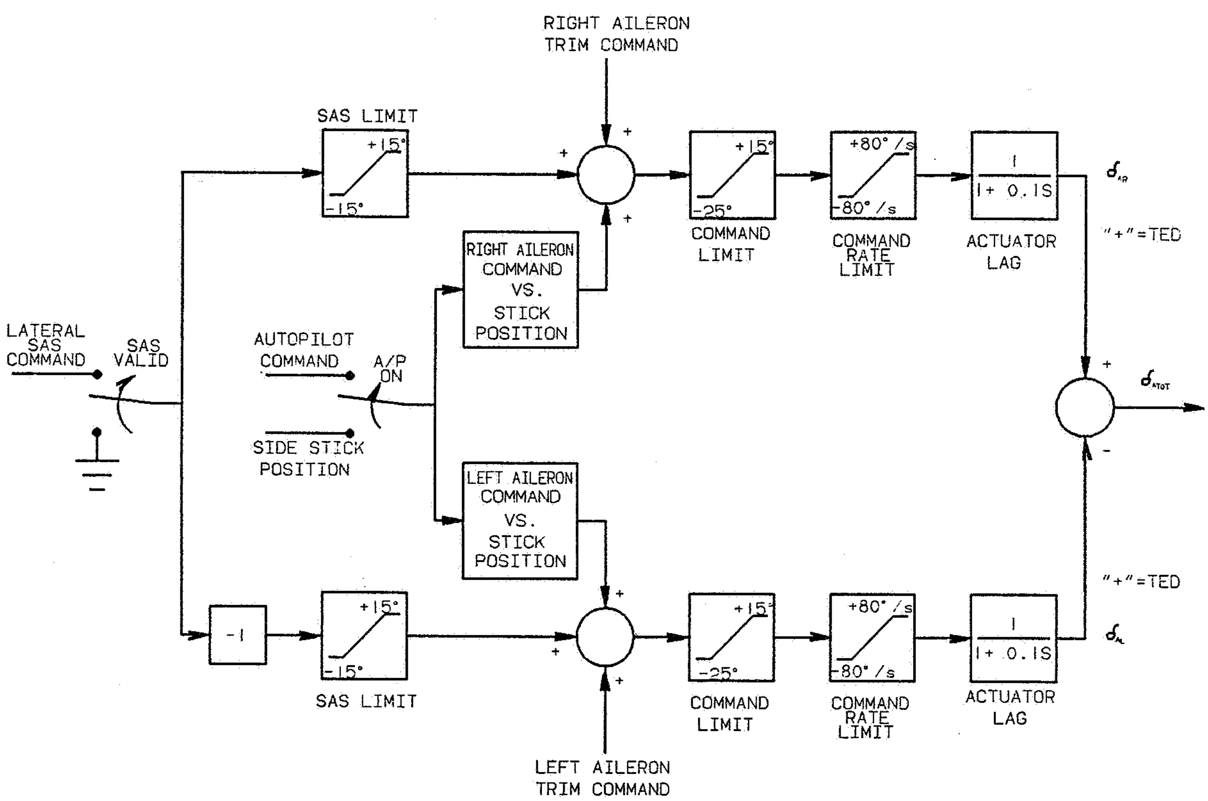


Figure A-4. Aileron System

ORIGINAL PAGE IS
OF POOR QUALITY

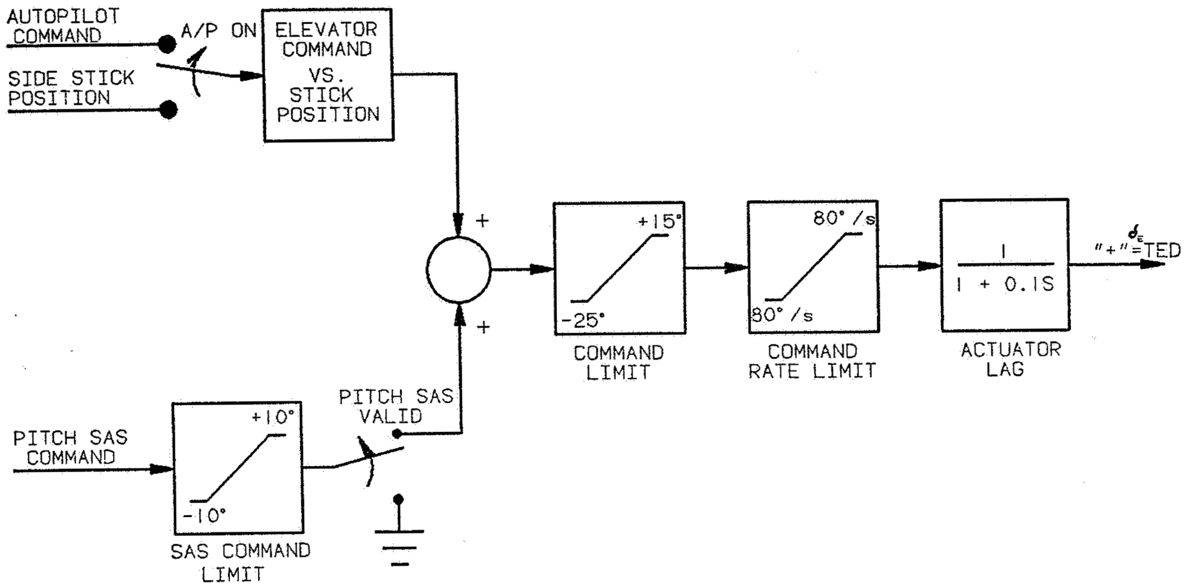


Figure A-5. Elevator System

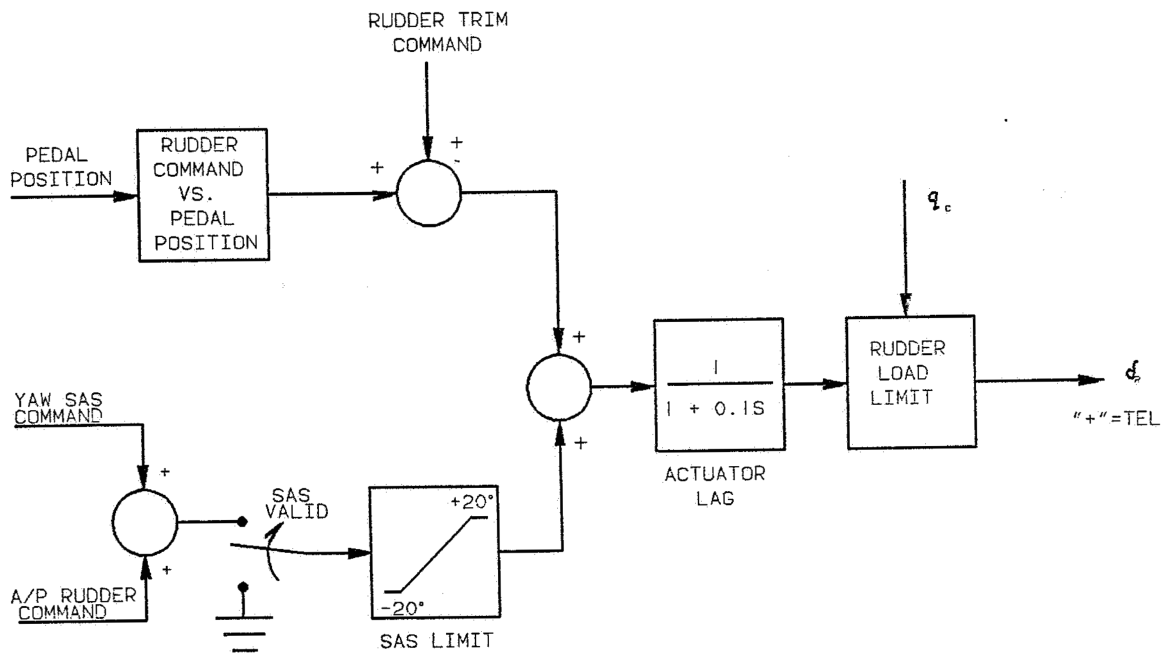


Figure A-6. Rudder System

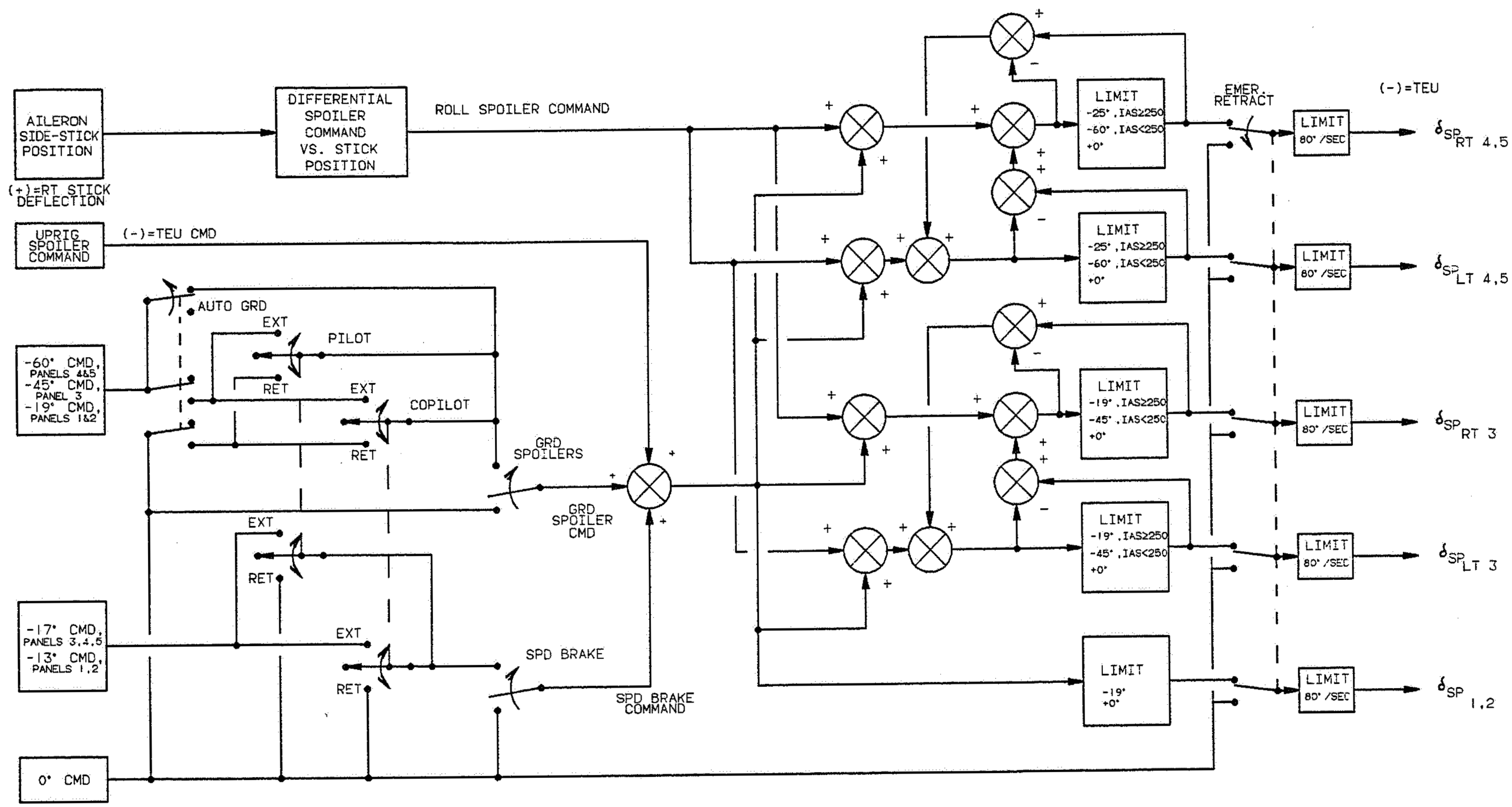


Figure A-7. Spoiler System

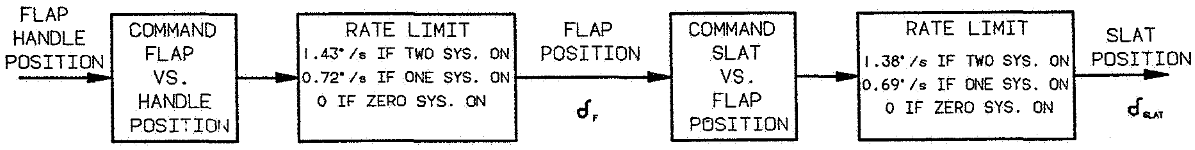


Figure A-8. Flap/Leading Edge Slat System

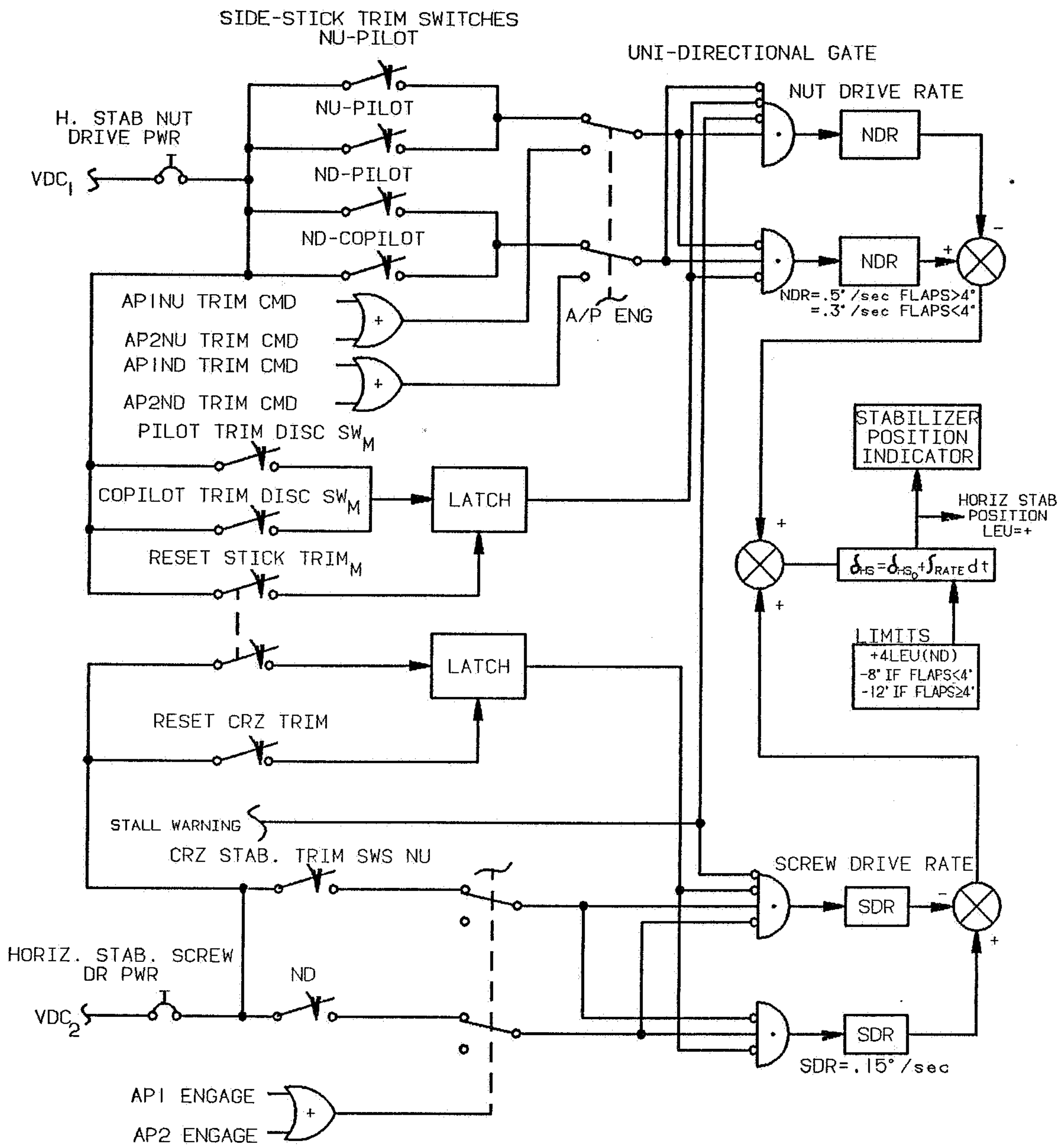


Figure A-9. Horizontal Stabilizer Trim Mechanization

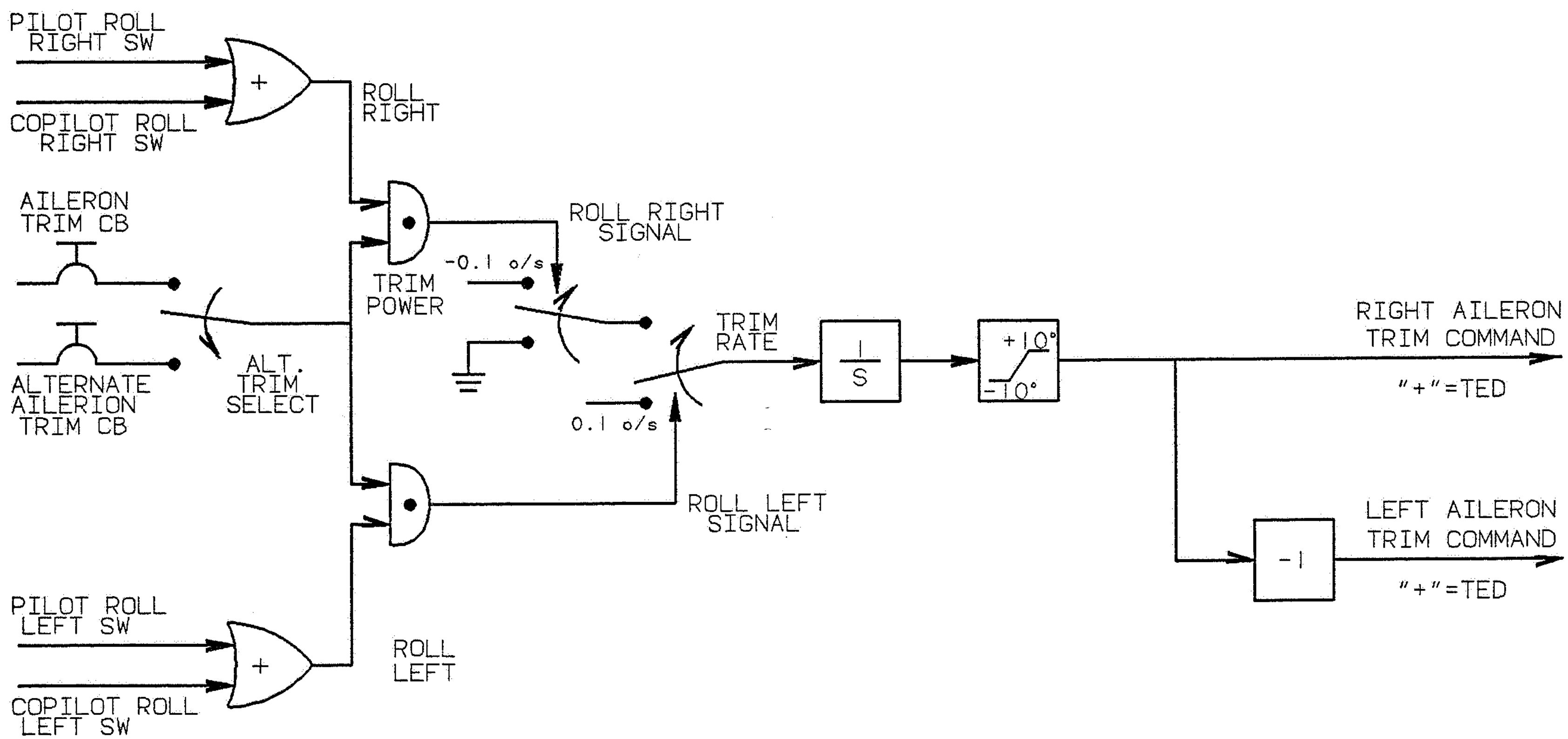


Figure A-10. Aileron Trim System

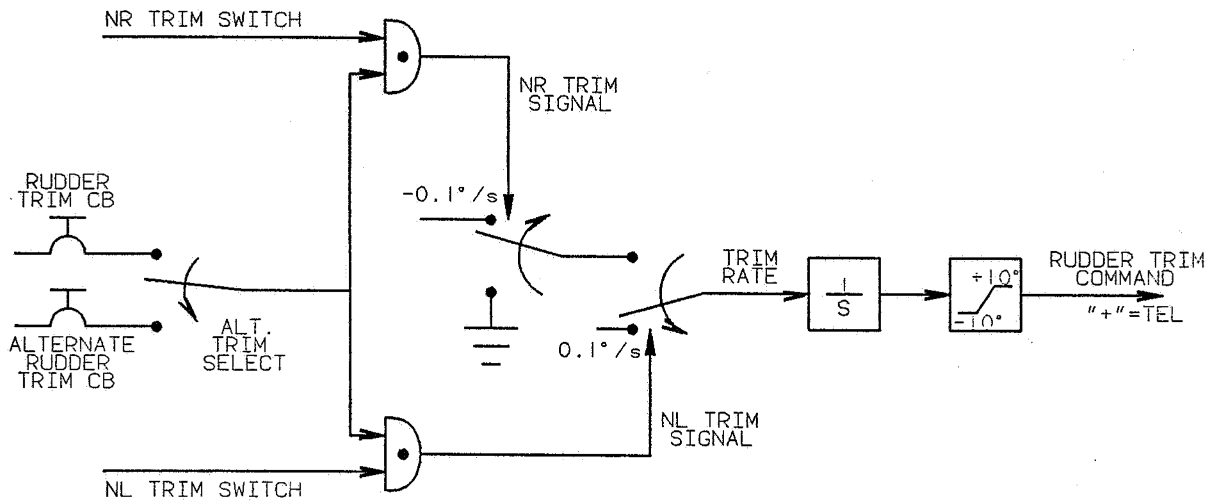


Figure A-11. Rudder Trim System

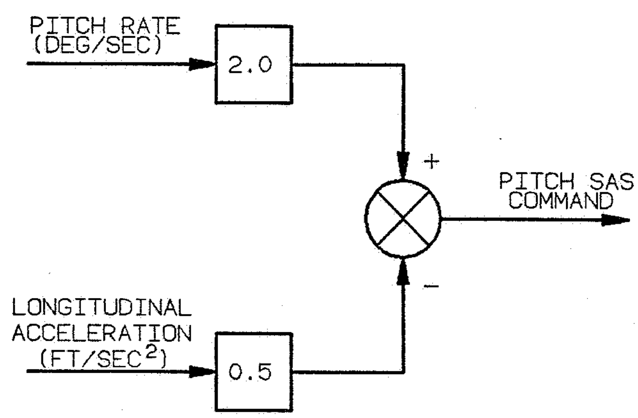


Figure A-12. Pitch Stability Augmentation System

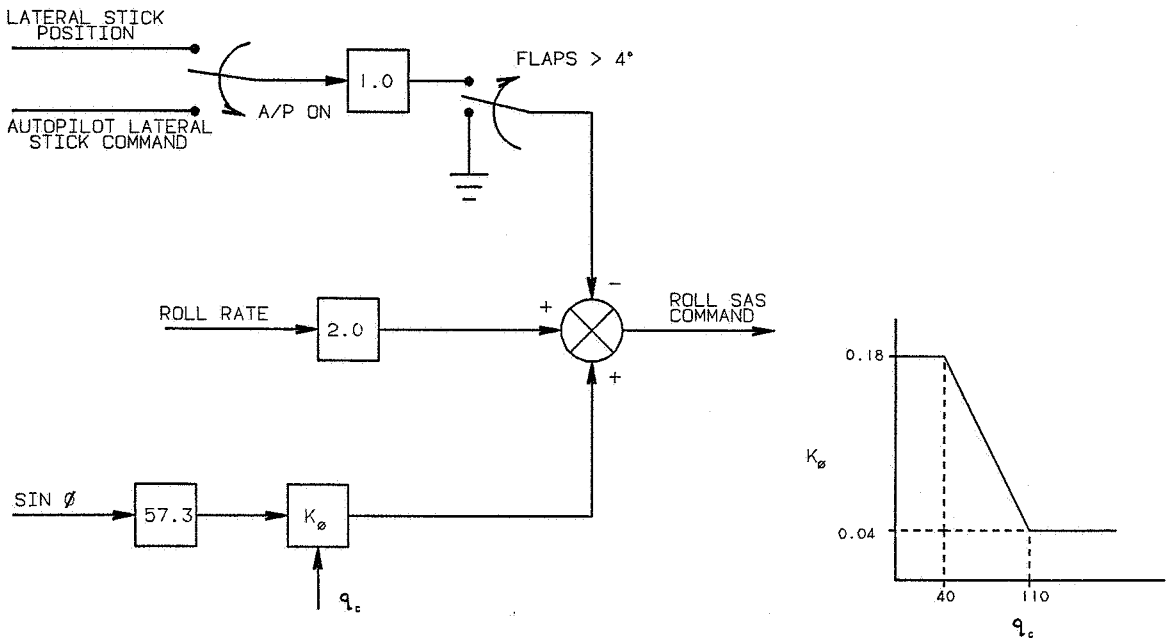


Figure A-13. Roll Stability Augmentation System

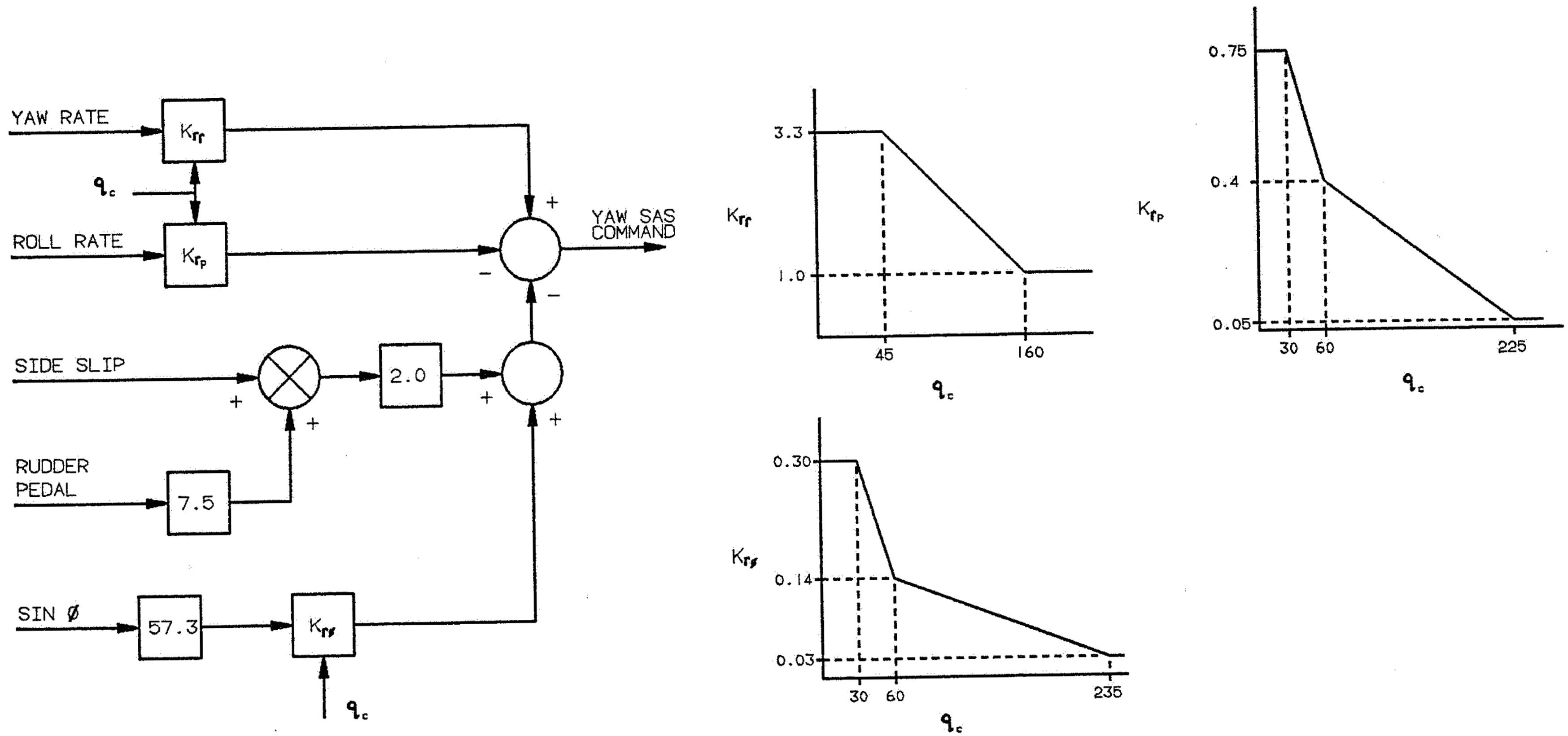


Figure A-14. Yaw Stability Augmentation System

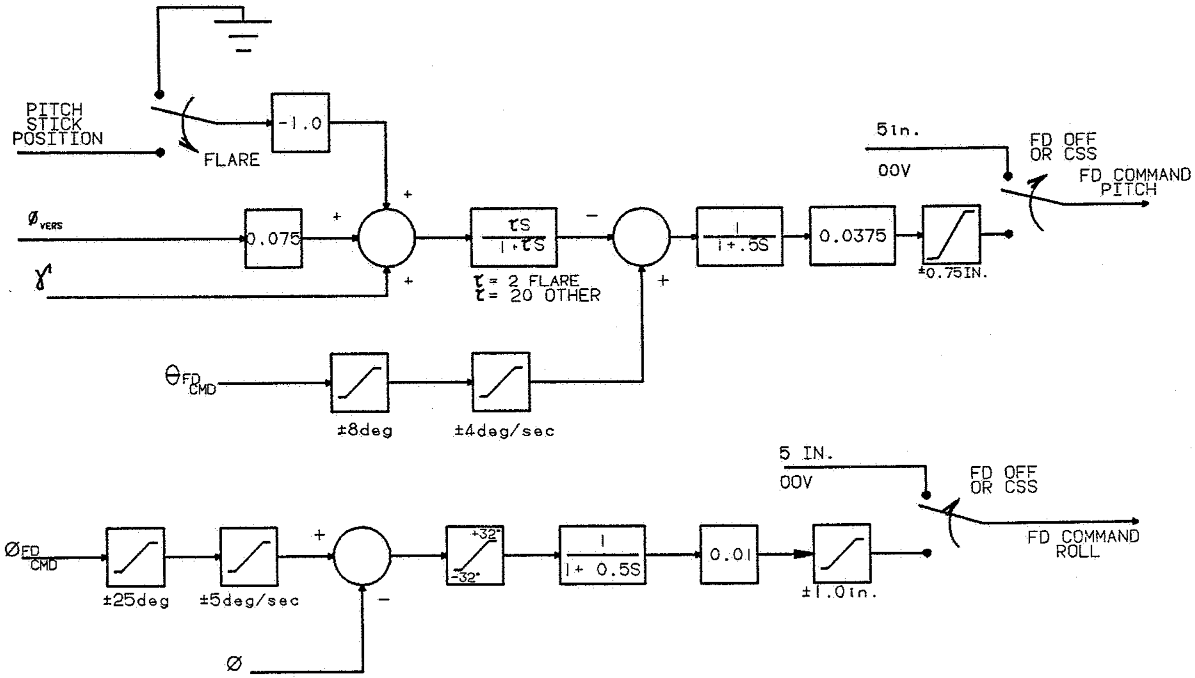


Figure A-15. Flight Director Innerloops

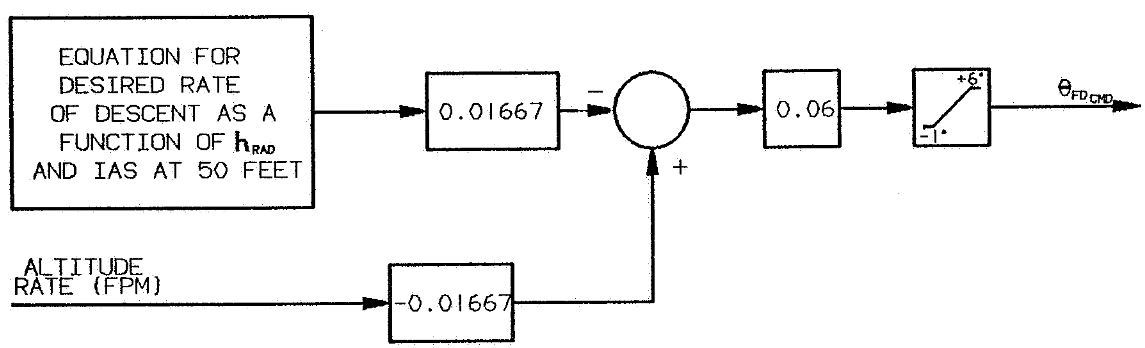


Figure A-16. Flare Flight Director Command

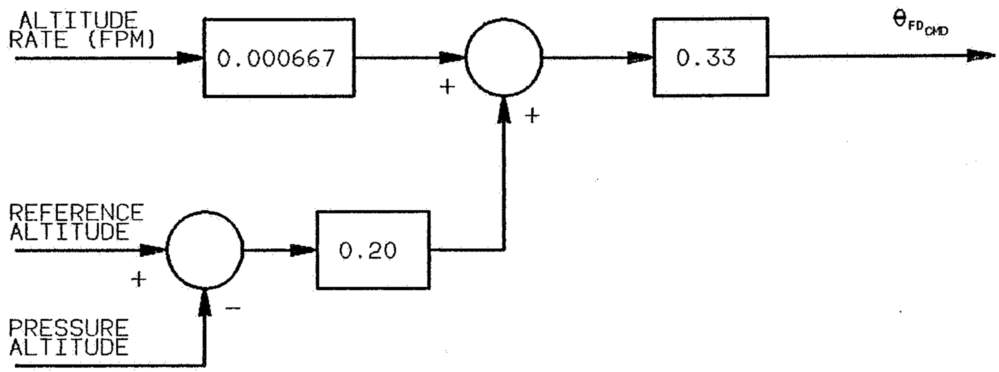


Figure A-17. Altitude Hold Flight Director Command

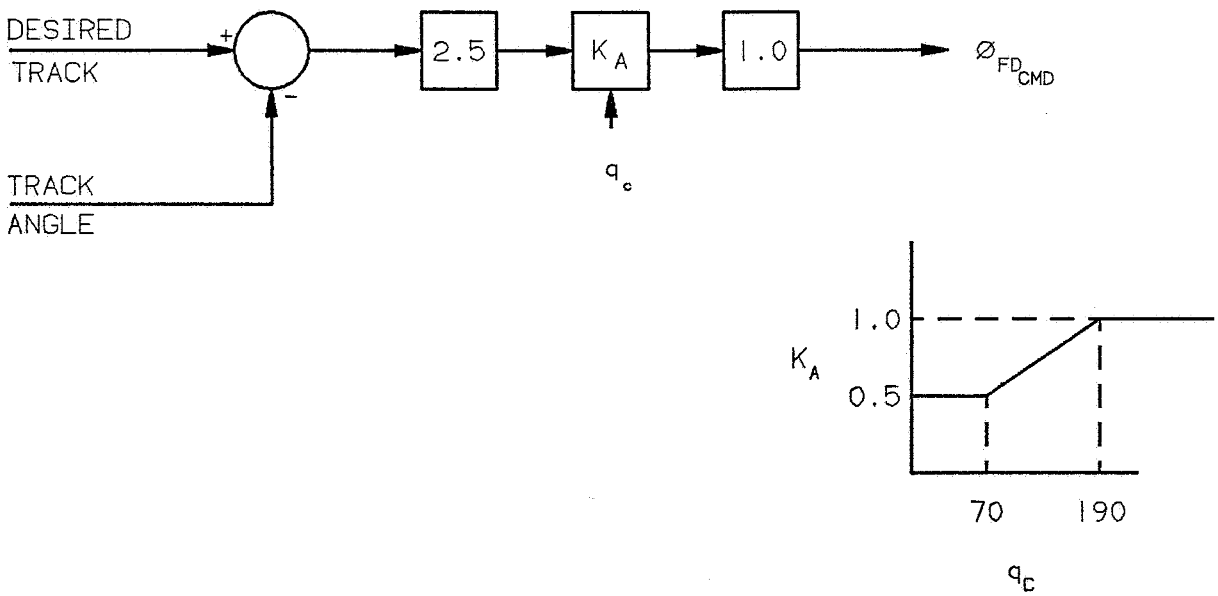


Figure A-18. Track Flight Director Command

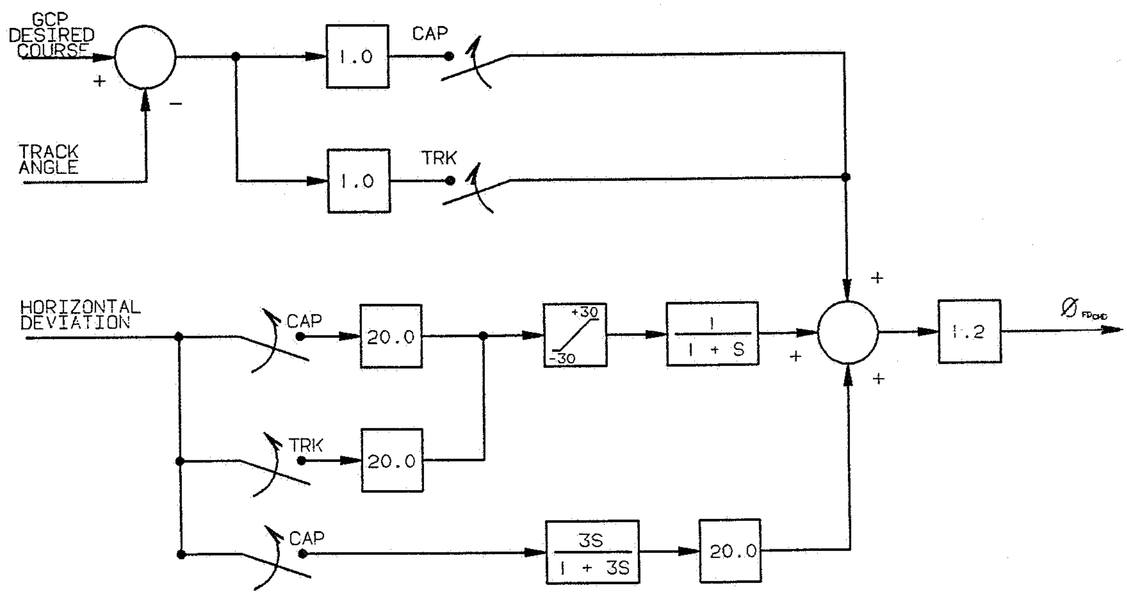


Figure A-19. ILS Localizer Flight Director Command

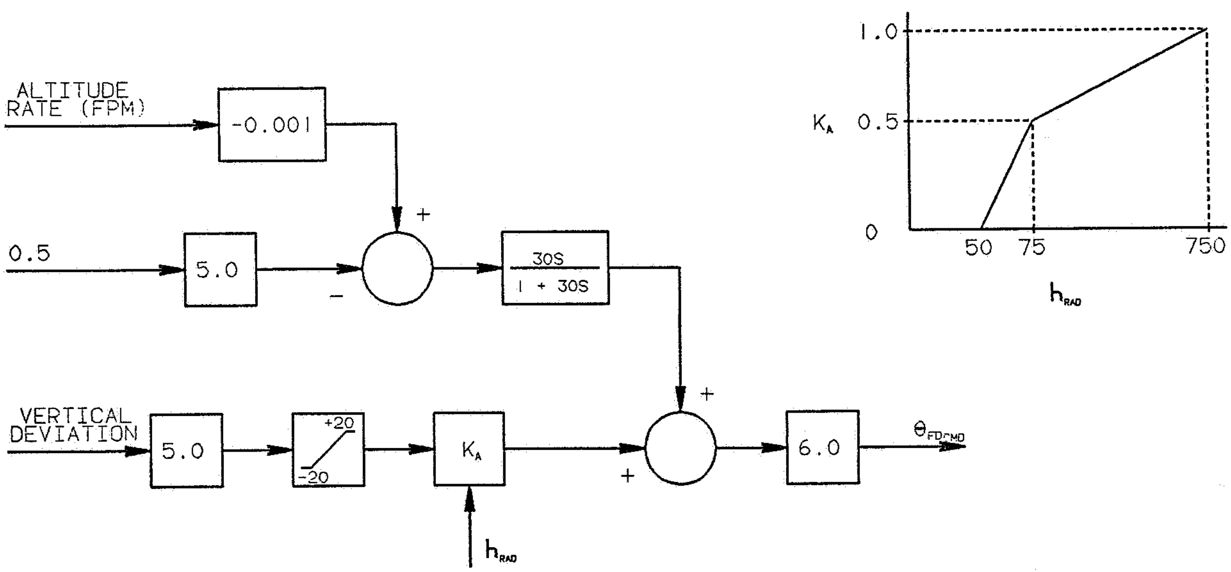


Figure A-20. ILS Glideslope Flight Director Command

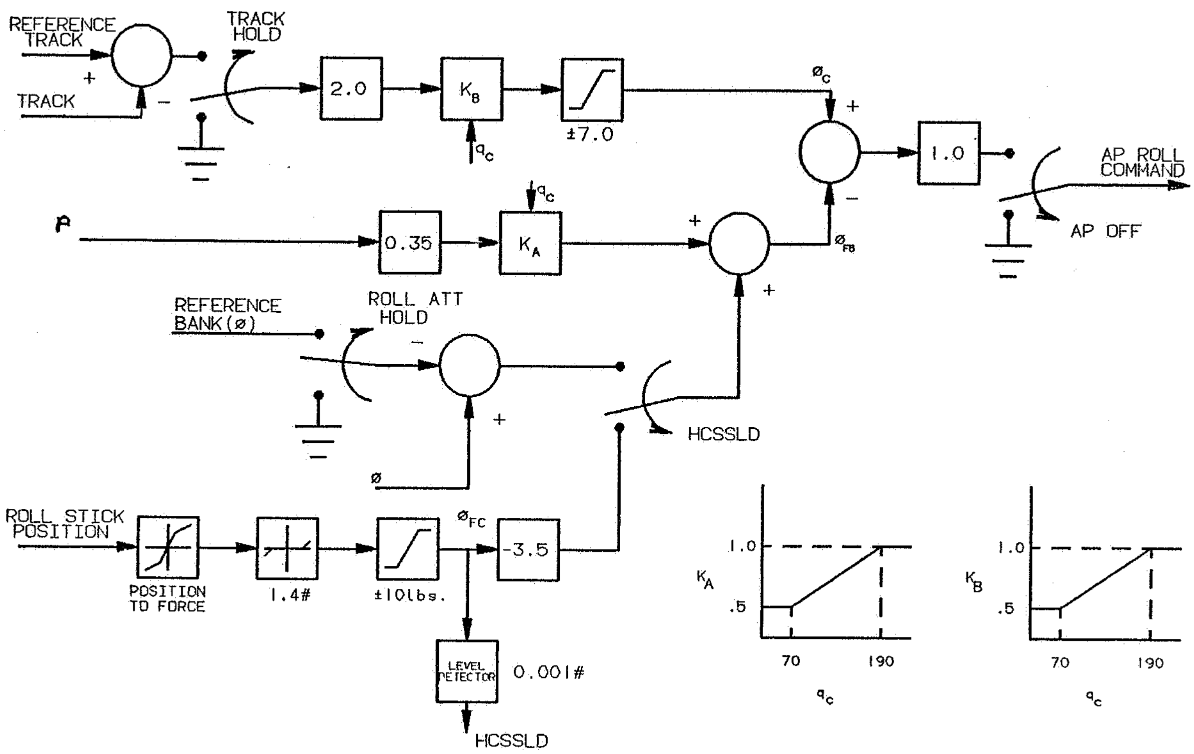


Figure A-21. Roll Autopilot Velocity Vector Control-Stick Steering Mechanization

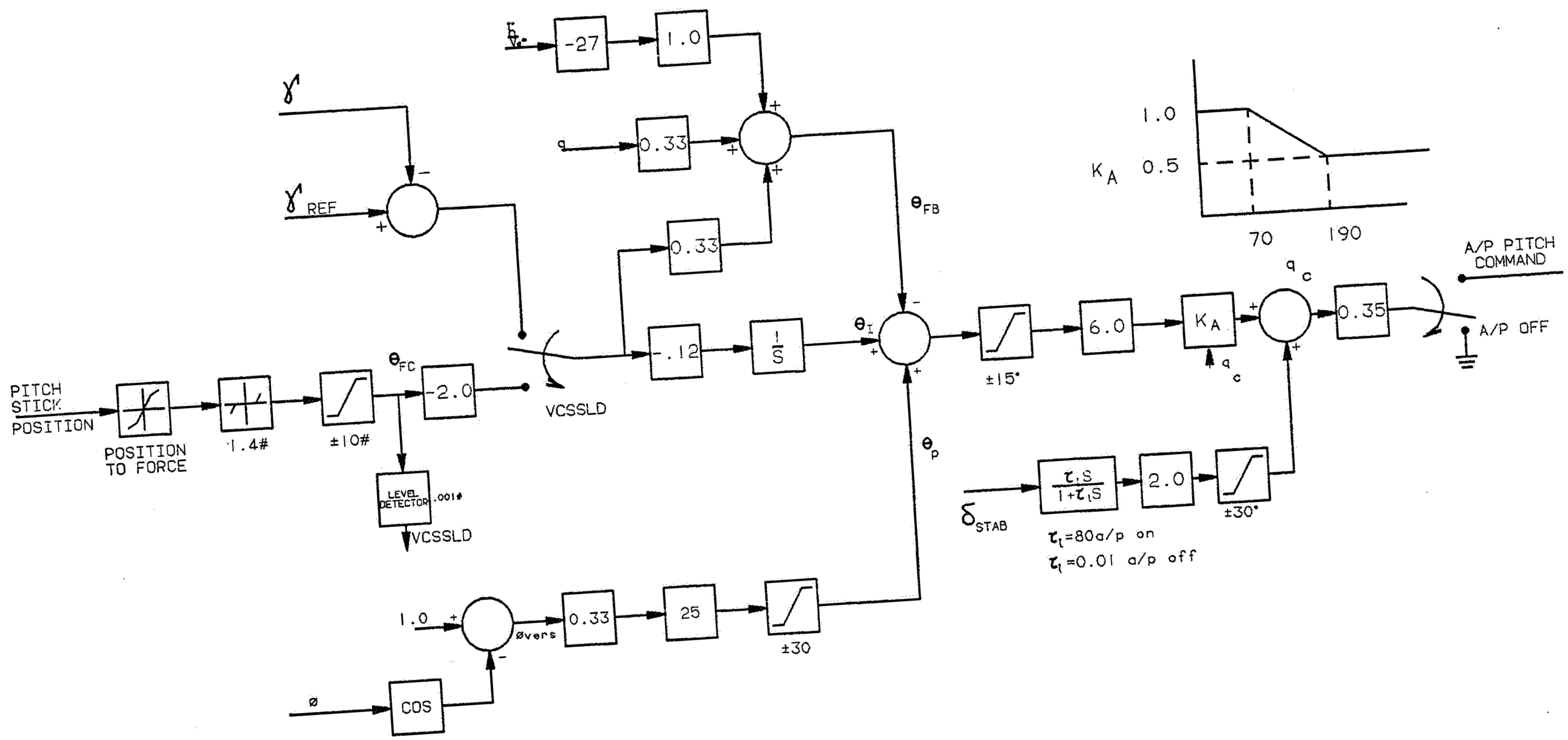


Figure A-22. Pitch Autopilot Velocity Vector Control-Stick Steering Mechanization

APPENDIX B
RESULTS OF ANOVA TEST

TABLE B-1. ANALYSIS OF VARIANCE FOR AIRSPEED DEVIATION FROM OM TO MM/MANUAL CONTROL MODE

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F TEST	PROBABILITY
FORMAT(F) ERROR					N.S.
WIND(W) ERROR					N.S.
VISIBILITY(V) ERROR					N.S.
F x W ERROR					N.S.
F x V ERROR					N.S.
W x V ERROR	2 6	28.64 14.59	14.32 2.43	5.89	0.048
F x W x V ERROR					N.S.

TABLE B-2. ANALYSIS OF VARIANCE FOR AIRSPEED DEVIATION AT D.H. MANUAL CONTROL MODE

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F TEST	PROBABILITY
FORMAT(F) ERROR					N.S.
WIND(W) ERROR					N.S.
VISIBILITY(V) ERROR					N.S.
F x W ERROR					N.S.
F x V ERROR	2 6	39.23 20.19	19.61 3.36	5.83	0.043
W x V ERROR	2 6	21.81 11.28	10.91 1.88	5.80	0.046
F x W x V ERROR					N.S.

PRECEDING PAGE BLANK NOT FILMED

PAGE 40 INTENTIONALLY BLANK

TABLE B-3. ANALYSIS OF VARIANCE FOR X-TRACK DEVIATION FROM OM TO MM/MANUAL CONTROL MODE

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F TEST	PROBABILITY
FORMAT(F) ERROR	1 3	115812.5 9941.4	115812.5 3313.8	34.95	0.0097
WIND(W) ERROR					N.S.
VISIBILITY(V) ERROR					N.S.
F x W ERROR					N.S.
F x V ERROR					N.S.
W x V ERROR					N.S.
F x W x V ERROR					N.S.

TABLE B-4. ANALYSIS OF VARIANCE FOR X-TRACK DEVIATION FROM OM TO MM/CSS CONTROL MODE

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F TEST	PROBABILITY
FORMAT(F) ERROR	1 4	140144.7 11960.1	140144.7 2990.0	46.87	0.0024
WIND(W) ERROR					N.S.
VISIBILITY(V) ERROR					N.S.
F x W ERROR					N.S.
F x V ERROR					N.S.
W x V ERROR					N.S.
F x W x V ERROR					N.S.

TABLE B-5. ANALYSIS OF VARIANCE FOR GLIDESLOPE DEVIATION AT D.H. MANUAL CONTROL MODE

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F TEST	PROBABILITY
FORMAT(F) ERROR					N.S.
WIND(W) ERROR					N.S.
VISIBILITY(V) ERROR	2 6	654.58 94.57	327.29 15.76	20.77	0.018
F x W ERROR					N.S.
F x V ERROR					N.S.
W x V ERROR					N.S.
F x W x V ERROR					N.S.

TABLE B-6. ANALYSIS OF VARIANCE FOR FLIGHT PATH ANGLE DEVIATION FROM OM TO MM/MANUAL CONTROL MODE

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F TEST	PROBABILITY
FORMAT(F) ERROR	1 3	218721.3 29913.1	218721.3 9971.0	21.94	0.018
WIND(W) ERROR					N.S.
VISIBILITY(V) ERROR					N.S.
F x W ERROR					N.S.
F x V ERROR					N.S.
W x V ERROR					N.S.
F x W x V ERROR					N.S.

TABLE B-7. ANALYSIS OF VARIANCE FOR FLIGHT PATH ANGLE DEVIATION FROM OM TO MM/CSS CONTROL MODE

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F TEST	PROBABILITY
FORMAT(F) ERROR	1 4	1.34 0.22	1.34 0.06	24.02	0.008
WIND(W) ERROR					N.S.
VISIBILITY(V) ERROR					N.S.
F x W ERROR					N.S.
F x V ERROR					N.S.
W x V ERROR					N.S.
F x W x V ERROR					N.S.

TABLE B-8. ANALYSIS OF VARIANCE FOR FLIGHT PATH ANGLE DEVIATION AT D.H. MANUAL CONTROL MODE

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F TEST	PROBABILITY
FORMAT(F) ERROR					N.S.
WIND(W) ERROR					N.S.
VISIBILITY(V) ERROR	2 6	4.80 1.00	2.40 0.17	14.44	0.030
F x W ERROR					N.S.
F x V ERROR					N.S.
W x V ERROR					N.S.
F x W x V ERROR	2 6	0.38 0.16	0.19 0.03	7.00	0.033

TABLE B-9. ANALYSIS OF VARIANCE FOR TRACK ANGLE ERROR FROM OM TO MM/MANUAL CONTROL MODE

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F TEST	PROBABILITY
FORMAT(F) ERROR	1 3	64.45 11.27	64.45 3.76	17.15	0.026
WIND(W) ERROR					N.S.
VISIBILITY(V) ERROR					N.S.
F x W ERROR					N.S.
F x V ERROR					N.S.
W x V ERROR					N.S.
F x W x V ERROR					N.S.

TABLE B-10. ANALYSIS OF VARIANCE FOR TRACK ANGLE ERROR FROM OM TO MM/CSS CONTROL MODE

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F TEST	PROBABILITY
FORMAT(F) ERROR	1 4	7.65 0.71	7.65 0.18	42.84	0.0028
WIND(W) ERROR					N.S.
VISIBILITY(V) ERROR					N.S.
F x W ERROR					N.S.
F x V ERROR					N.S.
W x V ERROR					N.S.
F x W x V ERROR					N.S.

TABLE B-11. ANALYSIS OF VARIANCE FOR LONGITUDINAL DISPERSION AT TOUCHDOWN/MANUAL CONTROL MODE

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F TEST	PROBABILITY
FORMAT(F) ERROR					N.S.
WIND(W) ERROR					N.S.
VISIBILITY(V) ERROR					N.S.
F x W ERROR					N.S.
F x V ERROR					N.S.
W x V ERROR	2 6	470187.57 170057.85	235093.79 28342.98	8.29	0.0198
F x W x V ERROR	2 6	300740.86 46532.21	150370.43 7755.37	19.39	0.0094

TABLE B-12. ANALYSIS OF VARIANCE FOR X-TRACK DEVIATION AT TOUCHDOWN/MANUAL CONTROL MODE

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F TEST	PROBABILITY
FORMAT(F) ERROR	1 3	4665.04 1080.91	4665.04 360.30	12.95	0.0368
WIND(W) ERROR	1 3	697.56 133.89	697.56 44.63	15.63	0.0298
VISIBILITY(V) ERROR					N.S.
F x W ERROR	1 3	112.77 6.35	112.77 2.12	53.29	0.0053
F x V ERROR					N.S.
W x V ERROR					N.S.
F x W x V ERROR					N.S.

TABLE B-13. ANALYSIS OF VARIANCE FOR X-TRACK DEVIATION AT TOUCH-DOWN/CSS CONTROL MODE

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F TEST	PROBABILITY
FORMAT(F) ERROR	1 4	3841.7 175.5	3841.7 43.9	87.58	0.0007
WIND(W) ERROR					N.S.
VISIBILITY(V) ERROR					N.S.
F x W ERROR					N.S.
F x V ERROR					N.S.
W x V ERROR					N.S.
F x W x V ERROR					N.S.

TABLE B-14. ANALYSIS OF VARIANCE FOR SINK RATE AT TOUCHDOWN/MANUAL CONTROL MODE

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F TEST	PROBABILITY
FORMAT(F) ERROR	1 3	921524.21 187460.99	921524.21 62487.00	14.75	0.0311
WIND(W) ERROR					N.S.
VISIBILITY(V) ERROR	2 6	714270.69 85929.20	357135.35 14321.53	24.94	0.0084
F x W ERROR	1 3	179611.93 33134.01	179611.93 11044.67	16.26	0.0274
F x V ERROR					N.S.
W x V ERROR	2 6	202079.73 57538.48	101039.86 14321.53	10.54	0.0116
F x W x V ERROR					N.S.

TABLE B-15. ANALYSIS OF VARIANCE FOR HEADING AT TOUCHDOWN/ MANUAL CONTROL MODE

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F TEST	PROBABILITY
FORMAT(F) ERROR	1 3	928.03 33.04	928.03 11.01	84.26	0.0027
WIND(W) ERROR					N.S.
VISIBILITY(V) ERROR					N.S.
F x W ERROR					N.S.
F x V ERROR					N.S.
W x V ERROR					N.S.
F x W x V ERROR					N.S.

APPENDIX C
PILOTS' QUESTIONNAIRES AND COMMENTS

PRE-EVALUATION QUESTIONNAIRE
GENERAL INFORMATION

NAME:

COMPANY:

MOST CURRENT AIRPLANE:

NEXT MOST CURRENT AIRPLANE(S):

CREW POSITION:

PHONE:

APPROXIMATE TOTAL PILOT TIME:

ARE YOU NATURALLY ______ LEFT HANDED? ______ RIGHT HANDED?
______ AMBIDEXTROUS?

DO YOU WEAR GLASSES/CONTACT LENSES WHILE FLYING? ______YES ______NO

HAVE YOU EVER HAD ANY HUD EXPERIENCE INCLUDING SIMULATORS AND STANDARD GUNSIGHTS? ______ YES ______ NO

BRIEFLY DESCRIBE PREVIOUS HUD EXPERIENCE:

HAVE YOU EVER HAD ANY EXPERIENCE, INCLUDING SIMULATORS, IN FLYING WITH CRTs AS THE PRIMARY FLIGHT INSTRUMENTS? ______ YES ______ NO

BRIEFLY DESCRIBE PREVIOUS EXPERIENCE:

HAVE YOU EVER HAD ANY EXPERIENCE, INCLUDING SIMULATORS, IN FLYING WITH SIDE-STICK CONTROLLERS? ______ YES ______ NO

BRIEFLY DESCRIBE PREVIOUS EXPERIENCE:

POST EVALUATION QUESTIONNAIRE
HUD VS HDD
<u>Flying Pilot Evaluation Sheet</u>

The following evaluation worksheet will provide you with the opportunity to perform a systematic evaluation of display and control methods you have just been using. While you are filling out the questionnaire, feel free to ask the project personnel any questions you wish to clarify your evaluation. These questions are directed toward conventional ILS approaches under various conditions of visibility and weather.

The "comment" sections have been provided to enable you to clarify and expand on system ratings. Please use them freely. Please explain all negative ratings that you give so that improvements can be made.

NOTE: For the following questionnaire answers from GROUP 1, refer to the 5 subject pilots who flew using the manual flight control mode and had flight director guidance on both head-down and head-up primary flight displays. GROUP 2 refers to the 5 subject pilots who flew in the CSS mode and had no flight director guidance.

Format Information Interpretability

Please use the following scale to rate the information interpretability of the display formats (i.e., the location and organization of the information) on the Head-Up Display and the Head-Down Display.

1. Excellent, all information is well-organized and easy to interpret.
2. Good, most information is organized and easy to interpret.
3. Fair, the information interpretability is acceptable.
4. Poor, some information is difficult to interpret.
5. Bad, the information in the format is impossible to interpret.

1a. Please rate the interpretability of the formats provided on the Head-Up display. ____________________

Comments:

GROUP 1: 2 *
GROUP 2: 1 *

1b. Is all required information for the completion of the flying task present? ______ YES ______ NO

Comments:

GROUP 1: YES
GROUP 2: YES

*NOTE: MEDIAN RATING SCORES ARE SHOWN

2a. Please rate the interpretability of the formats provided on the Head-Down Display. ____________________

Comments:

GROUP 1: 2 *
GROUP 2: 2 *

2b. Is all required information for the completion of the flying task present? ______YES ______ NO

Comments:

GROUP 1: YES
GROUP 2: YES

3. Which is your preferred method of displaying this information for the profile that you flew?

______ HUD ______ HDD ______ NO PREFERENCE

Comments:

GROUP 1: HUD
GROUP 2: HUD

*NOTE: MEDIAN RATING SCORES ARE SHOWN

4. Please rate the way that the aircraft flew using the steering mode that you used.

Best Case Wind/Visibility	Worst Case Wind/Visibility
_____ 1 Excellent, very easy to fly	_____ 1 Excellent, very easy to fly
_____ 2 Good	_____ 2 Good
_____ 3 Fair	_____ 3 Fair
_____ 4 Poor	_____ 4 Poor
_____ 5 Bad, very difficult to fly	_____ 5 Bad, very difficult to fly

Comments:

GROUP 1: 1 *	GROUP 1: 2 *
GROUP 2: 2 *	GROUP 2: 1 *

Workload

Please rate your workload under the worst case visibility and wind conditions while flying under the following conditions:

5.

Head-Up Display	Head-Down Display
_____ 1 Low	_____ 1 Low
_____ 2 Moderately Low	_____ 2 Moderately Low
_____ 3 Moderate	_____ 3 Moderate
_____ 4 Moderately High	_____ 4 Moderately High
_____ 5 High	_____ 5 High

Comments:

GROUP 1: 2 *	GROUP 1: 3 *
GROUP 2: 2 *	GROUP 2: 3 *

* NOTE: MEDIAN RATING SCORES ARE SHOWN

6. WHAT IS YOUR OPINION OF THE USE OF A HUD FOR CONVENTIONAL INSTRUMENT APPROACHES?

7. WHAT IS YOUR OPINION OF THE USE OF A SIDE-STICK CONTROLLER VERSUS A CONTROL WHEEL IN COMMERCIAL TRANSPORT AIRCRAFT?

8. WHAT IS YOUR OPINION OF THE USE OF A FLIGHT PATH FORMAT VERSUS AN ATTITUDE FORMAT ON THE HEAD DOWN DISPLAY?

9. DO YOU FEEL YOU WERE FULLY AND ADEQUATELY TRAINED TO CONDUCT THIS EVALUATION? IF NOT, PLEASE LIST AND DISCUSS DEFICIENCIES AND DISCREPANCIES. ALSO, LIST ANY SUGGESTIONS YOU MAY HAVE TO IMPROVE THE GROUND AND/OR SIMULATOR TRAINING.

10. WHAT IS YOUR OPINION OF THE WAY THE EVALUATION WAS CONDUCTED? PLEASE LIST ANY SUGGESTIONS FOR IMPROVEMENT.

11. WHAT IS YOUR OPINION OF THE VALUE OF THE STUDY TO THE AVIATION INDUSTRY?

COMMENTS ON POST EVALUATION QUESTIONNAIRE

1a. Please rate the interpretability of the formats provided on the Head-Up Display.

Display of information on the HUD unit was exceptionally good. Better warning of approach to localizer centerline or glide path intercept would be helpful. The one or two flashes of localizer bar were OK for the test but, with the distractions of real world flying, would be easily missed. A change of color or, alternatively, earlier continuous flashing would have been helpful.

Generally, HUD is the most valuable asset for both pilot and copilot to use during the low visibility approach. It should be standard for both pilots on transport aircraft. Overall, this HUD presented too much information in too small an area. Some of the data shown did not follow similar logic on other HUD's.

Considerable amount of information requires fast crosscheck to gather data during first runs -- quickly adapt to where to look when.

All information is easy to read and close enough to the central display that it is easy to access information.

At times, clarity of the symbology was difficult -- it was a matter of adjusting brightness with the surrounding lighting.

Generally good. I would like to see the "big Plus" information a little larger. Also, the raw data GS horizontal bar needs to be wider in my opinion so that it will not be mistaken for other horizontal symbols. The HUD flight director is a little slow to lead you in. You have to get lined up situationally, then follow flight director for fine corrections. I like the HUD.

Believe the near end of LOC/GS should be connected to form a big plus. Do not believe the F/D (Steering cue) is necessary for any reason, including manual control. I like (very much) the symbolic runway (edge lines) being in view as much as possible. Found your format easier to fly than standard FDI format.

1b. Is all required information for the completion of the flying task present?

The HUD is outstanding. Please sell it to the Air Force for Category III Fighter operations! Page 15 of the HUD pilot guide states that the symbolic runway is not displayed until 300 ft. I believe the simulator displayed to runway well before 300 feet. This display should be shown at the earliest possible time since it is very helpful.

Too much data.

I would like something to gauge rate of movement of CDI prior to initial movement. Otherwise, format acceptable -- is acceptable as is but, this request is "wish list."

Very good. A digital display of heading would be helpful.

Yes, I think so.

With the exception of intercept. I think this is still too difficult and easy to confuse. If intercept is made head down (which is very easy to do using map) then transition to HUD after intercept is made, everything works much easier.

2a. Please rate the interpretability of the formats provided on the Head-Down Display.

The Flight Director steering dot (ball) is too massive and covers up the informational focal point of the Head-Down display. At distances inside the OM, the Ball does not allow the symbolic runway movement relative to the flight path to be interpreted. This decreases the precision of flight path control. A hollow circle instead of the solid ball would remedy this problem.

Too much data -- HUD and HDD should be more closely aligned for symbology and interpretation of data.

It is my feeling that there might be too much symbology available, i.e., the "predictor." However, this seemed to improve as I gained experience. It may be a matter of learning to <u>use</u> everything available.

Again, workload very high initially due to adjusting to new format, but system is excellent.

Very good and easy to read.

As in any new system, once I got used to the system, it became easier.

Excellent. I wish you could see the symbolic runway through the flight director orange ball. Perhaps it could have a hollow center. I would like to see digital EPR for each engine displayed below the air speed dial on left side of CRT. Add digital EPR indications.

I like the big wedges. I like the center circle, better than the FDI "duck." I like the symbolic runway and find it very flyable. I would like to have the near end of the LOC/GS in view in center of display instead of edge and bottom tapes. I had no trouble with control with the scale of the display (being smaller than that of HUD).

2b. Is all required information for the completion of the flying task present?

Explained in 2a, additionally, the airspeed and altimeter displays need to be enlarged. The altimeter especially was ignored to too great a degree during my flight test which could create altitude excursion problems in the real world.

Too much data.

On HDD a bank angle indices on the bottom of the ADI would help. I found as I tensed and relaxed I tended to induce small bank angles that were not readily noticeable at first.

Yes.
Yes.
Yes.
Yes.
Yes.
Yes.
Yes.
Yes.

3. Which is your preferred method of displaying this information for the profile that you flew?

The HUD is so nice that it is tempting to ask, "Who could ask for anything more?" However, could reliance by aircrews exclusively on HUD information create a dangerous situation? Unfortunately, I do not feel qualified to answer this question at the present time.

HUD is <u>far superior</u> to HDD in time critical decision making at <u>low</u> altitudes and <u>low</u> visibilities. It (HUD) is needed for <u>both pilot and copilot</u> when approaches and landings are to be made at RVR less than 700-1000.

This was my first time to use HUD. With experience I think I would prefer it. There was a tendency on my part to find the symbolic runway interfered on visual approaches.

HUD allows extremely fine adjustments to flight path, heading and pitch -- angles smaller than I think are discernable with HDD. For CAT II, I would prefer HUD. Above CAT II, no preference.

Easier to transition to landing and the runway symbology on the HUD. Allows you to know what the runway environment is going to look like.

HUD was much more precise. The pilot is almost forced to avoid overcontrolling. In both methods, I felt there was a lot of redundancy. I found it impossible to include everything in the scan and I would focus on a few symbols. I would have no complaint if extra information is displayed for no other reason than system back-up.

Eliminates the need for a transition which occurs at the worst possible time.

HUD for approaches. HDD for other regimes of flight.

For approach and landing, including roll-out, the HUD is the better way. With HUD the transition from real world cues to symbology to real world takes place quickly and is constantly available throughout landing. With HDD, when transition from HDD to outside is complete, time does not allow cross reference.

I might prefer a good HDD format for enroute or anytime ground reference is not a factor.

4. Please rate the way that the aircraft flew using the steering mode that you used.

   Wind/visibility conditions made little difference in the air. The simulator overcontrolled in pitch in all modes. Roll control seemed neutral to slight undercontrol. However, on final, slight roll input caused immediate corresponding left/right change in flight path position. This would be possible only with Aileron-Rudder interconnect (ARI) programmed for more the neutral proverse rudder input.

   The flight path symbol made it easy to fly.

   When looking outside (best case), CSS required constant corrections when the situation did not necessarily call for it; on the other hand, when inside (worse case), constant minute corrections are required.

   Very responsive with side stick controller.

   This is one of the better simulators that I have flown. If the real A/C flew this well, it would be a nice one.

5. Please rate your workload under the worst case visibility and wind conditions while flying with the head-up and head-down displays.

   HUD workload came mostly from tendency to overcontrol the simulator. This is a standard simulator problem. HDD workload came mostly from interpretation of information with small airspeed and altimeter presentations and large steering dot obscuring the center of the ADI ball.

   HUD is easier than HDD.

   Again, there is a lot of information, so much so that I seldom looked at the engine instruments. A fast scan and practice makes these systems far superior to standard electro-mechanical.

   The flight path symbol made it easy to fly under any wind conditions.

   HDD required a much greater scan pattern.

   This is for the approach phase only. I believe it is a great improvement over the conventional format we now use.

6. What is your opinion of the use of a HUD for conventional instrument approaches?

   Everybody ought to have one. Especially Air Force Fighters.

   Outstanding! It's easier and more accurate. It's a superlative aid to executing a visual approach, especially when the runway has no published instrument approach.

Reduces difficulty in shooting the approach. Easy to transition to and from visual and instruments. On approach where the weather goes from good to bad it would be an easy transition back to instruments.

I like it!

It would be of considerable use.

Excellent way to have all the necessary information available while still being able to see outside with no distractions.

All for it!

I think it is excellent. The HUD would be very valuable during other than instrument conditions, for black hole night approaches or at airports with marginal or non-existent approach aids.

I have a high opinion of the HUD. It should be used all the time in VMC and IMC WX.

A vast improvement.

7. What is your opinion of the use of a side-stick controller versus a control wheel in commercial transport aircraft?

The right way vs a dinosaur.

Outstanding! All new aircraft should have a stick controller. Please consider putting the stick back between the pilot's legs. It can be short enough to use the keyboard and touch screen directly in front of the pilot and long enough to have the hands and arms in a natural position.

In my opinion it is the way to go! If the reliability and or back-up for loss of electrical can be worked out, it's a better way to fly today's aircraft. Once you are used to it, its easier to fly with light control inputs and with hands always on the throttle.

It certainly opens up a wider viewing area. With FBW controls, control wheel not necessarily needed.

Provides for a much more relaxed body position.

I like the idea of side-stick. It would depend on how sensitive inputs from the controller to aircraft performance would be in the simulator vs the "real" airplane. "Real" aircraft historically seem steadier.

It's excellent -- removes obstacles from pilot's view of instrumentation.

I like the control wheel better. I do see the versatility of the side-stick controller and acknowledge the fact that the forward panel is wide open with that arrangement.

Not much different. I don't think it will appreciably improve performance. Its major failing is that the distance of movement allowable will prevent any type of manual reversion.

8. What is your opinion of the use of a flight path format versus an attitude format on the head down display?

This is a much quicker input of what the aircraft is doing. Except for the tendency to overcontrol, flight path information is superior to attitude information.

Outstanding! It gives the pilot more accurate and useful information.

The flight path is good once you get used to it. It is a better way to display the information.

I normally fly an airplane using attitude format so the flight path format is new. With experience I think I might prefer the flight path format.

A vast improvement, I can't say enough about this one.

Give me flight path <u>anytime</u>. It readily simplifies the information and <u>reduces</u> pilot workload -- does away with having to use 8^{o} pitch for 130 knots, 4^{o} pitch for 210 knots, 1^{o} pitch for 250 knots, etc.

The flight path gave me a better idea of what was going to be the outcome of control movments.

I like it -- it eliminates a lot of overcontrolling.

I'm a big fan of the flight path due to its ability to provide excellent alignment cues and trend information.

The flight path is far, far superior to the attitude situation.

9. Do you feel you were fully and adequately trained to conduct this evaluation? If not, please list and discuss deficiencies and discrepancies. Also, list any suggestions you may have to improve the ground and/or simulator training.

Just like moving into a new house, it takes about one year to feel comfortable with a new airplane and the associated instrumentation. It is beyond the scope of your test to determine how this equipment could be operated by an experienced crew. In order to judge how new crewmembers can perform, the training is bare minimum to almost enough.

Yes.

Yes. A hand out labeling and explaining the function and use of the HUD and HDD display would be helpful. (before day 1).

Yes.

Yes, not only did George conduct an excellent briefing, but he also is an excellent instructor. His relaxed attitude and manner contributed significantly to making this exercise very enlightening and enjoyable.

Yes.

Very good. Its hard to apply reading material to the actual presentation. Its best to learn by doing.

For what was required -- yes.

I felt the training was excellent with adequate warm-up time for practice approaches.

Yes, I was adequately trained.

10. What is your opinion of the way the evaluation was conducted? Please list any suggestions for improvment.

One more period with mixed HUD and HDD flying would have given more consistent results. The conclusions would probably be the same, however. The HUD is superior if the crew is limited to hand flying the aircraft. Hand flying a CAT II or III approach is generally not allowed for commerical operations, however.

Excellent! I just wish I could have flown the simulator for more periods and other environments of flight.

Always start out with the easier approaches from each seat (i.e., good weather and no wind) and use the same order when you switch seats. The arm rest for the throttle arm needs to be wider for more comfort. More room is needed underneath for the outside knee.

Good.

I played with the system for one approach without control wheel steering and found the workload higher. It was a chance to compare my profile with what the others were flying. The only suggestions would be to tell pilots all approaches are to CAT III minimum, but delete telling them actual conditions.

Very relaxed and informal.

No complaints -- I would guard against `diminishing returns,' i.e., after so many approaches, performance declines.

Excellent, friendly, low key yet very professional.

Can't think of any improvements. I'm impressed by the way the whole program was conducted.

Everything appeared organized and relaxed. I'm not sure I can think of a way to improve.

11. What is your opinion of the value of the study to the aviation industry?

The transport industry is presently moving toward more automated systems for low visibility approaches. The military, on the otherhand, is moving nowhere in launch and recovery of aircraft in low visibility conditions. Perhaps the military is a better target for the HUD type advanced systems.

This type of data development is critical to aviation if we are going to operate aircraft down to 0' RVR.

It should be valuable as to the final design of the side-stick controller and as to which seat the captain should sit in. This study shows the great adaptability and feasibility of the HUD and flight path displays for commercial use.

I think the study will greatly benefit the aviation. I like the idea of using pilots from "outside" to evaluate.

I am eager to see these formats in the cockpit. They represent a quantum leap over present B-727 instruments.

By seeing the actual differences in the two display formats, I believe you can greatly appreciate the HUD.

Highly necessary -- anything to help improve efficiency and, ultimately, safety.

Its nice to come away from something feeling that you've made a contribution to your profession. I feel that this is an excellent program and should be pursued. We really need these changes out on the line where they could be invaluable during low visibility or at marginal airports.

Most important. I wish more pilots could participate in such a test so that they too would become advocates of HUD and flight path vector displays.

T. B. D. - To Be Determined.

REFERENCES

Lockheed-Georgia Company, "ACFS Simulator Software Requirements - Automatic Flight Control System," Report ACFS-C358-019 - Revision B, 1983.

BIBLIOGRAPHY

Boucek, G. P., T. A. Pfaff, and W. D. Smith, "The Use of Holographic Head-Up Display of Flight Path Symbology in Varying Weather Conditions. " SAE Technical Paper 831445, October 1983.

Bray, Richard S., "A Head-Up Display Format for Application Transport Aircraft Approach & Landing." NASA TM-81199, July 1980.

Bray, Richard S., & Barry C. Scott, "A Head-Up Display for Low Visibility Approach and Landing." NASA-Ames Research Center, AIAA 81-0130, January 1981.

Bray, Richard S. & Barry C. Scott, "A Head-Up Display Format for Transport Aircraft Approach & Landing." 1980 Aircraft Safety & Operating Problems. NASA CP-2170, Part 1, pp. 165-196, November 1980.

Desmond, John P., "A Holographic Head-Up Display for Low Visibility Landing Operations," SAE Technical Paper 831451, October 1983.

Lauber, John K., et al., "An Operational Evaluation of Head-Up Displays for Civil Transport Operations - NASA/FAA Phase III Final Report." NASA TP-1815, August 1982.

Lauber, John K., Richard S. Bray, and Barry C. Scott, "An Evaluation of Head-Up Displays in Civil Transport Operations." 1980 Aircraft Safety & Operating Problems. NASA CP-2170, Part 1, pp. 197-200, November 1980.

Midwest Systems Research, Inc., "Head-Up Display Symbology & Mechanization Study," Contract No. F33615-83-C-5125, March 1984.

Morello, Samuel A., Charles E. Knox, & George G. Steinmetz, "Flight-Test Evaluation of Two Electronic Display Formats for Approach to Landing Under Instrument Conditions," NASA TP-1085, 1977.

Naish, J. M., "A Review of Some Head-Up Display Formats," NASA TP-1499, October 1979.

Newman, Richard L. and Thomas G. Foxworth, "A Review of Head-Up Display Specifications," Crew Systems Consultants Report TR-84-04, April 1984.

Sexton, George A., "Crew Systems and Flight Station Concepts for a 1995 Transport Aircraft," NASA CR-166068, April 1983.

Steinmetz, George G., "Simulation Development & Evaluation of an Improved Longitudinal Velocity-Vector Control-Wheel Steering Mode & Electronic Display Format," NASA TP-1664, August 1980.

Steinmetz, George G., Samuel A. Morello, Charles E. Knox, & L. H. Person, Jr., "A Piloted-Simulation Evaluation of Two Electronic Display Formats for Approach & Landing," NASA TN D-8183, 1976.

TABLE 1. TOLERANCES FOR SELECTED PARAMETERS AT DECISION HEIGHT AND TOUCHDOWN

DECISION HEIGHT PARAMETER	TOLERANCE
AIRSPEED DEVIATION	± 5 KTS
X-TRACK DEVIATION	± 50 FEET
GLIDESLOPE DEVIATION	± 20 FEET
FLIGHT PATH ANGLE DEVIAITION	± 1°
TOUCHDOWN PARAMETER	**TOLERANCE**
LONGITUDINAL DISPERSION	-400 FEET +800 FEET
X-TRACK DEVIATION	± 50 FEET
SINK RATE	400 FEET/MINUTE
HEADING	± 3°

PRECEDING PAGE BLANK NOT FILMED

PAGE 68 INTENTIONALLY BLANK

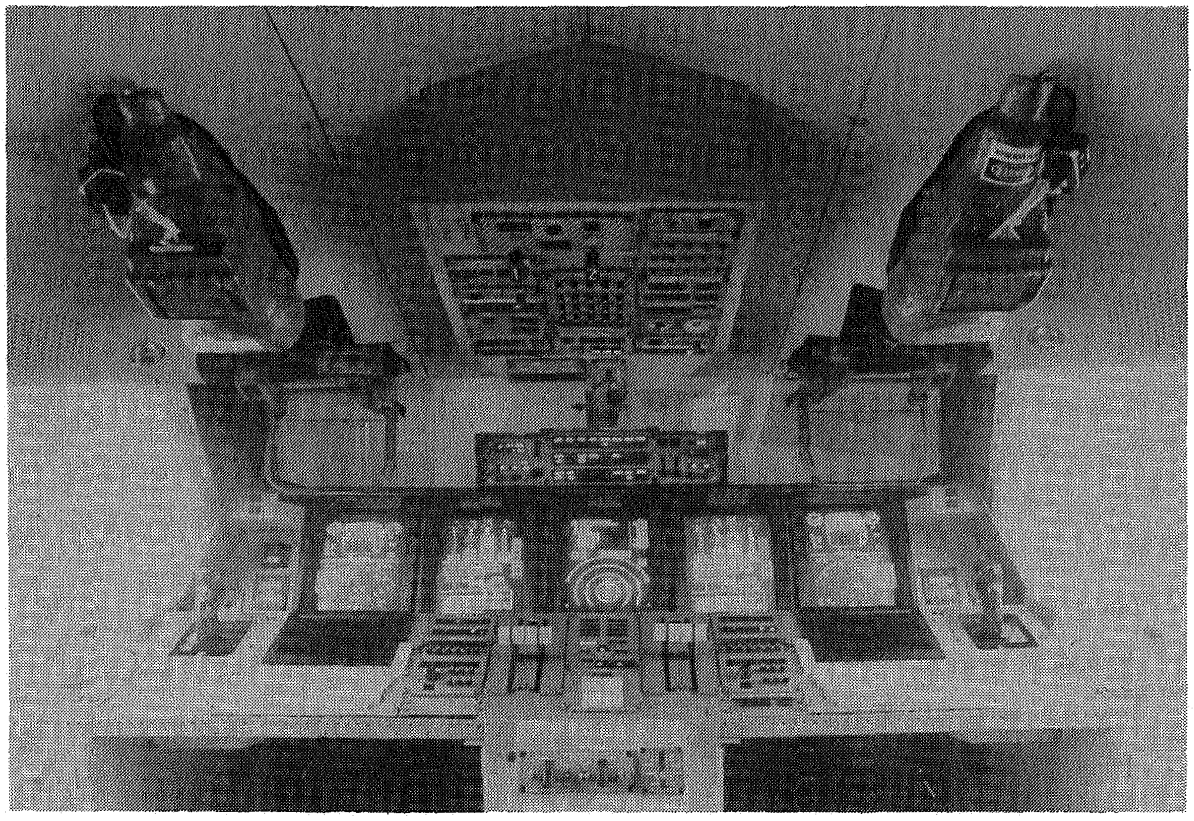


Figure 1. Pilot's Desk Flight Station in Research Simulators

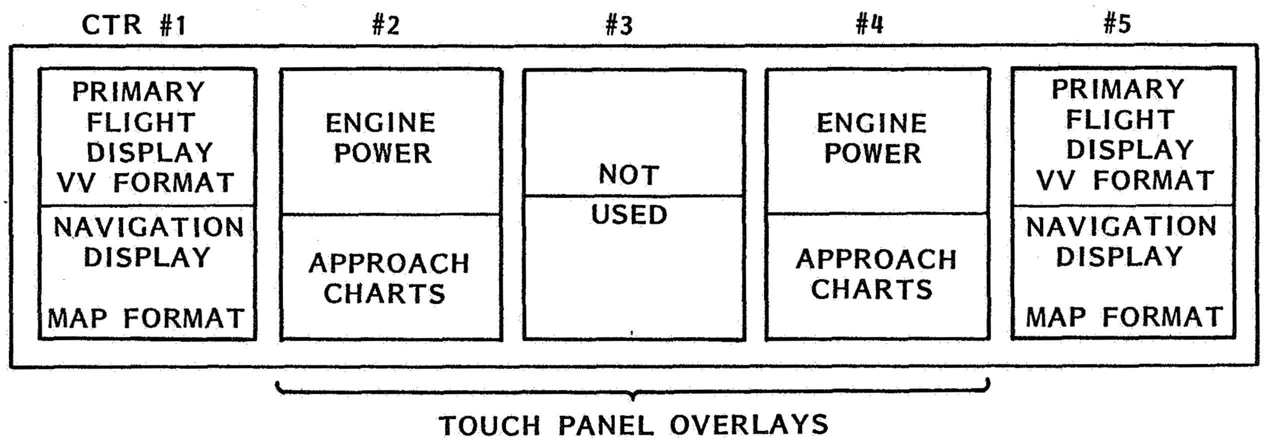


Figure 2. Head-Down Display Configuration for Study

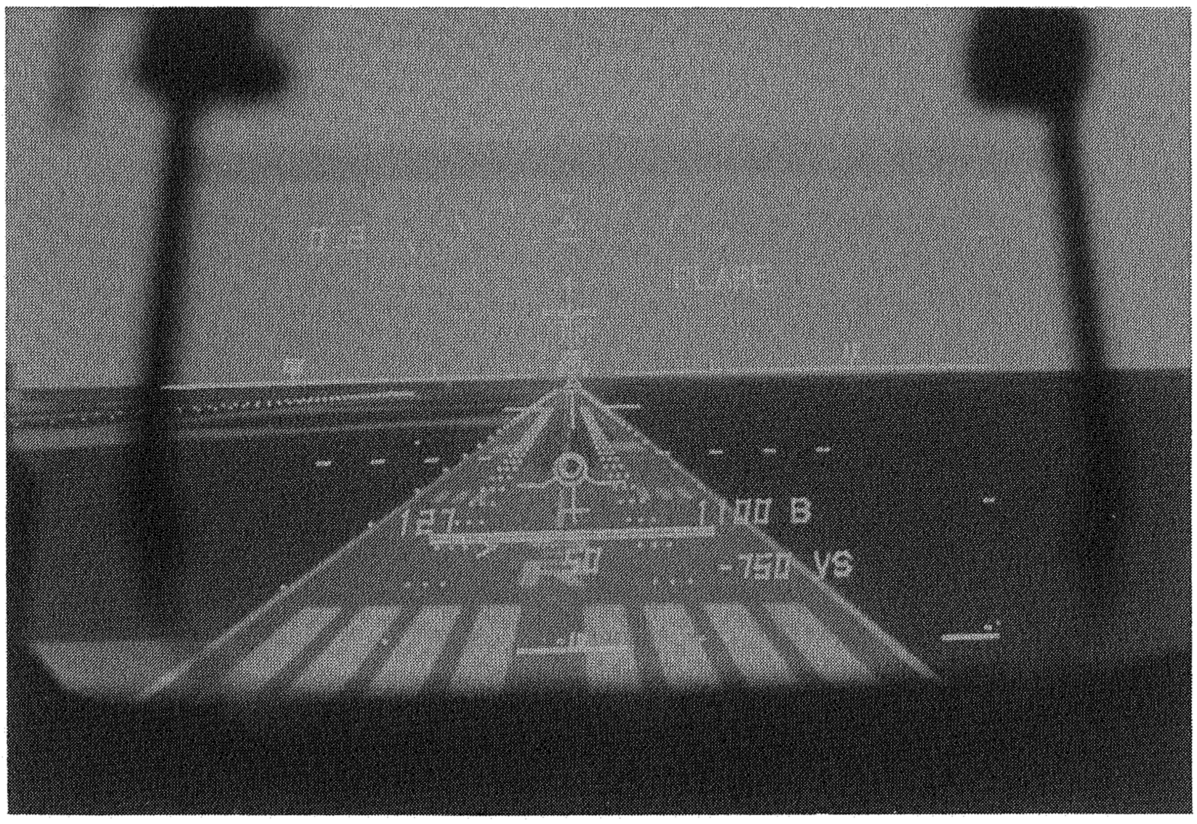


Figure 3. Out-of-the-Window View of the Runway with Head-Up Display Symbology

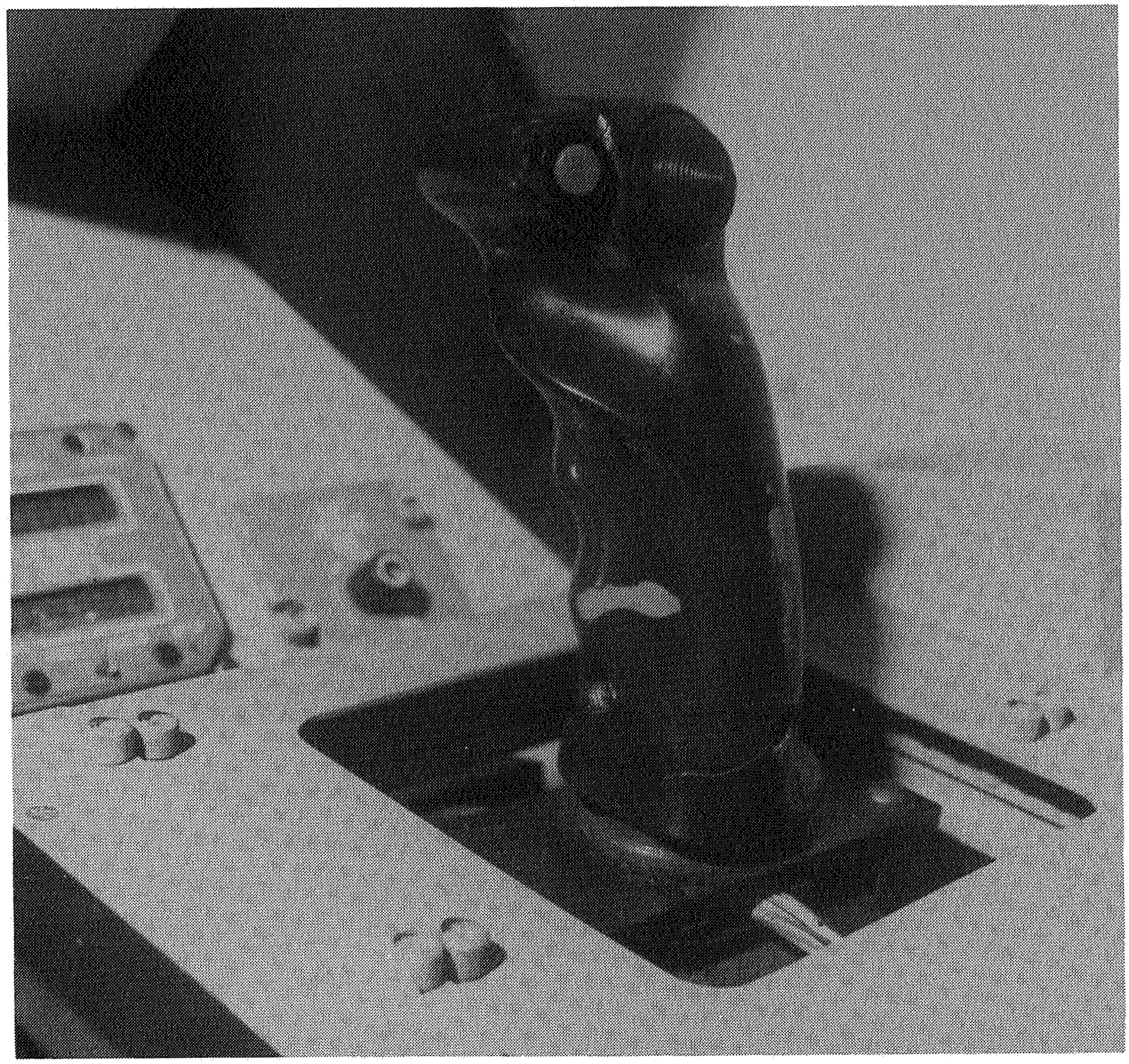


Figure 4. Pilots Fly the Aircraft with Side-Stick Controllers Containing Trim Switches

ORIGINAL PAGE IS
OF POOR QUALITY

ORIGINAL PAGE IS
OF POOR QUALITY

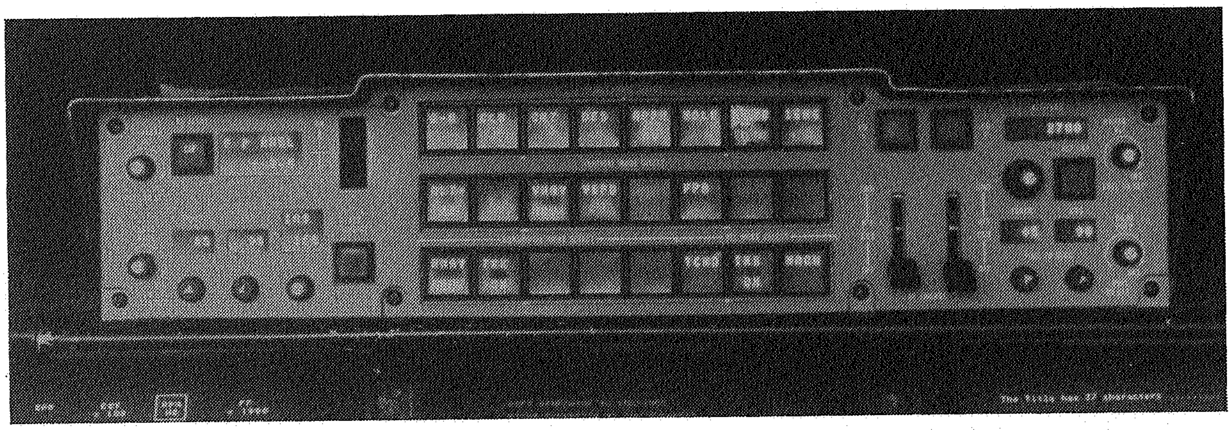


Figure 5. Guidance and Control Panel Used for Selection of Flight Phase and Mode Selection

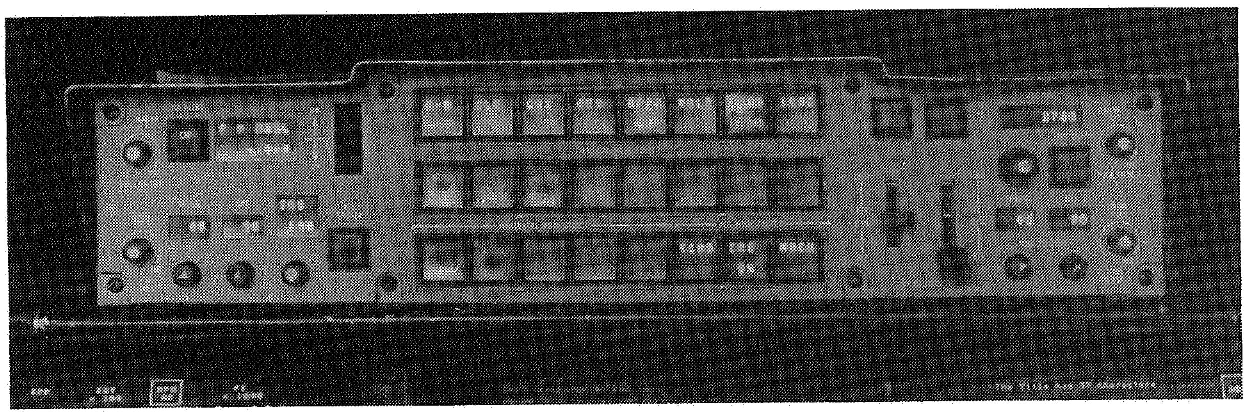


Figure 6. Guidance and Control Panel Set for Control-Stick Steering Flight

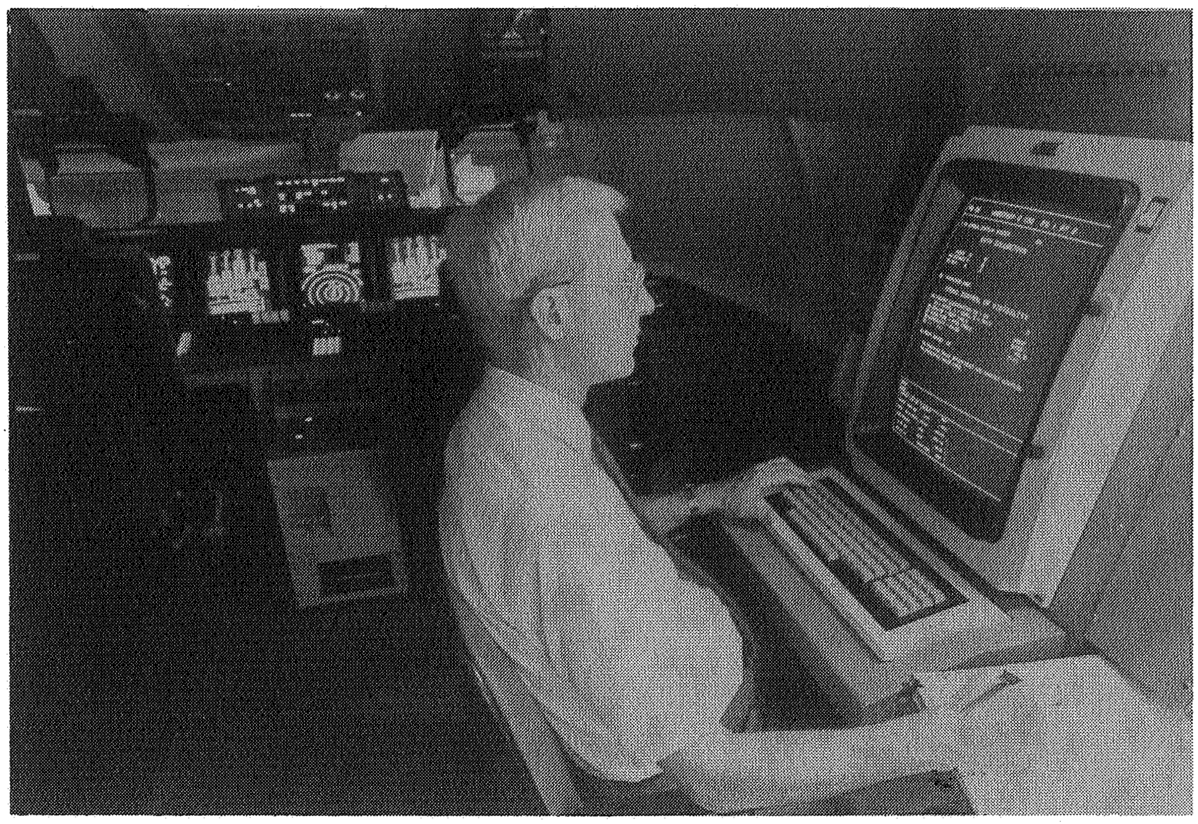


Figure 7. Data Trials are Controlled Through the Experimenter/Observer Station

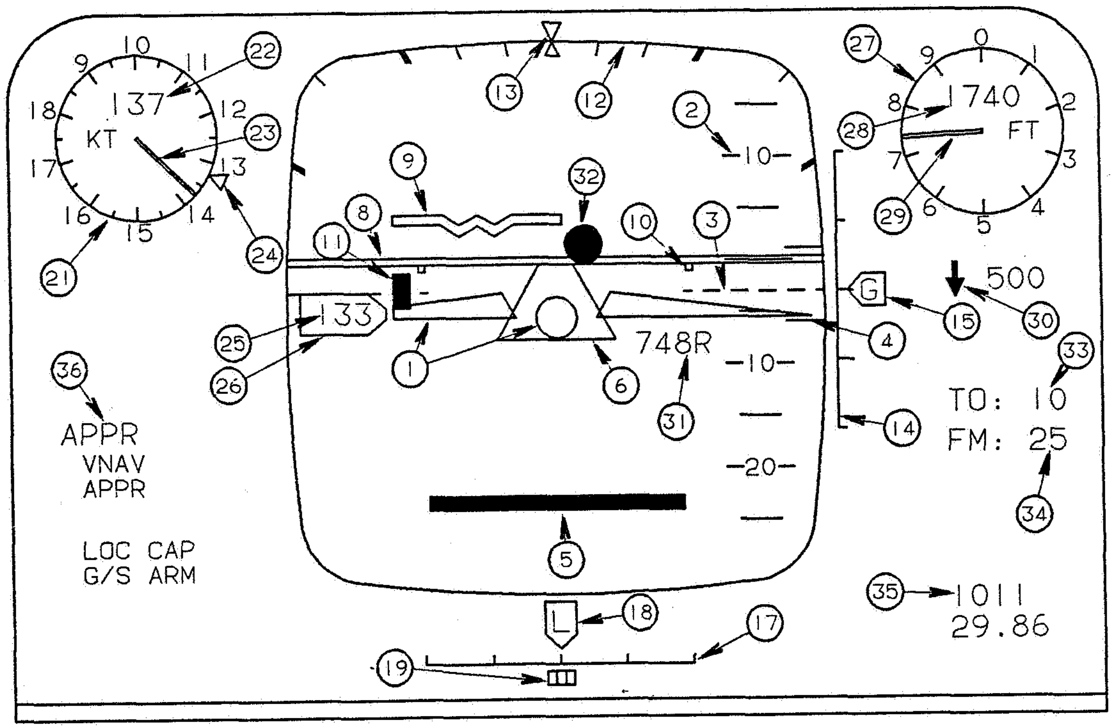


Figure 8. Head-Down Flight Path Primary Flight Display Symbology

#	SYMBOL	COLOR	LOCATION AND MOVEMENT
1	Aircraft Flight Path Angle Wedges	White	Always stationary. Shows aircraft flight path (FPA) in reference to FPA scale and commanded FPA. Represents velocity vector of the aircraft with components in both the horizontal and vertical planes.
2	Flight Path Angle & Pitch Scale	White	Moves vertically opposite aircraft FPA wedge (1). The right edge of the FPA wedge indicates FPA on this scale. The aircraft symbol (9), indicates pitch on this scale.
3	Reference Flight Path Angle	Amber	Dashed line through FPA scale to show referenced FPA when a value is dialed in on the guidance control panel (GCP). Limit position on screen to $\pm 20^{\circ}$ from center.
4	Flight Path Angle Bracket	White	Shows $\pm 3^{\circ}$ from referenced FPA (3).
5	Flare Bar	Magenta	Bar is parallel to horizon and always centered laterally, but moves up toward the horizon line in proportion to the radar altitude as the airplane approaches the ground.

#	SYMBOL	COLOR	LOCATION AND MOVEMENT
6	Perspective Runway	Green	Overlays real-world runway and comes into view at approximately 3 nm away. Approach is made by keeping circle of aircraft symbol over touchdown point on runway.
8	Horizon Line	White	This symbol represents an artificial horizon (pitch attitude 0 degrees). The pitch/flight path angle scale (2) is tied to the horizon (8) to form one unit. the unit moves in the vertical so that flight path angle can be read at the point where the scale (2) meets the flight path angle wedges (1). Pitch can be read where the scale meets the aircraft reference symbol (9). The horizon is also rotated to show roll.
9	Aircraft	White	Shows aircraft pitch in reference to pitch scale, and roll in reference to horizon. Moves laterally to show drift correction in relation to aim point. Drift is the difference between aircraft track and aircraft heading. Pitch is pitch angle, theta.
10	Cardinal Track Markers	Green	Move laterally across horizon line to show each 10^{o} of track change. This is based on aircraft track angle, not heading.
11	IAS Deviation Bar	Amber (Filled)	Bar grows down from bottom of left wing of the aircraft symbol to show deviation below commanded indicated airspeed (IAS). It grows up from top to the left wing to show deviation above commanded IAS. The length of the bar changes at a rate of 1/2 inch per 10 KIAS deviation to a maximum of 1.9 inches (38 KIAS). It disappears completely with plus or minus 2 knots deviation.
12	Roll Scale	White	Centered above pitch scale. Rotates with the horizon line as the aircraft banks. Scale markers are at 10, 20, 30, 45, and 60 degrees. Angle of bank is shown under the roll index (13). Max angle of bank is 90^{o}. Movement is based on roll angle, phi.
13	Roll Index	White	Centered on outside of ball at the top. Always stationary. Shows angle of bank by pointing to the roll scale (12).

#	SYMBOL	COLOR	LOCATION AND MOVEMENT
14	Vertical Deviation Scale	White	Centered along right-hand side of ball in fixed position. Full scale is ± 500 feet for fight management computer (FMC) management computer (FMC) non-precision navigation and ± 0.7 degrees on ILS glideslope.
15	Vertical Deviation Pointer	Box-White Letter - Green or Amber	Moves along the vertical scale to indicate vertical deviation from flight plan. In ILS mode, pointer is shown only when localizer and gideslope are valid. Full scale is plus or minus 0.7° vertical deviation from glide slope. Pointer stops moving when deviation reaches full scale at which time the letter "G" changes from green to amber. It is a "fly-to"symbol. The letter "V" indicates Vertical navigation validity, and the letter "G" indicates glideslope validity.
17	Horizontal Deviation and & Track Angle Error Scale	White	Centered below ball in a fixed position. Used with horizontal deviation pointer above track angle error pointer below.
18	Horizontal Deviation Pointer	Box-White Letter - Green or Amber	Moves along the top of the scale. Indicates amount of lateral deviation from flight plan. It is a "fly-to" indicator similar to the CDI on an HSI. Full scale is plus or minus 3 nm while enroute or 1 nm on approach when aircraft is outside the final approach fix (FAF). When inside the FAF and within 2.5° of the localizer, the horizontal deviation full scale changes to 2.5°. Pointer stops moving when deviation reaches full scale at which time the letters change from green to amber. The letter "H" indicates, horizontal navigation validity, and the letter "L" indicates localizer validity.
19	Track Angle Error Pointer	Amber	Moves along the bottom of the scale to indicate TAE of aircraft track from desired course. Full scale is plus or minus 20°. Pointer stops moving at max deviation. When aircraft track and desired course are parallel, regardless of whether it is on desired course, TAE pointer is centered. It moves away from center in the opposite direction to which the aircraft track (nose of aircraft with no wind) moves from a position parallel to desired course.

#	SYMBOL	COLOR	LOCATION AND MOVEMENT
21	IAS Scale	White	Occupies fixed position in upper left corner of display. Scaled in 5 knot increments from actual aircraft IAS (shown in digits and under the tip of the pointer). It shows a range of plus or minus 50 knots from actual IAS. The numbers on the scale change at a point 180° from the tip of the pointer. The total range of airspeed is from 0 to 999 knots.
22	Airspeed Digital Readout & Label	White	Upper center of airspeed circle. Digits show the IAS of the aircraft and agree with the position of the pointer on the airspeed scale. When acceleration or deceleration is so rapid that the last digit changes too fast to be readable, only the even numbers are displayed. If it gets too fast again, only the 0s and 5s are displayed. Total range is from 0 to 999 knots.
23	Airspeed Pointer	White	Extends from center to edge of airspeed scale, pivoting around the center. Tip points to the actual IAS on the scale.
24	Commanded Airspeed Index	Amber	Moves around the circumference of the airspeed scale and points to the commanded indicated airspeed. Difference between the index and the airspeed pointer is shown on IAS Deviation bar. The index disappears from view when the commanded value is more than 50 knots from the indicated. This symbol is not shown in takeoff mode.
25	Commanded Airspeed Digital Readout	White	Inside potential FPA box. Digital readout of commanded/reference airspeed which is set via the GCP.
26	Potential Flight Path Angle Box	White	Move vertically to show potential FPA for present thrust and drag configuration. The symbol is translated up or down from the FPA wedge through the valve of aircraft acceleration along the X-axis. Specifically, if the acceleration along the X-axis is in ft/s^2, the translation factor used is: $ft/s^2 * \frac{8\ degs}{10\ ft/sec^2} \frac{6\ inches\ on\ screen}{40\ degrees\ on\ screen} = 0.12$ (Normally use 40° = 3 inches but we expand the scale for this symbol.) The symbol is limited to ± 1.125 inches of travel from the wedge.

#	SYMBOL	COLOR	LOCATION AND MOVEMENT
27	Barometric Altitude Scale	White	Occupies fixed position in upper right corner of the display. Scaled in 100 foot increments indicated by single digits from 0 to 9.
28	Barometric Altitude Digital Readout	White	Digits show the barometric altitude of the aircraft. The last three digits reflect the position of the tip of the pointer. The total range necessary is from 0 to 50,000 feet. The number is rounded to the nearest 10 feet.
29	Barometric Altitude Pointer	White	Extends from center to edge of altimeter scale, pivoting around the center. Tip points to the 100 feet of altitude scale.
30	Vertical Velocity Pointer & Digital Readout	White	Indicates descent with a down-arrow or climb with an up-arrow. Digital readout indicates feet per minute of change. Readout shows nearest 10 foot/min. This is based on altitude rate of the aircraft.
31	Radar Altitude Digital Readout	Amber	Indicates height above ground below 2500 feet. Disappears above 2500 feet AGL. "R" indicates radar altitude. Reads to the nearest foot. Radar decision height is set through GCP.
32	Flight Director Ball/Crosshairs	Amber (Filled)	Moves left, right, up or down to indicate commanded vertical and lateral track. When aim point is flown so as to encircle the flight director ball, the aircraft will be flying the correct vertical and lateral profile to intercept or remain on desired paths. If only vertical command is present, a horizontal bar replaces the ball. If only lateral command is present, a vertical bar is shown. If neither command is available, no flight director is shown.
33	To Steerpoint	Green	Indicates desired altitude of the TO steerpoint (the one the aircraft is proceeding towards) in hundreds of feet. It changes to indicate the altitude of the next steerpoint when over or 90° abeam the TO steerpoint. This information is provided by the flight management computer.

#	SYMBOL	COLOR	LOCATION AND MOVEMENT
34	From Steerpoint Altitude	Green	Indicates flight planned altitude of the steerpoint that the aircraft has just passed (FROM steerpoint). It changes when the TO steerpoint changes. This information is provided by the flight management computer.
35	Barometric Pressure	Green	When barometric set knob on the GCP is pulled out, altimeter setting is displayed in milli bars and inches of mercury. Digits disappear when knob is pushed in.
36	Flight Phase & Mode	Green	Indicates selected mode of flight and status of that selection. These modes come from the autopilot and are selected on the GCP.

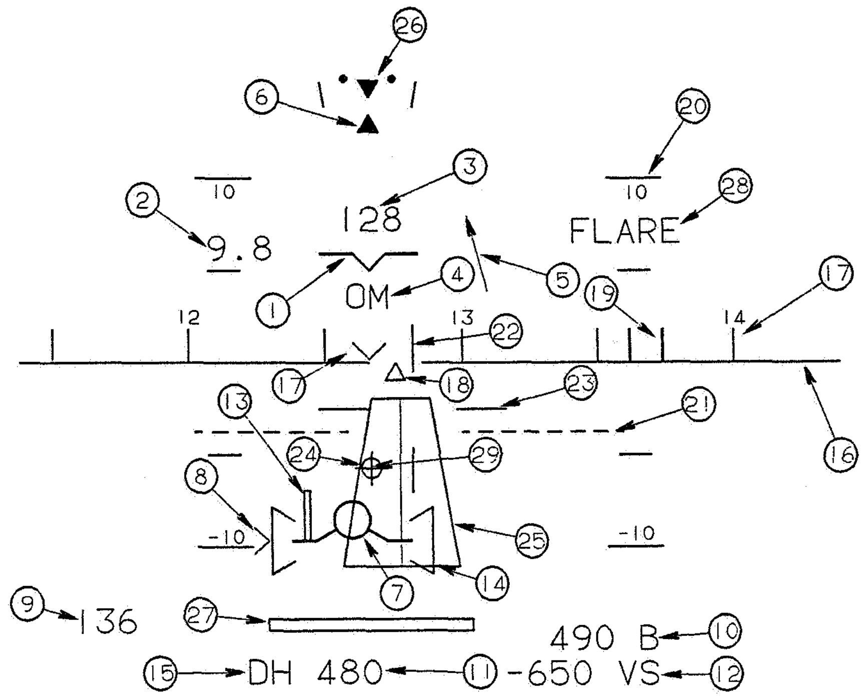


Figure 9. Head-Up Flight Path Primary Flight Display Symbology

1. Aircraft Reference - This symbol shows the position of the nose of the aircraft and represents the airplane's longitudinal frame axis. Heading and pitch are referenced to this symbol. The symbol is fixed to the lateral center, 7 degrees above the vertical center of the display. The center of the "wings" in the vertical direction and the lateral center of the display form the display rotation point and translation reference point.

   This symbol is similar to the aircraft symbol (9) on the head-down display except that here the symbol is static with the pitch and heading scales moving in reference to it rather than vice versa.

2. Digital DME - This symbol is a digital representation of distance to a DME station. Values are limited to between 0 and 100 nautical miles and are displayed in 0.1 nautical mile increments. The position of this symbol is static.

   The input is the same as that used for digital distance to go (11) on the MAP display.

3. Digital Magnetic Heading - This symbol is a digital representation of magnetic heading to the nearest whole degree, and is displayed only when the pitch is greater than 12 degrees. The position of this symbol is static. The readout value here is the same as the value used to translate the aircraft symbol (9) through drift on the HDD (i.e., drift is equal to heading minus track). The readout is also the same as the value used to position the heading index (6) on the MAP display.

4. Marker Beacon - This symbol flashes to indicate outer marker (OM), inner marker (IM), or middle marker (MM). The inputs come from the marker beacon model. The position of this symbol is static.

   This symbol is identical to the marker beacon message on the HDD.

5. CDI Needle - This symbol gives an indication of course deviation and course intercept. The Course Deviation Indicator (CDI) needle behaves exactly like a course deviation indicator on a conventional HSI relative to the aircraft reference (1). It points to the desired course as entered on the guidance control panel (based on heading = straight up). The CDI needle also acts as a deviation indicator to show horizontal (angular) deviation from the desired course.

   This symbol is similar to the horizontal deviation pointer (18) on the HDD except that on the HUD it bounces several times before it starts moving in from full scale.

6. Roll Pointer - This symbol gives an indication of the aircraft's roll attitude. The roll pointer is rotated by an angle proportional to the aircraft roll, and the roll value is read from the roll reference scale (26). It is displayed only when calibrated airspeed is greater than 80 knots.

   This symbol is driven in the same manner as the roll scale (12) and roll index (13) on the the HDD.

7. Flight Path - This symbol indicates the instantaneous direction of the aircraft's earth frame velocity relative to the aircraft longitudinal axis. During approach, the flight path symbol indicates where the airplane will touch down, if all controlling parameters remain constant. This symbol is used as the primary controlled element of the display. The flight path is at the center of the circle. The lateral position of symbol center is at the aircraft track angle on the heading scale (17). The vertical position of the symbol center is at the vertical flight path angle as read on the pitch scale (20). This symbol is similar to the aircraft flight path angle wedges and circle (1) on the VV. On the VV, the end of the wedge points to the flight path angle (FPA) on the FPA scale just as the HUD flight path symbol does. However, on the HUD, heading is always in the center of the screen with the flight path symbol being offset to the track. On the HDD, track is the center and heading offset is shown by the aircraft symbol (9).

8. Flight Path Acceleration - This symbol, along with the flight path symbol (7), provides an indication of the acceleration along the flight path of the airplane. If engine power is correct for maintaining current airspeed and flight path angle, the symbol is aligned with the wing of the flight path symbol, which is its reference. The symbol translates vertically as the aircraft accelerates along the x axis. The scaling for this symbol is 8 degs = 10 fps^2. Specifically, the translation factor is: fps^2 * (8 degs/10 fps^2) * (1 screen coordinate/15 degs) where 1 screen coordinate = 15 degrees = half the height of the screen. This symbol is identical to the potential flight path angle box (26) on the HDD, except for display scaling differences.

9. Digital Airspeed - This symbol is a digital representation of indicated airspeed to the nearest whole knot. Indicated airspeed is only displayed from 60 to 500 kts. This symbol is fixed with respect to the flight path symbol, but is limited to always remain within the field of view. This readout is the same as that shown on the HDD display in both digital (22) and analog (23) form.

10. Digital Barometric Altitude - This symbol is a digital representation of barometric altitude (above sea level). Barometric altitude is displayed in tens of feet and is distinguised by the character "B" to the right of the digital display. The symbol is fixed with respect to the flight path symbol, but is limited to always remain within the display field of view.

    The value shown on the HUD is barometric altitude based on pressure altitude which is computed from the pressure value (altimeter setting) dialed in on the GCP. Both the HUD and HDD display (31) values will be the same.

11. Digital Radio Altitude - This symbol is a digital representation of radio altitude (absolute altitude above ground level). Radio altitude is displayed in tens of feet from 500 to 50 feet, in five foot increments from 50 to 10 feet, and one foot increments below 10 feet. The location of the symbol is fixed with respect to the flight path symbol, but is limited so not to obscure the digital vertical speed readout. Radio altitude is displayed only below 500 feet.

    This readout is the same as the radio altitude readout (31) on the HDD except that it comes into view at 2500 feet on the HDD and is displayed to the nearest foot.

12. Digital Vertical Speed - This symbol is a digital representation of vertical speed. A minus sign is used to indicate a descent. Vertical speed is displayed in 50 feet units and is distinguished by the characters "VS" to the right of the digital readout. The location of the symbol is fixed with respect to the flight path symbol, however, it is limited to always remain within the display field of view. This same information is presented on the VV (30), except that on the VV the readout shows nearest 10 foot/min. On the HDD, an up or down arrow indicates climb or descent.

13. Speed Error Tape - The symbol represents the airplane deviation in calibrated airspeed from a present reference airspeed. Fast speed causes the tape to extend above the wing and slow speed causes the tape to extend below the wing. The scaling of the tape is 4 knots per degree. The speed error tape is normally laterally fixed from the left wing of the flight path symbol, but moves to the right wing during severe left crosswind conditions.

    This symbol is identical to the IAS deviation bar (11) on the HDD except for display scaling differences.

14. Bank Warning Scale - This symbol gives an indication of an aircraft roll angle that could cause a dangerous condition (roll magnitude greater than 5 degrees below 100 feet of radio altitude). The bank warning scale spans from -8 to +8 degrees of roll, and is only displayed below 100 feet radio altitude when the magnitude of the roll angle is greater than 5 degrees,

with a hysteresis of 2 degrees to remove the symbol.

The head-down display does not have a symbol that corresponds to the bank warning scale.

15. Decision Height - This symbol gives an indication of decision height passage. Decision Height is set for radio altimeter 1 or 2, respectively, by individual manual input of the pilot and copilot. "DH" will be displayed whenever the radio altitude is between the bug setting and 30 feet below that value with the same hysteresis factors used for the HDD.

    This symbol appears at the same time as it does on the HDD.

16. Artificial Horizon - This symbol represents an artificial horizon (pitch attitude 0 degrees). The pitch scale is always tied to the horizon. The horizon moves in the vertical so that the pitch value can be read at the point where the pitch scale meets the aircraft reference symbol (1) wing center. The selected course is represented by the center of the gap in the artificial horizon line. The entire artificial horizon vector is roll resolved; rotated about the aircraft reference symbol center by an angle equal to the negative of the roll attitude angle.

    This symbol is like the horizon line (8) on the HDD.

17. Heading Scale and Index - The digital magnetic track is referenced and input for display along the horizon reference. Headings are displayed in 10 degree increments, with every five degrees indicated by a tick mark. A down oriented chevron (also 17) indicates the actual heading of the aircraft. This heading index is always at the center of the screen. This is similar to the compass rose (2) and heading index (6) on the map display. However, on the MAP (and the HDD as well) track is in the center, while on the HUD, heading is always in the center.

18. Selected Course Mark - This symbol identifies the selected course on the heading scale. It is positioned vertically on the horizon line and laterally at the course selected via the GCP (graphically a distance equal to selected course minus magnetic heading and limited to +/-12.5 degrees from center heading). When the selected course mark is limited, the characters "LM" are displayed on the outer edge of the horizon line in the closest direction to the selected course.

    This information is presented on the MAP as the planned course line (9) and desired course readout (14) which, during normal operations, will be the same as the selected course.

19. Track Reference Mark - This symbol is manually set through the guidance control panel. The value read on the heading scale (17) represents the desired track after accounting for wind.

    This symbol is identical to the track marker (5) on the MAP display.

20. Pitch Reference Scale - This symbol, along with the aircraft reference symbol (1), gives an indication of the airplane's pitch altitude. The horizon line always indicates zero degrees pitch, and the pitch bars are tied to the horizon line. This scale is also used against the flight path symbol (7) to indicate the aircraft's vertical flight path. The entire unit (horizon line and pitch bars) move such that pitch is read at the point where the pitch scale intersects the aircraft reference (1) vertical wing center. The scale has two identical parts spaced 15 degrees apart along the heading scale on the horizon line.

    This is similar to the pitch scale (2) on the HDD, except that the pitch scale on the HUD moves laterally when heading changes (remaining 15 degrees apart) and the pitch scale on the HDD does not move laterally.

21. Flight Path Angle (FPA) Reference - This symbol represents the reference or null position for the flight path angle line (glideslope). The symbol reflects the value dialed in on the GCP, and is shown whenever the vertical command mode in the autopilot is other than "vertical speed." In the horizontal the reference is centered on the course mark symbol (18) and horizon gap. In the vertical, the symbol is positioned so as to read the reference value off of the pitch scale (20).

    This symbol is similar to the command flight path angle symbol (3) on the HDD.

22. Localizer - This symbol represents the airplane's lateral angular deviation from the localizer heading reference. It provides course guidance to the runway. It is a fine indication of course deviation. Localizer validity is required. The scale is expanded so that 1 degree of localizer equals 6 degrees on the display. In the horizontal, the localizer is referenced to the selected course marker (18) and horizon gap and deviates from that as center. In the vertical, the symbol is centered on the flight path angle reference (21).

    The deviation is the same as that shown by the horizontal deviation pointer (18) on the HDD.

23. Glideslope - This symbol represents the airplanes vertical angular deviation from the reference glideslope or FPA (21). If the airplane is below the reference glideslope, the glideslope line appears above the reference. Glideslope validity is required. The scale is expanded so that 1 degree of glideslope equals 8 degrees on the display. In the horizontal, the symbol is centered on the selected course (18) and deviates from there just like the localizer. In the vertical, it is centered on the FPA of glideslope reference, and moves through vertical angular deviation.

    The deviation is the same as that shown by the vertical deviation pointer (15) on the HDD.

24. Guidance Cue - The small circle represents the lateral and vertical flight path command. Overlaying the flight path symbol (17) onto the guidance cue provides for accurate and well damped beam (localizer and glideslope) following. Commands to drive this symbol come from the flight director model. It is similar to the flight director ball (32) on the HDD.

25. Runway - This symbol represents the position of the runway projected on the outside field of view. It comes into view whenever a valid ILS signal is received and the aircraft is approximately aligned with the runway. It is removed below 50 feet radio altitude.

26. Roll Reference Scale - This symbol gives an indication of the aircraft's roll attitude. The scale pointer (6) is rotated by an angle proportional to the aircraft roll, and the roll value is read from the roll reference scale. It is displayed only when calibrated airspeed is greater than 80 knots. This is like the roll scale (12) on the HDD.

27. Flare Bar - Bar is parallel to horizon and always centered on the aircraft reference symbol (1) laterally, but moves vertically up toward the horizon line in proportion to the radio altitude as the airplane approaches the ground. This is identical to the flare bar (5) on the HDD except for display scaling differences.

28. Flare Message - The word FLARE appears at 50 feet radio altitude and remains on until the aircraft is on the runway. It is similar to the FLARE message on the HDD.

29. Flare Symbol - It appears at 50 feet radio altitude, is a set of crosshairs superimposed on the guidance cue, blinks once per second and is removed on touchdown.

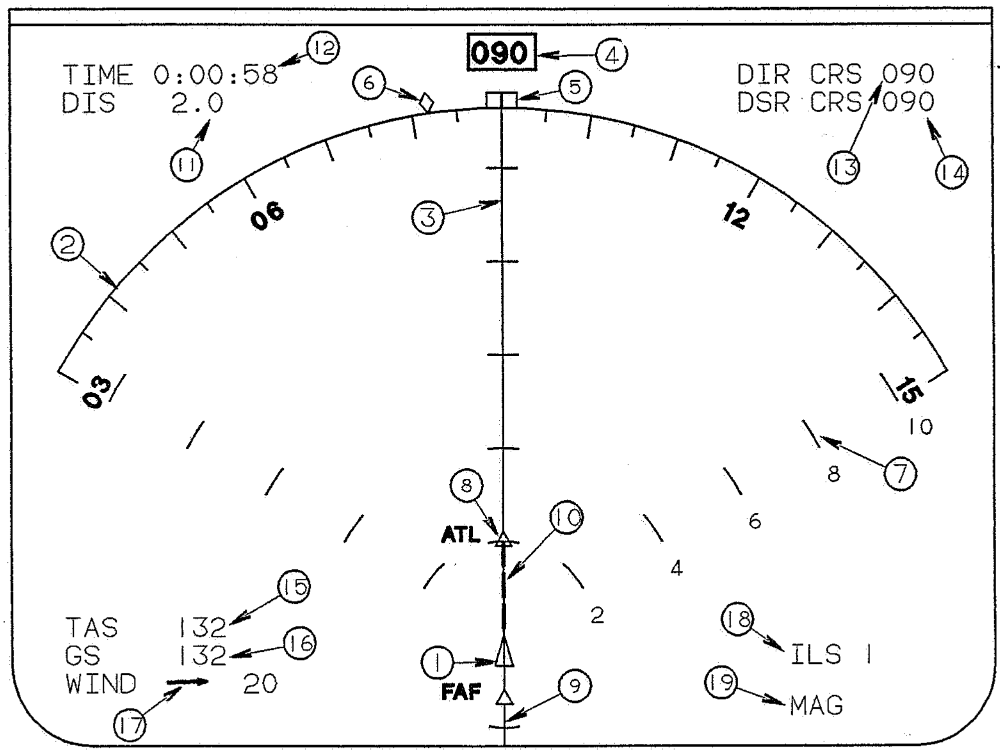


Figure 10. Head-Down Navigation Map Format Symbology

#	SYMBOL	COLOR	LOCATION AND MOVEMENT
1	Own Aircraft	White	Always remains in a fixed position with the uppermost point of the triangle at the center of the smallest range marker circle.
2	Compass Rose	White	120° arc with aircraft track at top center. Arc is divided into 5° increments with digits each 30° starting at 0°. Arc position does not move but scale changes as aircraft turns.
3	Track Lubber Line	White	Always oriented vertically from the own aircraft symbol to the compass rose. Shows aircraft track on the scale.
4	Aircraft Track Digital Readout and Box	White	Above top center of compass rose. Shows numbers from 001 to 360 degrees and agrees with reading under lubber line on compass rose.
5	Track Marker	Amber	Rotates around circumference of compass rose to indicate the desired track angle. It is positioned by pilot via the control on the GCP.
6	Aircraft Heading Index	Amber	Rotates around circumference of compass rose. Shows aircraft heading on the compass rose and drift correction angle as the difference between aircraft heading index and track lubber line.

#	SYMBOL	COLOR	LOCATION AND MOVEMENT
6	Aircraft Heading Index	Amber	Rotates around circumference of compass rose. Shows aircraft heading on the compass rose and drift correction angle as the difference between aircraft heading index and lubber line.
7	Range Markers	White	Equidistant marks between Own aircraft and maximum range selected. Marks maintain fixed position, but scaling can be changed by the pilot via a range marker switch. Scaled in NM and identified on right hand end.
8	Steerpoint Symbols and Identifiers	White	Three dimensional points defining route of flight. They move with respect to Own aircraft symbol at rate based upon ground speed and range scale selected. When aircraft is on desired track, nearest steerpoint is always shown vertically above Own aircraft symbol. Positional information is provided by the FMC.
9	Planned Course Line	Green	Line between waypoints defining route of flight. Moves with the waypoints. Terminates at largest range marker or furtherest waypoint on one end and bottom of display on other end. Positional information is provided by the FMC.
10	Position Predictor or Trend Vector	White	Three dashed lines extending from front tip of Own aircraft symbol. The end of each dash shows the predicted position of the tip of the Own aircraft symbol at 20, 40, and 60 seconds from the present time based upon present aircraft course, aircraft normal acceleration, and ground speed. Lines change length with respect to ground speed and display range scale.
11	Distance To Go Digits	Green	Upper left corner of display. In ILS mode, it shows nautical miles between own aircraft and the touchdown point (ILS Slant Range).
12	Time To Go Digits	Green	Upper left corner of display. In ILS mode, it shows hours, minutes and seconds required to travel from present position to touchdown. Leading zeros (insignificant) are not shown.

#	SYMBOL	COLOR	LOCATION AND MOVEMENT
13	Direct Course Digits	Green	Upper right corner of display. Shows course typically magnetic) between Own aircraft and next (TO) steerpoint. Information is provided by the FMC and not shown in ILS mode.
14	Desired Course Digits	Green	Upper right corner of display. Shows course (typically magnetic) between last (FROM) steerpoint and next (TO) steerpoint. Information is provided by the FMC.
15	True Airspeed Digits	Green	Lower left corner of display. Shows true airspeed of aircraft.
16	Ground Speed Digits	Green	Lower left corner of display. Shows ground speed of aircraft.
17	Wind Arrow and Digits	Green	Lower left corner of display. Shows wind vector (arrow) pointing from the direction that the wind is blowing relative to the aircraft track. Arrow disappears when wind is calm. Digits show wind velocity in knots.
18	Navigation Mode	Green	Lower right corner of display. Shows navigation mode selected.
19	True or Mag Label	Green	Lower right corner of display. Indicates whether navigation system is operating using true or magnetic headings.

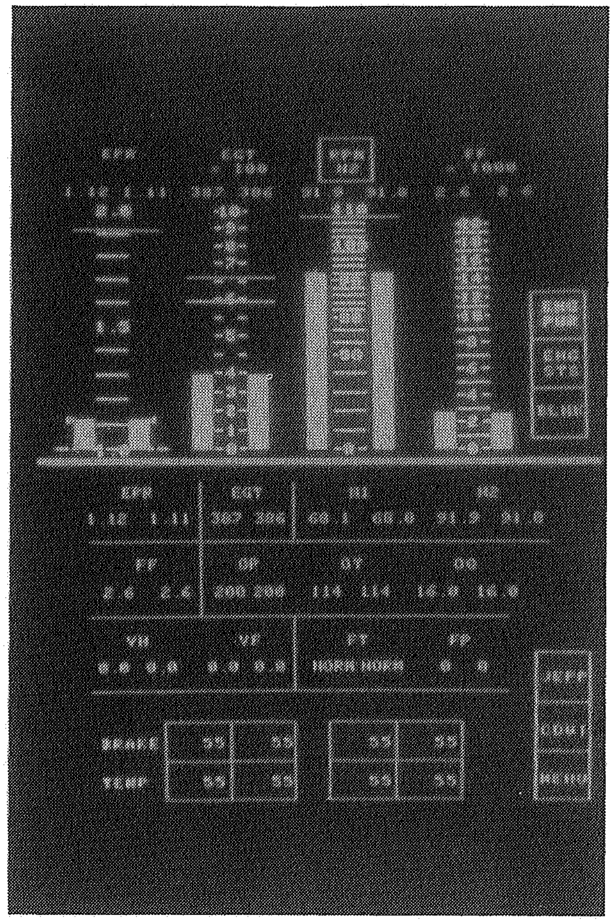


Figure 11. Engine Power Display on Top and System Status on Bottom

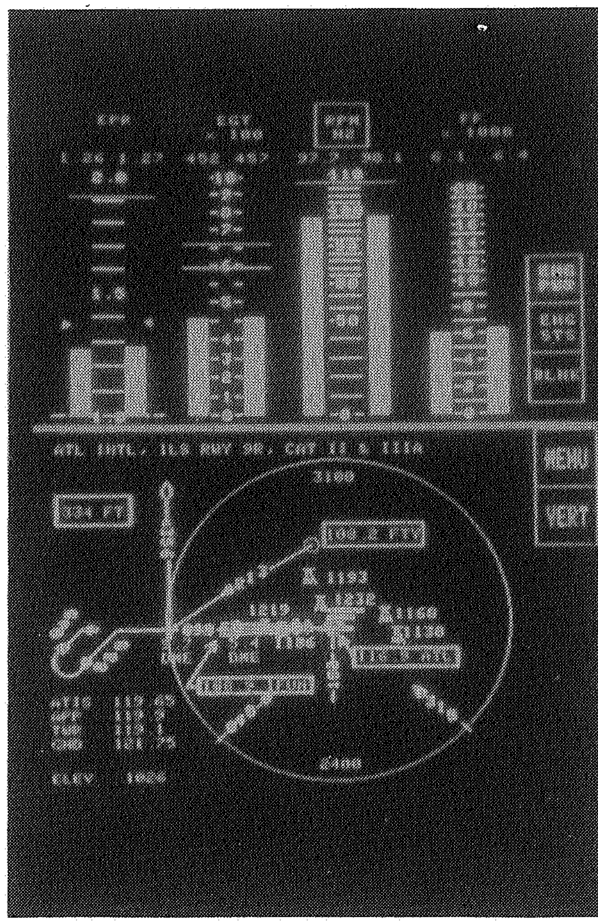


Figure 12. Approach Chart Information Shown on Bottom of #2 and #4 Display

ORIGINAL PAGE IS
OF POOR QUALITY

		HEAD-UP PFD						HEAD-DOWN PFD					
		5000'/10SM		200'/0.5SM		0'/1200'RVR		5000'/10SM		200'/0.5SM		0'/1200'RVR	
	SUBJECT	090/ 10KT	135/ 21KT	090/ 10KT	135/ 21KT	090/ 10KT	135/ 21KT	090/ 10KT	135/ 21KT	090/ 10KT	135/ 21KT	090/ 10KT	135/ 21KT
MANUAL	1												
	2												
	3												
	4												
	5												
CSS	6												
	7												
	8												
	9												
	10												

Figure 13. **Experimental Design is a 2 (Between) by 3 by 2 by 2 (Within) Design**

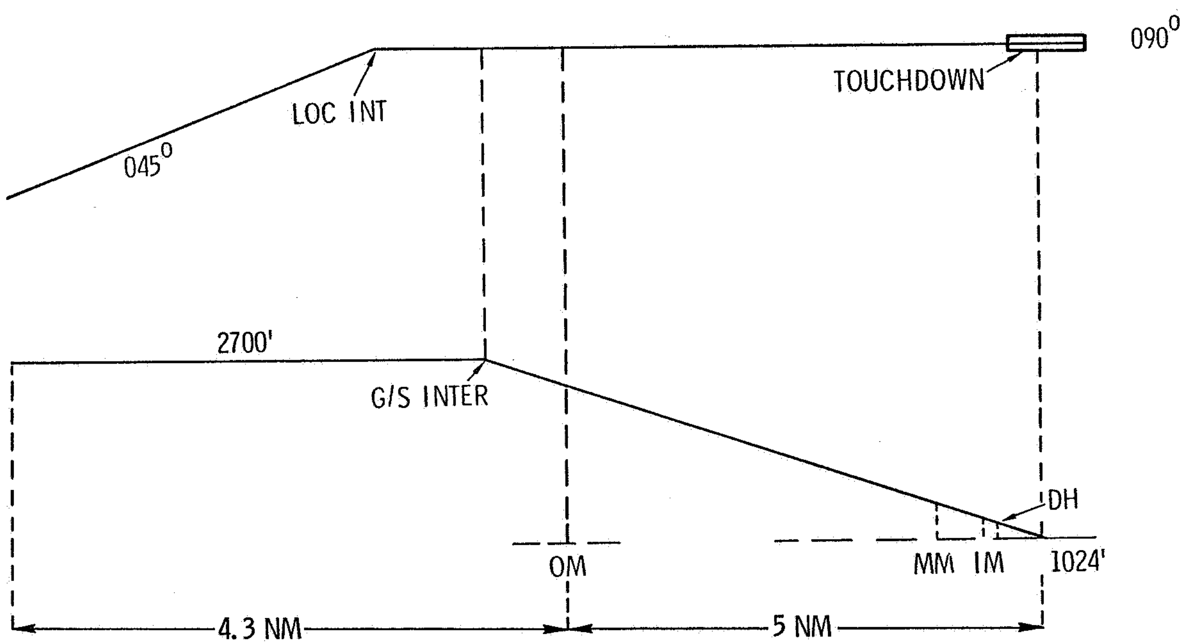


Figure 14. **Horizontal and Vertical Flight Profiles**

AIRLINE	MOST CURRENT AIRCRAFT	CREW POSITION	PILOT HOURS
DELTA	L - 1011	CAPT	6000
DELTA	757 / 767	CAPT	20000
DELTA	757 / F-15	F.O.	14000
DELTA	737	F.O.	7500
DELTA	727	S.O.	2400
EASTERN	727	CAPT	19000
EASTERN	DC-9	F.O.	3500
PIEDMONT	727	CAPT	19000
PIEDMONT	727	CAPT	8000
NORTHWEST	DC-9 / F-15	F.O.	7100

Figure 15. Subject Pilots Had a Wide Range of Experience

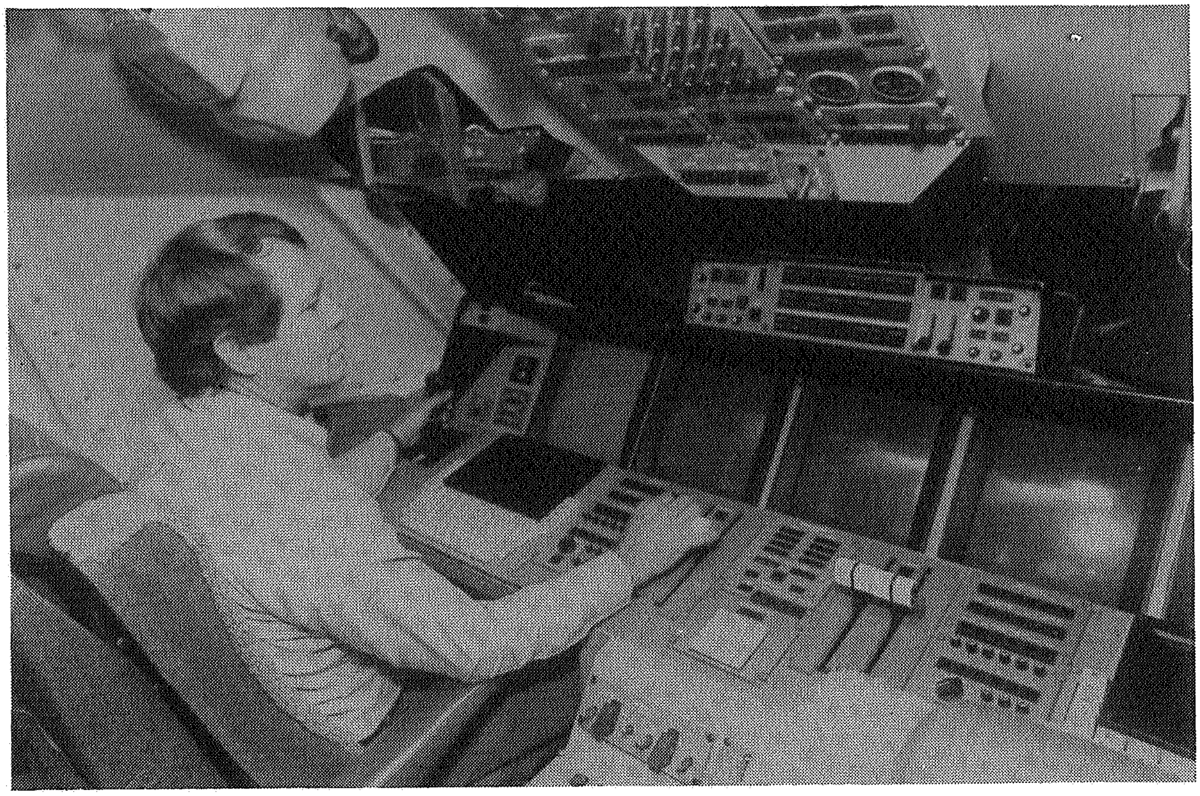


Figure 16. Subject Pilot Flying with Head-Down Display

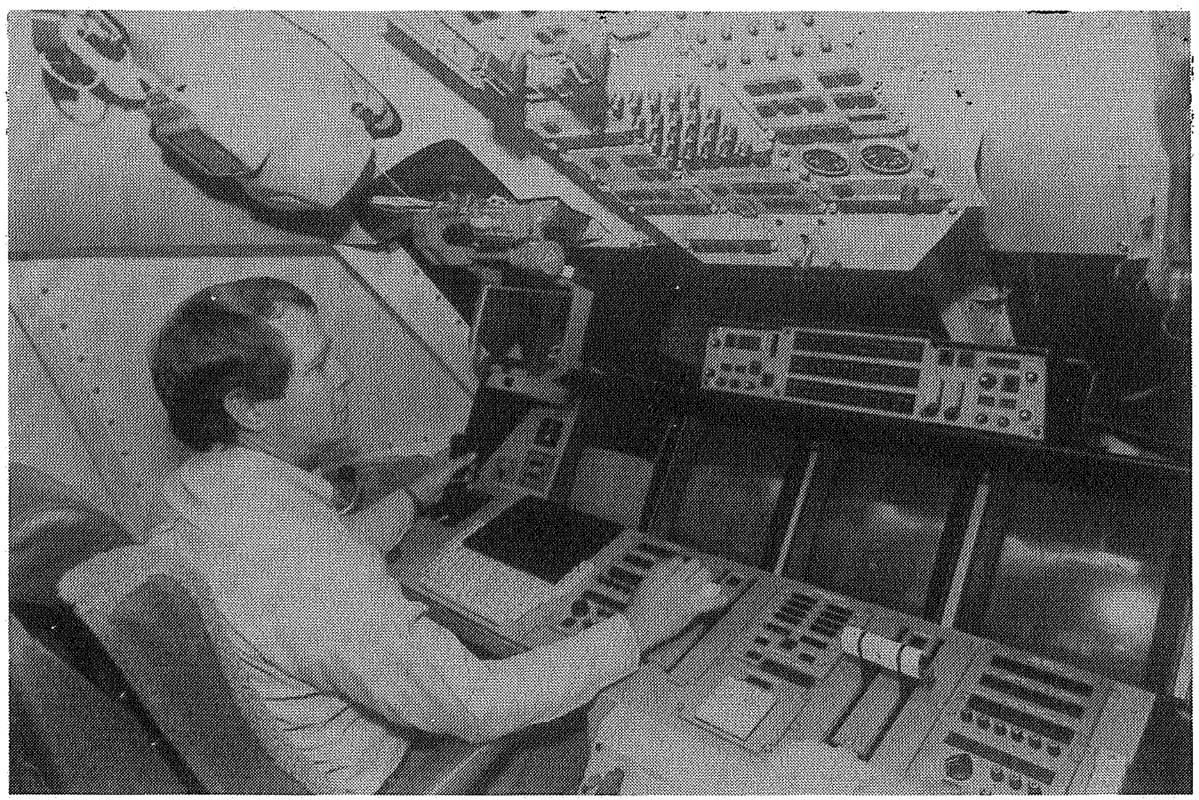


Figure 17. Subject Pilot Flying with Head-Up Display

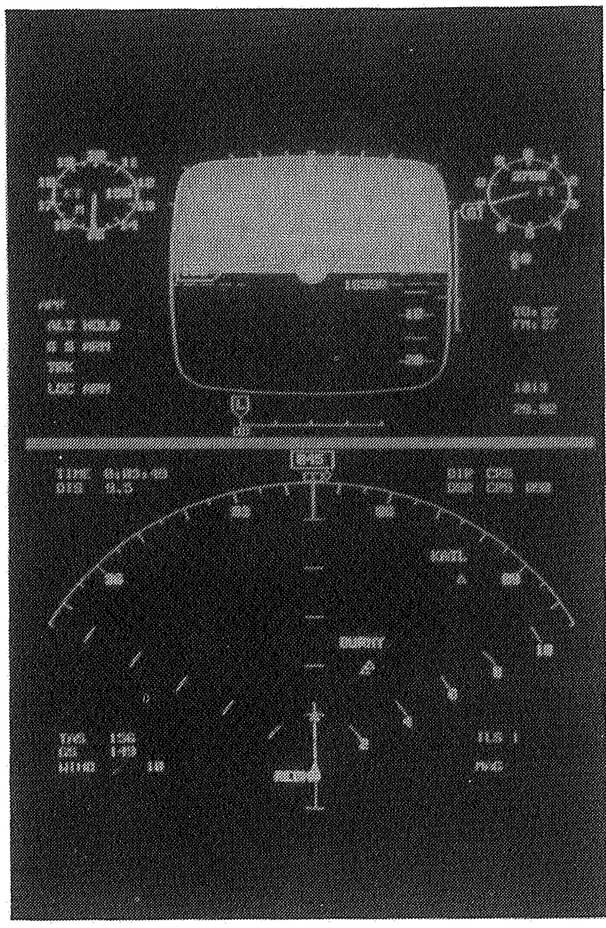


Figure 18. Head-Down Display at Start of Flight Profile

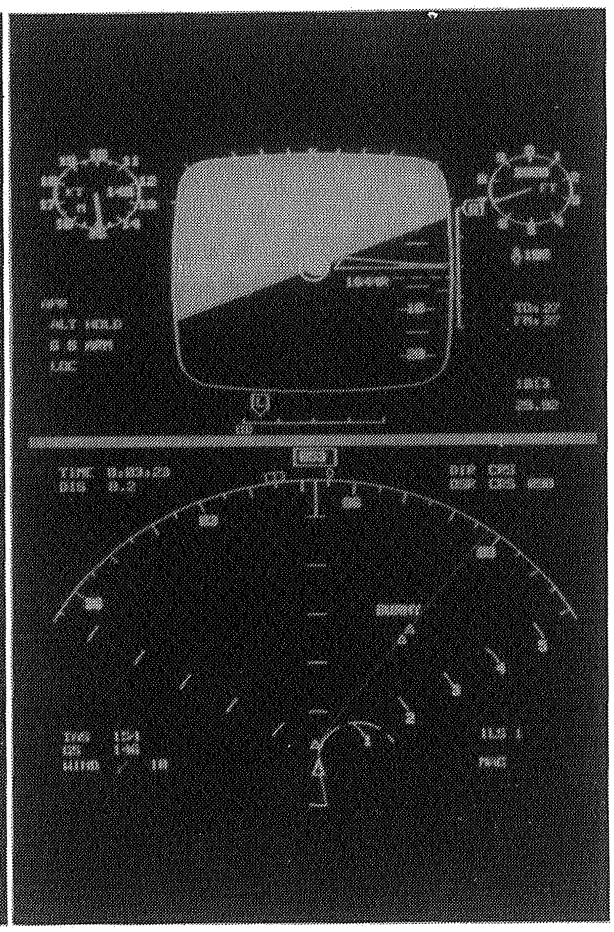


Figure 19. Turn to Intercept Localizer on HDD

ORIGINAL PAGE IS
OF POOR QUALITY

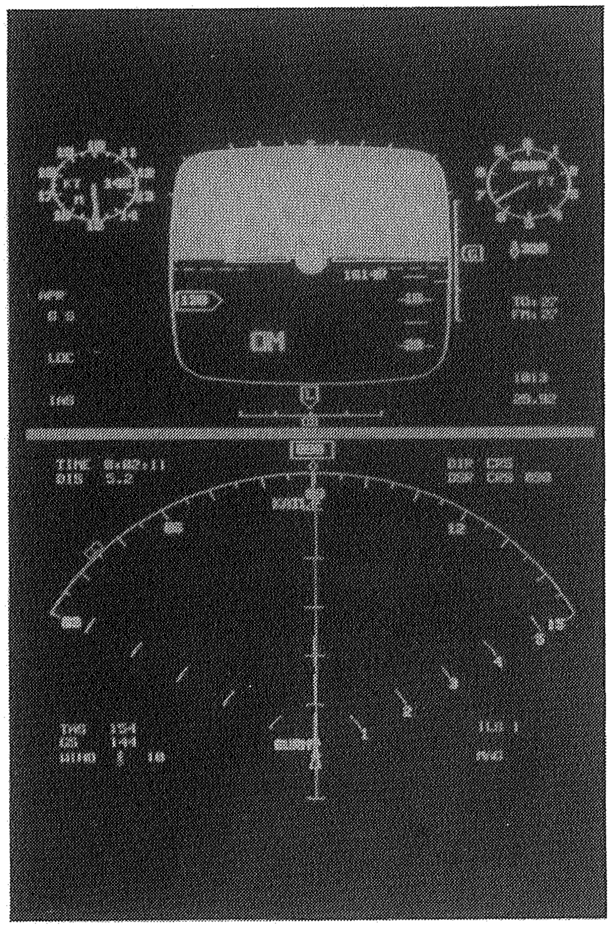


Figure 20. Over OM Using Manual Flight Control Mode with Flight Director

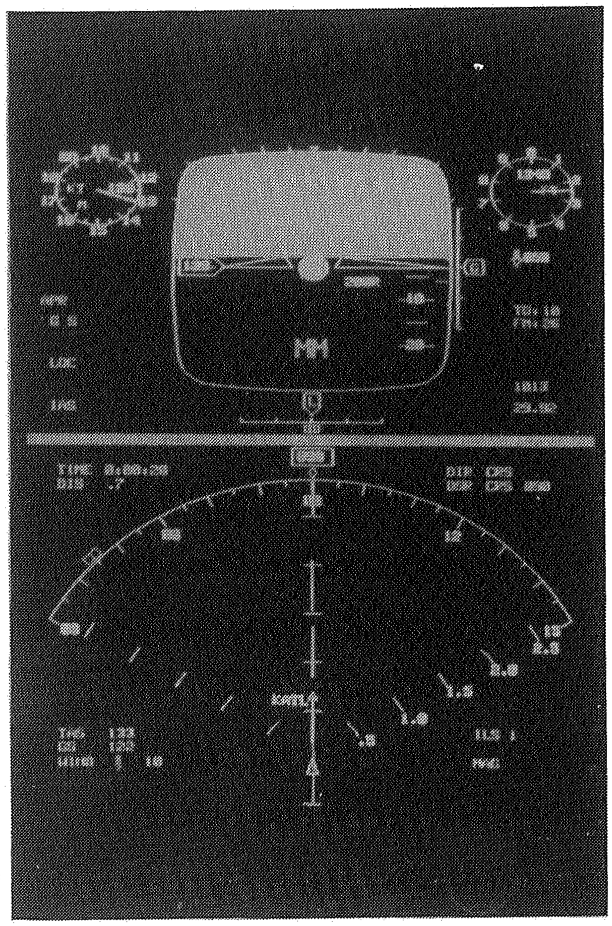


Figure 21. Over MM with 10 Knot Headwind on HDD

C-2

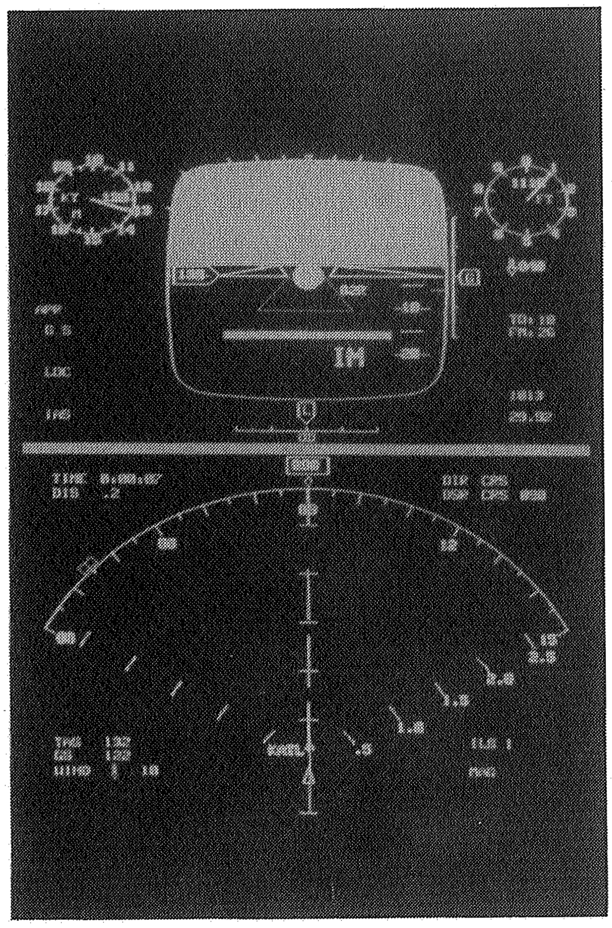


Figure 22. Over IM with Symbolic Runway in View

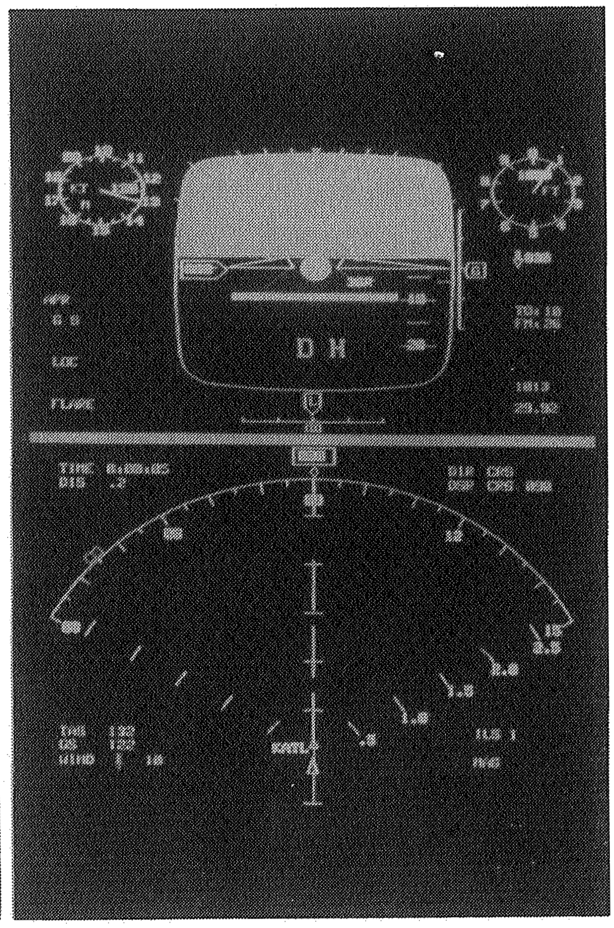


Figure 23. At Decision Height Approaching Flare

ORIGINAL PAGE IS
OF POOR QUALITY

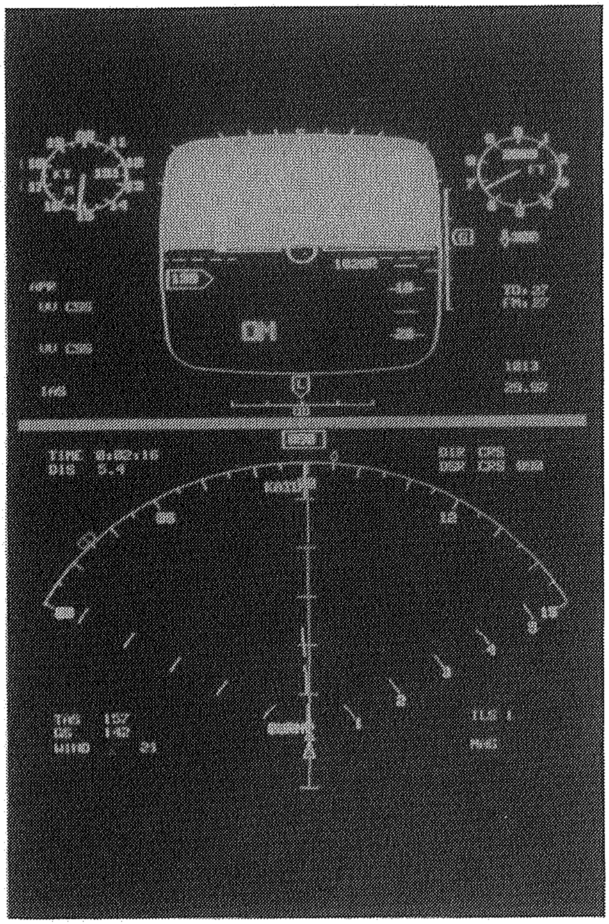


Figure 24. HDD over OM Using CSS Flight Control Mode Without Flight Director

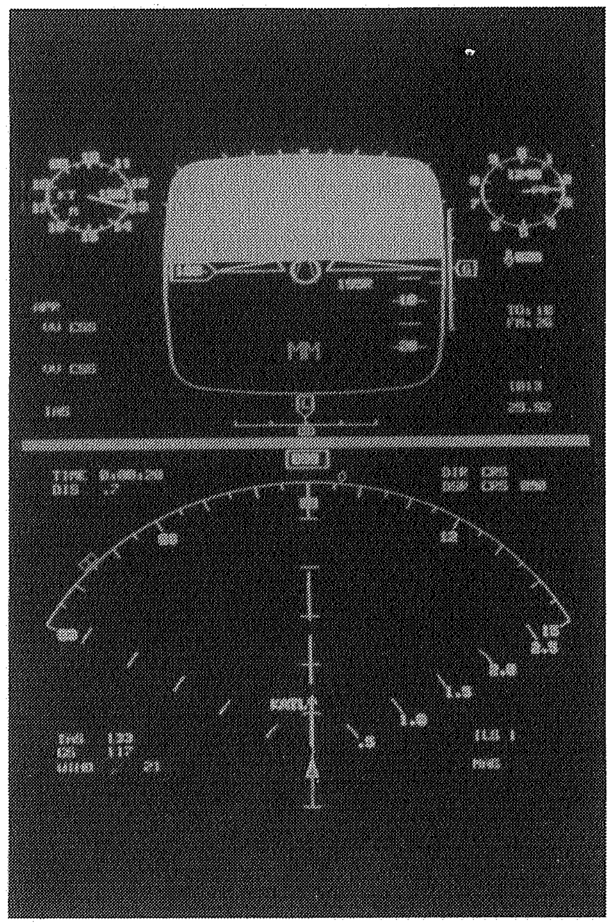


Figure 25. Over MM with Symbolic Runway in View

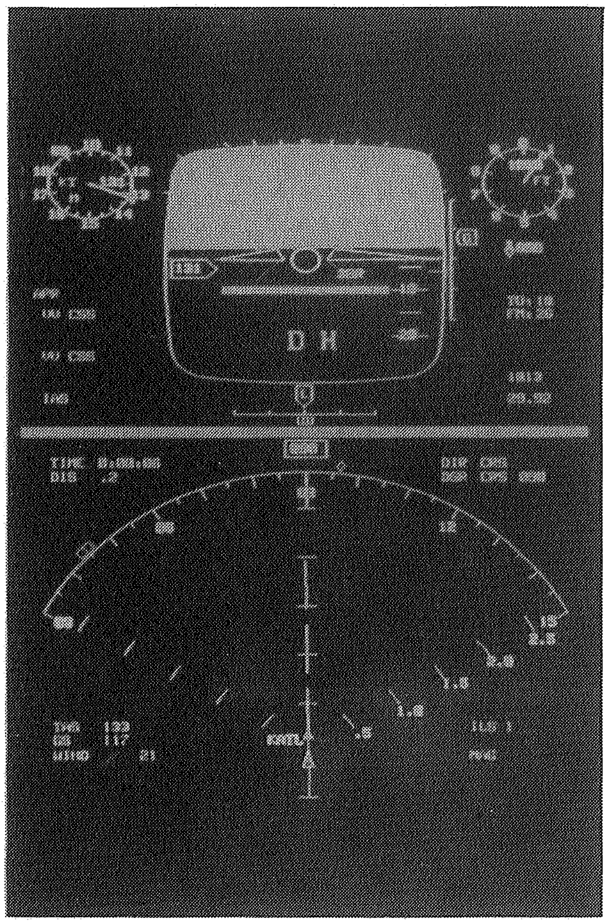


Figure 26. At Decision Height with Crosswind

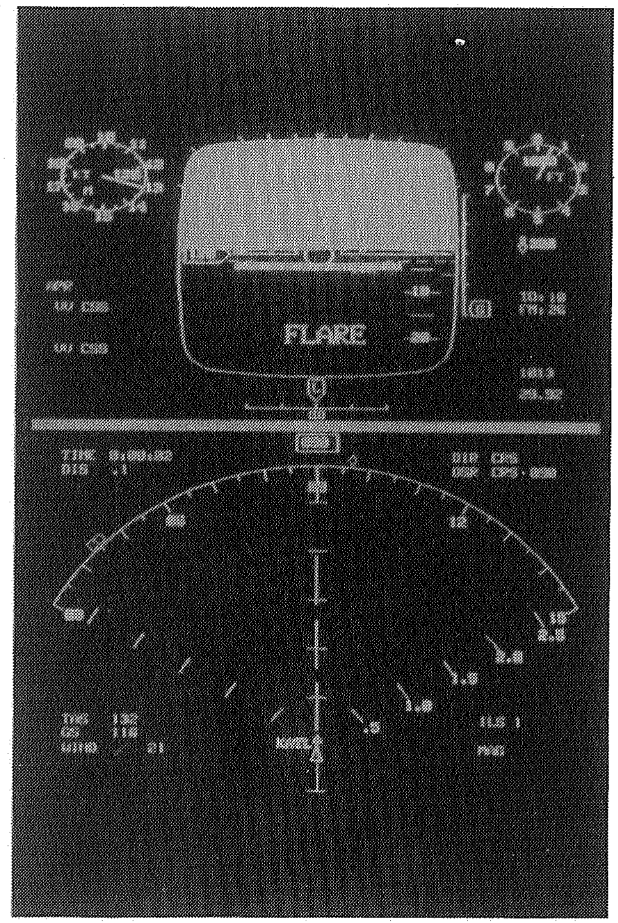


Figure 27. At Flare on HDD

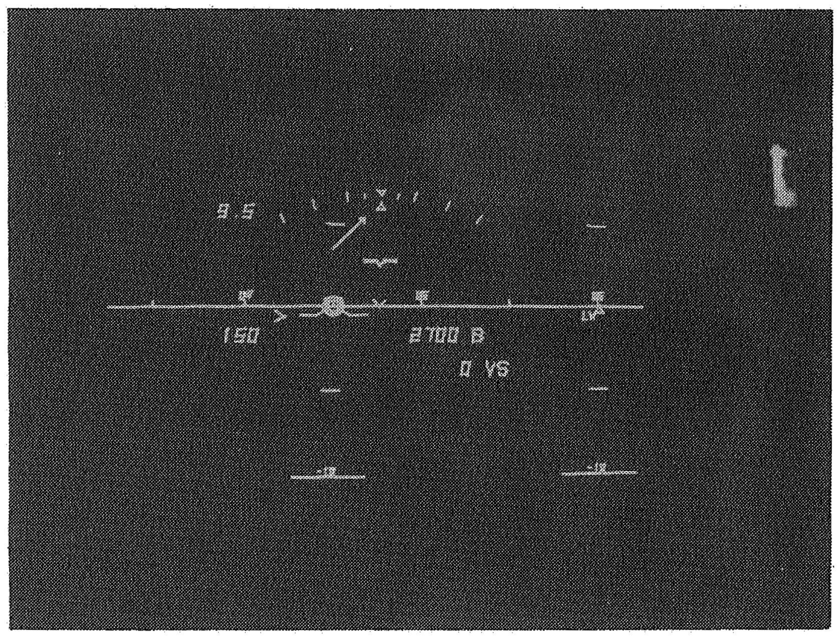


Figure 28. Head-Up Display at Start of Flight Profile

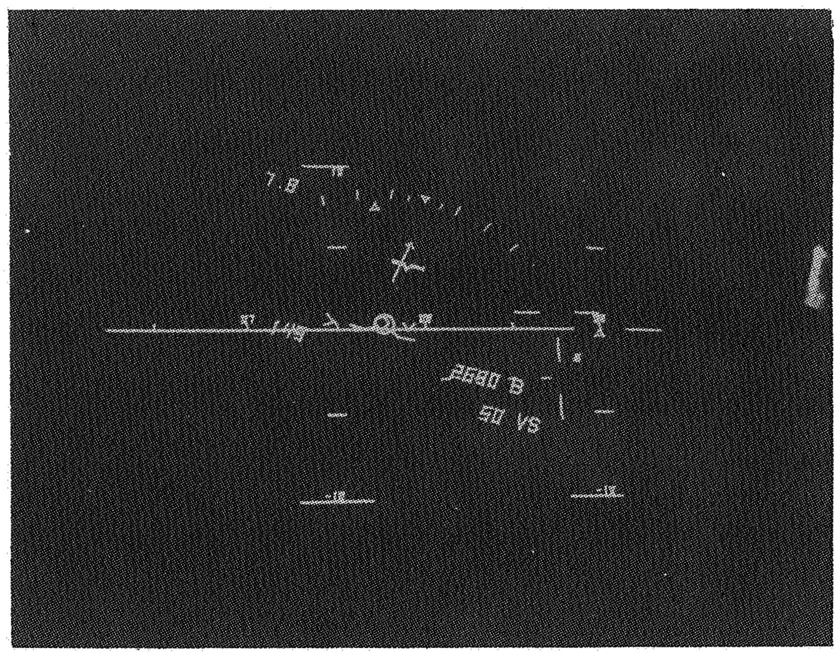


Figure 29. Turn to Intercept Localizer on HUD

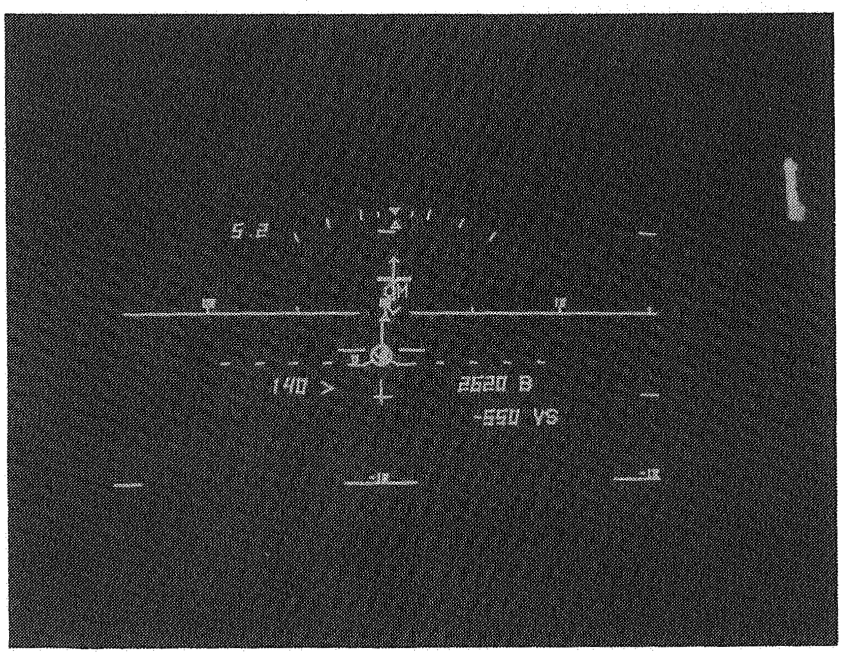


Figure 30. Over OM Using Manual Flight Control Mode with Guidance Cue

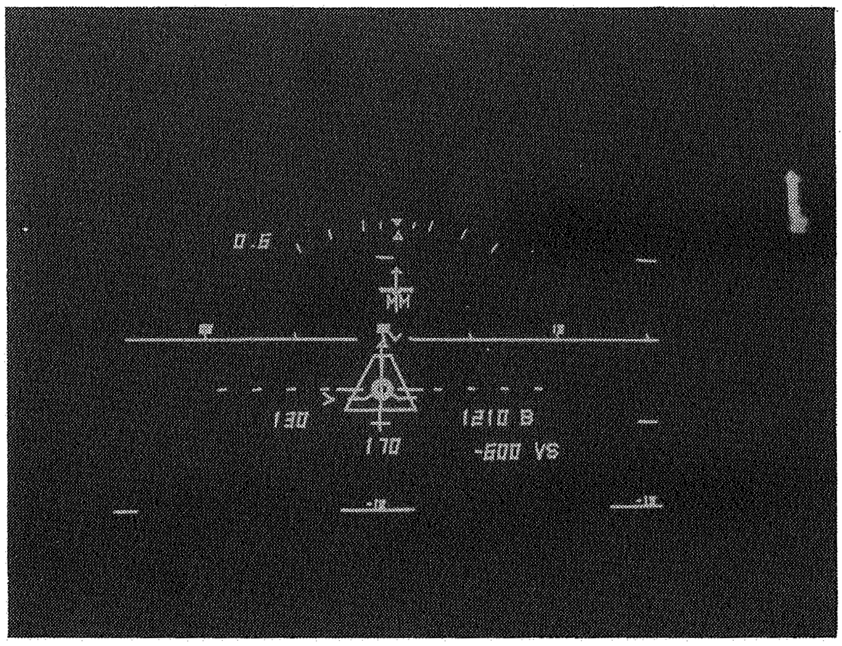


Figure 31. Over MM with Headwind on HUD

ORIGINAL PAGE IS
OF POOR QUALITY

ORIGINAL PAGE IS
OF POOR QUALITY

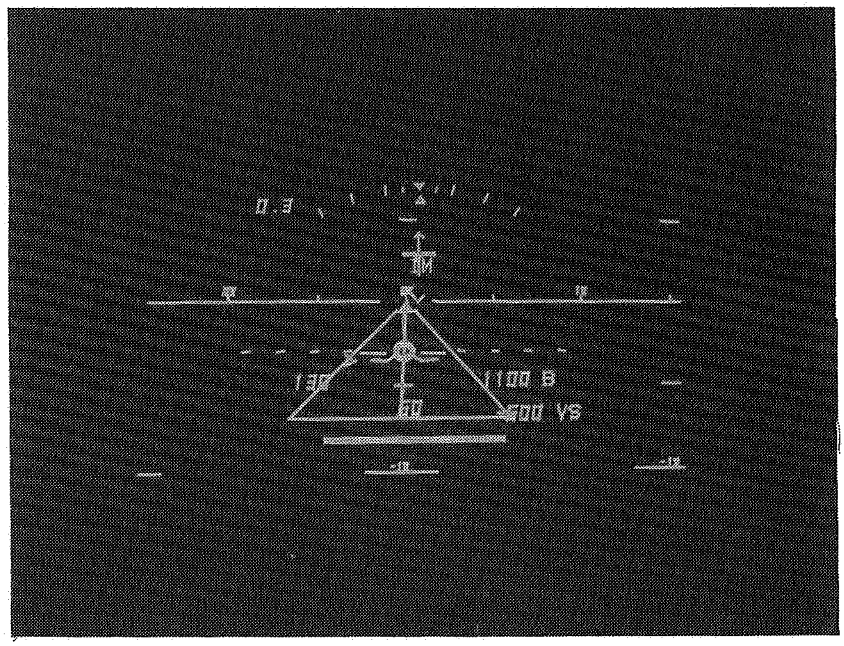


Figure 32. Over IM with Symbolic Runway and Flare Bar

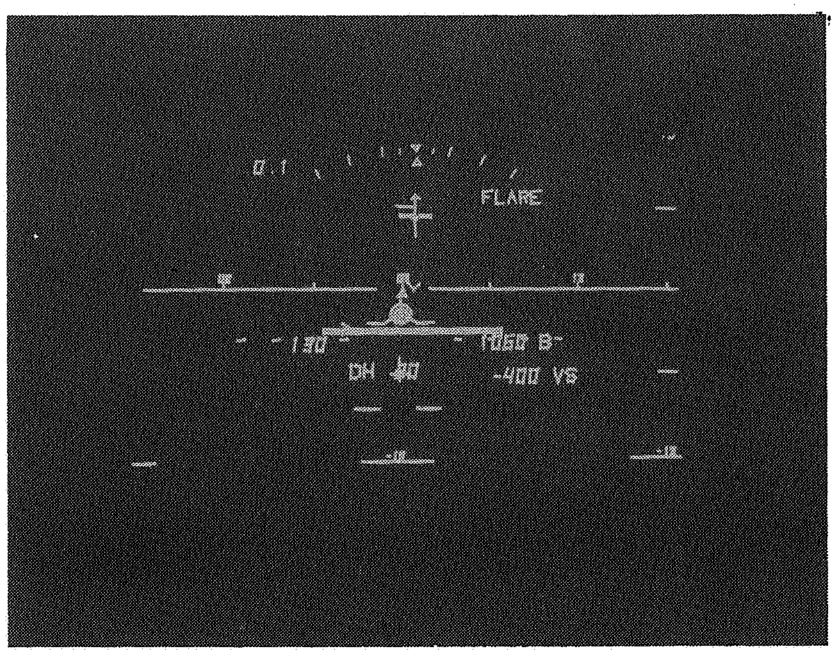


Figure 33. At Decision Height and Beginning to Flare

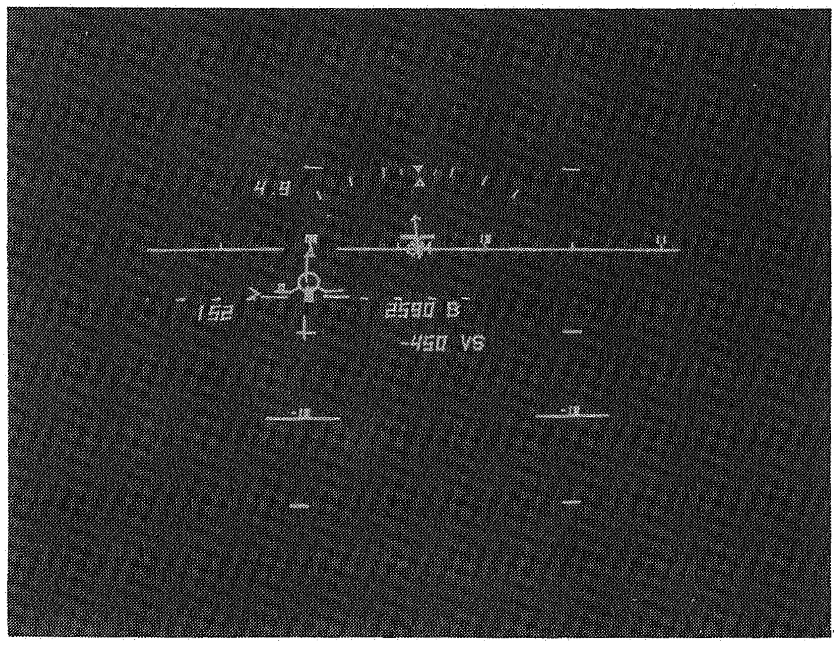


Figure 34. HUD over OM Using CSS Flight Control Mode Without Guidance Cue

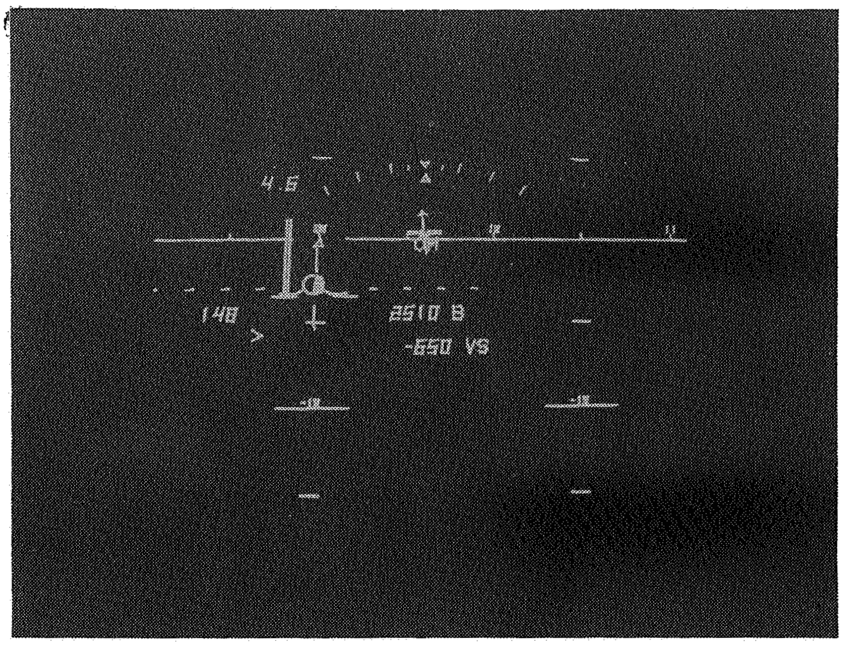


Figure 35. Changing Referenced Airspeed from 150KT to 130KT

ORIGINAL PAGE IS
OF POOR QUALITY

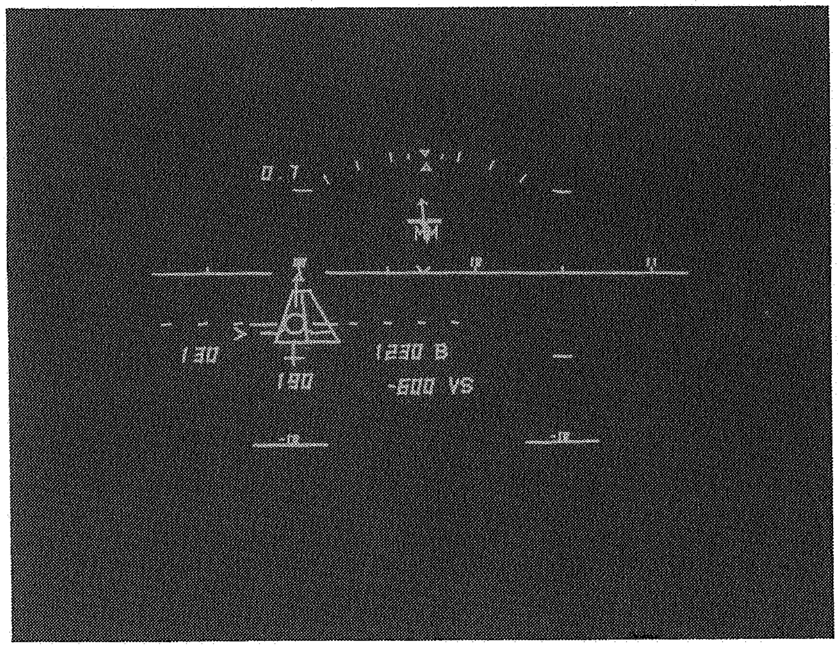


Figure 36. Over MM with 15 Knot Crosswind Component

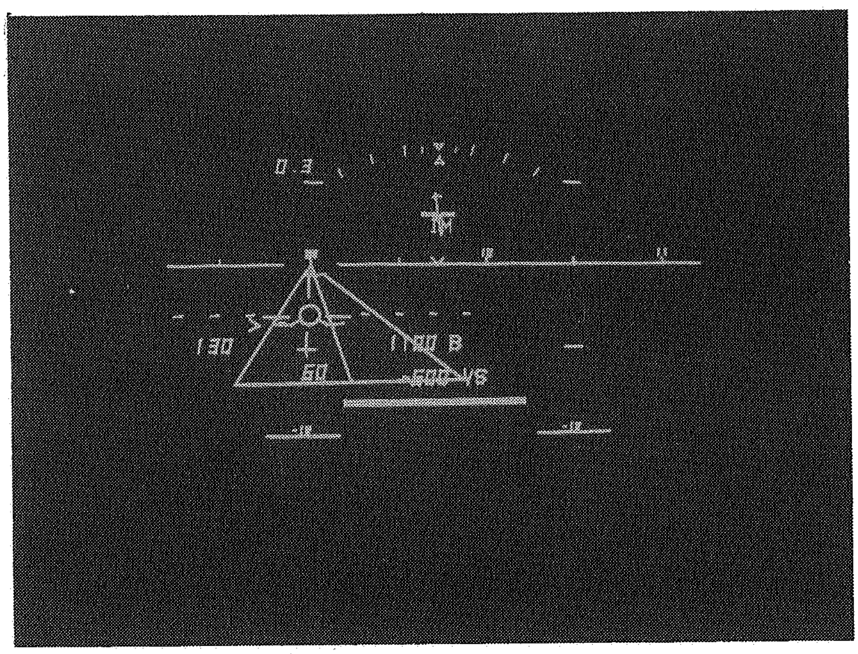


Figure 37. Over IM with Symbolic Runway and Flare Bar

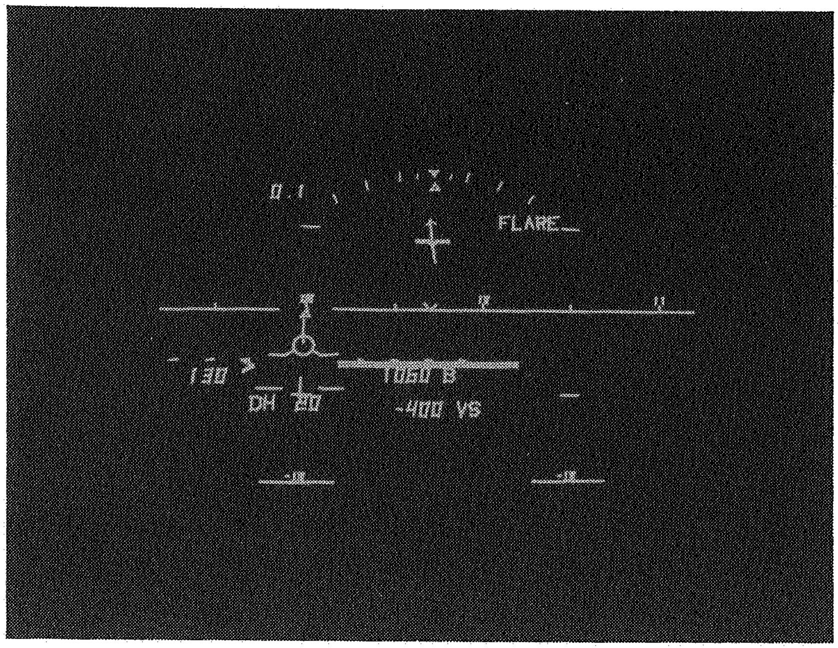


Figure 38. At Decision Height Approaching Flare and Decrab

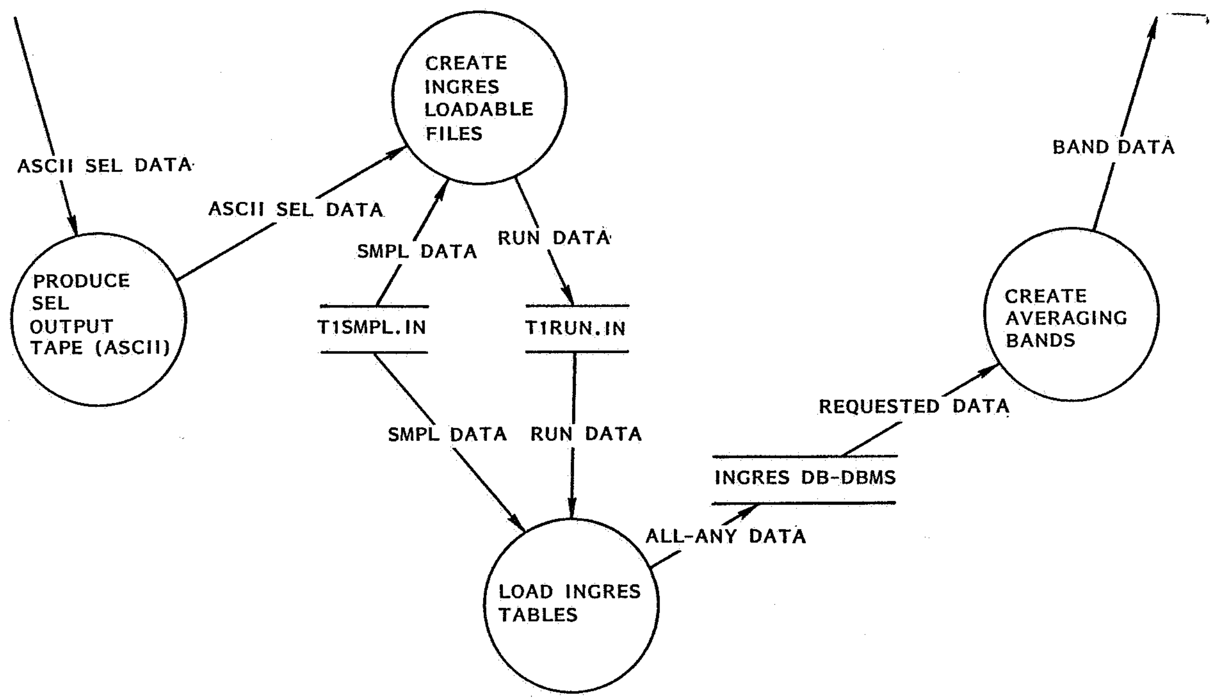


Figure 39. Data Reduction Procedure Provides a Powerful Tool

ORIGINAL PAGE IS OF POOR QUALITY

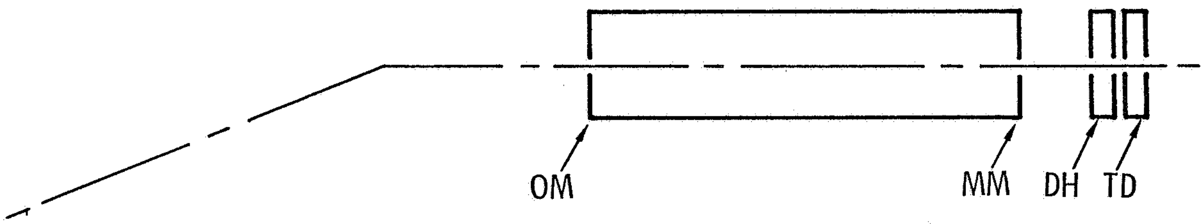
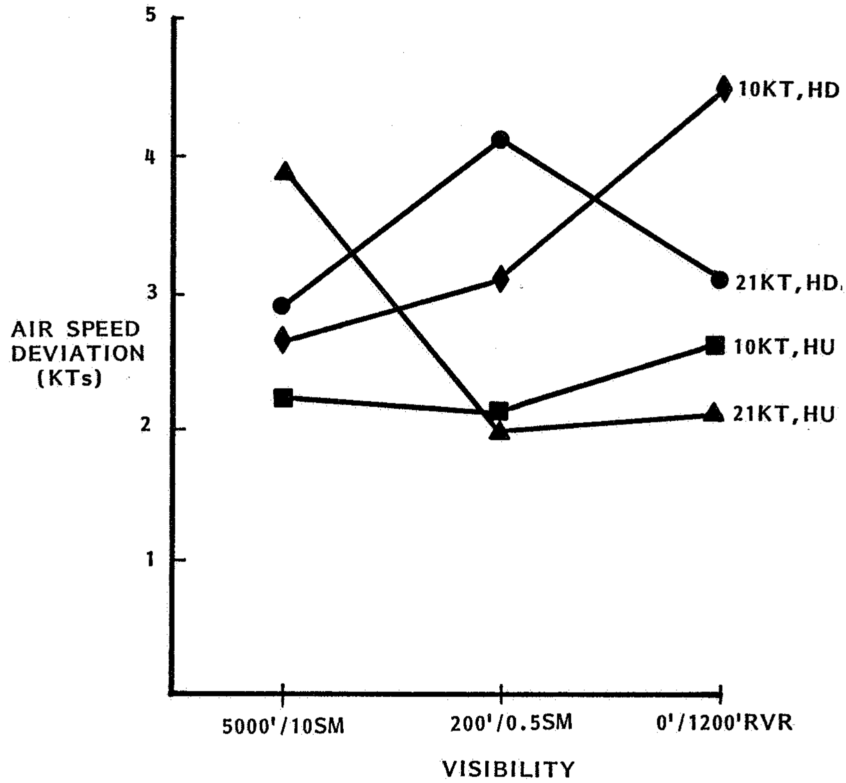


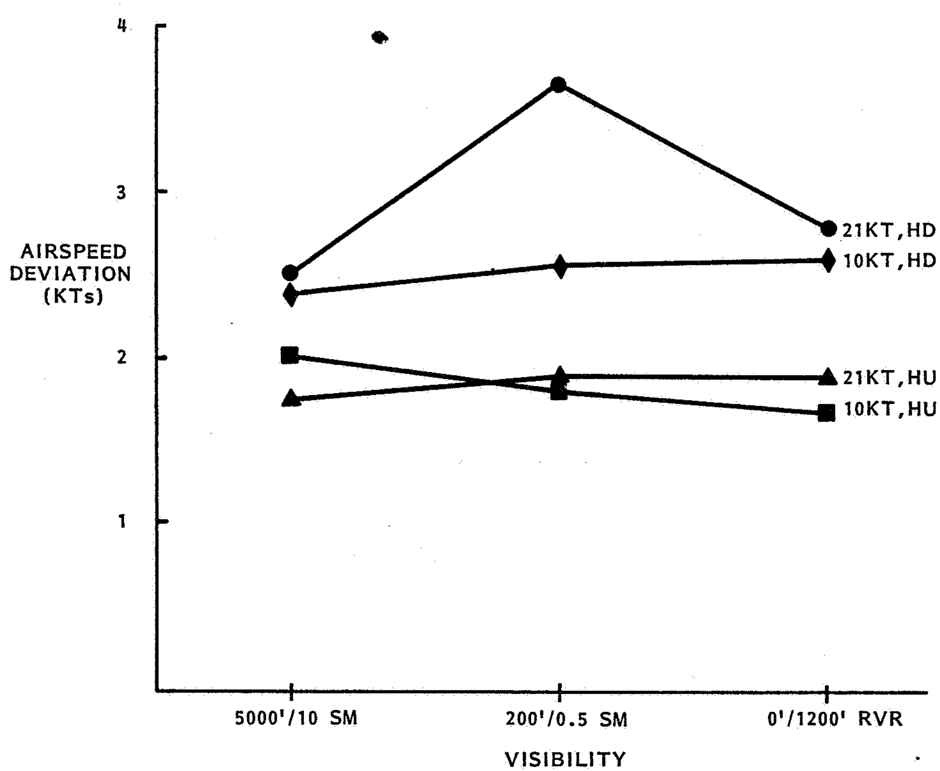
Figure 40. Data was Analyzed in Bands Along the Profile

	AIRSPEED DEVIATION		X-TRACK DEVIATION		GLIDESLOPE DEVIATION		FLIGHT PATH ANGLE DEVIATION		TRACK ANGLE ERROR (OM - MM)	LONGITUDINAL DISPERSION (TD)	X-TRACK DEVIATION (TD)	SINK RATE (TD)	HEADING (TD)
	OM-MM	DH	OM-MM	DH	OM-MM	DH	OM-MM	DH					
FORMAT (F)			MAN CSS				MAN CSS		MAN CSS		MAN CSS	MAN	MAN
WIND (W)											MAN		
VISIBILITY (V)						MAN		MAN				MAN	
F x W											MAN	MAN	
F x V		MAN											
W x V	MAN	MAN								MAN		MAN	
F x W x V								MAN	CSS	MAN			

Figure 41. Main and Interaction Effects (See Appendix B)

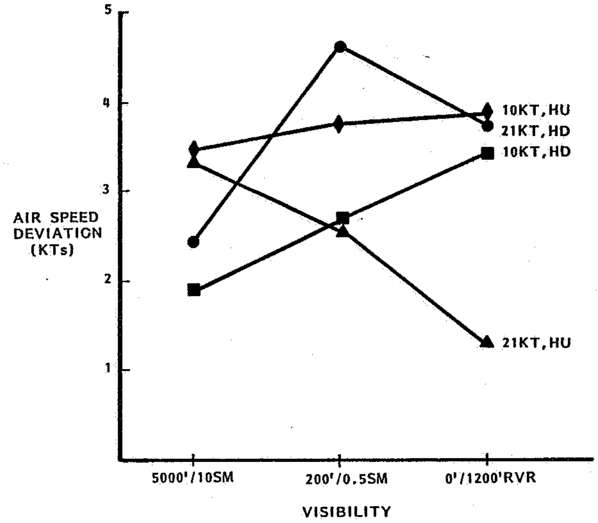


a) MANUAL STEERING MODE

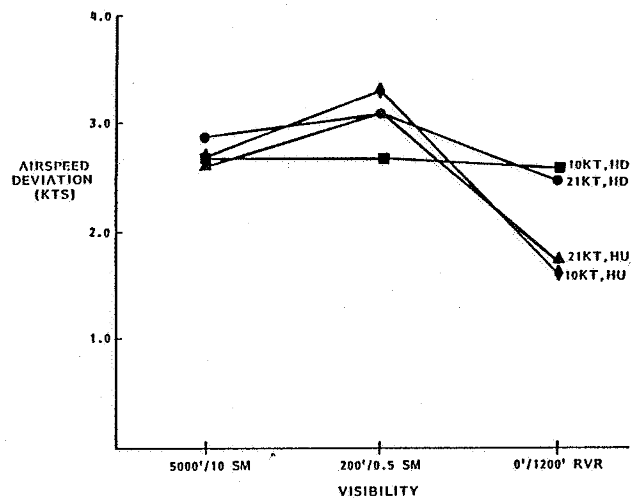


b) CSS MODE

Figure 42. Airspeed Deviation OM to MM



a) MANUAL STEERING MODE



b) CSS MODE

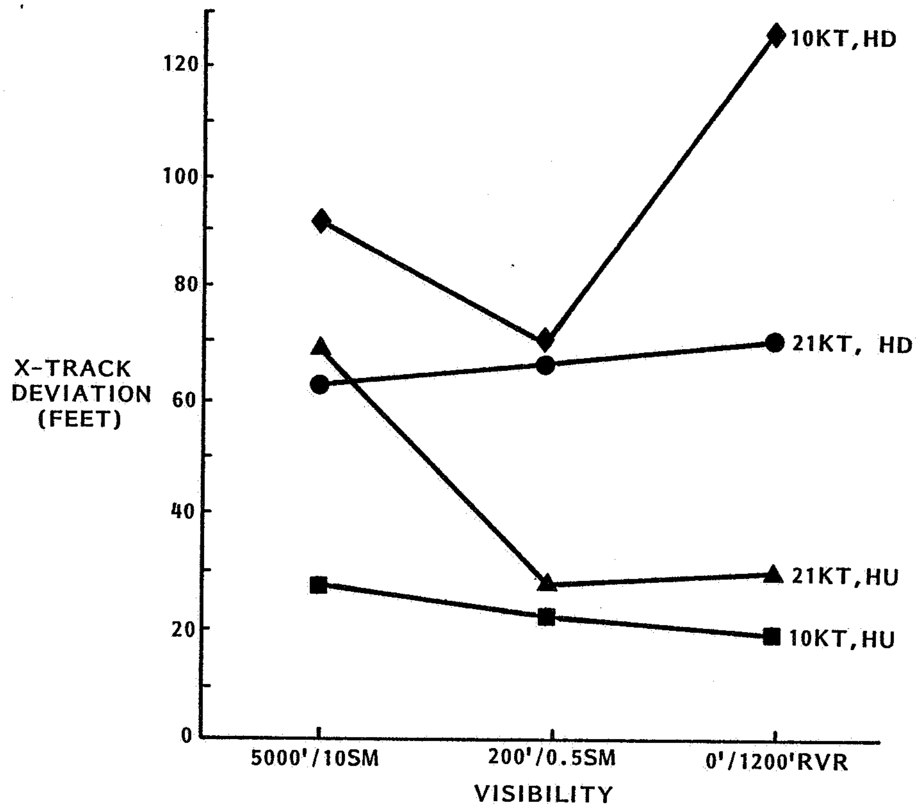
		MANUAL STEERING MODE				CONTROL-STICK STEERING MODE			
		HEAD-UP		HEAD-DOWN		HEAD-UP		HEAD-DOWN	
		090/10	135/21	090/10	135/21	090/10	135/21	090/10	135/21
5000'/ 10 SM	MEAN	3.4*	3.4*	1.9	2.5	2.7*	2.6*	2.7*	2.9*
	S.D.	2.0	2.6	1.0	1.7	2.7	2.5	2.5	2.3
200'/ 0.5 SM	MEAN	3.7*	2.6	2.7	4.6*	3.3*	3.1*	2.7	3.1*
	S.D.	2.7	1.6	2.1	3.5	2.9	2.6	2.1	2.3
0'/ 1200' RVR	MEAN	3.9*	1.3	3.4*	3.8*	1.6	1.7	2.6	2.5
	S.D.	2.7	1.2	2.3	2.7	1.5	1.7	1.9	2.3

*: MEAN + 1 S.D. VALUES EXCEED TOLERANCE

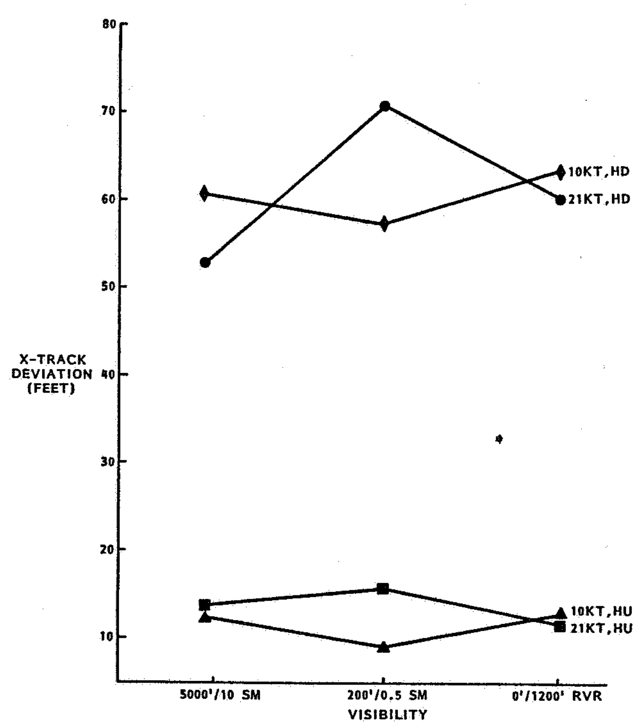
c) MEAN AND STANDARD DEVIATION VALUES

TOL: ± 5 KTS

Figure 43. Airspeed Deviation at DH

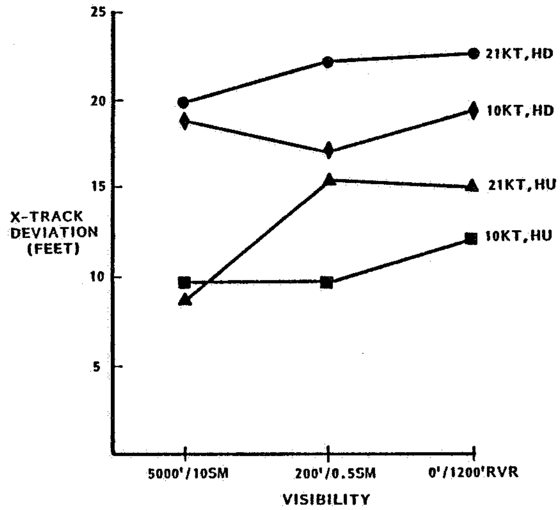


a) MANUAL STEERING MODE

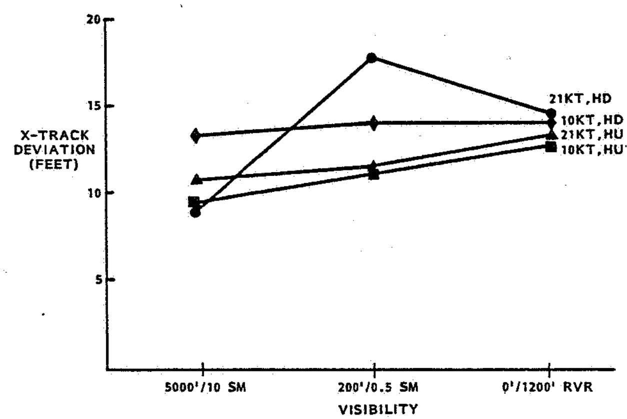


b) CSS MODE

Figure 44. X-Track Deviation OM to MM



a) MANUAL STEERING MODE



b) CSS MODE

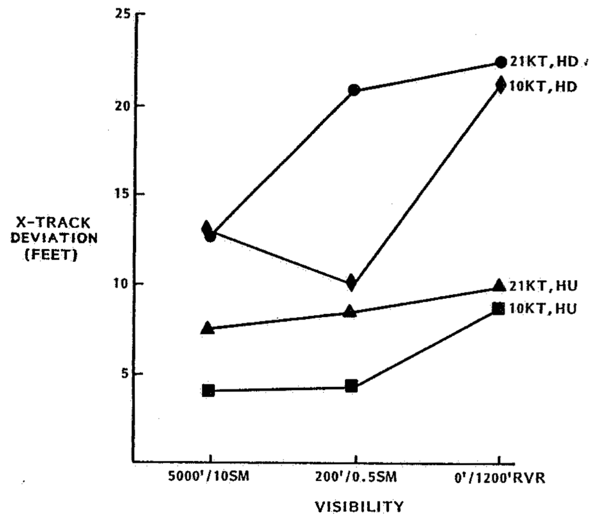
		MANUAL STEERING MODE				CONTROL-STICK STEERING MODE			
		HEAD-UP		HEAD-DOWN		HEAD-UP		HEAD-DOWN	
		090/10	135/21	090/10	135/21	090/10	135/21	090/10	135/21
5000'/ 10 SM	MEAN	9.73	8.77	18.92*	19.93*	9.53	10.75	13.20	9.10
	S.D.	4.88	7.43	13.67	16.13	4.50	5.75	7.15	5.15
200'/ 0.5 SM	MEAN	9.77	15.64	17.11*	22.07*	11.15	11.50	14.10	17.75*
	S.D.	2.28	9.39	14.13	17.17	3.00	3.35	9.10	15.25
0'/ 1200' RVR	MEAN	12.30	15.17	19.44*	22.49*	12.75	13.30	13.60	14.50
	S.D.	5.92	10.27	14.67	24.15	3.40	3.15	13.00	11.05

*: MEAN + 1 S.D VALUES EXCEED TOLERANCE

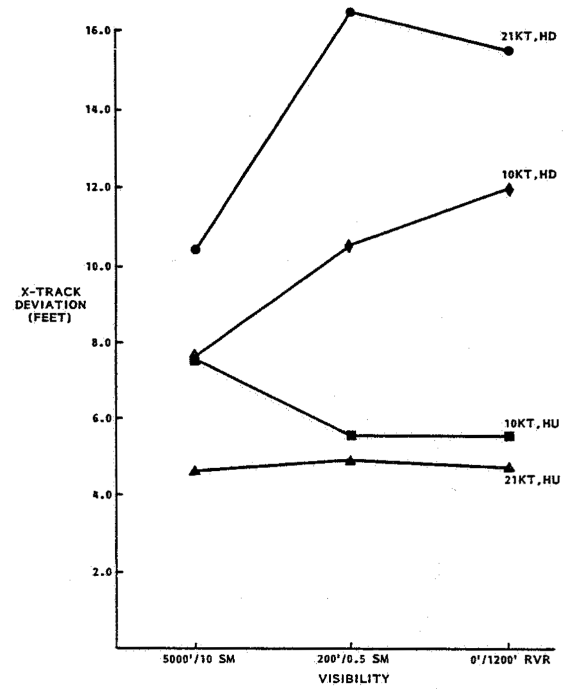
c) MEAN AND STANDARD DEVIATION VALUES

TOL: ± 50 FEET

Figure 45. X-Track Deviation at DH



a) MANUAL STEERING MODE



b) CSS MODE

		MANUAL STEERING MODE				CONTROL-STICK STEERING MODE			
		HEAD-UP		HEAD-DOWN		HEAD-UP		HEAD-DOWN	
		090/10	135/21	090/10	135/21	090/10	135/21	090/10	135/21
5000'/ 10 SM	MEAN	4.1	7.5	13.0	12.7	7.6	4.7	7.7	10.35
	S.D.	3.0	5.7	7.8	10.2	2.7	5.5	3.4	7.55
200'/ 0.5 SM	MEAN	4.2	8.4	10.0	20.9	5.5	4.9	10.5	16.6
	S.D.	2.9	4.0	9.9	22.0	2.4	6.9	7.8	14.1
0'/ 1200' RVR	MEAN	8.7	10.0	21.3	22.4	5.5	4.75	11.9	15.5
	S.D.	7.3	6.3	14.3	20.4	3.0	2.75	11.6	8.7

c) MEAN AND STANDARD DEVIATION VALUES

TOL: ± 50 FEET

Figure 46. X-Track Deviation at Touchdown

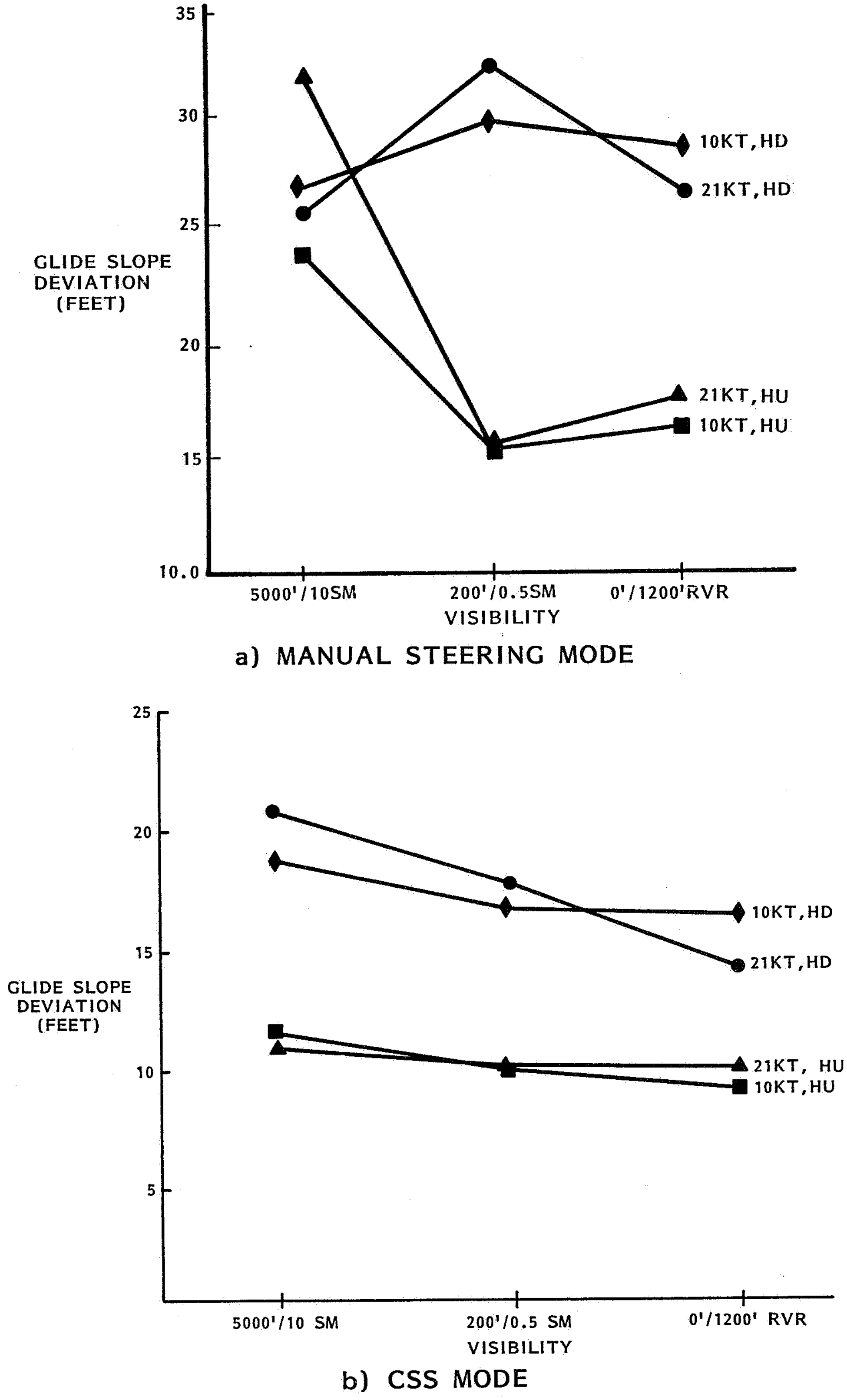
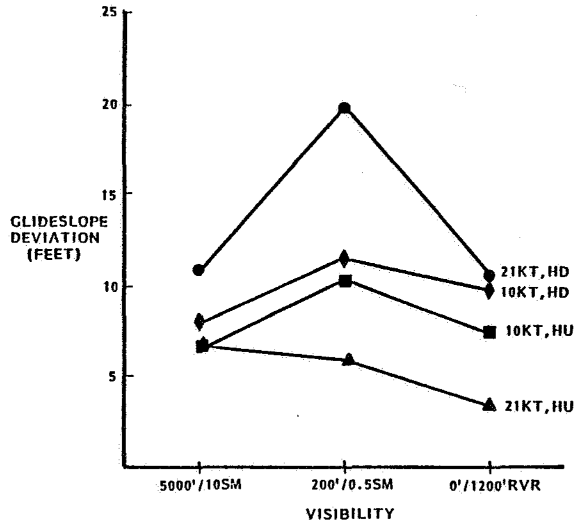
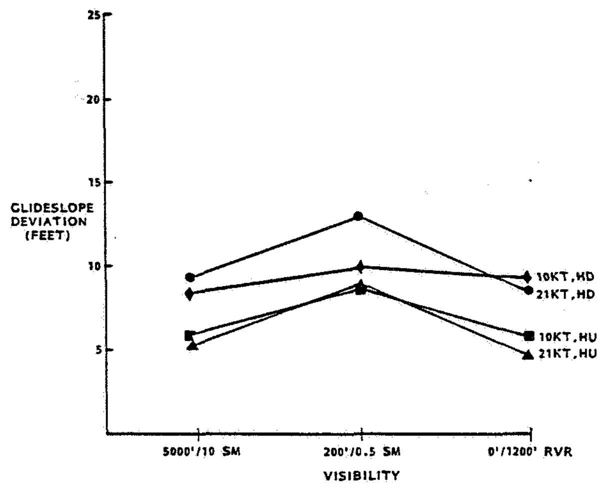


Figure 47. Glideslope Deviation OM to MM



a) MANUAL STEERING MODE



b) CSS MODE

		MANUAL STEERING MODE				CONTROL-STICK STEERING MODE			
		HEAD-UP		HEAD-DOWN		HEAD-UP		HEAD-DOWN	
		090/10	135/21	090/10	135/21	090/10	135/21	090/10	135/21
5000'/ 10 SM	MEAN	6.57	6.88	7.95	10.94	7.07	5.37	8.51	9.49*
	S.D.	6.03	7.07	6.47	7.64	9.00	6.34	8.39	12.23
200'/ 0.5 SM	MEAN	10.37*	5.92	11.67*	19.56*	8.83*	9.03*	10.03*	13.17*
	S.D.	10.64	3.80	9.86	11.95	13.13	13.93	11.85	16.83
0'/ 1200' RVR	MEAN	7.47	3.46	9.97	10.51	5.99	4.89	9.47	8.64
	S.D.	6.21	2.48	6.83	6.94	6.17	4.42	10.00	9.61

*: MEAN + 1 S.D. VALUES EXCEED TOLERANCE

c) MEAN AND STANDARD DEVIATION VALUES

TOL: ±20 FEET

Figure 48. Glideslope Deviation at DH

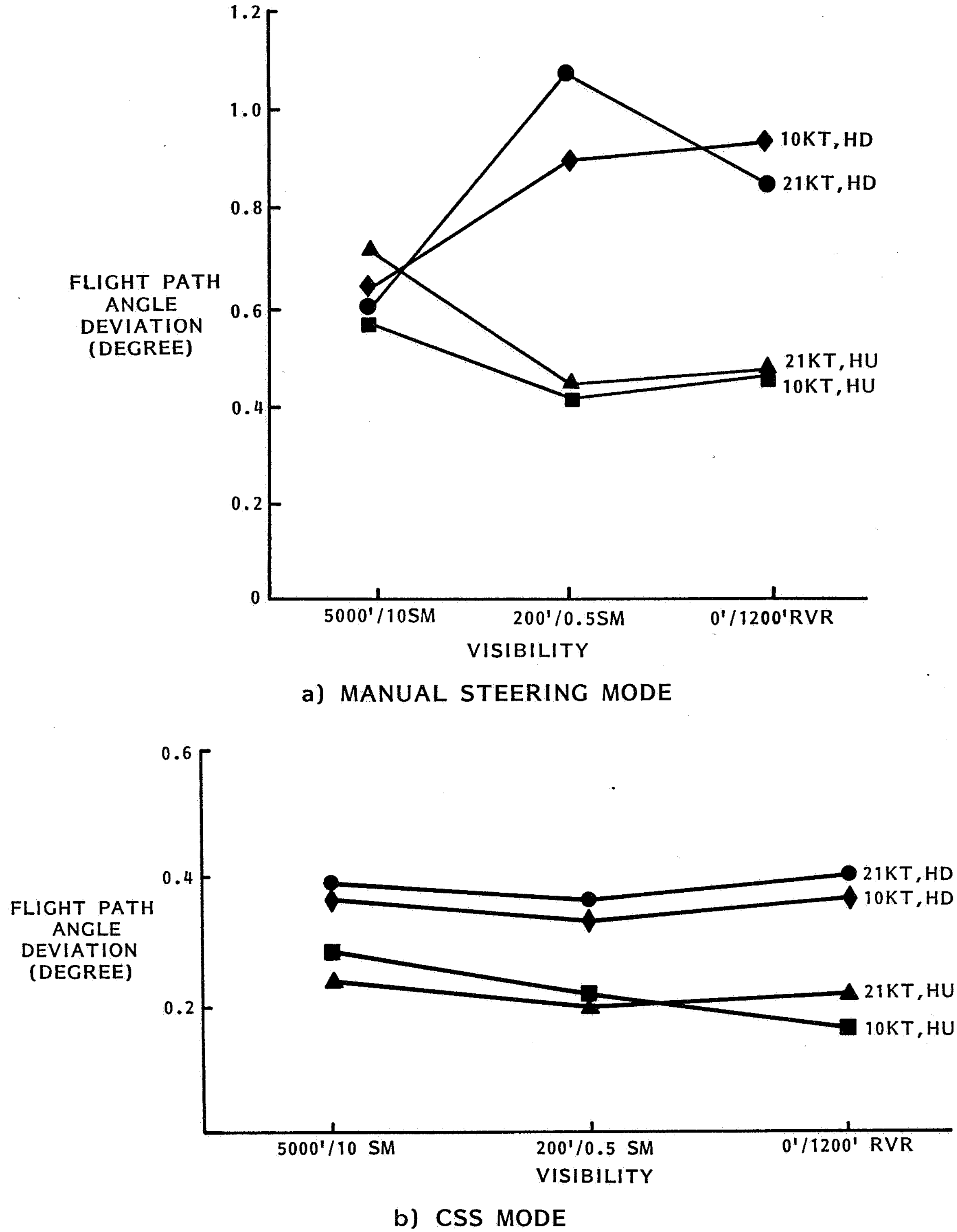
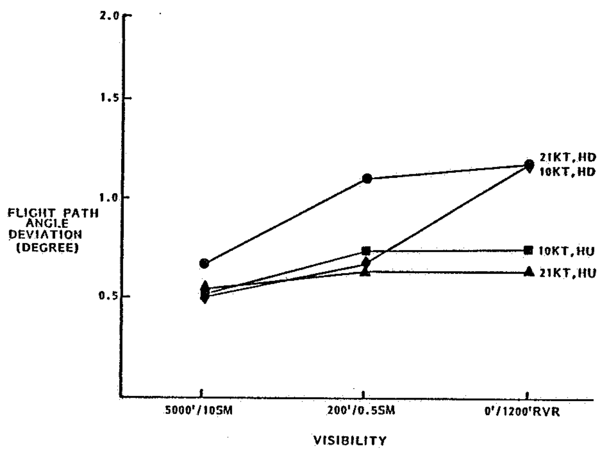
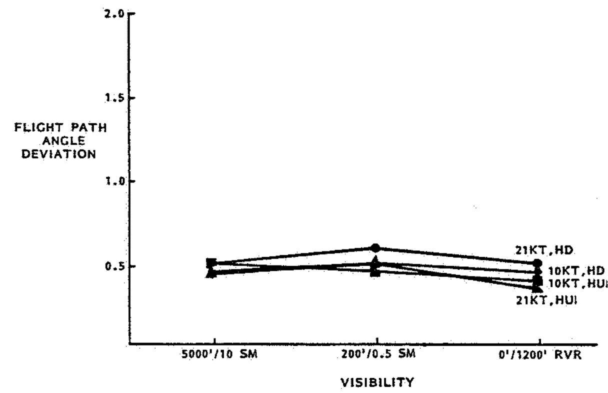


Figure 49. Flight Path Angle Deviation OM to MM



a) MANUAL STEERING MODE



b) CSS MODE

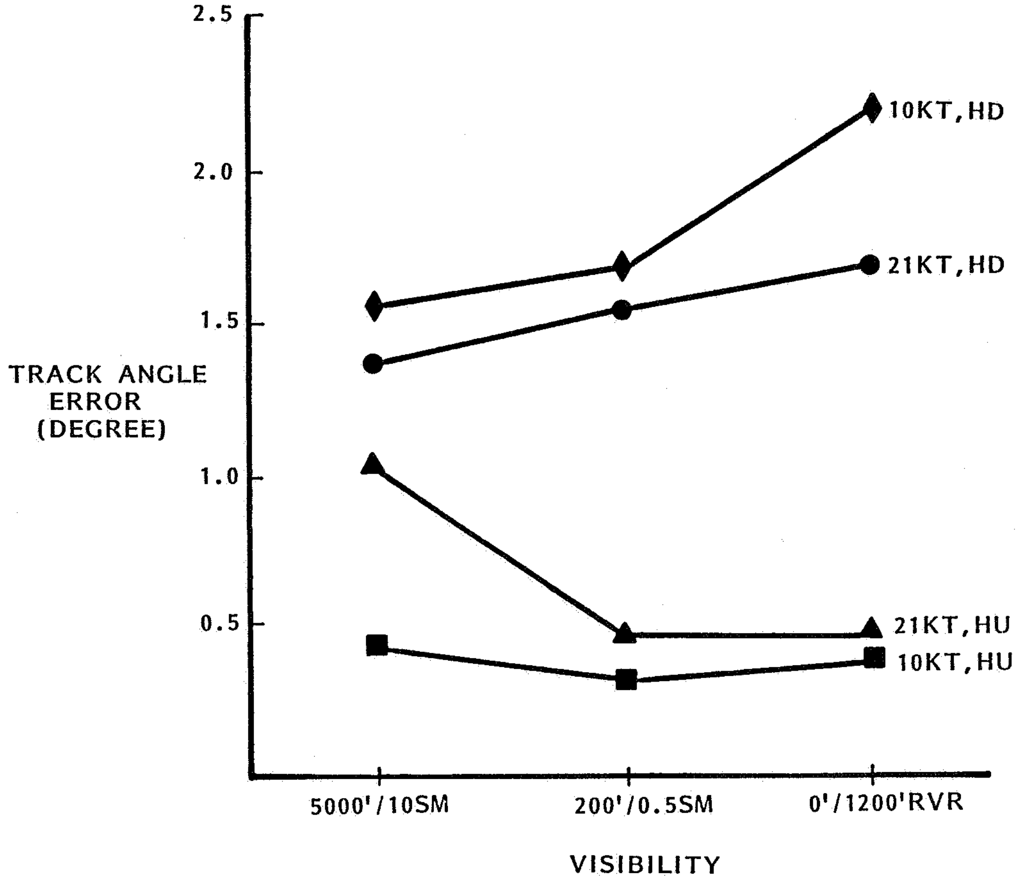
		MANUAL STEERING MODE				CONTROL-STICK STEERING MODE			
		HEAD-UP		HEAD-DOWN		HEAD-UP		HEAD-DOWN	
		090/10	135/21	090/10	135/21	090/10	135/21	090/10	135/21
5000'/ 10 SM	MEAN	0.51	0.53	0.50	0.67	0.50	0.50	0.50	0.50
	S.D.	0.17	0.27	0.24	0.29	0.40	0.30	0.40	0.40
200'/ 0.5 SM	MEAN	0.73*	0.63*	0.67*	1.09*	0.50	0.50	0.50	0.60*
	S.D.	0.45	0.56	0.43	0.50	0.50	0.50	0.50	0.60
0'/ 1200' RVR	MEAN	0.75*	0.63*	1.17*	1.17*	0.40	0.40	0.50	0.50
	S.D.	0.46	0.55	0.86	0.87	0.30	0.30	0.40	0.30

*: MEAN + 1 S.D. VALUES EXCEED TOLERANCE

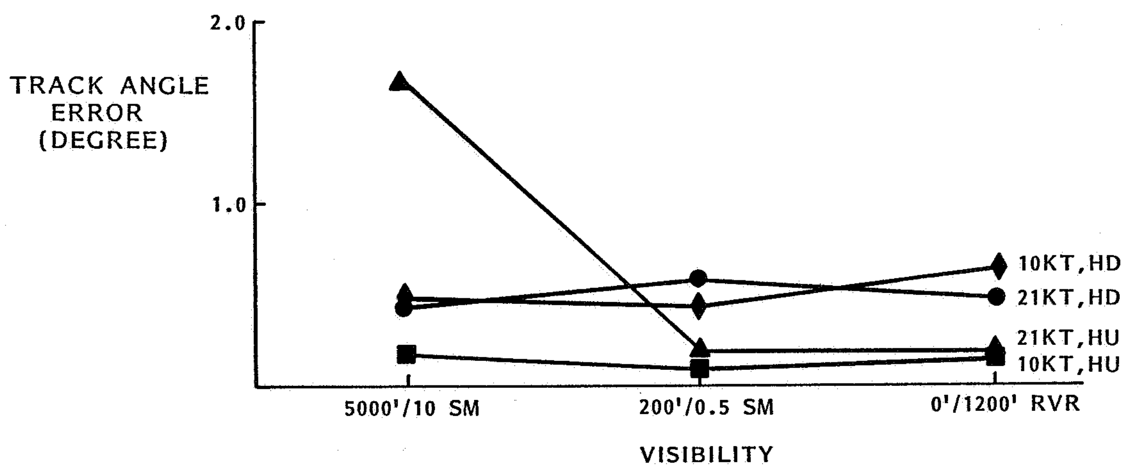
c) MEAN AND STANDARD DEVIATION VALUES

TOL: ± 1 DEGREE

Figure 50. Flight Path Angle Deviation at DH

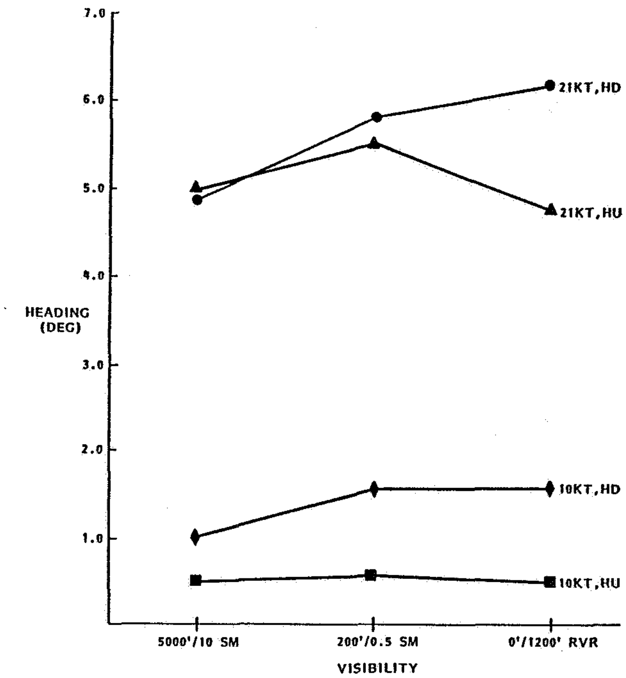


a) MANUAL STEERING MODE

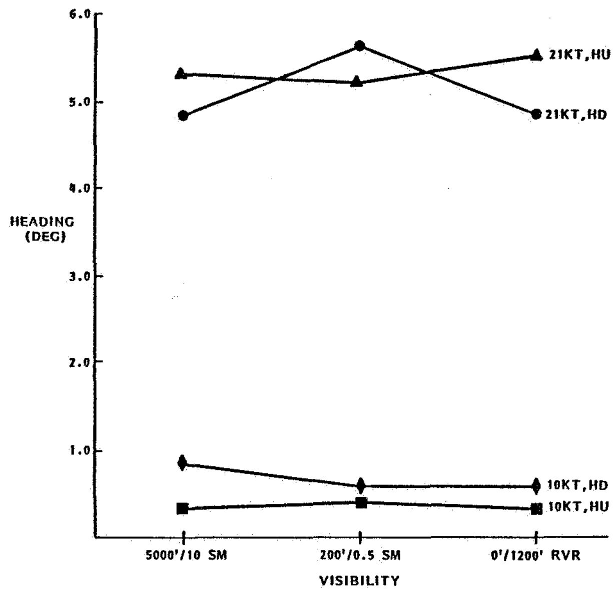


b) CSS MODE

Figure 51. Track Angle Error OM to MM



a) MANUAL MODE



b) CSS MODE

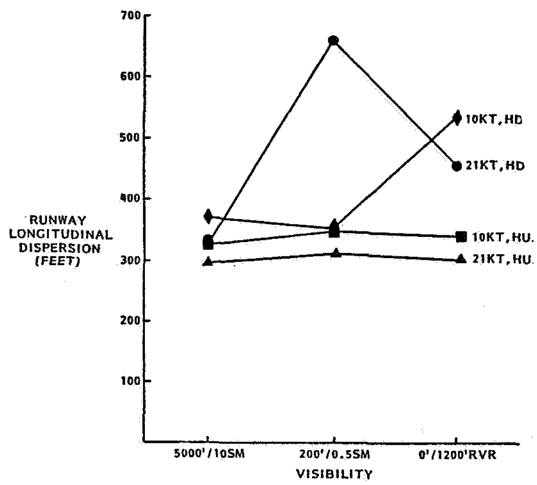
		MANUAL STEERING MODE				CONTROL-STICK STEERING MODE			
		HEAD-UP		HEAD-DOWN		HEAD-UP		HEAD-DOWN	
		090/10	135/21	090/10	135/21	090/10	135/21	090/10	135/21
5000'/ 10 SM	MEAN	0.49	4.95*	1.02	4.87*	0.35	5.3*	0.84	4.85*
	S.D.	0.25	1.76	0.74	2.82	0.39	1.5	0.81	1.95
200'/ 0.5 SM	MEAN	0.53	5.51*	1.55	5.81*	0.40	5.2*	0.60	5.65*
	S.D.	0.47	1.14	1.37	2.33	0.39	1.7	0.72	1.90
0'/ 1200' RVR	MEAN	0.49	4.70*	1.55*	6.19*	0.35	5.5*	0.59	4.85*
	S.D.	0.35	1.62	1.62	2.32	0.36	1.30	0.57	1.71

*: MEAN + 1 S.D. VALUES EXCEED TOLERANCE

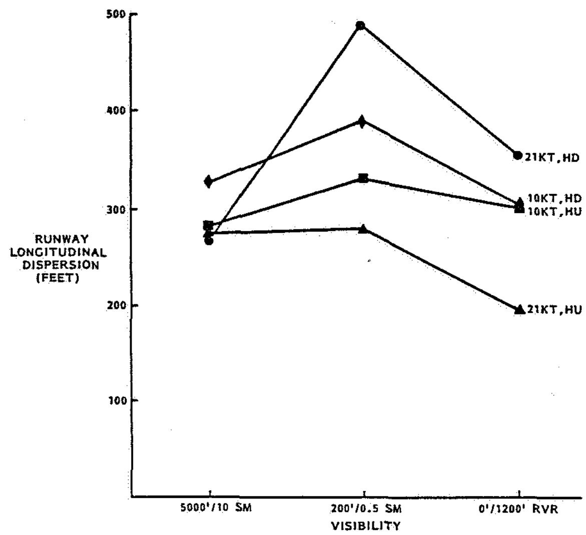
c) MEAN AND STANDARD DEVIATION VALUES

TOL: ± 3 DEGREES

Figure 52. Heading at Touchdown



a) MANUAL STEERING MODE

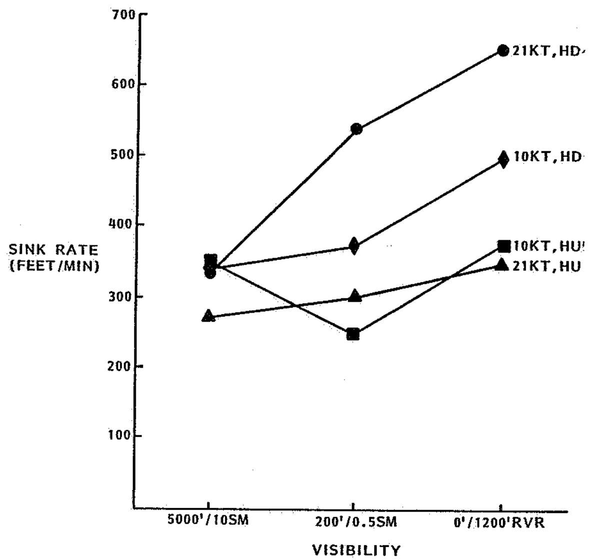


b) CSS MODE

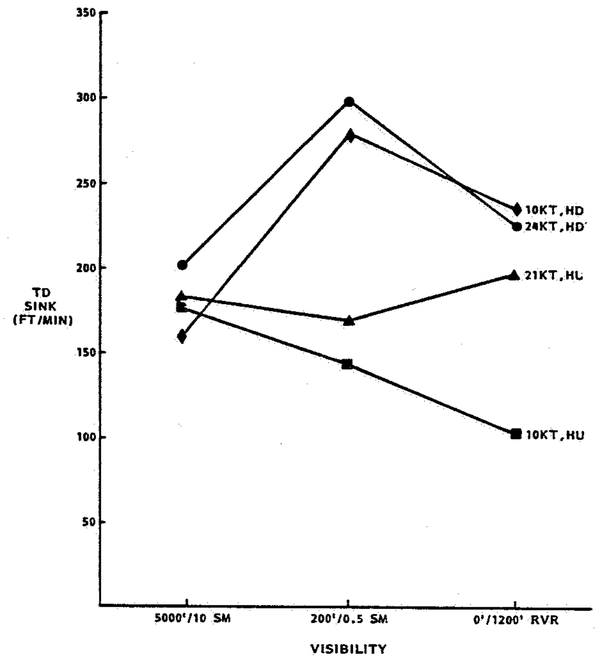
		MANUAL STEERING MODE				CONTROL-STICK STEERING MODE			
		HEAD-UP		HEAD-DOWN		HEAD-UP		HEAD-DOWN	
		090/10	135/21	090/10	135/21	090/10	135/21	090/10	135/21
5000'/ 10 SM	MEAN	329	297	371	325	283	277	327	270
	S.D.	237	244	201	268	289	246	215	349
200'/ 0.5 SM	MEAN	350	318	351	659	333	280	388	487
	S.D.	237	188	331	620	302	317	333	434
0'/ 1200' RVR	MEAN	339	300	538	457	301	177	305	356
	S.D.	261	172	379	207	279	149	235	254

c) MEAN AND STANDARD DEVIATION VALUES

Figure 53. Runway Longitudinal Dispersion



a) MANUAL STEERING MODE



b) CSS MODE

		MANUAL STEERING MODE				CONTROL-STICK STEERING MODE			
		HEAD-UP		HEAD-DOWN		HEAD-UP		HEAD-DOWN	
		090/10	135/21	090/10	135/21	090/10	135/21	090/10	135/21
5000'/ 10 SM	MEAN	350*	270*	339*	332*	180	181	165	205
	S.D.	212	173	148	189	109	95	141	65
200'/ 0.5 SM	MEAN	250	305*	372*	538*	145	117	285*	305*
	S.D.	106	166	188	321	84	79	193	183
0'/ 1200' RVR	MEAN	373*	350*	495*	655*	107	200	241*	235
	S.D.	198	265	319	238	79	107	195	139

*: MEAN + 1 S.D. VALUES EXCEED TOLERANCE

c) MEAN AND STANDARD DEVIATION VALUES

TOL: 400 FT/MIN

Figure 54. Sink Rate at Touchdown

	GROUP 1 MANUAL STEERING MODE WITH FLIGHT DIRECTOR	GROUP 2 CONTROL-STICK STEERING MODE WITHOUT FLIGHT DIRECTOR
INTERPRETABILITY		
• HEAD-UP	GOOD	EXCELLENT
• HEAD-DOWN	GOOD	GOOD
ALL REQUIRED INFORMATION PRESENT?		
• HEAD-UP	YES	YES
• HEAD-DOWN	YES	YES
PREFERRED DISPLAY	HEAD-UP	HEAD-UP
AIRCRAFT HANDLING QUALITY		
• BEST CASE WIND/VIS.	EXCELLENT	GOOD
• WORST CASE WIND/VIS	GOOD	EXCELLENT
WORKLOAD		
• HEAD-UP	MODERATELY LOW	MODERATELY LOW
• HEAD-DOWN	MODERATE	MODERATE

Figure 55. Median Subjective Rating Scores by Steering Mode

Report Documentation Page

NASA
National Aeronautics and Space Administration

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-4176		

4. Title and Subtitle	5. Report Date
An Evaluation of Flight Path Formats Head-Up and Head-Down	September 1988
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
George A. Sexton, Laura E. Moody, Jo Anne Evans, and Kenneth E. Williams	LG87ER0154
	10. Work Unit No.
9. Performing Organization Name and Address	11. Contract or Grant No.
Lockheed Aeronautical Systems Company Georgia Division 86 South Cobb Drive Marietta, Georgia 30063	NAS1-18029
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Contractor Report
National Aeronautics and Space Administration Washington, D.C. 20546-0001	14. Sponsoring Agency Code

15. Supplementary Notes

Langley Technical Monitor: George G. Steinmetz

Technical Representative of the Contracting Officer: Cary R. Spitzer

Final Report

16. Abstract

Flight path primary flight display formats were incorporated on head-up and head-down electronic displays and integrated into an Advanced Concepts Flight Simulator. Objective and subjective data were collected while ten airline pilots evaluated the formats by flying an approach and landing task under various ceiling, visibility and wind conditions.

Deviations from referenced/commanded airspeed, horizontal track, vertical track, and touchdown point were smaller using the head-up display (HUD) format than the head-down display (HDD) format, however, not significantly smaller.

Subjectively, the pilots overwhelmingly preferred (1) flight path formats over attitude formats used in current aircraft and (2) the head-up presentation over the head-down, primarily because it eliminated the head-down to head-up transition during low visibility landing approaches. This report describes the simulator, the flight displays, the format evaluation, and the results of the objective and subjective data.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Flight Path, Head-Up Display, Head-Down Display, Side Stick Controller, Advanced Concepts Simulator	Unclassified - Unlimited Subject Category 06

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	136	A07

NASA FORM 1626 OCT 86

NASA-Langley, 1988

For sale by the National Technical Information Service, Springfield, Virginia 22161-2171