

**AD-A253 363**



**Preliminary Assessment of Primary Flight Display  
Symbolism for Electro-optic  
Head-Down Displays**

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## FOREWORD

This Technical Memorandum (TM) documents the results of an in-house research effort accomplished for the United States Air Force Wright Laboratory's Joint Cockpit Office (WL/XPK), Wright-Patterson AFB, Ohio. The work was performed by Midwest Systems Research, Inc. (MSR) under contract F33615-88-C-3612. The monitor of this contract is Mr. George Palmer (WL/FIPB). Program Manager for the effort is Mr. Larry Butterbaugh (WL/FIPC).

Software development and integration was accomplished by Lt. Michael Cook and Mr. Antonio Ayala of Wright Laboratory's Cockpit Integration Division (WL/FIP) and Mr. James Stadler of Midwest Systems Research, Inc..

This study is an initial step supporting a USAF program to research and develop a recommended standard for the presenting primary flight information on an electro-optic head-down display. The purpose of this memo is to provide the technical community with the Cockpit Integration Division's assessment of two existing primary flight display formats that have evolved in commercial transport aircraft based on years of research and operation. This TM does not represent official Air Force position, but offers useful information and creates a data base from which further head-down primary flight display symbology development can proceed.

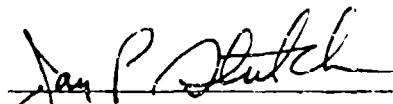
This Technical Memorandum has been reviewed and is approved.



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## **ABSTRACT**

This Technical Memorandum describes a preliminary study to assess the basic operational utility and pilot preference for head down primary flight display (PFD) symbology, in order to derive a preferred baseline PFD format for further evaluation. The PFD formats used in this study were based on display formats and symbology developed by Boeing Commercial Airplane Group (B747-400), McDonnell Douglas (MD-11), and concepts developed by the Wright Laboratory Cockpit Integration Division (WL/FIP). The thrust of these assessments was to identify a preferred symbology and display format which was easy to interpret during instrument flight, provided attitude awareness to the pilot during Instrument Meteorological Conditions (IMC), and provided appropriate cues for recovery from unusual attitudes in modern aircraft equipped with glass cockpits. No attempt was made to examine the various display or symbology enhancements needed for weapon delivery or other special mission activities. The resulting primary flight display, which was derived through pilot assessments of alternate formats in the Microprocessor Application of Graphics and Interactive Communication (MAGiC) cockpit, combines preferred features of the various concepts. The resulting baseline Primary Flight Display concept presented here is applicable, but not necessarily limited, to use in a transport or cargo type aircraft.

## INTRODUCTION

As part of an Air Force effort to standardize aircraft primary flight displays (PFDs), the Cockpit Integration Division has evaluated various formats for primary flight. The Air Force's concern for standardization stems from a proliferation of PFD formats as cockpits have transformed from electromechanical instruments to electro-optical displays. The resulting "glass" cockpits afford the designer almost unlimited freedom to create PFD formats, and a plethora of such formats has been the result. Additionally, there is concern that the "missionization" of the formats, i.e., incorporating mission related data and other recent changes into the basic flight format, has destroyed the T-scan concept and the Integrated Flight Instrument System arrangement which evolved from the Whole Panel Program conducted by the Flight Control Laboratory at Wright-Patterson AFB. Flight testing of these display concepts and systems was performed initially at WPAFB and later, in an OT&E context, at the Instrument Pilot Instructor School at Randolph AFB during the late 1950's and throughout the 1960's. (Ref.1)

### T-Scan Concept

Electromechanical instrument designs in use today that result from this work, line up certain control, performance and navigational information items in an arrangement that places the airspeed indicator, Attitude Director Indicator and altimeter along a horizontal line and the Attitude Director Indicator and Horizontal Situation Indicator on a vertical line (Fig. 1). This is known as the "T scan concept" and is the recommended instrument arrangement (Ref. 2). The horizontal line provides information related to pitch and power; the vertical line provides information related to bank and heading. As a result of this geometrical configuration, the critical flight and performance instruments formed a "T" scan pattern, an easily interpretable, integrated set of information items.

### Integrated Flight Instrument System

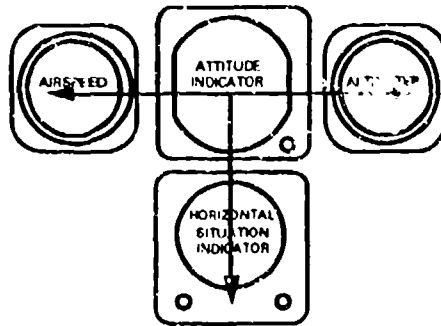
In a concurrent development and in support of an anticipated need for integrating ground, data linked, commands (heading, altitude and speed) to

the aircraft, the Integrated Flight Instrument System (IFIS) was developed by adding vertical scale performance displays in place of the conventional round dials. In this configuration, airspeed, mach number, pitch attitude, vertical velocity and altitude were read in reference to a single horizontal line. Command markers that could be set by the pilot, or remotely, were integrated into the displays in a "fly to" format to serve as memory devices and to provide consistent movement in response to pitch attitude control actions. Two advantages of the IFIS over the equivalent round dial system are command marker features and the "T-line" concept (Ref. 3).

Command Markers. Command markers are used with the vertical scale altitude and airspeed displays to show desired values relative to current values. The marker "rides" the tape, and when aligned with the fixed index line, indicates that the desired airspeed has been reached or is being maintained (Fig. 2). A command airspeed slewing switch is provided to manually set a command airspeed marker. The altimeter displays altitude on a movable tape scale and has the same command features as the air speed indicator (Fig. 3). The horizontal situation indicator (HSI) replaced the heading indicator, radio magnetic indicator, course indicator, and range indicator.

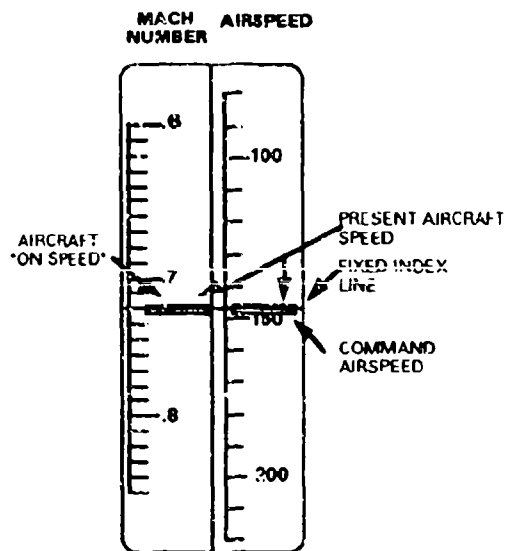
"T-Line" Concept. The "T-scan" concept that enables the pilot to perform an efficient crosscheck is refined by the design of the display components of the IFIS into the "T-line" concept. The horizontal portion of the "T-line" is formed when the command markers on the altitude and mach/airspeed indicators, and the pitch steering bar on the attitude director indicator (ADI) are aligned with their fixed index lines indicating aircraft performance is as desired. (Fig. 4)

The vertical portion of the "T-line" is composed of the course deviation indicator on the HSI and the bank steering bar of the ADI. When the course selector arrow and course deviation indicator on the HSI, and the bank steering bar on the ADI are centered, indicating all commands are satisfied, the vertical portion of the "T-line" is formed. Whenever aircraft performance or flight path deviate from the desired (commanded), the "T-line" is broken.



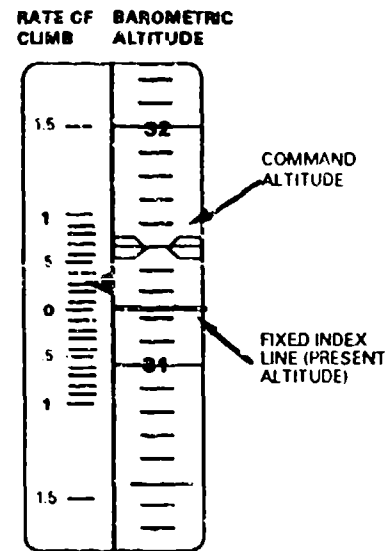
"T-SCAN" ARRANGEMENT OF BASIC FLIGHT INSTRUMENTS

FIGURE 1



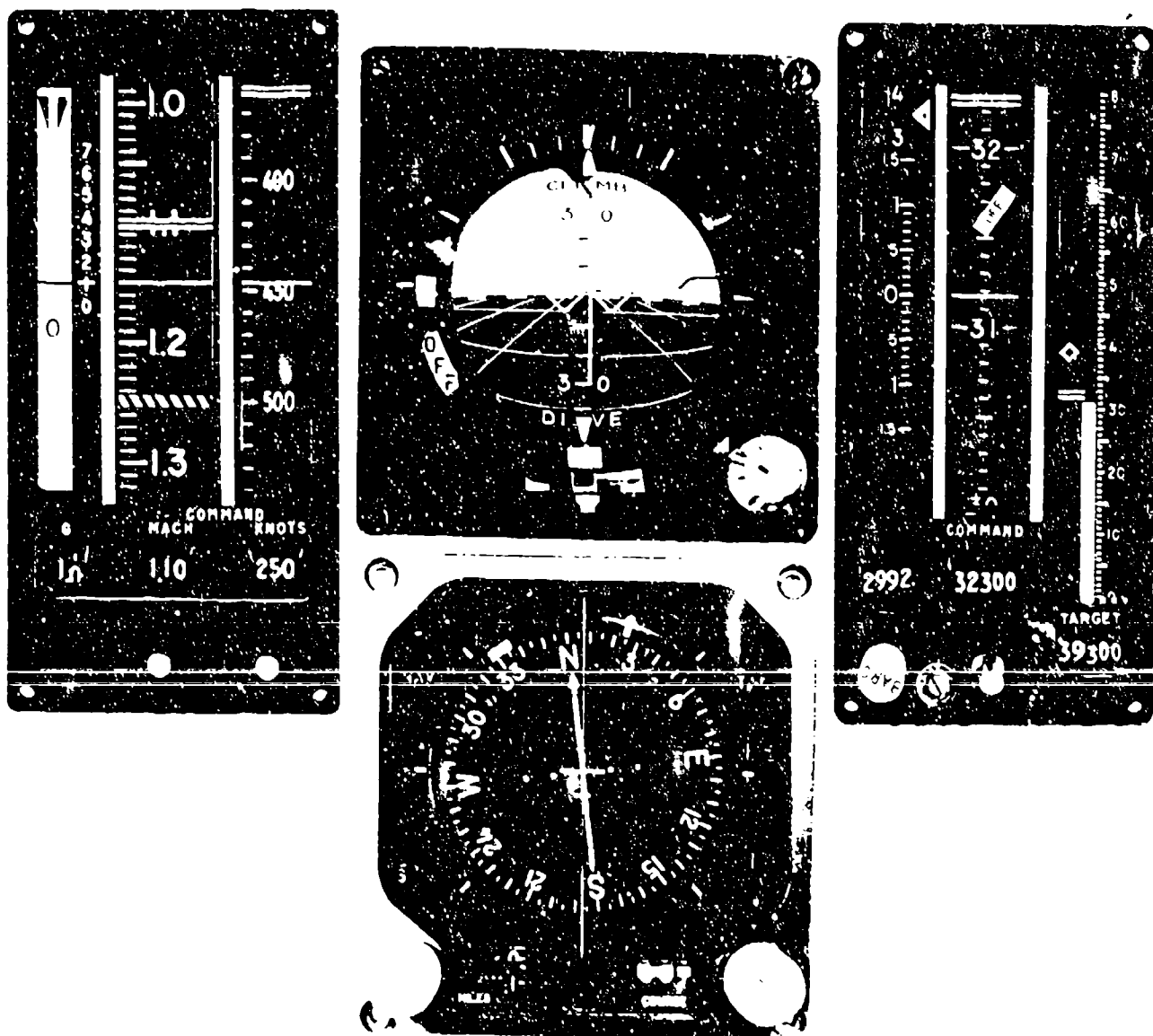
AIRSPEED INDICATOR FROM IFIS SHOWING DESIRED MACH/AIRSPEED ATTAINED

FIGURE 2



ALTITUDE INDICATOR FROM IFIS SHOWING PRESENT ALTITUDE BELOW DESIRED ALTITUDE

FIGURE 3



T-LINE CONCEPT OF AIRCRAFT CONTROL  
FIGURE 4

The strengths of the "T-line concept" are: minimum time to scan, all displays are "fly to", and markers serve as memory devices. By using the command features of the system, cross check is simplified and deviations from the desired are readily detectable. The task of cross-checking is much easier because the pilot can simultaneously observe the attitude indicator, his most important instrument, and the proper performance instruments. The T-line, first in flight test and later in actual operation in the F-105, F-106, F-111, C-141, C-5 and other aircraft, has shown itself to be a significant help to the pilot in utilizing the primary flight display in Instrument Meteorological Conditions.

The research documented here addressed two key questions: Can the basic, proven T-scan and the T-line concept of electromechanical cockpits be incorporated successfully into glass cockpits of modern multi-purpose display equipped USAF aircraft, and what symbology and configuration should be incorporated into the display format?

The initial PFD formats examined were not from military transport cockpits, which are just making the transition to glass cockpits, but rather based on commercial transport displays. Since the commercial transport community has been flying glass PFDs for over 10 years in aircraft such as the Boeing 757/767, and has built up extensive operational experience, it was decided to examine the latest thinking in the commercial aviation community. Therefore, the Boeing 747-400 and the McDonnell Douglas MD-11 were chosen as the basis for the formats used in this initial assessment.

Two obvious departures from the original Air Force convention are presented in these display systems. The first is in numbering the airspeed scale in reverse of the IFIS, resulting in a "fly-from" configuration. The second is the side-by-side arrangement of the two (vertical and horizontal) situation displays. In these, one presents attitude and pitch control related performance information while the other presents horizontal situation information in the form of a map or horizontal situation type of format. In this configuration, lateral and vertical deviation indicators on the "PFD" provide some minimal navigational information; for navigation situation awareness, however, the pilot must scan laterally to the adjacent display. This breaks the "T-scan" into two separate parts.

Following this initial assessment of the two PFD formats, the best features of both were combined to form a blended format. In future studies, this composite format will be evaluated as a baseline against a military mission.

It should be noted that efforts are underway to develop PFDs for fighter aircraft as well as transports. Following the completion of that research, it will be determined if a separate standard is needed for the two types of aircraft, or if a single standard will be sufficient for both.

## **OBJECTIVE**

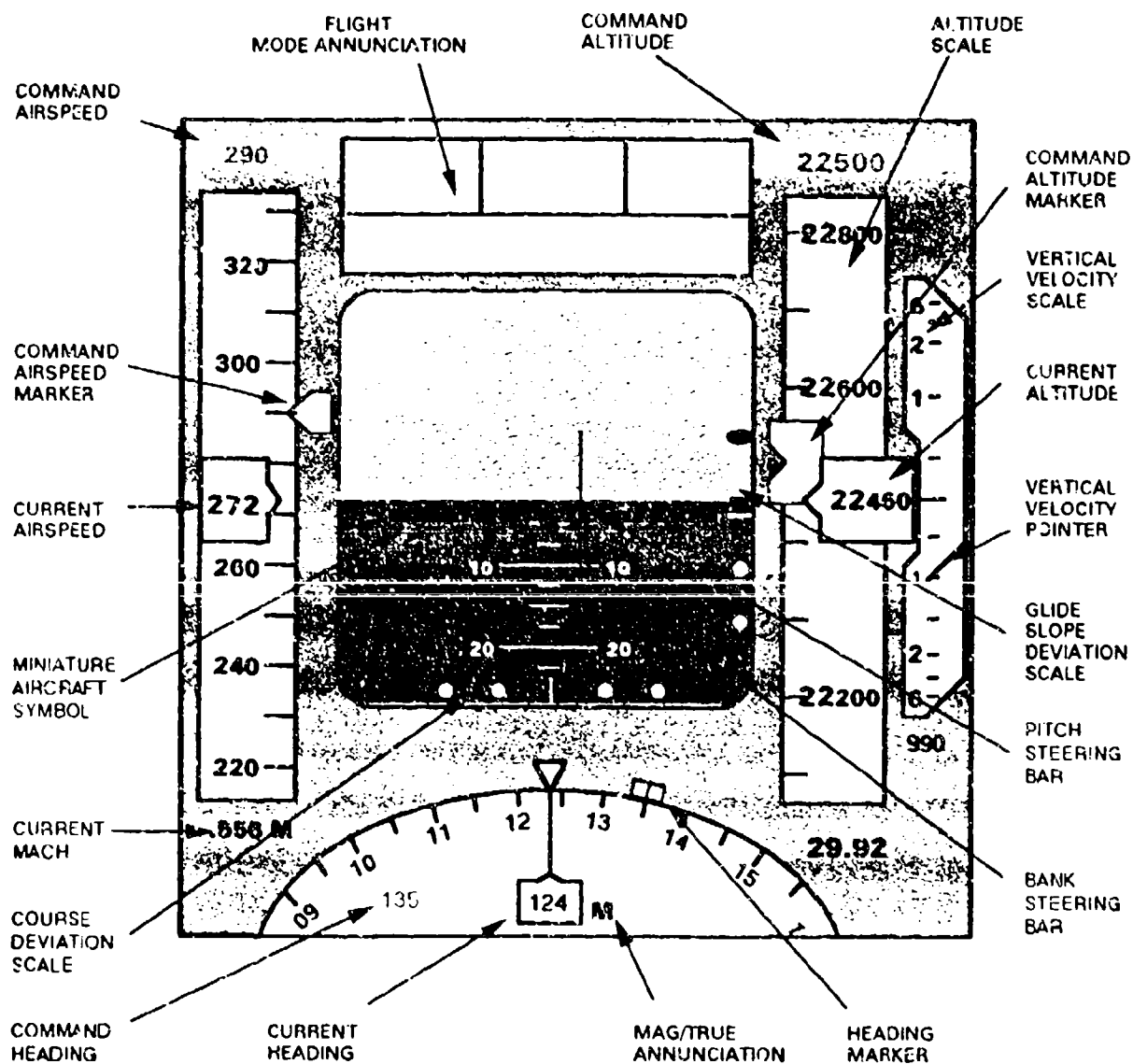
The objective of this initial study was to derive, through comparative assessments, a baseline for head-down display symbology and format for the presentation of primary flight information. This report documents the results of this assessment and the derived baseline.

## **METHOD**

### **Apparatus**

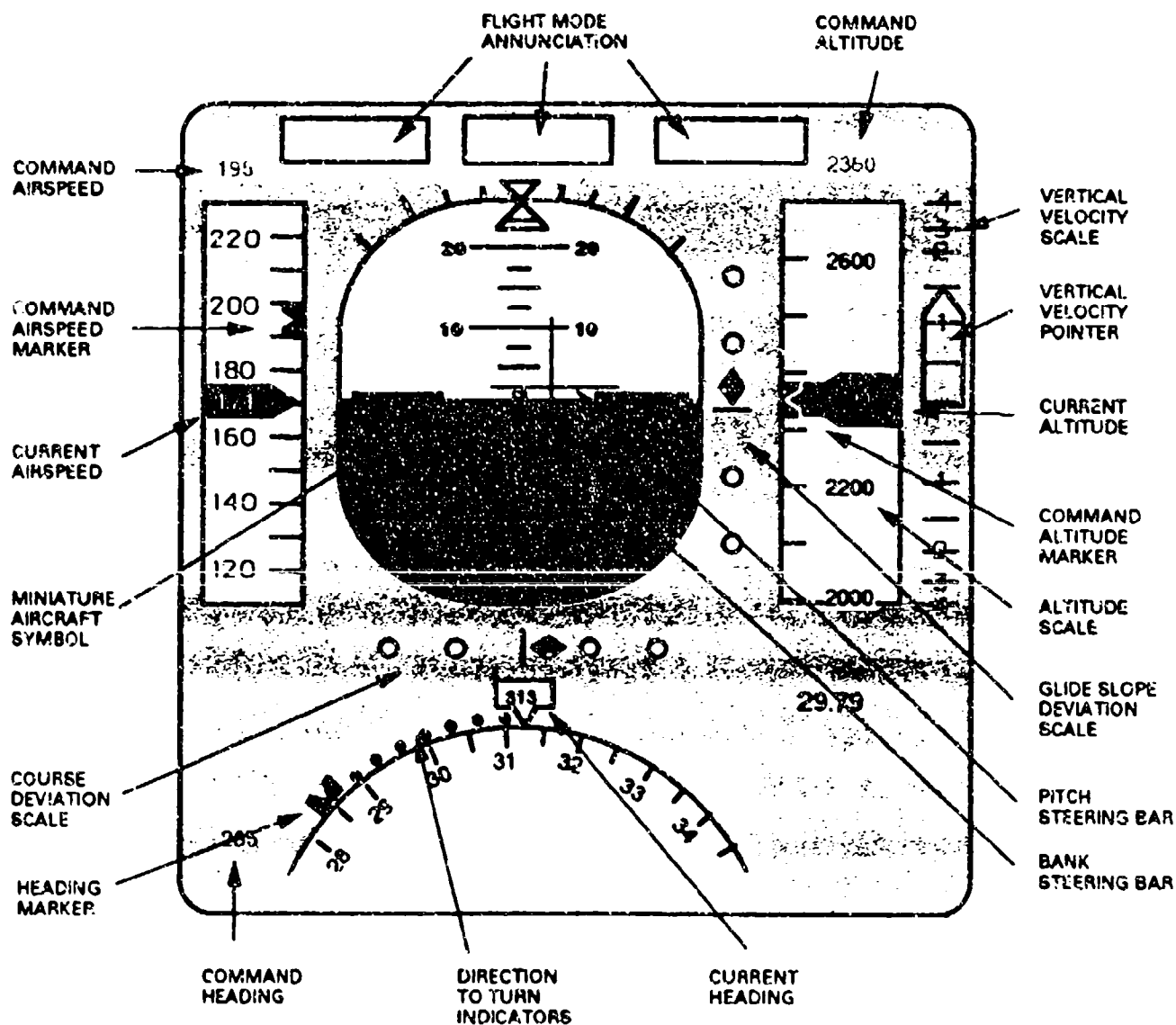
Cockpit. This study was conducted in a generic single-seat cockpit facility using a modified F-16 aeromodel.

Display Formats. The two formats used in this study were based on those of the Boeing 747-400 primary flight display (Ref. 4), as shown in Figure 5, and the McDonnell Douglas MD-11 primary flight display (Ref. 5), as shown in Figure 6. These formats are designed for presentation on 8-inch displays, and were reproduced to full-scale for this study. The display formats were programmed using Silicon Graphics IRIS 4Ds. Two additional formats were provided in order to perform the evaluation flying tasks: a navigation map (Figure 7); and a horizontal situation indicator (Figure 8). A stop watch with a second hand was present on one of the displays to time legs of the flight when required. There was also a touch-activated keypad to enter commanded airspeeds, altitudes, headings, and courses.



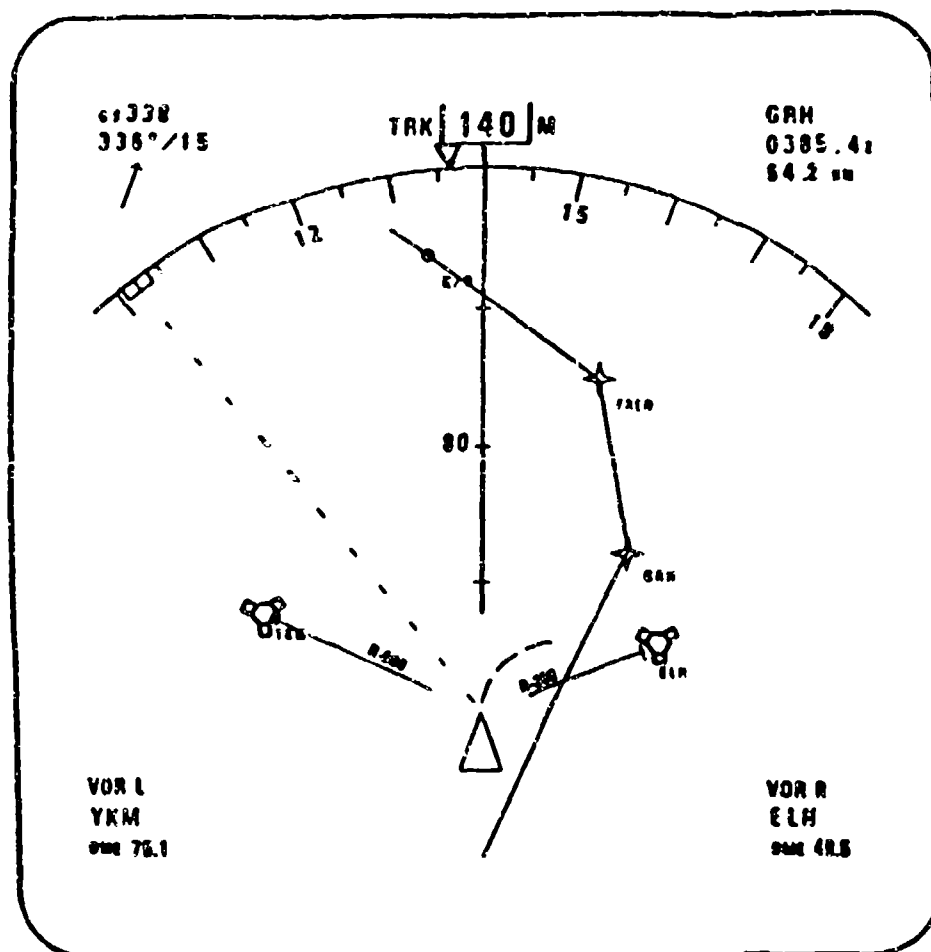
BOEING 747-400 DISPLAY

FIGURE 5

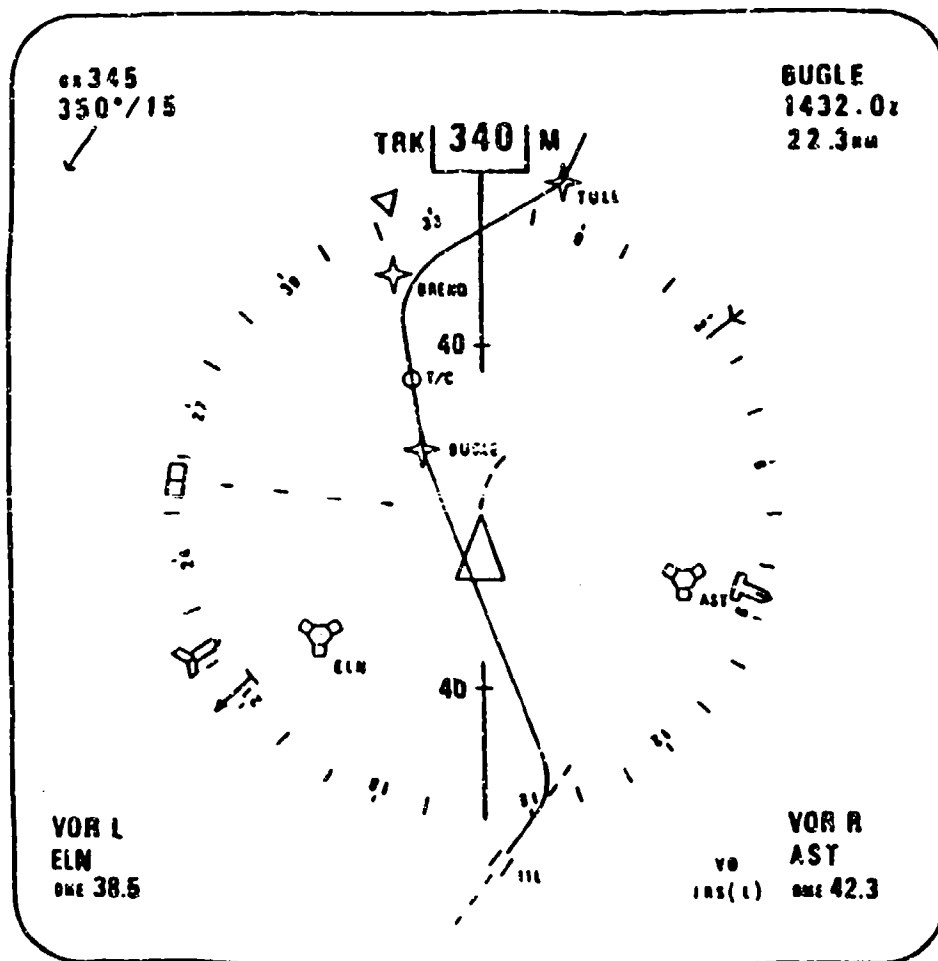


McDONNELL DOUGLAS MD-11 DISPLAY

FIGURE 6



Navigation Map Format  
Figure 7



Horizontal Situation Indicator Format  
Figure 8

## Primary Flight Display Key Differences.

ADI. The B747-400 and the MD-11 present the same information using different formats (See Figures 5 and 6). The MD-11 has a rounded ADI display with the glideslope and localizer scales and indicators appearing outside of the display window. The B747-400 has a square ADI display with the glideslope and localizer scales and indicators appearing inside the ADI viewport.

In each of the formats, the attitude indicator is displayed as the simulation of a mechanical ADI ball, shown in a clipped window. The ball is divided by a solid white horizon line extending from one side of the sphere to the other. The top or "sky" half is colored cyan; the lower or "ground" half is brown. Pitch reference lines and alphanumerics are colored white. The total viewable pitch range is approximately 45°. The pitch reference scale indicates pitch angle through 90° climb or dive. The pitch lines are graduated in 2 1/2° intervals with numerical indications at each 10° of pitch. The 5° tic marks are twice as long as the 2 1/2° tic marks and the 10° reference lines are twice as long as the 5° tic marks. Characters, pitch scale and horizon rotate and translate in pitch and roll about the fixed aircraft reference symbol. Bank attitude is indicated by the position of the bank pointer relative to the bank scale located at the top of the attitude indicator. The scale is marked with 0°, 10°, 20°, and 30° indices. The B747-400 also has a 45°, and the MD-11, a 60° bank index. The zero degree index is triangular shaped and the thirty degree indices are drawn longer than the other lines for easy reference. The points of the digital readout windows on the airspeed and altitude scales can be used for 90 degree bank reference points. The bank pointer moves in an arc from the attitude indicator center. The pointer is triangular shaped, solid white in color, and also serves as a sky pointer.

Vertical Velocity Indicator. The MD-11 presents the vertical velocity indicator outboard of the altitude scale. The "climb/dive" rate is shown by a black, outlined in white, arrow projecting upward or downward from the "0" (unlabeled) index on the scale. The usable scale is plus or minus 4000 feet per

minute. The B747-400 has a more conventional type moving needle that is read against a linear scale that is usable from plus or minus 6000 feet per minute. It is located outboard of the altitude scale. The actual rate of change is digitally displayed above, if climbing, or below, if descending, the vertical velocity scale.

Command Markers. For both formats the command markers represent the position of the pilot selected values of airspeed, altitude and heading on the respective scales. If the selected value is not visible (off scale) the marker rests at the end of the scale nearest to the point that it will appear. The marker "rides" the tape, and when aligned with the fixed index line, the commanded value has been reached or is being maintained. Pilot selected values for airspeed and altitude are shown in digital form immediately above their respective scales. Pilot selected headings are shown in digital form on the left side of the compass rose.

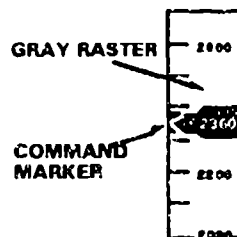
In both formats, the markers are "fly to" symbols with the exception of airspeed. The airspeed scale has the large numbers on top, thus making it a "fly from" command. The MD-11 has solid magenta colored "bow-ties" () for all three parameters. The length of the marker represents 10 knots when used on the airspeed scale. The markers are the same general shape for each of the scales. The B747-400 marker symbols are larger and in outline form () when selected and are colored solid magenta when riding the tape. Three different marker symbols are used with the three different scales.

Heading Dots. The MD-11 uses a series of dots around the heading scale to show the pilot the shortest direction to turn when a new heading is selected. The B747-400 does not have this feature.

#### Common Features of Both PFDs.

Information Scales. The airspeed and altitude scales are vertical and appear on the left and right sides of the display, respectively. Pointers are provided for each scale to provide an accurate readout. Each scale is provided with a digital readout of the current value in a window located in the middle of the scale. Each scale has provisions for a command marker to indicate reference airspeed, heading and altitude.

Airspeed. The total range of the displayed airspeed scale is approximately 110 knots. The scale is graduated in 10 knot increments and numbered each 20 knots. The scale is drawn on a gray colored background. An exact readout of current airspeed is presented in the window in the center of the scale. This readout changes whenever the airspeed changes by one knot.

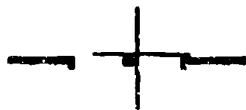


Altitude. Altitude is displayed on the altitude scale on the right side of the display. The total range of the displayed scale is approximately 800 feet with the higher numbers on the top of the scale. The scale is graduated in 100 foot increments numbered at each 200 foot increment. The scale is drawn on a gray colored background. A digital readout of altitude is provided in the window in the center of the scale.

Heading. The aircraft's heading is displayed at the bottom of the display. Seventy scale degrees are in view at all times. The scale is shown in 5 degree increments numbered with two digit numbers each 10 degrees. The aircraft heading is displayed to the nearest degree in the readout window in the middle of the scale. As the aircraft turns right, the scale moves from right to left. The scale can be selected to read magnetic, true, or grid heading. The default is the magnetic mode.

Flight Director. The flight director is used to intercept and maintain a selected track during navigation or ILS approaches. When dual cue cross bars

symbology is used for the flight director, the aircraft is flown so that the bank steering bar and the pitch steering bar are centered over the aircraft symbol.



If the bars are centered, the aircraft is either correcting properly or is flying the desired flight path. The bars are "fly to" commands and are colored magenta.

A second option is available for both formats. Flight director symbology is an aircraft symbol with command bars (wings).  The command bars are colored magenta ("fly to") and the aircraft symbol is colored black. The aircraft is flown so as to nestle the aircraft symbol into the wings to satisfy commands. For optimum operation a definite, thin open space (line) is viewed between the command bars and the aircraft symbol when steering commands are satisfied. The open area will widen or disappear as pitch attitude changes or command bars move to provide a new pitch command. Roll (heading correction) commands are seen as unbalanced line width, the low command bar side representing the direction of the turn command. Banking the airplane toward the low command bar until the lines on both sides appear equal satisfies the bank command.

Mach Number. The aircraft mach number is displayed in digital form immediately below the airspeed scale on the B747-400 and is shown in the cruise mode, inboard of the airspeed tape, opposite the airspeed pointer on the MD-11.

Sideslip Indicator. The aircraft sideslip is displayed as a trapezoid which moves relative to the bank pointer. Sideslip is represented by indicator movement along the bottom of the bank pointer (left or right, in the direction of the acceleration) regardless of the bank angle. The indicator is centered for zero acceleration. The indicator is white in color.  SIDESLIP TO RIGHT

Flight Path Marker. When selected, the flight path marker (FPM) provides the pilot with an outside world reference with regard to actual aircraft flight

path. It represents the point towards which the aircraft is flying at all times. The symbol used is a circle with wings and tail. The FPM is aircraft axis stabilized in roll (the FPM wings stay parallel to the aircraft wings). This symbol was not tested during the study.

Aircraft Symbol. The aircraft symbols used in both formats are similar when used with both the dual cue and single cue flight director. This symbol is displayed at all times. The symbol is analogous to the miniature aircraft symbol used with the standard attitude indicator and remains fixed at the center of the display.    Aircraft pitch may be determined by reading the aircraft symbol against the pitch scale.

Pitch Limit. The pitch limit (limiting angle of attack) indicator, is drawn on the pitch scale of the attitude indicator and represents a "not to exceed" angle of attack.   The values are determined by the aircraft computer. The symbol is white in color during normal flight, becomes amber as the pitch attitude approaches within  $2\frac{1}{2}^{\circ}$  of the limit, and changes to red as the limit is reached. This information is used by the pilot when avoiding wind shear. The symbol was not tested during the study.

Glide Slope Deviation Reference Scale. This scale with its magenta diamond shaped indicator shows the aircraft's vertical deviation from a commanded vertical path, such as found with an ILS glideslope, station keeping equipment or an autonomous landing system.

Course Deviation Reference Scale. A presentation of the primary guidance lateral deviation is displayed on the scale by a magenta diamond symbol. It is used to indicate deviation from a commanded path such as found with the localizer of an ILS approach, station keeping equipment, inertial navigation systems and TACAN/VOR radials.

## Subjects

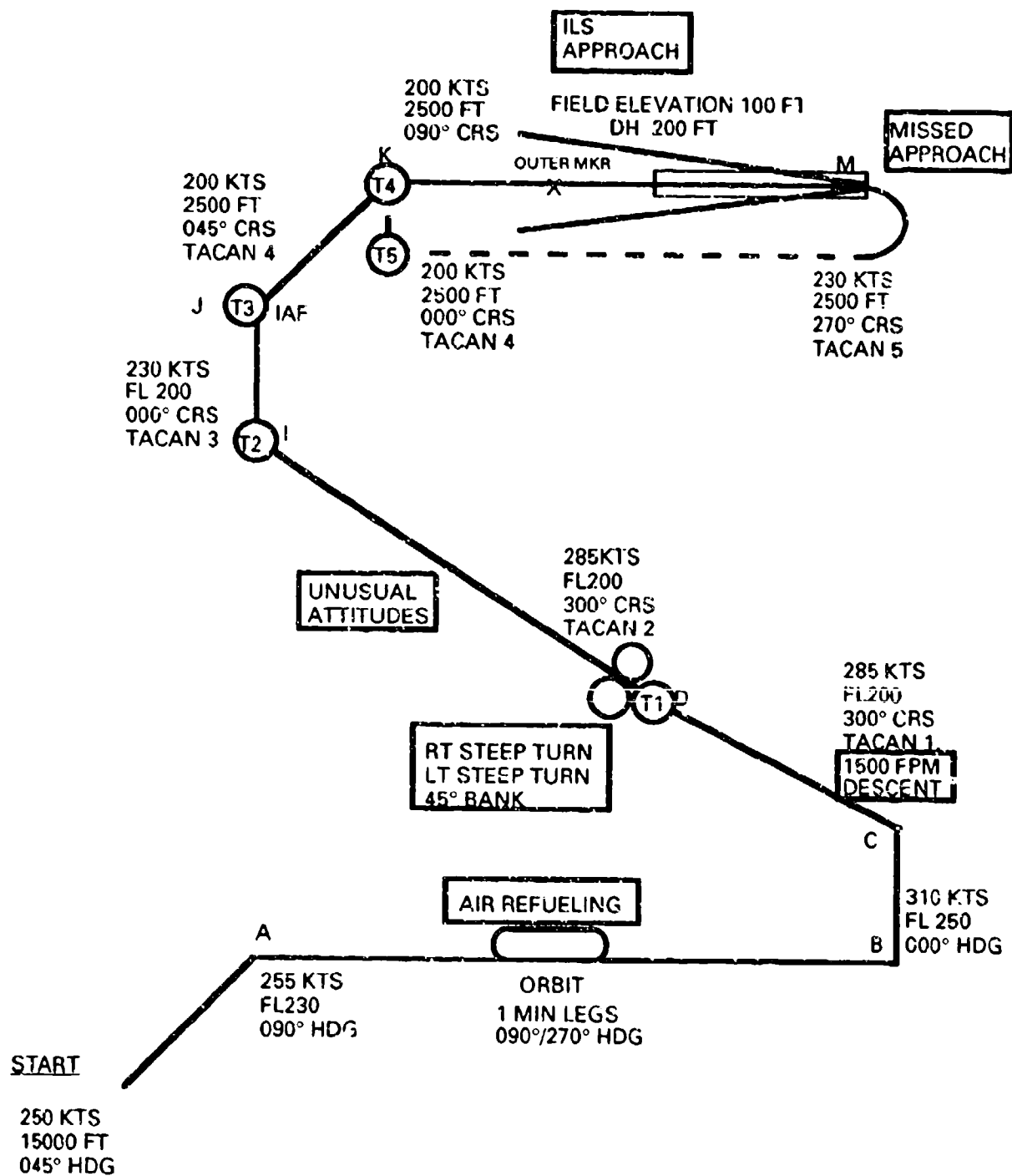
For this study, eight pilots were used to evaluate the displays. Participation was on a voluntary basis. Their experience varied from between 2500 and 7000 flying hours and was mixed between cargo/transport and fighter type aircraft.

## Procedure

All subjects received a standardized briefing on: 1) the purpose of the study, 2) display format information, 3) how to operate the controls in the cockpit, 4) the experimental procedures used during the study, and 5) the subject's task during the study. Each session lasted approximately 90 minutes.

The subject's task was to fly a defined profile with each of the two primary flight displays. The profile, shown in Figure 9, consisted of three task categories. Task 1 (Navigation and Control) contained straight navigation, turns at waypoints, holding patterns, altitude captures, airspeed captures, constant descents, and steep turns. Task 2 (Unusual Altitude Recovery) consisted of recoveries to straight and level flight from both nose high and nose low attitudes. Task 3 (Precision Approaches) contained two instrument landing system (ILS) approaches; the first, a missed approach used one flight director steering symbol and the second approach used the other flight director steering symbol.

Nominal times were established to fly from one point to the next taking into account the time to make directed changes. The desired airspeed, altitude, and heading for each leg were shown in a "data receive box" and the computer "beeped" prior to sending new commands. The subject was required to program the command markers with the keypad.



EVALUATION FLIGHT PROFILE

FIGURE 9

## Performance Measures

A summary of the objective performance measures used for the flight profile segments is presented in Table I.

Task 1 - Navigation and Control. Performance measures were used for the constant rate descent and steep turns portions of this task. During the constant rate descents, the measure was absolute average vertical velocity deviation (calculated using absolute maximum and minimum deviations from the nominal vertical velocity value). During the steep turns, the measures were absolute average airspeed and altitude deviations (calculated using absolute maximum and minimum deviations from the nominal airspeed and altitude values). Also calculated for steep turns was the percent time within 10 knots and 300 feet of the nominal airspeed and altitude values.

Task 2 - Unusual Attitude Recovery. the performance measure for this task consisted of total recovery time and absolute altitude change (calculated using absolute maximum and minimum altitude).

Task 3 - Precision Approach. For the instrument approach and landing task, the performance measures were separated into two parts: after localizer capture but before glideslope capture; after both localizer and glideslope capture. For the pre-glideslope part, the performance measures were absolute average airspeed deviation (calculated using absolute maximum and minimum airspeed deviation) and percent time within 1-dot localizer deviation. For the localizer and glideslope part, the performance measures were absolute average airspeed, percent time within 1-dot localizer deviation, and percent time within 1-dot glideslope deviation.

## Subjective Opinion Measures

The pilots were debriefed after the test session regarding what features of each primary flight display format they liked best, and why. They were also asked how they would combine the different features of both formats to create their "ultimate" primary flight display.

**TABLE I****Performance Measures Summary**

| <u>Task 1 Variables</u>                          | <u>Units</u> | <u>Description</u>                                                                  |
|--------------------------------------------------|--------------|-------------------------------------------------------------------------------------|
| Precision Descent<br>Vertical Velocity Deviation | feet/minute  | Absolute average vertical velocity deviation from nominal (2000 ft/min)             |
| Level Turns<br>Altitude Deviation                | feet         | Absolute average altitude deviation from nominal (20,000 ft)                        |
| Airspeed Deviation                               | knots        | Absolute average airspeed deviation from nominal (285)                              |
| Percent time within tolerance                    | percent      | Percent time within $\pm 300$ ft and $\pm 10$ kts of nominal values                 |
| <u>Task 2 Variables</u>                          | <u>Units</u> | <u>Description</u>                                                                  |
| Total Recovery Time                              | seconds      | Elapsed time from UA initiation until recovery criteria satisfied                   |
| Altitude change                                  | feet         | Absolute average altitude difference between altitude max/min and recovery altitude |
| <u>Task 3 Variables</u>                          | <u>Units</u> | <u>Description</u>                                                                  |
| Localizer only<br>Airspeed Deviation             | knots        | Absolute average airspeed deviation from nominal (200 kts)                          |
| Localizer Deviation                              | percent      | Percent time within $\pm 1$ dot (1.25 degrees) of nominal localizer                 |
| Localizer and Glideslope<br>Airspeed Deviation   | knots        | Absolute average airspeed deviation from nominal (200 kts)                          |
| Localizer Deviation                              | percent      | Percent time within $\pm 1$ dot (1.25 degrees) of nominal localizer                 |
| Glideslope Deviation                             | percent      | Percent time within $\pm 1$ dot (.25 degrees) of nominal glideslope                 |

## RESULTS

A summary of the performance data collected is in Table II.

Using these data, the formats were evaluated for various phases of the mission using the Multivariate Analysis of Variance (MANOVA) Statistical Package for Social Sciences (SPSS). The various phases included the unusual attitude recoveries, steep turns, descents, and the instrument landing data. None of the comparisons reached significance, however, trends indicate that the MD-11 format produced quicker recoveries from unusual attitudes, while the B747-400 showed less altitude change from the initial altitude and the maximum or minimum altitude during unusual attitude recoveries. Also, the B747-400 showed less deviation from the desired rate for the descent legs of the flight. For steep turns, the B747-400 showed a higher percent time within the commanded 300 feet and 10 knots than the MD-11. The B747-400 also had less deviations from airspeed and altitude than the MD-11. For the ILS data, the B747-400 had less deviations from commanded airspeed during the ILS but less percent time within one dot of the localizer than the MD-11 between TACAN 4 and the outer marker. Along the same lines, the B747-400 had less deviations from commanded airspeed during the ILS, but had less percent time within one dot of the localizer and glideslope than the MD-11 between the outer marker and the decision point.

Subjective data taken from the pilots after the completion of the flying part of the study reflect the same findings. Pilots preferred the overall ADI display from the B747-400. Also, the vertical velocity indicator from the B747-400 was liked better than that of the MD-11. There was no preference for command markers. Most pilots preferred the dots located on the heading scale of the MD-11 that showed the pilot where the commanded heading was. The flight director most liked by the pilots was the pitch and bank steering bars, although 3 out of 8 preferred the bat's wings.

## TABLE II

### Performance Data Summary

#### Task 1

|                                     | Format 1 | Format 2 |
|-------------------------------------|----------|----------|
| Absolute average VV Dev (ft/min)    | 751.0    | 1275.6   |
| Absolute average Altitude Dev (ft)  | 152.9    | 277.7    |
| Absolute average airspeed Dev (kts) | 8.7      | 16.2     |
| Percent within nominal              | 59.0     | 50.0     |

#### Task 2

|                                |        |        |
|--------------------------------|--------|--------|
| Total recovery time (seconds)  | 23.9   | 23.8   |
| Absolute Average Change (feet) | 2025.0 | 2261.0 |

#### Task 3

|                               | Format 1 |      | Format 2 |       |
|-------------------------------|----------|------|----------|-------|
|                               | Single   | Dual | Single   | Dual  |
| AAASD (knots)                 | 9.4      | 14.8 | 11.3     | 13.7  |
| Percent w/in 1 dot localizer  | 84.0     | 90.0 | 95.0     | 98.0  |
| AAASD (knots)                 | 3.1      | 4.7  | 7.1      | 4.1   |
| Percent w/in 1 dot localizer  | 100.0    | 75.0 | 100.0    | 100.0 |
| Percent w/in 1 dot glideslope | 83.0     | 76.0 | 98.0     | 95.0  |

## CONCLUSIONS AND RECOMMENDATIONS

The results of this study show that all of the alternative PFD formats were adequate to satisfy the basic requirement of flight information for the flying tasks represented. And further, that no one format was significantly better overall. Also, the data show there are some performance differences, although not significant, among the formats for specific parameters in specific flight segments.

Regarding the transition of the T-line concept to multi-purpose displays, this study has demonstrated that formats are feasible which retain this feature. Further, this information can be integrated into one 8"x8" display area.

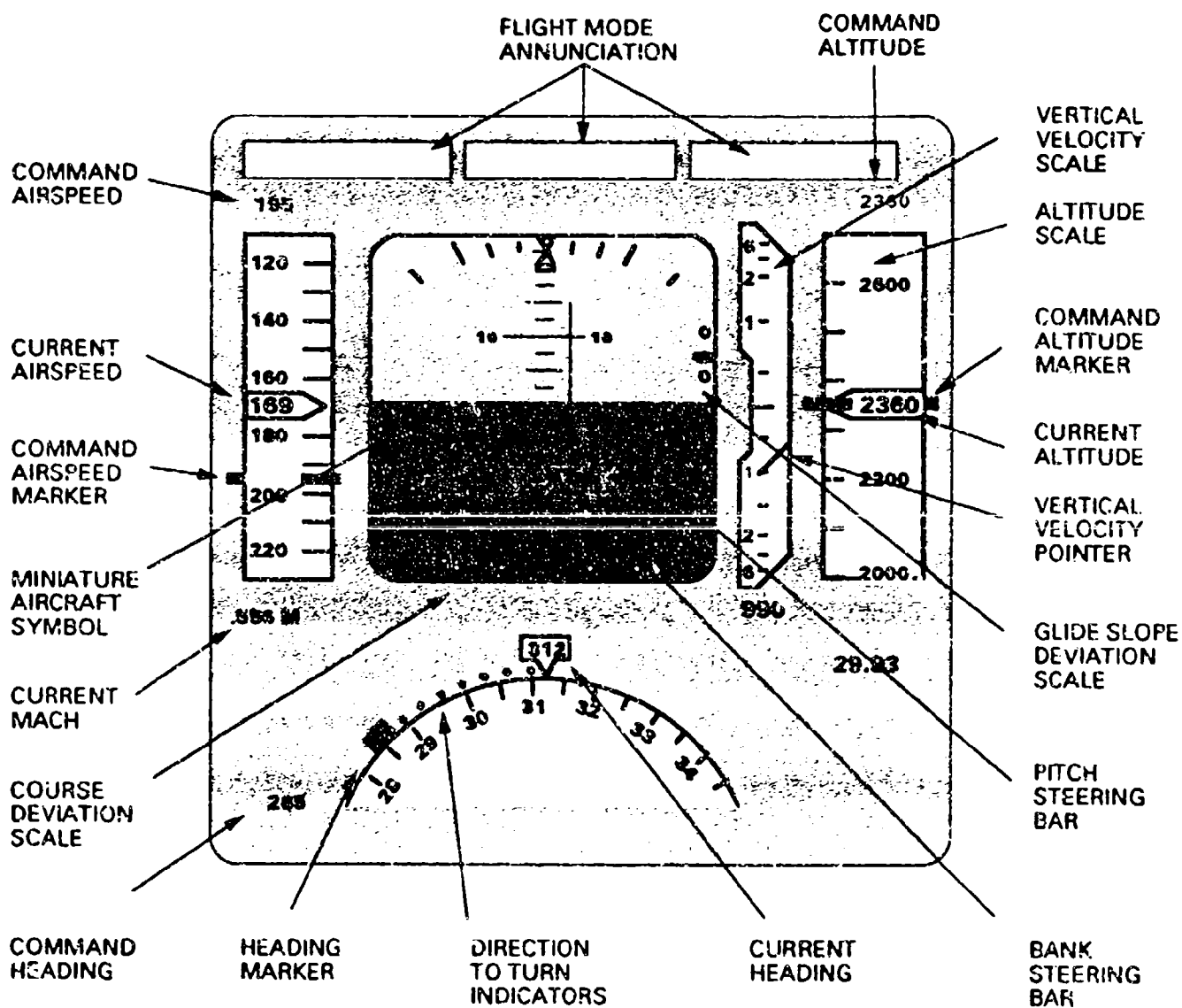
The resulting display format that is recommended as the baseline primary flight display for the follow-on study is shown in Figure 10. The layout, symbology and concepts are based on the subjective data and ideas obtained from the eight pilots who participated in this study.

### Attitude Director Indicator

Although unconventional by current USAF standards, the shape of the rectangular, similar to that of the B747-400. It was chosen in order to better wings level reference because the horizon line and the side of display were perpendicular at zero bank angle. Wings level attitude determined without reference to the airplane symbol.

and scale is on the left side of the display with the only change of the smaller numbers on the top of the scale. This provides on.

scale with the addition of the "direction to turn dots" was six of the eight subject pilots preferred this symbology.



BLEND PRIMARY FLIGHT DISPLAY

FIGURE 10

A digital readout of the current heading was included even though verbal comments of the subject pilots indicated that a lubber line to indicate the current heading would work just as well, if not better.

### Command Markers

There was no clear preference as to which type of command markers were better to use. Verbal/written responses indicated that in keeping with the shapes of command markers used with the integrated instrument systems, it would be best to use the "bar" shaped markers. This allows the solid line symbology used with the "T" scan concept.

### Vertical Velocity Indicator

The format of the vertical velocity indicator is the same as that of the B747-400, however, the location is changed from outboard to inboard of the altitude scale.

### Flight Director Symbology

The combination pitch and bank steering bars was the preferred symbology for the flight director.

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