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PILOT-IN-THE-LOOP EVALUATION OF THE APPROACH PROCEDURES EXPERT SYSTEM (APES)

MONA L. TOMS[*]
JOSEPH J. CAVALLARO
SCOTT M. CONE

VEDA INCORPORATED
5200 SPRINGFIELD PIKE, SUITE 200
DAYTON, OH 45431-1255

FRANK W. MOORE
WRIGHT STATE UNIVERSITY

AIRAM GONZALEZ-GARCIA
WL/FIGP

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FLIGHT DYNAMICS DIRECTORATE
WRIGHT LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT PATTERSON AFB OH 45433-7562

NOTICE

This technical report has been reviewed and is approved for publication.

AIRAM GONZALEZ-GARCIA
PROJECT ENGINEER
VEHICLE-PILOT INTERFACE BRANCH

RICHARD W. MOSS
CHIEF, VEHICLE-PILOT INTERFACE BRANCH
FLIGHT CONTROL DIVISION
FLIGHT DYNAMICS DIRECTORATE

30 OCT 1997

DAVID P. LEMASTER
CHIEF, FLIGHT CONTROL DIVISION
FLIGHT DYNAMICS DIRECTORATE
WRIGHT LABORATORY

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6. AUTHOR(S)

Mona L. Toms, Joseph J. Cavallaro, Scott M. Conem - Veda, Inc.
Frank W. Moore - Wright State University
Airam Gonzalez-Garcia - WL/FIGP

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Veda, Incorporated
5200 Springfield Pike, Ste 200
Dayton OH 45431-1255

Vehicle-Pilot Integration Br
2210 8th St, Ste 1
WPAFB OH 45433-1255

Wright State University, Dayton, Ohio

8. PERFORMING ORGANIZATION REPORT NUMBER

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The Vehicle-Pilot Integration Branch of Wright Laboratory(WL/FIGP) conducted a pilot-in-the-loop study to evaluate the utility of a prototype decision aid, the Approach Procedures Expert System (APES), to support the pilot's use of electronic approach plates in flying instrument approaches. This report describes the APES decision aid and the methodology and results of the Vehicle-Pilot Integration Branch's pilot-in-the-loop evaluation of the APES. The objectives of the study were to assess: 1) the effectiveness of APES for supporting approach tasks, 2) the performance of the decision aid and 3) the useability of the pilot-vehicle interface. To accomplish study objectives, 16 pilots flew a series of instrument approaches in a cockpit simulator. Pilot performance and subjective workload, situational awareness and acceptability ratings were obtained and analyzed to evaluate the study objectives. Overall, the results showed that the prototype Approach Procedure Expert System reduced pilot workload, increased pilot situational awareness, and improved flight performance compared to flying approaches without the decision aid. Refinements to the decision aid algorithm and pilot-vehicle interface were indicated. Potential areas for improvement of the APES and recommendations for further research are discussed.

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ACRONYMS, TERMS, AND ABBREVIATIONS

A/C	Aircraft
ADI	Attitude Director Indicator
AFB	Air Force Base
APES	Approach Procedures Expert System
ATC	Air Traffic Control
ANOVA	Analysis of Variance
CDI	Course Deviation Indicator
CLIPS	C Language Integrated Production System
CRT	Cathode Ray Tube
DH	Decision Height
DoD	Department of Defense
EAP	Electronic Approach Plate
FAF	Final Approach Fix
HSI	Horizontal Situation Indicator
IAF	Initial Approach Fix
IFR	Instrument Flight Rule
ILS	Instrument Landing System
MAGIC	Microprocessor Applications for Graphics and Interactive Communications
MAP	Missed Approach Point
MDA	Minimum Descent Altitude
NAVAID	Navigational Aid
PVI	Pilot-Vehicle Interface
RMS	Root-Mean-Square
SA	Situational Awareness
SWORD	Subjective Workload Dominance
TACAN	Tactical Air Navigation
VOR	VHF Omni-Directional Range
VVI	Vertical Velocity Indicator
WL/FIGP	Wright Laboratory Vehicle-Pilot Integration Branch

1. EXECUTIVE SUMMARY

The Vehicle-Pilot Integration Branch of Wright Laboratory (WL/FIGP) conducted a pilot-in the-loop study to assess the utility of a prototype decision aid to support the pilot's use of electronic approach plates in flying instrument approaches. The prototype decision aid system that was evaluated is the Approach Procedures Expert System (APES).

Sixteen pilots flew a series of instrument approaches in a cockpit simulator. The presence or absence of the decision aid, the orientation of the electronic approach plate (EAP) and task difficulty were varied across testing sessions. Two EAP orientations were investigated: North-Up and Track-Up. Task difficulty was implemented at two levels. In the high task loading condition, pilots flew non-precision approaches with wind gusts incorporated into the aeromodel. They also had no prior review the approach. In the low task loading condition, pilots flew precision approaches without wind gusts and reviewed the approach plate prior to flying the approach.

WL/FIGP conducted the experiments in the Microprocessor Applications for Graphics and Interactive Communications (MAGIC) single-seat fighter simulator. The simulator cockpit contained a force-control stick and color Cathode Ray Tube (CRT) displays that depicted head-down flight information, the EAP, APES textual output, and touch screen data entry information.

Flight performance, workload, situational awareness, and questionnaire data were collected. Analyses of Variance (ANOVA) and the appropriate post-hoc tests were applied to the performance, workload, and situational awareness data. For the questionnaire data, frequency distributions and means were calculated and comments were summarized.

The results showed that the APES enhanced the pilot's ability to perform instrument approach tasks (Objective 1) compared to flying the approaches without APES assistance. With APES assistance, pilots deviated less from assigned altitudes, especially during high task loading. They also deviated less from assigned airspeed during the initial and final approach phases. Pilots rated their workload lower with APES, particularly during high task loading, and their situational awareness higher. Study findings also indicate that APES effectiveness was not influenced by the electronic approach plate orientation (i.e., north-up or track-up).

Regarding the performance of the decision aid (Objective 2), pilots rated APES' logic, consistency and timeliness as above "moderately acceptable," however, some refinements were indicated. Pilot comments indicated that the deviation tolerance windows for APES voice activation were too stringent, especially the airspeed and altitude voice prompts. Also the timeliness of the procedural prompts, given at the approach fixes, were reported as being "hurried." In general, pilots thought that APES would improve flight safety, however, some expressed concern with the consequences of being over-reliant on the system.

Pilots rated the APES PVI as "acceptable" (Objective 3); however, refinements were suggested. Pilots commented that the phraseology of APES voice prompts should be more specific, particularly during the final phase of the approach. Pilots also commented that the PVI should allow for pilot settings and/or adjustments to tolerance values for decision aid activation.

2. INTRODUCTION

This report describes the Approach Procedure Expert System (APES); and the testing methodology and results of the WL/FIGP pilot-in-the-loop evaluation of the APES. Potential areas for improvement of the APES and recommendations for further research are also discussed.

2.1 Background

The approach and landing phase of flight is considered to be one of the most workload intensive. In fact, recent studies have shown that up to 50% of civilian aircraft accidents occur during this phase (Blanchard, 1991). A major factor contributing to these incidents is the extensive cognitive demand placed upon the pilot (Clay, M. and Barlow, T., 1994). The pilot must recall and apply specific instrument flight rules, remember correct task sequences, and calculate timings, while simultaneously controlling the aircraft and monitoring its performance. In addition, the pilot must integrate information from multiple sources and replan according to air traffic control's (ATC's) redirection. Because of the extensive cognitive load, number of procedures, and "rules of thumb" associated with the instrument approach, we believe the instrument approach domain is well-suited for a decision aid application.

Decision aiding has been used to help pilots perform such diverse tasks as threat avoidance, terrain following, mission planning and re-routing, and flight management. Decision aids produced through such efforts include the Pilot's Associate (Leavitt and Smith, 1989), the Cockpit Assistance System (Harrison, Saunders, and Janowitz, 1994), the Emergency Procedures Expert System (Harrison, Saunders, and Janowitz, 1994), and the Flight-plan Interactive Negotiation and Decision-Aiding System for Enroute Rerouting (Bitterman *et al*, 1994). In general, these efforts have demonstrated the potential utility of a computer-based decision aid for assisting the pilot in task accomplishment.

2.2 Study Objectives

The goal of this study was to assess the usefulness and performance of a prototype decision aid for flying instrument approaches by evaluating APES in a pilot-in-the-loop simulation. Because the decision aid is inseparable from its interface, both the decision aid and the pilot-vehicle interface (PVI) were evaluated; however, the emphasis of the study was placed on the value of the decision aid's advice. The objectives of the study were to:

1) Assess the *effectiveness of APES* for supporting approach tasks and its potential for reducing pilot workload, increasing situational awareness, and improving performance.

2) Assess the *performance of the decision aid* to determine if APES advice was accurate and timely enough to assist the pilot in flying instrument approaches.

3) Assess the *understandability and useability of the pilot-vehicle interface* to determine if the interface allowed the pilot to easily interpret and use APES advice.

3. APPROACH PROCEDURES EXPERT SYSTEM (APES)

The intent of the APES prototype is to reduce pilot workload, increase situational awareness, and improve performance and safety. The APES simultaneously monitors aircraft performance, informs the pilot of appropriate corrective actions when deviations occur, and provides procedural advice (see Table 1) according to the phase of the approach (i.e., holding, initial approach, final approach, missed approach). To accomplish this, the APES functions in two assistant roles: as an "advisory copilot" and as an "advisory pilot." As an "advisory copilot" the decision aid advises and prompts the pilot as a copilot would in a multi-crew environment, such as advising when the aircraft deviated from assigned parameters (e.g., altitude, airspeed, etc.). As an "advisory pilot" the decision aid provides guidance relevant to the instrument flight rules (IFRs) needed for the specific phases of the approach.

Audio, a natural form of communication that would exist between the pilot and copilot, is the primary pilot-vehicle interface for the APES. Visual messages are employed for redundancy and when it would be impractical to use audio.

The following sections describe the developmental process, the APES system architecture, and the Pilot-Vehicle Interface (PVI).

3.1 Overview of the APES Developmental Process

The first step in the development of the APES was capturing the expertise of experienced pilots through a knowledge acquisition process. A knowledge engineer conducted an iterative interview process with several subject matter experts. This process identified the precise steps that were necessary for flying the various phases of an approach. The knowledge engineer then modeled the actions recommended by the expert pilots and created process flow diagrams. The process flow diagrams served as a basis for the APES algorithm. Representative examples of these process flow diagrams are presented in Appendix D.

The APES prototype was then integrated into the MAGIC simulator and tested in an iterative check-out process. Test approaches were flown with various flying patterns to exercise all of APES decision points and to determine if APES was functioning as intended. Design flaws were identified and corrected. Upon completion of the check-out process, a verification test was conducted. A pilot, unfamiliar with the APES, flew all of the approaches that were used in the study. Design deficiencies that went undetected during the iterative design process were identified and corrected. APES was then formally evaluated in the current study.

3.2 APES Architecture

The APES prototype system consists of the following basic components:

1) a dynamic aircraft status file
2) a set of facts representing aircraft-specific and approach-specific databases
3) a set of rules where the expert knowledge resides
4) a forward-chaining inference engine that uses the Rete algorithm for deciding which rules to fire based on the facts.

The interaction of these components is depicted in Figure 1.

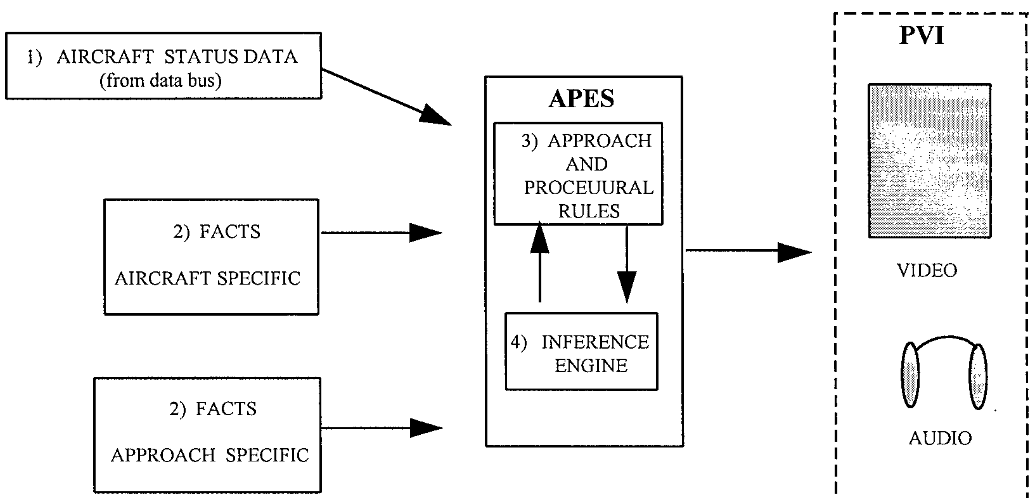

Figure 1. APES System Architecture

3.2.1 APES Inputs

As depicted in Figure 1, input to the APES comes from three sources: current aircraft flight parameters, a database of aircraft specific facts, and a database of approach specific facts. Examples of the types of input that are used by APES include the following

- Aircraft Status Data
  - Current Altitude / Heading / Airspeed
  - Current Navigation Aid Radial
  - Current Navigational Radio Channel
- Aircraft Specific Facts
  - Holding Airspeed
  - Fuel Weight
  - Approach Airspeed
- Approach Specific Facts
  - Holding Altitude
  - Final Approach Course

An aircraft specific input file is created for each aircraft type in order to allow a generic APES to be embedded in aircraft (or aircraft simulators) of different types. Data for the aircraft are loaded from the corresponding aircraft specific data file during program initialization. For purposes of this study, the aircraft specific facts were limited to an F-16 aircraft. Also, the approach specific facts were limited to eight approach plates, however, the APES can accommodate as many approach plates as computer storage availability allows.

Input data and their usage within the APES are illustrated in the process flow diagrams contained in Appendix D.

3.2.2 APES Implementation

The expert systems development tool used for this study was the C Language Integrated Production System (CLIPS) developed at the NASA Johnson Space Center (CLIPS, 1993). CLIPS is a distinguished member of the OPS-5 family of expert systems shells, and has been extensively used in many applications, including a variety of NASA missions. The CLIPS inference engine uses the highly efficient data-driven Rete algorithm (Forgy, 1982), which contributes to CLIPS' excellent run-time characteristics. CLIPS avoids the timing problems associated with slower running expert systems because the Rete algorithm does not reconsider a rule (that has already been executed) for activation until a subsequent change in the value of one or more of its antecedents has occurred.

3.3 APES Pilot-Vehicle Interface

The primary pilot interface for the APES is voice message presentation. To output a voice message, the APES passes a text string to the voice module of the Silicon Graphics host system. The Silicon Graphics system then generates the voice message by combining words that are contained in a vocabulary database of approximately 50 words.

APES voice messages are reinforced with the visual presentation of text information. The APES continually displays updated target values for radio channel/frequency, altitude, airspeed, heading, and course in a scratchpad area to allow the pilot to manipulate appropriate command marker and course indicator settings. APES also displays current (target) values for radio, altitude, airspeed, heading and course on a dedicated CRT. This CRT is also used to display more complex textual information, such as pre-approach and final approach checklists. The cockpit displays are described in more detail in Section 3.2 and depicted in Figure 2.

Table 1 shows the various types of correction advice given to the pilot as part of the APES "advisory copilot" component. As shown, this advice is given for airspeed, altitude, heading and course aircraft parameters, with each parameter having a preset tolerance window (determined by subject matter experts and pre-testing simulation runs) for decision aid activation. The APES advisory copilot is only activated when the aircraft deviates outside a parameter's tolerance window. When this occurs, APES advises the pilot of the target value and provides correction. For example, if the pilot deviates more than +/- 2 degrees from course, the APES "advisory copilot" component would compute a heading to re-intercept the course and announce "Turn (Right/Left) Heading XXX." Once reestablished on the course, APES would then announce "Maintain Course XXX." Target course is also displayed in the scratchpad area on the lower CRT.

Table 1. PVI Correction Prompts

"ADVISORY COPILOT" CORRECTION PROMPTS			
DECISION AID PARAMETER	**AUDIO ADVICE**	**VISUAL ADVICE**	**TOLERANCE WINDOW**
AIRSPEED	"Maintain XXX knots"	Desired airspeed displayed in the scratch- pad for command airspeed marker setting	+/- 10 knots
ALTITUDE	"Maintain altitude XXX"	Desired altitude displayed in the scratchpad for command altitude marker setting	+/- 100 feet
HEADING	"Come Right (Left) XXX degrees" "Turn (right/Left) Heading XXX" "Maintain Heading XXX"	Desired heading displayed in the scratchpad for setting of the heading "bug"	+/- 5 degrees
COURSE	"Turn (Right/Left)Heading XXX "Maintain Course XXX"	Desired course displayed in the scratchpad for setting of the course on the HSI	+/- 2 degrees

Table 2 depicts the various types of procedural advice of the APES "advisory pilot" component. The procedural advice is based on instrument procedures documented in Air Force Manual 51-37 (1986) and on specific requirements of the approach (which are displayed on the electronic approach plate). Unlike the "advisory copilot," the "advisory pilot" component will always give procedural advice to the pilots. This advice differs according to the approach and phase of flight (i.e., holding, initial approach, final approach, missed approach). For example, when the aircraft is approximately 0.5 mile from the Initial Approach Fix (IAF), the APES "advisory pilot" component would compute a heading and announce "Turn (Right /Left) Heading XXX" to intercept the initial approach course of that approach. The APES would also inform the pilot to descend to the target altitude and periodically remind the pilot to continue descent to the initial approach altitude.

Table 2. PVI Procedural Prompts

"ADVISORY PILOT" PROCEDURAL PROMPTS		
DECISION AID PARAMETER	**AUDITORY**	**VISUAL**
TURN	"Turn (left/right) Heading (XXX)"	Textual display of direction appeared on the right CRT and in the scratchpad.
AIRSPEED	"Set Airspeed XXX knots" "Maintain Airspeed XXX knots."	Displayed desired airspeed on the right CRT and in the scratchpad. Reversed video highlight Airspeed Select Button on lower CRT to cue for quick entry of command value.
ALTITUDE	"XXX feet (above/below)" "Minimum Altitude XXX feet" "Begin (Descent/Climb)"	Displayed desired altitude on right CRT and in scratch pad. Reversed video highlight Altitude Select Button on lower CRT to cue for quick entry of command value.
NAVAID	"Set Navaid Channel and / or Frequency (XXX / XXX.XX)"	Displayed desired freq./ch on right CRT and in scratch pad. Reversed video highlight Navaid Select Button on lower CRT to cue for quick entry of Navaid Channel and/or Frequency.
COURSE	"Set Inbound/Outbound Course (XXX)"	Displayed desired course on right CRT and in scratch pad. Reversed video highlight Course Select Button on lower CRT to cue HSI course entry.

4. METHODOLOGY

This section discusses the testing methodology that was used to accomplish the pilot-in-the-loop evaluation of the APES. Sixteen pilots flew a series of instrument approaches in a cockpit simulator. The presence of the decision aid, the orientation of the electronic approach plate (EAP) and task difficulty were varied across approaches. Task difficulty was implemented at two levels, high task loading and low tasking loading, to determine the benefits of the APES in both task environments. Two EAP orientations were also investigated, North-Up and Track-Up, to determine if the utility of the APES would vary with EAP orientation.

4.1 Background and Experience of Subject Pilots

Sixteen volunteer pilots participated in the study, with experience that ranged from first pilot to evaluator pilot and an average total flying time of 2448 hours. One half of the pilots flew multi-place transport aircraft and the other half flew fighter-type aircraft. Table 3 shows the background and experience of the pilots used in the study.

Table 3. Background and Experience of Subject Pilots

SUBJECT	PRIMARY AIRCRAFT	TOTAL FLYING TIME	ACTIVE FLYING STATUS WITHIN LAST 12 MONTHS
1	C-141	2300	YES
2	P-3	3200	YES
3	C-130	3000	NO
4	C-5	2900	NO
5	A-10	1900	NO
6	E-3A	3500	YES
7	F-111 A/E	2700	YES
8	F-15	2400	YES
9	C-20A	4400	YES
10	C-141	4575	YES
11	F-111	2800	NO
12	KC-135	2500	YES
13	F-16	1000	YES
14	F-16	2000	NO
15	F-16	1750	YES
16	F-16	600	YES

4.2 The MAGIC Simulator

The APES study was conducted in the MAGIC simulator cockpit. The single-seat fighter cockpit contained five color CRT displays (only four of which were used), three banks of programmable switches, an A-7 throttle, and a force-control stick. Two speakers were located behind the cockpit seat for announcing the APES audio advice. Figure 2 shows a layout of the cockpit. An F-16 aeromodel was used to drive the simulator.

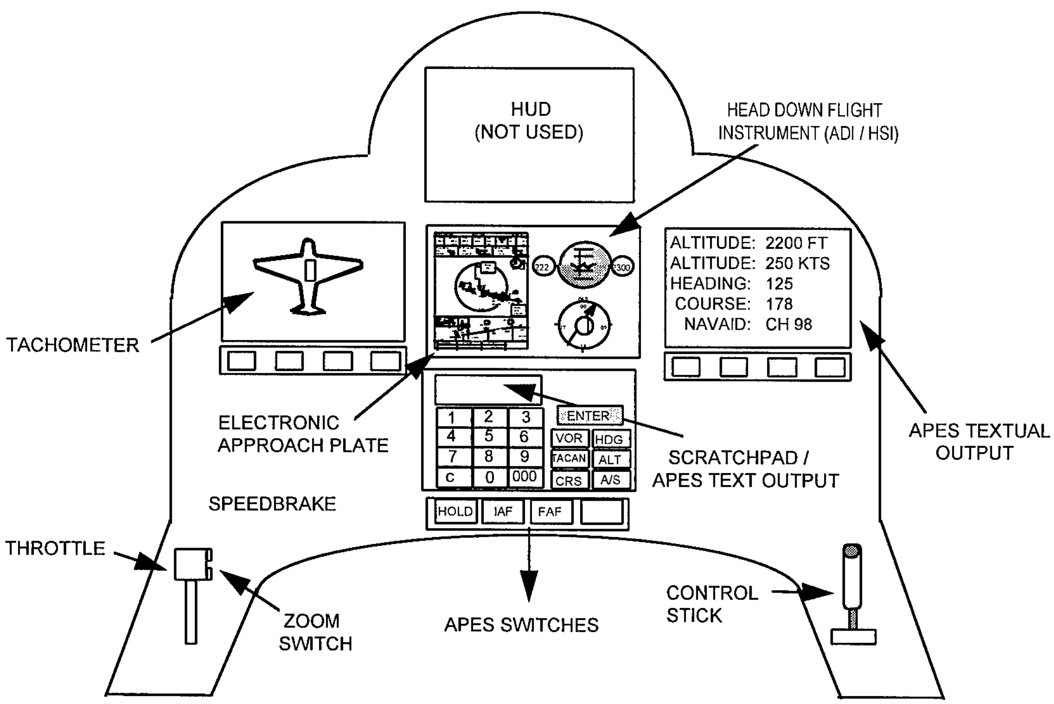

Figure 2. MAGIC Cockpit Layout

The center CRT was sectioned into two 6 x 8 inch areas. The left side was used to display the Electronic Approach Plate (EAP) formats. The right side was used to display Attitude Director Indicator (ADI) and Horizontal Situation Indicator (HSI) flight information. A round dial airspeed indicator and altimeter were located on the respective left and right sides of the ADI. The right CRT displayed textual output from the APES. The left CRT displayed crew alerting status and a tachometer.

The lower CRT displayed a touch-sensitive keypad and switches for entering navigation radio frequency/channel, course, airspeed, altitude and heading values. This CRT also displayed a scratchpad area that presented APES prompts of target values. These values could then be displayed as commanded values on the flight displays by pressing "enter" on the keyboard.

For this study, pilots only used the first three programmable switches below the lower center monitor and the first two programmable switches below the left monitor. The switches below the center monitor were used to select the approach phase. The first switch, labeled *Hold*, informed APES that holding was required prior to initiating the approach. The second switch, labeled *IAF*, informed APES that approach clearance had been received and to proceed to the Initial Approach Fix. The third switch, labeled *FAF*, informed APES that vectors to final had been received to proceed to the Final Approach Fix. The first two switches below the left monitor were used to select TACAN and VOR/ILS navigation radios, respectively.

4.2.1 Electronic Approach Plate Formats

The Electronic Approach Plates (EAPs) were electronic depictions of the paper approach plates that pilots use for flying instrument approaches. Because EAPs are integrated with the aircraft's navigational system, they also displayed current aircraft position with respect to the approach plate. The EAPs were developed using a vector product format (MIL-STD-600006), which is a Geographic Informational System data format created for transmitting geographical digital databases.

Aircraft position was presented in two map orientations on the EAP. In the North-Up orientation, north was always located at the top of the display and the aircraft symbol was fixed in the center of the display with the EAP moving underneath it to reflect current position. The aircraft symbol also rotated to reflect the correct heading. In the Track-Up orientation, the fixed aircraft's symbol was pointed toward the top of the display to reflect the aircraft's current track and the EAP moved underneath it to reflect the aircraft's position.

A continuous zoom function, operated by a thumb switch on the throttle, was provided to improve readability on the EAP vertical or plan view sections (Liggett, 1996). The section to be zoomed (i.e., plan view or vertical view) was selected by touch; however, the zoom center was always the aircraft position. Figure 3 illustrates a typical EAP that was used in the study.

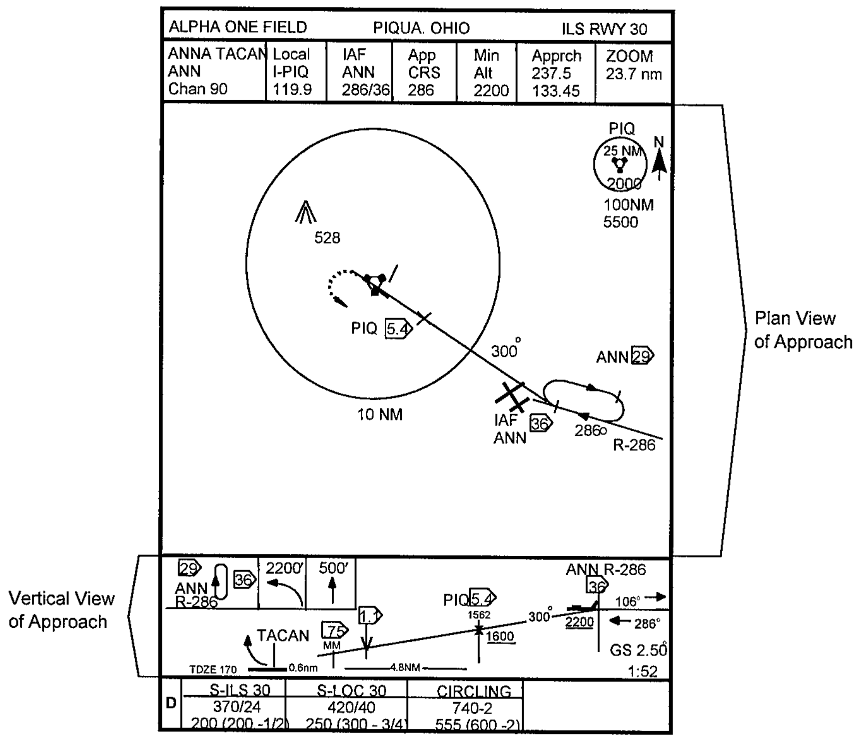

Figure 3. A Typical Electronic Approach Plate (EAP)

4.3 Training

Training consisted of two sessions: one hour of ground training and one hour of simulator flight training. The ground training consisted of a standardized briefing covering the purpose of the study, aeromodel characteristics, control use, cockpit layout, description of basic layout of EAP formats, and experimental procedures.

The simulator training familiarized the pilots with all aspects of the test scenario and study procedures. Pilots flew two practice approaches that were similar to the approaches they would fly in the data collection sessions. The first practice approach consisted of a precision approach, *without* decision aiding, to familiarize the pilot with the aeromodel and the EAP in a Track-Up orientation. The second practice approach consisted of a non-precision approach (no glideslope information) *with* decision aiding, in a North-Up orientation. This was to familiarize the pilot with the decision aid and the EAP in a North-Up Orientation, as well as to allow more practice with the aeromodel. The two practice trials also familiarized the pilots with both the precision and non-precision types of approach which were used, in part, to manipulate task difficulty.

4.4 The Approach Instrument Procedure Task

Each pilot flew eight approaches: four with decision aiding (Aid) and four without decision aiding (NoAid). There were four different approaches: one approach contained a short arc with a west runway, a second approach contained a short arc with a south runway, a third approach had a radial approach with a west runway, and a fourth had a radial approach with a south runway. The other four approaches were comparable to the four original approaches with minor changes, such as different altitude restrictions and Navaid frequencies. South runways were included to examine the complications of a North-Up orientation (e.g., left turns on the EAP could be misinterpreted as right turns).

For the low task loading condition, pilots flew precision approaches that gave both localizer and glideslope deviation and guidance information. They were also allowed to review the approach before flying it. For the high task loading condition, pilots flew non-precision approaches and were provided with only localizer deviation and guidance information. Also pilots did not review the approach and a gust model was incorporated into the aeromodel to induce the effect of turbulence.

The simulation started with the aircraft flying over the navigational aid serving the airfield, in the general direction of the initial approach fix, and at the assigned altitude and airspeed. The navigation radio was initially tuned to the appropriate navaid, however, the pilot was required to make all subsequent frequency changes. Position reports and air traffic control were not required. Pilots were cleared to maneuver as required within the guidelines of the Federal Aviation Administration Instrument Flight Rules (IFRs) and approach specific restrictions.

For each approach, the pilot flew one turn in holding and proceeded to the initial approach fix. The pilot flew the initial approach track to the final approach fix, flew the final approach to the missed approach point, and then executed missed approach procedures. The testing session was completed after the missed approach procedures were executed. Each approach session took approximately 25-30 minutes to complete, for approximately 4 hours for the eight approaches.

The following performance measures were collected at 5 Hertz during each instrument approach task: Root-Mean-Square (RMS) altitude deviations, RMS airspeed deviations, RMS glideslope deviations (precision approaches), RMS heading deviations, and RMS course deviations. These were calculated separately for the following approach phases: holding (holding fix to initial approach fix), initial approach (initial approach fix to final approach fix), and final approach (final approach fix to missed approach point).

4.5 Questionnaires

After completing each approach, the pilot was asked to rate the ease of performing basic approach tasks (Figure 4) and to give initial comments in a session questionnaire. Upon completion of all eight approaches, the pilot completed a final questionnaire. The final questionnaire asked for pilot ratings on the logic, consistency and timeliness of APES advice and its ability to support specific approach tasks. The final questionnaire also included questions concerning the understandability and useability of the PVI. The questionnaires allowed a detailed assessment of the APES so that potential deficiencies in the "advisory copilot" and "advisory pilot" components could be identified.

In conjunction with the final questionnaire, pilots also rated workload and situational awareness using the Subjective Workload Dominance (SWORD) technique (Vidulich, 1989). A SWORD form was used to collect pairwise comparisons between combinations of three test conditions: Decision Aid (Aid / NoAid), Approach Type (Non-Precision, EAP Review, NoWind / Precision, NoEAP Review, Wind) and EAP Orientation (North-Up / Track-Up) The comparisons were then entered into the SWORD computer program that calculated workload and situational awareness ratings.

4.6 Experimental Design

The study used a repeated measures 2 x 2 x 2 x 3 full factorial experimental design. The design consisted of 2 levels of Decision Aid (aid, no aid), 2 levels of Task Difficulty (low task load, high task load), 2 levels of EAP Orientation (north-up, track-up) and 3 levels of Approach Phase (holding, initial approach, final approach).

Each testing session consisted of the pilot flying three approach phases, consecutively flown in accordance with the instrument approach, with one of the eight testing conditions depicted in Table 4. This resulted in a total of 24 experimental conditions (2 Decision Aid Conditions x 2 Task Difficulty Levels, 2 EAP Orientations x 3 Approach Phases).

Table 4. Testing Conditions across Approach Phases

DECISION AID	TASK DIFFICULTY	ORIENTATION
AID	HIGH TASK LOAD	TRACK-UP
NOAID	HIGH TASK LOAD	NORTH-UP
AID	LOW TASK LOAD	TRACK-UP
NOAID	LOW TASK LOAD	NORTH-UP
AID	HIGH TASK LOAD	NORTH-UP
NOAID	HIGH TASK LOAD	TRACK-UP
AID	LOW TASK LOAD	NORTH-UP
NOAID	LOW TASK LOAD	TRACK-UP

The presentation order of the Decision Aid conditions was counterbalanced across pilots to reduce potential order effects. The presentation orders of the Task Difficulty and EAP Orientation conditions were blocked with respect to the counterbalanced Decision Aid conditions.

5. RESULTS AND DISCUSSION

This section provides a summary of the data analysis methods, significant Analysis of Variance (ANOVA) results, findings from the questionnaire data, and a discussion of the combined results for each study objective.

5.1 Effectiveness of APES (Objective 1)

Objective 1 of the study was to assess the effectiveness of APES for supporting approach tasks and its potential for reducing pilot workload, increasing situational awareness, and improving performance. The following sections discuss the analysis and study findings relevant to each of these potential benefits.

Statistical comparisons of RMS Performance, SWORD Situational Awareness and Workload ratings, using ANOVA techniques, were performed across the experimental conditions. For the questionnaire ratings, frequencies and averages were calculated and pilot comments were summarized. Appendix B provides the F-statistics, significance levels, and means associated with the tested effects of the performance, workload, and situational awareness data. Appendix C provides the questionnaire ratings and summarized pilot comments.

5.1.1 Effectiveness of APES for Supporting Approach Tasks

Average pilot ratings showed that APES "moderately enhanced" task accomplishment for most approach tasks. As shown in Figure 4, APES benefited pilots most in identifying and navigating to fixes.

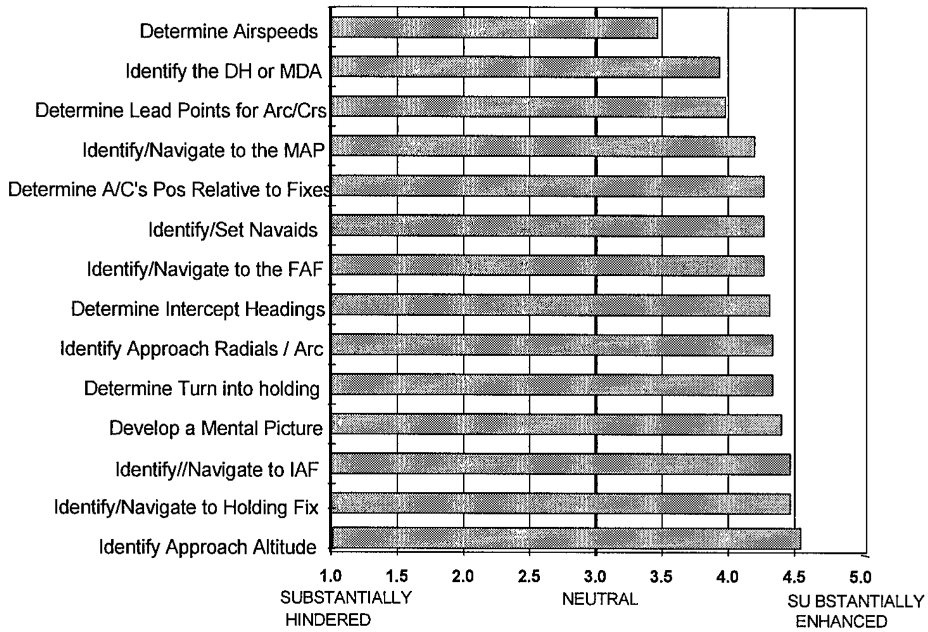

Figure 4. Pilot Ratings of APES Influence on Task Performance

Two-thirds of the pilots rated APES' overall utility as "extremely beneficial;" and the other one-third rated it as "moderately beneficial." Sixty percent of those pilots that rated APES as "extremely beneficial" were transport pilots and 40% were fighter-type pilots.

All pilots thought that APES would generally improve flight safety, although several pilots expressed concern with the consequences of over-reliance on the system. Pilot ratings also indicated that task performance and decision aid usage was not influenced by EAP orientation.

5.1.2 Pilot Workload

Statistical comparisons of SWORD workload ratings, using ANOVA techniques, were performed across the different decision aiding, task loading and EAP orientation conditions. One-way ANOVAs were performed on the interaction effects to identify the nature of the statistical differences.

The ANOVA results showed a significant main effect for decision aid ($p < 0.01$) and task loading ($p < 0.01$), and significant interaction ($p < 0.01$) between these two factors. Figure 5 illustrates this interaction. No significant results were found between EAP North-Up and Track-Up Orientation.

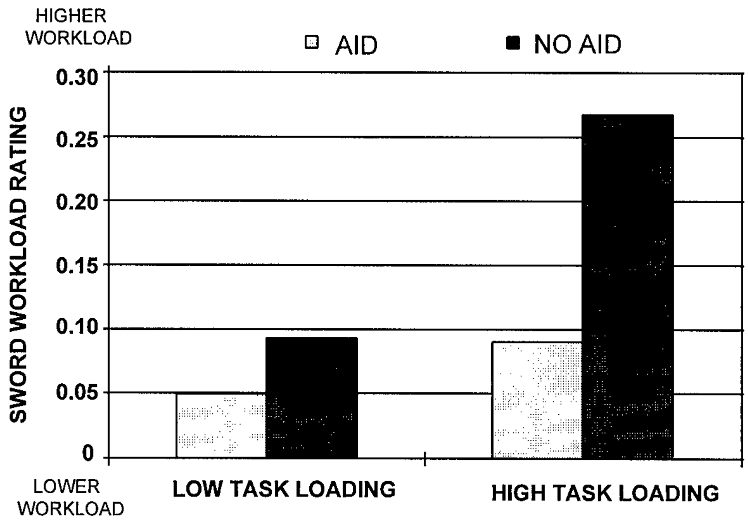

Figure 5. Decision Aiding and Task Difficulty as a Function of Subjective Workload

Questionnaire results substantiate that the high task loading condition induced workload, which was the intent of the experimental design. The majority of pilots (60%) thought that wind gusts and no prior EAP review "moderately increased workload." The other 40% thought that workload was "substantially increased" in the high task loading condition. These findings are consistent with the SWORD results which showed significantly higher workload ratings in the high task loading condition.

5.1.3 Situational Awareness

Situational awareness (SA) was defined as "the ability to assess current position relative to the approach and predict future actions." As with the SWORD workload ratings, statistical comparisons of the SWORD SA levels, using ANOVA techniques, were performed across the different decision aiding, task loading and EAP Orientation conditions.

As shown in Figure 6, pilots rated situational awareness as being significantly better ($p < 0.01$) with APES than without APES. This effect was across both low and high task loading conditions and EAP North-Up and Track-Up orientations. A significant effect was also found for task loading ($p < 0.01$), indicating that pilots considered their SA to be significantly better in the low task loading condition than in the high task loading condition.

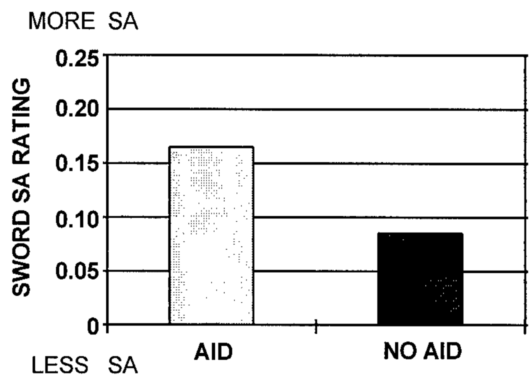

Figure 6. Decision Aiding as a Function of Situational Awareness

The questionnaire responses supported the SWORD SA ratings. Two-thirds of the pilots reported that their situational awareness was "substantially enhanced" with the APES advice.

5.1.4 Pilot Performance

The analysis for pilot performance was conducted by assessing RMS altitude, airspeed, heading, course and glideslope (precision approach) deviation data that were collected during the simulation testing sessions. Statistical comparisons of the RMS data, using ANOVA techniques, were performed across the different decision aiding, task loading and EAP Orientation and Approach Phase conditions. Unlike the SWORD Workload and Situational Awareness analysis, Approach Phase (i.e, Hold, Initial Approach and Final Approach), was included as a factor in the statistical analysis of the RMS performance data. One-way ANOVAs were performed on any interaction effects to identify the nature of the statistical differences.

The performance results generally showed that pilots performed better with decision aiding than without decision aiding. Pilots deviated significantly less from assigned altitude with APES advice; and that this effect was most prominent in the high task loading condition. Figure 7 illustrates this significant interaction ($p < 0.01$). The RMS altitude deviation data did not show any significant effects or interactions for Approach Phase or EAP orientation.

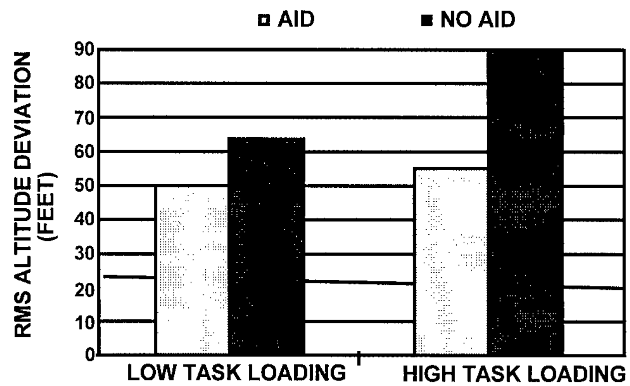

Figure 7. Decision Aiding and Task Difficulty as a Function of RMS Altitude Deviation

The benefits of APES may also be influenced by approach phase. With APES advice, pilots deviated significantly less from the assigned airspeed during the initial approach and final approach phases, than during holding. Figure 8 illustrates this significant interaction ($p < 0.01$). The RMS airspeed deviation data did not show any significant effects or interactions for Task Loading or EAP Orientation.

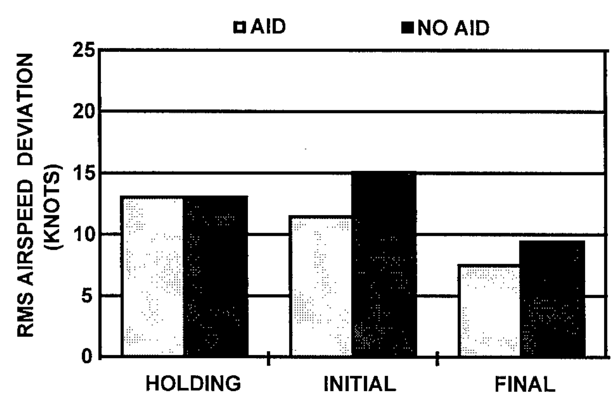

Figure 8. Decision Aiding and Approach Phase as a Function of RMS Airspeed Deviation

The performance results did not show any decision aid effects or interactions in the heading, course, and glideslope RMS deviation data. However, it was found that RMS heading and course deviations were significantly smaller in the Final Approach Phase than during the Initial Approach Phase. These effects are not surprising given that the navigation aid for the final approach gives more accurate and sensitive course information than the navigation aid for the initial approach.

5.1.5 Effectiveness of APES (Objective 1) Discussion

The combined results (from the questionnaire, workload, situational awareness, and performance data) demonstrate that APES was effective in supporting task performance; and in reducing workload, increasing situational awareness, and improving performance. The altitude deviation and workload results suggest that APES was most beneficial during high task loading conditions. The airspeed deviation results indicate that APES effectiveness was influenced by the task priority and the type of APES advice that is given during a particular approach phase. Because maintaining airspeed is considered to be a more critical task during initial and final approach phases than during holding, it is not surprising that APES airspeed advice was found to be more beneficial during these two phases.

The benefits that were found with the APES airspeed and altitude advice, however, may have obscured potential benefits associated with the APES course advice and heading advice. Because pilots simultaneously maintain course, heading, altitude, and airspeed, it is possible that course and heading were maintained at the expense of airspeed and altitude. This would explain why APES advice was shown to improve altitude and airspeed performance, but not heading and course performance. The effects of multi-tasking may also explain the lack of decision aid benefits for glideslope deviation. However, it is also possible that APES did not provide any value-added glideslope information because of the excellent "guidance" information that is provided by the pitch steering bar on the Attitude Director Indicator (ADI).

5.2 Decision Aid Performance (Objective 2)

Objective 2 of the study was to assess the performance of the decision aid to determine if APES advice was accurate and timely enough to assist the pilot in flying instrument approaches. To assess APES accuracy, pilot ratings of APES *logic* and *consistency* were analyzed. To assess whether APES advice was given at the time when it was most needed, pilot ratings of APES *timeliness* were analyzed. Frequencies and averages were computed for the questionnaire ratings and pilot comments were summarized.

5.2.1 APES Logic

Figure 9 shows pilot ratings of the APES logic for the procedural and correction advice (of the respective "advisory pilot" and "advisory copilot" components). Logic was defined as the APES advice being *correct and complete.* For all advice prompts, average pilot ratings for advice logic were above "moderately acceptable" (i.e, above 4.0).

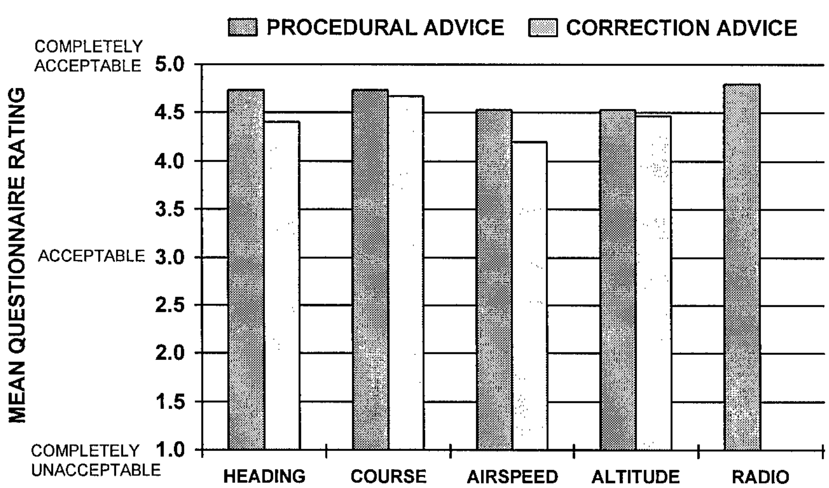

Figure 9. Pilot Ratings of APES Logic

The lower ratings of the airspeed and altitude correction advice were primarily due to the deviation tolerance windows that were established to activate the decision aid. In general, pilots indicated that the +/- 100 feet altitude window and the +/- 10 knots airspeed window were too stringent, especially during turbulent conditions. Several pilots commented that they would like to have the option of setting the window criteria themselves. One pilot thought that the APES should automatically adjust tolerance windows based on current or future operating conditions.

One pilot expressed concern regarding the potential of APES giving wrong information, such as when the ATC assigns an altitude restriction (which would be unknown to APES). Five pilots reported that APES' best feature was its capability for automatic setting of navaid channels / frequencies.

5.2.2 APES Consistency

Figure 10 shows pilot ratings of APES procedural and correction advice consistency. Consistency was defined as the APES advice being *consistently given whenever it was needed.*

For all advice types, the average ratings for advice consistency were well above "moderately acceptable (4.0)." There were no pilot comments regarding the consistency of the APES advice.

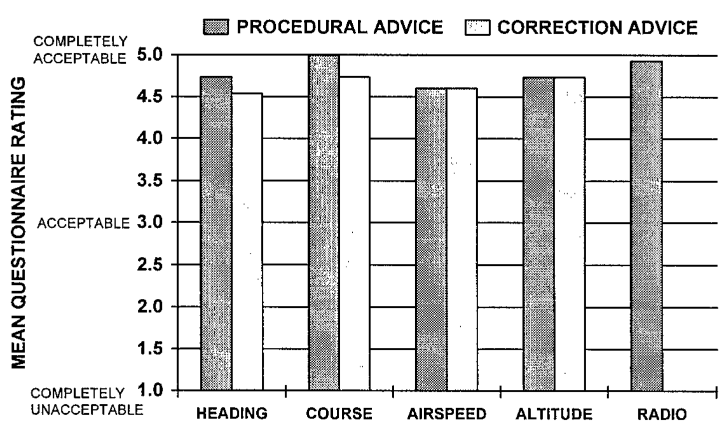

Figure 10. Pilot Ratings of APES Consistency

5.2.3 APES Timeliness

Figure 11 shows pilot ratings of the APES timeliness for the procedural and correction advice. Timeliness was defined as the APES advice *occurring at the time that it is needed.* For all advice types, average pilot ratings for advice timeliness were above "moderately acceptable." Course and radio prompts received the highest ratings.

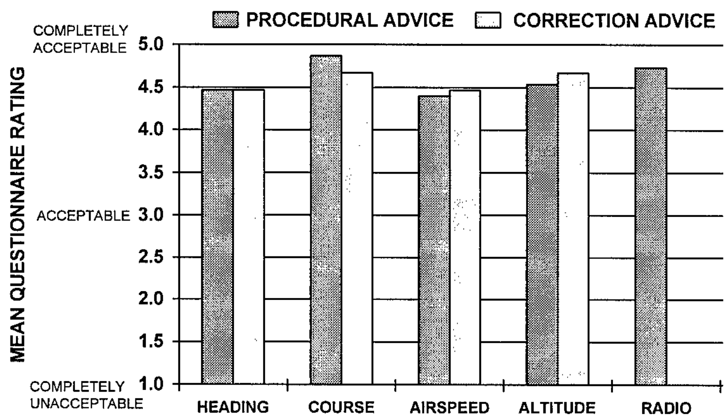

Figure 11. Pilot Ratings of APES Timeliness

Several pilots (3) commented that missed approach procedural prompts were "late" and "hurried." Four pilots reported that APES messages came too close together at the fixes (i.e., IAF, FAF) and that they should be spaced farther apart.

5.2.4 APES Performance (Objective 2) Discussion

The questionnaire data showed that pilots considered the performance of the APES to be acceptable in providing both "correction" and "procedural" advice to the pilot. Pilot comments regarding the APES performance primarily concerned the logic and timeliness of the airspeed and altitude corrrection advice and the stringent altitude and airspeed windows that were set for decision aid activation.

Pilot comments that "too many prompts occurred too close together" at the fixes (i.e., IAF, FAF) is contingent upon fixed approach requirements which can not be changed. One possible way of minimizing the "hurried appearance" of the APES voice messages would be to present the lower priority messages (or a specific type of message) in a textual format.

5.3 Pilot-Vehicle Interface Understandability and Useability (Objective 3)

Objective 3 of the study was to assess the understandability and useability of the pilot-vehicle interface to determine if the interface allowed the pilot to easily interpret and use APES advice. The analysis for this objective focused on questionnaire responses. Frequencies and averages were computed for the questionnaire ratings and pilot comments were summarized.

5.3.1 Questionnaire Results

On average, pilots rated the voice messages for altitude, airspeed, heading, course and radio advice as above "moderately acceptable." Most pilots (12) indicated that they did not use the APES message display on the right CRT because it was located outside their cross-check.

The average pilot ratings for the APES verbal advice are presented in Figure 12. As shown, pilots average ratings were above "moderately acceptable" for the parameters of: voice quality, sequence of voice messages and understandability of the voice messages. The average rating for the phraseology of the voice messages, however, were slightly below "moderately acceptable."

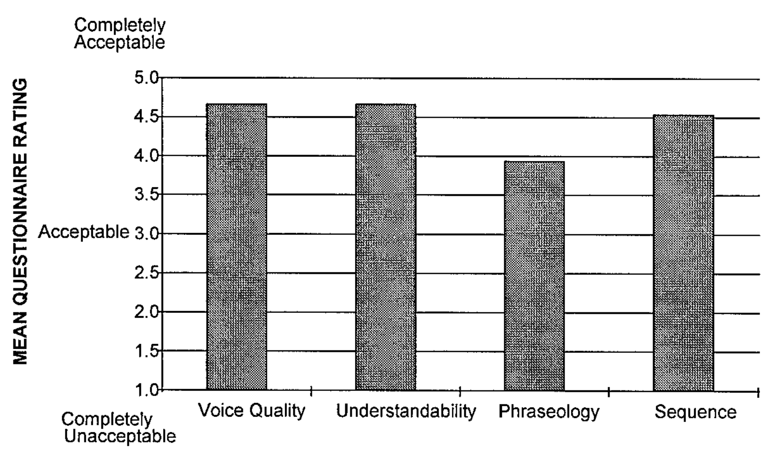

Figure 12. Pilot Ratings on APES Verbal Advice

Several pilots (6) commented that the phraseology of the airspeed and altitude verbal procedural advice needed to be more specific. Three pilots commented that when descending to decision height, the decision aid should say "descend to _____," instead of "maintain ______." Also, two pilots commented that pauses between verbal messages should be longer.

Another pilot thought that the voice messages may clutter the radio and interfere with ATC communications during critical phases of the flight. Two pilots indicated that they would like the option of being able to turn the APES verbal advice "off."

Also, one pilot commented that the PVI implementation of the scratchpad advice did not allow for meaningful interpretation. The "Enter" key (to set appropriate command markers and to clear the scratchpad) was often pressed without giving thought of the value being manipulated.

5.3.2 Pilot-Vehicle Interface Understandability and Useability (Objective 3) Discussion

The results showed that pilots rated the interface as being "acceptable," however, comments indicated that the phraseology of the voice advice could be improved.

APES textual display of advice messages also warrants further examination. Pilot comments overwhelmingly indicated that APES textual messages, displayed on the right CRT, were located too far outside the pilot's cross-check to be useful. In the current implementation, the right CRT primarily displayed information that was redundant of the APES voice message presentation. Future implementations would need to consider a location and format that is within pilot's cross-check, especially if it is a primary APES message display.

6. CONCLUSIONS AND RECOMMENDATIONS

Overall, the results provided strong evidence indicating that the prototype Approach Procedure Expert System (APES) reduces pilot workload and improves flight performance compared to flying approaches without the decision aid. APES appears to be most beneficial during high task-loading conditions where the pilot experienced high workload. Also, the majority of the pilots commented that that their situational awareness was "substantially enhanced" with the APES advice and significant SA ratings support this finding. Also, all pilots commented that they felt that APES would improve flight safety.

Although refinements were indicated, the results also showed that the APES "advisory pilot" and "advisory copilot" components consistently gave advice whenever it was needed, and that advice, for the most part, was complete and accurate for performing all tasks in all phases of flight. Finally, the results indicated that the pilot-vehicle interface was presented in a format that was both intelligible and operable for APES advice delivery, although refinements were again indicated.

6.1 Expert System General Design Considerations

As with any decision aid, careful consideration needs to be given to the known disadvantages associated with semi-automated systems. Because low-level decision making processes are automated, the pilot may view the system as a black box that generates outputs from inputs through some unknown mechanism, such as the algorithm. This may impair pilot confidence in the system and result in the pilot completely ignoring the advice of the decision aid. Conversely, too much trust and over-reliance on the decision aid may lead to reduced pilot situational awareness, which in turn, could adversely affect flight performance if the decision aiding system fails or an emergency occurs.

One way to mitigate the possible effects of reduced situational awareness and system confidence is through proper training of the decision aid logic. This training would enable the pilot to develop an accurate mental model of the reasoning behind the advice (Lehner and Zirk, 1987). Equally important is proper design of the pilot-vehicle interface to facilitate the human-computer interaction and allow the pilot to easily interpret the decision aid advice.

An effective decision aid may also need to include user-selectable options as part of its design, giving the pilot flexibility in configuring the PVI. For example, the pilot may find it useful to configure display modes (audio or visual) for certain types of advice (e.g., altitude, airspeed, course). The pilot may also find it beneficial to set the priority levels (e.g., primary and secondary) of the various advice types, as well as, adjust their tolerance windows (e.g., +/- 100 feet for altitude deviation).

6.2 Implications for Future Research

The results of this study strongly encourage future development of the approach plate expert system. We believe that the use of the APES could ultimately reduce the number of incidents and accidents during approach.

Enhancement of the APES algorithm is one area for follow-on research. Future implementations of APES altitude and airspeed correction advice may need to consider trend information. In its current implementation, APES could not provide explicit corrective altitude and airspeed advice (i.e., increase/decrease by XXX feet/XX knots) because altitude and airspeed were too dynamic for accurate input. APES procedural advice could also be augmented to provide a predictive rate of descent (i.e., VVI) to capture target altitude. In its current implementation, APES only periodically prompted the pilot of the target altitude.

The APES PVI is another area for follow-on research. Future APES implementations will need to address potential conflicts between the APES audio advice and radio communications. PVI developmental efforts should also focus on optimum formats for critical phases of flight where simultaneous changes on multiple flight parameters are required (e.g., IAF, FAF, MAP). This research should investigate pilot selectable options for configuring the PVI (e.g., setting deviation tolerance windows for decision aid activation). Issues involved in implementing an intelligent agent for automatic adjustments of display and advice settings should also be examined.

Future pilot-in-the-loop studies should evaluate APES to assess its robustness across a diversity of approach types, including high-altitude approaches (only low-altitude were used in the current study) and non-typical approaches. These evaluations should include air traffic control communications as part of the testing scenario.

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APPENDIX A - QUESTIONNAIRE AND SUBJECTIVE WORKLOAD DOMINANCE (SWORD) FORMS

Introduction

The questionnaires and SWORD forms that were used in the Pilot-in-the-Loop Evaluation of the Approach Procedures Expert System (APES) are provided in this Appendix. The questionnaire responses of the 16 pilots who participated in this study are summarized in Appendix C. A summary of the SWORD responses is presented in Appendix B.

SESSION QUESTIONNAIRE

Subject No. ______

Session No. ______

Decision Aid: Yes / No ***Orientation:*** N-Up / T-Up ***Prior Review:*** Yes / No

1. Use the scale below to rate the ease of performing the following tasks for this approach. For response ratings of "D" or "E," please explain under comments.

Rating Scale:

A = Extremely Easy
B = Moderately Easy
C = Neutral
D = Moderately Difficult
E = Extremely Difficult

Comments:

a) _______ Assessing aircraft performance

b) _______ Flying the holding pattern

c) _______ Flying the Initial Approach track

d) _______ Flying the Final Approach

e) _______ Executing Missed Approach procedures

f) _______ Overall Rating of Approach Tasks

2. What are your initial comments regarding this approach and (if applicable) the decision aid?

FINAL QUESTIONNAIRE

Subject No. ______

Instructions: Use the scale below to rate the quality of each type of "PROCEDURAL" advice given in each segment of the approach.

I. PROCEDURAL ADVICE

A = Completely Acceptable:
No changes needed; acceptable as is.
B = Moderately Acceptable:
Minor changes desirable; effectiveness not impaired.
C = Borderline:
Changes desirable; effectiveness may be impaired.
D = Moderately Unacceptable:
Changes required, effectiveness moderately impaired.
E = Completely Unacceptable:
Redesign required, effectiveness severely impaired.

HEADING PROMPTS

	Logic *(advice is correct and complete)*	**Timeliness** *(advice occurs at the proper time that it is needed)*	**Consistency** *(advice is consistently given whenever it is needed)*
HOLDING			
INITIAL APPROACH TRACK			
FINAL APPROACH TRACK			
MISSED APPROACH			
OVERALL			

Comments:

COURSE PROMPTS

	Logic *(advice is correct and complete)*	**Timeliness** *(advice occurs at the proper time that it is needed)*	**Consistency** *(advice is consistently given whenever it is needed)*
HOLDING			
INITIAL APPROACH TRACK			
FINAL APPROACH TRACK			
MISSED APPROACH			
OVERALL			

Comments:

I. PROCEDURAL ADVICE (CONT.)

Subject No. ______

Instructions: Use the scale below to rate the quality of each type of "PROCEDURAL" advice given in each segment of the approach.

A = Completely Acceptable:
No changes needed; acceptable as is.
B = Moderately Acceptable:
Minor changes desirable; effectiveness not impaired.
C = Borderline:
Changes desirable; effectiveness may be impaired.
D = Moderately Unacceptable:
Changes required, effectiveness moderately impaired.
E = Completely Unacceptable:
Redesign required, effectiveness severely impaired.

AIRSPEED PROMPTS

	Logic *(advice is correct and complete)*	**Timeliness** *(advice occurs at the proper time that it is needed)*	**Consistency** *(advice is consistently given whenever it is needed)*
HOLDING			
INITIAL APPROACH TRACK			
FINAL APPROACH TRACK			
MISSED APPROACH			
OVERALL			

Comments:

ALTITUDE PROMPTS

	Logic *(advice is correct and complete)*	**Timeliness** *(advice occurs at the proper time that it is needed)*	**Consistency** *(advice is consistently given whenever it is needed)*
HOLDING			
INITIAL APPROACH TRACK			
FINAL APPROACH TRACK			
MISSED APPROACH			
OVERALL			

Comments:

I. PROCEDURAL ADVICE (CONT.)

Subject No. ______

Instructions: Use the scale below to rate the quality of each type of "PROCEDURAL" advice given in each segment of the approach.

A = Completely Acceptable:
No changes needed; acceptable as is.
B = Moderately Acceptable:
Minor changes desirable; effectiveness not impaired.
C = Borderline:
Changes desirable; effectiveness may be impaired.
D = Moderately Unacceptable:
Changes required, effectiveness moderately impaired.
E = Completely Unacceptable:
Redesign required, effectiveness severely impaired.

RADIO FREQ/CHANNEL PROMPTS

	Logic *(advice is correct and complete)*	**Timeliness** *(advice occurs at the proper time that it is needed)*	**Consistency** *(advice is consistently given whenever it is needed)*
HOLDING			
INITIAL APPROACH TRACK			
FINAL APPROACH TRACK			
MISSED APPROACH			
OVERALL			

Comments:

II. DEVIATION ADVICE

Subject No. ______

Instructions: Use the scale below to rate the quality of each type of "DEVIATION" advice given during *all* segments of the approach.

A = Completely Acceptable:
No changes needed; acceptable as is.
B = Moderately Acceptable:
Minor changes desirable; effectiveness not impaired.
C = Borderline:
Changes desirable; effectiveness may be impaired.
D = Moderately Unacceptable:
Changes required, effectiveness moderately impaired.
E = Completely Unacceptable:
Redesign required, effectiveness severely impaired.

DEVIATION PROMPTS

	Logic *(advice is correct and complete)*	**Timeliness** *(advice occurs at the proper time that it is needed)*	**Consistency** *(advice is consistently given whenever it is needed)*
HEADING			
COURSE			
AIRSPEED			
ALTITUDE			
OVERALL			

Comments:

III. TASK ACCOMPLISHMENT AND EAP ORIENTATION

Subject No. ______

Rating Scale:
- **A = Substantially Enhanced**
- **B = Moderately Enhanced**
- **C = Did Not Affect**
- **D = Moderately Degraded**
- **E = Substantially Degraded**

Instructions: Use the scale above to rate the effectiveness of the decision aid versus no decision aid for performing the following tasks in Track-Up EAP Orientation, North-Up EAP Orientation, and Overall. Please provide comments for "D" or "E" ratings.

The Decision Aid _______ my ability to . . .	Track - Up	North - Up	Overall	Comments:
a) identify and navigate to the holding fix.				
b) determine direction of turn into holding.				
c) identify and navigate to the IAF.				
d) identify approach radials / arc.				
e) identify approach altitude.				
f) identify and navigate to the FAF.				
g) identify the decision height or minimum descent altitude.				
h) identify and navigate to the MAP.				
i) identify and set Navaids.				
j) determine intercept headings / angles.				
k) determine lead points for arcs / courses.				
l) determine airspeeds.				
m) determine aircraft's position relative to approach fixes.				
n) develop a mental picture for anticipating future events.				

IV. PILOT-VEHICLE INTERFACE

Subject No: ______

Rating Scale:

A = **Completely Acceptable:** No changes needed; acceptable as is.
B = **Moderately Acceptable:** Minor changes desirable; effectiveness not impaired.
C = **Borderline:** Changes desirable; effectiveness may be impaired.
D = **Moderately Unacceptable:** Changes required, effectiveness moderately impaired.
E = **Completely Unacceptable:** Redesign required, effectiveness severely impaired.

Instructions: Use the above scale to rate the overall quality of the "*pilot-vehicle interface*" for the following prompts. For response ratings of "C" or below, please identify the parameter(s) that is deficient by placing a check (√) on the appropriate line. Also please explain under comments.

Comments:

1. _____ Heading Prompts (overall)
   - a) _____ Audio Display (Voice)
   - b) _____ Visual Display (CRT)
   - c) _____ Frequency of Prompt Repetition
   - d) _____ Tolerance Window (+/- 5°)
2. _____ Altitude Prompts (overall)
   - a) _____ Audio Display (Voice)
   - b) _____ Visual Display (CRT)
   - c) _____ Frequency of Prompt Repetition
   - d) _____ Tolerance Window (+/- 100 ft)
3. _____ Airspeed Prompts (overall)
   - a) _____ Audio Display (Voice)
   - b) _____ Visual Display (CRT)
   - c) _____ Frequency of Prompt Repetition
   - d) _____ Tolerance Window (+/- 10 kts)
4. _____ Course Prompts (overall)
   - a) _____ Audio Display (Voice)
   - b) _____ Visual Display (CRT)
   - c) _____ Frequency of Prompt Repetition
   - d) _____ Tolerance Window (+/-2°)
5. _____ Frequency/Channel Prompts (overall)
   - a) _____ Audio Display (Voice)
   - b) _____ Visual Display (CRT)
   - c) _____ Frequency of Prompt Repetition

Additional Comments:

IV. PILOT-VEHICLE INTERFACE (continued)

Subject No. ______

Rating Scale:

A = **Completely Acceptable:** No changes needed; acceptable as is.
B = **Moderately Acceptable:** Minor changes desirable; effectiveness not impaired.
C = **Borderline:** Changes desirable; effectiveness may be impaired.
D = **Moderately Unacceptable:** Changes required, effectiveness moderately impaired.
E = **Completely Unacceptable:** Redesign required, effectiveness severely impaired.

Instructions: Use the scale above to rate the effectiveness of Pilot-Vehicle Interface. For response ratings of "C" or below, please explain under comments.

Comments:

6. ***Audio (Voice)*** parameters:

a) _____ Voice Quality /Ease of Hearing Voice Messages

b) _____ Understandability / Comprehensiveness of Voice Messages

c) _____ Phraseology of Voice Message

d) _____ Sequence of Voice Message Format

7. In what ways could the Voice Interface be improved?

8. ***Visual (CRT)*** parameters:

a) ______ Readability of the Messages

b) ______ Understandability / Comprehensiveness of Text Messages

c) ______ Phraseology of Text Messages

d) ______ Sequence of Message Presentations

e) ______ Location of Text Messages

9. In what ways could the Text Message Interface be improved?

V. GENERAL QUESTIONS

Subject No. ______

1. How frequently did you follow the procedural advice of the decision aid?

_____ Always
_____ Often
_____ Sometimes
_____ Almost Never
_____ Never

Comments:

2. When given, how frequently did you follow the deviation advice of the decision aid?

_____ Always
_____ Often
_____ Sometimes
_____ Almost Never
_____ Never

Comments:

3. Did EAP orientation (North-Up/Track-Up) affect your use of the decision aid?

______YES ______ NO

If YES, in what ways?

4. The combination of wind gusts and no prior review of the approach plates:

_____ Did not affect workload.
_____ Moderately increased workload.
_____ Substantially increased workload.

Comments:

5. How did wind gusts and no prior review of the approach plate *affect your use* of the decision aid?

______ Substantially increased usage
______ Moderately increased usage
______ Did not affect usage
______ Moderately decreased usage
______ Substantially decreased usage

Comments:

V. GENERAL QUESTIONS (cont.)

6. The decision aid improves safety when flying instrument approaches.

_____ Strongly agree
_____ Moderately agree
_____ Neutral
_____ Moderately disagree
_____ Strongly disagree

Comments:

7. How would you rate the *overall utility* of the decision aid for assisting you in performing instrument approaches.

_____ Extremely Beneficial
_____ Moderately Beneficial
_____ Neutral
_____ Moderate Hindrance
_____ Extreme Hindrance

Comments:

8. Are there other conditions, not simulated here, where you think this decision aid might be useful?

______YES ______ NO ______ NOT SURE

Comments:

9. Did you develop a particular strategy for using the decision aid?

______YES ______ NO

If YES, please comment.

10. What did you like _best_ about the decision aid?

11. What did you like _least_ about the decision aid?

12. Additional Comments:

SWORD QUESTIONNAIRE INSTRUCTIONS

The SWORD technique assesses workload / situation awareness by utilizing a series of pairwise comparisons between system configurations. For this study, you will be asked to make comparisons between: *2 decision aid conditions* (aid and no aid); *2 winds/approach review conditions* (with winds, no review and no winds, review), and *2 EAP orientation conditions* (track-up and north-up).

Rate to the best of your ability, the display configuration that you think causes <u>higher workload</u> or <u>promotes better situational awareness</u> (given questionnaire type). Base your responses on your experience flying approaches in the MAGIC simulator.

The examples below show comparison ratings that can be made between various conditions of this study.

Example 1- shows that the <u>AID</u> <u>TRACK-UP</u> causes *substantially more workload* or *SA* (*depending on scale)* than the <u>AID</u> <u>NORTH-UP</u> when winds are present and with no approach review (WNDS/NORVW).

>>> >>> >> > **EQUAL** < << <<< <<<<

AID WNDS/NORVW TRK-UP __ _√_ __ __ __ __ __ __ __ |___| __ __ __ __ __ __ __ __ __ AID WNDS/NORVW NORTH-UP

Example 2 -shows that the <u>AID NORTH -UP</u> causes *moderately more workload* or *SA (depending on scale)* than the <u>AID</u> <u>TRACK-UP</u> when winds are present and with no approach review (WNDS/NORVW).

>>> >>> >> > **EQUAL** < << <<< <<<<

AID WNDS/NORVW TRK-UP __ __ __ __ __ __ __ __ __ |___| __ __ __ _√_ __ __ __ __ AID WNDS/NORVW NORTH-UP

Example 3 - shows that workload or SA (depending on scale) between the <u>AID NORTH -UP</u> condition and the <u>NOAID</u> <u>TRACK-UP</u> conditions are *equal* when winds are present and with no approach review (WNDS/NORVW).

>>> >>> >> > **EQUAL** < << <<< <<<<

AID WNDS/NORVW NORTH-UP__ __ __ __ __ __ __ __ __ |_√_| __ __ __ __ __ __ __ __ __ NOAID WNDS/NORVW TRK--UP

WHICH CONFIGURATION ELICITS THE MOST WORKLOAD?

	>>>>	>>>	>>	>	EQUAL	<	<<	<<<	<<<<	
Aid NoWnds/Rvw Trk-Up										Aid NoWnds/Rvw North-Up
Aid NoWnds/Rvw Trk-Up										Aid Wnds/NoRvw Trk-Up
Aid NoWnds/Rvw Trk-Up										Aid Wnds/NoRvw North-Up
Aid NoWnds/Rvw Trk-Up										NoAid NoWnds/Rvw Trk-Up
Aid NoWnds/Rvw Trk-Up										NoAid NoWnds/Rvw North-Up
Aid NoWnds/Rvw Trk-Up										NoAid Wnds/NoRvw Trk-Up
Aid NoWnds/Rvw Trk-Up										NoAid Wnds/NoRvw North-Up
Aid NoWnds/Rvw North-Up										Aid Wnds/NoRvw Trk-Up
Aid NoWnds/Rvw North-Up										Aid Wnds/NoRvw North-Up
Aid NoWnds/Rvw North-Up										NoAid NoWnds/Rvw Trk-Up
Aid NoWnds/Rvw North-Up										NoAid NoWnds/Rvw North-Up
Aid NoWnds/Rvw North-Up										NoAid Wnds/NoRvw Trk-Up
Aid NoWnds/Rvw North-Up										NoAid Wnds/NoRvw North-Up
Aid Wnds/NoRvw Trk-Up										Aid Wnds/NoRvw North-Up
Aid Wnds/NoRvw Trk-Up										NoAid NoWnds/Rvw Trk-Up
Aid Wnds/NoRvw Trk-Up										NoAid NoWnds/Rvw North-Up
Aid Wnds/NoRvw Trk-Up										NoAid Wnds/NoRvw Trk-Up
Aid Wnds/NoRvw Trk-Up										NoAid Wnds/NoRvw North-Up

DECISION AID:
With Aiding (Aid)
Without Aiding (NoAid)

APPROACH TYPE:
No Winds, Review of EAP (NoWnds/Rvw)
Winds, No EAP Review (Wnds/NoRvw)

EAP ORIENTATION:
Trk-Up (Track-Up)
North-Up

WHICH CONFIGURATION ELICITS THE MOST WORKLOAD?

	>>>>	>>>	>>	>	EQUAL	<	<<	<<<	<<<<	
Aid Wnds/NoRvw North-Up										NoAid NoWnds/Rvw Trk-Up
Aid Wnds/NoRvw North-Up										NoAid NoWnds/Rvw North-Up
Aid Wnds/NoRvw North-Up										NoAid Wnds/NoRvw Trk-Up
Aid Wnds/NoRvw North-Up										NoAid Wnds/NoRvw North-Up
NoAid NoWnds/Rvw Trk-Up										NoAid NoWnds/Rvw North-Up
NoAid NoWnds/Rvw Trk-Up										NoAid Wnds/NoRvw Trk-Up
NoAid NoWnds/Rvw Trk-Up										NoAid Wnds/NoRvw North-Up
NoAid NoWnds/Rvw North-Up										NoAid Wnds/NoRvw Trk-Up
NoAid NoWnds/Rvw North-Up										NoAid Wnds/NoRvw North-Up
NoAid Wnds/NoRvw Trk-Up										NoAid Wnds/NoRvw North-Up

DECISION AID:
With Aiding (Aid)
Without Aiding (NoAid)

APPROACH TYPE:
No Winds, Review of EAP (NoWnds/Rvw)
Winds, No EAP Review (Wnds/NoRvw)

EAP ORIENTATION:
Trk-Up (Track-Up)
North-Up

WHICH CONFIGURATION PROMOTES BETTER SITUATIONAL AWARENESS?

	>>>>		>>>		>>		>		EQUAL		<		<<		<<<		<<<<	
Aid NoWnds/Rvw Trk-Up																		Aid NoWnds/Rvw North-Up
Aid NoWnds/Rvw Trk-Up																		Aid Wnds/NoRvw Trk-Up
Aid NoWnds/Rvw Trk-Up																		Aid Wnds/NoRvw North-Up
Aid NoWnds/Rvw Trk-Up																		NoAid NoWnds/Rvw Trk-Up
Aid NoWnds/Rvw Trk-Up																		NoAid NoWnds/Rvw North-Up
Aid NoWnds/Rvw Trk-Up																		NoAid Wnds/NoRvw Trk-Up
Aid NoWnds/Rvw Trk-Up																		NoAid Wnds/NoRvw North-Up
Aid NoWnds/Rvw North-Up																		Aid Wnds/NoRvw Trk-Up
Aid NoWnds/Rvw North-Up																		Aid Wnds/NoRvw North-Up
Aid NoWnds/Rvw North-Up																		NoAid NoWnds/Rvw Trk-Up
Aid NoWnds/Rvw North-Up																		NoAid NoWnds/Rvw North-Up
Aid NoWnds/Rvw North-Up																		NoAid Wnds/NoRvw Trk-Up
Aid NoWnds/Rvw North-Up																		NoAid Wnds/NoRvw North-Up
Aid Wnds/NoRvw Trk-Up																		Aid Wnds/NoRvw North-Up
Aid Wnds/NoRvw Trk-Up																		NoAid NoWnds/Rvw Trk-Up
Aid Wnds/NoRvw Trk-Up																		NoAid NoWnds/Rvw North-Up
Aid Wnds/NoRvw Trk-Up																		NoAid Wnds/NoRvw Trk-Up
Aid Wnds/NoRvw Trk-Up																		NoAid Wnds/NoRvw North-Up

DECISION AID:
With Aiding (Aid)
Without Aiding (NoAid)

APPROACH TYPE:
No Winds, Review of EAP (NoWnds/Rvw)
Winds, No EAP Review (Wnds/NoRvw)

EAP ORIENTATION:
Track-Up (Trk-Up)
North-Up

WHICH CONFIGURATION PROMOTES BETTER SITUATIONAL AWARENESS?

	>>>>		>>>		>>		>		EQUAL		<		<<		<<<		<<<<	
Aid Wnds/NoRvw North-Up																		NoAid NoWnds/Rvw Trk-Up
Aid Wnds/NoRvw North-Up																		NoAid NoWnds/Rvw North-Up
Aid Wnds/NoRvw North-Up																		NoAid Wnds/NoRvw Trk-Up
Aid Wnds/NoRvw North-Up																		NoAid Wnds/NoRvw North-Up
NoAid NoWnds/Rvw Trk-Up																		NoAid NoWnds/Rvw North-Up
NoAid NoWnds/Rvw Trk-Up																		NoAid Wnds/NoRvw Trk-Up
NoAid NoWnds/Rvw Trk-Up																		NoAid Wnds/NoRvw North-Up
NoAid NoWnds/Rvw North-Up																		NoAid Wnds/NoRvw Trk-Up
NoAid NoWnds/Rvw North-Up																		NoAid Wnds/NoRvw North-Up
NoAid Wnds/NoRvw Trk-Up																		NoAid Wnds/NoRvw North-Up

DECISION AID:

With Aiding (Aid)

Without Aiding (NoAid)

APPROACH TYPE:

No Winds, Review of EAP (NoWnds/Rvw)

Winds, No EAP Review (Wnds/NoRvw)

EAP ORIENTATION:

Track-Up (Trk-Up)

North-Up

APPENDIX B - ANALYSIS OF VARIANCE RESULTS

STATISTIC ANALYSIS SUMMARY

1. Introduction

The results of the analysis procedures performed on the performance, situational awareness, and workload data are provided in this Appendix. Each data group will provide a table of the results of the ad-hoc Analysis of Variance (ANOVA) procedures, including F statistics, degrees of freedom, and significance levels for each main effect and interaction. Additional tables will show the means used in the ANOVA analysis. The results of one-way ANOVAs used in the analysis of the significant interactions are also described. A table of the applicable means used in each interaction is presented.

2. Performance Data

The analyses treated in this section pertain to the performance data collected during the instrument approach flying sessions. The analyses will be presented separately for each of the following dependent performance variables: RMS altitude deviation, RMS airspeed deviation, RMS heading deviation, RMS course deviation, and RMS glideslope deviation.

2.1 Root Mean Square (RMS) Altitude Deviation

A 2×2×2×2 Repeated Measure ANOVA (2 Decision Aid conditions, 2 Task Loading conditions, 2 EAP Orientation conditions, 2 Approach Phase conditions) was performed on the Root Mean Square (RMS) altitude deviation data. Because RMS Altitude deviation was not appropriate for the Final Approach phase (the aircraft is descending), only the Holding and Initial Approach phases were included in the analysis. The results are provided in Table B-1. The means used in this analysis are provided in Table B-2.

Table B-1. ANOVA Results for Altitude Deviation

Tested Effect	ANOVA Results
Decision Aid	F(1,15) = 26.77, p = .000*
Task Loading	F(1,15) = 8.27, p = .009*
EAP Orientation	F(1,15) = 0.08, p = .781
Approach Phase	F(1,15) = 1.68, p = .215
Decision Aid × Task Loading	F(1,15) = 8.03, p = .013*
Decision Aid × EAP Orientation	F(1,15) = 0.03, p = .875
Decision Aid × Approach Phase	F(1,15) = 6.40, p = .023*
Task Loading × EAP Orientation	F(1,15) = 0.12, p = .730
Task Loading × Approach Phase	F(1,15) = 2.07, p = .171
Approach Phase × EAP Orientation	F(1,15) = 0.19, p = .672
Decision Aid × Task Loading × EAP Orientation	F(1,15) = 0.00, p = .962
Decision Aid × Task Loading × Approach Phase	F(1,15) = 0.45, p = .511
Task Loading × EAP Orientation × Approach Phase	F(1,15) = 0.66, p = .429
Decision Aid × Task Loading × EAP Orientation × Approach Phase	F(1,15) = 0.31, p = .588

* indicates statistical significance, $p < 0\ .05$

Table B-2. Means Used in the RMS Altitude Deviation (feet) Analysis

HOLDING						
	AID			NOAID		
	North-Up	Track-Up	Overall	North-Up	Track-Up	Overall
Low Task Loading	51.44	49.05	50.25	58.79	55.97	57.38
High Task Loading	52.47	55.38	53.92	68.10	76.15	72.13
Overall	51.96	52.52	52.08	63.45	66.06	64.57
INITIAL APPROACH						
	AID			NOAID		
	North-Up	Track-Up	Overall	North-Up	Track-Up	Overall
Low Task Loading	46.73	44.54	45.64	70.50	67.51	69.00
High Task Loading	52.68	52.21	52.45	100.81	93.00	96.91
Overall	49.71	48.38	49.05	85.66	80.26	73.65

ALL PHASES							
	AID			NOAID			Overall
	North-Up	Track-Up	Overall	North-Up	Track-Up	Overall	
Low Task Loading	49.08	46.80	47.94	64.02	61.74	62.83	55.39
High Task Loading	52.57	53.80	53.18	83.93	84.29	84.10	68.64
Overall	50.83	50.30	50.56	73.97	73.02	73.47	62.02

Significant main effects were found for Decision Aid ($F = 26.77$, $p < 0.001$) and Task Loading ($F = 8.27$, $p = 0.009$); and significant interactions were found between Decision Aid and Task Loading conditions ($F = 8.03$, $p = 0.013$) and between Decision Aid and Approach Phase conditions ($F = 6.40$, $p = 0.023$). No other significant main effects or interactions were found. One-way ANOVAs were performed to analyze the nature of the significant interactions.

For the Decision Aid by Task Loading interaction, a simple main effect was found for Task Loading in the No Aid condition ($F = 11.34$, $p = 0.004$), but not in the Aid condition. In the No Aid condition, RMS altitude deviation was significantly smaller with Low Task Loading (mean = 62.83 feet) than with High Task Loading (mean = 84.10 feet). The means used in this analysis are presented in Table B-3.

Table B-3. Means Used in Analysis of Decision Aid by Task Loading Interaction

RMS Altitude Deviation (feet)		
	Aid	NoAid
Low Task Loading	47.94	62.83
High Task Loading	53.19	84.10

For the Decision Aid by Approach Phase interaction, no significant simple main effects were found for Approach Phase for either the Aid or No Aid conditions; a however, a trend ($p = .056$) showed smaller RMS altitude deviations were found in the Aid condition (mean = 59.04 feet) compared to the No Aid condition (mean = 82.95 feet) during the Initial Approach phase. The means used for this analysis are presented in Table B-4.

Table B-4. Means Used in Analysis of Decision Aid by Task Loading Interaction

RMS Altitude Deviation (feet)		
	Aid	NoAid
Holding	52.09	64.57
Initial Approach	59.04	82.95

2.2 RMS Airspeed Deviation

A 2×2×2×3 Repeated Measure ANOVA (2 Decision Aid conditions, 2 Task Loading conditions, 2 EAP Orientation conditions, 3 Approach Phase conditions) was performed on the Root Mean Square (RMS) airspeed deviation data. The results are provided in Table B-5 and the means used in this analysis are presented in Table B-6.

Table B-5. ANOVA Results for RMS Airspeed Deviation

Tested Effect	**ANOVA Results**
Decision Aid	F(1,15) = 11.15, p = .004*
Task Loading	F(1,15) = 2.88, p = .110
EAP Orientation	F(1,15) = 0.27, p = .608
Approach Phase	F(2,30) = 50.10, p = .000*
Decision Aid × Task Loading	F(1,15) = 0.20, p = .657
Decision Aid × EAP Orientation	F(1,15) = 0.99, p = .336
Decision Aid × Approach Phase	F(2,30) = 6.58, p = .004*
Task Loading × EAP Orientation	F(1,15) = 0.17, p = .690
Task Loading × Approach Phase	F(2,30) = 14.55 p = .000*
Approach Phase × EAP Orientation	F(1,15) = 0.10, p = .907
Decision Aid × Task Loading × EAP Orientation	F(1,15) = 1.67, p = .215
Decision Aid × Task Loading × Approach Phase	F(2,30) = 1.78, p = .187
Task Loading × EAP Orientation × Approach Phase	F(2,30) = 0.12, p = .885
Decision Aid × Task Loading × EAP Orientation × Approach Phase	F(2,30) = 1.92, p = .164

* indicates statistical significance, $p < 0.05$

Table B-6. Means Used for RMS Airspeed Deviation Analysis

HOLDING						
	AID			NOAID		
	North-Up	Track-Up	Overall	North-Up	Track-Up	Overall
Low Task Loading	12.89	13.39	13.14	12.91	12.19	12.55
High Task Loading	13.46	11.75	12.61	11.73	13.95	12.84
Overall	13.18	12.57	12.88	12.32	13.07	12.70
INITIAL APPROACH						
	AID					
	North-Up	Track-Up	Overall	North-Up	Track-Up	Overall
Low Task Loading	10.26	11.43	10.84	15.28	14.51	14.90
High Task Loading	12.84	10.92	11.88	14.30	15.87	15.08
Overall	11.55	11.18	11.36	14.79	15.19	14.99

Table B-6 (cont.) Means Used for RMS Airspeed Deviation (knots) Analysis

FINAL APPROACH						
	AID					
	North-Up	Track-Up	Overall	North-Up	Track-Up	Overall
Low Task Loading	10.26	11.43	10.84	15.28	14.51	14.90
High Task Loading	12.84	10.92	11.88	14.30	15.87	15.09
Overall	11.55	11.18	11.36	14.79	15.19	15.00

ALL PHASES							
	AID			NOAID			Overall
	North-Up	Track-	Overall	North-Up	Track-Up	Overall	
Low Task Loading	9.56	10.44	10.00	11.43	11.41	11.42	10.71
High Task Loading	11.78	10.36	11.07	12.13	13.74	12.94	12.01
Overall	10.67	10.40	10.54	11.78	12.58	12.18	11.36

Significant main effects were found for Decision Aid ($F = 11.15$, $p = 0.004$) and Approach Phase ($F = 50.10$, $p < 0.001$); and significant interactions were found between Decision Aid and Task Loading conditions ($F = 6.58$, $p = 0.004$) and between Task Loading and Approach Phase conditions ($F = 14.45$, $p < 0.000$). No other significant main effects or interactions were found. One-way ANOVAs were performed to analyze the nature of the significant interactions.

For the Decision Aid by Approach Phase interaction, a simple main effect was found for Decision Aid for the Initial Approach ($F = 11.54$, $p = .004$) and the Final Approach phases ($F = 14.27$, $p = .002$), but not for the Holding phase. RMS airspeed deviation was significantly smaller in the Aid condition (compared to No Aid condition) for both the Initial Approach (Aid mean = 11.36 knots / No Aid mean = 14.96 knots) and the Final Approach phases (Aid mean = 7.57 knots / No Aid mean = 9.08 knots). The means used in this analysis are presented in Table B-7.

Table B-7. Means Used in Analysis of Decision Aid by Approach Phase Interaction

RMS Airspeed Deviation (knots)		
	Aid	NoAid
Holding	12.88	12.69
Initial Approach	11.36	14.96
Final Approach	7.57	9.08

For the Task Loading by Approach Phase interaction, a simple main effect was found for Task Loading for the Final Approach phase (F=23.43, $p < 0.001$), but not for the Holding and Initial Approach phases. For the Final Approach phase, RMS airspeed deviation was significantly smaller in the Low Task Loading (6.68 knots) compared to High Task Loading condition (9.97 knots). Means used for this analyses are provided in Table B-8.

Table B-8. Means Used in the Analysis of Task Loading by Approach Phase Interaction

RMS Airspeed Deviation (knots)		
	Low Task Loading	High Task Loading
Holding	12.65	12.72
Initial Approach	12.83	13.33
Final Approach	6.68	9.97

2.3 RMS Heading Deviation

A 2×2×2×2 Repeated Measure ANOVA (2 Decision Aid conditions, 2 Task Loading conditions, 2 EAP Orientation conditions, 2 Approach Phase conditions) was performed on the Root Mean Square (RMS)heading deviation data. Because of the potential for spurious data in the Holding phase (due to numerous heading changes), only Initial and Final Approach phases were included in the analysis. The results of the ANOVA analysis are provided in Table B-9 and the means used in this analysis are presented in Table B-10.

A significant main effect was found for Approach Phase (F = 113.49, $p < .000$). RMS heading deviation was smaller in the Final Approach phase (mean = 4.28 degrees) than in the Initial Approach phase (mean = 12.21 degrees). This result is not surprising given that the navigation aid for the final approach gives more accurate and sensitive course information than the navigation aid for the initial approach. No other significant main effects or interactions were found.

Table B-9. ANOVA Results for RMS Heading Deviation

Tested Effect	ANOVA Results
Decision Aid	F(1,15) = 0.04, p = .846
Task Loading	F(1,15) = 0.27, p = .608
EAP Orientation	F(1,15) = 0.77, p = .393
Approach Phase	F(1,15) = 113.49, p = .000*
Decision Aid × Task Loading	F(1,15) = 0.23, p = .639
Decision Aid × EAP Orientation	F(1,15) = 0.68, p = .422
Decision Aid × Approach Phase	F(1,15) = 0.03, p = .865
Task Loading × EAP Orientation	F(1,15) = 0.43, p = .522
Task Loading × Approach Phase	F(1,15) = 1.49, p = .241
Approach Phase × EAP Orientation	F(1,15) = 0.04, p = .850
Decision Aid × Task Loading × EAP Orientation	F(1,15) = 0.75, p = .399
Decision Aid × Task Loading × Approach Phase	F(1,15) = 0.28, p = .601
Task Loading × EAP Orientation × Approach Phase	F(1,15) = 0.39, p = .540
Decision Aid × Task Loading × EAP Orientation × Approach Phase	F(1,15) = 0.80, p = .384

* indicates statistical significance, $p < 0 .05$

Table B-10. Means used for RMS Heading Deviation (degrees) Analysis

INITIAL APPROACH						
	AID			NOAID		
	North-Up	Track-Up	Overall	North-Up	Track-Up	Overall
Low Task Loading	17.42	11.13	14.28	10.77	14.69	12.73
High Task Loading	7.49	13.02	7.14	10.23	13.16	11.69
Overall	12.46	12.08	10.71	10.50	13.93	12.21

FINAL APPROACH						
	AID			NOAID		
	North-Up	Track-Up	Overall	North-Up	Track-Up	Overall
Low Task Loading	1.77	1.28	1.53	1.32	3.32	2.32
High Task Loading	2.41	1.99	2.20	1.62	3.66	2.64
Overall	2.09	1.64	1.87	1.47	3.49	2.48

ALL PHASES							
	AID			NOAID			Overall
	North-Up	Track-Up	Overall	North-Up	Track-Up	Overall	
Low Task Loading	9.60	6.21	7.90	6.04	9.01	7.53	7.72
High Task Loading	4.95	7.51	6.23	5.93	8.41	7.17	6.70
Overall	7.28	6.86	7.07	5.98	8.71	7.35	7.21

2.4 RMS Course Deviation

A 2×2×2×2 Repeated Measure ANOVA (2 Decision Aid conditions, 2 Task Loading conditions, 2 EAP Orientation conditions, 2 Approach Phase conditions) was performed on the Root Mean Square (RMS) course deviation data. Because of the potential for spurious data in the Holding phase (due to the numerous course changes), only the Initial and Final Approach phases were included in the analysis. The results of the ANOVA analysis are provided in Table B-11 and the means used in this analysis are presented in Table B-12.

A significant main effect was found for Approach Phase (F = 755.95, $p < 0.001$). RMS course deviation was smaller in the Final Approach phase (mean = .092 dots) than in the Initial Approach phase (mean = 2.84 dots). This result is not surprising given that the navigation aid for the final approach gives more accurate and sensitive course information than the navigational aid for the initial approach. No other significant main effects or interactions were found.

Table B-11. ANOVA Results for RMS Course Deviation

Tested Effect	ANOVA Results
Decision Aid	F(1,15) = 3.83, p = .069
Task Loading	F(1,15) = 0.21, p = .654
EAP Orientation	F(1,15) = 0.84, p = .373
Approach Phase	F(1,15) = 755.95, p = .000*
Decision Aid × Task Loading	F(1,15) = 0.03, p = .858
Decision Aid × EAP Orientation	F(1,15) = 0.00, p = .951
Decision Aid × Approach Phase	F(1,15) = 3.64, p = .076
Task Loading × EAP Orientation	F(1,15) = 0.31, p = .585
Task Loading × Approach Phase	F(1,15) = 0.01, p = .927
Approach Phase × EAP Orientation	F(1,15) = 0.79, p = .387
Decision Aid × Task Loading × EAP Orientation	F91,15) = 0.00, p = .961
Decision Aid × Task Loading × Approach Phase	F(1,15) = 0.02, p = .883
Task Loading × EAP Orientation × Approach Phase	F(1,15) = 0.38, p = .548
Decision Aid × Task Loading × EAP Orientation × Approach Phase	F(1,15) = 0.00, p = .969

* indicates statistical significance, $p < 0.05$

Table B-12. Means Used for RMS Course Deviation (dots) Analysis

INITIAL APPROACH						
	AID			NOAID		
	North-Up	Track-Up	Overall	North-Up	Track-Up	Overall
Low Task	2.02	2.57	2.30	2.63	2.89	2.76
High Task	2.23	2.36	2.30	2.97	2.84	2.91
Overall	2.13	2.46	2.30	2.80	2.87	2.84
FINAL APPROACH						
	AID			NOAID		
	North-Up	Track-Up	Overall	North-Up	Track-Up	Overall
Low Task	.069	.051	.060	.052	.061	.057
High Task	.124	.117	.121	.111	.143	.127
Overall	.097	.084	.091	.082	.102	.092

ALL PHASES							
	AID			NOAID			Overall
	North-Up	Track-	Overall	North-	Track-Up	Overall	
Low Task	1.04	1.27	1.16	1.30	1.48	1.39	1.28
High Task	1.18	1.24	1.21	1.50	1.49	1.50	1.36
Overall	1.11	1.26	1.19	1.40	1.48	1.44	1.32

2.5 RMS Glideslope Deviation

A 2×2 Repeated Measure ANOVA (2 Decision Aid conditions, 2 EAP Orientation conditions) was performed on the Root Mean Square (RMS) course deviation data. Task Loading and Approach Phase were not included in the analysis because glideslope data could only be obtained on the Low Task Loading precision approach conditions and during the Final Approach phase. The results are provided in Table B-13 and the means used in the analysis are provided in Table B-14. No significant main effects or interactions were found in the analysis of the glideslope data.

Table B-13. ANOVA Results for RMS Glideslope Deviation

Tested Effect	ANOVA Results
Decision Aid	F(1,15) = 0.00, p = .952
EAP Orientation	F(1,15) = 0.09, p = .767
Decision Aid × EAP Orientation	F(1,15) = 3.21, p = .094

Table B-14. Means Used for RMS Glideslope Deviation Analysis

RMS Glideslope Deviation (dots)			
	AID	NOAID	Overall
North-Up Orientation	.339	.559	.449
Track-Up Orientation	.517	.290	.403
Overall	.428	.425	.426

3. Workload Data

A 2×2×2 Repeated Measure ANOVA (2 Decision Aid conditions, 2 Task Loading conditions, 2 EAP Orientation) was performed on the workload ratings gathered with the Subjective WORkload Dominance (SWORD) technique. The results are provided in Table B-13. The means for this analysis are provided in Table B-14.

Table B-13. ANOVA Results for Workload Ratings

Tested Effect	ANOVA Result
Decision Aid	F(1,15) = 42.03, p = .000*
Task Loading	F(1,15) = 33.73, p = .000*
EAP Orientation	F(1,15) = 1.16, p = .299
Decision Aid × Task Loading	F(1,15) = 61.96, p = .000*
Decision Aid × EAP Orientation	F(1,15) = 0.09, p = .774
Task Loading × EAP Orientation	F(1,15) = 0.26, p = .618
Decision Aid × Task Loading × EAP Orientation	F(3,33) = 1.16; p = .298

* indicates statistical significance, $p < 0.05$

Table B-14. Means Used for Workload Analysis

RMS SWORD Workload Ratings					
	AID		NOAID		Overall
	North-Up	Track-Up	North-Up	Track-Up	
Low Task Loading	.056	.042	.097	.089	.071
High Task Loading	.096	.084	.281	.255	.018
Overall	.076	.063	.189	.172	.045

Significant main effects were found for Decision Aid (F = 42.035, $p < 0.001$) and Approach Phase (F = 33.73, $p < 0.001$); and a significant interaction was found between Decision Aid and Task Loading conditions (F = 61.96, $p < 0.001$). No other significant main effects or interactions were found. One-way ANOVAs were performed to analyze the nature of the significant interaction.

For the Decision Aid by Task Loading interaction, significant simple main effects were found for Decision Aid in both Low Task Loading (F = 42.03, $p < .000$) $p = 0.003$) and High Task Loading conditions (F = 56.03, $p < 0.001$). The difference in mean workload ratings between the Low Tasking Loading and High Task Loading in the NoAid condition, however, was approximately 4 times larger (.268 - .093) than in the Aid condition (.090 - .049). Thus, the significant interaction would indicate that although the Aid condition reduced workload in both Low Task Loading and High Task Loading conditions, the Aid condition was more effective in reducing workload in the High Task Loading condition. The means that were used in this analysis are presented in Table B-15.

Table B-15. Means Used in the Workload Analysis

Decision Aid by Task Loading Interaction		
	Aid	NoAid
Low Task Loading	.049	.093
High Task Loading	.090	.268

4. Situational Awareness Data

A 2×2×2 Repeated Measure ANOVA (2 Decision Aid conditions, 2 Task Loading conditions, 2 EAP Orientation) was performed on the situational awareness ratings gathered with the Subjective WORkload Dominance (SWORD) technique. The results showed significant main effects for the Decision Aid (F = 32.89, $p < .001$) and Task Loading (F = 25.31, $p < .001$) conditions. No other significant main effects or interactions were found. The results are provided in Table B-16 and the means are provided in Table B-17.

Table B-16. ANOVA Results for Situational Awareness Ratings

Tested Effect	**ANOVA Result**
Decision Aid	F(1,15) = 32.89, p = .000*
Task Loading	F(1,15) = 25.31, p = .000*
EAP Orientation	F(1,15) = 0.15, p = .705
Decision Aid × Task Loading	F(1,15) = 1.98, p = .180
Decision Aid × EAP Orientation	F(1,15) = 0.30, p = .594
Task Loading × EAP Orientation	F(1,15) = 0.57, p = .461
Decision Aid × Task Loading × EAP Orientation	F(3,33) = 0.40, p = .535

* indicates statistical significance, $p < 0.05$

Table B-17. Means Used for Situational Awareness Ratings

RMS SWORD Workload Ratings					
	AID		NOAID		Overall
	North-Up	Track-Up	North-Up	Track-Up	
Low Task Loading	.237	.215	.106	.101	.165
High Task Loading	.127	.127	.042	.044	.041
Overall	.182	.171	.074	.073	.103

APPENDIX C - SUMMARY OF QUESTIONNAIRE RESPONSES

Introduction

The questionnaires used in the APES evaluation are provided in Appendix A. This Appendix summarizes questionnaire responses for 15 of the 16 pilots who participated in this study. (Final questionnaire ratings were not obtained for one pilot.) Where appropriate, the responses are summarized in tables.

SESSION QUESTIONNAIRE RESPONSES

The table below provides mean ratings for ease of task performance. These ratings were obtained after each approach test condition.

Ease of Task Performance Scale:

5 = A. Extremely Easy
4 = B. Moderately Easy
3 = C. Neutral
2 = D. Moderately Difficult
1 = E. Extremely Difficult

	AID				NOAID				OVERALL
	LOW TASK LOAD		HIGH TASK LOAD		LOW TASK LOAD		HIGH TASK LOAD		
	TRK-UP	NTH-UP	TRK-UP	NTH-UP	TRK-UP	NTH-UP	TRK-UP	NTH-UP	
Assess A/C Performance	3.75	4.05	3.50	3.67	4.06	4.07	3.42	3.38	**3.74**
Fly Holding Pattern	4.38	4.56	4.08	4.19	4.44	4.35	3.63	3.58	**4.15**
Fly Initial Approach	4.50	4.50	4.21	3.98	4.25	4.13	3.46	3.63	**4.08**
Fly Final Approach	4.46	4.56	3.63	3.69	4.31	4.38	3.31	3.04	**3.92**
Fly Missed Approach	4.13	4.06	3.67	3.58	3.94	4.05	3.69	3.27	**3.80**
Overall Rating	4.45	4.36	3.89	3.88	4.31	4.02	3.24	3.34	**3.94**
Overall Mean	**4.28**	**4.35**	**3.83**	**3.83**	**4.22**	**4.17**	**3.46**	**3.37**	

FINAL QUESTIONNAIRE RESPONSES

SECTION I. QUALITY OF APES "PROCEDURAL" ADVICE

The tables on the following pages provide the means and the frequencies of the acceptability ratings used to evaluate APES performance. Pilot comments are provided below each table.

Acceptability Scale:

5 = A. Completely acceptable: No changes needed; acceptable as is.
4 = B. Moderately acceptable: Minor changes desirable; effectiveness not impaired.
3 = C. Borderline: Changes desirable; effectiveness may be impaired.
2 = D. Moderately unacceptable: Changes required, effectiveness may be impaired.
1 = E. Completely unacceptable: Redesigned required, effectiveness severely impaired.

HEADING PROMPTS						
	MEAN	FREQUENCY				
		5	4	3	2	1
Holding						
Logic	4.80	12	3	0	0	0
Timeliness	4.60	10	4	1	0	0
Consistency	4.67	11	3	1	0	0
Initial Approach						
Logic	4.67	11	3	1	0	0
Timeliness	4.80	12	3	0	0	0
Consistency	4.93	14	1	0	0	0
Final Approach						
Logic	4.80	12	3	0	0	0
Timeliness	4.67	10	5	0	0	0
Consistency	4.93	14	1	0	0	0
Missed Approach						
Logic	4.80	12	3	0	0	0
Timeliness	4.33	7	6	2	0	0
Consistency	4.87	13	2	0	0	0
Overall						
Logic	4.73	11	4	0	0	0
Timeliness	4.47	7	8	0	0	0
Consistency	4.73	11	4	0	0	0

COMMENTS:

Subject 1: At one missed approach, the computer told me to turn prior to reaching the designated turn altitude.

Subject 2: Final approach track - some calls seem early, some late.

Subject 3: Missed approach prompts are late.

Subject 7: If you are heading to a fix, she needs to ensure that the Navaid, radial/course is set.

Subject 8: Need immediate MAP instructions.

Subject 9: Announce the missed approach point with "and or go-around" call or something.

Subject 10: Holding timeliness - was late to recognize overshoots. Consistency - sometimes gave numerous small corrections in holding that were not significant enough to voice prompt - Let the bank steering bar silently guide the pilot more.

Subject 11: One of the heading prompts placed me inside an arc, then the voice reminded me to stay on the arc! Missed approach instructions seemed rushed. Might be better not to even have them.

Subject 13: Missed approach turn was given early on every approach. Lead turn for Final Approach consistently early.

Subject 14: Need to release large heading changes coming to IAF or holding fix. Will promote chasing as is.

Subject 16: There was a couple of times when I would have teardropped but the D.A. recommended a turn to parallel.

COURSE PROMPTS						
	MEAN	**FREQUENCY**				
		5	**4**	**3**	**2**	**1**
Holding						
Logic	4.80	12	3	0	0	0
Timeliness	4.93	14	1	0	0	0
Consistency	4.93	14	1	0	0	0
Initial Approach						
Logic	4.67	11	3	1	0	0
Timeliness	4.80	12	3	0	0	0
Consistency	5.00	15	0	0	0	0
Final Approach						
Logic	4.80	12	3	0	0	0
Timeliness	4.93	14	1	0	0	0
Consistency	5.00	15	0	0	0	0
Missed Approach						
Logic	4.80	12	3	0	0	0
Timeliness	4.73	12	2	1	0	0
Consistency	5.00	15	0	0	0	0
Overall						
Logic	4.73	11	4	0	0	0
Timeliness	4.87	13	2	0	0	0
Consistency	5.00	15	0	0	0	0

COMMENTS:

Subject 3: (Missed approach prompts) are too late to be safe.

Subject 4: Course prompts ignored on large intercepts until initial roll-out completed.

Subject 7: Just telling me to maintain an arc when a deviation occurs is not really adequate - help me make a correction, i.e., "turn 10° left to intercept 12 DME ARC."

Subject 8: Need immediate MAP prompt. Should direct "maintain ___ are" during initial turn. Should / Could direct next course input sooner.

AIRSPEED PROMPTS						
	MEAN	**FREQUENCY**				
		5	**4**	**3**	**2**	**1**
Holding						
Logic	4.60	11	2	2	0	0
Timeliness	4.40	9	4	1	1	0
Consistency	4.60	11	2	2	0	0
Initial Approach						
Logic	4.60	11	2	2	0	0
Timeliness	4.33	8	5	1	1	0
Consistency	4.60	11	2	2	0	0
Final Approach						
Logic	4.53	10	3	2	0	0
Timeliness	4.40	9	4	1	1	0
Consistency	4.60	11	2	2	0	0
Missed Approach						
Logic	4.60	11	2	2	0	0
Timeliness	4.33	8	5	1	1	0
Consistency	4.60	11	2	2	0	0
Overall						
Logic	4.53	10	3	2	0	0
Timeliness	4.40	9	4	1	1	0
Consistency	4.60	11	2	2	0	0

COMMENTS:

Subject 1: When making the turn to final, I would like to start slowing to approach speed prior to localizer intercept.

Subject 2: Call for slower airspeed earlier. Get setup sooner so as to be stabilized on profile earlier.

Subject 3: (Missed approach prompts) are too late to be safe.

Subject 5: Airspeed prompts were too sensitive. The airspeed warnings should be pilot selectable.

Subject 7: Tolerance should be -0/+15 - you should never be slow without a prompt. 15 kt fast should be allowed for gusts.

Subject 9: Airspeed prompts fit this scenario but it greatly simplified from the way airspeed is dealt with in the planes I've flown.

Subject 10: Overall the airspeed prompt tolerances are too tight and some (missed approach) aren't even necessary. Probably just appropriate for Final. and then +15, - 10 knots.

Subject 11: Missed approach instructions seemed rushed. Might be better not to even have them.

Subject 14: Simply call airspeed - don't say maintain 250 knots.

ALTITUDE PROMPTS						
	MEAN	FREQUENCY				
		5	4	3	2	1
Holding						
Logic	4.60	11	2	2	0	0
Timeliness	4.73	13	1	0	1	0
Consistency	4.80	13	1	1	0	0
Initial Approach						
Logic	4.67	12	1	2	0	0
Timeliness	4.73	13	1	0	1	0
Consistency	4.80	13	1	1	0	0
Final Approach						
Logic	4.20	9	2	2	2	0
Timeliness	4.47	11	2	0	2	0
Consistency	4.80	13	1	1	0	0
Missed Approach						
Logic	4.47	11	1	2	1	0
Timeliness	4.40	10	3	0	2	0
Consistency	4.60	12	1	1	1	0
Overall						
Logic	4.53	11	1	3	0	0
Timeliness	4.53	11	2	1	1	0
Consistency	4.73	12	2	1	0	0

COMMENTS:

Subject 3: (Missed approach prompts) are too late to be safe.

Subject 5: Altitude prompts were too sensitive. The airspeed warnings should be pilot selectable.

Subject 7: Tolerance should be -0ft/+200ft for mandatory or at-or-above, +0ft/-100ft for at or below. Verbage should be "climb to . . . .," "descend to . . . . " or "maintain . . . ." as appropriate

Subject 8: "Descend to DH of _____" recommended versus "maintain _____."

Subject 9: The aid given seems real busy at the IAF/FAF and MAP points. Maybe some of the info can be spread out more.

Subject 10: Too many missed approach altitude prompts (about 4) during climbout. Voice prompt once and then visual display is enough.

Subject 11: This was very useful to me. Missed approach instructions seemed rushed. Might be better not to even have them.

Subject 13: When flying an ILS & intercepting G.S. above a step down fix altitude, a warning is unnecessarily given. Often, altitudes depicted are min altitudes and not mandatory. "Minimum altitude 2600 feet" might be better than "descend to . . . ."

Subject 14: Same as airspeed - simply call.

Subject 15: On almost every missed approach. the altitude prompt was given several times within a short time span. When descending to the ILS DH, the prompt should say "Descend to 480 feet" instead of maintain 480 feet When climbing on missed approach, the prompt should say "climb to 2500 feet."

RADIO CHANNEL/FREQUENCY PROMPTS						
	MEAN	FREQUENCY				
		5	4	3	2	1
Holding						
Logic	4.86	13	0	1	0	0
Timeliness	4.93	13	1	0	0	0
Consistency	5.00	14	0	0	0	0
Initial Approach						
Logic	4.93	14	1	0	0	0
Timeliness	4.87	13	2	0	0	0
Consistency	5.00	15	0	0	0	0
Final Approach						
Logic	4.93	14	1	0	0	0
Timeliness	4.80	12	3	0	0	0
Consistency	4.93	14	1	0	0	0
Missed Approach						
Logic	4.93	14	1	0	0	0
Timeliness	4.80	12	3	0	0	0
Consistency	4.93	14	1	0	0	0
Overall						
Logic	4.80	13	1	1	0	0
Timeliness	4.73	11	4	0	0	0
Consistency	4.93	14	1	0	0	0

COMMENTS:

Subject 1: During holding, while using TACAN for navigation. I would like to set the ILS frequency in my VOR receiver. The decision aid did not like this idea.

Subject 2: I felt that when NAVAID changes were required, TACAN to ILS, they could have happened earlier. You can fly the course you are on using the head or tail of the needle.

Subject 3: (Missed approach prompts) are too late to be safe.

Subject 8: Could go to some NAVAIDs sooner when done with last one.

Subject 10: Excellent aid - should also include mode select prompt from TAC to ILS on Final and vice Versa on Missed Approach.

Subject 11: This was the most useful prompt of all with some of multiple changes required on some of the approaches.

Subject 13: The automatic selection is outstanding (with pilot consent required before entering).

Subject 15 I didn't look to see what altitude the prompts came on during the missed approach, but they should wait until the aircraft is above 1000 feet AGL.

SECTION II. QUALITY OF APES "DEVIATION" ADVICE

The table below depicts the means and the frequencies of the Acceptability Ratings used to evaluate APES performance Pilots comments are also provided.

Acceptability Scale:

5 = A. Completely acceptable: No changes needed; acceptable as is.
4 = B. Moderately acceptable: Minor changes desirable; effectiveness not impaired.
3 = C. Borderline: Changes desirable; effectiveness may be impaired.
2 = D. Moderately unacceptable: Changes required, effectiveness may be impaired.
1 = E. Completely unacceptable: Redesigned required, effectiveness severely impaired.

DEVIATION PROMPTS						
	MEAN	FREQUENCY				
		5	4	3	2	1
Holding						
Logic	4.40	8	5	2	0	0
Timeliness	4.47	10	3	1	1	0
Consistency	4.53	10	3	2	0	0
Initial Approach						
Logic	4.67	11	3	1	0	0
Timeliness	4.67	12	2	0	1	0
Consistency	4.73	12	2	1	0	0
Final Approach						
Logic	4.20	7	4	4	0	0
Timeliness	4.47	10	3	1	1	0
Consistency	4.60	11	2	2	0	0
Missed Approach						
Logic	4.47	9	4	2	0	0
Timeliness	4.67	12	2	0	1	0
Consistency	4.73	12	2	1	0	0
Overall						
Logic	4.43	8	6	1	0	0
Timeliness	4.50	10	4	0	1	0
Consistency	4.63	11	3	1	0	0

COMMENTS:

Subject 1: When the gust model is active, keeping an airspeed within 10 knots is nearly impossible. yet the decision aid still gives deviation warnings.

Subject 2: Would suggest adding the direction you need to go. (i.e., "go up," "turn left," "slow down," "come right" etc.

Subject 3: Aggravating, but necessary and challenging.

Subject 5: Airspeed and altitude prompts were too sensitive. The airspeed warnings should be pilot selectable.

Subject 6: Should have a feature that turns off voice prompt as soon as you hit the "enter" button. Example: Go of airspeed by 10 kts. You realize it right away and then the voice prompts tell you. You hit the "enter' button but the voice has to say the entire prompt, you can't turn it off.

Subject 7: See previous comments regarding tolerances.

Subject 8: I really liked these!

Subject 9: Heading deviations of less the than 5 degrees carried for a long can result in large track deviations. For holding entries of teardrops maybe the tolerance should be tighter. Also holding teardrop heading to the full DME distance can cause nav errors. Maybe hold teardrop heading for 1-1 1/2 minutes then parallel course. Give 100 above/below call instead of maintain altitude. Give airspeed as "slow" or "fast" instead of maintain airspeed. Or "slow to 250") (increase to 250) .

Subject 10: Too many minor deviation voice prompts. Remember other systems have beepers, bells, alarms, buzzers, whistles, plus there's radio and intercom messages to hear. All together we are beginning to overload pilots with talking airplanes.

Subject 13: Altitude warnings, as previously stated, may be given when the altitude depicted is a minimum only and your are intentionally high.

Subject 14: Too often, and too much sensitivity - need to better capture logic.

Subject 15: The tolerance bands at which the prompts "come on" should be pilot selectable (to a point) in a real aircraft.

Subject 16: A couple of times the verbal and written heading and altitude prompts appeared different by up to 10 degrees or 100 feet (may just be pilot perception)

SECTION III. TASK ACCOMPLISHMENT AND EAP ORIENTATION

The table on the following page provide means and frequencies of pilot response ratings to the statement:

The Decision Aid __________ my ability to . . . .

Rating Scale:

5 = A. Substantially Enhanced
4 = B. Moderately Enhanced
3 = C. Did Not Affect
2 = D. Moderately Degraded
1 = E. Substantially Degraded

	MEAN	FREQUENCY				
		5	4	3	2	1
a) identify and navigate to the holding fix.						
Track-Up EAP Orientation	4.40	7	7	1	0	0
North-Up EAP Orientation	4.13	4	9	2	0	0
Overall	4.47	7	8	0	0	0
b) determine direction of turn into holding.						
Track-Up EAP Orientation	4.20	8	2	5	0	0
North-Up EAP Orientation	3.87	4	5	6	0	0
Overall	4.33	9	2	4	0	0
c) identify and navigate to the IAF.						
Track-Up EAP Orientation	4.40	8	5	2	0	0
North-Up EAP Orientation	4.13	6	5	4	0	0
Overall	4.47	9	4	2	0	0
d) identify approach radials / arc.						
Track-Up EAP Orientation	4.33	8	4	3	0	0
North-Up EAP Orientation	4.38	4	6	5	0	0
Overall	4.33	8	4	3	0	0
e) identify approach altitude.						
Track-Up EAP Orientation	4.27	6	7	2	0	0
North-Up EAP Orientation	4.24	6	6	3	0	0
Overall	4.53	8	7	0	0	0
f) identify and navigate to the FAF.						
Track-Up EAP Orientation	4.20	6	6	3	0	0
North-Up EAP Orientation	3.93	4	6	5	0	0
Overall	4.27	7	5	3	0	0
g) identify the DH or MDA.						
Track-Up EAP Orientation	3.67	4	4	5	2	0
North-Up EAP Orientation	4.14	3	5	5	2	0
Overall	3.93	6	4	3	2	0
h) identify and navigate to the MAP.						
Track-Up EAP Orientation	4.20	8	3	3	1	0
North-Up EAP Orientation	4.07	5	4	5	1	0
Overall	4.20	8	3	3	1	0
i) identify and set Navaids.						
Track-Up EAP Orientation	4.07	7	3	4	1	0
North-Up EAP Orientation	4.00	6	4	4	1	0
Overall	4.27	8	4	2	1	0
j) determine intercept headings / angles.						
Track-Up EAP Orientation	4.31	7	6	2	0	0
North-Up EAP Orientation	3.98	4	7	4	0	0
Overall	4.31	7	6	2	0	0
k) determine lead points for arcs / courses.						
Track-Up EAP Orientation	3.98	3	9	3	0	0
North-Up EAP Orientation	3.71	2	7	6	0	0
Overall	3.98	3	9	3	0	0
l) determine airspeeds.						
Track-Up EAP Orientation	3.27	1	2	12	0	0
North-Up EAP Orientation	3.94	2	1	12	0	0
Overall	3.47	3	1	11	0	0
m) determine a/c's position relative to fixes.						
Track-Up EAP Orientation	4.27	9	1	5	0	0
North-Up EAP Orientation	3.91	6	2	7	0	0
Overall	4.27	9	1	5	0	0
n) develop a mental picture.						
Track-Up EAP Orientation	4.40	10	1	4	0	0
North-Up EAP Orientation	4.07	7	2	6	0	0
Overall	4.40	10	1	4	0	0

COMMENTS:

A) IDENTIFY AND NAVIGATE TO THE HOLDING FIX.

Subject 13: Heading for Fix to Fix nav is outstanding.

B) DETERMINE DIRECTION OF TURN INTO HEADING

Subject 2: Both modes definitely assisted in this area.

Subject 16: EAP provided necessary picture.

E) IDENTIFY APPROACH ALTITUDE

Subject 11: Some of the altitudes of some approach plates was difficult to see.

F) IDENTIFY AND NAVIGATE TO THE FAF

Subject 2: For all of these seeing a/c and any fix and that relationship is invaluable. This comment applies to all these categories.

G) IDENTIFY THE DECISION HEIGHT OR MINIMUM DESCENT ALTITUDE

Subject 7: The type of alt should be identified, i.e., "at decision height."

Subject 10: Don't say "maintain" when prompting DH altitude. Call it "DH" or "MDA" at the voice prompt.

Subject 13: Maybe use "Decision Height 646" instead of "descend to . . . " for Precision Approach.

Subject 16: The text was too small on the EAP - D.A. helped.

H) IDENTIFY AND NAVIGATE TO THE MAP

Subject 7: Could add "at the missed approach point."

Subject 8: Should cue MAP.

Subject 11: Comments seemed to rapid.

Subject 16: Good verbal cues - basically a no-brainer.

I) IDENTIFY AND SET NAVAIDS

Subject 1: Some of the frequency / channels are difficult to read.

Subject 11: Very good.

J) DETERMINE INTERCEPT HEADINGS / ANGLES

Subject 9: Logic seemed a bit off.

Subject 13: Slightly slow on course correction Headings (?) early lead points.

K) DETERMINE LEAD POINTS FOR ARCS / COURSES

Subject 5: More could be done here.

Subject 8: Could use slightly larger turn radius.

Subject 9: Logic seemed a bit off.

Subject 16: Takes away the mental gymnastics.

L) DETERMINE AIRSPEEDS

Subject 10: Let pilots pick speeds.

M) DETERMINE AIRCRAFT'S POSITION RELATIVE TO APPROACH FIXES
Subject 15: I don't recall the decision aid telling me my position relative to approach fix.
Subject 16: EAP was enough.

N) DEVELOP A MENTAL PICTURE FOR ANTICIPATING FUTURE EVENTS
Subject 15: The EAP performed this function, not the decision aid.

SECTION IV. PILOT-VEHICLE INTERFACE

The table below shows the means and the frequencies of the Acceptability Ratings used to evaluate the Pilot-Vehicle Interface. Pilot comments are also provided.

Acceptability Scale:

5 = A. Completely acceptable: No changes needed; acceptable as is.
4 = B. Moderately acceptable: Minor changes desirable; effectiveness not impaired.
3 = C. Borderline: Changes desirable; effectiveness may be impaired.
2 = D. Moderately unacceptable: Changes required, effectiveness may be impaired.
1 = E. Completely unacceptable: Redesigned required, effectiveness severely impaired.

PILOT-VEHICLE INTERFACE						
	MEAN	**FREQUENCY**				
		5	**4**	**3**	**2**	**1**
1. Heading Prompts	4.33	8	6	0	0	1
2. Attitude Prompts	4.00	6	6	1	1	1
3. Airspeed Prompts	4.07	5	8	1	0	1
4. Course Prompts	4.67	11	3	1	0	0
5. Freq/Chan Prompts	4.73	12	2	1	0	0
6. Audio						
a. Voice Quality	4.67	11	3	1	0	0
b. Understandability	4.67	12	1	2	0	0
c. Phraseology	3.93	5	7	1	1	1
d. Sequence	4.53	9	5	1	0	0
7. Visual						
a. Readability	4.70	7	3	0	0	0
b. Understandability	4.70	7	3	0	0	0
c. Phraseology	4.60	6	4	0	0	0
d. Sequence	4.60	6	4	0	0	0
e. Location	3.91	4	4	1	2	0

COMMENTS:

1. HEADING PROMPTS

Subject 5: Either make pilot selectable, re-evaluate windows (e.g., percentage of altitude vs. +/- 100 feet), or leave off of design.

Subject 9: Tolerance window (+/- 5 degrees) situation dependent.

Subject 13: Tolerance slightly high.

2. ALTITUDE PROMPTS

Subject 3: Tolerance Window (+/- 100 feet) - too small for my fists.

Subject 5: Either make pilot selectable, re-evaluate windows (e.g., percentage of altitude vs. +/- 100 feet), or leave off of design.

Subject 7: Tolerance Window should be -0/+200ft.

Subject 10: Audio Display: too many minor deviation prompts. Too many repeats on climb to/descent. Too tight -"ok, ok - I'm going.

Subject 13: Tolerance slightly high.

3. AIRSPEED PROMPTS

Subject 1: Perhaps too frequent.

Subject 5: Either make pilot selectable, re-evaluate windows (e.g., percentage of altitude vs. +/- 100 feet), or leave off of design.

Subject 6: Audio Display: Would be able to turn it off if you know you're at altitude or airspeed.

Subject 7: Tolerance Window should be -0/+15kts.

Subject 10: OK on Final, but too (+/-10 kts) tight for approach maneuvering.

Subject 11: In windy conditions, this was a little distracting.

4. COURSE PROMPTS

Subject 10: Tolerance window of +/- 2 degrees too tight for approach maneuvering.

ADDITIONAL COMMENTS

Subject 9: Tolerance windows need to be situation dependent with certain defaults and maybe pilot programmable to other windows.

Subject 14: Need to give the tasks and put the next event in line to accommodate different situations and pilot foresight levels.

7. WAYS VOICE INTERFACE COULD BE IMPROVED

Subject 2: Add direction to correct.

Subject 3: Seems OK to me.

Subject 4: Instead of "Maintain ____" on approach segments - could use - "descend and maintain."

Subject 5: Either make (prompts) pilot selectable, re-evaluate windows (e.g., percentage of altitude vs. +/- 100 feet), or leave off of design.

Subject 6: As stated before, be able to turn it off.

Subject 7: Verbage: when directing altitudes specify the type, i.e., descend to decision height, 600ft, or maintain at or above two thousand five hundred.

Subject 8: Phraseology of Voice Message: DH callout; change terminology.

Subject 9: Different phrasing for altitude/airspeed deviations (10 knots fast/slow, 100 above, below) Put climb or descend before the no. of feet above/below call.

Subject 10: Maintain altitude "xyz" when its the DH, we never "maintain DH - potential safety issue here.

Subject 11: A little more excitement would help!

Subject 13: Use of "decision height" and "minimum attitude" would be helpful.

Subject 14: Need better speech synthesizer, pause longer between phrases.

Subject 15: Phraseology of Voice Message: When descending to the ILS DH, the prompt should say "descend to "480 feet." ... When climbing on missed approach, the prompt should say "climb to 2500 feet." .... Voice should be less "mechanical."

Subject 16: Sequence of Voice Message Format: Sometimes the multiple info phrases came too close together.

9. WAYS TEXT MESSAGE DISPLAY COULD BE IMPROVED

Subject 1: I found I hardly ever looked at the message display.

Subject 2: They were find, but honestly I only looked at them maybe twice. What was displayed was acceptable. I feel that you really didn't need that screen.

Subject 3: Only viewed twice- well out of visual window for me.

Subject 5: No comment - I never used the CRT. I actually think that it is unnecessary.

Subject 7: Phraseology of text messages - abbreviate more. I didn't really use it.

Subject 8: Didn't even use it. Not required. I think it is of little use (ex. occasional cross reference if bug does appear on gauges.

Subject 9: Didn't really use them because they were so far out of the cross-check region.

Subject 10: Make it more obvious what Navaids are selected. Overall the CRT is the best feature of the system. The old saying " a picture is worth a thousand words really applies here. Thus the project should focus heavily on the visual and cut much of the voice stuff. I think that if you have to pick one track - then track-up is the way to go. But, you'll need to add one feature - Allow slewing the displayed aircraft position so I can see what's behind me when I'm heading outbound. The bottom line is that I know my relative position to the airfield and navaids. I don't care about the North Pole - except in December!

Subject 13: Rarely used text messages, cockpit space, and pilot workload/interpretation, may limit usefulness of textual messages.

Subject 14: Didn't use text messages hardly at all. Not necessary.

Subject 15: I never looked at it.

Subject 16: Instead of highlighting the text box and giving me an altitude above (author comment: scratch pad), use this format (author comment: as in the textual window)

SECTION V. GENERAL QUESTIONS

The table below shows the frequencies of pilot ratings to general questions. The rating scale is for each question is presented in the right column. Pilot comments to these and open-end questions are provided.

QUESTION	FREQUENCY					RATING SCALE
	5	**4**	**3**	**2**	**1**	
1. Follow Procedural Advice	4	11	0	0	0	5=Always, 4=Often, 3=Sometimes, 2=Almost Never, 1=Never
2. Follow Deviation Advice	7	7	1	0	0	5=Always, 4=Often, 3=Sometimes, 2=Almost Never, 1=Never
3. EAP Orientation Affect Decision Aid Usage	n/a	n/a	n/a	4	10	2=Yes, 1=No
4. Wind/Rvw affect on Workload	0	0	10	5	0	3=Substantially Increased, 2= Moderately Increased, 1=Did Not Affect
5. Wind/Rvw affect on DecAid	6	3	6	0	0	5=Substan Increase, 4=Mod increase 3=No Affect, 2=Mod Decrease, 1=Subtant Decrease
6. Decision Aid Improve Safety	7	8	0	0	0	5=Strongly Agree, 4=Mod Agree, 3=Neutral, 2=Mod Disagree, 1=Strong Disagree
7. Overall Usefulness of Decision Aid	10	5	0	0	0	5=Extreme Benefit, 4=Mod Benefit, 3=Neutral, 2=Mod Hinder, 1=Extreme Hinder
8. Other Conditions	n/a	n/a	6	7	2	3=Yes, 2=Not Sure, 1=No
9. Develop a Strategy Using Decision Aid	n/a	n/a	2	13	n/a	3=Yes, 2=No

COMMENTS:

1. FREQUENCY OF FOLLOWING PROCEDURAL ADVICE

Subject 1: Sometimes I would choose my own headings when I didn't like the one the computer gave me.

Subject 2: Most of the time the prompts were necessary.

Subject 3: Some turn/descend messages occur before the fix - they are then a prompt vs. a command.

Subject 5: Always, some number of exceptions.

Subject 11: Most of the time it was accurate.

2. FREQUENCY OF FOLLOWING DEVIATION ADVICE

Subject 2: Most of the time the prompts were necessary

Subject 15: Was usually already correcting back to the desired parameters.

3. EAP ORIENTATION EFFECT ON DECISION AID USE

Subject 4: Track-Up - picture great help in Viewing (?) Aids directions.

Subject 5: Either way is satisfactory.

Subject 10: There are pros and cons to each. Give the pilot the option to select track type as desired.

Subject 11: Track-Up caused some portion of the displays to be hidden during parts of the approach. The decision aid helped most in these situations.

Subject 13: Track-Up orients correctly with HSI, less confusing.

Subject 14: Provided both confidence in answer and safety vent for not following DA.

Subject 16: Not consciously.

4. EFFECT OF THE COMBINATION OF WIND GUSTS AND NO PRIOR REVIEW OF THE APPROACH ON WORKLOAD

Subject 1: The wind gusts more than the "no prior review" increased workload, because it was easy to review the approach enroute to the holding fix.

Subject 2: Required more concentration to "avoid" the prompts which is good.

Subject 3: Approaches became a handful w/winds and no review - do-able but much more work.

Subject 4: Made it necessary to concentrate alot on aircraft control - to the extent that I ignored keeping up with AID (i.e., hit "enter" tot get freq settings)

Subject 5: The wind gusts were more severe than reality (by a factor of 102).

Subject 16: Wind model was bogus! Airplane does not cause that many deviations. Also no review is not a big deal except that part of an approach calls for an approach plate review.

5. WIND GUST AND NO PRIOR REVIEW OF THE APPROACH PLATE EFFECT ON THE USE OF THE DECISION AID

Subject 2: Did not rely on it any more, just made me work hard.

Subject 4: Last two runs - approach would have been impossible without it.

Subject 5: Not enough confidence in the D.A. yet to let it tell me what to do.

Subject 15: I used the Decision Aid regardless of wind condition.

Subject 16: This is only due to increased amount of deviations caused by bogus wind model.

6. DECISION AID IMPROVES SAFETY WHEN FLYING INSTRUMENT APPROACHES

No Comments

7. OVERALL UTILITY OF THE DECISION AID FOR ASSISTING IN PERFORMING INSTRUMENT APPROACHES

Subject 2: Anyone assisting someone shooting an instrument approach is always welcome.

Subject 8: With improvements as system matures.

Subject 11: I think it would have a tendency to make people lazy about studying approaches before flying them.

Subject 13: Moderately beneficial if the pilot doesn't miss or forget anything. Potential for avoiding large deviations warrants the system as extremely beneficial.

8. OTHER CONDITIONS WHERE THIS DECISION AID MIGHT BE USEFUL?

Subject 1: Departures

Subject 2: Navy aircraft carrier landings. This system adapted to that environment would be great.

Subject 9: Low level routes and airdrop operations. Air refueling.

Subject 11: Pop-up to dive bomb attacks.

Subject 15: Aircraft emergencies . . . Display ore read the checklist to you (especially in a single-seat fighter).

Subject 16: Couple it to the autopilot and let the pilot monitor the approach in very bad weather.

9. STRATEGY WHEN USING DECISION AID

Subject 4: Used it for Fix to Fix - incredibly "natural" and easy to adapt to. Also arcs and approach segments.

Subject 7: Accepted "scratch pad" data all at once, then confirmed it using the voice prompts.

Subject 13: Experimented with using instruments conventionally, expanding the depiction and using it for deviations, etc.

10. WHAT DID YOU LIKE BEST ABOUT THE DECISION AID?

Subject 1: Its ability to monitor HDG/A/S/ALT and automatic setting of courses and NAVAID frequency.

Subject 2: During the times when I wasn't paying any attention, it was real nice knowing it was.

Subject 3: Track-Up increased SA immeasurably.

Subject 4: The MAP.

Subject 6: Great tool when there was no review.

Subject 5: The visual display of IAP with the aircraft tracking throughout.

Subject 7: Auto input of prompts /freq/heading,/course/alt.

Subject 8: Corrections, initial headings.

Subject 9: Hearing what to do next at the right time. Prompting and timeliness.

Subject 10: Again the visual display was great. (from his other comments, I think subject was referring too EAP)

Subject 11: The reminders of frequency./ channel changes on busy approaches.

Subject 13: Automatic selection of frequency and courses, and the overall safety aspect.

Subject 14: 1) Rapid selection of the point to point problems. 2) Back-up on altitude deviation.

Subject 15: The NAVAID frequency and course/heading changes . . . just press "enter" and everything is set for you . . . a big workload reducer.

Subject 16: Altitude prompting - This is easy to miss in the jet.

11. WHAT DID YOU LIKE LEAST ABOUT THE DECISION AID?

Subject 1: Its authoritarian altitude.

Subject 2: Not much at all.

Subject 3: Late missed approach prompts.

Subject 4: Prompts sometimes wrong.

Subject 5: The altitude/airspeed prompts.

Subject 6: Voice prompts were excessive at times.

Subject 7: Text Monitor display

Subject 8: MAP

Subject 9: Long streams of instruction without a pause at IAF/FAF.

Subject 10: The nuisance voice inputs - "airplane - be quiet!"

Subject 11: The hurried nature of missed approaches.

Subject 13: Frequent distracting altitude warnings approaching decision height.

Subject 14: It's single-mindedness. When I chose an alternative outside the D.A., it wouldn't help much.

Subject 15: The mechanical sound of the voice.

Subject 16: 1) Verbal cues sometimes too close together. 2) The way the textual info is presented. You tend to just hit "enter" without interpreting the info.

12. ADDITIONAL COMMENTS

Subject 2: This system should be considered for carrier use if not already.

Subject 3: Possible to become reliant/complacent while using the decision aid.

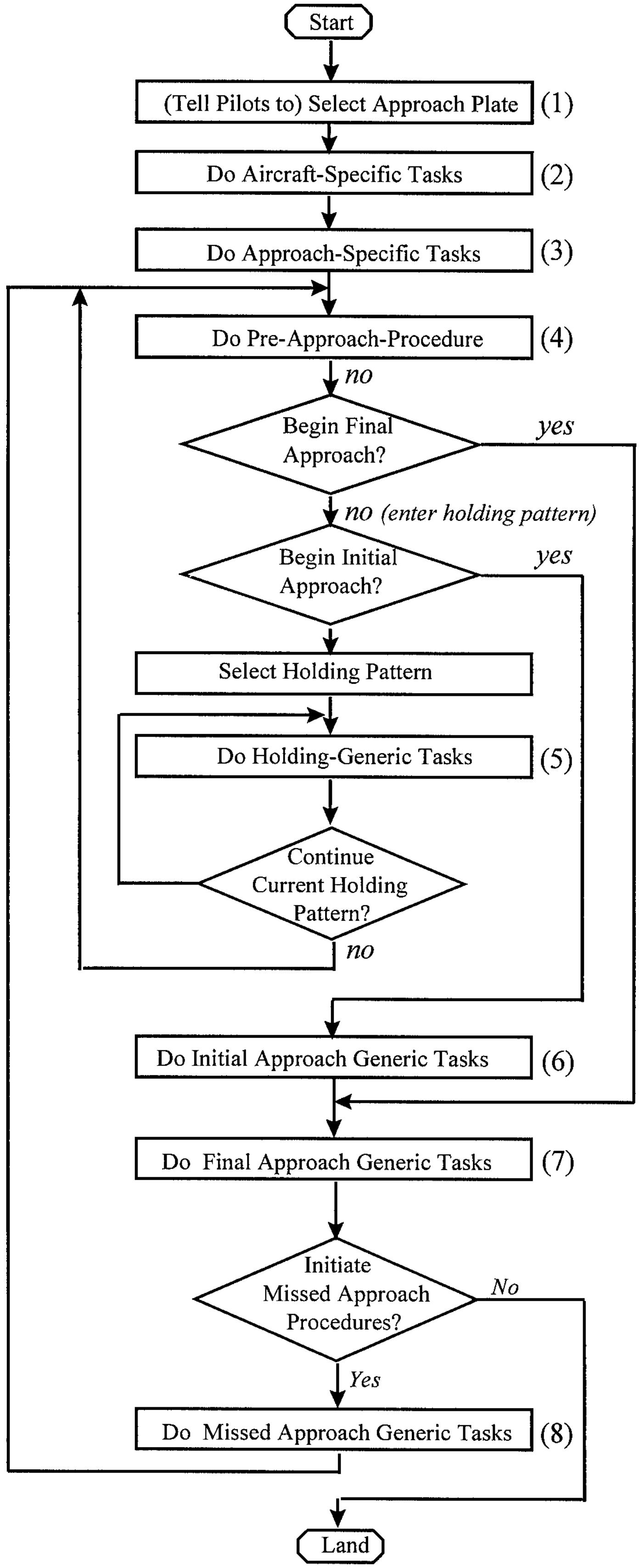
Subject 4: On large intercepts - maybe turn rate and winds could be taken into account as well as (?) objective.

Subject 9: Maybe some way to delay certain comments until previous commands acknowledged.

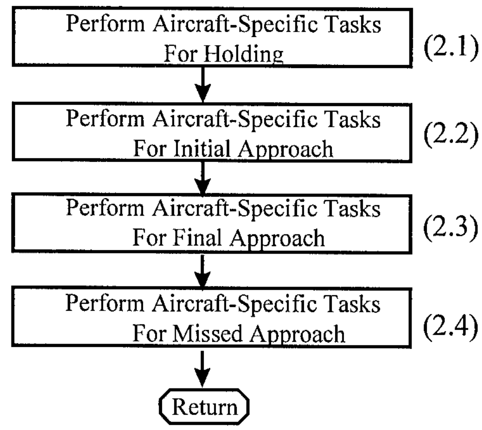
Subject 15: Gotta have the EAP with or without the decision aid.

APPENDIX D - REPRESENTATIVE PROCESS FLOW CHARTS FOR EXPERT SYSTEM DEVELOPMENT

F-16 Approach Task
Process Flow

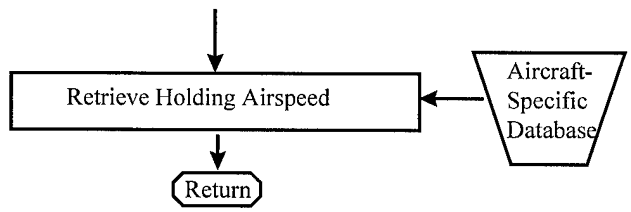


***Aircraft-Specific* Tasks Process Flow**



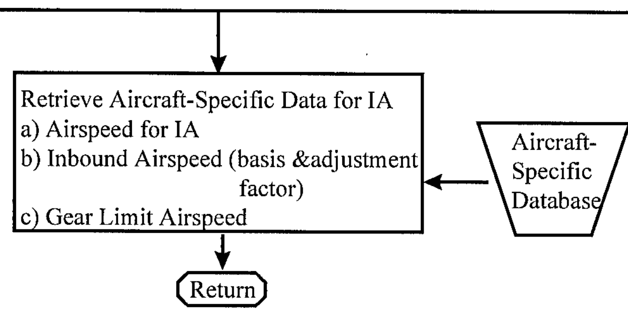
(2)

Aircraft-Specific Tasks for Holding Process Flow



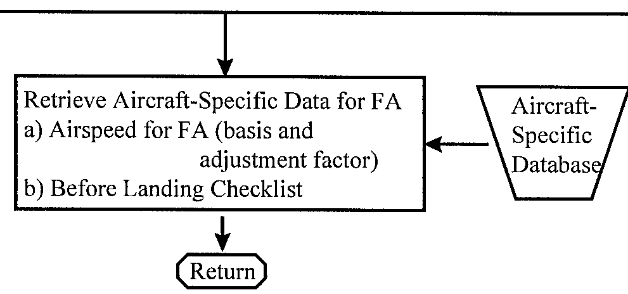
(2.1)

Aircraft-Specific Tasks for Initial Approach (IA) Process Flow



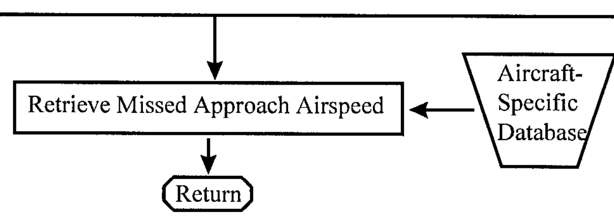
(2.2)

Aircraft-Specific Tasks forFinal Approach (FA) Process Flow



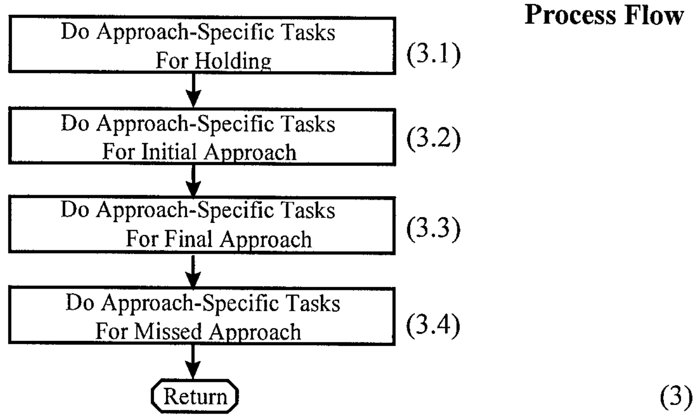
(2.3)

Aircraft-Specific Tasks for Missed Approach (MA) Process Flow

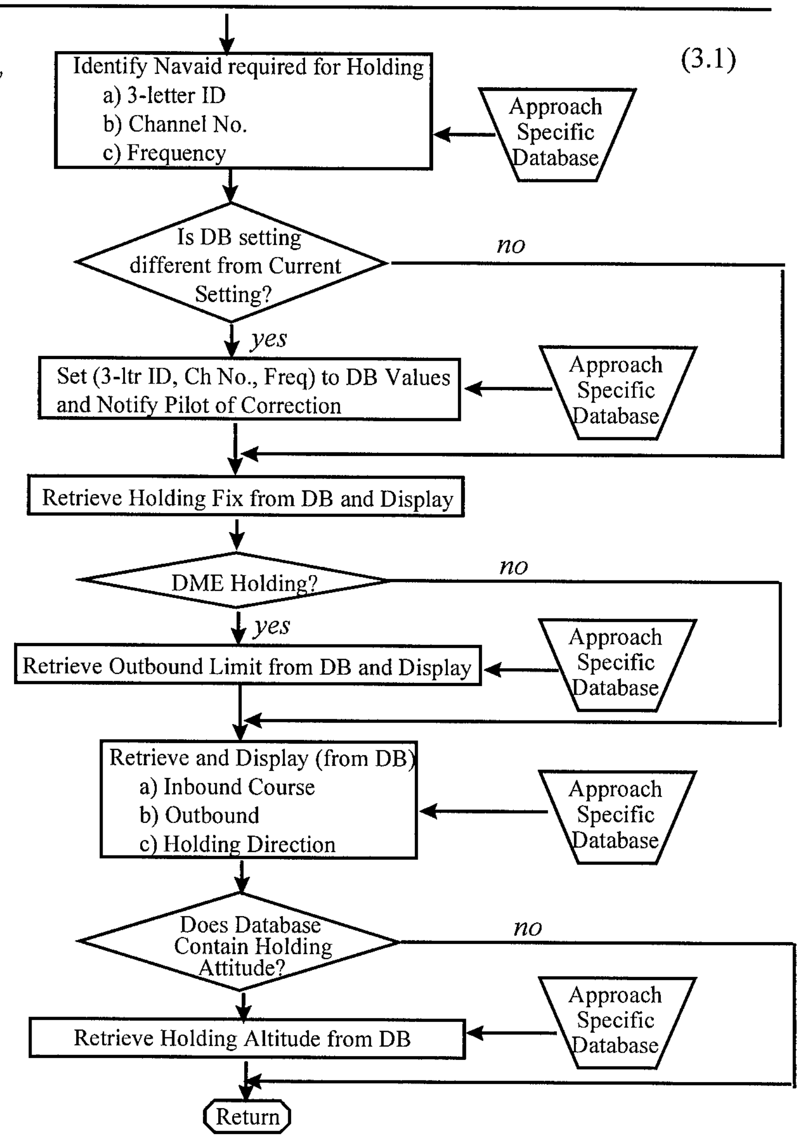


(2.4)

Approach-Specific Tasks Process Flow

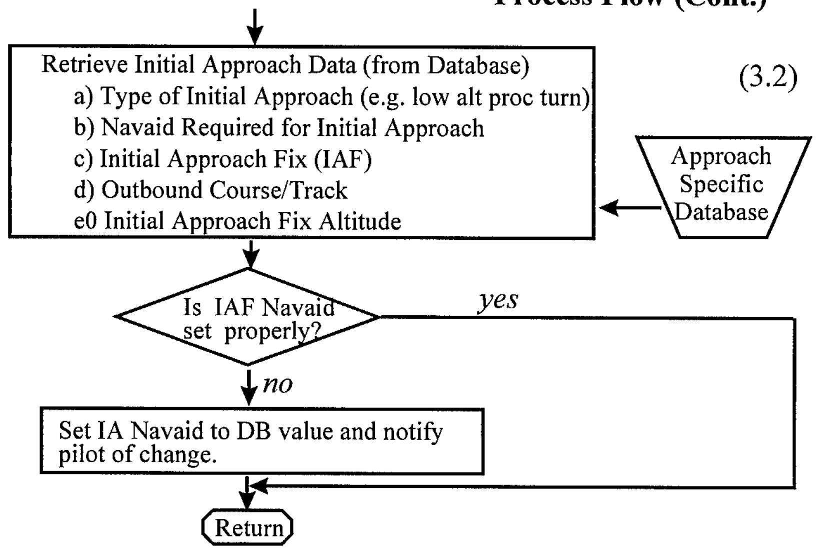


Approach-Specific Tasks for Holding Process Flow

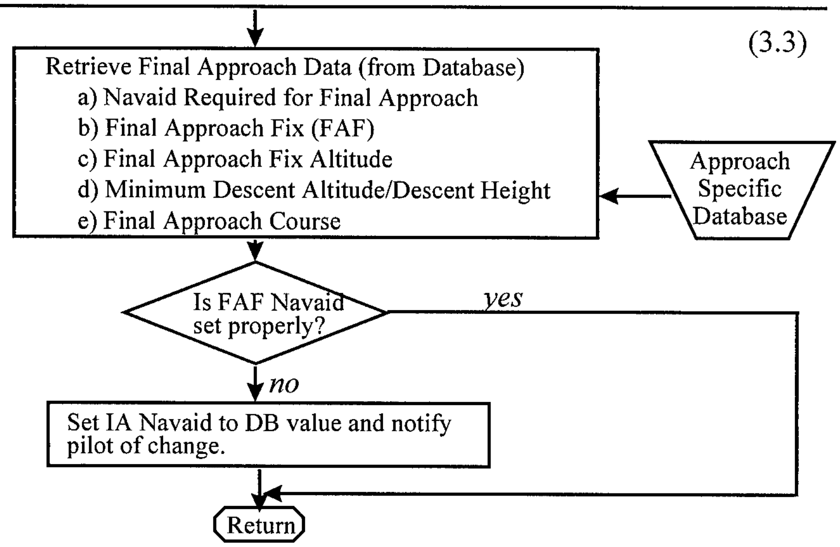


Approach-Specific Tasks Process Flow (Cont.)

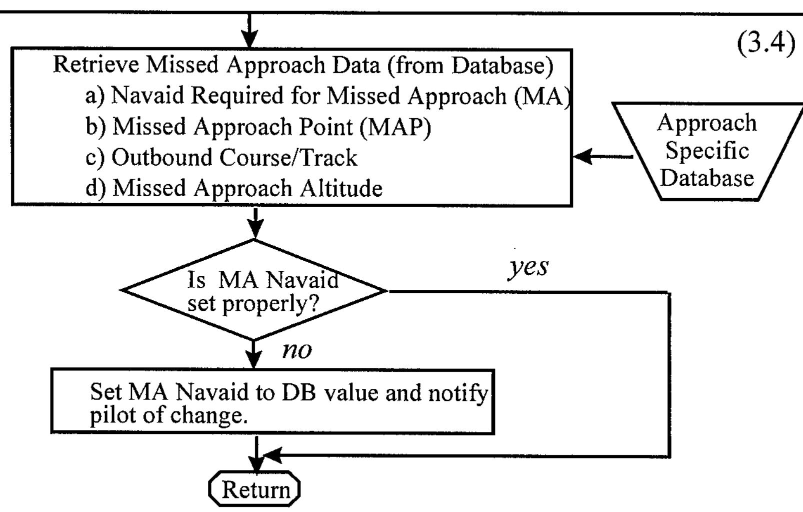
Approach-Specific Tasks for Initial Approach Process Flow



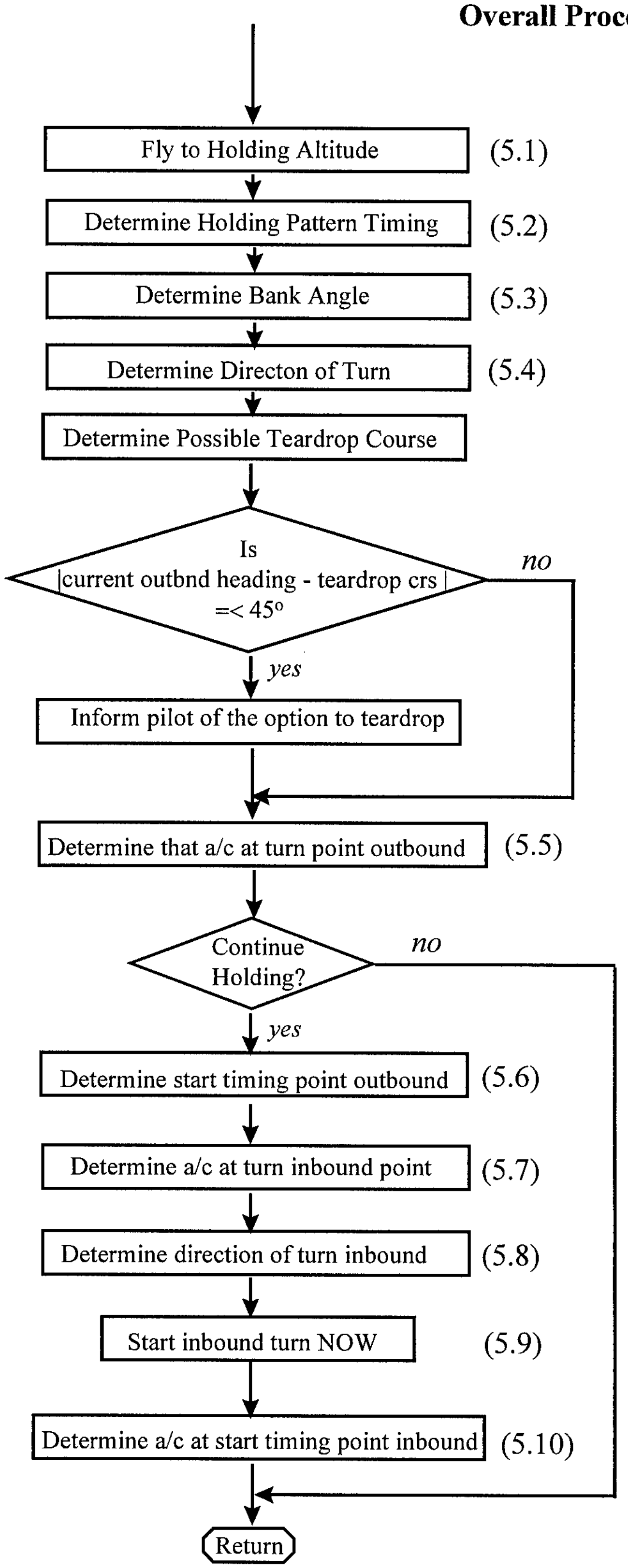
Approach-Specific Tasks for Final Approach Process Flow



Approach-Specific Tasks for Missed Approach Process Flow



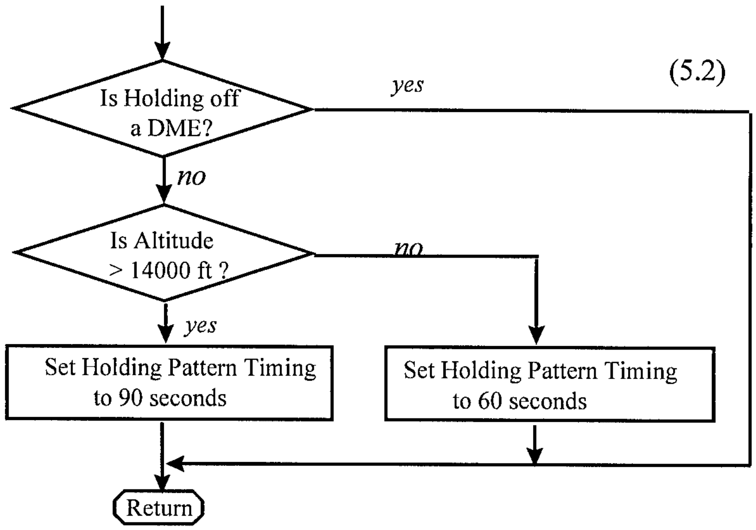
Holding
Generic Tasks
Overall Process Flow (5)



Holding Example
Generic Subtasks
Process Flows - (5)

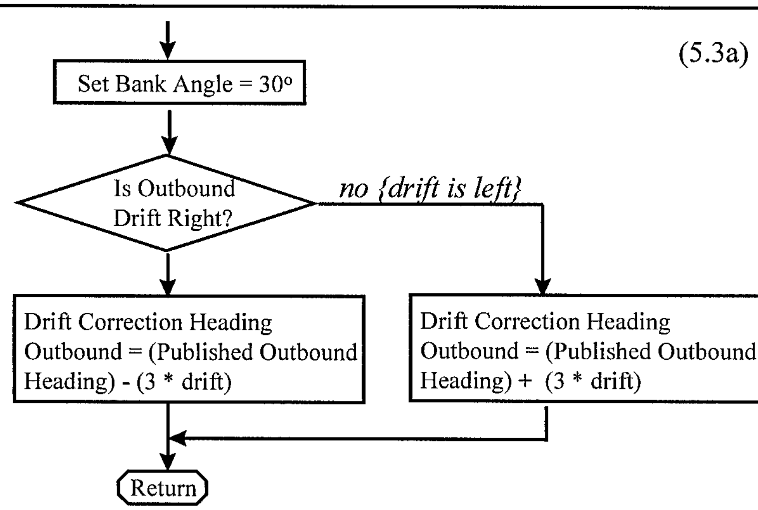
Determine Holding Pattern Timing

(5.2)



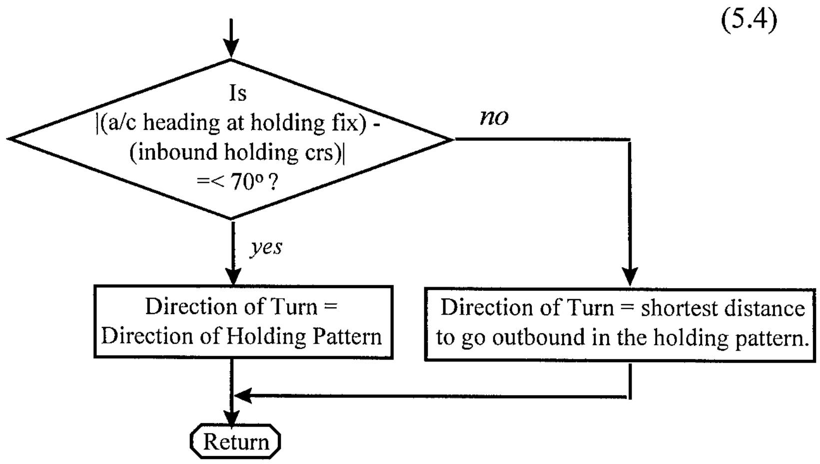
Determine Bank Angle Correcting for Drift

(5.3a)

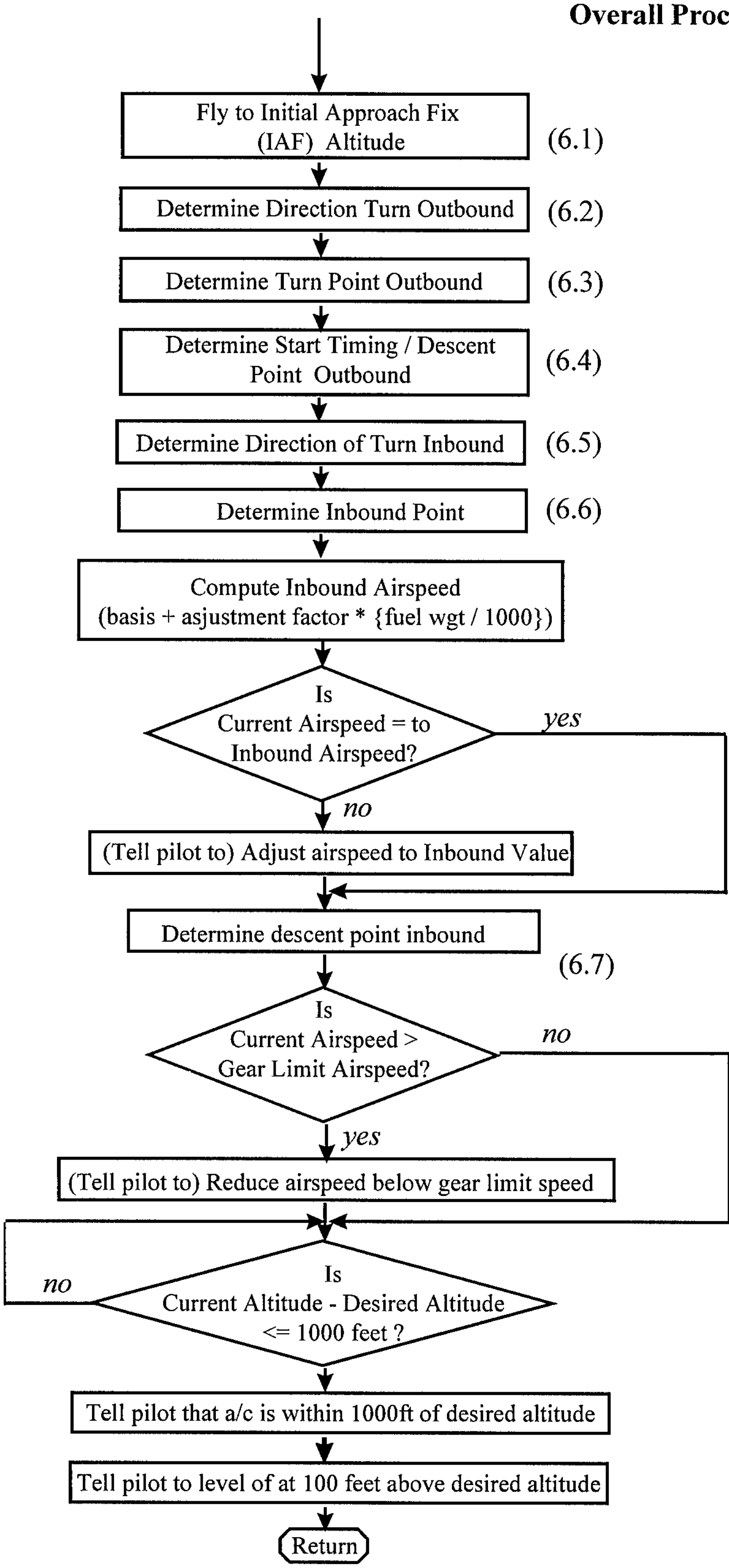


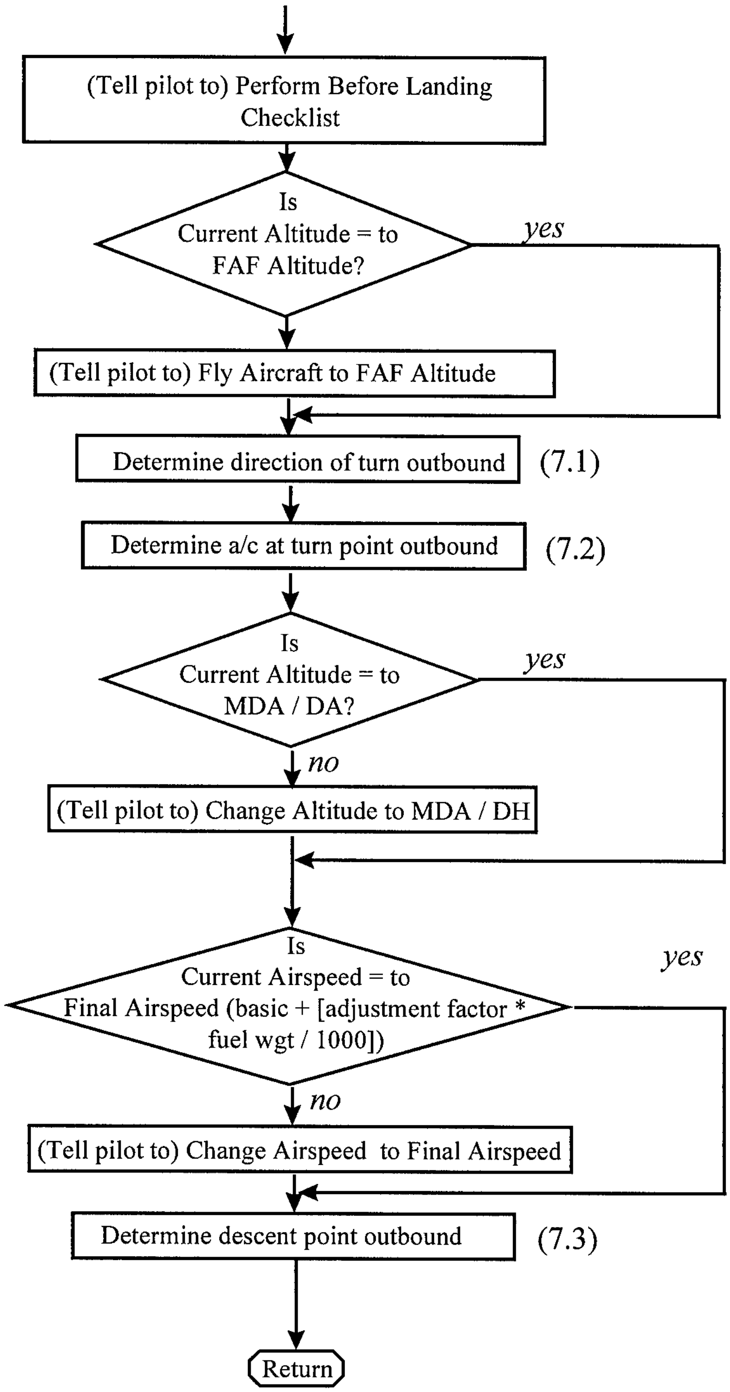
Determine Direction of Turn

(5.4)



Initial Approach
GenericTasks
Overall Process Flow - (6)




(Tell pilot to) Perform Before Landing Checklist
Is Current Altitude = to FAF Altitude?
yes
(Tell pilot to) Fly Aircraft to FAF Altitude
Determine direction of turn outbound
(7.1)
Determine a/c at turn point outbound
(7.2)
Is Current Altitude = to MDA / DA?
yes
no
(Tell pilot to) Change Altitude to MDA / DH
Is Current Airspeed = to Final Airspeed (basic + [adjustment factor * fuel wgt / 1000])
yes
no
(Tell pilot to) Change Airspeed to Final Airspeed
Determine descent point outbound
(7.3)
Return

Missed Approach
Generic Tasks
Overall Process Flow - (8)