Project Report
ATC-263

Evaluation of Boeing 747-400 Performance During ATC Directed Breakouts on Final Approach

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16. Abstract

The effects of three different levels of pilot training on the breakout response of pilots and the Boeing 747-400 aircraft were studied. The study examined responses during ATC-directed breakouts on final approach and was conducted in three phases. Phase 1 tested performance during manual and autopilot-coupled approaches given current procedures and pilot training. Phase 2 tested the effect of increased pilot situational awareness and proposed ATC breakout phraseology on breakouts during manual and autopilot-coupled approaches. Phase 3 tested the effect of two B747-400-specific breakout procedures on breakouts during autopilot-coupled approaches. Pilot preferences regarding procedures and the tested training materials were also solicited.

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EXECUTIVE SUMMARY

Two Federal Aviation Administration (FAA) programs were initiated in 1987 with the purpose of developing new procedures to increase airport capacity during instrument meteorological conditions (IMC) to levels near visual meteorological condition (VMC) capacity while maintaining existing safety levels. The Precision Runway Monitor (PRM) Program concluded in 1991 with the recommendation to allow dual simultaneous instrument landing system (ILS) approaches to parallel runways spaced 3400 to 4300 feet apart, given certain equipment and operational requirements. The Multiple Parallel Approach Procedure (MPAP) Program has developed and tested new procedures for dual, triple and quadruple parallel ILS approached in IMC.

Both programs utilized simulations of worst-case blunders on final approach to assess the relative safety of the tested procedures. A blunder occurs when an aircraft on final approach deviates towards an aircraft on the adjacent approach course and that deviation is large enough to require Air Traffic Control (ATC) intervention. A worst-case blunder is one in which the deviating aircraft does not return to its own approach course and continues into the adjacent approach stream. Any potentially threatened aircraft are broken out of the adjacent approach stream by ATC in response to the blunder. This action is called an ATC-directed breakout.

Three aircraft performance studies were conducted during the PRM Program, and the threatened aircraft tracks were incorporated into a risk assessment model. These studies used Boeing 727 (B727) and McDonnell Douglas 10 (DC10) full-motion cockpit simulators and type-rated pilots to test threatened aircraft/air crew breakout response. The risk analysis concluded that if the distribution of threatened aircraft responses was based on increased pilot situational awareness rather than on the existing training and ATC phraseology, then the desired safety level could be achieved. The turn response times for these tracks had a mean time from start of ATC breakout transmission to start of turn of less than 8 seconds, and a maximum time to start of turn of less than 17 seconds.

Additional blunder-resolution evaluations that incorporated remote-site cockpit simulators were conducted for the PRM and MPAP Programs. The tested simulators included newer aircraft types such as McDonnell Douglas 80 (MD80) and Boeing 747-400 (B747-400). Observations made during both programs indicated that the air crews had difficulty with the avionics and that these newer aircraft had slower response times during ATC-directed breakouts than the older, analog aircraft.

In response to these observations, two studies were commissioned to evaluate the breakout performance of B747-400 and Airbus 320 (A320), both advanced-avionics aircraft. This report documents the B747-400 study, which was conducted in 1995 using the B747-400 cockpit simulator at NASA Ames Research Center in Moffett Field, California. Subjects were type-rated commercial airline pilots. The main purpose of the study was to measure pilot/aircraft responses to ATC-directed breakouts given three levels of pilot training. The secondary purpose was to solicit pilot preferences regarding breakout procedures and the tested training materials.

TEST DESIGN

Phase 1 of the B747-400 study evaluated crew and aircraft breakout performance given current procedures and pilot training. The ATC phraseology was:

> <Aircraft> TURN <left/right> IMMEDIATELY HEADING <heading>.
> <Climb/Descend> AND MAINTAIN <altitude>.

Phase 2 tested the effect of additional pilot awareness training combined with proposed ATC breakout phraseology on breakout performance. The awareness training package included a video that explained close parallel approach operations and what is expected of the air crew. The subject crews also read an 11-0 Information Page and a pilot awareness training bulletin. The ATC phraseology included "Traffic Alert" at the beginning, as follows:

> <Aircraft> TRAFFIC ALERT. <Aircraft> TURN <left/right> IMMEDIATELY HEADING <heading>. <Climb/Descend> AND MAINTAIN <altitude>.

In Phase 1 and Phase 2, ATC-directed climbing breakouts during manual and autopilot-coupled approaches were tested at various altitudes along final approach. Descending breakouts outside the outer marker were also tested for both approach modes. The test criterion for both phases was that mean and maximum time from the start of the ATC breakout instruction to start of turn be less than or equal to the values from the successful PRM risk analysis: 8 and 17 seconds, respectively.

Based on the preliminary results from Phase 2, a third study was designed to test the effect of two written breakout procedures on breakout performance during autopilot-coupled approaches. In Phase 3, the subject crews received the same awareness training package used in Phase 2. The controller phraseology was also the same as tested in Phase 2. During one half of each test session, the crews received a written procedure in which the autopilot remained connected. During the other half-session, the crews received a written procedure which required that they disconnect the autopilot and fly the breakout manually. Breakouts occurred at various altitudes along the final approach. Two scenarios were descending breakouts.

TEST RESULTS

Breakout performance during Phase 1 did not meet the test requirement for either approach mode. Mean time to start of turn was less than 8 seconds for manual approaches, but two trials had a time to start of turn value greater than 17 seconds. Mean time to start of turn was greater than 8 seconds for autopilot-coupled approaches, and 29 percent had a time to start of turn value greater than 17 seconds. Although response times were shorter for breakouts following manual approaches, the pilots expressed a preference for flying autopilot-coupled approaches because the workload is less. In addition, the pilots expressed a need for procedure training and practice. The pilots also liked the idea of an additional word or phrase in the breakout instruction to alert the pilots that a non-standard operating procedure is required.

The situational awareness training and additional controller phraseology in Phase 2 did not improve breakout performance sufficiently to meet the test criteria. Mean and maximum times to the start of turn were similar to those observed in Phase 1 for both manual and autopilot-coupled approaches. All pilots agreed that the additional phraseology was useful, although some pilots felt that another phrase would be better. All but one pilot also felt that the 11-0 Information Page and approach plate notes increased situational awareness.

In Phase 3, the autopilot breakout procedure did not improve performance sufficiently to meet the test criteria. Mean time to start of turn was approximately 15 seconds, and 21 out of 76 breakouts had a time to start of roll value greater than 17 seconds. The manual breakout procedure, however, did improve performance for autopilot-coupled approaches sufficiently to meet the test criteria. Mean time to start of turn was less than 8 seconds and all times to start of turn were less than 17 seconds. Pilot preference for either the manual or autopilot breakout procedure was mixed; although more pilots said that, based on their experience in the study, they would choose to execute a hand-flown breakout. The pilots agreed that the tested ATC phraseology encouraged a quicker response and that the video material increased their awareness of simultaneous close parallel approaches. There was less agreement about the effectiveness of the approach plate notes and airport information page.

CONCLUSION

With respect to the level of B747-400 pilot training required for ATC-directed breakouts, one conclusion was that there was not a significant problem executing the breakouts during manual final approaches. The small number of long times to start of turn may have been avoided if the pilots had been trained to ignore the flight director. Overall breakout performance could also improve if ATC-directed turn maneuvers were discouraged below 400 feet above ground level. The other conclusion was that the combination of additional ATC breakout phraseology, increased situational awareness, and a manual breakout procedure was necessary in order to meet the test criteria during autopilot-coupled approaches.

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1. INTRODUCTION

In 1987, the Federal Aviation Administration (FAA) initiated two programs with the purpose of increasing airport capacity during instrument meteorological conditions (IMC) to levels near visual meteorological condition (VMC) capacity while maintaining the safety of the operations. One program was the Precision Runway Monitor (PRM) Development and Demonstration Program, which concluded in 1991 with the recommendation to allow simultaneous instrument landing system (ILS) approaches to dual parallel runways spaced 3400 to 4300 feet apart, given certain equipment and operational requirements [1]. The other is the Multiple Parallel Approach Procedure (MPAP) program, an on-going FAA effort that started in 1988. The MPAP technical working group (TWG) has developed and tested new procedures for simultaneous dual, triple, and quadruple parallel approaches in IMC utilizing existing and/or new technology along with proposed air traffic control (ATC) procedures [2, 3].

During simultaneous ILS approaches, FAA regulations require air traffic controllers to staff a special radar-monitoring position dedicated to maintaining separation between aircraft. If an aircraft wanders or blunders into the no transgression zone (NTZ), then the monitor controller is required to break any threatened aircraft out of its approach path and away from the blundering aircraft. The ATC-directed breakout scenario is described in more detail in Section 1.1.1.

While the monitor controller response to a blunder is critical to the safety of simultaneous parallel ILS approaches, the responses of the threatened air crew and aircraft also affect the safety of the operation. If the combined pilot/aircraft response to the ATC-directed breakout is not sufficient in either time or magnitude, then a near miss or mid-air collision could occur. Thus, it is important to know the limitations of the threatened crew/aircraft response for the major aircraft types.

There is a concern with newer aircraft with "advanced avionics" that the flight management system and autopilot are not designed for emergency maneuvers in the terminal area. In order to evaluate breakout performance in newer aircraft, the FAA contracted for two breakout performance studies using digital aircraft types with advanced avionics systems. The Airbus 320 (A320) and Boeing 747-400 (B747-400) were selected for the studies. This report documents the B747-400 study.

The remainder of this section provides details about previous performance studies, the PRM Demonstration Program, and the Multiple Parallel Approach Program. Section 2 details the experimental designs used in the B747-400 study. Section 3 describes the test and analysis procedures for the B747-400 study. Section 4 describes the measures taken to validate the data. Section 5 presents the breakout performance analysis, and Section 6 presents pilot survey results. Section 7 summarizes the findings.

1.1 BACKGROUND

1.1.1 Simultaneous Parallel Approach Blunder Scenario

This section describes the events that occur when an aircraft on a simultaneous parallel approach deviates towards an adjacent approach. A blunder occurs when the deviation is sufficient to require human intervention. A deviation in which the aircraft continues towards the adjacent approach without responding to the intervention is called a "worst-case" blunder. A go-around executed by an aircraft on the adjacent approach because of an air traffic control instruction is termed an ATC-directed breakout.

During simultaneous parallel approaches, aircraft along the final approach courses are monitored by air traffic controllers at special radar positions. There is one monitor controller and display for each parallel approach course. For dual parallel approaches at runway separations of 4300 feet or greater, the radar displays depict a 2000-foot wide no transgression zone (NTZ) centered between the runways. For multiple parallel approaches and for dual parallel approaches at smaller runway separations, the NTZ is depicted on a special high-resolution color display. In addition, the color-display software includes alert logic to detect when an aircraft is deviating towards the NTZ.

Figure 1-1 depicts the sequence of events during a worst-case blunder event on close parallel approaches (runway separation between 3400 and 4300 feet). The blunder begins when an aircraft starts deviating towards the adjacent approach (1). A caution alert is generated at (2), and the monitor controller decides to break the adjacent aircraft out of the approach stream at (3). The breakout instruction is received by the air crew at (4), and the breakout maneuver begins at (5). The closest point of approach between the two aircraft occurs at (6), after which separation increases.

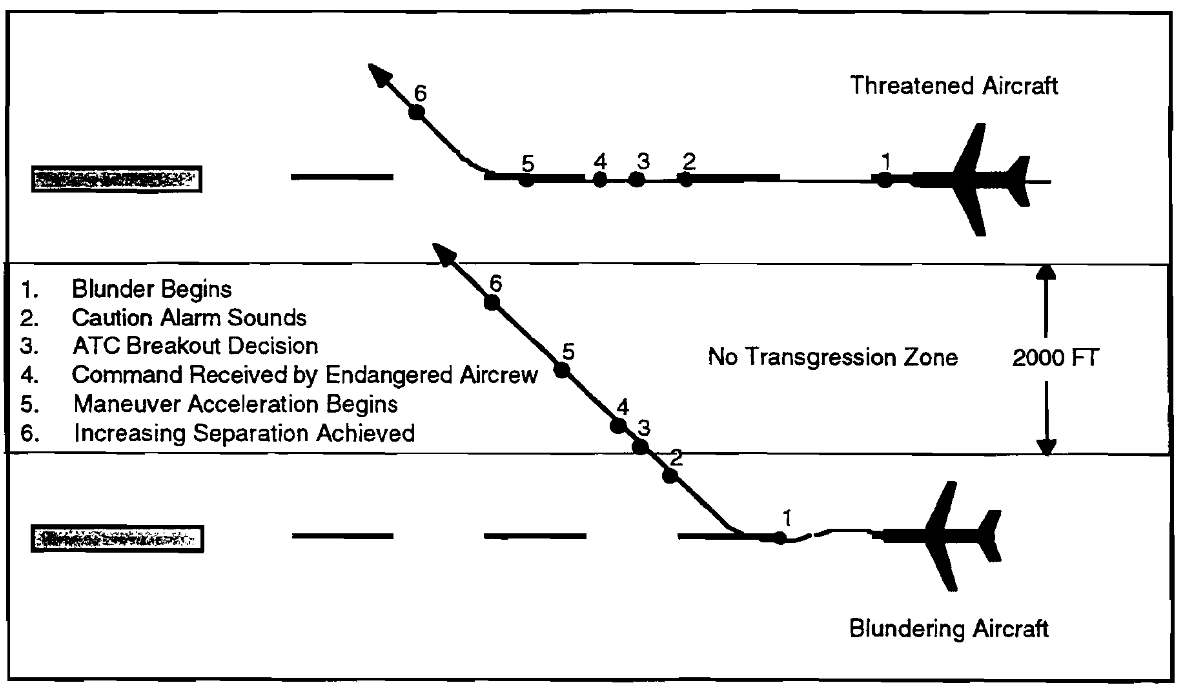


Figure 1-1. Sequence of events during an approach blunder.

1.1.2 B727 and DC10 Performance Studies

The FAA Standards Development Branch conducted two studies in 1989 to measure air crew performance during missed approaches and ATC-directed breakouts [4, 5]. These studies utilized the Boeing 727 (B727) cockpit simulator at the Mike Monroney Aeronautical Center, Oklahoma City, Oklahoma, and the Federal Express McDonnell Douglas 10 (DC10) cockpit simulator in Memphis, Tennessee. Both simulators were certified equipment with six degrees of motion. Three groups of go-around scenarios were evaluated: missed approaches where the crew turned when able; missed approaches where the crew followed company policy; and, ATC-directed breakouts at low and high altitudes. The results of all three scenario groups were used in the development of the obstacle assessment surfaces required in FAA Order 8260.41 [6]. The ATC-directed breakout scenarios were also incorporated into the PRM Demonstration Program risk assessment [1]. The performance study goals that relate to the current study were:

- Evaluate pilot performance and reaction time to an ATC-directed breakout given normal and adverse operating conditions;
- Determine the minimum height above ground at which an aircraft is operationally capable of initiating a turn; and
- Determine pilot acceptability of ATC-directed turns during low-altitude transition from approach to missed approach.

The ATC-directed breakouts were at 6 nautical miles from the threshold (1800 feet above ground level (AGL)), at 200 feet AGL (Category I decision altitude (DA)), and at 100 feet AGL (Category II DA). In addition, two trials in each study measured breakout performance when the crew was distracted. Based on discussions with the user community, engine failure was selected as a representative mechanical failure distraction. The ATC phraseology used during these trials came from FAA 7110.65F, paragraph 5-126:

> (Aircraft) TURN (left/right) HEADING (degrees) IMMEDIATELY, CLIMB AND MAINTAIN (altitude).

For the breakouts at decision altitude, the pilots generally found the workload to be more demanding than average and passenger comfort to be slightly unacceptable. The DC10 pilots also felt that the altitude was slightly unsafe. Some DC10 pilots did not have a problem with the low-altitude breakouts, while others were concerned that they had to reconfigure the aircraft, thus delaying the turn. In both studies, the pilots felt that knowledge of another aircraft on a simultaneous approach in instrument meteorological conditions (IMC) would have affected their response. Finally, there was general consensus among the participating pilots and controllers that the ATC phraseology needed to be revised to more clearly reflect the urgency of the situation.

For the ATC-directed breakouts, the statistics for the time delay from start of the controller breakout instruction to the start of the turn are listed in Table 1-1. Start of turn was declared when the aircraft achieved a 3-degree roll in the appropriate direction. In general, the pilots were able to initiate the turn within 17 seconds; a few pilots exceeded 20 seconds. The engine-out distraction added 2 to 3 seconds to the average response time. A conclusion of the studies was that the long response times may have been due to various interpretations of the meaning of the word "immediately."

Table 1-1. Time from Start of ATC Instruction to Start of Turn (seconds) from the B727 and DC10 Studies*

Scenario	B727			DC10		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
100 ft AGL	7.3	2	22	6	2	15
200 ft AGL	4.9	2	13	3	1	17
1800 ft AGL	4.5	2	16	5	1	23
Engine Out	7.7	3	18	8	1	17
Follow-on Study	5.6	2	11	-	-	-

* Time was measured in 1-second intervals.

Because of the long response times observed in the studies, a follow-on study was conducted using the B727 simulator [7]. In this study, the pilots were briefed that the word "immediately" meant that the controller had observed a situation that required an urgent response from the pilot in order to ensure the safety of the aircraft. In addition, the ATC phraseology was changed to:

> (Aircraft) TURN (left/right) IMMEDIATELY HEADING (degrees), CLIMB AND MAINTAIN (altitude).

All ATC-directed breakouts were at decision altitude. The statistics for the time to start of turn are included in Table 1-1. The mean time to turn was similar to the values from the first B727 study. However, the longest response time was 11 seconds. The conclusion was that improving the situational awareness of the pilots to the meaning of the word "immediate" did not affect the general response characteristics for the subject populations, but it did remove the unwanted long responses. A recommendation for safety improvement was:

> ... to include the meaning of the word "immediately" or another word that conveys this concept of urgency as it applies to ATC direction to pilots for aircraft maneuvers in all phases of training, and specifically, include ATC directed missed approaches during recurrent simulator training [7].

1.1.3 PRM Demonstration Program

The purpose of the Precision Runway Monitor (PRM) Demonstration Program was to evaluate the use of new radar and display technology together with the monitor controller position for the safe conduct of simultaneous parallel ILS approaches to runways spaced between 3400 and 4300 feet apart. Operational issues associated with conducting simultaneous approaches to runways separated by less than 4300 feet were also considered.

The primary goal was to maintain current safety levels during blunder events. To assess the safety of the PRM system, a Monte Carlo simulation of the events depicted in Figure 1-1 was developed. Field and/or experimental data were collected for each of the blunder parameters: aircraft geometry; radar and blunder alert performance; controller response time; communication delays; and, performance of the threatened (evader) aircraft.

Tracks from the B727 and DC10 performance studies described in Section 1.1.2 were used in the Monte Carlo simulation as the threatened aircraft maneuvers. The distributions of times to start of turn are depicted in Figure 1-2. One risk analysis included all responses from the DC10 and first B727 studies. The results indicated an unacceptable level of safety for the operation. A second analysis was based on the conclusions of the second B727 study, which indicated that pilot awareness could improve breakout performance. For this second evaluation, all breakout maneuvers with a time to start of turn greater than 20 seconds were removed from the data set. As illustrated in Figure 1-2, this resulted in a distribution of responses with a maximum time to start of turn of 17 seconds. Limiting evader turn responses to 17 seconds or less resulted in an acceptable level of safety [1].

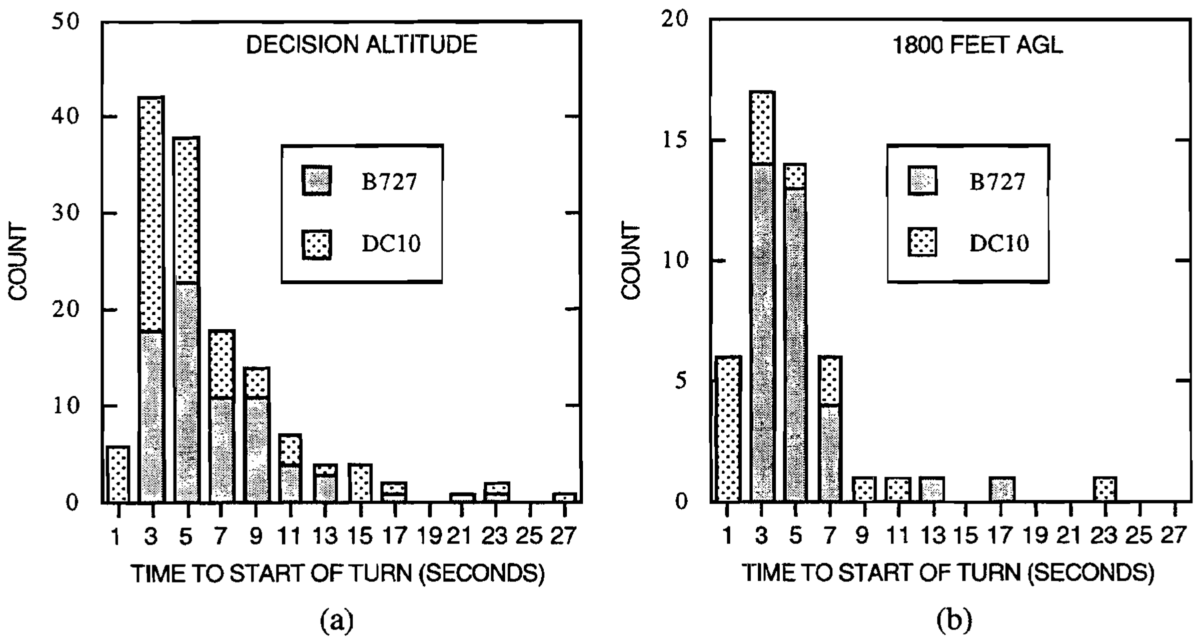


Figure 1-2. B727 and DC10 data used in the PRM risk analysis. Values are times from start of ATC breakout instruction to start of turn at: (a) 100-foot DA and 200-foot DA, combined (b) 1800 feet AGL.

The distributions of controller response times used in the safety analysis were based on two studies conducted in Memphis, Tennessee, and Raleigh, North Carolina [1, 8]. The Raleigh controller study incorporated real-time data from a McDonnell Douglas 80 (MD80) flight simulator. During one of the breakout scenarios, the MD80 pilot had difficulty disconnecting the autoland in order to fly the breakout manually. Since the MD80 has a more modern avionics system than the B727 and DC10, this event raised the issue of possible difficulty executing an ATC-directed breakout by newer aircraft types such as the B747-400, Boeing 757, and Boeing 767 when the approach is flown using the autopilot.

Another operational issue addressed during the PRM Program was the possibility of simultaneous missed approaches because there is no positive course guidance during missed approaches. Studies have shown that aircraft may deviate from the missed approach course by up to 15 degrees in either direction [9, 10]. This is not a problem at airports with runways separations greater than 4300 feet because the distributions of aircraft dispersion do not overlap during the straight-ahead segment of the missed approach. But, the dispersions along the missed approach courses can overlap at smaller runway separations. As the allowable runway separation for simultaneous ILS approaches is decreased, the possibility of simultaneous missed approaches due to weather increases. Thus, simultaneous operations at smaller runway separations increase the potential for crossing missed approach trajectories.

Because of the concern about dual missed approaches at smaller runway separations, one recommendation was that the monitoring zone extend beyond the departure end of the runways. An 11:1 obstacle clearance surface to protect aircraft broken out at low altitude was also developed based on the missed approach data from the B727 and DC10 studies [6].

The PRM Program concluded in 1991 with documentation of the issues, the supporting data and results, and the following recommendation:

> It is recommended that the FAA issue a national standard for runway spacing of 3,400 feet, provided the approaches can be monitored by displays equivalent to those used in the demonstration, driven by a radar accurate to within 1 milliradian with an update interval of 2.4 seconds or less. ... A familiarization program to ensure that all pilots understand their responsibilities during a closely spaced parallel approach will also be required. An off-centerline obstruction evaluation will be conducted at all airports where PRM is to be installed [1].

1.1.4 MPAP Simulations

The Multiple Parallel Approach Procedure (MPAP) program started in 1988 with real-time simulations of proposed multiple parallel approach procedures for Dallas-Fort Worth International Airport [3]. Since then, the sophistication of the simulation facility at the FAA Technical Center has increased, with improvements in the design of test cases (blunders) and incorporation of live modem feeds to remote-site cockpit simulators. Currently, the facility has the capacity to incorporate up to seven remote simulator sites.

One of the first MPAP simulations to incorporate multiple simulators was the study of dual parallel ILS approaches to runways spaced 3000 feet apart, conducted in 1994 [11]. This study used Boeing 747-400, Lockheed 1011, Boeing 727, and Boeing 737 cockpit simulators as threatened aircraft during blunder scenarios in order to provide realistic air crew and aircraft response characteristics. Although some of the test acceptance criteria were met, the target safety level criterion was not met. One of the factors identified with poor blunder resolution performance was inadequate breakout maneuvering responses. The MPAP technical working group concluded that the pilots were unfamiliar with ATC-directed breakouts between glide slope intercept and decision altitude. Lack of familiarization was compounded by the specific cockpit procedures required to elicit a breakout in aircraft with highly automated flight control management systems during autopilot-coupled approaches.

The MPAP technical working group decided that the effectiveness of improving pilot awareness as well as improving cockpit breakout technique needed to be evaluated for advanced automation aircraft such as the B747-400. The group requested that its research be incorporated into the A320 and B747-400 test plans. The group then used the results of the two studies during the development of pilot training programs for subsequent simulations conducted in October 1995 [11] and April 1996 [12]. Both of these simulations were successful; and improved pilot training was mentioned as a contributing factor.

1.2 STUDY OBJECTIVES

Because of the difficulty observed with the MD80 automation during the PRM Demonstration Program, the current study was commissioned to measure air crew and aircraft breakout performance for newer aircraft types, given current procedures. Because of the slow responses observed during the MPAP simulations in 1994, this study was expanded to include evaluation of the effect of pilot training on breakout performance.

The main objective of the B747-400 study was to determine the level of pilot training required to produce an acceptable distribution of breakout responses. Phase 1 of the study had no training and was used as a baseline to measure B747-400 breakout performance given current procedures and air crew training. Phase 2 included a training package designed to increase the pilots' situational awareness of close parallel approach procedures. Phase 3 added written cockpit breakout procedures to the situational awareness training. If breakout performance was determined to be acceptable during a given phase, the study was halted. If not, the study continued. The decision to stop the study or to continue was made at the conclusion of each phase by a task group consisting of members of the MPAP technical working group.

In order to assess the effectiveness of pilot training, a measure for "acceptable breakout performance" had to be agreed upon. Although a breakout maneuver involves pitch, speed, and roll changes, time to start of roll was identified as the critical measure of performance. Thus, time to start of turn was used in the current study as the test variable for determining acceptable performance.

The B727 and DC10 breakout performance data that resulted in the successful PRM risk analysis were used as the measure for "acceptable breakout performance." As mentioned in Section 1.1.3, the PRM risk analysis was acceptable when the breakout maneuvers with times to start of turn greater than 20 seconds were removed. The resulting distributions of times to start of turn had mean values of 7 to 8 seconds, and maximum values of 17 seconds. These statistics were used as test criteria for the current study. Thus, the B747-400 study was halted if preliminary review of the data indicated that all times to start of turn for that phase were less than 17 seconds and the mean value was less than 8 seconds. If either of these conditions was not met, then the study continued.

The secondary objective of the study was to evaluate factors which can affect B747-400 breakout performance. The tested factors included the use of autopilot, the altitude at which the breakout was executed, and the vertical direction of the breakout (climb or descend). Interactions among factors were also evaluated.

To summarize, the testable questions were as follows:

Phase 1: What is the B747-400 breakout performance given current air traffic control breakout phraseology and airline procedures? How does this performance compare to the B727 and DC10 response distributions used in the PRM risk analysis?

Phase 2: Does situational awareness about close parallel approaches combined with proposed air traffic control breakout phraseology improve B747-400 breakout performance by reducing the time to start of maneuver? How does this performance compare to the B727 and DC10 response distributions used in the PRM risk analysis?

Phase 3: Does situational awareness combined with aircraft-specific breakout procedures improve B747-400 breakout performance by reducing the time to start of maneuver? How does this performance compare to the B727 and DC10 response distributions used in the PRM risk analysis?

1.3 REPORT TERMINOLOGY

While the jargon used in this report is based on the jargon used by line pilots, there may be some differences in the application of the phrases. In order to avoid confusion, the context of each term, as used in the remainder of this report, is defined below.

Breakout (BO): An ATC-directed deviation away from the final approach course in response to the actions of another aircraft on the adjacent parallel approach. The instruction includes a new heading, turn direction (left or right), new altitude, and vertical direction (climb or descend). In air traffic jargon, this may also be called a go-around.

Approach Mode: The flight director and autopilot configuration during final approach. **HF mode** indicates the flight director is on, the autopilot is off, and the pilot is flying manually using the flight director for guidance. **AP mode** indicates that both the flight director and autopilot are on, and the flight management system is controlling the aircraft. In this report, HF mode is also referred to as a hand-flown, or manual, approach, and AP mode is also referred to as an autopilot-coupled approach.

Breakout Mode: The autopilot configuration at the start of the turn. **HF mode** indicates that the autopilot is off at the start of the turn; the flight director may be on or off. **AP mode** indicates the autopilot is on at the start of the turn. This distinction is made because some subjects disengaged the autopilot after the start of turn. In this report, HF mode is also referred to as a hand-flown, or manual, breakout and AP mode is also referred to as an autopilot-coupled breakout.

Approach/Breakout (Appr/BO) pair: **HF/HF** indicates a hand-flown approach followed by a hand-flown breakout, even if the crew turns on the autopilot after the start of the breakout maneuver. This distinction is made because some crews engaged the autopilot once they had achieved the breakout heading and altitude. **AP/HF** indicates an autopilot-coupled approach followed by a manual breakout, meaning the autopilot was disconnected at some time after the start of the ATC breakout instruction and before the start of turn. **AP/AP** indicates an autopilot-coupled approach followed by an autopilot-coupled breakout.

Start of Turn: Data record at which the aircraft has achieved a 3-degree or greater roll to the left and maintains the roll until the final heading is reached.

Start of Climb: Data record at which descent is arrested and vertical speed has increased at least 150 feet per minute above the value at the start of the ATC transmission.

2. EXPERIMENTAL DESIGN

As indicated by the length of the Acknowledgment section, this study was a collaborative effort by many individuals within many organizations. Each organization had or shared main responsibility for at least one aspect of the study, with several organizations participating at varying levels in the design of each phase. In addition, the design of the study was an iterative process. The experimental designs for Phases 2 and 3 were dependent on the knowledge gained from the previous stage. Because of the dependency of the later stages on the previous stage(s) and because of the time frame available for initial test development, the three phases were not designed concurrently.

While the phases shared the objective of measuring pilot and aircraft performance given an ATC-directed breakout, the point of view for each phase was unique. The purpose of Phase 1 was to measure performance given the current air traffic control breakout procedure and current airline pilot training. The purpose of Phase 2 was to test if increased situational awareness training would decrease pilot response times and improve breakout performance. Breakout performance given hand-flown approaches appeared to improve during Phase 2, but the breakout response times given autopilot-coupled approaches were still too long. So, Phase 3 was designed to test if the combination of increased situational awareness and cockpit procedure training could improve breakout performance given autopilot-coupled approaches.

The following sub-sections describe the experimental design developed for each phase of the study.

2.1 PHASE 1

Phase 1 was designed to be comparable to the B727 and DC10 studies in order to facilitate comparison. Since this was also the first study specifically designed to evaluate the performance of an advanced avionics aircraft during the final approach phase, the test scenarios included missed approaches and ATC-directed breakouts at decision altitude. The value of the breakouts at decision altitude was two-fold. First, since the breakouts were executed close to the ground, the pilots had to achieve a positive climb rate before the turn could be executed. This provided an upper bound on the time required to turn away from the approach. Second, since the pilots would start the turn earlier than they would for a missed approach, the low-altitude breakouts also provided a bound for the required obstacle assessment surface. Although included as a design consideration, the obstacle clearance evaluation is not reported in this document.

The Phase 1 design included breakouts at decision altitude and at 1800 feet above ground level (AGL); the same as in the previous studies. Scenarios at 500 feet AGL were added so the pilots would not learn to expect breakouts at only two altitudes. The 500-foot scenarios also provided information about breakout performance near the transition altitude of 400 feet AGL. In order to satisfy user-community concerns about the realism of the breakout scenarios, the distraction scenarios were retained. Due to time constraints, aircraft-specific distractions could not be developed, so the engine failure distraction was used. For the B747-400, the failure occurred in the right outboard engine. Finally, two scenarios were added in which the air traffic controller directed the aircraft to descend rather than climb.

2.1.1 Independent Variables

In evaluating evader breakout performance given current procedures, there were four independent variables: approach mode, level of distraction, altitude at start of breakout, and vertical direction of the breakout. The levels for each variable are listed in Table 2-1. The design was treated as a two-factor random model, with approach mode combined with each of the other three variables: approach mode and level of distraction; approach mode and altitude of breakout; approach mode and direction of breakout.

Table 2-1. Independent Variables For Phase 1

Independent Variable	Test Levels	Control Variables
Approach Mode	1. Hand-flown using Flight Director (HF) 2. Autopilot-coupled (AP)	N/A
Altitude	1. Decision Altitude (DA) 2. 500 feet AGL (500') 3. 1800 feet AGL (1800')	Distraction (None) Direction (Climb)
Direction	1. Climb 2. Descend	Distraction (None) Altitude (1800')
Distraction	1. None 2. Engine Out	Altitude (DA) Direction (Climb)

For test sequence development, approach mode was treated as one test condition, and the other three variables were combined under the condition "breakout group." The number of replicates assigned to each pair of conditions are listed in Table 2-2. The reported weather for all hand-flown approaches was at Category I weather minimum (200-foot ceiling), while the reported weather for all autopilot-coupled approaches was at Category II weather minimum (100-foot ceiling). The crews were instructed to follow company procedure where applicable. Otherwise, they were instructed to alternate the pilot flying the approach (captain or first officer). Because the crews were to follow company procedures, the scenarios could not be assigned to each subject a priori. This was because airline company policy may dictate who is required to act as "pilot flying" under certain conditions such as approach category. Thus, it was not possible to design repeated measurements for each subject pilot. The test was treated as a between-subject random model. The same scenario sequence was used for all subject crews. The sequence and test conditions for each scenario are given in Appendix A.

Table 2-2. Number of Replicates for Phase 1 Scenarios

Approach	Breakout Group				
Mode	DA	500'	1800'	Descend	Distraction
hand-flown	2	2	2	1	1
autopilot	2	2	2	1	1

2.2 PHASE 2

The purpose of Phase 2 was to evaluate the effectiveness of situational awareness training plus proposed ATC phraseology on breakout performance. The training package used during the study is described in Section 3.3.2 and in Appendix D. A secondary design consideration was the estimation of practice effects; i.e., did a subject's performance change as the test session progressed.

The design was based on the same two conditions as in Phase 1: breakout group and approach mode. Because the purpose was to test the effect of training, only the breakout groups most likely to occur were carried over from Phase 1: 500', 1800', and Descend. Climbing breakouts at 700 feet AGL (700') were added to reduce subject anticipation of when the breakout would occur and to provide data for use in future risk assessments.

2.2.1 Independent Variables

In evaluating the effect of awareness training, there were three independent variables: approach mode, altitude at start of breakout, and vertical direction of the breakout. The levels for each variable are listed in Table 2-3. The design was treated as a two-factor model, with approach mode combined with each of the other two factors: approach mode and altitude of breakout; approach mode and direction of breakout.

Table 2-3. Independent Variables For Phase 2

Independent Variable	Test Levels	Control Variable
Approach Mode	1. Hand-flown using Flight Director (HF) 2. Autopilot-coupled (AP)	N/A
Altitude	1. 500 feet AGL (500') 2. 700 feet AGL (700') 3. 1800 feet AGL (1800')	Direction (Climb)
Direction	1. Climb 2. Descend	Altitude (1800')

The reported weather for all scenarios was Category I weather minimum. This removed the airline policy constraint that was observed in Phase 1 and allowed for sequence assignment by crew member: captain or first officer. Assignment of scenarios by pilot resulted in a mixed design: within subject for altitude and direction, and between subject for approach mode. Within-subject replicates for the 500' and 1800' autopilot-coupled scenarios were used for analysis of practice effects. The distributions of test scenarios for each crew member, identified as subject A or B, are listed in Table 2-4. The sequence of scenarios was designed to be symmetrical with respect to the 500' and 1800' breakout groups, and asymmetrical with respect to the 700' and Descend groups. One half of the crews experienced the sequence in the forward order, while the other crews experienced the sequence in reverse order. In addition, crew assignments were varied, meaning subject A was the captain in one half of the crews and subject A was the first officer in the other crews. This resulted in four test sequences. The scenario order and configurations for each test sequence are given in Appendix A.

Table 2-4 Number of Replicates for Phase 2 Scenarios

Pilot Flying	Approach Mode	Breakout Group			
		500'	700'	1800'	Descend
A	hand-flown	1	1	1	-
	autopilot	2	-	2	1
B	hand-flown	1	-	1	1
	autopilot	2	1	2	-

2.3 PHASE 3

The purpose of Phase 3 was to evaluate the effectiveness of increased pilot situational awareness and specific cockpit procedures together on breakout performance. Based on the results of Phase 2, the design was limited to autopilot-coupled approaches only. Procedure training for hand-flown approaches was not tested because preliminary Phase 2 results suggested that increased situational awareness was sufficient for this mode of approach. The written procedures that were tested are described in Section 3.3.3 and in Appendix E. As with Phase 2, estimation of practice effects was a secondary design consideration.

Two breakout procedures were tested: one using the autopilot, and one for which the crew was instructed to disconnect the autopilot and fly the breakout manually. Thus, the factor of approach mode was replaced with the factor of breakout mode: autopilot-coupled (AP) breakout and manual (HF) breakout. For the breakout group, the 500', 1800', and Descend groups were retained. The 700' group was found to be too close to the 500' group in distance from the runway threshold, so it was replaced with breakouts at 1000 feet AGL (1000'). Finally, the breakouts at decision altitude (DA) were reinstated.

In order to maximize the number of subjects for each training procedure, each test session was divided into two halves. During one half, each crew was trained and tested for the autopilot (AP) breakout procedure. During the other half, the crew was trained and tested for the manual (HF) breakout procedure. The order of training was counter-balanced; one half of the crews were tested on the autopilot breakout training first, and the other crews were tested on the manual breakout procedure first. Thus, all subjects were tested for both procedures.

2.3.1 Independent Variables

In evaluating the effect of procedure training, there were three independent variables: breakout mode, altitude at start of breakout, and vertical direction of the breakout. The levels for each variable are listed in Table 2-5. The design was treated as a two-factor model, with breakout mode combined with each of the other two factors: breakout mode and altitude of breakout; breakout mode and direction of breakout.

Table 2-5. Independent Variables For Phase 3

Independent Variable	Test Levels	Control Variable
Breakout Mode	1. Hand-flown (HF) 2. Autopilot-coupled (AP)	N/A
Altitude	1. Decision Altitude (DA) 2. 500 feet AGL (500') 3. 1000 feet AGL (1000') 4. 1800 feet AGL (1800')	Direction (Climb)
Direction	1. Climb 2. Descend	Altitude (1800')

The reported weather for all scenarios except those at DA was at Category I minimum. The reported weather for the DA scenarios was at Category II minimum. Scenarios were assigned by crew members, resulting in a within-subject design for either altitude and breakout mode or for direction and breakout mode. Within-subject replicates for the 500' and 1800' groups were used for analysis of practice effects. The distribution of test scenarios for each crew member (A and B, where A is either the captain or first officer, depending on the crew number) is listed in Table 2-6. The same sequence of scenarios was used for all subject crews, but the order of training and the subject assignments were counter-balanced, resulting in four test sequences. The scenario order and configurations for each test sequence are given in Appendix A.

Table 2-6. Number of Replicates for Phase 3 Scenarios

Pilot Flying	Breakout Mode	Breakout Group				
		DA	500'	1000'	1800'	Descend
A	hand-flown	-	1	-	2	1
	autopilot	-	1	-	2	1
B	hand-flown	1	2	1	2	-
	autopilot	1	2	1	2	-

2.4 RESEARCH QUESTIONS

Phase 1 of the study was designed to answer the following research questions:

1. Does breakout performance, given current procedures, meet the requirements established during the PRM Demonstration Program for mean and maximum values of time to start of turn?
2. Are pilots comfortable with executing breakouts at <u>low altitudes</u> (less than 400 feet AGL)?
3. Are pilots comfortable with executing <u>descending</u> breakouts at higher altitudes (above 1000 feet AGL)?

4. Do cockpit distractions affect breakout performance?

Phase 2 of the study was designed to answer the following research questions:

5. Does situational awareness training improve the mean and/or maximum time to start of turn sufficiently to meet the requirements established during the PRM Demonstration Program?
6. Which tools were most effective in increasing pilot situational awareness?

Phase 3 of the study was designed to answer the following research questions:

7. Given a negative response to research question 5 for autopilot-coupled approaches, does the tested cockpit procedure training for either breakout procedure (manual or autopilot-coupled) improve the mean and/or maximum time to start of turn sufficiently to meet the requirements established during the PRM Demonstration Program?
8. Is there pilot preference for either the manual or autopilot-coupled breakout procedure?

Finally, the study was designed to answer the following research questions for each phase:

9. Does altitude affect breakout performance?
10. Does vertical direction of the breakout affect breakout performance?
11. Does approach mode affect breakout performance (Phases 1 and 2 only)?

3. METHODS

3.1 SUBJECTS

Commercial airline pilots were recruited through notices to the Air Line Pilots Association (ALPA) and to United States air carriers that operate B747-400 aircraft. Subjects were also recruited from a list of B747-400 rated pilots that participated in previous studies at NASA Ames Research Center. Subject pilots came from United Airlines and Northwest Airlines.

3.2 FACILITY

The study was conducted at NASA Ames Research Center in Moffett Field, California. The subject crew and one or two test observers occupied the certified full-motion B747-400 cockpit simulator. The observers sat behind the subject crew. The observer duties were to verify that the simulator was properly configured for each test run, help the subjects with test- and equipment-related problems, and take notes during the session. The observers were instructed not to provide information to the crews that might affect the results nor to provide suggestions about cockpit procedures.

Another test person operated a separate control room. The control room housed the consoles used to configure the simulator, data-recording equipment, and communication equipment. The control-room operator was responsible for resetting the simulator parameters before each trial and recording the data. The control-room operator also acted as local and monitor controllers; reading from the test script and responding to pilot transmissions as necessary. All test personnel who acted as controller had previous air traffic control experience.

3.2.1 B747-400 Cockpit Instruments

The instrument panel of the NASA Ames B747-400 cockpit simulator is shown in Figure 3-1. This section describes the controls and displays that were used for data collection. The purpose of this section is to provide the reader with an understanding of how data were measured as well as to provide insight needed for interpreting the results. This is not intended to be a primer on cockpit procedures. In order to facilitate the description of the cockpit displays, the simulator is referred to as the "aircraft."

The autopilot is engaged by pressing any one of the three "autopilot engage" buttons on the mode control panel. The autopilot is disengaged by pushing down the disengage bar on the mode control panel or by pressing the autopilot disconnect switch on the control wheel.

Take off/go around thrust (TO/GA) is engaged by pressing one of the TO/GA switches located on the throttles. When TO/GA is activated, the flight management system calculates optimal speed and pitch to achieve a 2000-foot per minute climb to the altitude displayed on the mode control panel. The climb rate can be increased to a maximum rate for that phase of flight by pressing the TO/GA switch a second time.

Airspeed, vertical speed, heading, and altitude information can be entered by the crew using the knobs on the mode control panel. During normal flight, the displays above the knobs indicate the values used by the computer for that phase of flight. The crew can override the programmed information by turning the appropriate knob to the desired value then pressing the knob to enter the information. For the heading knob, the direction in which the knob is turned also indicates the desired direction of the turn: clockwise for a right-hand turn; counterclockwise for a left-hand turn.

Navigational information is provided to the crew on the navigational display (ND). There are two navigational displays; one in front of each crew member. Each display shows the recommended and actual aircraft trajectories. Wind speed and relative bearing are displayed in the upper right corner. When a new heading is selected by the crew, a dashed heading vector appears. The heading vector rotates from the current indicated heading to the heading being dialed in by the crew. The heading vector was used during data processing as an indicator that a new heading was being entered by one of the subject pilots during the breakout maneuver. The wind vector was used to confirm that wind conditions were correctly entered by the control-room operator at the start of each trial.

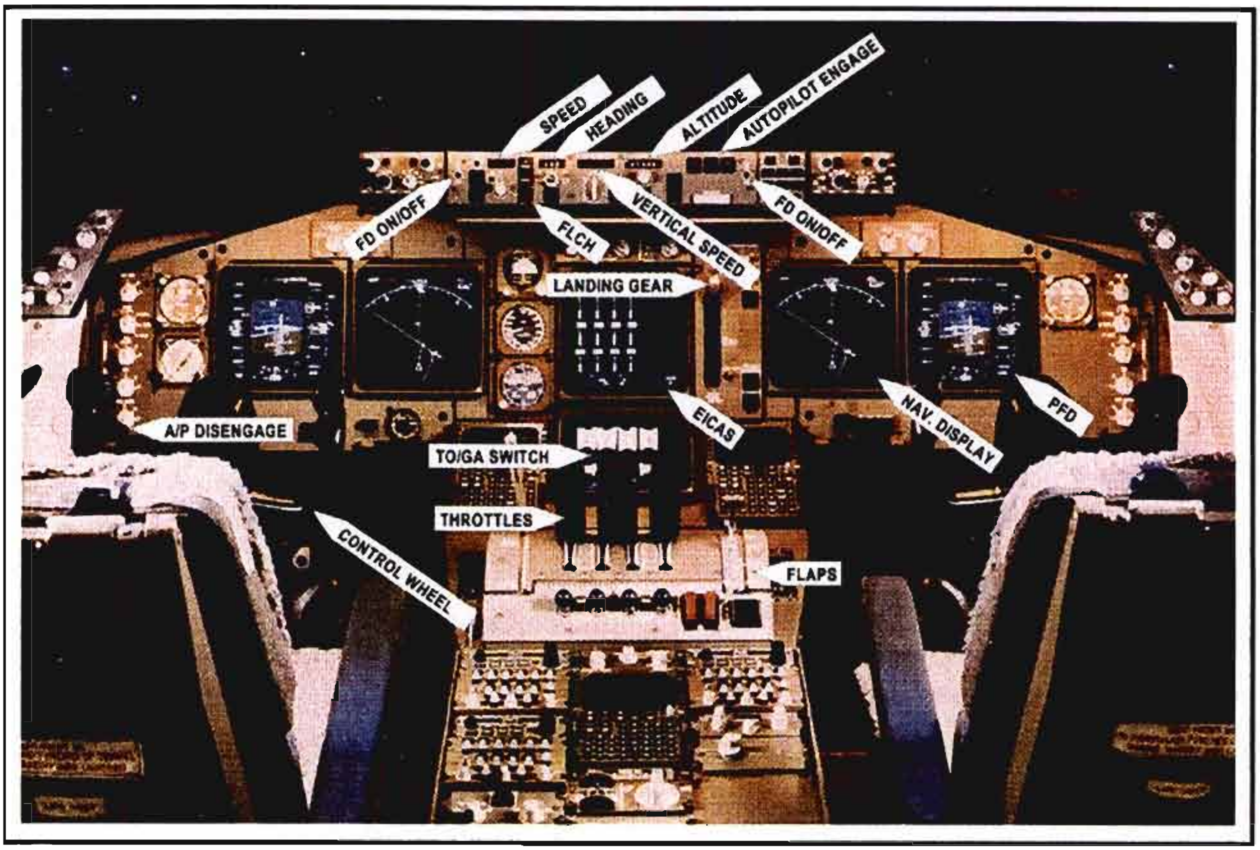


Figure 3-1. B747-400 Cockpit. Photograph courtesy of NASA Ames Research Center.

Flight information is provided to the crew on the primary flight display (PFD). There are two primary flight displays; one in front of each crew member. Figure 3-2 shows a schematic of the display. The center of the PFD provides attitude information. Depending on the phase of flight and the mode of operation, command bars may be present. There are two command bars per display in this cockpit simulator. The vertical command bar indicates lateral deviation from the course. For example, if the aircraft is left of course, the vertical bar is right of center, indicating that the aircraft should roll to the right. The horizontal command bar indicates vertical deviation from the course. For example, if the aircraft is below the course altitude, the horizontal bar is above centerline, indicating that the aircraft should climb. The presence of command bars is controlled by a switch on the glare shield panel above the displays. There is a separate flight director (FD) on/off switch for each primary flight display. During the study, both flight directors were on at the beginning of each trial. During Phases 1 and 2, the subjects had the option of turning off the command bars and flying a manual breakout "raw," i.e., without course guidance from the flight director. In Phase 3, part of the manual breakout procedure was to cycle both flight directors off then on.

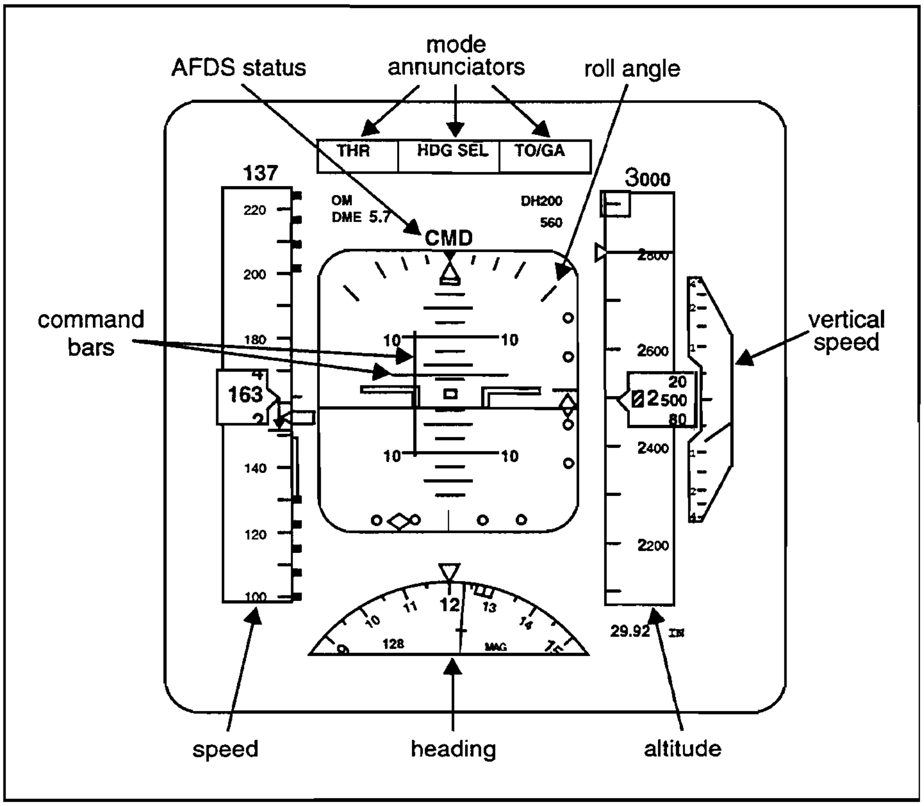


Figure 3-2. Schematic of B747-400 primary flight display.

The flight mode annunciators on the primary flight display are, from left to right: autothrottle, roll, and pitch information. When TO/GA is engaged, the roll and pitch annunciators display "TO/GA." When a new heading is selected, the roll annunciator displays "HDG SEL." When a new altitude is selected, the pitch annunciator displays "ALT" after the new altitude is captured. The roll and pitch annunciators were used during data processing to measure when the TO/GA switch was pressed, and when the crew entered new heading and altitude information into the computer.

The autopilot flight director system (AFDS) status is displayed below the mode annunciators. When any autopilot is on, "CMD" is displayed. The display may change to LAND2 or LAND3 when the aircraft is inside the outer marker, depending on the number of autopilots engaged. If all autopilots are off, but the flight director is on, "FD" is displayed. If both the autopilot and the flight director are off, this area is blank. The AFDS status was used during data processing to measure when the autopilot was turned on or off, and when the flight director was turned off during the breakout.

Movement of the flap lever was used during data processing to measure when the subject crew reconfigured the flaps during a breakout. Movement of the gear lever was used during data processing to measure when the crew retracted the landing gear.

3.3 TEST PROCEDURES

Phases 1 and 2 occurred during March 1995, and Phase 3 occurred during June and July 1995. Upon arrival, each subject crew was sent to a briefing room. Test personnel used a briefing script to inform the subjects that they would be flying approaches to Memphis International Airport runway 36L. The approach plate to be used was given to each crew member. For Phase 1, the current Category I and Category II NOS approach plates were used. For Phases 2 and 3, the Jeppeson approach plates were modified to include information about close parallel approaches. The Phase 1 approach plates are presented in Appendix B, and the modified approach plates are in Appendix C.

In Phase 1, the subjects were told to follow company procedures and to follow air traffic control instructions when given. In Phases 2 and 3, the subjects received training material to review before the test session. The training materials are described in Sections 3.3.2 and 3.3.3.

Each crew was given the opportunity to fly practice approaches before the test session if the subjects were not familiar with the configuration of the NASA Ames cockpit simulator. Each test session lasted approximately three hours. There was a half-hour break mid-way through the test sequence. In Phase 3, the subjects returned to the briefing room after the break to review a second training package, as described in Section 3.3.3.

After the test session, the subjects completed a pilot survey. The survey for each phase of the study was designed based on the research questions for that phase.

3.3.1 Flight Procedures

By design, the simulator maintained the maximum gross landing weight for a B747-400 during the entire final approach. Before each trial, the simulator was set to intercept altitude at 8 nautical miles from the threshold. Landing gear and flaps were set according to company procedure. Altimeter was set to 29.92" Hg. The captain and first officer both flew the aircraft. In Phase 1, the pilot flying was based on company policy where it existed. Otherwise, the crew members alternated who flew the aircraft. In Phases 2 and 3, the pilot flying was based on the test sequence. In Phases 1 and 2, the approach was flown either manually, with the flight director on, or autopilot-coupled according to the test sequence. In Phase 3, all approaches were autopilot-coupled.

3.3.2 Phase 2 Training

In Phase 2, the subjects reviewed a situational awareness training package during the briefing. The training package consisted of a short video [13] describing close parallel approach operations, an 11-0 Information Page describing close parallel procedures, an awareness training bulletin, and a self-administered multiple-choice test. The 11-0 Information Page and the bulletin emphasized the need for prompt compliance when instructed to break out of the approach by the monitor controller. The test was open-book and intended to reinforce the ideas presented in the video and written material. The written training materials are presented in Appendix D.

3.3.3 Phase 3 Training

In Phase 3, the subjects received the same situational awareness training package presented in Phase 2. In addition, they received two written breakout procedure packages: one which trained the crew to execute the breakout with the autopilot on, and another which trained the crew to disengage the autopilot, cycle the flight director off then on, and fly the breakout manually. The written material was the only procedure training received by the subjects. There was no simulator training, and the subjects did not practice the breakout procedure before the test. The two procedures are summarized below, and the complete procedure training materials are found in Appendix E.

The autopilot-coupled (AP) breakout procedure required the pilot flying to engage TO/GA in order to get the flight director out of approach mode. Below 400 feet above ground level (AGL), the crew was to follow normal missed approach procedure to above 400 feet AGL, then turn as directed. Above 400 feet AGL, the pilot flying was directed to make all mode control panel inputs. The inputs depended on the direction of the breakout (climb or descend).

The manual (HF) breakout procedure required the pilot flying (PF) to disconnect the autopilot and follow the ATC direction. The pilot not flying was to turn off both flight directors, then turn his own back on. He was to then set the new heading and altitude and engage flight level change (FLCH). Once the flight director command bars matched the approach path, the pilot not flying turned on the PF's flight director.

Each test session was split into two parts. For the first half, the crew received either the autopilot or the manual breakout training package during the initial briefing session. All breakouts during the first half were conducted using that breakout procedure. After the break, the crew returned to the briefing room and reviewed the training package for the other breakout procedure. All breakouts in the second half were executed using the second procedure. One half of the crews reviewed and were required to follow the autopilot procedure first, then the manual procedure after the break. The other crews reviewed and followed the manual procedure during the first half; and the autopilot procedure after the break. The order in which the crew received the breakout training was based on crew number.

3.3.4 Air Traffic Control Phraseology

The air traffic control breakout phraseology used in Phase 1 was taken from FAA Order 7110.65H [14]:

(Aircraft) TURN (left/right) IMMEDIATELY HEADING (degrees), CLIMB AND MAINTAIN (altitude).

The air traffic control breakout phraseology used in Phases 2 and 3 included additional information at the beginning:

(Aircraft) TRAFFIC ALERT. (Aircraft) TURN (left/right) IMMEDIATELY HEADING (degrees), CLIMB AND MAINTAIN (altitude).

The addition of "Traffic Alert" at the beginning was recommended by a sub-group of the Multiple Parallel Approach Procedure technical working group. It was felt that the phrase would alert all air crews using the local controller frequency to expect transmission of an emergency procedure. In addition, the additional text would reduce the chance that the breakout instruction was clipped or blocked. For the B747-400 study, the word "HEAVY" was inserted after the aircraft identification.

3.4 DATA COLLECTION AND PROCESSING

Aircraft metric data were recorded at the facility on a Unix computer networked to the computer controlling the NASA-Ames B747-400 flight simulator. The data files created were ASCII text files containing a number of tracks, and they were transferred to Lincoln Laboratory via the Internet for processing after each day of testing.

The basic format of the NASA data files was a header with time and date information followed by some number of data records with aircraft metric data, repeated for each track. Data records were written at a rate of approximately 3.5 Hertz. Each record included a time stamp, information about test settings and the aircraft position, orientation, and configuration.

Aircraft position and orientation data included x and y position relative to the arrival threshold, altitude above ground level and vertical speed, heading, bank angle and roll rate, pitch angle and rate, ground speed, indicated airspeed, glideslope deviation, and localizer deviation. Aircraft configuration data included engine one exhaust pressure ratio (EPR), flap position, gear position, TO/GA indicator, and autopilot indicator. Test settings included the ATC event marker which indicated when the ATC pressed a button, wind direction and speed, altimeter setting, and test identification string which encoded scenario number, date, and trial.

In addition to the computer data, videotape recordings of the cockpit and selected pilot displays were made. Images from four separate video cameras were combined into a four-panel screen with a highly accurate time stamp superimposed. One camera was above and behind the first officer with a wide field of view showing both pilots, the throttles and yokes, and the instrument panel. The other three cameras showed close-up images of cockpit displays: first officer's primary flight display (PFD), engine indication and crew alerting system (EICAS), and navigation display (ND). Both cockpit chatter and radio transmissions between the crew and air traffic control were recorded on the audio channel.

3.5 DATA EXTRACTION

Data used in the analyses were extracted from both the digital and video data recordings. Data extraction from the video tapes was manual, while digital data extraction was automated. The software was written in C and run under OpenVMS on VAX computers, and used the

CA-Disspla graphics library for plotting. Computed results from both sources were transferred to Macintosh computers where the analysis was performed.

3.5.1 Digital Data

The data extraction software calculated time-to-event values for the test variables of interest. The results for each track were saved in files which were imported to spreadsheets for review and analysis.

The program first read an entire track file into memory and located the ATC event mark record, which was the first record with an event marker status flag of "on" and signified the approximate time at which the breakout instruction was issued. As described in Section 4.1, the marker record was corrected to remove any human error in coordinating the event mark with the start of the transmission. The records at which events of interest occurred were then identified and used to compute the time-to-event values and the altitude and distance from the threshold of the aircraft at each of the events.

The calculated test variables are listed in Table 3-1. Appendix F provides detailed algorithms and examples for each variable. The algorithm for identifying the start of the turn was the most complicated. The event was nominally the point at which the aircraft had rolled at least three degrees to the left (recall the aircraft is on approach to the left parallel approach), a criterion consistent with previous studies. But, it was possible for the aircraft to roll back to level or towards the right. Since such an action would delay the start of the turn maneuver, the algorithm also identified the last time that the aircraft rolled greater than 3 degrees to the left. Usually, the final time the aircraft rolled left was considered the start of the turn maneuver. Because of the variety of special cases encountered, all data were manually verified and corrected, if necessary.

The starts of the thrust, pitch, and climb events were determined by comparing the values of those metrics at the time of the breakout instruction (given by the marker record) with the values in successive records, using the empirically-determined thresholds listed in Table 3-1. Note that the relative change criteria do not always indicate a positive value. For example, vertical speed during the approach was typically -950 feet per second. The start of climb event would thus be the record at which the vertical speed was greater than -800 feet per second, indicating that the aircraft was still descending but had started accelerating towards a positive climb rate.

Identifying the change in TO/GA and autopilot status was a matter of finding the first record after the marker record whose value for the status had changed. Flaps position was recorded as degrees of extension and landing gear position was given as a value between 0 (down) and 1 (up). Examination of the data showed that these values did not change other than in reaction to pilot input for a new configuration, so the event was identified as the first change in value after the start of the breakout event. The maximum roll angle and minimum height above ground were extracted within the 90-second period following the marker record.

Table 3-1. Digital Data Measurements

Variable Name	Measure	Criterion
dt_roll	Time to start of aircraft roll	Bank angle of at least 3 deg to left, with restrictions
dt_throttle	Time to change in throttle lever position	Change of more than 5 deg over value at marker record
dt_engine	Time to increase in engine 1 thrust	Increase of 0.05 EPR over value at marker record
dt_pitch	Time to change in pitch	Increase of 1.2 deg over value at marker record
dt_vertical_speed	Time to change in climb rate	Increase of 150 ft/min over value at marker record (positive rate not required)
dt_heading	Time to change in heading	Change of 3 deg to the left in aircraft heading
dt_toga	Time to change in TO/GA status	Status changed from off (0) to engaged (1)
dt_autopilot	Time to change in autopilot status	Status changed from on (1) to disengaged (0) (if in AP approach mode)
dt_flaps	Time to change in flap position	Any change in degrees of flap
dt_gear	Time to change in gear position	Change in gear position from down to up
maximum_roll	Greatest roll angle	Largest roll angle magnitude achieved during the turn maneuver
dx_turn	Distance traveled until start of turn	Difference between ground position at start of turn and at start of ATC instruction

3.5.2 Video Data

The information extracted from the videotapes included what pilots and testers did and said, time-to-event values used to verify the digital data, and time-to-event values not available in the digital data. The time measurements are listed in Table 3-2. Five time measurements were comparable to the digital data: time to TO/GA engagement (dt_toga and t_toga); time to autopilot disengagement (dt_autopilot and t_autopilot); time to flap change (dt_flaps and t_flaps); time to gear up (dt_gear and t_gear); and time to start of roll (dt_roll and t_roll). The remaining measurement, t_heading_select, provided information not available in the digital data.

The duration and exact phrasing of the ATC breakout instruction was also recorded, and any additional radio transmissions were noted, such as when a pilot asked for part of the instruction to be repeated. Also noted were: the pilot flying; approach mode before the breakout (autopilot on or off); and, sequence of pilot actions.

Table 3-2. Video Data Measurements*

Variable Name	Measure	Criterion
t_roll	Time to start of left roll	Movement of roll indicator on PFD
t_autopilot	Time to autopilot on or off	Change in AFDS status (CMD to FD; FD to CMD)
t_flaps	Time to change in flap setting	Movement of flap lever by pilot; EICAS indicator
t_gear	Time to gear retraction	Movement of gear lever by pilot; EICAS indicator
t_toga	Time to TO/GA engage	TO/GA appears on PFD mode annunciators
t_heading_select	Time to enter new heading	HDG appears on PFD mode annunciator

* Measurements started at beginning of ATC breakout instruction.

3.6 DATA ANALYSIS

Exploratory analysis was used to identify relationships between test variables and to identify representative variables for more-detailed analysis. A subset of test variables representing turn performance, climb performance, and speed performance during the breakout maneuver were selected for further analysis using SPSS™, a statistical software package. As described in Section 2, each phase was designed as a two-factor model. The main effect of each test factor as well as the possible interaction between test factors were determined using analysis of variance (ANOVA). The null hypothesis for each analysis was that the test means were equal. If the calculated F value was greater than $F_{.05}$, then the null hypothesis was rejected at the 0.05 significance level. If the null hypothesis was rejected for a factor with more than two levels, then the Tukey's b multiple range test was used to determine which factor levels were statistically similar.

The ANOVA formulas used depended on the study phase. The formulas may be found in a statistical text such as [15]. For Phase 1, the assignment of subjects to each combination of test factors was assumed to be random. In reality, however, there was some overlap, with each subject experiencing more than one combination of test factors. Because the scenarios were not assigned to each crew member a priori, there was no consistency in the repeated measures. As shown in Table 2-2, some Phase 1 scenarios had replicate samples. But, one subject was the pilot flying for both replicates for some crews, while both subjects flew one replicate each in other crews. Because of the small sample size, it was not possible to separate the data into two groups based on the repeated measures. Therefore, it was necessary to assume a random model for all factors. Collapsing the model with respect to the subjects (all comparisons were assumed to be between-subject) resulted in a more conservative analysis than if a within-subject model had been applied.

A mixed-factor (within and between subject) model was used for the Phase 2 design. Approach mode was the between-subject factor. This means that for a given analysis, each subject was assigned to fly either all manual approaches or all autopilot-coupled approaches, but not both. Altitude and Direction were the within-subject factors, meaning that for a given analysis each subject experienced all levels for that factor.

A repeated-factor design was used for Phase 3. This means that for a given set of test factors, each subject was assigned to all combinations of all factor levels. All subjects executed both manual and autopilot-coupled breakouts. In addition, one pilot in each crew experienced all levels of the Altitude factor, while the other crew member experienced both levels of the Direction factor.

The use of analysis of variance requires the assumption that the observations from all test cells are normally distributed and have the same variance. Similar assumptions about the differences between observations are required for the mixed-factor and repeated measure analyses. Before each analysis, the assumptions were tested using the appropriate tests provided with SPSS. If, for a given analysis, the observations did not satisfy the required assumptions, then the data were transformed. Any data transformations are noted in the results section (Section 5).

Since Phases 2 and 3 included within-subject factors, these ANOVA required a complete set of data. Missing data values were replaced with the mean value for that test cell. The degrees of freedom for the denominator was then reduced by the number of missing values. Any missing values are noted in Section 5.

If a subject experienced a set of conditions more than once (repeated measured), the data for these trials were averaged together and treated as a single data sample for the analysis of variance. This was done to equalize the sample sizes for each set of conditions. For example, every subject experienced autopilot breakouts at 500' and at 1800' twice during Phase 2. But, there was only one replicated per subject for the other combinations of approach mode and breakout group.

4. DATA VALIDATION

Before the extracted performance variables were used, the data for each trial were manually reviewed. If a false time to event was declared by the data-extraction software, then the correct time to event was manually calculated. The simulation errors and corrections described below were ones that affected a number of trials.

4.1 TIMING PROBLEMS

The digital data had two types of timing errors which had to be corrected. The first was due to a problem with the data recording software and resulted in the time stamp increasing slower than real time. The second was due to the procedure used by the control-room tester in pressing the event marker and resulted in the ATC event mark being recorded at the wrong time.

4.1.1 Incorrect Time Stamp Increments

Comparison of timing data made from videotapes and those made from the digital data revealed a timing error in the first six days of Phase 1 testing: the time-to-event values extracted from the computer data were approximately 10 percent shorter than those from the videotapes. The source of the error was identified as the priority level set within the real-time simulator software for the routine that increments the time stamps. The problem was resolved by increasing the task priority, and it did not manifest during the subsequent data collection sessions.

For each of these sessions in which the error occurred, a correction factor was computed by comparing the ground speed calculated using the position and time information to the recorded ground speed for each record, then averaging the differences over the entire track. Factors for several tracks were averaged to get a single correction factor for each day. The time field for each data record was corrected by dividing the offset from the initial time value by the correction factor, then adding the corrected offset to the initial value.

4.1.2 ATC Event Mark Bias

Because of logistical problems created by the location of the event marker button, the tester reading the controller script pressed the event mark button at some time other than the start of the breakout instruction; usually several seconds before the start of the message. This action resulted in an inaccurate event mark time. The magnitude of the error varied between trials. Comparison of timings made from videotapes to those made from the computer data confirmed that the problem existed in all of the data.

A bias correction was calculated for each trial from the differences between time-to-event values extracted from the videotapes and computer data. Five comparable digital and video times-to-event were used: time to start of roll; time to change in autopilot status; time to change in TO/GA status; time to change in flap position; and, time to change in gear position. In order to calculate the correction, it was assumed that a change in the primary flight display (PFD) roll indicator occurred at the same time as an equivalent change in the recorded roll information. Assuming this to be true, the differences between the digital and video values for the other four timings included an offset. Display of "TO/GA" in the PFD mode annunciators occurred after the change in the TO/GA status bit. Change in the PFD AFDS status occurred at the same time as change in the autopilot status bit. Movement of the flap lever by the pilot occurred before the flaps started changing position. Movement of the gear lever by the pilot occurred before the gears started retracting. The mean offsets between the digital and video events were calculated for each phase. The ATC event mark bias correction was then calculated for each trial as follows:

Bias Correction = [(dt_roll - t_roll) + (dt_autopilot - t_autopilot + 0.0) + (dt_toga - t_toga + 0.4) + (dt_flaps - t_flaps -0.9) + (dt_gear - t_gear -1.9)] / 5

The event mark bias computed for each track was used to "move" the event mark temporarily during processing. Rather than adjust the time-to-event values by the bias, the "true" marker record was changed to the record whose time stamp was nearest to the original marker record time stamp plus the bias as follows:

Corrected Event Mark Time = Recorded Event Mark Time + Bias Correction

To validate the procedure, a set of test scenarios was recorded after Phase 3 using the same experimental setup with a minor enhancement: the output of a video camera showing the ATC marker button was videotaped in place of the Navigation Display quadrant. This allowed timing the actual delay between when the tester pressed the button and started to speak, which could be compared to the delay calculated by the procedure. The results of the test showed the procedure was valid, and it was applied to all the tracks.

4.2 TRIAL CONFIGURATION ERRORS

The identification strings for some trials had to be changed because the recorded information was incorrect or because the scenario number did not match the executed scenario. For example, the tester might have read the script from one scenario; but the autopilot setting, pilot flying, and wind settings were configured for another scenario. These mixed scenarios were used if the breakout location and direction were similar to the script for the assumed scenario. If there was no scenario description corresponding to the initial configuration and breakout location, the data for that trial were not used in the analyses.

The wind settings for some of the tracks were set incorrectly. There were three kinds of problems: varying wind settings instead of the intended constant wind, wind settings that changed abruptly during a track, and zero wind setting (i.e., calm conditions). Tracks with an abrupt setting change were due to the correct setting being entered by the control-room tester after the trial had started. Since there were only two wind settings used in the study, it was readily apparent when this happened. The varying winds were primarily found in Phase 3 tracks, and occurred because the simulator was configured with a variable wind profile, with different winds at different altitudes, rather than the constant profile used in the earlier phases. The trajectory data for the trials with incorrect wind settings were reviewed, and a given trial was retained if the incorrect or varying wind setting was judged to have no noticeable effect on the data. If the problem potentially affected aircraft behavior during the breakout, such as when a crosswind condition was entered shortly before the breakout, then the data for that trial were not used in the analyses.

5. RESULTS

5.1 PILOT PARTICIPATION

The original plan was to have ten crews participate in each phase of the study. Ten crews did participate in Phase 1. However, Phase 2 was discontinued after seven crews by consensus among the test coordinators because there was no apparent improvement in breakout performance. Finally, only nine crews participated in Phase 3 because of difficulty in scheduling crews during the available time period.

The participating pilots were from Northwest Airlines and United Airlines. One crew in Phase 3 was mixed: the captain and first officer were not from the same airlines. The remaining 25 crews were matched; the captain and first officer were from the same airline. A total of 30 pilots participated; 16 participated in more than one phase. Seven out of 14 pilots in Phase 2 had participated in Phase 1. Fifteen out of 18 pilots in Phase 3 had participated in a previous phase of the study. Pilot participation by phase is listed in Table 5-1.

Table 5-1. Subject Participation by Phase of Study

Study	Subject Number														
Phase	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2		x	x	x	x				x		x				x
3	x	x	x	x	x	x			x		x	x			
Study	Subject Number														
Phase	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	x	x	x	x	x										
2						x	x	x	x	x	x	x			
3		x	x			x	x	x	x				x	x	x

5.2 LENGTH OF CONTROLLER BREAKOUT INSTRUCTIONS

The duration of the controller breakout instruction for each trial was measured to determine when the crews started the breakout maneuvers: before or after the controller transmission finished. Table 5-2 lists the group statistics for the controller transmissions for each phase of the study. The breakout instructions during Phases 2 and 3 included additional words (<Aircraft> heavy, traffic alert). With the additional words, the controllers had difficulty completing the entire instruction at once, and often had to take a breath before completing the instruction.

Table 5-2. Duration of ATC Breakout Instruction (seconds)

Phase	Count	Median	Mean	S.D.	Minimum	Maximum
1	156	4.9	4.9	0.6	3.6	7.2
2	112	6.8	6.9	0.7	4.4	8.5
3	158	6.7	6.7	0.5	5.7	8.3

5.3 PRACTICE EFFECTS

The experimental designs for Phases 2 and 3 included replicate trials for each subject at 500 feet and 1800 feet AGL in order to test for possible practice effects. In contrast, there was no design to test for practice effects in Phase 1. But, the assignments of pilot flying for each trial in Phase 1 resulted in a sufficient number of paired samples to also test for practice effects.

Assessing practice effects in Phases 2 and 3 was confounded because the majority of pilots participated in more than one phase of the study. The experienced pilots may have retained strategies developed during the previous phase. In order to compensate for the possible carry-over effect, practice effect was assessed several ways. First, the paired samples for each phase were tested separately. Second, the subjects in each phase were classified as either being new to the study (no experience), or as having participated previously (experience). Third, the data were qualitatively evaluated for possible trends during each session.

Practice effects were tested using paired-sample t-tests. The null hypothesis was that the differences between replicate trials, or samples, were random and that the difference between sample means was zero. Significance at the 0.05 level was tested for six of the performance variables listed in Table 3-1: dt_engine, dt_throttle, dt_pitch, dt_vertical_speed, dt_roll, and maximum_roll.

5.3.1 Paired T-tests by Phase of Study

For Phase 1, the paired samples were grouped several ways, then each group was tested separately. Thus, each paired sample was tested multiple ways for possible learning effects. First, the paired data were grouped by approach mode: either the replicates were both manual approaches (HF) or they were both autopilot-coupled approaches (AP). This tested whether or not practice effects were more obvious for one mode than the other. Second, the paired data were grouped by altitude: decision altitude (DA), or 1800 feet AGL (1800'). This tested whether or not practice affected response times at one altitude but not another. Third, the first and last trial for each crew were manual approaches with breakouts at 500 feet AGL (500'). Paired samples for these trials were tested in order to determine if response times changed significantly from the beginning to the end of each session. Finally, all paired samples were tested as a single group in order to test for possible overall practice effects.

For each of the six sample groups mentioned above, one t-test was performed for each of the six performance variables. Out of 36 paired-sample t-tests, five indicated a significant difference between the first and second replicate: four indicated a decrease in speed and climb response times; and one indicated an increase in turn response time. The other 31 t-tests indicated no statistical differences at the .05 level between the first and second replicates. Table 5-3 summarizes the results.

Table 5-3. Phase 1 Paired-Sample T-Tests for Practice Effects

Sample Group	Variables with significant differences
All paired samples	dt_vertical_speed ($t = 2.60$, d.f. = 32, $p = .01$, $Mean_1 = 6.8s$, $Mean_2 = 6.2s$)
HF approaches	None
AP approaches	dt_engine ($t = 2.37$, d.f. = 16, $p = .03$, $Mean_1 = 6.7s$, $Mean_2 = 5.9s$) dt_pitch ($t = 2.43$, d.f. = 16, $p = .03$, $Mean_1 = 7.1s$, $Mean_2 = 6.2s$) dt_vertical_speed ($t = 2.48$, d.f. = 16, $p = .03$, $Mean_1 = 7.3s$, $Mean_2 = 6.5s$)
Breakouts at DA	None
Breakouts at 1800'	None
First, last trials	dt_roll ($t = -5.42$, d.f. = 3, $p = .01$, $Mean_1 = 5.6s$, $Mean_2 = 7.0s$)

The data for Phase 2 were grouped based on the within-subject replicates from the experimental design. All samples were for autopilot-coupled approaches, so approach mode was not a factor. The data were grouped according to altitude: 500 feet AGL (500') and 1800 feet AGL (1800'). This tested if practice effects were more pronounced at one breakout altitude. Another sample group included the first and last trial only. This tested whether or not there was a significant change in response times over the course of the session. Finally, all paired samples were grouped together in order to test for possible overall practice effects. Out of 24 paired-sample t-tests, two indicated a reduction in engine response times for breakouts at 1800 feet AGL level. The other 22 t-tests indicated no statistical differences at the .05 level between the first and second replicates. The results are summarized in Table 5-4.

Table 5-4. Phase 2 Paired-Sample T-Tests for Practice Effects

Sample Group	Variables with significant differences
All paired samples	None
Breakouts at 500'	None
Breakouts at 1800'	dt_engine ($t=2.47$, d.f.=9, $p=.04$, $Mean_1=9.8s$, $Mean_2 = 7.7s$) dt_throttle ($t=2.72$, d.f.=9, $p=.02$, $Mean_1=9.1s$, $Mean_2 = 6.9s$)
First, last trials	None

The data for Phase 3 were grouped based on the within-subject replicates from the experimental design. All samples were for autopilot-coupled approaches, so approach mode was not a factor. However, the data could be grouped by breakout mode: autopilot-coupled (AP), or manual (HF). The data were also grouped according to altitude: 500 feet AGL (500') and 1800 feet AGL (1800'). Next, the samples were grouped by whether they occurred in the first or second half of each session. Finally, all paired samples were grouped together. In total, there were seven sample groups and six performance variables. Out of 42 paired-sample t-tests, two indicated a reduction in time to increasing pitch angle. The other 40 t-tests indicated no statistical differences at the .05 level between the first and second replicates. The results are summarized in Table 5-5.

Table 5-5. Phase 3 Paired-Sample T-Tests for Practice Effects

Sample Group	Variables with significant differences
All paired samples	None
AP Breakouts	None
HF Breakouts	None
First Half-Session	None
Second Half-Session	dt_pitch ($t = 2.16$, d.f. = 14, $p = .05$, $Mean_1 = 9.6s$, $Mean_2 = 7.2s$)
Breakouts at 500'	None
Breakouts at 1800'	dt_pitch ($t = 2.14$, d.f. = 16, $p = .05$, $Mean_1 = 10.7s$, $Mean_2 = 8.5s$)

5.3.2 Paired-Sample T-Tests by Experience

In order to combine experience levels across all three phases of the study, only autopilot-coupled approaches at 500 feet AGL (500') and 1800 feet AGL (1800') were considered for testing practice effects by experience level. All 20 subjects in Phase 1 had no previous experience in this study. Seven out of 14 subjects in Phase 2 and three out of 18 subjects in Phase 3 also had no previous participation in this study. Paired-sample t-tests were run for the six performance variables for the four combinations of altitude and experience. Out of 24 t-tests, significant differences were indicated for climb performance (dt_pitch and dt_vertical_speed) given pilots with previous experience and 1800-foot altitude, and for engine performance (dt_throttle and dt_engine) given pilots with no previous experience and 1800-foot altitude. The other 20 t-tests indicated no statistical differences at the .05 level between the first and second replicates. The results are summarized in Table 5-6.

Table 5-6. Practice Effect Paired-Sample T-Tests by Experience Level

Sample Group	Variables with significant differences
500', no experience	None
500', experience	None
1800', no experience	dt_engine ($t = 2.25$, d.f. =14, $p = .04$, $Mean_1 = 8.9s$, $Mean_2 = 7.3s$) dt_throttle ($t = 2.24$, d.f. = 14, $p = .04$, $Mean_1 = 8.1s$, $Mean_2 = 6.6s$)
1800', experience	dt_pitch ($t = 2.33$, d.f. = 19, $p = .03$, $Mean_1 = 10.1s$, $Mean_2 = 8.5s$) dt_vertical_speed ($t = 2.35$, d.f. = 19, $p = .03$, $Mean_1 = 10.7s$, $Mean_2 = 9.1s$)

5.3.3 Qualitative Assessment of Practice Effects

In order to search for possible practice effects not identified by the paired-sample t-tests, the performance variables for each scenario were grouped by crew within each phase, then ordered by scenario sequence. The results for each crew were separated out by approach mode for

Phases 1 and 2 and by breakout mode for Phase 3. The ordered variables were then reviewed for any increasing or decreasing trends that might not have been detected by the t-tests. The ordered performance variables for Phases 1, 2, and 3 are graphically depicted in Appendix G.

No trends were identified for Phase 1. If a straight line were fitted to the data for each performance variable, then there would be no significant increase or decrease in the performance variables from the beginning to the end of each session. Similarly, no linear trends were identified for the Phase 2 performance variables. There were no apparent increases or decreases in the performance variables with increasing scenario number. There were fluctuations over the course of each session, but these were attributed mainly to differences in performance for the two approach modes and to between-subject variation.

The response times for Phase 3 also appeared to be fairly constant with increasing scenario number. The only exception in Phase 3 was the first breakout in the second half for those crews which received the autopilot (AP) breakout procedure training in the second half-session. These crews followed the manual (HF) breakout procedure during the first half-session, took a break, then were trained for the autopilot breakout procedure. For these crews, the first trial in the second half-session had larger values for dt_pitch and dt_vertical_speed than the remaining trials. This trend is illustrated in Figure 5-1, which depicts the ordered response times for vertical speed increase. The lines in the figure connect the data for each crew. For the first autopilot-coupled breakout after the break, the time to increasing vertical speed was longer than for the remaining autopilot-coupled breakouts. This trend was not observed for autopilot-coupled breakouts in the first half-session or for manual breakouts in either half-session. As shown in Figure 5-1, there was a difference in distributions between the first and second manual breakout after the break, but this was likely due to between-subject variability rather than to a scenario-order effect.

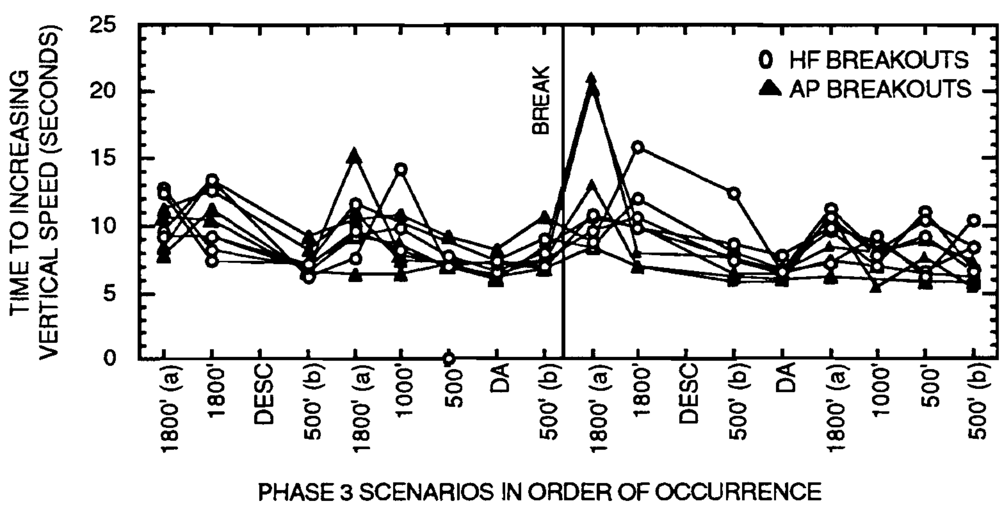


Figure 5-1. Sequence-ordered vertical speed data from Phase 3. The crews that conducted manual breakouts during the first half conducted autopilot-coupled breakouts during the second half. The scenarios followed by a letter (a or b) identify the within-subject replicates.

5.3.4 Summary

The tests results are inconclusive as to whether or not there were practice effects during the three phases of the study. There may have been improvement in speed and climb performance, but there was no consistency in the t-test results. If there were improvement during each session, the average decrease in response time for speed and climb variables was one to two seconds over the course of 16 to 18 breakout scenarios. This would average out to approximately a 0.1-second improvement for each breakout. This is less than the sample variability, thus not measurable.

Notes taken during the review of the video tapes suggest that the crews gained confidence with the breakout maneuver during each session. Crew coordination visibly improved over time for some crews. Between trials, several crews were recorded discussing the procedure and crew coordination. However, the t-test results indicate that although the crews were more comfortable with executing a breakout at the end of the session, the learning experience did not significantly change the observed breakout performance, especially turn performance.

5.4 EXPLORATORY ANALYSIS

A breakout maneuver is a complex event that involves coordination of several actions between crew members. These actions result in changes in aircraft speed, pitch, and roll which then translate into altitude and heading changes. There is more than one way in which to effect each change, depending on aircraft configuration, height above ground, and pilot preference or training. For example, if the approach is flown with the autopilot connected, then the pilot currently has the choice of executing the breakout using the autopilot or of disconnecting the autopilot and manually executing the breakout. Another choice is the use of the TO/GA button in order to increase vertical speed.

In order to capture the complexity of the breakout event, many simulator variables were recorded and processed. The performance variables that were then calculated and used in this study are summarized in Table 3-1. Based on the exploratory analysis, some performance variables were found to be redundant. For example, time from the start of the ATC breakout instruction to the start of the roll (dt_roll) and to the start of a heading change (dt_heading) both measured turn performance. But, there was a relationship between the two variables that could be exploited in order to simplify the detailed data analysis.

This section summarizes the exploratory analysis and the relationships that were identified. The variables associated with speed, climb, and turn performance were analyzed for dependent relationships. Pilot actions such as pressing the TO/GA buttons or disconnecting the autopilot were also explored to determine their possible effects on the variable distributions.

5.4.1 Speed and Climb Performance Variables

Five performance variables were associated with speed and climb performance: time to throttle lever movement (dt_throttle); time to increasing engine pressure ratio (dt_engine); time to increasing pitch (dt_pitch); time to increasing vertical speed (dt_vertical_speed); and, time to pressing a TO/GA button (dt_toga). Summary statistics for these variables are listed by phase of study in Appendix H.

One relationship that was explored was the possible correlation between dt_engine and dt_throttle. Figure 5-2 (a) illustrated the close linear relationship between the two variables. Dt_engine was always larger than dt_throttle, indicating that throttle movement was associated with increased engine thrust. The time difference between the two events (dt_engine - dt_throttle) had a mean value of 0.8 seconds. Almost all time differences were less than 1.2 seconds. Of the 13 time differences that were greater than 1.2 seconds, most were for hand-flown breakouts at 1800 feet AGL. In ten cases, either the TO/GA button was not pressed or it was pressed after the throttle position had changed.

Another relationship that was explored was the possible correlation between dt_pitch and dt_vertical_speed. The data in Figure 5-2 (b) suggest a close relationship between the two events, but there was greater variability than was observed between dt_engine and dt_throttle. In general, dt_vertical_speed was larger than dt_pitch. The time differences between the two events (dt_vertical_speed - dt_pitch) had a mean value of 0.6 second, and 90 percent of the differences were between 0.0 and 1.5 seconds. All but two of the outlier differences were for hand-flown breakouts. Most occurred in Phase 1 or Phase 2, and there was even distribution among breakout groups. For most of the cases with a time difference greater than 1.5 seconds, pitch increased before the TO/GA button was pressed or, if TO/GA thrust was not engaged, pitch increased before the throttle moved.

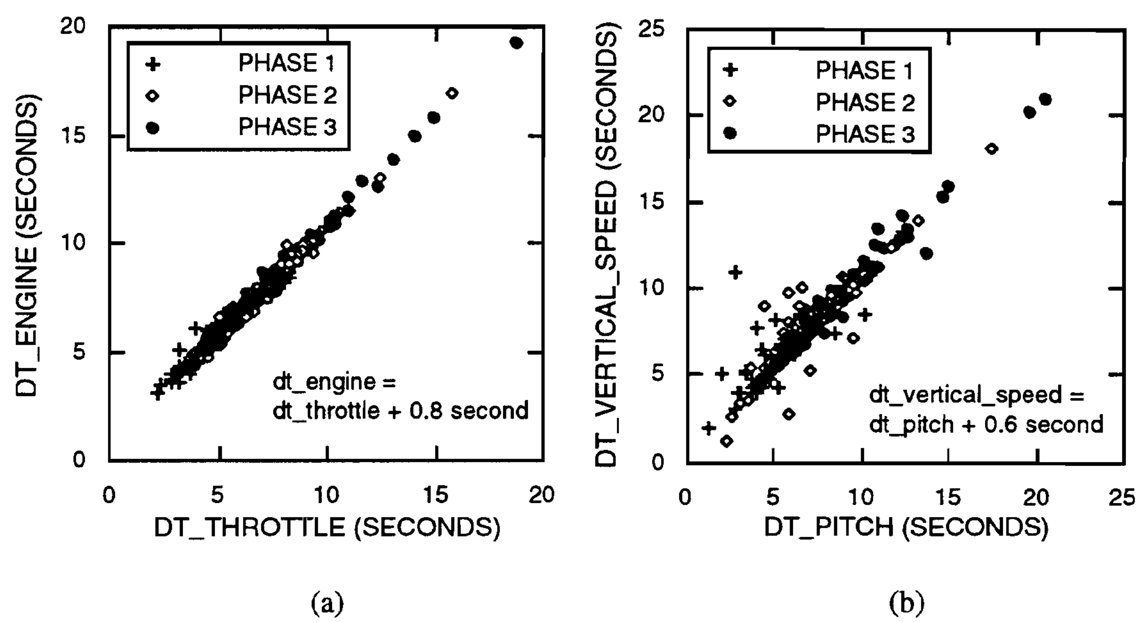


Figure 5-2. Relationships between speed and climb performance variables. (a) dt_engine and dt_throttle. (b) dt_vertical_speed and dt_pitch.

The next relationship that was explored was between speed and climb events, using dt_throttle and dt_pitch as representative variables. Figure 5-3 illustrates the loose relationship between the two variables: although dt_pitch increased as dt_throttle increased, the change in pitch angle occurred equally before or after the change in throttle position. The mean for the difference between the two (dt_pitch - dt_throttle) was 0.5 second, with a range of differences between -5.7

and 13.6 seconds. This suggests little or no correlation between the two events. The effect of TO/GA use on the relationship was also explored. The distribution of time differences was not affected by the use of TO/GA thrust for manual approaches: dt_pitch was independent of dt_throttle whether or not the TO/GA button was pressed. For autopilot-coupled approaches, dt_throttle was independent of dt_pitch when the TO/GA button was not pushed. But, dt_pitch most frequently occurred 0.6 to 1.2 seconds after dt_throttle when the TO/GA button was pushed during autopilot-coupled approaches. In Phases 1 and 2, when use of TO/GA was at the discretion of the pilot flying, the TO/GA button was pressed in 80 percent of the breakouts.

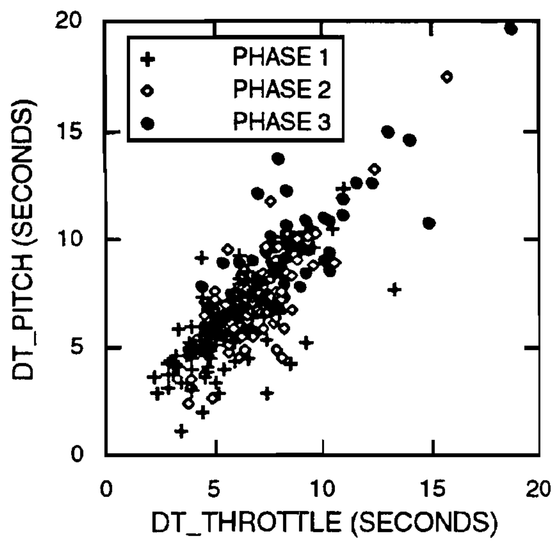


Figure 5-3. Relationship between speed and climb performance.

5.4.2 Turn Performance

Six performance variables were associated with turn performance: time to start of roll (dt_roll); time to start of heading change (dt_heading); time to entering the new heading into the flight management computer (t_heading_select); maximum roll angle (maximum_roll); ground distance traveled to start of roll (dx_roll); and time to disengage the autopilot (dt_autopilot). Summary statistics for these variables are listed in Appendix H. The distance traveled until the start of roll is not explored in this section because it is approximately equal to dt_roll multiplied by aircraft speed.

The first relationship that was explored was between start of roll and start of heading change. As illustrated in Figure 5-4 (a), there was a correlation between the two. In all but 11 cases, dt_heading was longer than dt_roll. When the outliers were excluded, the mean difference between the two (dt_heading - dt_roll) was 3.3 seconds, with a range in values of 1.5 to 5.1 seconds. Those cases in which the difference between the two variables was less than 1.0 second exhibited the following trends: 7 out of 11 were associated with one pilot who participated in all three phases of the study; 7 cases were autopilot-coupled approaches; and 10 cases were hand-flown breakouts. Review of the performance data indicated the following causes: either fast acceleration into the roll (difference values near 0.0 second) or TO/GA thrust was applied while the autopilot was engaged and the aircraft rolled back towards center after the turn had started (difference values less than 0.0 second). Those cases for which dt_heading was more than 5.1 seconds longer than dt_roll exhibited the following trends: 9 out of 15 occurred during Phase 1 of the study; 12 were hand-flown breakouts; and 12 occurred at 1800 feet AGL. Review of the data indicated slow roll accelerations which resulted in longer-than-normal delays to heading change.

The other relationship that was explored was between manual heading input into the computer and start of roll. As illustrated in Figure 5-4 (b), time to start of roll was independent of time to heading-select input for hand-flown breakouts; the pilots flying did not need the flight director in order to execute the turn. However, there was a correlation for autopilot-coupled breakouts: dt_roll always occurred after t_heading_select, and the mean time difference (dt_roll - t_heading_select) was 3.3 seconds.

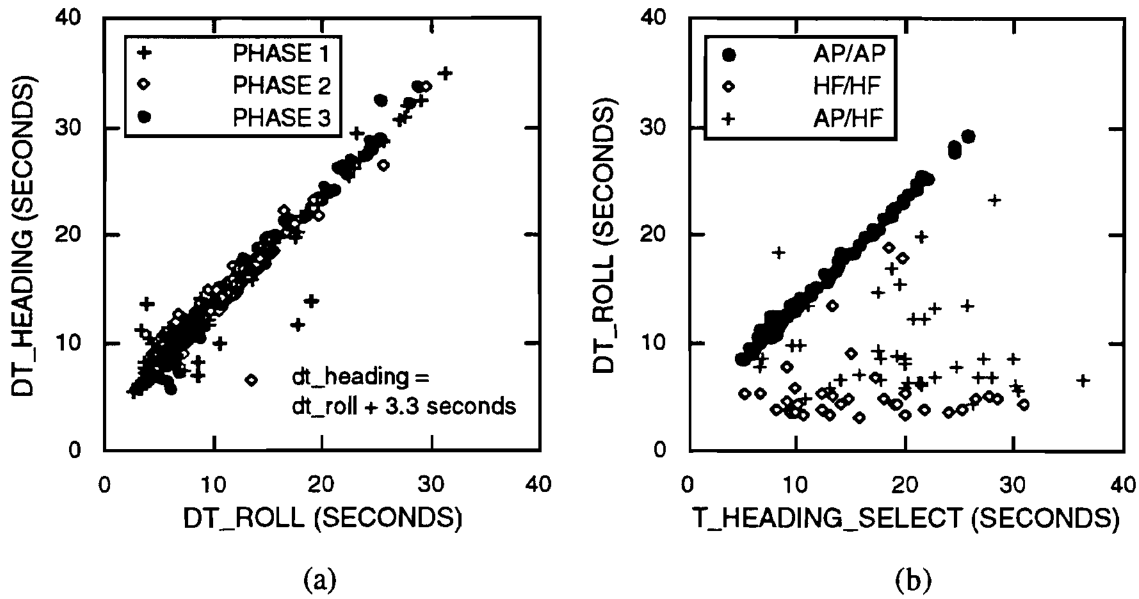


Figure 5-4. Relationships between turn performance variables. (a) dt_heading and dt_roll. (b) dt_roll and t_heading_select.

Use of the autopilot was at the subjects' discretion during Phases 1 and 2. Of the 26 pilots who participated in these phases, 15 disconnected the autopilot more than 80 percent of the time. In contrast, four pilots used the autopilot during the breakout more than 80 percent of the time. There was no pattern with the other 7 subjects for when they disconnected the autopilot; frequency of disconnect for these 7 subjects did not change with time into the session.

Use of the autopilot during the breakout did affect turn performance. For Phases 1 and 2, the longest mean time to start of roll was for autopilot-coupled approaches and the shortest mean time to start of roll was for manual breakouts following manual approaches. Since turn response time was affected by the autopilot breakout mode, the detailed analyses for Phases 1 and 2 were modified to include this effect.

There was also an observed relationship between use of the autopilot during the breakout and maximum roll angle. When the autopilot remained on during the turn, the maximum roll angle was consistently around 27 degrees. When the turn was manually executed, there was greater variability in the maximum roll angle and some values exceeded 30 degrees. These trials were individually reviewed to determine if there were common traits.

In Phase 1, 13 out of 114 manual breakouts (11 percent) had a maximum roll angle greater than 30 degrees: 9 of these were less than 33 degrees. All except one of these cases occurred after the crew had experienced several breakouts: eleven occurred during the second half of the session. Ten followed an autopilot-coupled approach, and six were for breakouts at decision altitude. There was an even distribution among the other breakout groups (500 feet AGL, 1800 feet AGL, and descending).

In Phase 2, four out of 85 manual breakouts (5 percent) had a maximum roll angle value between 30 and 33 degrees. All four breakouts followed an autopilot-coupled approach. Three were for subjects who had not participated in Phase 1, and the trial was their first or second breakout as pilot flying. Three breakouts had a time to start of roll value between 14 and 20 seconds.

In Phase 3, five out of 82 manual breakouts (6 percent) had a maximum roll angle value between 30 and 34 degrees. There was no trend with respect to altitude of the breakout. However, three of the cases were for the same subject.

5.3.3 Start of Maneuver Relative to ATC Transmission Length

The previous analyses were based on the time from start of ATC breakout transmission to start of each event. There was additional interest in exploring the start of pilot response relative to the duration of the breakout instruction, and whether or not the pilots waited until after receiving the entire instruction before initiating the breakout maneuver. This section explores the start of pilot inputs relative to receiving the complete instruction for climbing breakouts.

Three performance variables were selected as the earliest recorded pilot breakout actions: time to throttle change (dt_throttle), time to pitch increase (dt_pitch), and time to start of roll (dt_roll). The time delays from the start of the ATC instruction to each of these events were compared to the length of the controller transmission for each trial. A negative value indicated that the subject initiated that event before the controller finished speaking. A positive value indicated that the subject initiated the event after the end of the transmission.

As illustrated in Figure 5-5, the time distributions for each event were similar for all three phases. In general, pitch increase occurred before the end of the ATC transmission during 39 percent of the climbing breakouts. Throttle position changed before the end of the ATC transmission in 51 percent of the climbing breakouts, and the roll was initiated before the end of the transmission in 32 percent of the cases. The trials in which pilot input occurred more than 2 seconds before the end of transmission were associated with long transmissions. As listed in Table 5-2, maximum length of ATC transmission was 7.2 to 8.5 seconds, depending on the phase.

There was a significant difference in percentages between breakouts below 1000 feet AGL (decision altitude, 500 feet, and 700 feet) and breakouts at or above 1000 feet AGL (1000 feet and 1800 feet) for throttle and pitch, but not for roll. Pitch and throttle changed before the end of the transmission in more than 50 percent of the trials below 1000 feet AGL, but in less than 30 percent of the trials at 1000 feet or 1800 feet AGL. These results are summarized in Table 5-7.

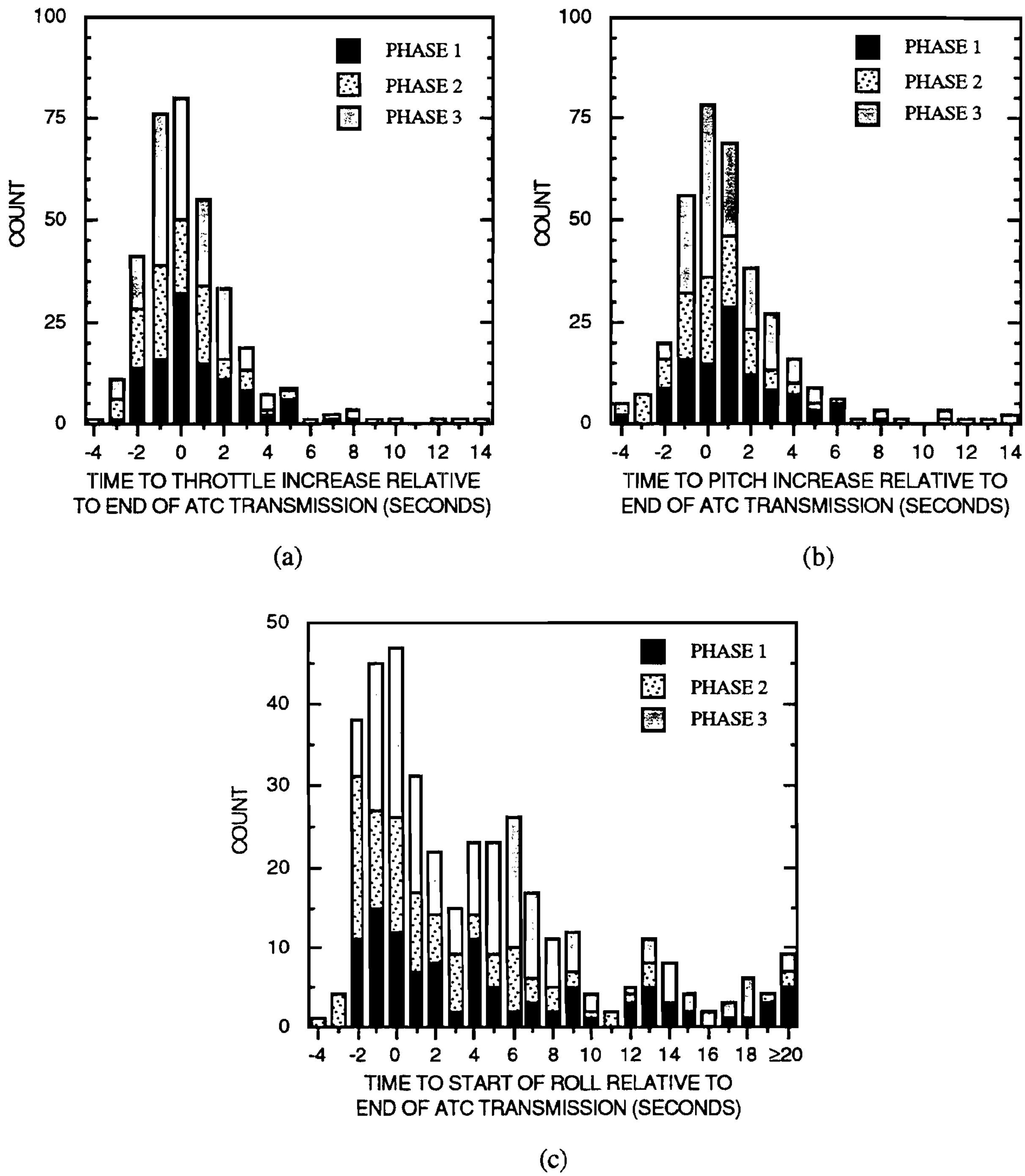


Figure 5-5. Start of maneuver relative to length of ATC transmission. (a) Speed. (b) Climb. (c) Turn. A negative number indicates the event occurred before the end of the transmission.

Table 5-7. Percent of Maneuvers Initiated Before End of ATC Breakout Instruction

Breakout Event	Breakout Altitude		
	< 1000 feet	≥ 1000 feet	All
Throttle Change	67 %	26 %	51 %
Pitch Increase	51 %	22 %	39 %
Start of Roll	31 %	33 %	32 %

5.3.4 Summary

The relationships among related performance variables could be exploited in order to minimize the number of variables used in the detailed analyses. For example, there was a high correlation between time to throttle change and time to increasing engine pressure ratio. Thus, analysis of variance results would be comparable for the two. Similarly, there was a high correlation between time to pitch increase and time to vertical speed increase; and among time to start of roll, time to start of heading change, and distance traveled to start of roll. Based on the correlations, three of these seven variables were selected for further analysis: time to engine pressure ratio increase (dt_engine), time to vertical speed increase (dt_vertical_speed), and time to start of roll (dt_roll).

There was no comparable variable for maximum roll angle, so it was also selected for further analysis. Time to flap and gear changes were not analyzed because these events usually occurred after the other events and were associated with changing aircraft configuration from approach to cruise configuration ("clean up"), therefore not critical to initial breakout performance. Summary statistics are listed in Appendix H for all ten performance variables.

The use of TO/GA did not affect time to throttle or pitch change, so it was not considered in the detailed analyses. But, whether or not the subject executed the breakout turn with the autopilot connected did affect turn performance, so breakout mode as well as approach mode was considered for the Phase 1 and 2 analyses.

Ancillary analysis explored the frequency of "excessive" roll angle; i.e., maximum roll angles greater than 30 degrees in magnitude. These cases were mostly associated with manual breakouts following autopilot-couple approaches. It appeared as though some subjects were concerned by the slow aircraft turn response and may have over-reacted in an attempt to expedite the turn. Although some maximum roll angles were larger than 30 degrees, the durations were not measured. There were no results indicating how soon the subjects returned the aircraft to a typical roll angle.

The start of breakout response relative to the length of the ATC breakout instruction was also explored. At low altitudes, throttle input occurred before the end of the transmission in 67 percent of the trials, and pitch input occurred before the end of the transmission in 51 percent of the trials. At altitudes of 1000 feet or more, throttle and pitch input did not appear to be as critical, and occurred before the end of the transmission in 22 to 26 percent of the trials. Roll input was not affected by altitude, and occurred after the end of the transmission in 68 percent of the trials.

5.5 DETAILED ANALYSES

5.5.1 Phase 1

Phase 1 was treated as a between-subject design for each pair of analysis of variance (ANOVA) factors: approach mode with altitude; and approach mode with direction. Exploratory analysis indicated that dt_roll and dt_engine did not satisfy the assumption of homogeneity of variances and required transformation. The best transformations were the inverses: 1/dt_roll and 1/dt_engine. The other two test variables did not need transformation.

5.5.1.1 Approach Mode with Altitude

The analysis of variance using approach mode and altitude as the independent variables yielded significant main effects for both independent variables, but no significant interaction between the two. Specifically, approach mode affected climb and turn performance but not engine performance while altitude affected engine and climb performance, but not turn performance. The results listed in Table 5-8 indicate that mean time to increasing vertical speed (dt_vertical_speed) and mean time to start of roll (dt_roll) were significantly smaller for hand-flown approaches than for autopilot-coupled approaches. In addition, the mean value for maximum roll angle was significantly smaller for hand-flown approaches than for autopilot-coupled approaches.

Table 5-8. ANOVA Results for Approach Mode

Dependent Variable	Analysis of Variance Result	Mean*	
		Hand-Flown	Autopilot
dt_vertical_speed	$F(1, 68) = 9.39, p < 0.01$	6.0 s	7.0 s
maximum_roll	$F(1, 68) = 8.62, p < 0.02$	24.3 deg	26.5 deg
dt_roll*	$F(1, 68) = 64.61, p < 0.01$	5.6 s (0.179)	13.1 s (0.076)
dt_engine*	$F(1, 68) = 2.47, p > 0.05$	6.0 s (0.167)	6.5 s (0.154)

* Mean values in parentheses () are for the transformed variable used in the analysis

The ANOVA results listed in Table 5-9 indicate that the mean value for at least one level of altitude was significantly different than the mean values for the other levels for time to increasing vertical speed (dt_vertical_speed) and time to engine increase (dt_engine). Since there were three levels for altitude, oneway analysis of variance using the Tukey's b multiple range test was used to identify altitude levels with significant differences between sample means. This test indicated that no two altitude levels had similar mean times to increasing vertical speed: the mean value for dt_vertical_speed at decision altitude (DA) was significantly less than the mean at 500 AGL; and both mean values were significantly less than the mean at 1800 feet AGL. Mean times to engine increase were similar at 500 feet and 1800 feet AGL, but the mean for breakouts at decision altitude was significantly less.

Although the mean time to start of roll (dt_roll) was larger for breakouts at decision altitude than at the other two altitudes, there was sufficient between-subject variability that the difference was not statistically significant. Response times following both hand-flown and autopilot-coupled approaches were combined to produce this mean value. Review of the data indicated that the higher mean time to start of roll at decision altitude resulted from slower autopilot-coupled responses at that altitude relative to the means at the other altitudes. The difference in mean times for autopilot-coupled approaches is evident in the statistics presented in Appendix H.

Table 5-9. ANOVA Results for Altitude

Dependent Variable	Analysis of Variance Result	Mean*		
		DA	500'	1800'
dt_vertical_speed	$F(2, 68) = 28.32, p < 0.01$	5.2 s	6.6 s	8.1 s
dt_engine*	$F(2, 68) = 16.77, p < 0.01$	5.0 s (0.200)	6.3 s (0.159)	7.6 s (0.132)
maximum_roll	$F(2,68) = 2.08, p > 0.05$	26.5 deg	25.3 deg	24.4 deg
dt_roll*	$F(2, 68) = 1.23, p > 0.05$	11.5 s (0.087)	8.8 s (0.114)	8.3 s (0.120)

* Mean values in parentheses () are for the transformed variable used in the analysis

5.5.1.2 Approach Mode with Direction

Since descending breakouts did not require a positive climb rate, speed and climb performance were not factors in descending breakout performance. Thus, speed and climb performance were not considered for this analysis. Only the two turn performance variables, 1/dt_roll and maximum_roll, were considered.

The analysis of variance using approach mode and breakout direction as the independent variables yielded a significant main effect for approach mode, which was consistent with the main effect observed in the previous analysis. As indicated by the results listed in Table 5-10, the mean values for dt_roll and maximum_roll were significantly smaller for hand-flown approaches than for autopilot-coupled approaches.

Table 5-10. ANOVA Results for Approach Mode

Dependent Variable	Analysis of Variance Result	Mean*	
		Hand-Flown	Autopilot
maximum_roll	$F(1, 31) = 7.06, p < 0.02$	22.9 deg	26.8 deg
dt_roll*	$F(1, 31) = 94.20, p < 0.01$	4.6 s (0.217)	13.7 s (0.073)

* Mean values in parentheses () are for the transformed variable used in the analysis

As indicated in Table 5-11, the analysis did not yield a main effect for breakout direction, meaning that mean times to start of roll were statistically similar for descending and climbing breakouts at 1800 feet AGL. Mean values for maximum roll angle were also statistically similar for the two breakout directions. In addition, there was no significant interaction between the independent variables.

Table 5-11. ANOVA Results for Direction

Dependent Variable	Analysis of Variance Result	Mean*	
		Climb	Descend
maximum_roll	$F(1, 31) = 0.33, p > 0.05$	24.4 deg	25.4 deg
dt_roll*	$F(1, 31) = 1.58, p > 0.05$	8.3 s (0.120)	10.0 s (0.100)

* Mean values in parentheses () are for the transformed variable used in the analysis

Although the observed turn performances for climbing and descending breakouts were similar, the descending breakouts appeared to be an unexpected possibility for some of the crews. After the first time they were requested to descend, several crews made the following comments:

- "Descends throw off your whole routine."
- "Why are we doing this?"
- "Descend and maintain 1800. I wonder what that's for."

5.5.1.3 Effect of Approach/Breakout Pairing on Turn Performance

In Phase 1, the independent variables were breakout group (altitude and direction) and approach mode. The aircraft configuration during the breakout was at the discretion of the subject acting as "pilot flying." For autopilot-coupled approaches, the autopilot was disconnected 70 percent of the time and the turn was manually flown. A separate analysis of variance was conducted to test for possible difference in turn performance among the three combinations of approach and breakout mode: hand-flown approach followed by hand-flown breakout (HF/HF), autopilot approach followed by hand-flown breakout (AP/HF), and autopilot approach continued with an autopilot-coupled breakout (AP/AP). For this analysis, all Phase 1 trials, excluding engine-out scenarios, were used without averaging within-subject replicates. This was necessary because some subjects left the autopilot on for one replicate, but disengaged it for the other replicate. These data points would have been removed from the data set with averaged results, thus reducing the sample size. As with the analyses in Sections 5.5.1.1 and 5.5.1.2, the cases were treated as random samples.

The independent factors were approach/breakout pair (HF/HF, AP/HF, AP/AP) and breakout group (DA, 500', 1800', Descend). The dependent variables were maximum_roll and 1/dt_roll. The analysis of variance yielded a significant main effect for approach/breakout pair, but not for breakout group. There was no significant interaction between the independent variables. The analysis results for approach/breakout pair main effect are summarized in Table 5-12.

Table 5-12. **ANOVA Results for Approach/Breakout Pair**

Dependent Variable	Analysis of Variance Result	Mean*		
		HF/HF	AP/HF	AP/AP
maximum_roll	$F(1, 112) = 6.16, p < 0.01$	24.1 deg	27.0 deg	25.8 deg
dt_roll*	$F(1, 112) = 56.62, p < 0.01$	5.5 s (0.182)	10.8 s (0.093)	18.2 s (0.055)

* Mean values in parentheses () are for the transformed variable used in the analysis

The Tukey's b multiple range test was used to identify approach/breakout pairs with statistically different mean values. The test indicated that mean time to start of roll was statistically different for all three pairs: the mean for HF/HF was significantly less than the mean for AP/HF; and the means for HF/HF and AP/HF were both significantly less than the mean for AP/AP. For maximum roll angle, the mean for AP/HF was significantly larger than the mean for HF/HF. However, the mean for AP/AP was not significantly different than the mean for either HF/HF or AP/HF.

5.5.1.4 Distraction Scenarios

The engine-out scenarios were intended to be a general-case distraction similar to the B727 and DC10 breakout performance studies, but the results were not as expected. Rather than causing a delay of a few seconds in the pilot response times, the loss of the right outboard engine resulted in catastrophic performance failure. As soon as engine thrust was increased, the cockpit simulator rolled to the right. The subject crews had difficulty stabilizing the aircraft and executing the breakout maneuver. Because the effect of the engine-out event was greater than anticipated, the effect of the distraction was not statistically analyzed. Instead, a qualitative assessment is presented. Summary statistics are presented in Appendix H.

For autopilot-coupled approaches, all but one crew disconnected the autopilot and flew the breakout manually. For hand-flown approaches, two crews were unable to correct the roll to the right, and these trials ended when the aircraft touched ground. In addition, a third crew declared an emergency and said they were turning to the right instead of to the left. In general, performance was better for the autopilot scenario than for the hand-flown scenario.

Although the results did not provide useful information about the effect of normal cockpit distractions on crew compliance with the breakout instruction, the data were used to estimate the maximum possible cross-track deviation given an engine failure on a B747-400.

For autopilot-coupled approaches, the subjects were able to quickly overcome the right-hand roll, resulting in minimal deviation of the aircraft towards the adjacent approach. Three crews had maximum deviations to the right of 313 feet, 402 feet, and 441 feet. The maximum heading offsets were 10, 11, and 11 degrees right of course, respectively. These results are illustrated in Figure 5-6.

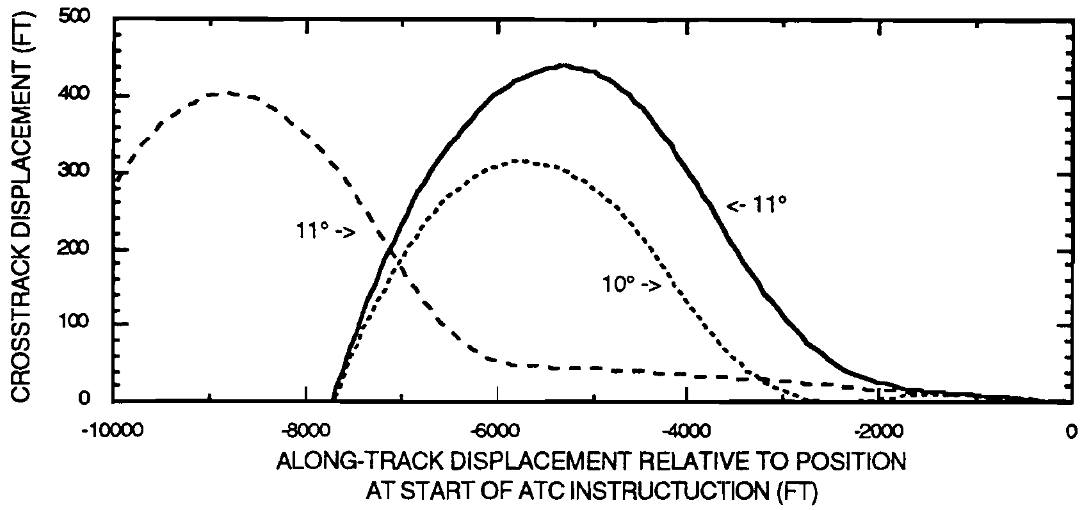


Figure 5-6. Autopilot-coupled engine-out breakouts with extreme deviations to the right. Tracks are relative to their location at the start of ATC breakout transmission. Runway threshold is to the left. Positive crosstrack displacement is towards the adjacent approach course.

For hand-flown approaches, half of the crews were able to prevent a large deviation to the right of course. Three crews had maximum deviations of 909, 1208, and 1609 feet. As depicted in Figure 5-7, maximum heading offsets from the approach course were 14, 16, and 23 degrees, respectively. A fourth crew decided to ignore the breakout instruction, and continued turning to the right. At the time data collection stopped for this trial, the aircraft had achieved a 180-degree heading change, and was 6756 feet to the right of the approach course.

5.5.1.5 Summary

As indicated by the analysis of variance results, approach mode affected breakout performance during Phase 1 of the study. Turn and climb response times were slower for autopilot-coupled approaches than for hand-flown approaches. In addition, time to start of roll was slower when the autopilot remained engaged during the breakout than when the autopilot was disconnected. Although the subjects manually initiated the turn more quickly than the autopilot coupled to the flight director, they were more conservative than the flight director in executing the turn as indicated by maximum roll angle. The mean value for maximum roll angle was smaller for hand-flown approaches than for autopilot-coupled approaches. There was an apparent contradiction, however, in maximum roll angle distributions for manual breakouts when the effect of approach/breakout pair was analyzed: mean roll angle following autopilot-coupled approaches was larger than mean roll angle following hand-flown approaches. As discussed in Section 5.3.2, this may have been a reaction by some subjects to compensate for a slow time to start of turn.

The analysis of variance also indicated that the altitude at which the breakout occurred affected speed and climb response times, but did not affect turn response. Engine and vertical speed acceleration occurred more quickly at decision altitude than at higher altitudes. In addition, acceleration into the climb occurred later at 1800 feet AGL than at 500 feet AGL.

The analysis of variance indicated that direction of the breakout did not affect turn performance. Time to start of roll and maximum roll distributions were similar for climbing and descending breakouts at 1800 feet AGL even though some subjects voiced surprise after receiving a descending breakout instruction.

Speed and climb performance were not components of descending breakouts, therefore they were not evaluated. The effect of cockpit distraction also was not evaluated because the engine-out scenario was more challenging than expected.

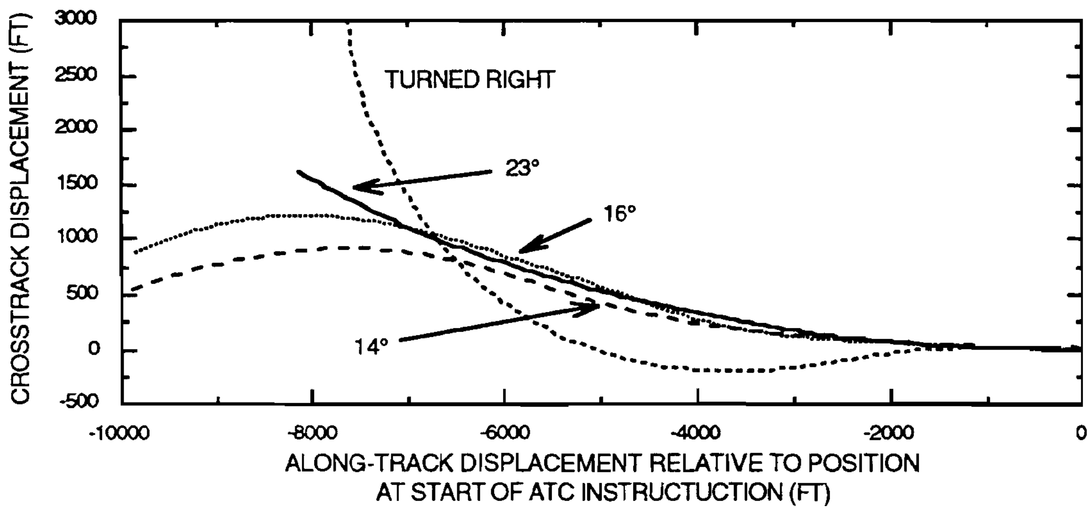


Figure 5-7. Hand-flown engine-out breakouts with extreme deviations to the right. Tracks are relative to their location at the start of ATC breakout transmission. Runway threshold is to the left. Positive crosstrack displacement is towards the adjacent approach course.

5.5.2 Phase 2

Phase 2 was designed for within-and-between analysis of variance, with approach mode as the between-subject factor and breakout group as the within-subject factor. As listed in Table 2-4, the within-subject assignments for breakout group were such that altitude (500', 700', 1800') and direction (climb, descend) were assigned to different subjects, therefore, the effects of altitude and breakout direction were analyzed separately.

Exploratory analysis indicated that dt_roll and dt_engine did not satisfy the assumption of homogeneity of variances and required transformation. The best transformations were the inverses: 1/dt_roll and 1/dt_engine. The other test variables did not need transformation.

Because some trials were rejected during the data validation process, there were incomplete within-subject data: three trials were missing for the approach mode x altitude data set, and one trial was missing for the approach mode x direction data set. These missing data were replaced by the appropriate means, and the denominator degrees of freedom were reduced by the number of missing samples. If the calculated F value was greater than the adjusted critical value, then the null hypothesis of no effect was rejected.

5.5.2.1 Approach Mode with Altitude

The analysis of variance using approach mode and altitude as independent variables yielded significant main effects for both independent variables, but no significant interaction. As listed in Table 5-13, the ANOVA yielded a main effect for approach mode with time to increasing vertical speed (dt_vertical_speed): i.e., mean time to start of climb was significantly smaller for hand-flown approaches than for autopilot approaches. The F values for the other test variables were less than the critical, and the null hypotheses were not rejected. This suggests that approach mode had no significant effect on engine or turn performance, and that the differences between the means were due to chance.

Table 5-13. ANOVA Results for Approach Mode

Dependent Variable	Analysis of Variance Result	Mean*	
		Hand-Flown	Autopilot
dt_vertical_speed	$F(1, 9) = 24.29, p < 0.05$	6.1 s	8.3 s
maximum_roll	$F(1, 9) = .69, p > 0.05$	24.2 deg	25.2 deg
dt_roll*	$F(1, 9) = 1.23, p > 0.05$	7.7 s (0.130)	9.1 s (0.110)
dt_engine*	$F(1, 9) = 1.12, p > 0.05$	7.1 s ((0.141)	7.8 s (0.128)

* Mean values in parentheses () are for the transformed variable used in the analysis

As listed in Table 5-14, the analysis of variance yielded a main effect for altitude with the transformed time to engine increase, 1/dt_engine. Because altitude was the within-subject factor, paired-sample t-tests were applied to the data instead of oneway analysis of variance. The t-tests yielded a significant difference in mean time to engine increase between 1800 feet AGL and the other two altitudes. The analysis of variance did not yield a main effect for altitude with the other dependent variables (dt_vertical_speed, 1/dt_roll, and maximum_roll), suggesting that altitude did not have a significant effect on climb or turn performance, and that the differences among these means were due to chance.

Table 5-14. ANOVA Results for Altitude

Dependent Variable	Analysis of Variance Result	Mean*		
		500'	700'	1800'
dt_engine*	$F(2, 21) = 4.58, p < 0.05$	7.2 s (0.139)	7.0 s (0.144)	8.3 s (0.120)
dt_vertical_speed	$F(2, 21) = .47, p > 0.05$	7.0 s	7.1 s	7.9 s
maximum_roll	$F(2, 21) = 1.35, p > 0.05$	24.0 deg	25.5 deg	25.0 deg
dt_roll*	$F(2, 21) = 2.39, p > 0.05$	7.7 s (0.130)	9.5 s (0.106)	8.6 s (0.116)

* Mean values in parentheses () are for the transformed variable used in the analysis

5.5.2.2 Approach Mode with Direction

Because speed and climb performance were not factors for descending breakout performance, only turn performance was tested. The analysis of variance using approach mode and direction as independent variables yielded a significant main effect for approach mode with the transformed time to start of roll, 1/dt_roll. The mean values listed in Table 5-15 indicate that start of turn occurred later following autopilot-coupled approaches than following hand-flown approaches.

Table 5-15. ANOVA Results for Approach Mode

Dependent Variable	Analysis of Variance Result	Mean*	
		Hand-Flown	Autopilot
dt_roll*	$F(1, 11) = 9.72, p < 0.05$	6.7 s (0.149)	13.6 s (0.074)
maximum_roll	$F(1,11) = 1.92, p > 0.05$	22.8 deg	25.1 deg

* Mean values in parentheses () are for the transformed variable used in the analysis

The analysis did not yield a main effect for breakout direction, meaning that mean times to start of roll and average maximum roll angle were not significantly different for descending and climbing breakouts at 1800 feet AGL. These results are summarized in Table 5-16. Although the mean time to start of roll (dt_roll) was larger for descending breakouts, the within-subject variability was great enough that the difference between means was not statistically significant. In addition, there was no significant interaction between the independent variables.

Table 5-16. ANOVA Results for Direction

Dependent Variable	Analysis of Variance Result	Mean*	
		Climb	Descend
dt_roll*	$F(1, 11) = 0.08, p > 0.05$	8.8 s (0.114)	12.0 s (0.083)
maximum_roll	$F(1,11) = 0.03, p > 0.05$	24.0 deg	24.1 deg

* Mean values in parentheses () are for the transformed variable used in the analysis

Only one crew commented about the descending breakouts. This crew consisted of two subjects who had not participated in Phase 1. After the first descending breakout, one crew member asked, "Is that a legal command?" This suggests that reading about descending breakouts in the 11-0 Information Page was not sufficient to alert all pilots to the possibility of receiving a request to descend along the final approach.

5.5.2.3 Comparison Among Approach-Breakout Modes

The analyses in Sections 5.5.2.1 and 5.5.2.2 were based on approach mode. However, the subjects had the option of disconnecting the autopilot and executing a manual breakout when the approach was autopilot-coupled. A separate analysis of variance was conducted to test for possible differences in turn performance among the three combinations of approach and breakout modes: HF/HF, AP/HF, and AP/AP. As was done for the Phase 1 analysis, all Phase 2 trials were used without averaging within-subject replicate samples. Since all valid results were used in the analysis, they could not be organized within-subject. The samples were thus collapsed with respect to subject, and each case was treated as a random sample. Maximum_roll and the transformed variable, 1/dt_roll, were the dependent variables.

The analysis of variance using approach/breakout pair and breakout group as independent variables yielded a significant main effect for approach/breakout pair with the transformed time to start of roll, 1/dt_roll. The analysis of variance did not yield a main effect for breakout group. Oneway analysis of variance indicated that the mean values for each approach/breakout pair were significantly different from one another. Mean time to start of roll was largest for autopilot-coupled breakouts following autopilot-coupled approaches (AP/AP), and smallest for manual breakouts following manual approaches (HF/HF). The results for approach/breakout pair main effect are listed in Table 5-17.

Table 5-17. ANOVA Results for Approach/Breakout Pair

Dependent Variable	Analysis of Variance Result	Mean*		
		HF/HF	AP/HF	AP/AP
dt_roll*	$F(2, 95) = 14.96, p < 0.05$	7.1 s (0.141)	9.2 s (0.109)	13.9 s (0.072)
maximum_roll	$F(2, 95) = 2.18, p > 0.05$	24.0 deg	24.8 deg	25.6 deg

* Mean values in parentheses () are for the transformed variable used in the analysis

5.5.2.4 Summary

As indicated by the analysis of variance results, approach mode and altitude had less effect on breakout performance than was observed for Phase 1. Engine performance was affected by altitude only: mean time to engine increase was significantly larger at 1800 feet AGL than at 500 to 700 feet AGL. Climb performance was affected only by approach mode: mean time to increasing vertical speed was smaller for hand-flown approaches than for autopilot-coupled approaches.

The effect of approach mode on turn performance was inconclusive. When only climbing breakouts at 500 to 1800 feet AGL were considered, there was not a significant difference in mean time to start of roll between hand-flown and autopilot-coupled approaches. But, when climbing and descending breakouts at 1800 feet AGL were considered, mean time to start of turn was larger for autopilot-coupled approaches. Approach mode did not affect maximum roll angle.

As was found in Phase 1, disconnecting the autopilot before the start of turn did affect turn performance. Mean time to start of roll following an autopilot-coupled approach was significantly less when the subject disconnected the autopilot than when the breakout was flown autopilot-coupled. Mean time to start of roll was significantly less following manual approaches than following autopilot approaches.

As was found in Phase 1, breakout direction did not have a significant effect on turn performance in Phase 2. Although mean time to start of turn was larger for descending breakouts than for climbing breakouts at 1800 feet AGL, the difference was due to random variability.

5.5.3 Phase 3

Phase 3 was designed as a within-subject x within-subject test, with both breakout mode (HF, AP) and breakout group as within-subject factors. The assignment of trials to each subject was such that breakout group was treated as two separate factors: altitude (DA, 500', 1000', 1800') and direction (climb, descend). All approaches were flown with the autopilot engaged, so approach mode was not a factor.

Exploratory analysis indicated that two dependent variables required transformation in order to satisfy the assumptions required for repeated-measure analysis of variance: dt_roll and dt_vertical_speed. The best transformation for each variable was the inverse: 1/dt_roll and 1/dt_vertical_speed. Time to engine increase, dt_engine, did not require transformation. Maximum roll angle was not tested because the variability for autopilot-coupled breakouts was much less than for manual breakouts.

Because some trials were rejected during the data validation process, there were four missing values out of 36 for the altitude factor and five missing values out of 18 for the direction factor. These missing values were replaced by the appropriate sample means, and the denominator degrees of freedom were reduced by the number of missing values. If the calculated F value were greater than the adjusted critical value, then the null hypothesis of no effect was rejected at the 0.05 level, and the difference in means was considered statistically significant.

During three trials which were to be flown with the autopilot engaged, the subjects disconnected the autopilot and flew manual breakouts. Two cases were the first breakout event for those subjects, and the autopilot was disengaged at 4.6 and 12.2 seconds after the start of the ATC transmission. The pilot observer reminded the subjects afterwards that they were to leave the autopilot on. The third was the last breakout using the autopilot for that subject. It was at decision altitude, and the subject disconnected the autopilot 10.2 seconds after the start of the ATC transmission. These trials were included in the analysis as autopilot breakouts.

5.5.3.1 Breakout Mode with Altitude

The analysis of variance using breakout mode and altitude as independent variables yielded a significant main effect for both independent variables, but no significant interaction. Specifically, breakout mode affected start of turn, but not speed or climb performance, while altitude affected speed and climb performance, but not turn performance. The results for the breakout mode main effect, listed in Table 5-18, indicate that mean time to start of roll (dt_roll) was significantly larger for autopilot breakouts than for hand-flown breakouts.

Although there was no significant difference in mean time to start of climb between hand-flown and autopilot breakouts, qualitative assessment of track plots indicated a larger difference in climb acceleration than was observed for the other phases of the study. Appendices I, J, and K show trajectory plots for Phase 1, 2, and 3, respectively. Figure 5-8 is an example of the vertical profile for Phase 3 climbing breakouts at 500 feet AGL for both hand-flown and autopilot-coupled approaches. Although the distribution of times to start of climb acceleration were similar for the two breakout modes, the data indicated that positive climb was achieved sooner for autopilot-coupled breakouts. For example, by the time the aircraft had climbed 250 feet above its altitude at the start of the ATC transmission, it had traveled 5000 to 7500 feet along-track during most hand-flown breakouts, but only 4000 to 5000 feet along-track during most autopilot-coupled breakouts.

Table 5-18. ANOVA Results for Breakout Mode

Dependent Variable	Analysis of Variance Result	Mean*	
		Hand-Flown	Autopilot
dt_roll*	$F(1, 3) = 67.19, p < 0.05$	7.7 s (0.130)	15.8 s (0.110)
dt_vertical_speed*	$F(1, 3) = 3.33, p > 0.05$	8.8 s (0.114)	7.9 s (0.126)
dt_engine	$F(1, 3) = 1.84, p > 0.05$	7.9 s	7.4 s

* Mean values in parentheses () are for the transformed variable used in the analysis

The results for the altitude main effect, listed in Table 5-19, indicate a significant difference in mean time to start of climb (dt_vertical_speed) and start of speed increase (dt_engine) for at least one level of altitude. Since Phase 3 had a within-subject design, paired-sample t-tests were used to test for significant differences between altitudes.

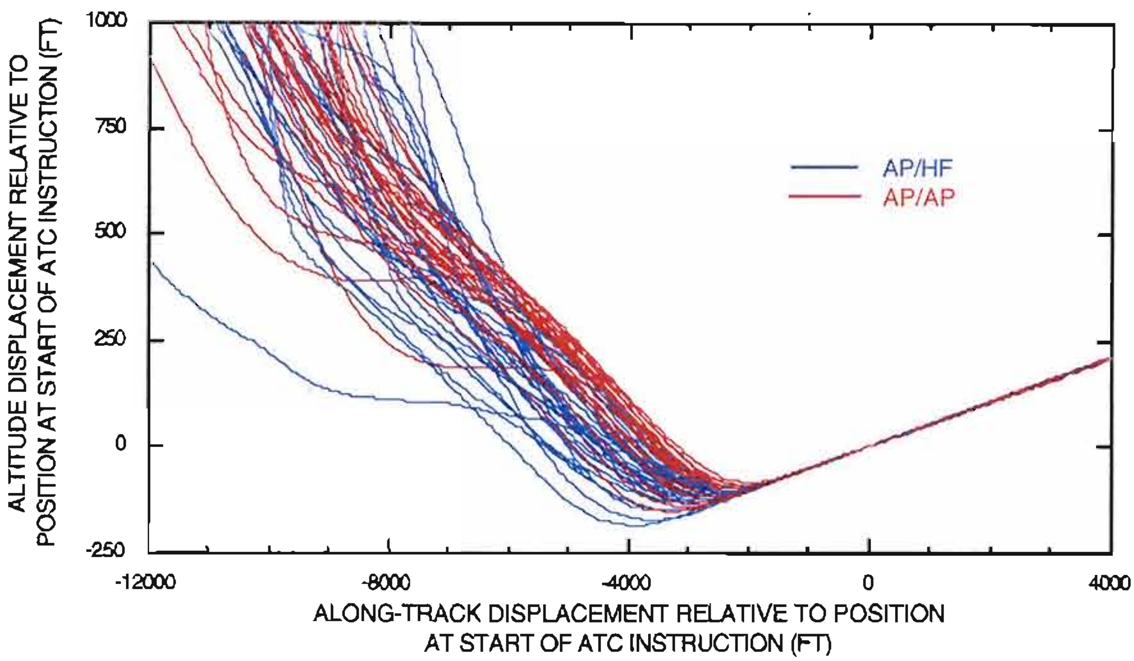


Figure 5-8. Vertical profile for Phase 3 climbing breakouts at 500 feet AGL. Trajectories are color-coded by approach/breakout pair.

For dt_engine, the mean at decision altitude (DA) was significantly less than the means at the other three altitudes; and the mean at 1800 feet AGL (1800') was significantly greater than at the other altitudes. There was no significant difference between mean time to start of engine increase between 500 feet AGL and 1000 feet AGL.

Table 5-19. ANOVA Results for Altitude

Dependent Variable	Analysis of Variance Result	Mean*			
		DA	500'	1000'	1800'
dt_engine	F(3, 17) = 22.84, p < 0.05	6.1 s	7.1 s	7.4 s	9.9 s
dt_vertical_speed*	F(3,17) = 34.39, p < 0.05	6.6 s (0.152)	7.6 s (0.132)	8.4 s (0.119)	10.6 s (0.094)
dt_roll*	F(3, 17) = 1.96, p > 0.05	14.1 s (0.071)	10.4 s (0.096)	10.7 s (0.093)	11.7 s (0.085)

* Mean values in parentheses () are for the transformed variable used in the analysis

For dt_vertical_speed, the mean value at decision altitude was significantly less than the means at the other three altitudes. The mean at 500 feet AGL was significantly less than the mean at 1800 feet AGL. But, the mean at 1000 feet AGL was not significantly different from the means for either 500 feet AGL or 1800 feet AGL. This suggests that there was a gradual increase in mean time to start of climb with increasing altitude.

There were no comments by the subjects during the sessions concerning the relative ease or difficulty of the climbing breakouts. There were several comments, however, about problems with entering heading select into the flight director for autopilot-coupled breakouts at decision altitude.

5.5.3.2 Breakout Mode with Direction

The analysis of variance using breakout mode and direction as independent variables yielded a significant main effect for breakout mode with 1/dt_roll ($F(1, 3) = 24.50$), indicating that the mean time to start of turn for hand-flown breakouts (8.1 seconds) was significantly less than for autopilot-coupled breakouts (15.8 seconds). This was consistent with the results from the previous analysis. The analysis of variance did not yield a significant main effect for direction, indicating that mean times to start of roll were similar for climbing and descending breakouts. The means were 11.5 and 12.5 seconds, respectively. There also was no interaction effect between the independent variables.

Climb and speed performance were not evaluated because speed and vertical speed accelerations did not occur during descending breakouts. Maximum roll angle was not evaluated because there was greater variability among the hand-flown breakouts than among the autopilot-coupled breakouts.

There were no comments recorded during the sessions concerning the ability of the crews to execute descending breakouts. Although there were no measured tests variables for vertical speed performance, review of the vertical profiles for descending breakouts indicated that the autopilot breakout procedure delayed the aircraft descent in some trials. This is because the crews were trained to always engage TO/GA thrust when instructed to breakout, then to arrest the climb as soon as possible if a descent were requested. The effect of TO/GA engage on hand-flown and autopilot-coupled vertical profiles is illustrated in Figure 5-9 for the descending breakout scenarios.

5.5.3.3 Summary

As indicated by the analysis of variance results, breakout mode had a significant main effect on time to start of roll (dt_roll): mean time to start of roll was smaller for manual breakouts than for autopilot breakouts. This result was consistent with the main effect observed for approach/breakout pair in Phases 1 and 2. In Phase 3, speed and climb performance were not significantly affected by breakout mode: mean times to engine increase and vertical speed increase were similar for manual and autopilot-coupled breakouts. The effect of breakout mode on maximum roll angle was not tested.

The analysis of variance indicated that altitude affected speed and climb performance but not turn performance. Mean time to engine increase and vertical speed increase were smallest at decision altitude and increased with increasing altitude. Time to start of roll was similar for all altitudes. The effect of altitude on maximum roll angle was not tested.

Analysis of variance also indicated that breakout direction did not affect turn performance: mean time to start of roll was similar for descending and climbing breakouts at 1800 feet AGL. Although the effect of breakout direction on vertical speed performance could not be tested, qualitative assessment of the descending breakout vertical profiles suggested that engaging TO/GA impeded descent during the autopilot procedure. Use of TO/GA was not a problem during manual descending breakouts.

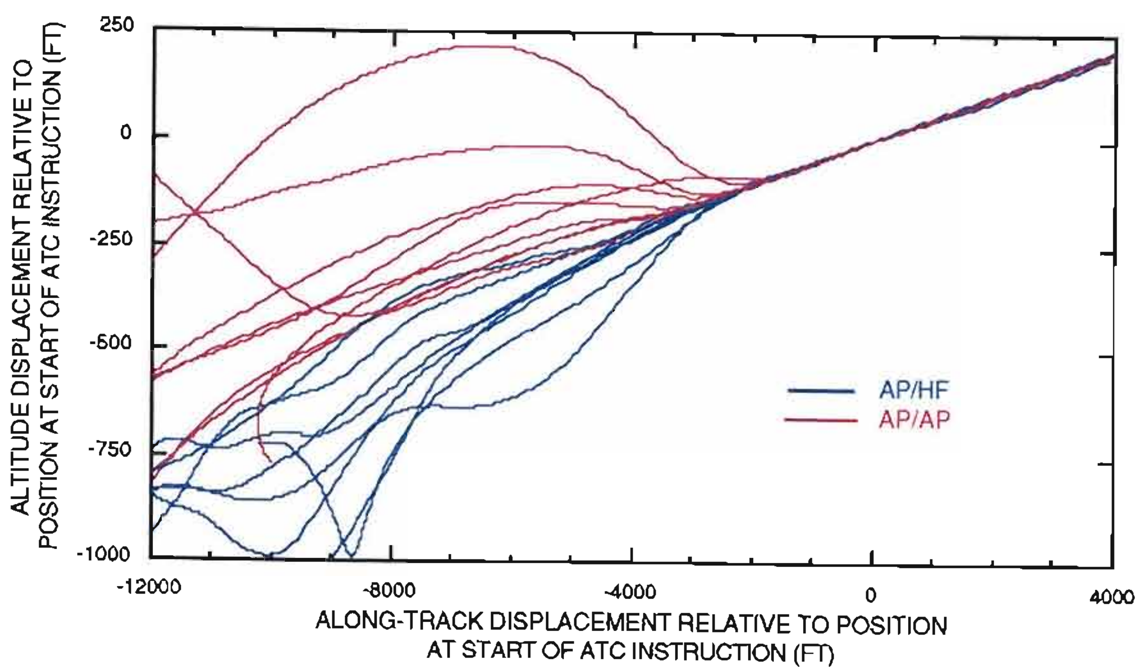


Figure 5-9. Vertical profile for Phase 3 descending breakouts.

5.6 COMPARISONS WITH PRM RESULTS

The mean and maximum value statistics for time to start of roll (dt_roll) from each phase of the study were compared to the statistics for the B727 and DC10 data used in the successful Precision Runway Monitor Program risk analysis. In order to test if the combination of approach mode and breakout mode affected turn performance, the data for each phase were separated by approach/breakout pair: hand-flown approach followed by hand-flown breakout (HF/HF);

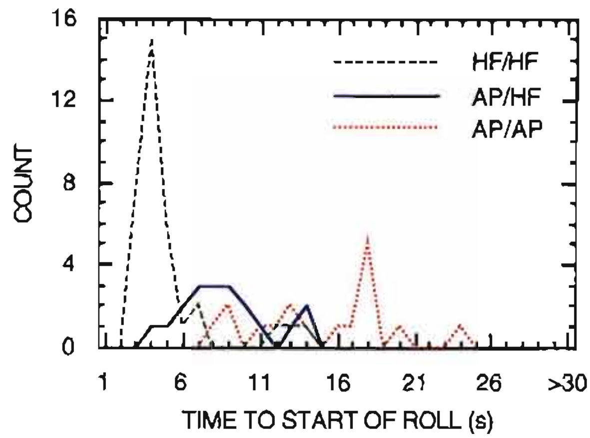
autopilot-coupled approach followed by manual breakout (AP/HF); and autopilot-coupled approach followed by autopilot-coupled breakout (AP/AP). In order to facilitate comparison among the three levels of pilot training in the three phases, the data were further grouped by breakout scenarios: climbing breakouts at decision altitude (DA); climbing breakouts above 400 feet AGL (500', 700' (Phase 2 only), 1000' (Phase 3 only), and 1800'); and, descending breakouts at 1800 feet AGL. The distraction scenarios from Phase 1 were not included in this analysis.

For each phase, or level of training, a given combination of approach and breakout modes was classified acceptable if all response times were less than or equal to 17 seconds and mean times to start of roll was less than or equal to 8 seconds for the three scenario groups. If either of these criteria was not met, the level of training was considered unsuccessful for that approach/breakout pair.

The distributions of times from start of ATC transmission to start of roll are presented in Figure 5-10 for climbing breakouts above 400 feet AGL. Statistics for each phase of study and approach/breakout pair are also presented. For Phase 1 (current training), only hand-flown approaches followed by hand-flown breakouts (HF/HF) had a mean of less than 8 seconds. For Phase 2 (increased situational awareness), the mean time to start of turn for the HF/HF pair and for autopilot-coupled approaches followed by manual breakouts (AP/HF) were acceptable. For Phase 3 (procedure training), the mean for the manual breakouts (AP/HF) was less than 8 seconds. For all three phases, the means for autopilot-coupled breakouts (AP/AP) were much larger than 8 seconds. The minimum time to start of roll for the AP/AP pair was 8.1 seconds in Phase 1, 8.7 seconds in Phase 2, and 8.5 seconds in Phase 3. This suggests that at least 8 seconds are required from the start of the ATC breakout instruction to initiate the turn in an AP/AP breakout.

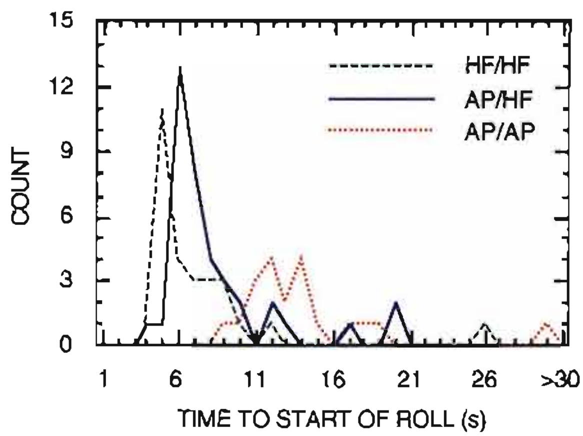
The distributions and statistics for times from start of ATC transmission to start of roll are presented in Figure 5-11 for descending breakouts. In Phase 1, only manual breakouts following hand-flown approaches (HF/HF) had a mean of less than 8 seconds. For autopilot-coupled approaches, only one subject left the autopilot connected, and that time to start of roll was 27.9 seconds. The results for Phase 2 were similar: only the mean for HF/HF pair was less than 8 seconds, and only one subject flew the descending breakout using the autopilot. For Phase 3, the mean for the manual breakouts (AP/HF) was less than 8 seconds. For all three phases, the minimum time to start of roll for the AP/AP approach/breakout pair was 10.5 seconds, combined. This was two seconds longer than the minimum time to start of turn for AP/AP climbing breakouts above 400 feet AGL.

The distributions and statistics for times to start of roll are presented in Figure 5-12 for breakouts at decision altitude (DA). There were no DA scenarios in Phase 2. The mean time to start of roll was 6.9 seconds for hand-flown breakouts following hand-flown approaches (tested in Phase 1 only). In Phase 1, the mean time to start of roll was greater than 12 seconds following autopilot-coupled approaches. The procedure training in Phase 3 improved the turn response time distributions for both manual and autopilot-coupled breakouts following autopilot-coupled approaches by approximately 3.5 seconds, but only mean time to start of turn for the AP/HF breakout procedure was acceptable.



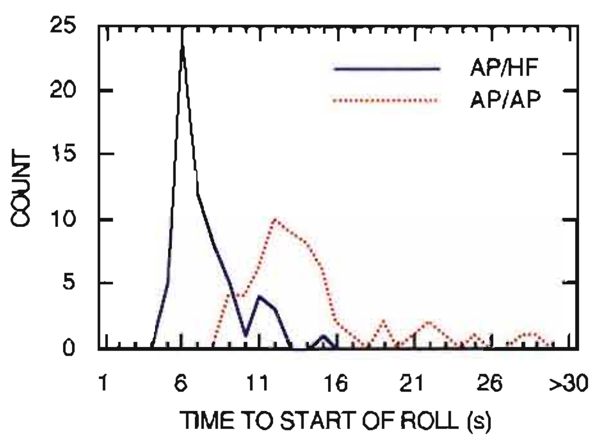
Phase 1

Approach/ Breakout	Count	Mean (S)	Median (S)	S.D. (S)	Max (S)
HF/HF	35	5.1	4.2	2.8	14.1
AP/HF	20	8.6	8.5	2.7	13.5
AP/AP	18	15.1	16.2	4.4	23.9



Phase 2

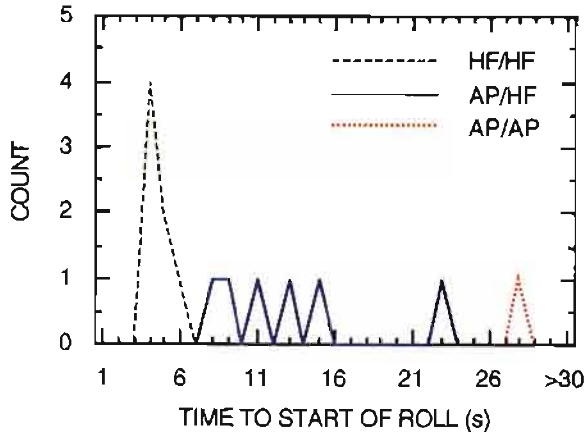
Approach/ Breakout	Count	Mean (S)	Median (S)	S.D. (S)	Max (S)
HF/HF	31	7.0	5.5	3.8	25.8
AP/HF	42	8.1	6.8	3.6	19.9
AP/AP	21	14.0	13.3	4.4	29.7



Phase 3

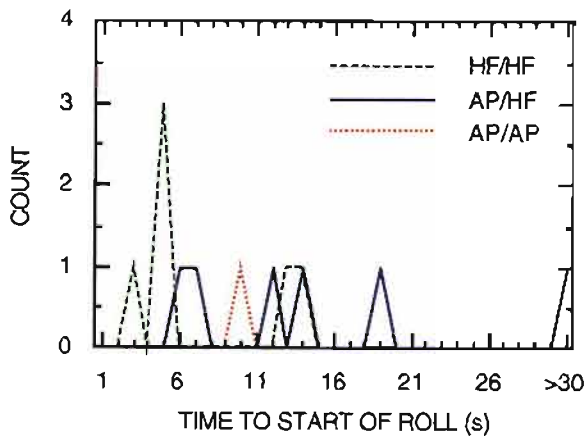
Approach/ Breakout	Count	Mean (S)	Median (S)	S.D. (S)	Max (S)
HF/HF	--	--	--	--	--
AP/HF	63	7.4	6.7	2.0	14.7
AP/AP	59	14.1	12.9	4.4	29.0

Figure 5-10. Climbing breakouts above 400 feet AGL for Phases 1, 2, and 3.



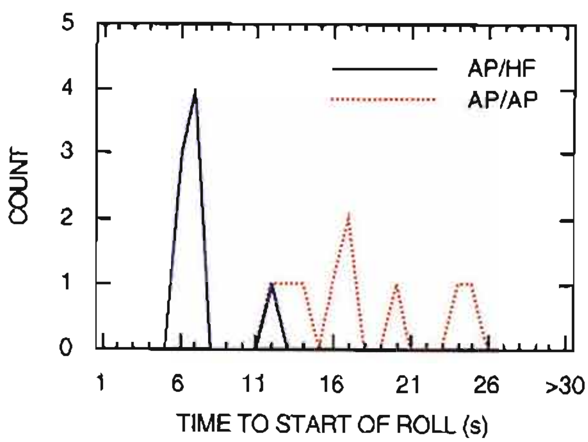
Phase 1

Approach/ Breakout	Count	Mean (S)	Median (S)	S.D. (S)	Max (S)
HF/HF	7	4.8	4.4	0.9	6.5
AP/HF	6	13.2	12.0	5.7	23.3
AP/AP	1	27.9	27.9	N/A	N/A



Phase 2

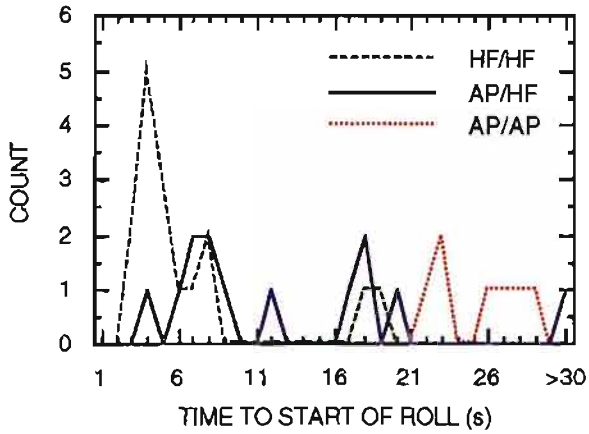
Approach/ Breakout	Count	Mean (S)	Median (S)	S.D. (S)	Max (S)
HF/HF	6	7.4	5.2	4.6	13.6
AP/HF	6	16.9	13.3	13.5	42.5
AP/AP	1	10.5	10.5	N/A	N/A



Phase 3

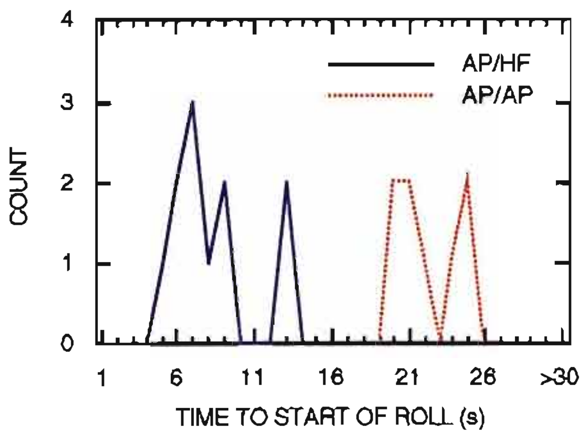
Approach/ Breakout	Count	Mean (S)	Median (S)	S.D. (S)	Max (S)
HF/HF	--	--	--	--	--
AP/HF	8	7.2	6.7	2.1	12.2
AP/AP	9	17.6	16.7	4.8	25.5

Figure 5-11. Descending breakouts at 1800 feet AGL for Phases 1, 2, and 3.



Phase 1

Approach/ Breakout	Count	Mean (S)	Median (S)	S.D. (S)	Max (S)
HF/HF	17	6.9	5.1	4.7	19.0
AP/HF	13	12.7	8.5	7.8	31.5
AP/AP	7	25.5	25.6	2.6	29.2



Phase 3

Approach/ Breakout	Count	Mean (S)	Median (S)	S.D. (S)	Max (S)
HF/HF	–	–	–	–	–
AP/HF	11	8.3	7.2	2.8	13.4
AP/AP	8	22.2	21.5	2.2	25.4

Figure 5-12. Climbing breakouts at decision altitude for Phases 1, 2, and 3.

There were 21 trials with a time to start of turn greater than 17 seconds in Phase 1. Data for these trials are listed in Table 5-20. Two cases were at decision altitude for the HF/HF pair. These were the only HF/HF trials with a time to start of roll greater than 17 seconds. Fourteen of the remaining 19 cases were for autopilot-coupled breakouts (AP/AP), and these were distributed evenly between decision altitude and above 400 feet AGL. For the five cases in which the autopilot was disconnected and the breakout was manually flown (AP/HF), the subjects waited at least 15 seconds before disconnecting the autopilot. There were no trends with respect to scenario sequence and subject number, except that subject 20 was the pilot flying in five cases.

Time to start of roll was greater than 17 seconds for eight trials in Phase 2. Data for these trials are listed in Table 5-21. There were no trends with respect to breakout group or subject number. Seven long response times were for autopilot-coupled approaches; three subjects elected to leave the autopilot engaged (AP/AP), and three subjects disconnected the autopilot (AP/HF).

For the single case with a manual breakout following a hand-flown approach (HF/HF), the subject waited for the heading information to be entered into the flight director, then followed the command bars. This was the only HF/HF trial with a long time to start of roll. Times to start of roll for the remaining HF/HF cases were less than 14 seconds.

In Phase 3, time to start of roll was less than 15 seconds for all breakouts using the manual procedure (AP/HF). There were 21 autopilot-coupled breakouts (AP/AP) with a time to start of turn value greater than 17 seconds. Data for these trials are listed in Table 5-22. All eight valid AP/AP trials at decision altitude required more than 17 seconds to start of turn. The other cases with long turn response times were evenly distributed among the other three breakout groups. There were no trends with respect to subject or sequence number. For one descending breakout, the subject disengaged the autopilot after 19 seconds even though the autopilot breakout procedure was being tested

Table 5-20. Phase 1 Time to Roll Values Greater Than 17 Seconds

Breakout Group	Approach/ Breakout	Sequence Number	Subject Number	dt_roll (seconds)	dt_autopilot (seconds)
DA	AP/AP	3	1	22.40	-
DA	AP/AP	13	2	22.98	-
DA	AP/AP	3	3	27.66	-
DA	AP/HF	13	3	18.35	16.89
DA	AP/HF	13	6	17.56	15.82
DA	AP/AP	3	7	27.06	-
DA	AP/HF	3	12	19.99	18.02
DA	AP/AP	3	18	29.24	-
DA	AP/HF	3	20	31.46	24.13
DA	AP/AP	3	20	25.59	-
DA	HF/HF	14	5	19.00	-
DA	HF/HF	14	9	17.86	-
500'	AP/AP	8	2	18.43	-
500'	AP/AP	8	12	18.02	-
500'	AP/AP	8	18	17.67	-
1800'	AP/AP	15	20	18.43	-
1800'	AP/AP	11	2	18.43	-
1800'	AP/AP	11	6	20.16	-
1800'	AP/AP	11	20	23.89	-
Descend	AP/AP	10	12	27.86	33.21
Descend	AP/HF	10	20	23.26	19.60

Table 5-21. Phase 2 Time to Roll Values Greater Than 17 Seconds

Breakout Group	Approach/ Breakout	Sequence Number	Subject Number	dt_roll (seconds)	dt_autopilot (seconds)
500'	AP/HF	2	23	19.92	19.03
500'	AP/HF	2	24	19.77	5.43
700'	HF/HF	14	24	25.77	-
700'	AP/AP	14	2	17.53	-
1800'	AP/AP	4	3	29.74	-
1800'	AP/AP	1	9	19.33	-
Descend	AP/HF	12	9	19.29	9.37
Descend	AP/HF	5	24	42.50	37.13

Table 5-22. Phase 3 Time to Roll Values Greater Than 17 Seconds

Breakout Group	Approach/ Breakout	Sequence Number	Subject Number	dt_roll (seconds)	dt_autopilot (seconds)
DA	AP/AP	8	1	24.20	-
DA	AP/AP	14	4	19.97	-
DA	AP/AP	14	6	19.84	-
DA	AP/AP	8	11	20.70	-
DA	AP/AP	15	17	24.70	-
DA	AP/AP	8	21	22.24	-
DA	AP/AP	8	22	25.36	-
DA	AP/AP	14	23	20.67	-
500'	AP/AP	4	30	19.03	-
500'	AP/AP	19	17	18.50	-
1000'	AP/AP	16	6	21.14	-
1000'	AP/AP	6	29	25.23	-
1800'	AP/AP	5	9	21.50	-
1800'	AP/AP	1	12	22.66	-
1800'	AP/AP	10	18	28.17	-
1800'	AP/AP	2	29	28.97	-
1800'	AP/AP	2	30	21.94	-
Descend	AP/AP	3	2	24.33	-
Descend	AP/HF*	12	3	20.19	19.90
Descend	AP/AP	3	22	25.50	-
Descend	AP/AP	12	28	17.10	-

* Was supposed to be an autopilot-coupled breakout (AP/AP).

6. SURVEY RESULTS

During each phase of the study (Phase 1, 2, or 3), all subjects were asked to complete a survey. Different surveys were used for each phase of study. As discussed in the Section 3, Methods Section, this study was a collaborative effort by many individuals within several organizations. In addition, the design of the study was an iterative process. The development of the experimental design for Phases 2 and 3 were dependent on the knowledge gained from the previous phase. The combination of shared responsibility and independent test design among phases resulted in limited consistency among test scenarios and pilot surveys.

Since the surveys were developed in response to lessons learned from the previous phases or phases and reflected the input of several organization, the reader will note that the wording of questions varies from survey to survey, as well as, the type of responses requested of the subjects. For example, the Phase 1 Survey called for ratings on a calibrated 5-point scale, the Phase 2 Survey called for "yes" or "no" responses, and the Phase 3 Survey called for ratings on a more loosely defined 5-point scale.

Since the surveys varied in content and format, one-to-one comparisons were not made from one survey to the next. Therefore, the results of each survey are reported separately. Prior to reporting the results for each question, the question is printed in its entirety.

Section 6.1 provides the survey results for Phase 1, ending with Section 6.1.1, which summarizes the results for Phase 1. Section 6.2 provides the survey results for Phase 2, ending with Section 6.2.1, which summarizes the results for Phase 2. Finally, Section 6.3 provides the survey results for Phase 3, ending with Section 6.3.1, which summarizes the results for Phase 3.

In reporting results, verbatim comments made by the subjects are included. In some cases, subjects used abbreviations for commonly used terms. Abbreviations are translated the first time they appear. The translation of abbreviated words is provided in parenthesis by the data analyst. In addition, a glossary is provided for reference. Common among all three surveys is the fact that each participating pilot was assigned a subject-number to assure the anonymity of his or her responses.

6.1 SURVEY RESULTS FOR PHASE I

Ten crews, each consisting of a captain and first officer, participated in the B747 Phase 1 Study. Eight crews were from United Airlines and two crews were from Northwest Airlines.

Each crew worked together in completing the survey. It was originally intended that one survey would be completed by each pilot independently. However, in administering the survey, site staff asked each crew to complete the survey together. Therefore, although twenty pilots participated in the study; the total number of completed surveys is ten. In the subsequent phases, each pilot completed his or her own survey.

Pilots were asked to list their total flight time and the total hours in the aircraft type tested, i.e., B747-400. Table 6-1a and Table 6-1b, respectively, list the total, mean, and range for "total flight time" and "hours in type" for both captains and first officers. The values below were calculated from the data provided by all pilots who responded to the questions. When the number of respondents (n) is less than 10, this indicates that either the pilot did not respond to the question or that the response was illegible.

Table 6-1a. Flight Time (hours)

Position	Total Flight Time	Mean	Range
Captain (n = 8)	139,100	17,387	11,000 - 25,000
First Officer (n = 5)	51,800	10,360	7,800 - 12,000

Table 6-1b. Hours in Type

Position	Total Flight Time	Mean	Range
Captain (n = 9)	13,300	1,477	800 - 2,200
First Officer (n = 5)	9,500	1,900	1,500 - 2,500

<u>Survey Items 1 through 4</u>.

Items 1 through 4 of the survey refer to various types of breakouts at various points along the approach path. For each of these items the crews were asked to give their opinions specific to flying a coupled approach or hand flying the approach. Items 1 through 3 refer to climbing breakouts, while Item 4 refers to descending breakouts. Crews were asked to rate the level of difficulty of each of the cases below by circling a number on a 5-point scale:

0	1	2	3	4
Not at all Difficult	Somewhat Difficult	Moderately Difficult	More than Moderately Difficult	Very Difficult

<u>Survey Item 1a</u>. **Rate the difficulty of a climbing breakout at DH/DA (Decision Height/Decision Altitude) during the simulation when flying a <u>coupled approach</u>.**

<u>Survey Item 1b</u>. **Rate the difficulty of a climbing breakout at DH/DA during the simulation when <u>hand flying</u> (flight director) the approach.**

<u>Survey Item 2a</u>. **Rate the difficulty of a climbing breakout inside the outer marker during the simulation when flying a <u>coupled approach</u>.**

<u>Survey Item 2b</u>. **Rate the difficulty of a climbing breakout inside the outer marker during the simulation when <u>hand flying</u> (flight director) the approach.**

<u>Survey Item 3a</u>. **Rate the difficulty of a climbing breakout outside the outer marker during the simulation when flying a <u>coupled approach</u>.**

Survey Item 3b. **Rate the difficulty of a climbing breakout outside the outer marker during the simulation when hand flying (flight director) the approach.**

Survey Item 4a. **Rate the difficulty of a descending breakout outside the outer marker during the simulation when flying a coupled approach.**

Survey Item 4b. **Rate the difficulty of a descending breakout outside the outer marker during the simulation when hand flying (flight director) the approach.**

Table 6-2 lists the number of crew responses for each of the ratings in Survey Items 1 through 4. Figure 6-1 graphically illustrates the distribution of responses to each of the ratings in Survey Item 1 through 4. The data in Figure 6-1 are presented as percentage of crew responses for each of the ratings. Comments regarding the difficulty of each of the breakouts are included.

Table 6-2. Crew Ratings of Difficulty of Breakouts

Type of Breakout	Approach Mode	RATINGS OF DIFFICULTY				
		Not at All	Somewhat	Moderately	More than Moderately	Very
1. Climbing Breakout at Decision Altitude	a. coupled	0	4	4	1	1
	b. hand flown	2	3	2	1	1
2. Climbing Breakout inside the Outer Marker	a. coupled	2	4	2	1	1
	b. hand flown	3	3	1	1	1
3. Climbing Breakout outside the Outer Marker	a. coupled	6	1	1	1	1
	b. hand flown	5	2	0	1	1
4. Descending Breakout outside the Outer Marker	a. coupled	1	1	2	4	2
	b. hand flown	2	1	1	3	2

Crew comments were most prevalent in response to the survey items regarding descending breakouts. The following comments were made regarding descending breakouts:

- not trained for, TO/GA (take off/go around thrust) is a climb profile only
- just unfamiliar clearance to descend rather than climb
- not trained for descending breakouts
- psychologically very difficult – completely contrary to everything we do
- moderately difficult due to thrust increase
- not used to go arounds and go down!
- this goes against all pilot learned procedures – never descend on a missed approach

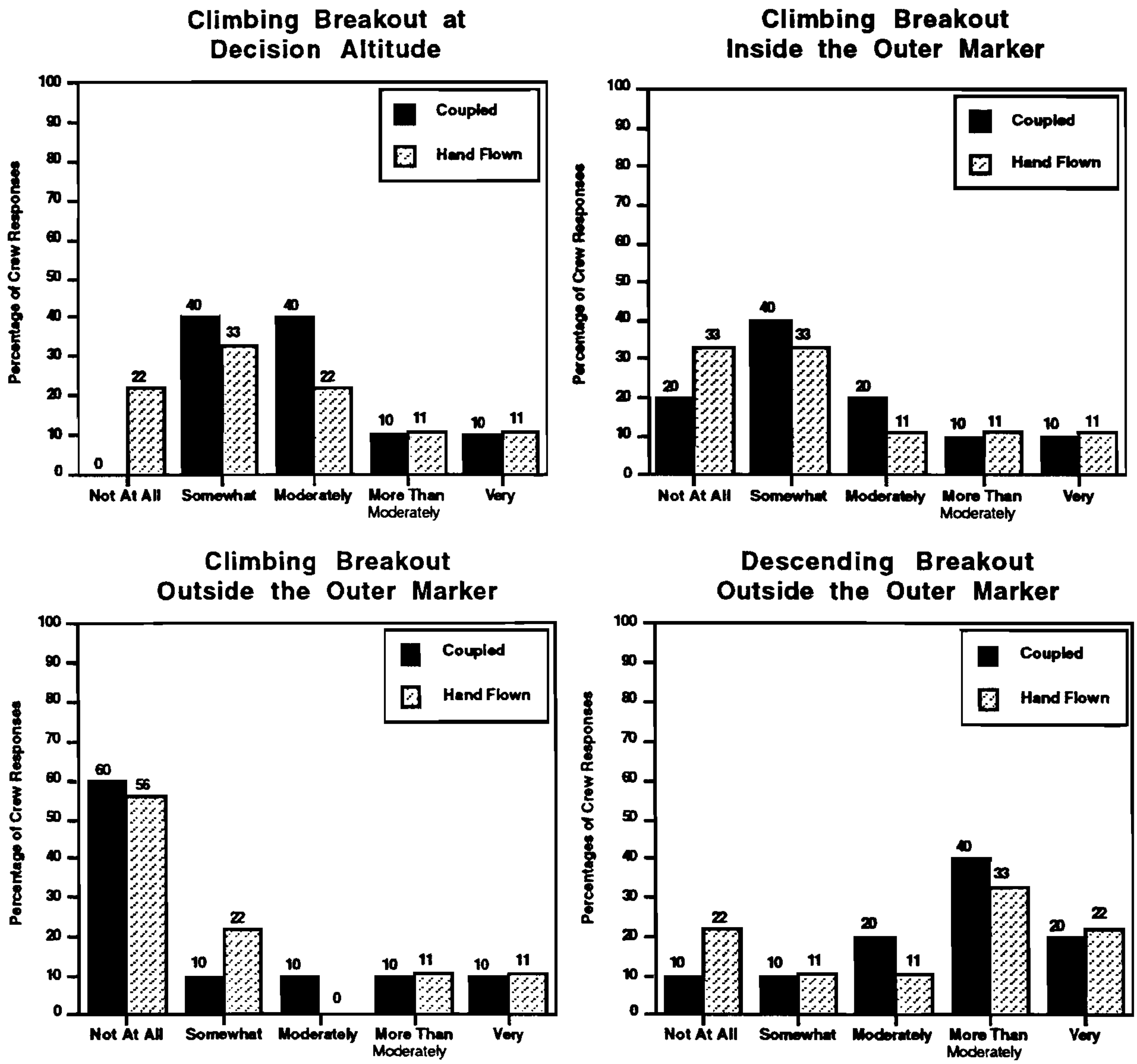


Figure 6-1. Crew ratings of difficulty of breakouts.

In part "c" of survey items 1 through 4 (regarding climbing and descending breakouts), the crews were asked to answer the following question:

When you were directed by ATC to turn immediately, did you use the following as a basis for your decision to start turning?

A list of attributes was provided and crews were asked to respond "yes" or "no" to each of the attributes, including: altitude, aircraft configuration, air speed, company policy, and passenger comfort.

Table 6-3 lists the percentage of "yes" responses. A "yes" response indicates that an attribute was part of the basis on which the crew decided to make the turn. For example, as seen below, 50% of the crews said that "yes," altitude was a factor in basing the decision to start turning in the case of a climbing breakout at decision altitude.

Table 6-3. Basis for Deciding to Turn (Percentage of "yes" responses)

	Type of Breakout	Altitude	Configuration	Air Speed	Company Policy	Passenger Comfort	Other
1c.	Climbing Breakout at Decision Altitude	50	10	30	10	0	37.5
2c.	Climbing Breakout inside the Outer Marker	10	0	20	10	0	40
3c.	Climbing Breakout outside the Outer Marker	10	0	20	0	0	22
4c.	Descending Breakout outside the Outer Marker	30	10	30	10	10	22

Some comments were given by crews who reported "other," indicating some other factor was involved in basing their decision to turn. Comments were:

- positive rate of climb
- started climb first
- just ATC (Air Traffic Control) direction

As part of Item 4c (regarding descending breakout outside the outer marker), one additional attribute was listed: "Obstacles/Minimum Vectoring Altitude." One (10%) of the ten crews said "yes," that this was a consideration. The comment that accompanied this "yes" response was:

- unfamiliar with airport

Item 4c (regarding descending breakout outside the outer marker), also contained the following question: **"Was thrust management a factor?"**

Eight crews (80%) reported "yes," while one crew (10%) reported "no." and the remaining one crew response was illegible. The comments of the crews who responded "yes" are listed below:

- to use or not use TO/GA
- but this should not have been a factor since selecting another heading mode would be all that was necessary
- sorting out automatics
- increased thrust for maneuvering made descent more difficult

- programmed to increase thrust not decrease
- A/T (auto thrust) didn't work as needed
- GA (go around) thrust not required

Further analysis of the data from items 1 through 4 was performed in the form of t-tests (paired two sample for mean). This analysis was performed to determine if there was a significant difference in pilot response to the "a" and "b" part of each item, i.e., rating the difficulty of a breakout when flown as a coupled versus hand flown approach. Table 6-4 lists the means and standard deviations for the data used in the t-tests. All four t-tests showed no significant difference in the mean ratings. That is, no significant difference was found in mean pilot ratings of difficulty of breakouts, whether they be flown coupled or hand flown.

Table 6-4. Mean Pilot Ratings of Difficulty of Breakouts

Type of Breakout	Approach Mode	Mean	Standard Deviation
1. Climbing Breakout at Decision Altitude	a. coupled	1.22	0.94
	b. hand flown	1.55	1.77
2. Climbing Breakout inside the Outer Marker	a. coupled	1.22	0.94
	b. hand flown	1.33	2.00
3. Climbing Breakout outside the Outer Marker	a. coupled	0.66	1.25
	b. hand flown	1.00	2.25
4. Descending Breakout outside the Outer Marker	a. coupled	2.33	1.50
	b. hand flown	2.22	2.40

To compare differences in ratings of difficulty of breakouts in the case of climbing versus descending breakouts two t-tests were performed with the data from Items 3 and 4. The data from Item 3a (climbing breakout outside the outer marker, flown coupled) were compared to the data from Item 4a (descending breakout outside the outer marker, flown coupled). The t-test results were $t(9) = -4.39$, $p < .001$, i.e., indicating a highly significant difference. The data from item 3b (climbing breakout outside the outer marker, hand flown) were compared to the data from item 4b (descending breakout outside the outer marker, hand flown). The t-test results were $t(8) = -3.35$, $p < .01$, i.e., indicating a significant difference. Therefore, it was found that on average, pilots rated the difficulty of the descending breakouts to be significantly greater than the difficulty of the climbing breakout, in the case of breakouts outside the outer marker. The pilot comments regarding descending breakouts (reported earlier), reinforce this finding.

<u>Survey Item 5</u>. Does your company direct a minimum altitude for all turns?

Six crews (60%) responded "yes," the company directs a minimum altitude for all turns, while four crews (40%) responded "no." Comments were:

- 300 AGL (above ground level)
- 400 feet
- 500 feet
- 500 feet
- safe operating altitude

<u>Survey Item 6</u>. Given the runway spacing during the test, if you knew that another aircraft was on a simultaneous parallel instrument approach in IMC, would that have made any difference in your response to an ATC instruction to make an immediate turn at low altitude?

Six crews (60%) responded "yes" and four crews (40%) responded "no." Only one crew responding "no" made a comment and that was "No, we depend on ATC to give required vector." Comments of the crews who responded "yes" were:

- more urgency knowing proximity of parallel aircraft
- if it was toward the other runway we would start the turn but question ATC
- we assume other aircraft is not on track
- if the vector was toward the other aircraft
- make sure it is right direction
- would tend to hand fly it, decouple

<u>Survey Item 7</u>. Would your reaction to an ATC instruction to make an immediate turn at low altitude be any different if, in addition to the circumstances described in Item 6 above, you also had a written procedure which emphasized the need for an immediate response? For example: "An immediate pilot response is expected and required. Execution of these ATC instructions must be as rapid as practical."

Five crews (50%) responded "yes" and five crews (50%) responded "no." The crews responding "no" gave no comments. The comments of the crews who responded "yes" were:

- with additional training for an immediate turn below 400 RA (radio altitude)
- instructions should be briefed prior to approach by crew
- highlights need for prompt action

- if trained
- would have to hand fly, decouple

Survey Item 8. What, if any, B747 aircraft limitations do you think could cause an inherent unwanted delay?

Crews responded:

- lack of training, aircraft limitations in autoflight
- Mode control panel / autopilot design leads to slower response than hand flying raw data. Delay also caused by the steps which must be taken to disengage the AP/FD (autopilot / flight director) approach mode once it has been engaged.
- no HDG SEL until 400'. Inability to disengage LOC & GS after capture without turning F/D, etc., off
- heading select is not readily available after localizer and glide slope capture
- time to recycle out of the autocoupled approach mode
- If not programmed into FMC (flight management computer) there's too many steps to follow the instructions: Below 400' AGL HDG select will not engage which adds a great deal of difficulty to the maneuver.
- 1) HDG SEL not available when on LOC

  2) engine failure
- flight management - APS & FDS (autopilot system and flight director system)
- inability to get into heading select, LNAV (lateral navigation mode) is designed for published miss only

Survey Item 9. What degree of urgency does the term "immediate" convey to you?

Comments by all crews indicated that the term "immediately" was associated with a high or very high degree of urgency. Comments were:

- great urgency, within cockpit duties priorities, as soon as physically practical
- immediate is immediate
- very to extreme urgency depending on inflection of controllers voice
- indicates need to comply now!
- high
- close proximity of aircraft or terrain
- high urgency!!!
- as soon as you can
- high
- highest degree

Survey Item 10. **During the testing, did you develop any strategy for making a decision to turn and then executing the turn?**

All ten crews (100%) responded "yes." Comments were:

- after several test runs, felt more comfortable and knew what to expect.
- The decision to turn was mostly an ATC function: the execution - TO/GA button, then heading mode, altitude window, finally disconnect A/P inside marker and hand fly. Execution became a case of first starting a climb with TO/GA, then doing whatever was necessary to start the turn.
- turn off automatics and hand fly - look through F/D
- strategy for executing a turn -- yes, disengage autopilot, start turn, then re-engage
- disconnecting the autopilot and hand-flying the turn
- turning off the autopilot to execute the maneuver
- hand fly
- let the autopilot do it

Survey Item 11. **Do you think that training or better situational awareness would have enhanced your performance during the ATC-directed breakout?**

Eight crews (80%) said "yes" and two crew (20%) said "no." Comments regarding the need for training or better situational awareness were:

- more training on unusual situations
- previous training emphasizes no turns off the localizer after capture, particularly inside the marker prior to MAP (missed approach point)
- These maneuvers are never done in training on the line and a corporate strategy should be addressed. If parallel approaches are conducted, ATC should be required to inform both airplanes of the presence of the other.
- training in auto coupled missed approaches involving immediate turns
- practice in disconnecting from the autocoupled approach mode
- for safety
- brief on technique for a MA without LNAV VNAV (vertical navigation mode)

Survey Item 12. **Any other comments?**

- This has been an excellent and valuable learning experience.
- Software, training, company policy needs to be addressed.
- good experience to have to better understand autoflight characteristics
- This procedure would be much better in the GLASS (glass cockpit aircraft) if a separate FMS procedure were given for closely spaced parallel approaches. This

procedure would use a canned heading and altitude and the missed approach would be only TO/GA - LNAV. You should NEVER be given a descending missed approach.

6.1.1 Summary of Phase 1 Survey Findings

In ratings of difficulty of breakouts when they were flown coupled versus autopilot, no significant difference was found. In ratings of difficulty of breakouts, significant differences were found in the area of descending versus climbing breakouts outside the outer marker. Descending breakouts were rated as being significantly more difficult than climbing breakouts. T-test results and pilot comments supported this finding.

Responses to the items seeking pilot opinion on the need for training and heightened situational awareness indicated that many pilots felt there indeed was a need. Subsequently, the planners of the study decided to provide means for training and heightened situational awareness in Phase 2. The planners of the study also decided, that the ATC phraseology used should be changed to heighten awareness. Therefore, in Phase 2 the term "traffic alert" was added to the phraseology.

6.2 SURVEY RESULTS FOR PHASE 2

Seven crews, each consisting of a captain and first officer, participated in the B747 Phase 2 Study. Six crews were from United Airlines and one crew was from Northwest Airlines.

Each pilot completed his or her own survey. The focus of this survey was on the benefit derived from the training received on simultaneous approaches to closely-spaced parallel runways. Unlike the surveys for Phase 1 and Phase 3, this survey did not include a question regarding pilot experience. The first three survey items focused on assessing the contribution of the approach plate notes, airport advisory page and new ATC phraseology in heightening awareness. Table 6-5 summarizes the results of Survey Items 1 through 3. Following this table, the questions and comments in response to each question are listed.

Table 6-5. Pilot Ratings of Information Sources

Survey Item	Information Source	Pilot Responses	
		Yes	No
1	approach plate notes	13 (93%)	1 (7%)
2	airport advisory page	13 (93%)	1 (7%)
3	new ATC phraseology	14 (100%)	0

<u>Survey Item 1</u>. **Did the approach plate notes regarding "Simultaneous Approaches" heighten your awareness to the possibility of another aircraft's close proximity on the adjacent runway?**

The vast majority of pilots responded "yes" to this question, i.e., 13 of the 14 pilots who responded. The comments of pilots who responded "yes" were:

- very helpful to remind me of possible traffic alert
- "Simultaneous Approaches" is a term in general use today and doesn't heighten awareness. "Close Parallel" is not familiar to me and so would make me more aware.
- It will feel a little "goosey" until we have flown a bunch of these "close" approaches.
- mentioned on the ATIS (Automatic Terminal Information System) would also reinforce it
- printed with bold print would help
- It heightened it, but should be more emphatic about the potential of a possible "abnormal" breakout. Something like "breakout instructions require immediate compliance."

The pilot who responded "no" commented:

- The approach plates did not have it on.

<u>Survey Item 2</u>. **Did the "Airport Advisory Page" provide sufficient information to heighten your awareness level similar to that of a CAT (category) II or CAT III approach?**

The vast majority of pilots responded "yes" to this question, i.e., 13 of the 14 pilots who responded. The comments of pilots who responded "yes" were:

- Should be part of the approach brief, as a traffic alert requires a non-SOP (standard operating procedure) missed approach technique.
- Listing of the minimum vectoring altitudes would be helpful.
- Helped some, depends on where it would be in the Jepp (Jeppeson) manuals.

The pilot who responded "no" commented:

- Not at this time. Perhaps when as much emphasis / training has been done on close parallel approaches as has been done on CAT II/CAT III this will change.

<u>Survey Item 3</u>. **Was the new ATC phraseology ("Traffic Alert") a factor in the manner that you performed the ATC Breakout Maneuver? <u>Did it heighten your sense of urgency</u>?**

All 14 pilots responded "yes" to this question. Comments were:

- alerted that something was about to happen
- absolutely required
- I still prefer to take my time in IMC (instrument meteorological conditions), rather than initiating a "yank & bank" maneuver.
- I believe a different word such as "now" would emphasize urgency.

- Perhaps "Conflict Alert" might be better, but term used was a factor in making me much more aware of an impending immediate turn.
- Definitely catches the attention.
- I expect to abandon the approach and a heading change and assigned altitude.
- The "Traffic Alert" message allowed the crew to mentally prepare for the maneuver.
- Absolutely!! This word was not used to the best of my recollection in the first phase, and therefore, the sense of urgency was not there.
- Helps in urgency.

<u>Survey Item 4</u>. **What difference, if any, did the training materials (ATIS, Airport Advisory Page, Approach Plate, and Flight Ops Bulletin/Video) make in your awareness level for these approaches versus a Dependent (Parallel) ILS approach?**

Responses were:

- how close other aircraft are
- good video
- very much - a must
- Just that a "breakout" maneuver may be directed by ATC.
- Big difference – heighten my alertness
- All helped your awareness
- helped
- Material review prior to the approach would be critical to the safety.
- more than adequately cover, might highlight the new term w/definition somewhere on page.
- Made me more confident and aware -- in the maneuver, procedures, terminology -- should the situation arise.
- awareness of runway proximity and the "red zone"
- It had me/us focus on possibility of this type incursion.
- It emphasized the urgency of the breakout maneuvers and the need for immediate compliance.
- Helped made me aware of what to expect.

<u>Survey Item 5</u>. **In your opinion, is there any difference in <u>crew coordination</u> required for these Simultaneous Close Parallel ILS Approaches versus a normal ILS?**

The vast majority of pilots responded "yes" to this question, i.e., 12 (86%) of the 14 pilots. Two pilots (14%) responded "no." The comments of pilots who responded "yes" were:

- Both pilots must listen to instruction, i.e., turn direction (note: pilot drew arrows indicating climb and descend).
- Brief traffic alert actions to be accomplished so it is fresh in their minds.
- Complete briefing required as to go around selections as turning on miss not normal.
- I think procedures need to change so that heading select can be obtained ASAP (as soon as possible).
- for descending alt (altitude) procedures
- Sequence of steps required. Recommend SOP/standard procedure.
- Glass cockpit training and procedures do not lend themselves to adapting to this type of breakout maneuver. Current autoflight training emphasizes an auto go around from an auto approach.
- basically a missed approach procedure with an immediate turn involved
- not only to review normal missed approach procedure, but to reconfigure glass FMS for better guidance on breakout
- The training received for many years stressed a completely different missed approach methodology. Much more disciplined coordination is required for a close parallel breakout than a "normal" missed approach.
- We are not practiced in this type of breakout.

The pilot who responded "no" commented:

- Operated aircraft by SOP per airline operations.

Survey Items 6 and 7 concerned ratings of the level of difficulty in executing an ATC-directed breakout after glide slope capture during the simulation. Pilots were asked to assess the level of difficulty in regard to climbing breakouts when using coupled autopilot and when using hand flown flight director (Survey Item 6). Pilots were asked to assess the level of difficulty in regard to descending breakouts when using coupled autopilot and when using hand flown flight director (Survey Item 7). Pilots indicated their ratings by circling one of five numbers on a five-point scale:

1	2	3	4	5
Very Easy	Easy	Moderate	Difficult	Very Difficult

Table 6-6 lists the number and percentage of pilot responses to Survey Items 6 and 7. Figure 6-2 graphically illustrates the results of Survey Item 6 and 7. Following Figure 6-2 pilot comments made regarding the difficulty of each of the breakouts are reported.

Table 6-6. Pilot Ratings of Difficulty in Executing an ATC-Directed Breakout

Item	Type of Breakout	Approach Mode	Very Easy	Easy	Moderate	Difficult	Very Difficult
6	Climbing	a. coupled	0	5 (36%)	9 (64%)	0	0
		b. hand flown	3 (21%)	7 (50%)	4 (29%)	0	0
7	Descending	a. coupled	0	1 (7%)	4 (29%)	7 (50%)	2 (14%)
		b. hand flown	0	5 (36%)	5 (36%)	3 (21%)	1 (7%)

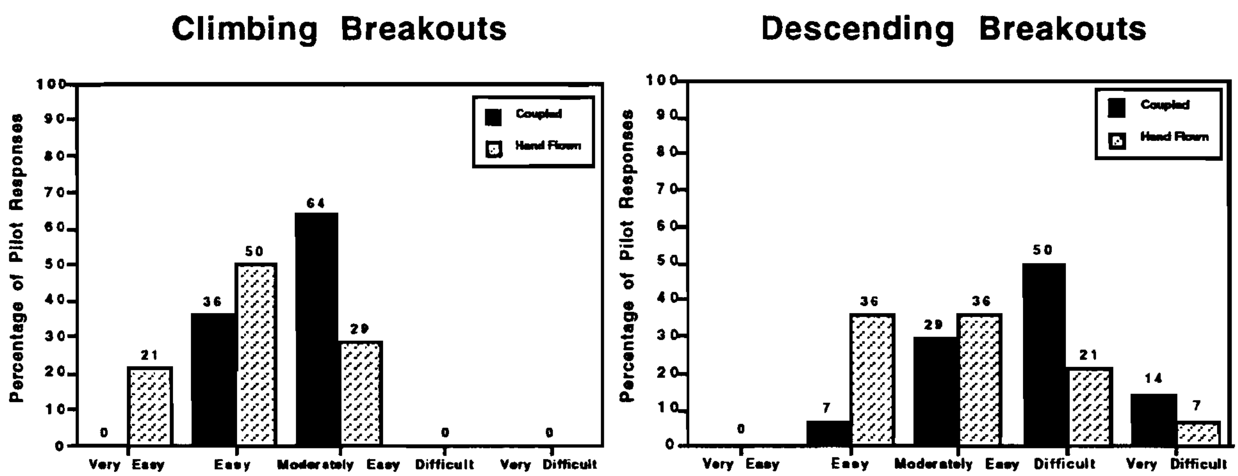


Figure 6-2. Pilot Ratings of Difficulty in Executing an ATC-Directed Breakout.

<u>Survey Item 6a</u>. **Rate the level of difficulty for executing an ATC-directed <u>climbing</u> breakout after glide slope capture during the simulation using coupled autopilot.**

Pilot comments regarding ATC-directed <u>climbing</u> breakouts after glide slope capture during the simulation using <u>coupled autopilot</u> are listed below. Each comment is preceded by the rating selected by the pilot.

- (easy) slight time lag for autoflight to initiate turn
- (easy) climb out on TO/GA is easy
- (easy) This was an SOP.
- (easy) became easy to very easy once you've got the hang of it
- (moderate) Problem in both coupled and hand flown is the turn required if TO/GA mode not engaged. Getting into the heading select mode becomes a major distraction for the PNF (pilot not flying) resulting in a "solo" flight with no X check (cross check) by the PF (pilot flying).
- (moderate) extra step of heading select

- (moderate) more difficult because of disconnecting the autopilot, followed by configuration changes along with a heading and F/D changes
- (moderate) found myself hand flying the "breakout" until stabilized on appropriate heading/climb or descend.
- (moderate) Breaking the approach mode must be done manually and without flight directors, hence the breakout must be done manually. I believe there must be a change in the autoflight system which will allow the approach mode to be broken without having to turn off everything.
- (moderate) From the first, I decided to disconnect the AP (autopilot) as soon as possible.

Survey Item 6b. **Rate the level of difficulty for executing an ATC-directed climbing breakout after glide slope capture during the simulation using hand flown flight director.**

Pilot comments regarding ATC-directed climbing breakouts after glide slope capture during the simulation using hand flown flight director were. Each comment is preceded by the rating selected by the pilot.

- (very easy) easier to initiate but puts a/c (aircraft) in more unstable configuration
- (very easy) This is easy as it has been the mindset for years.
- (easy) less monitoring required from the PF
- (easy) a simple turn and vertical maneuver without autopilot interference
- (easy) more prepared to hand fly the breakout
- (moderate) never practiced it so it was a little abnormal

Survey Item 7a. **Rate the level of difficulty for executing an ATC-directed descending breakout after glide slope capture during the simulation using coupled autopilot.**

Pilot comments regarding ATC-directed descending breakouts after glide slope capture during the simulation using coupled autopilot are listed below. Each comment is preceded by the rating selected by the pilot.

- (easy) less throttle positioning and a continuous descent path
- (moderate) not a normal, as trained, maneuver
- (moderate) hard maneuver to execute due to different commands required to complete
- (moderate) Moderate to easy before you've figured out what's going on and a technique, then it is easy. More challenging than a climbing breakout.
- (moderate) I was prone to give it power and climb the descent caught me off guard.
- (difficult) After you think through it, it is easy.

- (difficult) System is designed to go "up" not "down."
- (difficult) confusing altitude call out
- (very difficult) Not SOP, too many hands trying set ALT / HDG SEL (altitude / heading select) and getting out of "LOC" mode.
- (very difficult) In either case 100% of the pilots have had no training, no experience, and no procedure to cover a descent maneuver.

Survey Item 7b. **Rate the level of difficulty for executing an ATC-directed descending breakout after glide slope capture during the simulation using hand flown flight director.**

Pilot comments regarding ATC-directed descending breakouts after glide slope capture during the simulation using hand flown flight director were as follows. Each comment is preceded by the rating selected by the pilot.

- (easy) still an unusual ATC clearance
- (easy) To make autoflight descent is very cumbersome. Easier to do by hand.
- (moderate) To descend on a g/a (go around) is out of the normal.
- (moderate) I always disconnected the AP (autopilot) as soon as I received instructions.
- (difficult) You must look through F/D (flight director) until PNF (pilot not flying) gets it set up, but the turn can be initiated much sooner than the coupled mode.
- (difficult) After you think about it, it is easy.
- (difficult) confusing
- (very difficult) Autoflight aircraft were not designed to do this type maneuver and it is difficult to program.

As seen in Table 6-7 below, ratings to Items 6 and 7 indicated that pilots rated descending versus climbing breakouts as being more difficult to perform. Whether the breakout was a climbing or descending breakout, pilots rated them as being more difficult when coupled versus hand flown. Pilot comments confirmed their ratings.

Table 6-7. Mean Pilot Ratings of Difficulty of Executing an ATC-directed Breakout After Glide Slope Capture

Type of Breakout	Approach Mode	Mean (n = 14)	Standard Deviation
6. Climbing Breakout after Glide Slope Capture	a. coupled	2.64	0.24
	b. hand flown	2.07	0.53
7. Descending Breakout after Glide Slope Capture	a. coupled	3.71	0.68
	b. hand flown	3.00	0.92

Although (as seen in Table 6-7) the mean ratings of difficulty for descending breakouts was higher than the mean ratings of difficulty for climbing breakouts, to determine if the difference in ratings was significant and not attributable to chance, t-test analysis (paired two sample for mean) was conducted. A t-test was performed to determine if there was a significant difference in the ratings for items 6a (level of difficulty for executing an ATC-directed climbing breakout after glide slope capture using coupled autopilot) versus 7a (level of difficulty for executing an ATC-directed descending breakout after glide slope capture using coupled autopilot). T-test results were $t\ (13) = -4.01$, $p < .001$, i.e., indicating a highly significant difference. A t-test was performed to determine if there was a significant difference in the ratings for item 6b (level of difficulty for executing an ATC-directed climbing breakout after glide slope capture using hand flown flight director) versus 7b (level of difficulty for executing an ATC-directed descending breakout after glide slope capture using hand flown flight director). T-test results were $t\ (13) = -3.78$, $p < .01$, i.e., indicating a significant difference. The conclusion is that pilots expressed that the descending breakouts were more difficult and that the difference in ratings is not attributable to chance.

The next set of t-tests was performed to determine: 1) within climbing breakouts there was a significant difference in the level of difficulty when using coupled autopilot versus hand flown flight director, and 2) within descending breakouts there was a significant difference in the level of difficulty when using coupled autopilot versus hand flown flight director. In both cases, it was found that ratings for coupled were significantly higher (indicating more difficult) than ratings for hand flown. In the case of climbing breakouts $t\ (13) = 3.30$, $p < .01$. In the case of descending breakouts $t\ (13) = 4.37$, $p < .001$. Both cases indicated a significant difference. The conclusion is that pilots expressed that executing a breakout was more difficult in the coupled condition and that the difference in ratings is not attributable to chance.

Survey Item 8. **Based on the information presented on your approach plates and airport advisory page, in IMC weather with CAT (category) I minima, how would you choose to fly "Close Parallel Approaches":**

(1) Coupled Autopilot (2) Hand Flown Flight Director (3) No Preference

Thirteen of the fourteen pilots responded to this question. Of the thirteen pilots, eleven (84.6%) responded "coupled autopilot," one pilot (7.7%) responded "hand flown flight director" and, one pilot (7.7%) responded "no preference." The distribution of responses is seen in Figure 6-3.

Comments were made by pilots who responded "coupled autopilot" and are listed below:

- Required by company procedures, acceptable maneuver after training.
- It reduces my workload so I can listen better for a "traffic alert."
- It allows more time for independent thought and oversight.
- better tracking of the localizer and less a possibility of deviation.
- With two-man crew compliment on large complex aircraft, I would use all automated systems available. However, if this type of approach is approved we all should review and train for the breakout maneuver because of its urgency and level of difficulty. The automated approach is still my choice because we do not plan to expect the traffic incursion into our airspace.

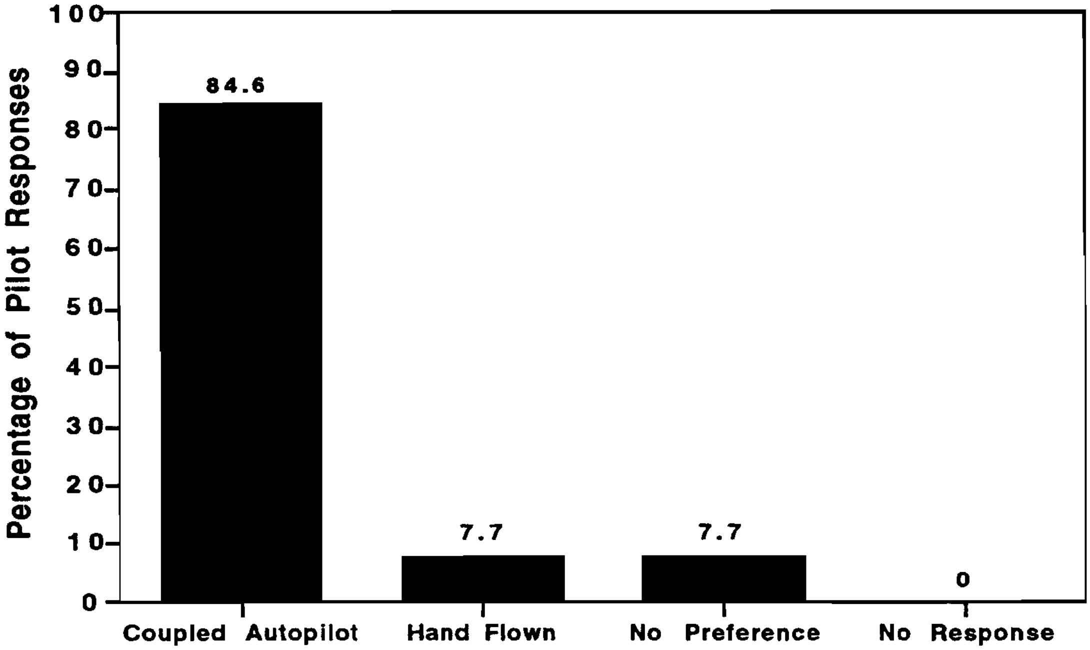


Figure 6-3. Pilot preferences for flying in IMC weather with CAT I minima.

- Even though I believe the breakout maneuver is more difficult to get into from a coupled approach, I think the extra monitoring capability afforded by being coupled is worth the extra effort. However, you must be very aware of how you will initiate the breakout if one is required.

6.2.1 Summary of Phase 2 Survey Findings

As a result of the training materials provided, pilots reported a sense of heightened awareness and urgency regarding simultaneous approaches to closely-spaced parallel runways in instrument meteorological conditions (IMC). Pilots also reported a heightened awareness and sense of urgency due to the new air traffic control phraseology that included the term "Traffic Alert."

Pilots reported that increased crew coordination is required for simultaneous close parallel approaches. They reported that it is not a standard procedure, i.e., something that is not routine and that they are not use to performing. It was expressed that the crew needs to brief themselves in advance, not only to review normal missed approach procedure but on reconfiguring glass Flight Management System.

Regarding ratings of the level of difficulty for executing various types of ATC-directed breakouts after glide slope capture. Pilots rated descending breakouts to be more difficult than climbing breakouts. Within both descending and climbing breakouts pilots, rated the level of difficulty for executing an ATC-directed breakout after glide slope capture as higher when using coupled autopilot versus hand flown flight director. However, when pilots were asked "Based on the information presented on your approach plates and airport advisory page, in IMC with CAT I minima, how would you choose to fly 'Close Parallel Approaches,' " pilots responded overwhelmingly that they prefer coupled autopilot. Their reasons were reported earlier, but may best be summed up in the comment of one pilot wrote, "Even though I believe the breakout maneuver is more difficult to get into from a coupled approach, I think the extra monitoring capability afforded by being coupled is worth the extra effort. However, you must be very aware of how you will initiate the breakout if one is required."

6.3 SURVEY RESULTS FOR PHASE 3

Nine crews, each consisting of a captain and first officer, participated in the B747-400 Phase 3 Study. The pilots of all nine crews completed the Phase 3 Survey. Of the nine crews who completed the survey, six crews were from United Airline, two crews were from Northwest Airline, and one crew consisted of a captain from United Airlines and a first officer from Northwest Airlines.

Pilots were asked to list their total flight time and the total hours in the aircraft type tested, i.e., B747-400. Table 6-8a and Table 6-8b, respectively, list the total, mean, and range for "total flight time" and "hours in type" for both captains and first officers. The values below were calculated from the data provided by all pilots who responded to the questions. When the number of respondents (n) is less than 9, this indicates that either the pilot did not respond to the question or that the response was illegible. Each pilot completed his or her own survey, resulting in a total of eighteen survey forms for nine crews.

Table 6-8a. Flight Time (hours)

Position	Total Flight Time	Mean	Range
Captain (n = 8)	130,200	16,275	2,000 to 26,000
First Officer (n = 9)	106,500	11,833	8,000 to 16,000

Table 6-8b. Hours in Type (B747)

Position	Total Hours in Type	Mean	Range
Captain (n = 8)	26,500	3,312	1,000 to 6,000
First Officer (n = 9)	16,780	1,864	80 to 3,500

<u>Survey Items 1 through 4.</u>

Items 1 through 4 of the survey refer to various types of ATC-directed breakouts when using autopilot versus when autopilot is not used. For each of these items the each pilot was asked to indicate a rating by circling one of five numbers on a five-point scale:

1	2	3	4	5
Strongly Disagree		Neutral		Strongly Agree

The survey items are listed below. Table 6-9 lists the number and percentage of pilot responses to Survey Items 1 through 4. Figure 6-4 graphically depicts the ratings of ease of executing ATC-directed breakouts when autopilot is used versus when it is not used for both climbing and descending breakouts.

Survey Item 1. **The ATC-directed climbing breakout is easy to execute when using autopilot.**

Survey Item 2. **The ATC-directed climbing breakout is easy to execute when autopilot is not used.**

Survey Item 3. **The ATC-directed descending breakout is easy to execute when using autopilot.**

Survey Item 4. **The ATC-directed descending breakout is easy to execute when autopilot is not used.**

Table 6-9. Ratings of Ease of Executing ATC-Directed Breakouts

Item	Type of Breakout	Operation Mode	Strongly Disagree		Neutral		Strongly Agree
			1	2	3	4	5
1	climbing	using autopilot	0	3 (16.7%)	2 (11.1%)	4 (22.2%)	9 (50%)
2	climbing	autopilot not used	1 (5.6%)	4 (22.2%)	2 (11.1%)	5 (27.8%)	6 (33.3%)
3	descending	using autopilot	5 (27.8%)	7 (38.9%)	2 (11%)	3 (16.7%)	1 (5.6%)
4	descending	autopilot not used	1 (5.6%)	3 (16.7%)	6 (33%)	7 (38.9%)	1 (5.6%)

Comments made by pilots in response to each of the four questions are listed below. For purposes of categorizing comments, the data analyst has assumed that a response of "2" is indicative of "disagree" and a response of "4" is indicative of "agree."

Survey Item 1. **The ATC-directed climbing breakout is easy to execute when using autopilot.**

Comments were:

- (disagree) autopilot too slow
- (disagree) Anything on final approach other than normal go-around SOP (standard operating procedure) is not easy.

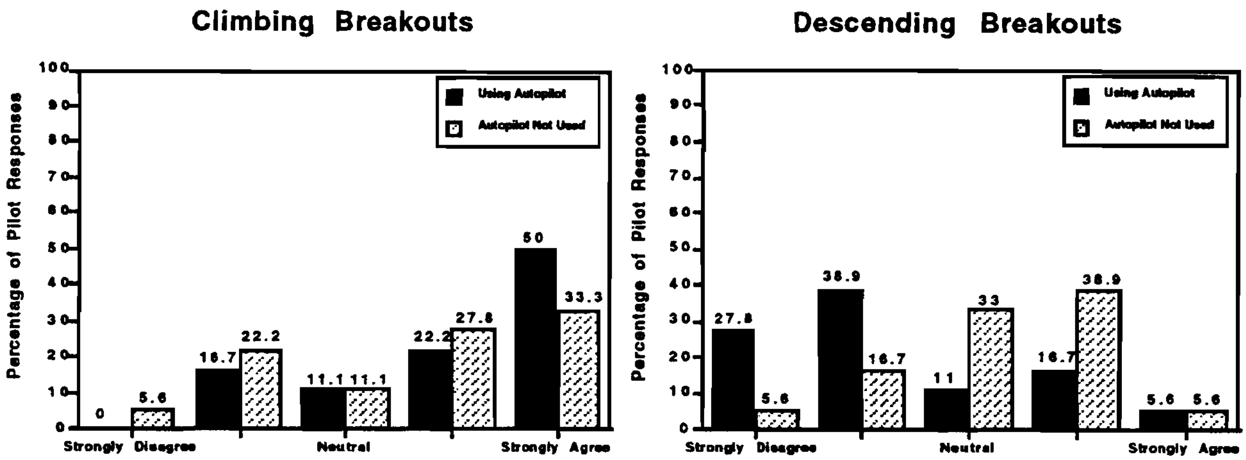


Figure 6-4. Ratings of ease of executing ATC-directed climbing and descending breakouts.

- (neutral) Proficiency makes it easier but under normal conditions where proficiency is difficult to maintain, hand flying is easier.
- (agree) after practice
- (strongly agree) The autopilot provides bank angle protection.
- (strongly agree) PF and PNF hands conflict with one selecting heading and other altitude.
- (strongly agree) follows practiced SOP

<u>Survey Item 2</u>. **The ATC-directed <u>climbing</u> breakout is easy to execute when <u>autopilot is not used</u>.**

Comments were:

- (agree) easier than using autopilot
- (strongly agree) follows practiced SOP
- (strongly agree) Non-autopilot procedures don't require as much mental thinking or time to execute.

<u>Survey Item 3</u>. **The ATC-directed <u>descending</u> breakout is easy to execute when <u>using autopilot</u>.**

Comments were:

- (strongly disagree) Descending breakout is such an abnormal maneuver it would require extensive training and would still not be a safe operation in real operations.
- (strongly disagree) potentially dangerous situation
- (strongly disagree) Descending is hard to do if using TO/GA.
- (strongly disagree) This is the toughest maneuver on autopilot because of the configuration required.

- (disagree) fights aircraft auto logic design
- (disagree) This is the hardest of the scenarios.
- (disagree) Too many button pushes that must be done quickly and in the proper sequence, too many chances for errors.
- (neutral) only because altitude command is not given first
- (neutral) not a normal expected clearance for a go around or missed approach procedure

Survey Item 4. **The ATC-directed descending breakout is easy to execute when autopilot is not used.**

Comments were:

- (disagree) Descending breakout idea is a bad one. Close parallel approaches need to be redesigned if they depend on this as an ATC option.
- (disagree) Altitude should be selected prior to use of the vertical speed (altitude protection).
- (neutral) easier to accomplish raw data
- (neutral) You can pull off power.
- (neutral) An unnatural maneuver for most pilots, i.e., diving towards the ground.

As seen in Table 6-10 below, mean ratings to Items 1 through 4 show that pilots rated descending versus climbing breakouts as being more difficult to perform (please note that in the scale used, higher numbers mean that the task was easier and lower numbers mean that the task was more difficult).

Table 6-10. Mean Ratings of Ease of Executing a Breakout

Type of Breakouts	Mean (n = 18)	Standard Deviation
1. Climbing Breakout, Using Autopilot	4.05	1.34
2. Climbing Breakout, When Autopilot Not Used	3.61	1.78
3. Descending Breakout, Using Autopilot	2.33	1.52
4. Descending Breakout, When Autopilot Not Used	3.22	1.00

To determine whether within climbing and descending breakouts, there is a significant difference in ratings when autopilot is used versus not used, two t-tests (paired two sample for mean) were performed. Ratings to item 1 (climbing breakout, using autopilot) versus ratings to

Item 2 (climbing breakout, not using autopilot) were compared. T-test results were $t(17) = 3.68$, $p < .001$; i.e., indicating a highly significant difference. Ratings to Item 3 (descending breakout, using autopilot) versus ratings to item 4 (descending breakout, not using autopilot) were compared. T-test results were $t(17) = -5.57$, $p = <.001$, i.e., indicating a highly significant difference. The conclusion is that pilots expressed that the climbing breakouts were easier to perform when the autopilot was used versus when autopilot is not used. Conversely, pilots expressed that the descending breakouts were easier to perform when the autopilot is not used versus when it is used.

Survey Item 5. More crew coordination is required for simultaneous close parallel approaches than for normal ILS (Instrument Landing System) approaches.

Each pilots was asked to respond by using a 5-point scale of Strongly Disagree (1) to Strongly Agree (5). Fourteen of the eighteen pilots (77.7%) responded "4" or "5" indicating that they agreed or strongly agreed that more crew coordination is required for simultaneous close parallel approaches than for normal ILS approaches. The remaining four pilots responded "3" indicating that their opinion to be "neutral." Comments were:

- (neutral) Only because of one additional maneuver required. Once briefed, crew coordination should be no more difficult than other operations.
- (neutral) Faster adherence may require more coordination.
- (strongly agree) Once inbound we only think about landing and go arounds. This third super NON-SOP (non-standard operating procedure) breakout just about doubles workload with autopilot.

Survey Items 6, 7 and 9 concerned the use of various types of information sources and training materials and their ability to help to increase situational awareness. Each question is listed below. Figure 6-5 graphically illustrates the responses to each of the questions. Eighteen pilots responded to each of these questions except in response to Survey Item 7, seventeen pilots responded.

Survey Item 6. The approach plate notes regarding simultaneous close parallel approaches increased my awareness of possible traffic in close proximity on the adjacent approach.

Survey Item 7. The airport information page increased my awareness of simultaneous close parallel approach procedures.

Survey Item 9. The video material increased my awareness of simultaneous close parallel approach operations.

Following Survey Items 6 (regarding approach plate notes), 7 (regarding airport information page) and 9 (regarding video material), each pilot was asked to list comments. Comments were made only regarding the approach plate notes and are listed below:

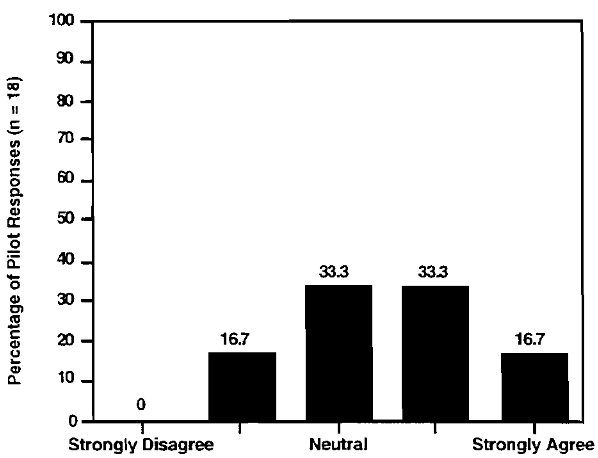
Approach Plate Notes

- Yes, but need much more reinforcement before doing breakout.

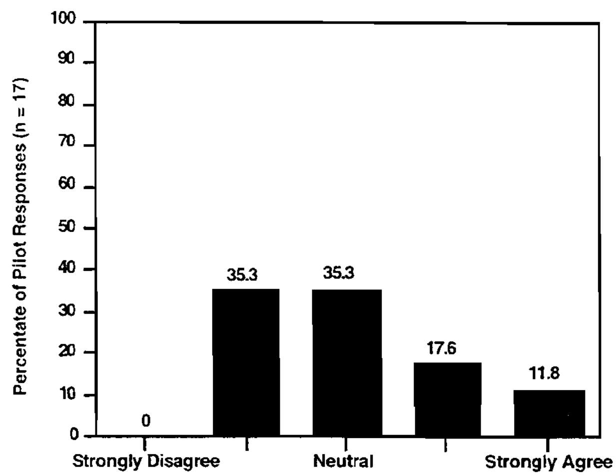
Approach Plate Notes

- Yes, but need much more reinforcement before doing breakout.
- ATIS (Automatic Terminal Information System) information or Approach Controller reminds is enough awareness.
- Verbal notification that such procedures are actually in effect are most helpful.
- Should have extra large, extra bold print, if not a separate approach plate like converging approach.
- ATIS or Tower Advisory would be a better "heads up."

6. Approach Plate Notes



7. Airport Information Page



9. Video Material

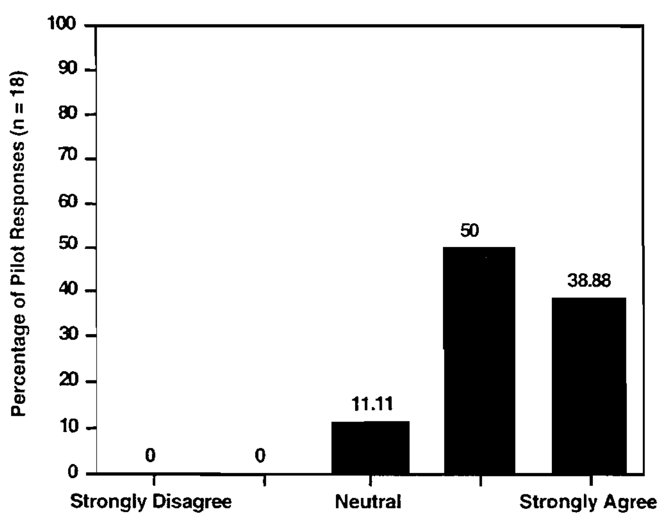


Figure 6-5. Ratings of Approach Plate Notes, Airport Information Page, and Video Material for increasing situational awareness.

<u>Survey Item 8</u>. The <u>new ATC phraseology</u> ("Traffic Alert") coupled with the word "immediately" encouraged me to respond <u>more quickly</u> to the breakout maneuver than I would have if only the work "immediately" were used.

As seen in Figure 6-6, the vast majority of pilots agreed or strongly agreed that the new ATC phraseology ("Traffic Alert") coupled with the word "immediately" encouraged them to respond more quickly to the breakout maneuver than they would have if only the work "immediately" were used.

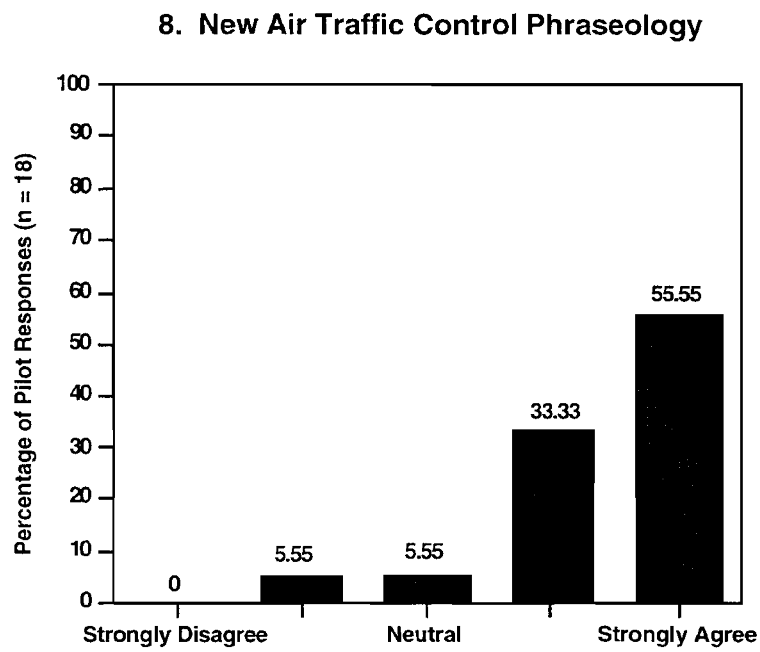


Figure 6-6. Ratings of new Air Traffic Control phraseology's effectiveness in encouraging a quicker response.

Pilot comments regarding the new Air Traffic Control phraseology were:

- Key word is trigger, not necessarily "Traffic alert," just a phrase specific to the maneuver.
- I found I was waiting for the HDG and ALT longer than I expected before hearing the information. Maybe less verbiage like, "United 426 ... Traffic Alert ... Left heading 280, climb 4000."
- I agree, however, it too closely resembles "traffic, traffic" from TCAS (Traffic Alert and Collision Avoidance System). It should say "collision or crash alert."
- "Traffic Alert" tells me what the reason for the clearance might be, but when I hear "immediately" anytime from ATC it conveys the importance of compliance "NOW."

- "Traffic Alert" should probably be said twice, such as, "Traffic Alert, Northwest 426, Traffic Alert, turn left immediately heading 285, etc."
- In the interest of safe operation doing any "flying" task more quickly is ill advised.

<u>Survey Item 10</u>. **The <u>training bulletins</u> increased my <u>understanding</u> of what is expected of me during simultaneous close parallel approaches.**

<u>Survey Item 11</u>. **The <u>training bulletins</u> helped me to <u>execute</u> the ATC-directed breakout.**

As seen in Figure 6-7, the vast majority of pilots agreed or strongly agreed on the positive effects of the training bulletins.

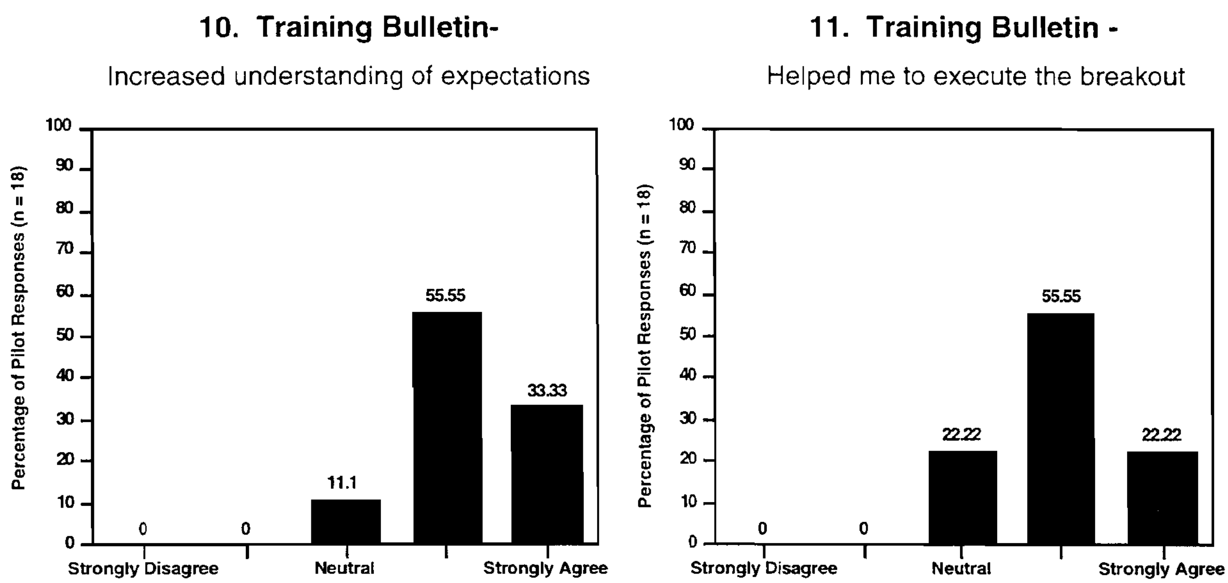


Figure 6-7. Ratings of the effectiveness of the training bulletin.

Comments made regarding the statement in Item 10 were:

- These were good. Directed attention to specific action required. However, they are very ambiguous and contradict SOP.
- It is important to emphasize the immediacy of the required action.

Comments made regarding the statement in Item 11 were:

- Maneuver has to be reinforced in simulation training.
- Company bulletins and training at NWA (Northwest Airlines) will be enough to train me to proficiency.
- A good start, need more work on details

- Some airline training differences, United versus Northwest, had to be compensated for. (Experimenter's Note: This comment was from a crew composed of one pilot from each of these airlines.)

<u>Survey Item 12</u>. **During the <u>hand-flown breakout</u> procedure, I preferred to (circle one choice):**

(1) have the flight director turned back on immediately and ignore the pitch and roll commands (i.e., fly through the flight director).

(2) keep the flight director off until the pitch and roll commands matched the desired flight path, then turn the flight director back on.

(3) no preference

Pilots responded by circling one of the above choices. Two of the 18 pilots (11.11%) chose item (1), to fly through the flight director. The majority, 15 out of 18 pilots (83.33%), selected item (2) to keep the flight director off until it matched the desired flight plan. One pilot (5.55%) reported no preference. The distribution of responses is depicted in Figure 6-8.

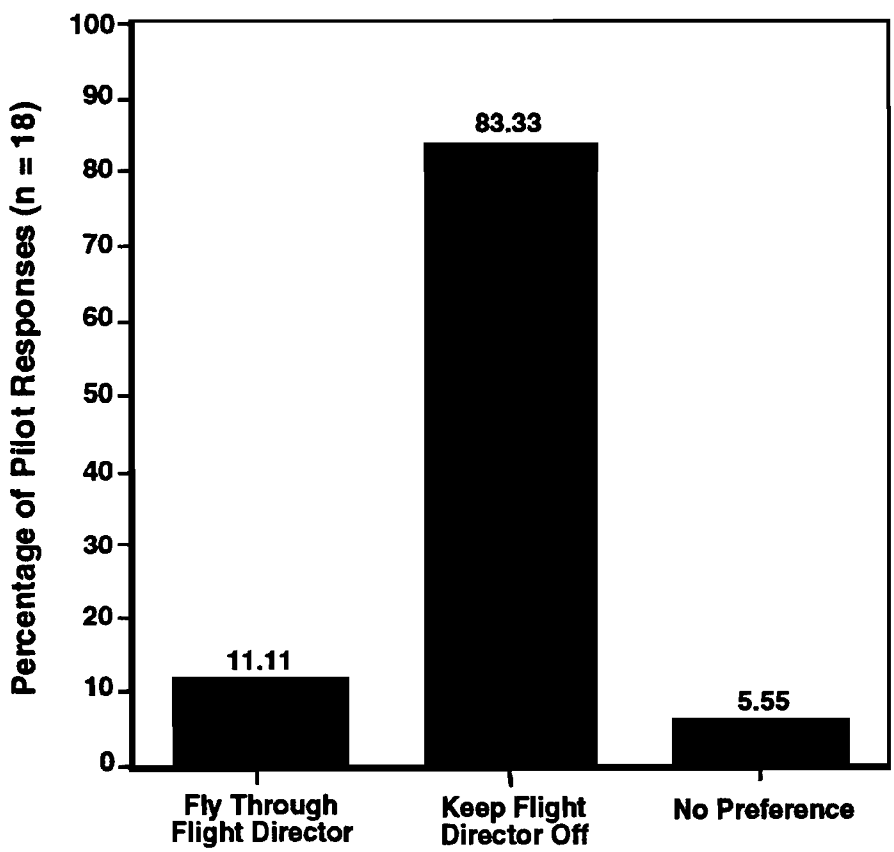


Figure 6-8. Mode preference for flying the hand-flown breakout procedure.

Comments were made by pilots who selected "hand flown/flight director":

- turned back on as soon as valid information is available on heading and altitude
- I like it back on when called for by the PF.
- Same thing applies to the auto throttle.
- I tend to fly through the flight director until it tends to match what I'm doing.

<u>Survey Item 13</u>. **Based on your experience in this study, I would choose to execute the ATC-directed breakout?**

Each pilot responded by selecting from the following choices:

1	2	3
Using Autopilot	Hand Flown	No Preference

Seven pilots of the eighteen pilots (39%) chose "using autopilot." Nine pilots of the eighteen pilots (50%) chose "hand flown" and two pilots (11%) reporting having "no preference." The distribution of responses is seen in Figure 6-9.

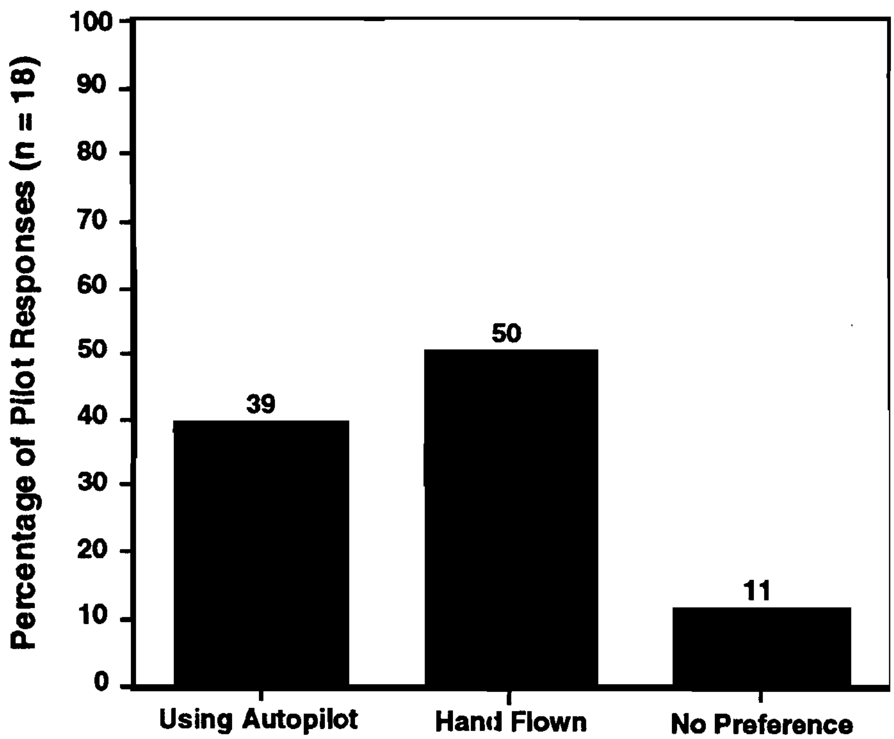


Figure 6-9. Mode preference for executing the ATC-directed breakout.

Comments were made by pilots who selected "hand flown/flight director":

- This is my SOP for quick reaction.
- much faster response
- It is more difficult to hand-fly rather than autopilot, but I feel hand flying turns the aircraft away from danger sooner, which was stressed several times to be extremely important. Autopilot operation is easier and requires less crew input, and may be safer when all factors (crew alertness, turbulence, crew abilities (time in aircraft), etc.) are brought into the equation. Personally, I found the actual flying of relatively manageable demand.
- The autopilot requires intimate/thorough familiarity with the step-by-step sequence in order to execute the procedure.

Comments were made by pilots who selected "using autopilot":

- staying in autopilot mode would ease subsequent workload
- Much smoother operation when done properly.
- If the autopilot is on at the time. If not, then hand fly.

<u>Survey Item 14.</u> **Should Approach Procedure Charts for simultaneous close parallel approach procedures have a special title similar to Category II/III approach charts?**

Each pilot was asked to indicate a rating by circling one of five numbers on a five-point scale. The number of pilot ratings selected are shown in Figure 6-10.

Comments were:

- a different color or chart would help as well
- The ATIS (Automatic Terminal Information System) could also include information that close parallel approaches are in use.

<u>Survey Item 15.</u> **Have you participated in other simulations for the FAA? If yes, which studies and/or when?**

Pilots were asked to respond "Yes" or "No." Seventeen (94%) pilots of the eighteen pilots indicated "yes," i.e., that they had participated in another simulation for the FAA. One pilot indicated "no." Comments were:

- taxi practice at ORD (Chicago O'Hare)
- converging approaches, low visibility taxing
- converging ILS (Instrument Landing System) / missed approach @ ORD
- too many to list
- taxi - low visibility and data link
- glass cockpit B747 Phase 2
- Glass cockpit Phase 2, Ground Navigation Study

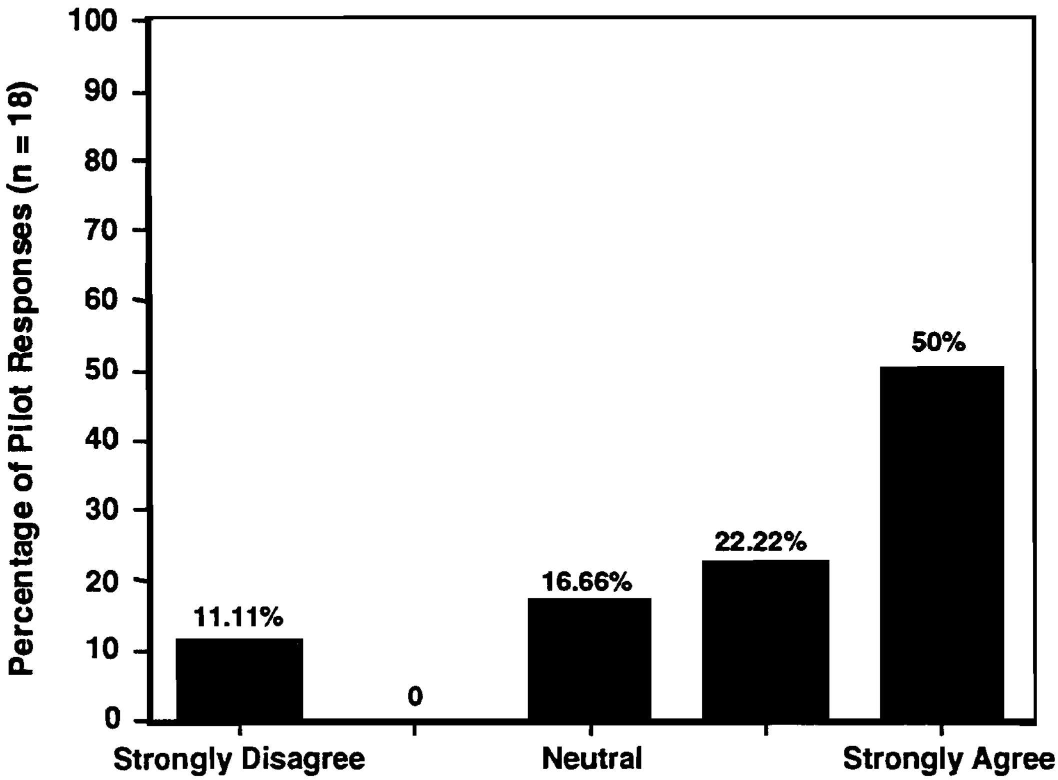


Figure 6-10. The need for special titles on approach plate charts for simultaneous close parallel approaches.

- converging approaches, moving map / ground operations 1995, data link 1993 - 1994
- MLS (Microwave Landing System) Study, approximately 1991
- earlier stages of this study
- 1995, close parallel approaches and 1995, moving map
- parallel / low visibility / TCAS
- close parallel approaches, Phase 1
- close parallel approaches without training (Phase 1)
- taxi, map, others
- close parallel approaches, earlier phase

<u>Survey Item 16</u>. **What additional information or training would you like to have for simultaneous close parallel approach procedures?**

Comments were:

- Canned procedure would be helpful. The words "climb" or descend" should be issued first, would speed up action for pitch.

- The crews will need to fly multiple approaches – simultaneous close parallel approach procedures – if you expect them to do them correctly. Very seldom is any missed approach ever done. Descending go arounds especially need to be practiced.
- These missed approaches added to initial training and recurrence.
- Information provided was adequate.
- This seems to be enough to me, but what about all the rest of the line pilots that are not afforded this very valuable opportunity?
- Have a unified company procedure for ascending and descending breakouts.
- Need a defined and practiced maneuver done each year at ART (annual recurrency training?).
- Just more of the simulator training like we just had.
- A special training package would be needed as some of the procedures differ so greatly from the SOP we practice now just as some airports require special qualification training, these approaches require the same.
- Breakout training will definitely need to be practiced and should be incorporated with UAL (United Airlines) SOPs. I believe everyone will find the hand-flown more expeditious.
- Would need at least one simulator period to become comfortable with these procedures.
- This is a procedure that will have to be practiced frequently – particularly the descending breakout with autopilot engaged. The need for immediate compliance with breakout instructions must be stressed in training.
- With TCAS display it may help to increase reaction times, as to where to turn and climb the aircraft.
- an exact step-by-step procedure to be used under each type of breakout maneuver
- written material and simulator training
- Suggestion: As an approach plate has bold lettering for CAT III, an approach chart should have large, bold lettering, alerting flight crew that "Traffic Alert" commands may be issued.
- A company procedure in place would decrease surprise factor.

<u>Survey Item 17</u>. **Additional comments about the training materials, test scenarios, or other aspects of the study:**

- Should be recurrent training requirement. TA - Traffic Alert - is used with TCAS.
- For the second half it should be emphasized that only: (1) manual go arounds are to be done, autopilot must be off, (2) TO/GA should not be used, and (3) more thinking needs to be done for these kinds of go arounds. "Climb" or "descend" should be given in first part of instruction by ATC.

- all satisfactory
  (1) On a climbing breakout, I preferred to hit the TO/GA button once to establish a climb power setter; then have autopilot disengaged.
  (2) It seems to me from a mathematical viewpoint, the NTZ (no transgression zone) should narrow and disappear by touchdown point – say at 50' - 100' you only have a couple seconds to touch down and the seconds to get to your runway seems apparently meaningless.
- well done
- well run, well organized
- It would have been more realistic to move from 36L (left) to 36R (right) randomly so that the turn out procedure would differ on each approach.
- For hand-flown I prefer the heading first and altitude from instruction. Using the autopilot where we have to deal with pitch control first, I found ATC directions backwards and had to get repeats many times.
- Very interesting, enjoyed this very much.
- Very good, enlightening study. Shows some things you have to put some thought into. Something that would be very helpful would be an easier way to get out of the approach mode. Perhaps a button which will arm an "escape" mode so that pushing heading select will put the autopilot into heading select mode directly without having to go through TO/GA.
- Vary the profiles to include localizer turn-ons and clearances to keep crews from becoming complacent. Initial ATC instructions should be turn left or right and climb or descend. Then specific HDG and ALT can be assigned.
- The autopilot use during a breakout maneuver can create problems with both set of hands attempting to operate the Mode Control Panel, even though the autopilot would be preferable to hand flying. Modify the V/S before setting an altitude on the descending breakout.
- This type of procedure requires significant training, if it is to produce acceptable performance. If it will be placed in service, then every recurrent training should practice the maneuvers and switch manipulations.
- Good training. Need this type training proficiency checks to air carriers.

6.3.1 Summary of Phase 3 Survey Findings

Pilots expressed that the climbing breakouts were easier to perform when the autopilot was used versus when autopilot is not used. Conversely, pilots expressed that the descending breakouts were easier to perform when the autopilot is not used versus when it is used.

In Survey Item 12, the following was asked: "During the hand-flown breakout procedure, I preferred to (circle one choice):

(1) have the flight director turned back on immediately and ignore the pitch and roll commands (i.e., fly through the flight director)

(2) keep the flight director off until the pitch and roll commands matched the desired flight path, then turn the flight director back on.

(3) no preference

The vast majority of pilots responded with the preference to keep the flight director off.

When pilots were asked (in Item 13) "Based on your experience in this study, how would you choose to execute the ATC-directed breakout?", opinion was mixed with a tendency toward hand flown versus using autopilot.

In both Phases 2 and 3 it was found that, as a result of the training materials provided pilots reported a sense of heightened awareness and urgency regarding simultaneous approaches to closely space parallel runways in IMC. Pilots also reported a heightened awareness and sense of urgency due to the new Air Traffic Control phraseology that included the term "Traffic Alert." In both Phase 2 and 3 it was found that pilots reported that increased crew coordination is required for simultaneous close parallel approaches.

7. DISCUSSION

7.1 RESEARCH QUESTIONS

The three testable questions posed in Section 1.2 asked about the B747-400 breakout performance during each phase and how the performance compared to that observed in the B727 and DC10 studies. These questions were further refined into the eleven research questions posed in Section 2.4.

Research question 1 asked if Phase 1 turn performance met the test criteria for mean and maximum values. The conclusion was that turn performance given current training and procedures did not meet the test criteria for either hand-flown or autopilot-coupled approaches. Although the mean time from start of ATC transmission to start of roll was less than 8 seconds for hand-flown breakouts following hand-flown approaches (HF/HF), there were two trials at the Category I decision altitude in which time to start of roll was greater than 17 seconds. If breakouts at decision altitude were removed from the data set, then HF/HF turn performance would have been acceptable. Breakout performance following autopilot-coupled approaches was unacceptable for all breakout groups: mean time to start of roll was greater than 8 seconds and 29 percent of the time to start of roll values were greater than 17 seconds. The breakouts were faster, in general, when the autopilot was disconnected and the turn was manually executed (AP/HF) rather than automatically executed (AP/AP), but AP/HF performance still did not meet the test criteria.

Research questions 2 and 3 asked about pilot comfort executing climbing breakouts below 400 feet AGL and descending breakouts above 1000 feet AGL during Phase 1. The majority of pilots rated climbing breakouts at decision altitude as somewhat to moderately difficult. In comparison, the majority rated climbing breakouts inside the outer marker as somewhat difficult and climbing breakouts outside the outer marker as not at all difficult. Descending breakouts were rated as being significantly more difficult than climbing breakouts. There was no significant difference in the ratings for autopilot-coupled approaches versus hand-flown approaches.

These survey findings were in contrast to the observed breakout performance. The analysis of variance indicated that autopilot-coupled approaches took longer, on average, to turn initiation, especially at decision altitude. In response to the survey question, some pilots indicated that they preferred autopilot mode because of reduced pilot workload. These differing results suggest that while autopilot breakouts reduced the workload, the pilots were not aware of the significant difference in overall breakout performance between the two modes of operation. The analysis of variance also indicated no significant difference in mean time to start of turn for descending versus climbing breakouts while the pilots rated descending breakouts as being significantly more difficult. Several pilots commented that descending breakouts were not expected. These differing results suggest that although the pilots were not prepared for descending breakouts and found them to be more challenging because they were not standard operating procedure, the lack of familiarity did not prevent the majority of pilots from executing descending breakouts as quickly as climbing breakouts.

Research question 5 asked if the Phase 2 situational awareness training resulted in faster response times that met the test criteria. The conclusion was that increased situational awareness did not sufficiently improve turn performance. As presented in Figures 5-10 and 5-11, the majority of times to start of turn following hand-flown approaches were around 4 seconds in Phase 1, and 5 seconds in Phase 2. The increase is attributable to the increased length of the ATC breakout transmission. In addition, there was one time to start of turn greater than 17 seconds for a breakout at 700 feet AGL. The observer notes indicated that this pilot waited for the heading information to be entered, then followed the flight director. There also was no significant improvement in mean or maximum time to start of roll for breakouts following autopilot-coupled approaches.

Research question 6 asked which of the situational awareness aids were most helpful to the pilots. All pilots agreed that the additional phraseology was useful, although some felt that a phrase other than "Traffic Alert" would be better. All but one pilot also felt that the approach plate notes heightened awareness to the possibility of another aircraft nearby and that the airport advisory page increased crew awareness to a level similar to that for a Category II or Category III approach.

In addition, the pilots were asked to rate the difficulty of executing climbing and descending breakouts with and without the autopilot connected. The pilots rated descending breakouts as being more difficult than climbing breakouts, whether or not the autopilot was engaged. This was similar to the finding in Phase 1. In addition the pilots rated both climbing and descending breakouts to be more difficult when the autopilot was engaged than when they were flying manually using the flight director. Pilot perception of the difficulty of executing the various breakouts was in partial agreement with the analysis of variance. As with Phase 1, mean time to start of turn was significantly larger following autopilot-coupled approaches than following manual approaches. However, although the mean time to start of turn was greater for descending breakouts than for climbing breakouts, there was sufficient within-subject variability that the difference was not considered to be statistically significant.

Research question 7 asked if the addition of the written breakout procedure in Phase 3 resulted in turn performance that met the test criteria. The conclusion was that turn performance met the test criteria for the hand-flown breakout procedure but that there was no improvement in autopilot breakout performance given the tested autopilot breakout procedure. All turns were initiated in less than 17 seconds when the pilots were required to disconnect the autopilot and fly the breakout manually. This suggests that giving the pilots a manual breakout procedure could have also eliminated the few slow response times following hand-flown approaches that were observed in Phase 1 and in Phase 2, because the pilots would have been trained to not wait for the flight director to prompt the roll. The results for the autopilot breakout procedure indicate that there was a physical limit as to how quickly the pilots could enter the new heading into the flight management system and how quickly the automation would respond. There was a delay while the pilot assimilated the ATC instruction, then a delay while he moved his hand to the heading knob and entered the new heading. The exploratory analysis indicated that there then was a 3.3-second delay from the time the heading was selected to when the roll was automatically initiated. For autopilot-coupled breakouts at decision altitude, there was an additional delay because the flight management system would not accept heading input until the aircraft was above 400 feet AGL. The pilot comments in Phase 3 suggest that not all pilots were aware that the aircraft must be above 400 feet before they could select the new heading.

Research question 8 asked if the Phase 3 pilots preferred either the manual or autopilot breakout procedure. The results from the pilot survey were inconclusive. The pilots felt that climbing breakouts were easier to perform when the autopilot was used, but that descending breakouts were easier to perform when the autopilot was not used. In addition, there was no clear consensus that either breakout mode was preferable, although more pilots said that, based on their experience in the study, they would choose to execute a hand-flown breakout.

As in Phase 1 and Phase 2, the pilots were asked about the difficulty of executing the various breakouts. Similar to the findings in the previous surveys, the pilots agreed that climbing breakouts were easy to execute, with or with the autopilot. The pilots disagreed that descending breakouts were easy when the autopilot was used; however they were mostly neutral or agreed that descending breakouts were easy when the autopilot was not used. This is in contrast with the previous phases, when the pilots rated all descending breakouts as being difficult to execute. Because the majority of pilots in Phase 3 had participated in at least one of the previous phases, it cannot be ascertained if this change in perception was a result of the manual breakout procedure or of their previous experience.

As in Phase 2, the pilots were asked to rate the effectiveness of the approach plate notes, airport information page and video material. The majority were neutral or agreed that the approach plate notes increased awareness of possible nearby traffic. Several pilots commented that verbal notice such as ATIS or a tower advisory would be more useful. The majority were neutral or disagreed that the airport information page increased their awareness of simultaneous close parallel approach procedures. This result differs from the finding in Phase 2. Finally, all but one subject agreed or strongly agreed that the video material increased their awareness of simultaneous close parallel operations. The pilots also agreed that the new ATC phraseology encouraged a quicker response.

Research questions 4, 9, 10, and 11 asked if any of the test conditions (independent variables) affected breakout performance in general. One conclusion was that altitude affected mean times to thrust increase and start of climb but not mean time to start of roll. As altitude increased, mean times to thrust and vertical speed changes increased. This suggests that the priority at low altitudes was to expedite the climb and increase altitude in order to execute the turn safely. As altitude increased, obstacle clearance appeared to be less of a concern, and the crews could concentrate on other actions such as expediting the turn. Another conclusion was that approach mode affected mean times to start of roll and start of climb but not mean time to thrust increase. The third conclusion, as mentioned above, was that breakout direction did not significantly affect mean time to start of roll. Thrust and vertical speed usually remained constant during descending breakouts, therefore were not tested. No conclusion was made concerning the effect of cockpit distractions on breakout performance because the engine-out event resulted in an emergency rather than a distraction. If there were an engine failure, however, the results indicate that it would be better if the autopilot were engaged.

With respect to the level of B747-400 pilot training required for ATC-directed breakouts, one conclusion was that there was not a significant problem executing the breakouts following manual (hand-flown) approaches, especially if ATC-directed breakouts were restricted to altitudes greater than 400 feet AGL. One HF/HF breakout out of 79 executed above 400 feet AGL had a time to start of turn greater than 17 seconds. There may have been no long response times if the pilots had been trained to ignore the flight director. The other conclusion was that increased pilot situational awareness and the modified ATC phraseology together with the manual breakout procedure were required when the autopilot was connected during final approach in order to meet the test criteria for turn performance.

7.2 ANCILLARY ISSUES

There were additional survey questions that solicited pilot opinion regarding other aspects of ATC-directed breakouts. Based on their experience in Phase 1, the pilots felt there was a need for training and heightened situational awareness; the majority felt that their response would have been different at low altitude if they had received the additional training. All crews responded that they developed a strategy for executing the breakout. These responses suggest that practicing a specific breakout procedure would improve pilot comfort with the maneuver. When asked what, if any, aircraft limitations did they think caused an inherent unwanted delay, the most frequent responses were that there was no heading select below 400 feet, and that the autopilot design led to slower autopilot responses versus hand-flying the breakout. These observations confirm the observed breakout performance, especially at decision altitude.

In Phase 2, several pilots commented that the ATC-directed breakout is not standard operating procedure, and that descending breakouts are not expected and/or should not be allowed. In response to another question, 85 percent stated that they would prefer flying close parallel approaches with the autopilot rather than manually even though the breakout maneuver may be more difficult because the normal workload is less, and the pilots could concentrate on the breakout.

During the planning stage for this study, there was concern that the observed breakouts would not realistically represent what would be observed during live operations. ATC-directed breakouts are rare events, yet each subject would execute several within a short time period. One concern was that the pilots would quickly "learn the game" and the response times would be faster than expected. The other concern was that the pilots would be more aggressive than they would in a real aircraft.

The data indicated that normal operating envelope was not exceeded during most of the trials, as measured by maximum roll angle. Out of 265 manually-executed turns, 8.3 percent (22) had a maximum roll angle that exceeded 30 degrees. Of these, 18 values were less than 34 degrees. The length of time that the roll angles remained above 30 degrees was not measured, so it is unknown if these were temporary events that resulted from the acceleration into the turn or if the pilots maintained the large roll. In contrast, there was a greater number of manual breakouts for which the maximum roll angle was less than what was achieved using the automation. These results suggest that, in general, the pilots were more conservative than the automation in executing the turn. There were a few unexpected roll angles, but they may have been a result of the pilots compensating for slow aircraft response rather than an indication of aggressive behavior.

The within-subject repeated measures in Phase 2 and Phase 3 were designed to test whether or not there were observable practice effects. Although the pilots indicated on the surveys that they developed strategies and cockpit coordination was observed to improve with time, the increasing pilot comfort with executing the breakouts did not result in measurably-faster performance.

7.3 RECOMMENDATIONS FOR FUTURE STUDIES

This study highlights the need to evaluate the performance of representative aircraft during ATC-directed breakouts. The B727 and DC10 originally tested in 1989 are older, analog aircraft that are not as difficult to fly as newer advanced avionics aircraft. The results from the B727 and DC10 studies did not indicate a need for additional pilot training. Awareness of the intent of the word "immediate" was sufficient for a distribution of breakout responses that resulted in the successful risk analysis during the Precision Runway Monitor Demonstration Program.

The results from this study, however, indicate that the B747-400 automation induced an unwanted delay in start of turn. The results also indicated that the best way to effectively minimize the effect of the automation was to train the pilots to disconnect the autopilot and hand-fly the breakout. It would be useful to know if the automation in other newer aircraft models can also result in undesirable breakout performance. Thus, we recommend that breakout performance testing continue with other advanced avionics aircraft.

As with any simulation, there was concern about the realism of this study, and whether or not a large number of breakouts in a short period would induce more aggressive responses than would be observed during field operations. Ideally, the experimental design would have interspersed a few breakout scenarios among many standard operations such as landings and missed approaches. However, time and fiscal constraints required a larger percentage of breakout scenarios in order to test the effect of all the independent variables within a few hours.

Based on observations during this study, there are several recommendations as to changes that could be effected that would mitigate the concerns in future studies. The first observation is that within-subject variability was larger than any practice effects, therefore it is unnecessary to include as many (or any) within-subject replicates. Since breakout maneuvers are a complex system in which multiple pilot actions affect overall performance, any attempt to measure practice effects within a short time frame will lead to inconclusive results. Four out of 20 breakout scenarios in the Phase 3 design were within-subject replicates. If these had been replaced with landing or missed approach scenarios, breakout scenarios would have accounted for 67 percent instead of 83 percent of the trials.

Another recommendation to mitigate practice effects is to vary the order in which the breakouts are presented. In Phase 1, all crews received the breakouts in the same order. In Phase 2 and Phase 3, half the crews received the breakouts in the reverse order, which was similar to the forward order. A simple implementation that varies the order would be to keep the same scenario sequence but to start each session at a different trial index. For example, the first crew would start with the first trial, the second crew could start with the third scenario, the third crew could start with the sixth scenario; and so forth. This approach is similar to the concept of a latin square design.

Finally, practice effects could be mitigated by testing altitude groups rather than discrete altitudes. The motivation for this recommendation is that the range from threshold and altitude are displayed on the navigation display and primary flight display in advanced avionics aircraft, so the pilots may learn at which altitudes to expect a breakout. The results from Phase 2 indicated that there was no measurable difference in performance above 400 feet AGL for breakouts within 200 feet of one another. Thus, instead of testing all breakouts outside the outer marker at 1800 feet AGL and all breakouts inside the outer marker at 500 feet AGL, replicate samples could occur between 1700 and 2000 feet AGL and between 500 and 800 feet AGL. This 300-foot variability in altitude is equivalent to a 1-nautical mile variability in range.

7.4 CONCLUSIONS

The main purpose of this study was to determine the level of B747-400 pilot training required for ATC-directed breakouts in order to ensure a satisfactory level of safety. The only available quantitative measures for acceptable performance were the statistics for time to start of turn from the Precision Runway Monitor Demonstration Program. Because of significant differences in performance, breakouts during manual approaches were assessed separately from breakouts during autopilot-coupled approaches.

Breakout performance during manual approaches was marginally unacceptable. Mean time to start of turn was less than 8 seconds during both Phase 1 and Phase 2, but three trials had time to start of turn values greater than 17 seconds. Two of the long response times occurred at decision altitude. The third long response was attributed to the pilot flying waiting until the heading information was entered into the flight director before starting the turn.

Breakout performance during autopilot-coupled approaches was unacceptable during Phases 1 and 2. Mean time to start of turn was greater than 8 seconds during both phases, and a significant number of breakouts took longer than 17 seconds to start of turn. The autopilot breakout procedure tested in Phase 3 did not improve turn performance for autopilot-coupled breakouts. Mean time to start of turn for climbing breakouts above 400 feet above ground level was greater than 13 seconds; and performance was worse for descending breakouts and for climbing breakouts at decision altitude. But, the hand-flown breakout procedure, together with increased situational awareness, did significantly improve turn performance for manual breakouts following autopilot-coupled approaches. Mean time to start of turn was less than 8 seconds and maximum time to start of turn was less than 17 seconds for all Phase 3 AP/HF breakouts, including those at decision altitude.

One conclusion was that there was not a significant problem executing the ATC-directed breakouts during manual final approaches. The majority of the times to start of turn were less than 5 seconds, so the small frequency of long response times should not adversely affect the safety of the operation. Although increased situational awareness did not improve breakout performance during manual approaches, training pilots to ignore the flight director during manual breakouts may remove the undesirably-slow responses. Overall breakout performance could also improve if ATC-directed turn maneuvers were discouraged below 400 feet above ground level.

The other conclusion was that the combination of additional ATC phraseology, increased situational awareness, and a manual breakout procedure was necessary in order to meet the test criteria for breakouts during autopilot-coupled approaches.

APPENDIX A. SCENARIO SEQUENCES

The following sections list the information for each test scenario in Phases 1, 2, and 3 in the order in which they were conducted. Breakout DME was the range (nautical miles) from the distance measuring equipment (DME) at which the air traffic controller started the breakout instruction. For Memphis runway 36L, the DME was 1.5 nautical miles beyond the runway threshold. Breakout heading, direction, and altitude were the values used in the breakout phraseology. Simulator scenario was the actual weather condition entered into the simulator, while the weather card was the weather reported to the air crew for that scenario. The actual and reported weather information are listed in Table A-1.

In Phase 1, the approaches were either hand-flown with the flight director on (HF) or using the autopilot coupled to the flight director (AP). Whether or not the breakout was conducted using the autopilot was at the discretion of the pilot flying. All HF approaches were Category I and all AP approaches were Category II. The scenario sequence was the same for all subject crews. The subjects were not assigned a priori to each scenario.

In Phase 2, the approaches were either hand-flown with the flight director on (HF) or using the autopilot coupled to the flight director (AP). Pilot flying was either the captain (C) or first officer (F). All approaches were Category I. Scenario order and pilot assignments were rotated among four sequence sheets listed in Section A.2.

In Phase 3, the approaches were all autopilot coupled to the flight director. Pilot flying was either the captain (C) or first officer (F). All approaches were Category I except scenarios 303 and 310, which were Category II. One half of the crews were trained for the autopilot-coupled breakout procedure (AP) for the first half session, and the manual breakout procedure (HF) for the second half session. The other crews were trained for the HF procedure in the first half and for the AP procedure in the second half. The same scenario order was used for all crews, but procedure training order and pilot assignments were rotated among the four sequence sheets listed in Section A.3.

Table A-1. Weather Conditions

Simulator Scenario:	001	300 overcast, visibility 1, wind 350/5
(actual weather)	002	Zero/Zero visibility, winds 350/5
	003	Zero/Zero visibility, winds 270/15
Weather Card:	1	300 overcast, visibility 1, wind 350/5, altimeter 29.92
(reported weather)	2	100 overcast, visibility 1/4, wind 350/5, altimeter 29.92
	3	200 overcast, visibility 1/2, wind 270/15, altimeter 29.92

A.1 PHASE 1

Phase 1 Test Sequence

Scenario	Approach	Simulator Scenario	Weather Card	Breakout DME	Breakout Heading	Breakout Direction	Breakout Altitude
100	HF	001	1	lands	—	—	—
111	HF	002	1	4.7	300	Climb	3500
116	HF	003	3	7.1	285	Descend	1800
105	AP	001	1	lands	—	—	—
103	AP	002	2	1.9	290	Climb	3000
108	HF	005	1	2.3	290	Climb	3000
109	HF	003	3	7.1	280	Climb	4000
100	HF	001	1	lands	—	—	—
115	HF	003	3	7.1	285	Climb	4200
113	HF	003	3	2.3	285	Climb	3000
112	HF	002	1	MA	—	—	—
110	AP	002	2	MA	—	—	—
106	AP	002	2	3.3	300	Climb	3000
107	AP	004	2	1.9	270	Climb	4000
117	AP	002	2	7.1	300	Descend	1800
104	AP	002	2	7.1	290	Climb	5000
100	HF	001	1	lands	—	—	—
114	AP	002	2	4.7	280	Climb	4000
103	AP	002	2	1.9	290	Climb	3000
113	HF	003	3	2.3	285	Climb	3000
101	AP	002	2	7.1	280	Climb	4000
102	HF	003	3	4.8	290	Climb	3700

* 107 and 108 include right engine failure shortly before breakout.

A.2 PHASE 2

Phase 2 Sequence 1 (Crews 1, 5)

Scenario	Approach	Pilot Flying	Simulator Scenario	Weather Card	Breakout DME	Breakout Heading	Breakout Direction	Breakout Altitude
201	AP	C	002	1	7.1	280	Climb	4000
214	AP	C	002	1	3.2	280	Climb	4000
205	AP	F	001	1	lands	—	—	—
218	AP	F	002	1	3.8	285	Climb	3500
204	AP	F	002	1	7.1	290	Climb	5000
217	AP	C	002	1	7.1	300	Descend	1800
211	HF	F	002	1	3.2	300	Climb	3500
206	AP	F	002	1	3.2	300	Climb	3000
212	HF	C	002	1	MA	—	—	—
209	HF	C	003	3	7.1	280	Climb	3500
215	HF	F	003	3	7.1	285	Climb	4200
216	HF	F	003	3	7.1	285	Descend	1800
214	AP	F	002	1	3.2	280	Climb	4000
202	HF	C	003	3	3.2	290	Climb	3700
200	HF	C	001	1	lands	—	—	—
201	AP	F	002	1	7.1	280	Climb	4000
219	HF	C	003	3	3.8	300	Climb	3000
210	AP	F	002	1	MA	—	—	—
206	AP	C	002	1	3.2	300	Climb	3000
204	AP	C	002	1	7.1	290	Climb	5000

Phase 2 Sequence 2 (Crews 2, 6)

Scenario	Approach	Pilot Flying	Simulator Scenario	Weather Card	Breakout DME	Breakout Heading	Breakout Direction	Breakout Altitude
201	AP	F	002	1	7.1	280	Climb	4000
214	AP	F	002	1	3.2	280	Climb	4000
205	AP	C	001	1	lands	—	—	—
218	AP	C	002	1	3.8	285	Climb	3500
204	AP	C	002	1	7.1	290	Climb	5000
217	AP	F	002	1	7.1	300	Descend	1800
211	HF	C	002	1	3.2	300	Climb	3500
206	AP	C	002	1	3.2	300	Climb	3000
212	HF	F	002	1	MA	—	—	—
209	HF	F	003	3	7.1	280	Climb	3500
215	HF	C	003	3	7.1	285	Climb	4200
216	HF	C	003	3	7.1	285	Descend	1800
214	AP	C	002	1	3.2	280	Climb	4000
202	HF	F	003	3	3.2	290	Climb	3700
200	HF	F	001	1	lands	—	—	—
201	AP	C	002	1	7.1	280	Climb	4000
219	HF	F	003	3	3.8	300	Climb	3000
210	AP	C	002	1	MA	—	—	—
206	AP	F	002	1	3.2	300	Climb	3000
204	AP	F	002	1	7.1	290	Climb	5000

Phase 2 Sequence 3 (Crews 3, 7)

Scenario	Approach	Pilot Flying	Simulator Scenario	Weather Card	Breakout DME	Breakout Heading	Breakout Direction	Breakout Altitude
204	AP	C	002	1	7.1	290	Climb	5000
206	AP	C	002	1	3.2	300	Climb	3000
210	AP	F	002	1	MA	—	—	—
219	HF	C	003	3	3.8	300	Climb	3000
201	AP	F	002	1	7.1	280	Climb	4000
200	HF	C	001	1	lands	—	—	—
202	HF	C	003	3	3.2	290	Climb	3700
214	AP	F	002	1	3.2	280	Climb	4000
216	HF	F	003	3	7.1	285	Descend	1800
215	HF	F	003	3	7.1	285	Climb	4200
209	HF	C	003	3	7.1	280	Climb	3500
212	HF	C	002	1	MA	—	—	—
206	AP	F	002	1	3.2	300	Climb	3000
211	HF	F	002	1	3.2	300	Climb	3500
217	AP	C	002	1	7.1	300	Descend	1800
204	AP	F	002	1	7.1	290	Climb	5000
218	AP	F	002	1	3.8	285	Climb	3500
205	AP	F	001	1	lands	—	—	—
214	AP	C	002	1	3.2	280	Climb	4000
201	AP	C	002	1	7.1	280	Climb	4000

Phase 2 Sequence 4 (Crew 4)

Scenario	Approach	Pilot Flying	Simulator Scenario	Weather Card	Breakout DME	Breakout Heading	Breakout Direction	Breakout Altitude
204	AP	F	002	1	7.1	290	Climb	5000
206	AP	F	002	1	3.2	300	Climb	3000
210	AP	C	002	1	MA	—	—	—
219	HF	F	003	3	3.8	300	Climb	3000
201	AP	C	002	1	7.1	280	Climb	4000
200	HF	F	001	1	lands	—	—	—
202	HF	F	003	3	3.2	290	Climb	3700
214	AP	C	002	1	3.2	280	Climb	4000
216	HF	C	003	3	7.1	285	Descend	1800
215	HF	C	003	3	7.1	285	Climb	4200
209	HF	F	003	3	7.1	280	Climb	3500
212	HF	F	002	1	MA	—	—	—
206	AP	C	002	1	3.2	300	Climb	3000
211	HF	C	002	1	3.2	300	Climb	3500
217	AP	F	002	1	7.1	300	Descend	1800
204	AP	C	002	1	7.1	290	Climb	5000
218	AP	C	002	1	3.8	285	Climb	3500
205	AP	C	001	1	lands	—	—	—
214	AP	F	002	1	3.2	280	Climb	4000
201	AP	F	002	1	7.1	280	Climb	4000

A.3 PHASE 3

Phase 3 Sequence S1-AH (Crews 1, 5, 9)

Scenario	Pilot Flying	Breakout	Simulator Scenario	Weather Card	Breakout DME	Breakout Heading	Breakout Direction	Breakout Altitude
301	C	AP	002	1	7.6	280	Climb	4000
305	C	AP	001	1	lands	–	–	–
324	F	AP	003	3	7.7	280	Climb	3500
317	C	AP	002	1	7.9	300	Descend	1500
306	F	AP	002	1	3.5	300	Climb	3000
310	C	AP	002	*2*	MA	–	–	2500
304	C	AP	002	1	7.5	290	Climb	5000
318	F	AP	002	1	4.9	285	Climb	3500
327	C	AP	002	1	3.6	300	Climb	3500
303	F	AP	002	*2*	2.3	290	Climb	3000
314	F	AP	002	1	3.5	280	Climb	4000
320	C	HF	002	1	7.6	300	Climb	4000
332	F	HF	001	1	lands	–	–	–
325	F	HF	003	3	7.4	285	Climb	4200
330	C	HF	003	3	8.0	285	Descend	1400
321	F	HF	003	3	3.6	270	Climb	3000
331	F	HF	003	3	2.6	285	Climb	3000
323	C	HF	002	1	7.5	280	Climb	4000
326	F	HF	003	3	5.1	285	Climb	3000
328	C	HF	003	3	3.4	290	Climb	3700
329	C	HF	002	1	MA	–	–	2500
322	F	HF	003	3	3.5	290	Climb	4000

Phase 3 Sequence S1-HA (Crews 2, 6)

Scenario	Pilot Flying	Breakout	Simulator Scenario	Weather Card	Breakout DME	Breakout Heading	Breakout Direction	Breakout Altitude
301	C	HF	002	1	7.6	280	Climb	4000
305	C	HF	001	1	lands	–	–	–
324	F	HF	003	3	7.7	280	Climb	3500
317	C	HF	002	1	7.9	300	Descend	1500
306	F	HF	002	1	3.5	300	Climb	3000
310	C	HF	002	*2*	MA	–	–	2500
304	C	HF	002	1	7.5	290	Climb	5000
318	F	HF	002	1	4.9	285	Climb	3500
327	C	HF	002	1	3.6	300	Climb	3500
303	F	HF	002	*2*	2.3	290	Climb	3000
314	F	HF	002	1	3.5	280	Climb	4000
320	C	AP	002	1	7.6	300	Climb	4000
332	F	AP	001	1	lands	–	–	–
325	F	AP	003	3	7.4	285	Climb	4200
330	C	AP	003	3	8.0	285	Descend	1400
321	F	AP	003	3	3.6	270	Climb	3000
331	F	AP	003	3	2.6	285	Climb	3000
323	C	AP	002	1	7.5	280	Climb	4000
326	F	AP	003	3	5.1	285	Climb	3000
328	C	AP	003	3	3.4	290	Climb	3700
329	C	AP	002	1	MA	–	–	2500
322	F	AP	003	3	3.5	290	Climb	4000

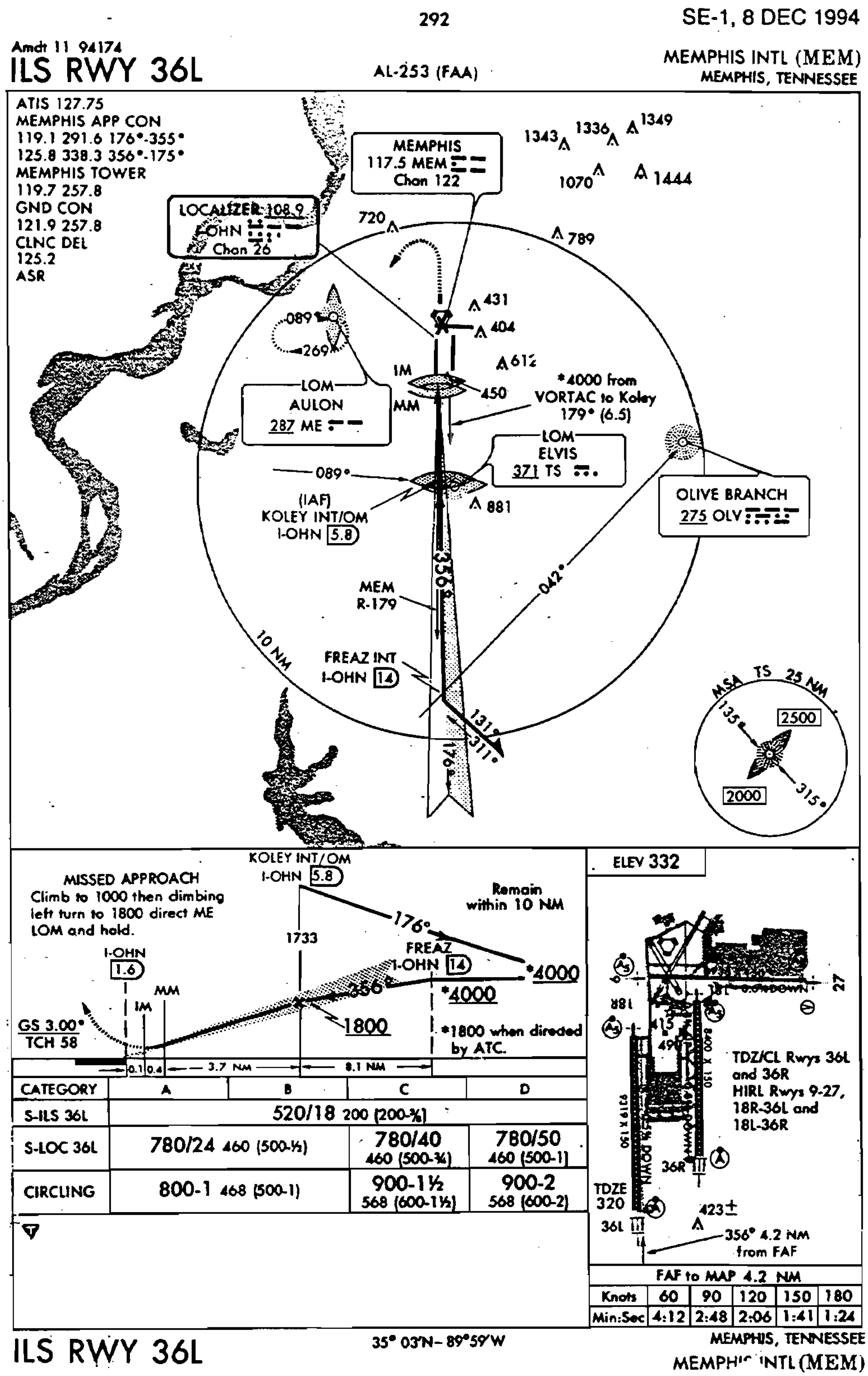
Phase 3 Sequence S2-AH (Crews 3, 7)

Scenario	Pilot Flying	Breakout	Simulator Scenario	Weather Card	Breakout DME	Breakout Heading	Breakout Direction	Breakout Altitude
301	F	AP	002	1	7.6	280	Climb	4000
305	F	AP	001	1	lands	–	–	–
324	C	AP	003	3	7.7	280	Climb	3500
317	F	AP	002	1	7.9	300	Descend	1500
306	C	AP	002	1	3.5	300	Climb	3000
310	F	AP	002	*2*	MA	–	–	2500
304	F	AP	002	1	7.5	290	Climb	5000
318	C	AP	002	1	4.9	285	Climb	3500
327	F	AP	002	1	3.6	300	Climb	3500
303	C	AP	002	*2*	2.3	290	Climb	3000
314	C	AP	002	1	3.5	280	Climb	4000
320	F	HF	002	1	7.6	300	Climb	4000
332	C	HF	001	1	lands	–	–	–
325	C	HF	003	3	7.4	285	Climb	4200
330	F	HF	003	3	8.0	285	Descend	1400
321	C	HF	003	3	3.6	270	Climb	3000
331	C	HF	003	3	2.6	285	Climb	3000
323	F	HF	002	1	7.5	280	Climb	4000
326	C	HF	003	3	5.1	285	Climb	3000
328	F	HF	003	3	3.4	290	Climb	3700
329	F	HF	002	1	MA	–	–	2500
322	C	HF	003	3	3.5	290	Climb	4000

Phase 3 Sequence S2-HA (Crews 4, 8)

Scenario	Pilot Flying	Breakout	Simulator Scenario	Weather Card	Breakout DME	Breakout Heading	Breakout Direction	Breakout Altitude
301	F	HF	002	1	7.6	280	Climb	4000
305	F	HF	001	1	lands	–	–	–
324	C	HF	003	3	7.7	280	Climb	3500
317	F	HF	002	1	7.9	300	Descend	1500
306	C	HF	002	1	3.5	300	Climb	3000
310	F	HF	002	*2*	MA	–	–	2500
304	F	HF	002	1	7.5	290	Climb	5000
318	C	HF	002	1	4.9	285	Climb	3500
327	F	HF	002	1	3.6	300	Climb	3500
303	C	HF	002	*2*	2.3	290	Climb	3000
314	C	HF	002	1	3.5	280	Climb	4000
320	F	AP	002	1	7.6	300	Climb	4000
332	C	AP	001	1	lands	–	–	–
325	C	AP	003	3	7.4	285	Climb	4200
330	F	AP	003	3	8.0	285	Descend	1400
321	C	AP	003	3	3.6	270	Climb	3000
331	C	AP	003	3	2.6	285	Climb	3000
323	F	AP	002	1	7.5	280	Climb	4000
326	C	AP	003	3	5.1	285	Climb	3000
328	F	AP	003	3	3.4	290	Climb	3700
329	F	AP	002	1	MA	–	–	2500
322	C	AP	003	3	3.5	290	Climb	4000

APPENDIX B. PHASE 1 APPROACH PLATES



Amdt 11 94174 (CAT II)

ILS RWY 36L

AL-253 (FAA)

SE-1, 13 OCT 1994
MEMPHIS INTL (MEM)
MEMPHIS, TENNESSEE

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125.8 338.3 356°-175°
MEMPHIS TOWER
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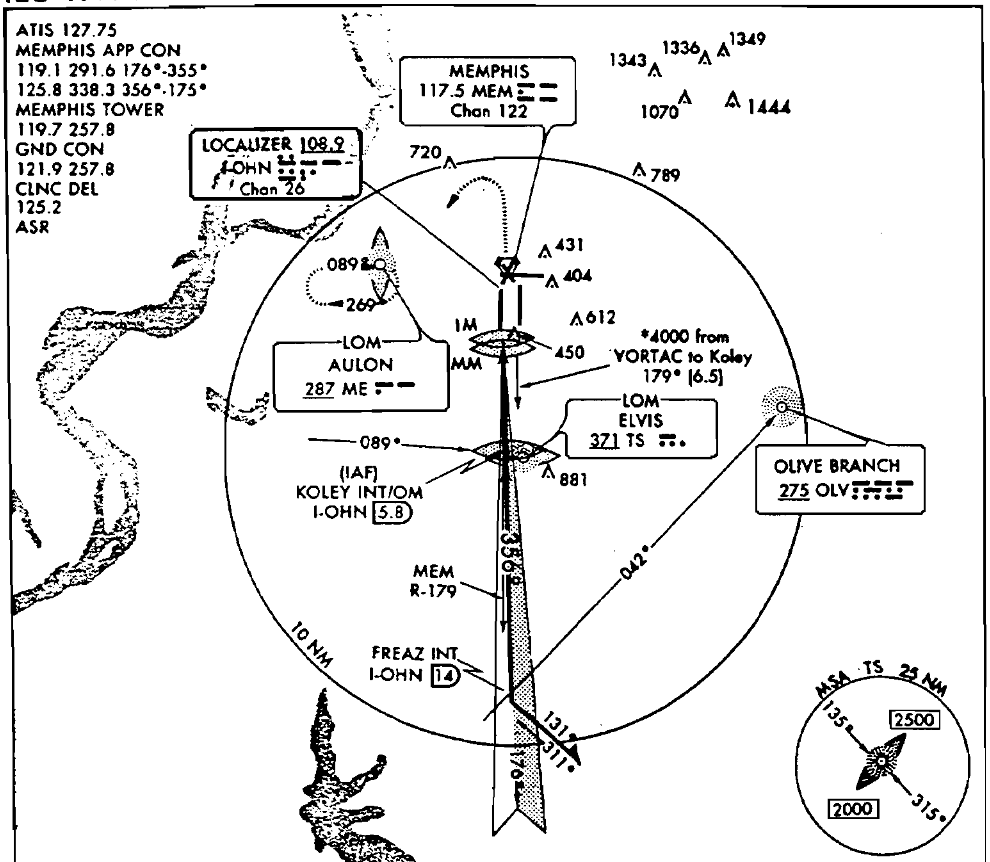
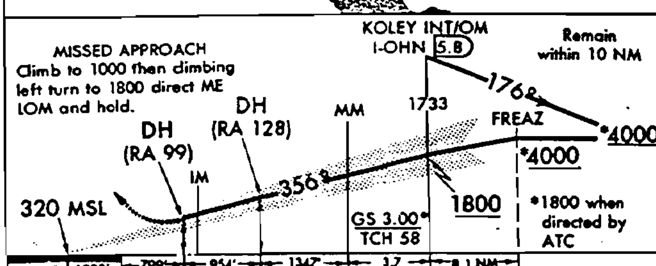
GND CON
121.9 257.8
CLNC DEL
125.2
ASR



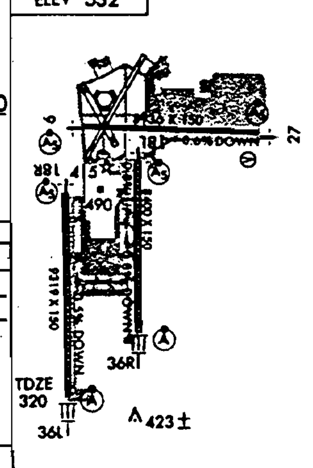


CATEGORY	A	B	C	D
S-ILS 36L	470/16 150 (RA 128)			
S-ILS 36L	420/12 100 (RA 99)			

▽ Simultaneous CLOSE PARALLEL approaches authorized with ILS Rwy 36R having 3400 feet runway centerline separation; GLIDE SLOPE REQUIRED.

CATEGORY II ILS–SPECIAL AIRCREW & AIRCRAFT CERTIFICATION REQUIRED

ELEV 332



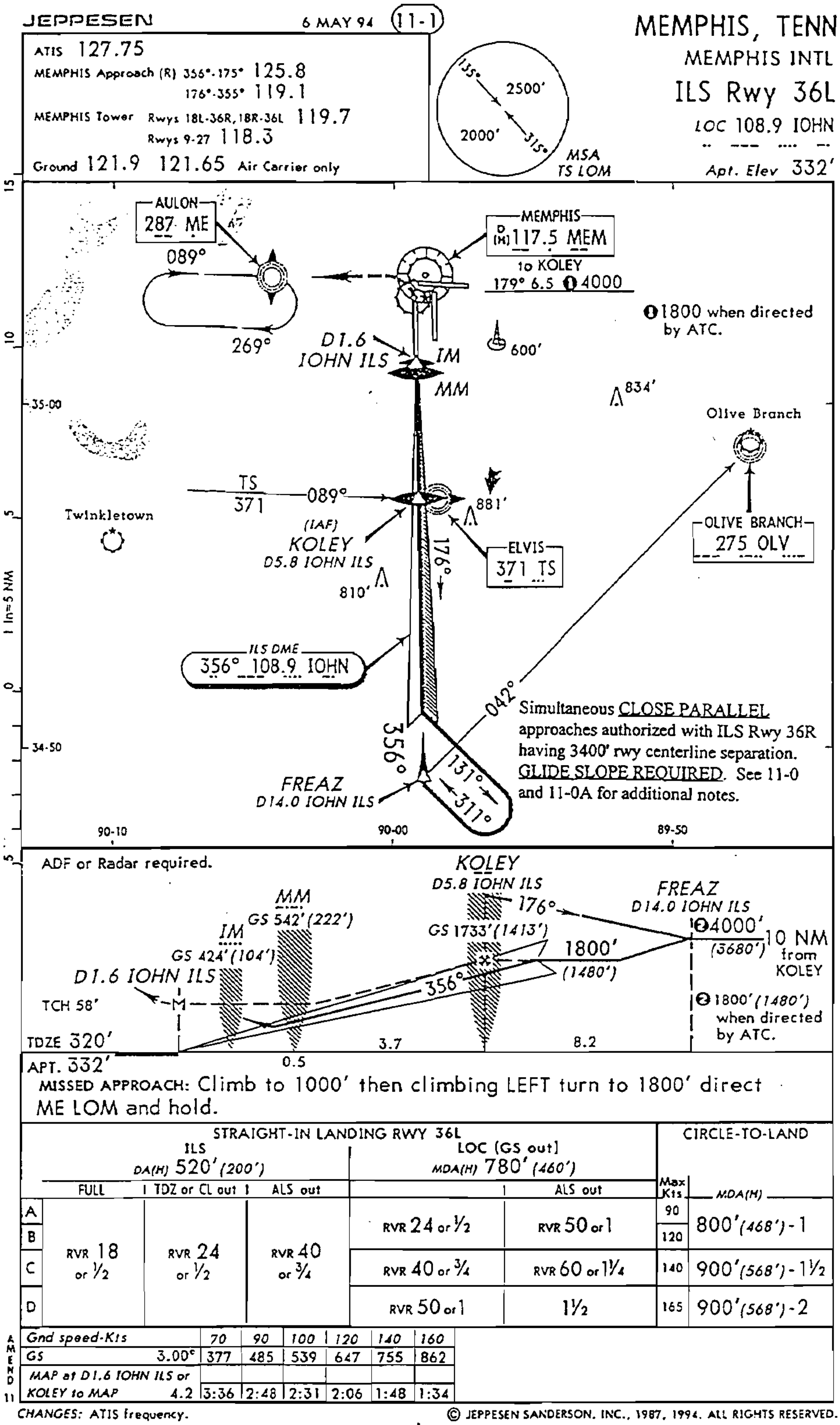
TDZ/CL Rwys 36L and 36R
HIRL Rwys 9-27, 18L-36R and 18R-36L

ILS RWY 36L
(CAT II)

35°03'N–89° 59'W

MEMPHIS, TENNESSEE
MEMPHIS INTL (MEM)

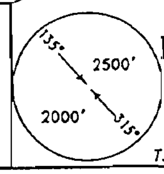
APPENDIX C. PHASES 2 AND 3 APPROACH PLATES

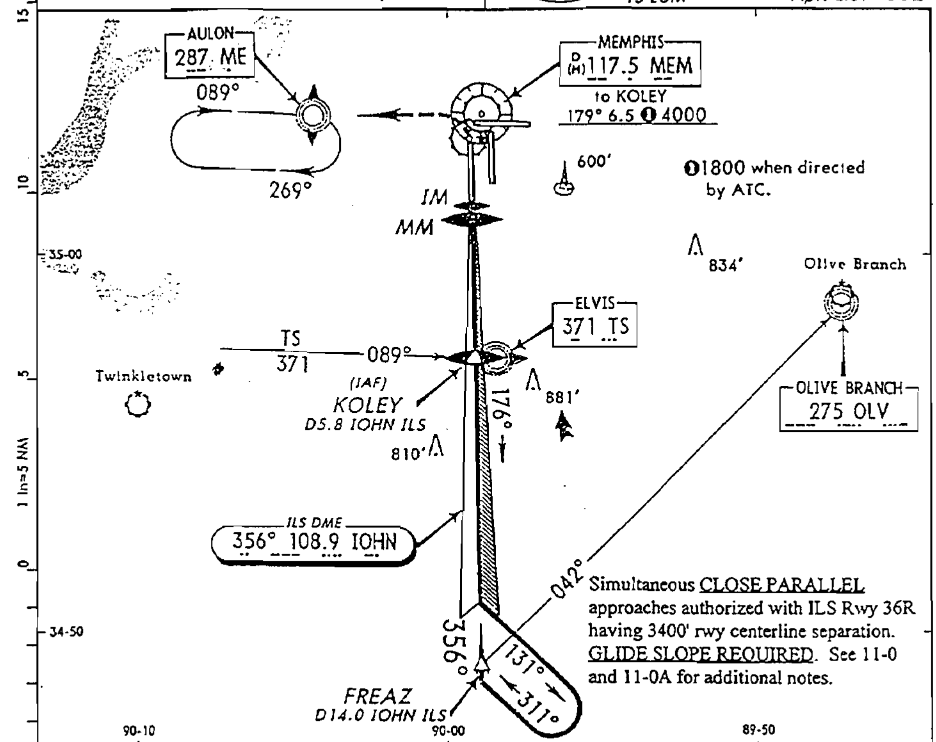


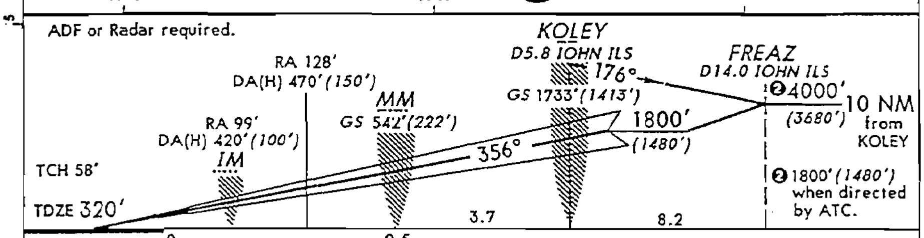
JEPPESEN 6 MAY 94 (11-1A)

MEMPHIS, TENN
MEMPHIS INTL
ILS Rwy 36L CAT II & III
Special Aircrew & Acft Certification Required
LOC 108.9 IOHN
Apt. Elev 332'

ATIS 127.75
MEMPHIS Approach (R) 356°-175° 125.8
176°-355° 119.1
MEMPHIS Tower Rwys 18L-36R, 18R-36L 119.7
Rwys 9-27 118.3
Ground 121.9 121.65 Air Carrier only







MISSED APPROACH: Climb to 1000' then climbing LEFT turn to 1800' direct ME LOM and hold.

STRAIGHT-IN LANDING RWY 36L

CAT IIIB ILS	CAT IIIA ILS	CAT II ILS	
		RA 99' DA(H) 420' (100')	RA 128' DA(H) 470' (150')
RVR 6	RVR 7	RVR 12	RVR 16

AMEND 11

Gnd speed-Kts	70	90	100	120	140	160
GS 3.00°	377	485	539	647	755	862

CHANGES: ATIS frequency.

APPENDIX D. PHASE 2 TRAINING PACKAGE

The briefing to the subject crews before each session in Phase 2 included material that presented information about close parallel simultaneous ILS approaches. Each crew was required to view a short video [13] which showed the Precision Runway Monitor radar and controller displays used to monitor these approaches. The video also discussed possible interventions by the monitor controller, and emphasized the need for pilot compliance with any breakout instructions.

After viewing the video, each pilot was required to read an 11-0 Information Page and a pilot awareness training bulletin, both of which were designed for this test. After reading the training bulletin, each pilot took a self-administered (i.e., open-book) test which reinforced the important concept presented in the bulletin. The pilots were not graded on the test.

The subject pilots did not receive training on how to conduct the breakout maneuver. The sequence of cockpit actions during each breakout event was at their discretion. If the breakout instruction occurred during an autopilot-coupled approach, the pilot flying made the decision whether or not to disconnect the autopilot and/or to cycle the flight director off and on.

The following pages present the written training package: the 11-0 Information page; the Pilot Awareness Training Bulletin; and the Pilot Awareness Open Book Test.

*******FOR SIMULATION PURPOSES ONLY****

PRECISION RUNWAY MONITORING

RUNWAYS 36 L/R

SIMULTANEOUS CLOSE PARALLEL APPROACHES

FAA Order 7110.65H paragraph 5-127 authorizes simultaneous ILS approaches to parallel runways with centerlines separated by a minimum of 3400'. The previous standard was 4300'. To qualify for reduced separation, parallel runways must be serviced by high update radar and high resolution ATC radar displays collectively called a Precision Runway Monitor (PRM). MEM runways 36 L/R centerlines are separated by 3400', and are served by PRM, permitting simultaneous ILS approaches.

The enhanced PRM system provides controllers almost instantaneous radar information. The supporting automated tracking software furnishes the controller with aircraft identification and position, a ten second projected position, as well as visual and aural alerts. These alerts signal the controller when an aircraft deviates off the localizer towards the "No Transgression Zone" (NTZ) between final approach courses. The NTZ standard width for all simultaneous parallel approaches (all locations) is 2000'. It is established equidistant between final approach courses and is depicted on the controller's monitor display.

If an aircraft is observed to be on a track that is left/right of the final approach course and may penetrate the NTZ, the controller will provide instructions to return the aircraft to the final approach course.

Phraseology:

"You have crossed the final approach course. Turn (left/right) IMMEDIATELY and return to localizer azimuth/course."
or
"Turn (left/right) and return to the localizer/azimuth course".

If an aircraft is observed penetrating the NTZ, ATC instructions will be given to the aircraft on the **adjacent** final approach course to alter course to avoid the deviating aircraft.

Phraseology:

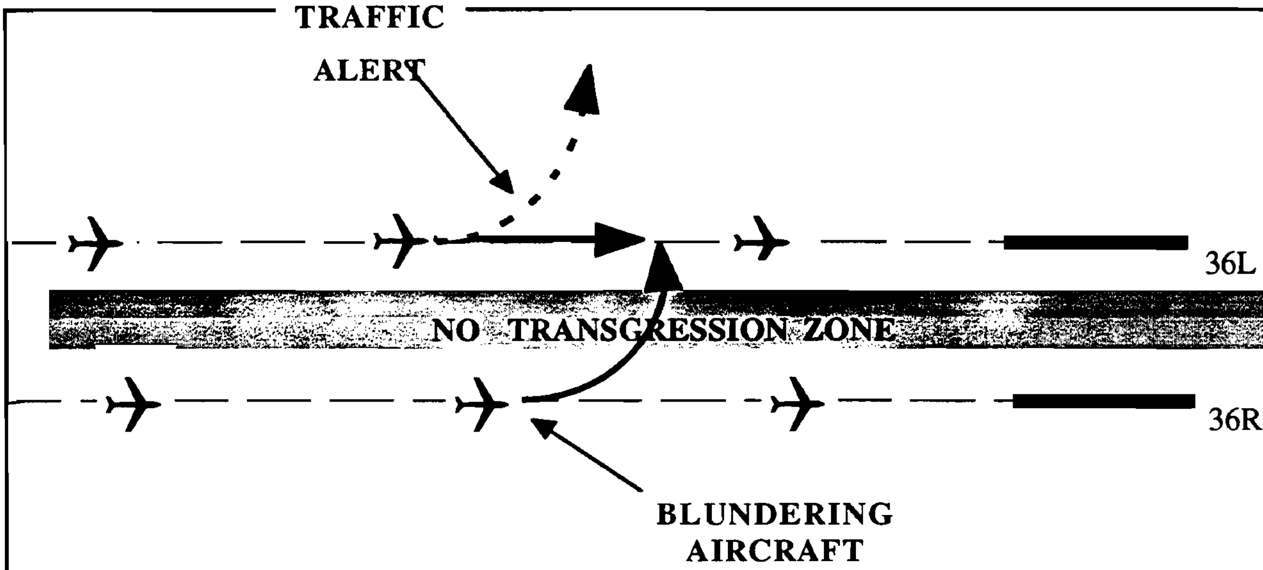
"(Aircraft callsign) TRAFFIC ALERT (aircraft callsign) turn (left/right) IMMEDIATELY heading (degrees). Climb/descend and maintain (altitude)".

An immediate pilot response is expected and required to avoid the imminent situation. Execution of these ATC instructions must be as rapid as practical. This maneuver may be performed either manually or on autopilot, in compliance with aircraft/company operating procedures.

Simultaneous ILS approaches are authorized for both parallel runways at Memphis International Airport and will be conducted when conditions such as weather and traffic flow dictate. The ATIS broadcast will advise pilots when closely spaced simultaneous ILS approaches are in progress.

For questions, please contact: Supervisor, Memphis TRACON, 1-800-555-1212.

MEMPHIS, TENN
MEMPHIS INTL



WHEN FLYING A SIMULTANEOUS CLOSE PARALLEL APPROACH, NOT COMPLYING WITH ATC INSTRUCTIONS

PROMPTLY

CAN HAVE SERIOUS CONSEQUENCES.

FOR SIMULATION PURPOSES ONLY

PILOT AWARENESS

TRAINING BULLETIN

Pilot AWARENESS Training for Simultaneous Close Parallel ILS Approaches

At 180 kts. an aircraft that has entered the No Transgression Zone can cross the adjacent parallel course centerline in as little as *NINE SECONDS*. Inattention, or failure to expeditiously comply with a final monitor controller's breakout instructions could result in a midair collision. Remember, you are being broken off the ILS because an aircraft from the adjacent ILS has probably deviated off course and is **HEADING YOUR WAY**. When pilots hear or read the word "CLOSE" in association with simultaneous parallel approaches, they should be especially aware that any instructions issued by a controller should be immediately followed.

This Flight Operations Bulletin imparts important information necessary for pilots to attain the increased level of pilot awareness required for safe, efficient, simultaneous close parallel ILS approach operations. Important pilot questions of "why", " how will I know", "what can I expect", and "what will I do" are answered. Hopefully, "SIMULTANEOUS CLOSE PARALLEL ILS APPROACHES" will be put on your list of important aviation terms or "buzzwords".

WHY?

Increased crew awareness is necessary because in all probability, there is an aircraft operating on the adjacent parallel localizer course as close as 3400' from your wingtip. Failure to comply with ATC clearances, tune the proper localizer frequency, accurately track the localizer course centerline, or respond to controller breakout instructions in an expeditious manner are all factors that may lead to loss of lateral separation, near-midair collisions, or midair collisions. Attention to detail is mandatory!

HOW WILL I KNOW?

Key words such as **"simultaneous"** and **"close parallel"** should alert pilots of the need to increase their awareness level. ATIS will broadcast phraseology such as "Simultaneous Close Parallel Approaches to RWYS (number) L/R in use". For a **new approach procedure** the approach plate for close parallel approaches will be titled "CLOSE PARALLEL ILS RWY (number)R". For **existing approach procedures** the approach plate will contain the note "SIMULTANEOUS CLOSE PARALLEL APPROACHES AUTHORIZED WITH RUNWAYS (number) L/R", and "GLIDESLOPE REQUIRED".

WHAT CAN I EXPECT?

If you or the aircraft on the adjacent localizer course fail to track the localizer course centerline (or worse yet, track the wrong localizer course!), final monitor controllers with frequency override capabilities will issue instructions. Each runway has a dedicated frequency therefore you **will not** hear final monitor radio transmissions to aircraft on the adjacent localizer course. The two scenarios requiring final monitor intervention are aircraft deviations from the localizer course centerline, and penetration of the No Transgression Zone by the aircraft on the adjacent parallel localizer course. For aircraft observed deviating from the localizer course centerline or observed to overshoot the turn-on, final monitor controllers will use phraseology such as "TURN (left/right) AND RETURN TO THE LOCALIZER COURSE" or "YOU HAVE CROSSED THE FINAL APPROACH COURSE. TURN (left/right) IMMEDIATELY AND RETURN TO THE LOCALIZER COURSE". When an aircraft fails to respond to final monitor controller instructions or is observed penetrating the No Transgression Zone, the aircraft on the **adjacent** parallel localizer course will be issued breakout instructions such as "(A/C callsign) TRAFFIC ALERT (A/C callsign) TURN (left/right) IMMEDIATELY HEADING (degrees) CLIMB/DESCEND AND MAINTAIN (altitude)". A descending breakout is contrary to what pilots would normally expect but the pilot should be aware that ATC will use it when necessary. If the final monitor controller issues a descending breakout, the descent will not take the pilot below the Minimum Vectoring Altitude (MVA).

WHAT WILL I DO?

To ensure proper preparation for "what will I do" the approach briefing shall address the possibility of an **ATC directed breakout.** The briefing should also include how that breakout will be accomplished. Pilots must comply immediately with all final monitor controller instructions. Having been "cleared for the approach" pilots are in a "land the aircraft" mode. For this reason it feels unnatural to be broken off the approach particularly if you have the localizer and glideslope "wired". For these reasons, pilots can be tempted to question, or hesitate in complying with the final monitor controller's breakout instructions.

During close parallel approach operations, **immediate** execution of the final monitor controller's instructions is **mandatory**. Remember, you are being broken off the approach because the aircraft assigned to the adjacent parallel localizer course has failed to respond to the final monitor controller's instructions or has entered the No Transgression Zone--the aircraft is heading your way. There is simply not enough "real estate" between you and the deviating aircraft to execute the breakout in a leisurely manner. For example, at 140 kts. ground speed an aircraft is traveling 236' per second!

Pilots must be knowledgeable of aircraft autoflight systems as well as procedures and limitations. This is necessary to avoid slow, or improper aircraft response to an issued clearance. Crew coordination items must be thoroughly understood and briefed prior to commencement of the approach. This is particularly critical for automated cockpits. Remember, during an ATC directed breakout, you can be given any combination of turn and/or climb/descent instructions.

PILOT AWARENESS
OPEN BOOK TEST

Pilot Awareness Training for Simultaneous Close Parallel ILS Approaches.

1. "Close Parallel" in describing a simultaneous ILS approach means:

   a) Runway centerlines are less than 4,300' apart.

   b) Runway centerlines might be only 3,400' apart.

   c) There might be someone making an approach to the adjacent runway who is very, very close.

   d) All of the above.

2. If a pilot is flying a simultaneous close parallel ILS approach and the controller tells him to turn off the localizer the pilot should:

   a) Take his time because the passengers don't like sudden maneuvers.

   b) Move the aircraft as quickly as practical to avoid a potential mid-air collision.

   c) Not turn off the localizer, because the instruments read on course and you've been cleared for the approach.

3. Can a controller give a pilot a descending turn off the localizer when the pilot is on an ILS approach?

   a) No, not if the aircraft has captured the localizer and glideslope.

   b) No, all turns off the localizer must be accompanied by a climb.

   c) Yes, provided the aircraft is not descended lower than the minimum vectoring altitude (MVA). If that is what it takes to avoid a collision, the controller will direct a descending turn off the localizer.

4. What are the most important things to remember about simultaneous close parallel ILS approaches?

   a) Don't make any abrupt turns because of passenger comfort, and always question every turn off the ILS localizer given by ATC.

b) If you don't turn immediately off the localizer when directed by ATC, perhaps maybe he'll forget about you and you can get in on time. If the controller is being unreasonable by making you late, stand your ground and don't let him intimidate you, after all you're an airline captain.

c) There is probably someone very close along side of you making an approach to the other runway. If ATC tells you to turn off the localizer it means that the airplane along side of you is now heading your way and it might hit you unless you move the airplane quickly.

5. When you hear ATC transmit "TRAFFIC ALERT", what kind of message is going to follow?

   a) A turn off the ILS for someone because an aircraft on the parallel runway is heading his way.

   b) There is a new ATIS coming up and the controller wants everyone to listen to it.

   c) The highway leading into the airport is really jammed up with cars.

   d) How should the briefing for simultaneous close parallel ILS approaches be conducted?

   e) No briefing is necessary.

   f) Use the standard briefing for ILS approaches.

   g) Use the standard briefing for ILS approaches. Additionally brief for the "close" aspect of the approach, the possibility of an ATC directed breakout and how it should be conducted.

6. How should the briefing for simultaneous close parallel ILS approaches be conducted?

   a) No briefing is necessary

   b) Use the standard briefing for ILS approaches.

   c) Use the standard briefing for ILS approaches. Additionally, brief for the "close" aspect of the approach, the possibility of an ATC-directed breakout and how it should be conducted.

[Answers to Questions: 1. D 2. B 3. C 4. C 5. A 6. C]

APPENDIX E. PHASE 3 TRAINING PACKAGES

In Phase 3, the subjects received the same situational awareness training package presented in Phase 2. In addition, they received two written breakout procedure packages: one which trained the crew to execute the breakout with the autopilot on (AP), and another which trained the crew to disengage the autopilot, cycle the flight director off then on, and fly the breakout manually (HF). The written material was the only procedure training received by the subjects. There was no simulator training, and the subjects did not practice the breakout procedure before the test.

Each test session was split into two parts. For the first half, the crew reviewed one of the training packages during the initial briefing session. All breakouts during the first half were conducted using that breakout procedure. After the break, the crew returned to the briefing room and reviewed the training package for the other breakout procedure. All breakouts in the second half were executed using the second procedure. One half of the crews reviewed and were required to follow the autopilot procedure first, then the manual procedure after the break. The other crews reviewed and followed the manual procedure during the first half; and the autopilot procedure after the break.

Each training package consisted of a B747-400 procedure bulletin and a self-administered (open-book) test. The subjects read the bulletin then took the test, which was designed to reinforce the important concepts of the procedure. The subjects were allowed to keep the procedure pages and review them if needed during the session.

The rest of this section presents the training packages in the following order:

1. Manual (HF) breakout procedure bulletin
2. Manual (HF) procedure open-book test
3. Autopilot (AP) breakout procedure bulletin
4. Autopilot (AP) procedure open-book test

This procedure is for simulation purposes only

B-747-400 Breakout Procedure Bulletin

HF

General Discussion:

Closely spaced (less than 4300 feet between parallel runway centerlines) ILS simultaneous approaches have created the need for a "breakout" procedure. "Breakout" is defined as an ATC directed departure from an ILS approach prior to reaching the D/H. Before the advent of closely spaced ILS simultaneous approaches, ATC rarely diverted an aircraft from an ILS approach. If a breakout was initiated by ATC, it was usually the result of a spacing problem and not a potential collision problem with another aircraft. It is forecast that closely spaced ILS simultaneous approaches will increase the frequency of breakouts and the spacing between the parallel localizers dictates that a procedure be implemented to reduce the maneuver times of the evading aircraft.

A breakout to avoid a collision is considered to be an emergency-like maneuver and extraordinary steps in the breakout procedure are needed. Although autopilot use is mandated for a closely spaced ILS simultaneous approach, the breakout procedure will be hand flown. It is very important that the breakout transmission from ATC be followed immediately and the only way this can be accomplished quickly is by disconnecting the autopilot and hand flying the airplane through the maneuver. The pilot must keep in mind that a descent might be one of the options that the controller might use, providing the aircraft is above the minimum vectoring altitude (MVA). The pilot can count on the MVA not being below 1,000' AGL and in all probability the MVA will be considerably higher, because the MVA provides at least 1,000' clearance above obstacles.

There are three ways the pilot can disengage the flight director from the ILS after LOC and GS capture and have the flight director provide relevant information They are:

1. Engaging TOGA - the relevant information provided is climb straight ahead.

2. Disengaging the autopilot and turning off both flight directors (<u>both</u> flight directors have to be <u>off</u> at the same time, turning one off and on, then the other off and on will not suffice). After one flight director is turned back on, roll and pitch inputs can be made through the mode control panel (MCP).

3. Turning off both flight directors, deselecting the ILS frequency, turning on both flight directors and engaging a roll and pitch mode.

Unfortunately, all of the above methods take too much time. Disconnecting the autopilot and performing a hand flown breakout will result in the shortest breakout times achievable.

This procedure is for simulation purposes only

The following procedure is to be used when conducting an ATC directed breakout from a closely spaced ILS simultaneous approach:

PILOT FLYING (PF):

- Disconnect autopilot and point the aircraft in the direction the controller has directed (including climb or descent).

- Monitor speed and consider disconnecting autothrottles or overriding with manual throttle inputs.

- Command to clean up aircraft using normal procedures - wheels can be raised before "positive rate" as no touch down is probable.

PILOT NOT FLYING (PNF) - catch up the flight director to the aircraft's flight path:

- Turn off both flight directors

- Turn on PNF's flight director

- Push heading knob and set new heading.

- Set new altitude

- Engage FLCH

- When PNF's flight director matches the desired aircraft's flight path, turn on PF's flight director.

NOTE: It is important that the PNF ensure that all mode control panel (MCP) commands are reflected in the primary flight display (PFD). For example, if the PF engages TO/GA, any pitch and roll inputs made previously are canceled and are replaced with a wings level climb. If a breakout is made at 500' AGL, it is conceivable that the aircraft will continue below 400' AGL before a climb occurs. If this is the case and even though one flight director has been turned on, any MCP pitch and roll inputs will be disabled until the airplane climbs above 400' AGL.

THIS BREAKOUT PROCEDURE SHOULD BE BRIEFED ALONG WITH THE NORMAL APPROACH BRIEFING PRIOR TO ALL CLOSELY SPACED SIMULTANEOUS ILS APPROACHES.

B-747-400 BREAKOUT PROCEDURE

HF

OPEN BOOK TEST

1. When accomplishing a hand flown breakout the PF should:
    a. Wait for the PNF to setup the flight directors before taking any action.
    b. Immediately turn and point the aircraft (climb or descent) as directed by the controller.
    c. Leave the aircraft coupled to the Autopilot.
2. In order to cancel the "Approach Mode", the PNF needs to turn off:
    a. Only his Flight Director to program the new information in the MCP.
    b. Only the flight director of the PF.
    c. Both flight directors
3. If TO/GA is engaged <u>after</u> the PNF enters pitch and/or roll MCP inputs:
    a. TO/GA will not be accepted.
    b. The PNF should engage the autopilot.
    c. The pitch and roll inputs previously entered will be canceled and replaced with a wings level climb.
4. The PNF should turn on the flight director of the PF:
    a. Immediately.
    b. No urgency, the PF is experienced and has no need for a flight director.
    c. As soon as the his flight director matches the desired aircraft flight path.
5. In order to cancel the "Approach Mode", the PF needs to:
    a. Leave the aircraft on autopilot while the PNF cycles the flight directors.
    b. Disconnect the autopilot in conjunction with the PNF turning off the flight directors.
    c. Do nothing, the aircraft will cancel the approach mode automatically.
6. During hand flown breakouts the PF should:
    a. Always keep the autothrottles engaged.
    b. Consider disconnecting the autothrottles and applying manual inputs.
    c. Never use autothrottles.

[Answers to questions: 1.-B 2.-C 3.-C 4.-C 5.-B 6.-B]

*** This procedure is for simulatiopn purposes only ***

B-747-400 Breakout Procedure Bulletin

AP

General Discussion:

Closely spaced (less than 4300 feet between parallel runway centerlines) ILS simultaneous approaches have created the need for a "breakout" procedure. "Breakout" is defined as an ATC directed departure from an ILS approach prior to reaching the D/H. Before the advent of closely spaced ILS simultaneous approaches, ATC rarely diverted an aircraft from an ILS approach. If a breakout was initiated by ATC, it was usually the result of a spacing problem and not a potential collision problem with another aircraft. It is forecast that closely spaced ILS simultaneous approaches will increase the frequency of breakouts and the spacing between the parallel localizers dictates that a procedure be implemented to reduce the maneuver times of the evading aircraft.

All closely spaced ILS simultaneous approaches will be made with the autopilot. In the event ATC breaks an aircraft away from the localizer and glide slope, the "breakout" maneuver will be done using the autopilot. All missed approaches will be conducted using the autopilot.

The possibility of the controller descending the aircraft during a breakout changes the traditional TO/GA response of the pilot. Although TO/GA will still be engaged during a descending breakout, the pilot has to quickly send a pitch mode input to the autopilot so that the aircraft will continue to descend and avoid the blundering aircraft from the adjoining localizer. This requires listening very carefully to the ATC breakout command to determine whether ATC wants the breakout aircraft to climb or descend. ATC will not descend an aircraft below the minimum vectoring altitude (MVA), but the pilot has no way at present to know what that altitude is. The pilot can count on the MVA not being below 1,000' AGL and in all probability the MVA will be considerably higher, because the MVA provides at least 1,000' clearance above obstacles.

*** This procedure is for simulatiopn purposes only ***

Breakout Procedure:

THE AUTOPILOT SHOULD REMAIN ENGAGED THROUGHOUT THE MANEUVER

Above 400' AGL (All MCP inputs will be made by Pilot Flying (PF):

- If the command is to DESCEND:
    - Engage TO/GA
    - IMMEDIATELY select V/S.
    - Dial in a rate of descent not to exceed 1,000 ft. per minute.
    - Press heading knob and set assigned heading in window.
    - Set altitude in window
    - Push speed button (If this is not done the autothrottle will not adjust the power to the speed in the speed window, but will remain in the THR or THR REF mode).
    - Monitor speed and cleanup aircraft. No need to wait for positive rate for bringing the gear up because landing is not an option.

- If the command is to CLIMB:
    - Engage TO/GA
    - Press heading knob and set assigned heading in window
    - Set altitude in window.
    - Monitor speed and cleanup aircraft

400' AGL and below:

- Engage TO/GA
- Follow normal missed approach procedure to above 400' AGL, then turn as directed.

NOTE: After engaging TO/GA and with the autopilot and flight directors on, pitch and roll inputs below 400' AGL are not accepted by the mode control panel (MCP). Even if the go around was initiated at 500' AGL, there is a strong possibility that the aircraft will descend below 400' AGL after TO/GA was engaged and disable the MCP pitch and roll inputs. It is very important that the pilot check the primary flight display (PFD) after making a mode control panel (MCP) input to insure that the input was accepted.

THIS BREAKOUT PROCEDURE SHOULD BE BRIEFED ALONG WITH THE NORMAL APPROACH BRIEFING PRIOR TO ALL CLOSELY SPACED SIMULTANEOUS ILS APPROACHES.

B-747-400 BREAKOUT PROCEDURE

AP

OPEN BOOK TEST

1. After engaging TO/GA during a descending breakout, what is your first action?

    a) Press heading knob and set assigned heading in window.

    b) Immediately select V/S and dial in a rate of descent not to exceed 1000' per minute.

    c) Turn off the autopilot.

2. Why shouldn't mode control panel (MCP) pitch and roll inputs be made below 400' AGL?

    a) Below 400' AGL the MCP will not accept pitch and roll inputs.

    b) There are too many other things to be doing at such a low altitude.

    c) All the primary flight displays mode annunciations are blocked out below 400' AGL.

3. Why do the primary flight displays (PFD) mode annunciations have to be monitored?

    a) To keep the pilot not flying busy.

    b) To ensure that the MCP pitch and roll commands are accepted.

    c) To catch any last minute messages that dispatch might send.

4. In a descending breakout, why does the crew have to wait for a positive rate before the gear is raised?

    a) Even though the aircraft is turning off the localizer a touchdown might occur.

    b) A descending breakout can be given as low as 100' and the airplane could touch down before the turn and descent could be initiated.

    c) During a descending breakout, the crew DOESN'T have to wait for a positive rate.

5. A descending breakout may occur at:

   a) 500'

   b) 2500'

   c) a and b

6. During a descending breakout the PF must push the speed button to accomplish which of the following:

   a) Move the throttles to Idle.

   b) Keep the autothrottles in Thrust Reference mode.

   c) To select A/T speed mode, which will maintain IAS in speed window.

[Answers to Questions: 1. - B 2. - C 3. - B 4. - C 5. - B 6. - C]

APPENDIX F. DATA EXTRACTION ALGORITHMS

The analysis software began by reading an entire track file into memory, giving it access to all the data. The first task was locating the marker record, which is the first record with an event marker status flag of "on" and signifies the time at which the breakout instruction began.

The next step was to crop off the "bad" data. Bad data were records at the beginning and/or end of a track file that were not part of the flight. They generally resulted from simulator actions such as holding a fixed position before a flight or resetting the position to a fixed location (i.e. on approach for the next track after a landing). The cropping algorithm looked for "frozen" positions by comparing the x position (distance from threshold) of various records. If there was a marker record, the algorithm started there and moved towards the ends of the tracks until it found three consecutive identical positions (in x). All records beyond the three (on both ends) were cropped off. If there was no ATC mark the algorithm started in the middle of the track. The cropping was done only on the records in memory during processing so it did not alter the track data files.

The final adjustment before measuring the time-to-event values was the correction of the location of the marker record to remove any bias (see Section 4.1.2). The marker record was originally the first one recorded after the ATC event mark button was pressed. To correct, the marker record was reassigned to the record whose timestamp was nearest to the original marker record's timestamp plus the bias. The exact adjustment for each track differed by as much as half a time interval between records (about 0.29 seconds at 3.5 Hertz). This approach was consistent with what would have happened if the ATC had pressed the event marker at the same time he started speaking the breakout instruction, because it moves the mark to the record that would have been the marker record if the ATC had pressed the button at the correct time. As with cropping, these changes were not permanent.

The algorithms to measure time-to-event values then operated on the unbiased, cropped track, identifying numerous events of interest after the marker record. The time difference between the marker record and the various event records gave the time-to-event values. After tracks were processed, staff members viewed plots of the results to monitor the performance of the algorithms; any unusual results were investigated and either explained or corrected.

The following sections describe the algorithms used to identify each event.

F.1 TIME TO ROLL

Two algorithms were used to identify a roll starting point. The algorithms identified the same point for the majority of tracks, but identified differing points for unusual tracks. Nominally the aircraft had no roll at the time of the breakout instruction and then several seconds later started a roll to the left to make the turn, as illustrated in Figure F-1.

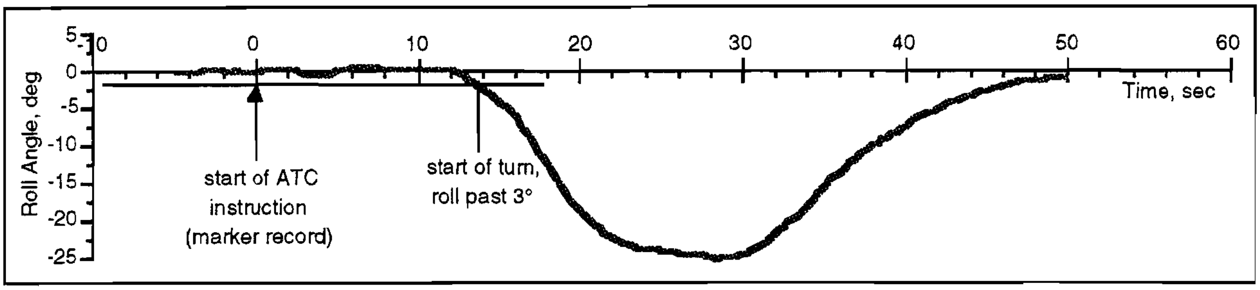


Figure F-1. Roll angle data for a breakout with nominal roll characteristic.

However, some tracks were not nominal and showed a "double roll" as illustrated in Figure F-2. This sometimes occurred when the pilots started the roll maneuver before entering TO/GA mode. The flight director would return the aircraft to level flight based on the stored missed approach course. The pilot would then have to over-ride the flight director and reinitiate the roll for the breakout maneuver.

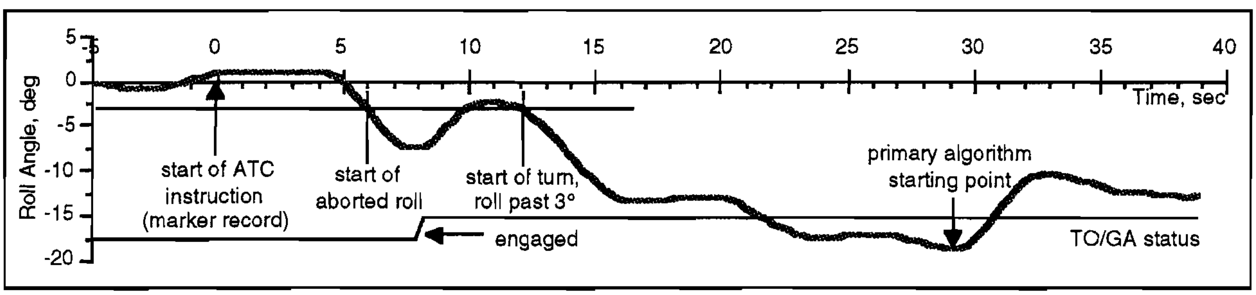


Figure F-2. Roll angle data for a breakout with a double roll. Note return to center after TO/GA was engaged.

One algorithm found the first record in which the roll angle was greater than 3 degrees to the left (all breakouts were to the left in the study) by stepping forward from the marker record and checking the roll angle at each subsequent record. This approach was used on every track and recorded as one start of roll determination. For the example in Figure F-2, this algorithm returned a time to roll of about 6 seconds.

The other algorithm worked from the other direction. Starting from the point of greatest roll angle magnitude within the 60 seconds following the marker record, it stepped backwards until the roll angle crossed 3 degrees, then called that record the start of the roll. This approach was also used on every track, and the result was recorded as the primary start-of-roll determination. For the example in Figure F-2, the algorithm started working backwards from the starting point near 29 seconds and returned a time to start of roll of about 12 seconds.

When the start of roll time calculated by the two methods did not agree, the data for that track were manually reviewed and the correct starting point was identified.

F.2 TIMES TO OTHER EVENTS

F.2.1 Status

Calculating time-to-event values for status-type data required finding the first record after the marker record for which the value for the status had changed. Status-type data had values of either 0 or 1, and included autopilot and TO/GA status. The events of interest were the disengagement of the autopilot or the engagement of TO/GA, but the algorithm identified the opposite status changes as well. There is an example of the TO/GA status values in Figure F-2 at the bottom of the plot.

F.2.2 Gear and Flaps

Landing gear and flaps data varied continuously, unlike the status data. The gear values ranged from 0 to 1, with 0 being full up and 1 being full down. Any value in-between indicated that the gear was moving. Flap values ranged from 0 to 30 degrees, reflecting the amount of flaps deployed. Figure F-3 presents a sample flap and gear plot

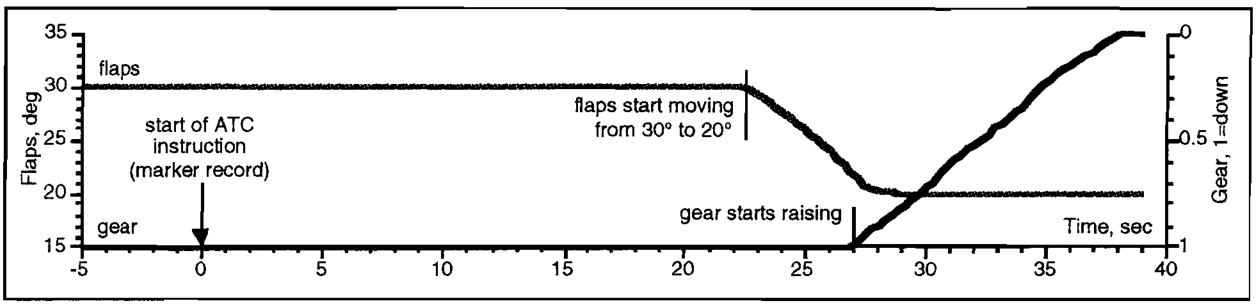


Figure F-3. Gear and flaps data during a breakout.

Since the gear data were constant when the gear was not moving, any change in the value of the gear position after the marker record indicated the start of a change in gear position event.

The flaps data varied to reflect the actual position of the flaps, including when they were moving between settings. As with gear, once the flaps stopped moving the position data remained constant, so the algorithm checked for any change in the value to indicate the start of change in flaps setting and took the first such change after the marker record as the event.

F.2.3 Pitch, Heading, Vertical Speed, and EPR

The time-to-event measurements for these metrics were similar to that of the first time-to-roll measurement (stepping forward). There was no time limit imposed; each event could occur any time after the marker record. For each metric, a delta value parameter was determined empirically and the event was identified when the data changed by at least as much as the parameter. The parameter value depended on whether the scenario was a climbing or descending breakout. Parameter values were relative to the value at the marker record (start of ATC transmission). Table F-1 lists the parameters.

Table F-1. Delta-Value Parameters for Times to Event

metric	climbing breakout	descending breakout
pitch	+1.2 degrees	- 1.2 degrees
heading	- 3 degrees	- 3 degrees
vertical speed	+150 feet/minute	- 100 feet/minute
EPR	+0.05	n/a

Examples of pitch and heading event determination are depicted in Figure F-4. Figure F-5 illustrates vertical speed and engine pressure ratio (EPR) data times to event. These data are for the same track illustrated in Figures F-2 and F-3.

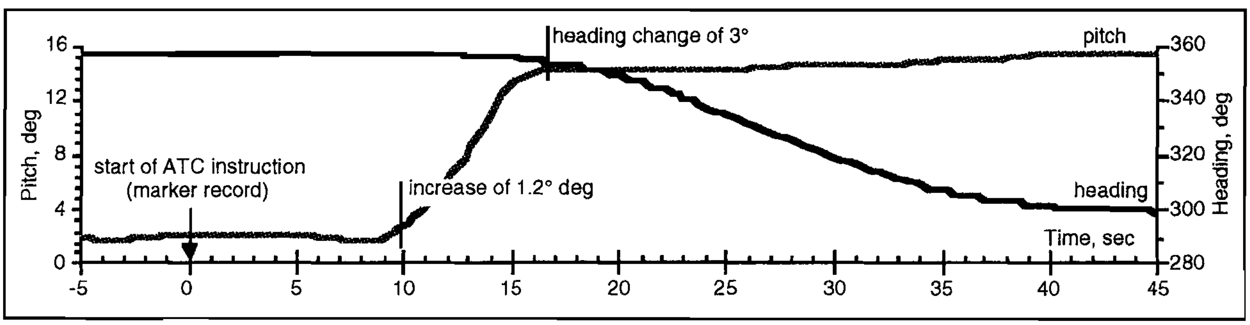


Figure F.4. Pitch and heading data during a breakout.

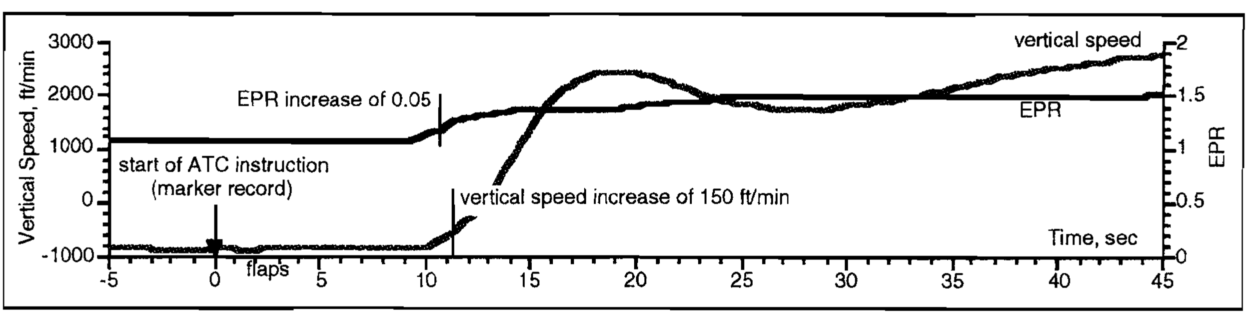


Figure F-5. Vertical speed and engine pressure ratio (EPR) data during a breakout.

APPENDIX G. SCENARIO-ORDERED RESULTS

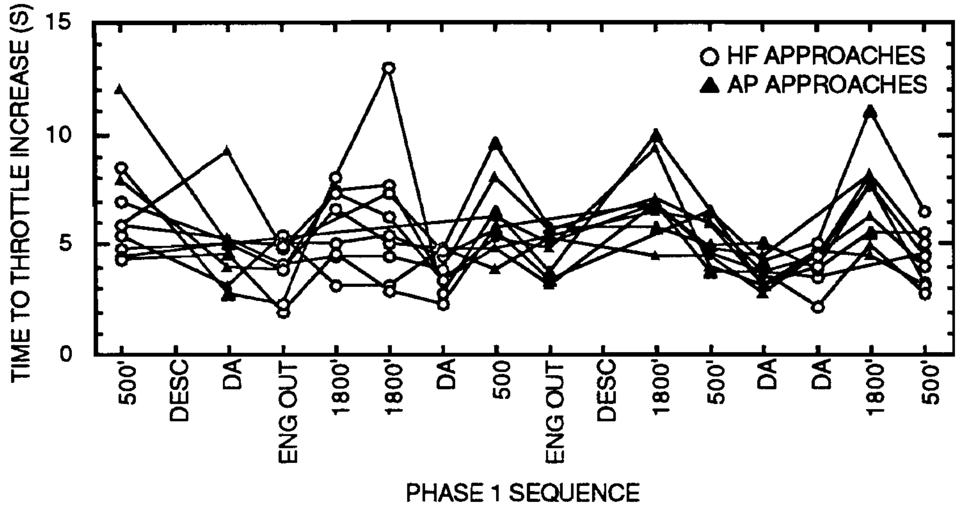
The following sections present selected performance variables. The results are graphically depicted in the order of occurrence. The first (left-hand) value was from the first trial in the session, and the last (right-hand) value was from the last trial in the session. The lines connect results for a given crew. This aided in the qualitative assessment for practice effects (Section 5.3.3).

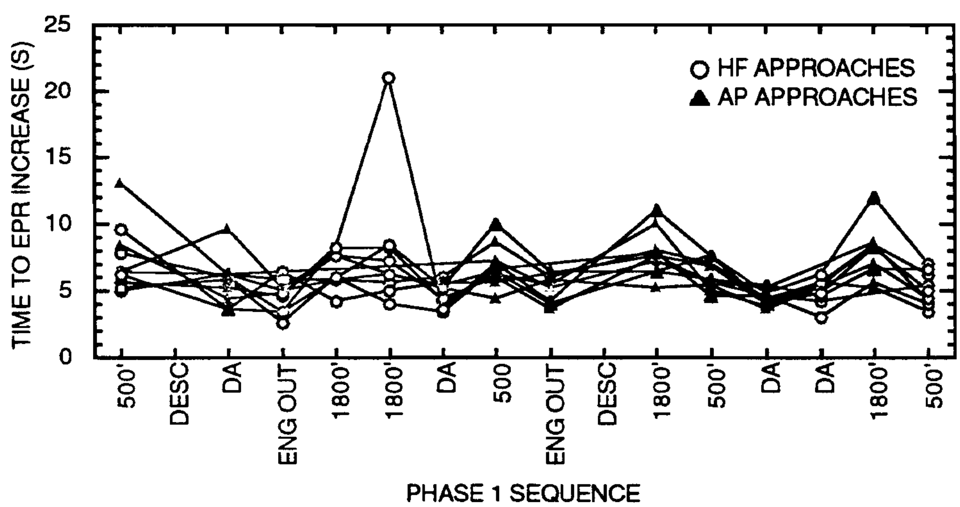
Six performance variables are presented for each phase of the study: time to throttle increase (dt_throttle); time the engine pressure ratio (EPR) increase (dt_engine); maximum roll angle (maximum_roll); time to start of roll (dt_roll); time to pitch increase (dt_pitch); and, time to increasing vertical speed (dt_vertical_speed). These variables represent speed, turn, and climb performance during the breakout. All times were measured from the start of the air traffic controller's breakout instruction to the event. Maximum roll angle was the largest value observed during the breakout. The duration of the maximum roll angle was not measured.

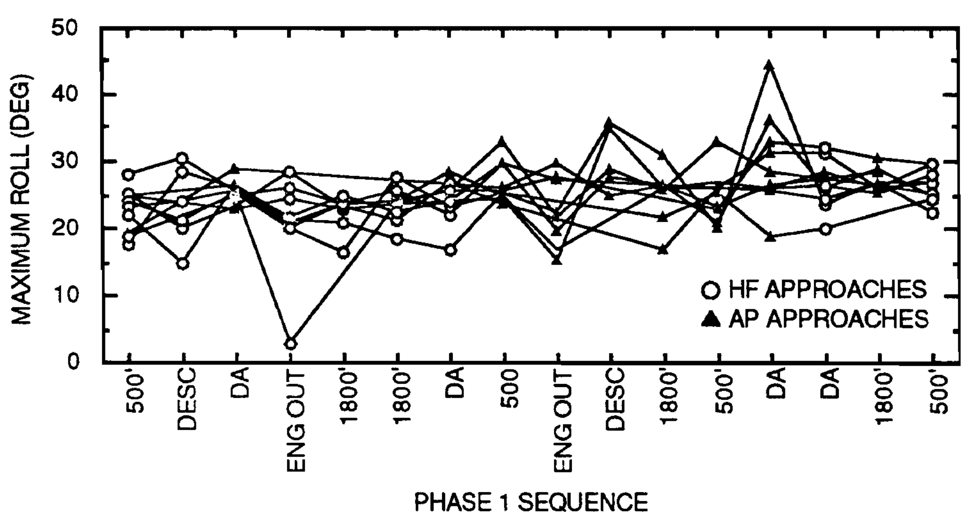
The codes along the ordinate axis represent the breakout groups. For Phases 2 and 3, some codes also include a letter, (a) or (b), after the code. These letters identify scenarios which were within-subject replicates; and the letters, a and b, identify which subject flew that trial. The code key is:

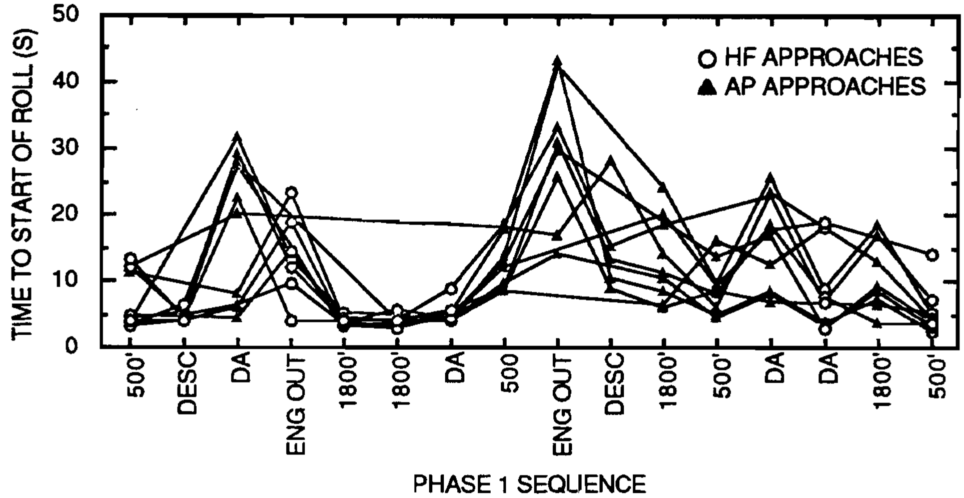
Code	Breakout Group
DA	Climbing breakout at Decision Altitude
500'	Climbing breakout at 500 feet AGL
700'	Climbing breakout at 700 feet AGL
1000'	Climbing breakout at 1000 feet AGL
1800'	Climbing breakout at 1800 feet AGL
DESC	Descending breakout at 1800 feet AGL
ENG OUT	Climbing breakout at DA, with engine out distraction

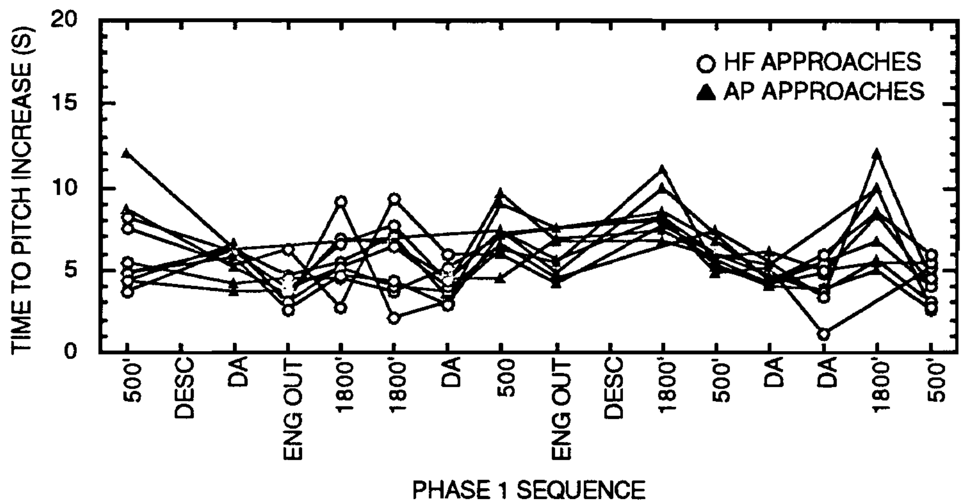
G.1 PHASE 1

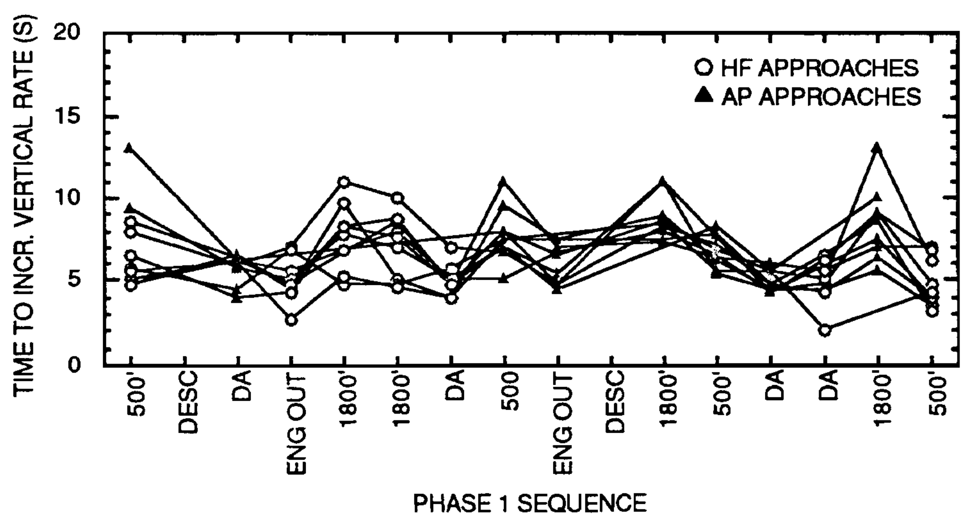

TIME TO THROTTLE INCREASE (S)
15
10
5
0
HF APPROACHES
AP APPROACHES
500'
DESC
DA
ENG OUT
1800'
1800'
DA
500
ENG OUT
DESC
1800'
500'
DA
DA
1800'
500'
PHASE 1 SEQUENCE


TIME TO EPR INCREASE (S)
25
20
15
10
5
0
HF APPROACHES
AP APPROACHES
500'
DESC
DA
ENG OUT
1800'
1800'
DA
500
ENG OUT
DESC
1800'
500'
DA
DA
1800'
500'
PHASE 1 SEQUENCE

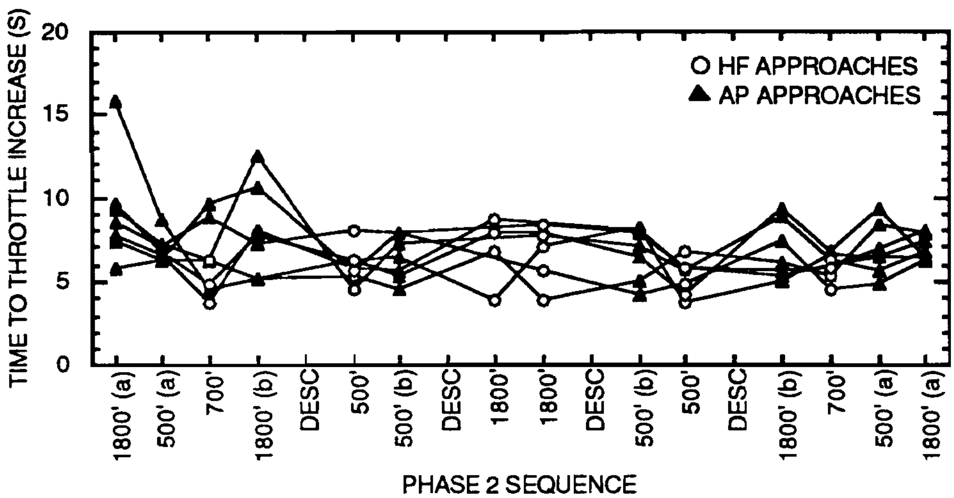

MAXIMUM ROLL (DEG)
50
40
30
20
10
0
HF APPROACHES
AP APPROACHES
500'
DESC
DA
ENG OUT
1800'
1800'
DA
500
ENG OUT
DESC
1800'
500'
DA
DA
1800'
500'
PHASE 1 SEQUENCE


TIME TO START OF ROLL (S)
50
40
30
20
10
0
HF APPROACHES
AP APPROACHES
500'
DESC
DA
ENG OUT
1800'
1800'
DA
500
ENG OUT
DESC
1800'
500'
DA
DA
1800'
500'
PHASE 1 SEQUENCE

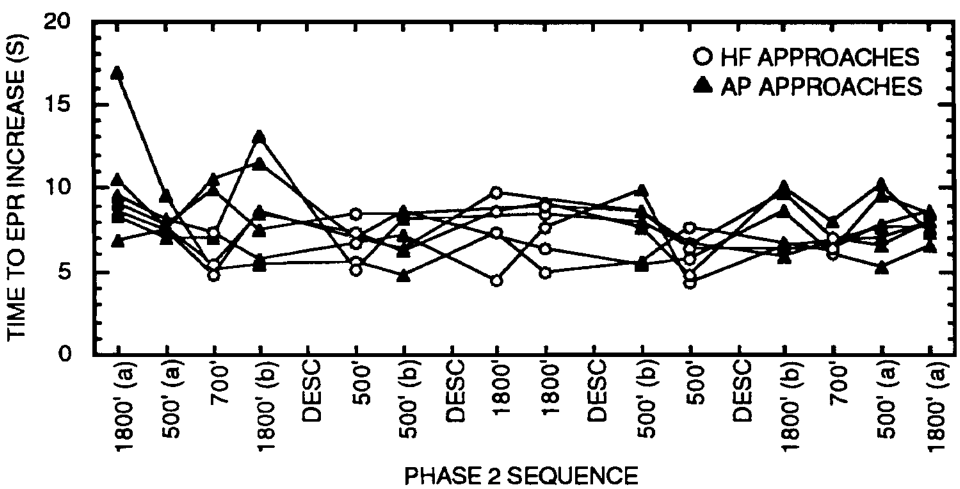

TIME TO PITCH INCREASE (S)
20
15
10
5
0
HF APPROACHES
AP APPROACHES
500'
DESC
DA
ENG OUT
1800'
1800'
DA
500
ENG OUT
DESC
1800'
500'
DA
DA
1800'
500'
PHASE 1 SEQUENCE


TIME TO INCR. VERTICAL RATE (S)
20
15
10
5
0
HF APPROACHES
AP APPROACHES
500'
DESC
DA
ENG OUT
1800'
1800'
DA
500
ENG OUT
DESC
1800'
500'
DA
DA
1800'
500'
PHASE 1 SEQUENCE

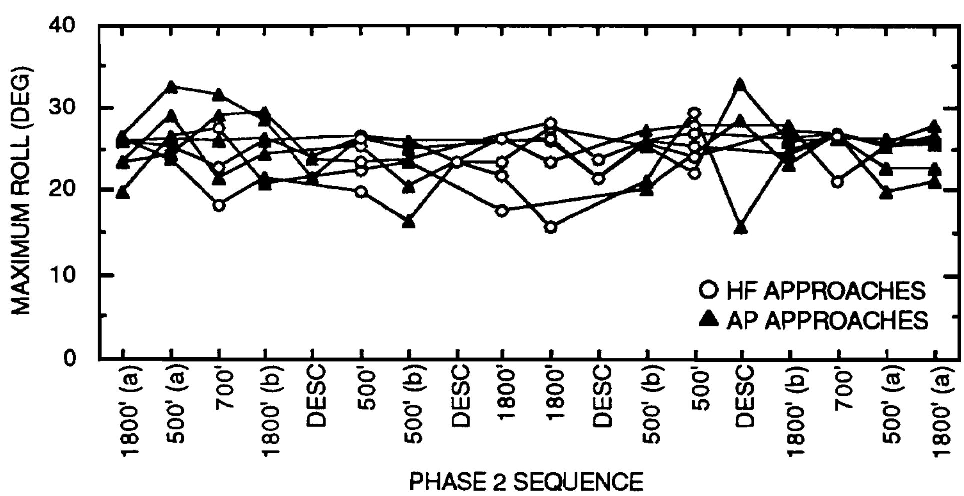
G.2 PHASE 2



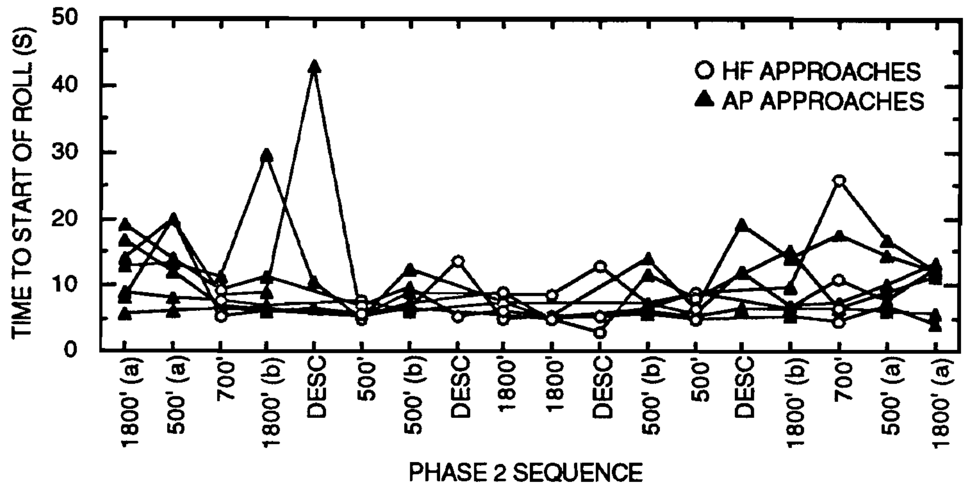
TIME TO THROTTLE INCREASE (S)
20
15
10
5
0
O HF APPROACHES
▲ AP APPROACHES
1800' (a)
500' (a)
700'
1800' (b)
DESC
500'
500' (b)
DESC
1800'
1800'
DESC
500' (b)
500'
DESC
1800' (b)
700'
500' (a)
1800' (a)
PHASE 2 SEQUENCE

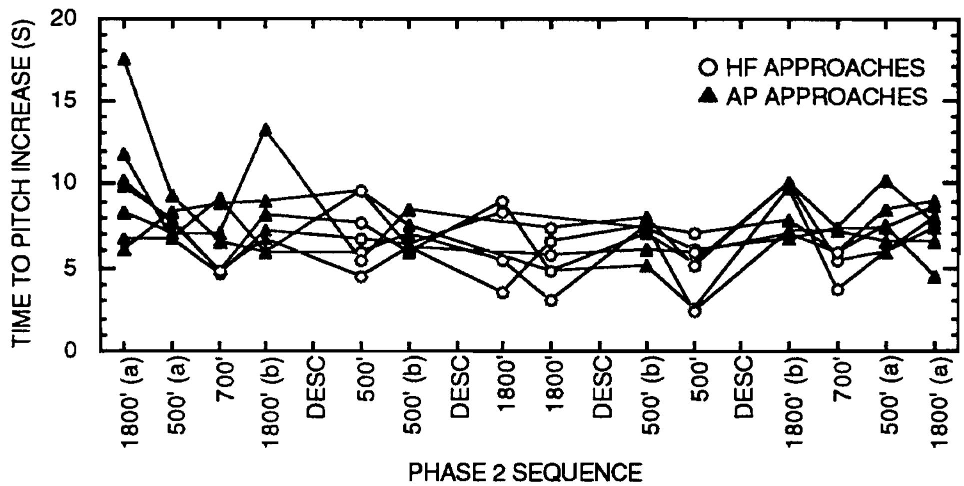


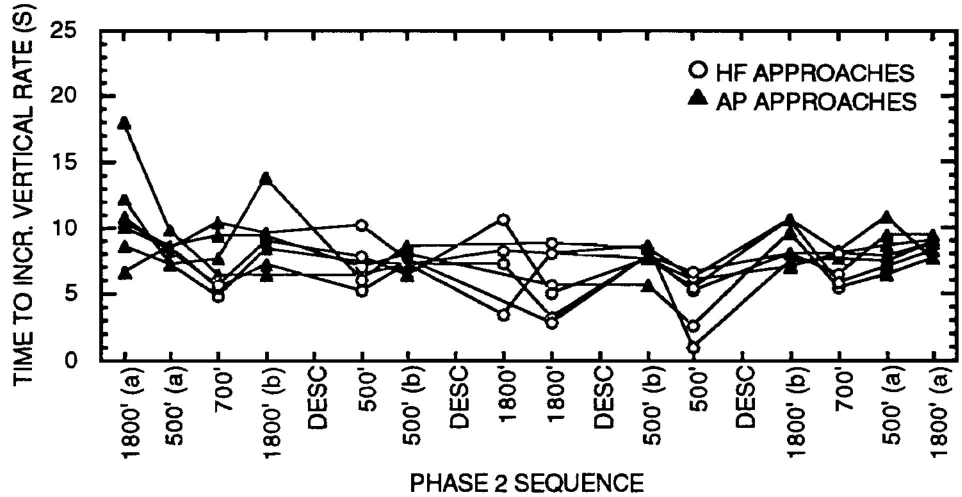
TIME TO EPR INCREASE (S)
20
15
10
5
0
O HF APPROACHES
▲ AP APPROACHES
1800' (a)
500' (a)
700'
1800' (b)
DESC
500'
500' (b)
DESC
1800'
1800'
DESC
500' (b)
500'
DESC
1800' (b)
700'
500' (a)
1800' (a)
PHASE 2 SEQUENCE



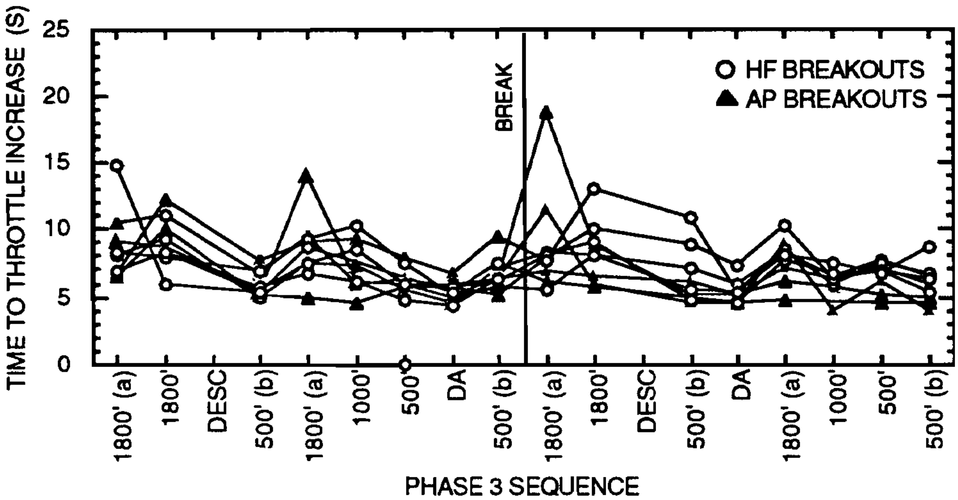
MAXIMUM ROLL (DEG)
40
30
20
10
0
O HF APPROACHES
▲ AP APPROACHES
1800' (a)
500' (a)
700'
1800' (b)
DESC
500'
500' (b)
DESC
1800'
1800'
DESC
500' (b)
500'
DESC
1800' (b)
700'
500' (a)
1800' (a)
PHASE 2 SEQUENCE


TIME TO START OF ROLL (S)
50
40
30
20
10
0
O HF APPROACHES
▲ AP APPROACHES
1800' (a)
500' (a)
700'
1800' (b)
DESC
500'
500' (b)
DESC
1800'
1800'
DESC
500' (b)
500'
DESC
1800' (b)
700'
500' (a)
1800' (a)
PHASE 2 SEQUENCE

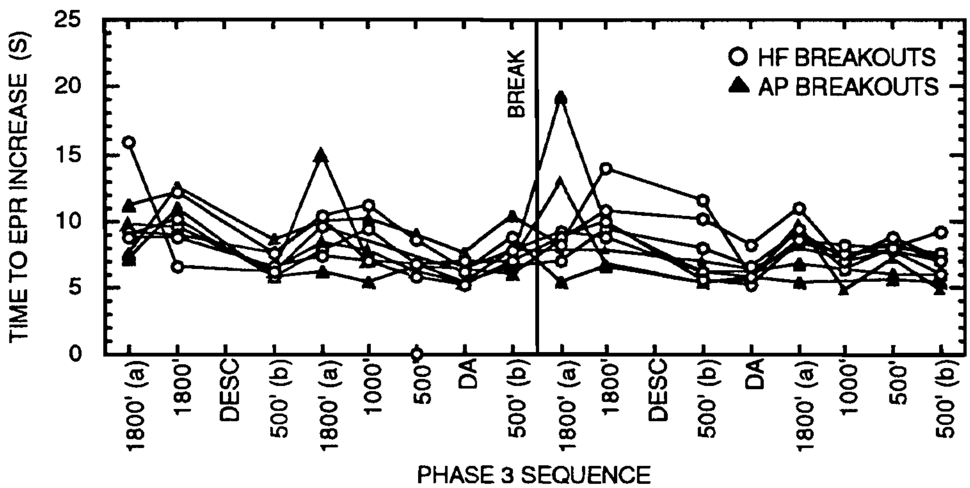

TIME TO PITCH INCREASE (S)
20
15
10
5
0
O HF APPROACHES
▲ AP APPROACHES
1800' (a)
500' (a)
700'
1800' (b)
DESC
500'
500' (b)
DESC
1800'
1800'
DESC
500' (b)
500'
DESC
1800' (b)
700'
500' (a)
1800' (a)
PHASE 2 SEQUENCE


TIME TO INCR. VERTICAL RATE (S)
25
20
15
10
5
0
O HF APPROACHES
▲ AP APPROACHES
1800' (a)
500' (a)
700'
1800' (b)
DESC
500'
500' (b)
DESC
1800'
1800'
DESC
500' (b)
500'
DESC
1800' (b)
700'
500' (a)
1800' (a)
PHASE 2 SEQUENCE

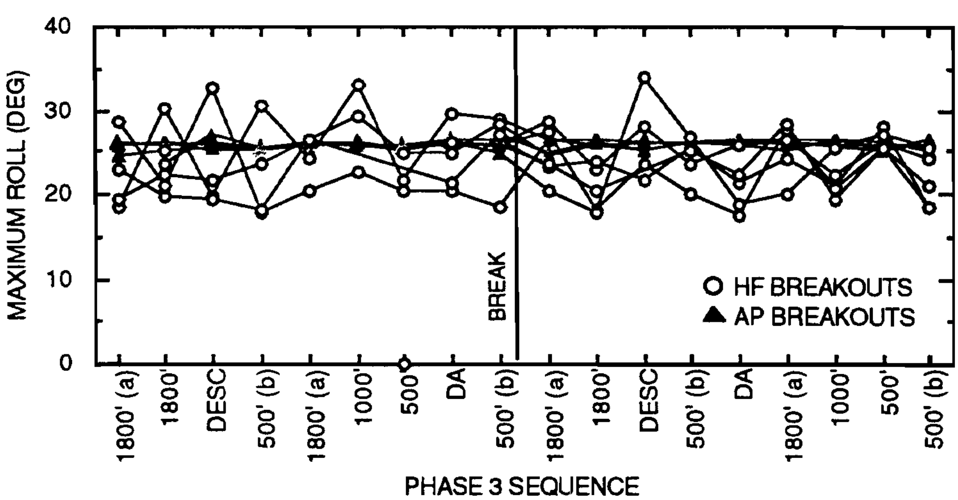
G.3 PHASE 3



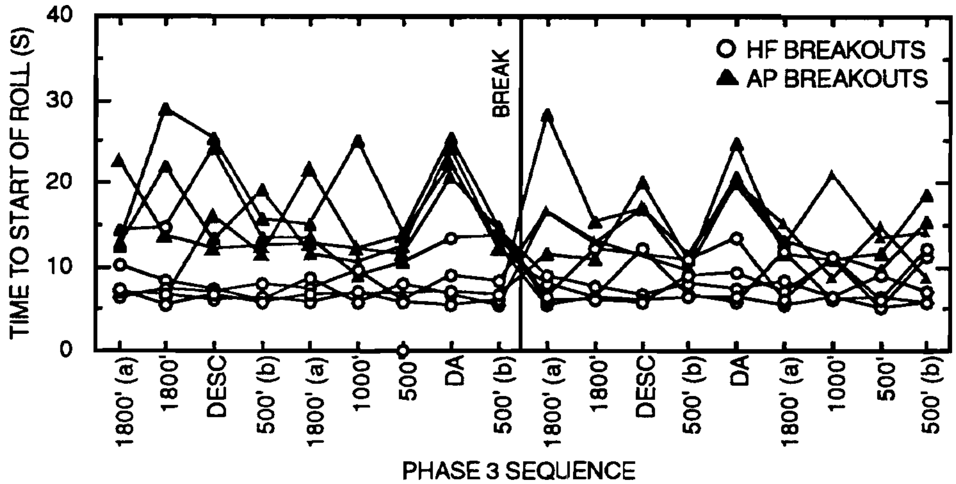
TIME TO THROTTLE INCREASE (S)
25
20
15
10
5
0
BREAK
HF BREAKOUTS
AP BREAKOUTS
1800' (a)
1800'
DESC
500' (b)
1800' (a)
1000'
500'
DA
500' (b)
1800' (a)
1800'
DESC
500' (b)
DA
1800' (a)
1000'
500'
500' (b)
PHASE 3 SEQUENCE

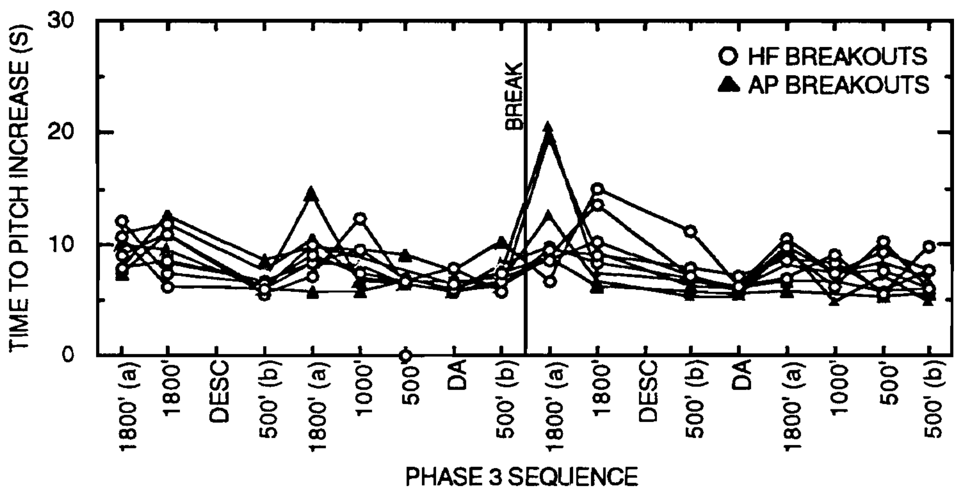


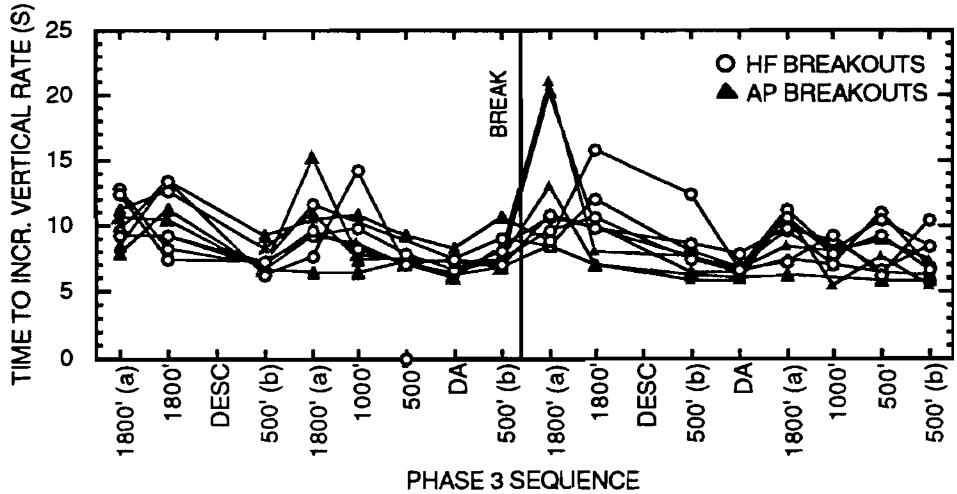
TIME TO EPR INCREASE (S)
25
20
15
10
5
0
BREAK
HF BREAKOUTS
AP BREAKOUTS
1800' (a)
1800'
DESC
500' (b)
1800' (a)
1000'
500'
DA
500' (b)
1800' (a)
1800'
DESC
500' (b)
DA
1800' (a)
1000'
500'
500' (b)
PHASE 3 SEQUENCE



MAXIMUM ROLL (DEG)
40
30
20
10
0
BREAK
HF BREAKOUTS
AP BREAKOUTS
1800' (a)
1800'
DESC
500' (b)
1800' (a)
1000'
500'
DA
500' (b)
1800' (a)
1800'
DESC
500' (b)
DA
1800' (a)
1000'
500'
500' (b)
PHASE 3 SEQUENCE


TIME TO START OF ROLL (S)
HF BREAKOUTS
AP BREAKOUTS
BREAK
1800' (a)
1800'
DESC
500' (b)
1000'
500'
DA
PHASE 3 SEQUENCE


TIME TO PITCH INCREASE (S)
HF BREAKOUTS
AP BREAKOUTS
BREAK
PHASE 3 SEQUENCE


TIME TO INCR. VERTICAL RATE (S)
HF BREAKOUTS
AP BREAKOUTS
BREAK
PHASE 3 SEQUENCE

APPENDIX H. SUMMARY STATISTICS FOR ALL TEST VARIABLES

DT_ROLL: Time from start of ATC instruction to start of roll (seconds)

BREAKOUT GROUP	MEDIAN	MEAN	S.D.	MINIMUM	MAXIMUM	COUNT
PHASE 1						
HAND-FLOWN APPROACHES, HAND-FLOWN BREAKOUTS						
DA	5.07	6.86	4.75	2.82	19.00	17
500'	4.40	5.88	3.67	2.59	14.11	17
1800'	4.11	4.25	1.04	3.10	7.28	18
DESCEND	4.37	4.78	.88	3.90	6.47	7
DISTRACTION	13.23	13.62	6.10	4.26	23.04	9
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
DA	8.53	12.71	7.76	4.44	31.46	13
500'	8.62	8.97	3.06	4.30	13.53	12
1800'	7.89	8.44	2.41	5.90	12.95	8
DESCEND	12.00	13.18	5.70	7.67	23.26	6
DISTRACTION	29.59	28.88	11.27	14.03	43.11	7
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
DA	25.59	25.47	2.63	22.40	29.24	7
500'	12.67	13.74	3.93	8.15	18.43	9
1800'	16.73	16.04	4.80	8.54	23.89	9
DESCEND	27.86	27.86	N/A	27.86	27.86	1
DISTRACTION	33.18	33.18	N/A	33.18	33.18	1
PHASE 2						
HAND-FLOWN APPROACHES, HAND-FLOWN BREAKOUTS						
500'	5.52	6.29	1.45	4.79	8.83	14
700'	7.44	9.88	7.34	4.47	25.77	7
1800'	5.20	6.01	1.55	4.69	8.73	10
DESCEND	5.16	7.35	4.60	2.87	13.63	6
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
500'	7.07	8.53	4.29	5.57	19.92	19
700'	6.77	6.94	.80	6.27	8.23	5
1800'	6.65	7.95	3.24	4.14	16.63	18
DESCEND	13.26	16.87	13.48	6.40	42.50	6
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
500'	13.30	12.81	2.53	8.70	16.90	9
700'	14.25	14.25	4.65	10.96	17.53	2
1800'	13.47	15.14	5.68	11.00	29.74	10
DESCEND	10.47	10.47	N/A	10.47	10.47	1
PHASE 3						
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
DA	7.23	8.30	2.78	5.24	13.40	11
500'	6.42	7.16	1.88	5.19	11.97	26
1000'	6.70	7.82	2.25	5.61	11.17	8
1800'	6.86	7.56	2.20	5.44	14.73	29
DESCEND	6.72	7.20	2.08	5.76	12.20	8
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
DA	21.47	22.21	2.25	19.84	25.36	8
500'	12.53	12.91	2.53	8.60	19.03	27
1000'	11.33	13.61	6.14	8.50	25.23	8
1800'	13.47	15.69	5.14	10.70	28.97	24
DESCEND	16.76	17.62	4.81	11.97	25.50	9

DT_HEADING: Time from start of ATC instruction to start of heading change (seconds)

BREAKOUT GROUP	MEDIAN	MEAN	S.D.	MINIMUM	MAXIMUM	COUNT
PHASE 1						
HAND-FLOWN APPROACHES, HAND-FLOWN BREAKOUTS						
DA	8.18	9.03	2.70	5.35	13.82	17
500'	8.27	9.44	3.90	5.23	18.71	17
1800'	7.34	7.77	1.70	5.64	11.36	18
DESCEND	8.34	9.08	2.29	7.10	13.56	7
DISTRACTION	19.80	21.10	6.36	13.20	30.50	9
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
DA	11.53	15.47	8.23	6.94	34.86	13
500'	11.79	11.73	3.04	6.84	16.30	12
1800'	10.72	11.44	2.91	7.37	16.33	8
DESCEND	15.82	16.81	7.17	10.04	29.37	6
DISTRACTION	22.20	21.06	11.83	6.00	35.20	7
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
DA	28.76	28.79	2.67	25.53	32.50	7
500'	15.49	16.92	4.06	11.06	21.84	9
1800'	21.84	19.58	5.91	7.07	27.60	9
DESCEND	31.81	31.81	N/A	31.81	31.81	1
DISTRACTION	30.35	30.35	N/A	30.35	30.35	1
PHASE 2						
HAND-FLOWN APPROACHES, HAND-FLOWN BREAKOUTS						
500'	9.62	9.73	1.49	7.89	12.93	14
700'	9.34	12.26	6.53	7.50	26.36	7
1800'	8.52	9.30	2.09	7.36	12.93	10
DESCEND	8.68	9.35	4.13	5.70	17.27	6
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
500'	9.70	11.40	4.20	8.33	23.19	19
700'	9.64	10.17	.97	9.61	11.86	5
1800'	10.74	11.92	3.84	6.97	22.26	18
DESCEND	17.18	20.60	13.55	10.03	46.44	6
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
500'	16.17	15.87	2.71	11.27	20.30	9
700'	17.51	17.51	4.84	14.09	20.93	2
1800'	17.90	19.48	5.56	15.23	33.74	10
DESCEND	14.90	14.90	N/A	14.90	14.90	1
PHASE 3						
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
DA	10.33	11.18	3.05	6.70	16.73	11
500'	9.54	10.16	2.09	6.43	15.61	26
1000'	9.70	10.93	2.40	8.14	14.23	8
1800'	10.23	10.64	2.35	7.27	17.33	29
DESCEND	10.17	10.43	2.61	5.80	14.77	8
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
DA	24.94	25.63	2.23	23.30	29.00	8
500'	15.84	16.21	2.40	12.43	22.47	27
1000'	14.92	16.88	6.17	11.70	28.60	8
1800'	17.55	19.79	5.44	13.79	33.67	24
DESCEND	20.93	21.99	5.61	15.84	32.47	9

MAXIMUM_ROLL: Maximum roll angle (degrees)

BREAKOUT GROUP	MEDIAN	MEAN	S.D.	MINIMUM	MAXIMUM	COUNT
PHASE 1						
HAND-FLOWN APPROACHES, HAND-FLOWN BREAKOUTS						
DA	25.44	25.23	3.75	17.03	32.16	17
500'	24.85	24.76	3.37	17.44	29.60	17
1800'	23.43	22.87	2.52	16.32	27.61	18
DESCEND	22.15	22.99	5.17	14.80	30.23	7
DISTRACTION	21.08	20.60	7.22	2.94	28.24	9
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
DA	26.44	28.37	6.58	19.02	44.43	13
500'	24.26	25.55	4.74	19.27	32.88	12
1800'	26.74	26.26	4.19	16.65	30.45	8
DESCEND	28.54	28.27	7.38	14.87	35.47	6
DISTRACTION	22.50	23.54	4.61	16.96	29.42	7
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
DA	25.93	25.96	.21	25.68	26.26	7
500'	25.34	25.44	.50	24.60	26.15	9
1800'	26.11	26.07	2.36	21.53[1]	30.86[2]	9
DESCEND	24.67	24.67	N/A	24.67	24.67	1
DISTRACTION	15.20	15.20	N/A	15.20	15.20	1
PHASE 2						
HAND-FLOWN APPROACHES, HAND-FLOWN BREAKOUTS						
500'	25.20	24.84	2.54	19.72	29.32	14
700'	26.57	24.22	3.61	18.34	27.47	7
1800'	24.58	23.51	4.13	15.64	27.95	10
DESCEND	22.99	22.59	1.03	21.28	23.61	6
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
500'	24.36	24.14	3.64	16.41	32.56	19
700'	26.86	27.06	3.77	21.25	31.46	5
1800'	24.26	24.52	2.83	19.81	29.26	18
DESCEND	25.94	25.71	6.78	15.61	32.96	6
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
500'	25.20	25.50	.44	25.04	26.04	9
700'	25.87	25.87	.16	25.75	25.98	2
1800'	25.91	25.90	.16	25.64	26.18	10
DESCEND	23.88	23.88	N/A	23.88	23.88	1
PHASE 3						
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
DA	21.39	22.63	3.64	17.48	29.69	11
500'	25.08	23.86	3.77	17.87	30.46	26
1000'	22.39	24.22	4.78	19.26	33.14	8
1800'	23.69	23.52	3.51	17.85	30.08	29
DESCEND	22.61	25.09	5.80	19.42	34.19	8
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
DA	25.99	26.04	.25	25.74	26.43	8
500'	25.65	25.64	.41	24.89	26.37	27
1000'	26.01	26.05	.21	25.79	26.38	8
1800'	25.96	25.80	.57	24.35	26.35	24
DESCEND	25.84	25.81	.52	25.20	26.68	9

1. Trial ended before the turn was completed.
2. Autopilot was disconnected after the start of the turn.

T_HEADING_SELECT: Time from start of ATC breakout instruction to heading input (seconds)

	MEDIAN	MEAN	S.D.	MINIMUM	MAXIMUM	COUNT
PHASE 1						
HAND-FLOWN APPROACHES, HAND-FLOWN BREAKOUTS						
DA	17.40	16.48	6.09	8.20	27.70	17
500'	11.10	15.02	11.01	5.20	41.00	17
1800'	14.20	15.69	5.34	9.90	26.50	18
DESCEND	22.70	23.35	4.27	19.50	28.50	7
DISTRACTION	14.40	15.85	11.13	6.10	28.50	9
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
DA	22.25	23.14	7.30	8.60	36.40	13
500'	12.75	17.66	13.01	5.40	50.70	12
1800'	11.70	11.65	4.17	7.10	17.70	8
DESCEND	19.50	18.55	8.81	6.90	28.30	6
DISTRACTION	25.50	25.38	2.96	22.00	28.50	7
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
DA	19.85	19.53	4.90	10.90	25.90	7
500'	13.90	13.64	.79	12.50	14.50	9
1800'	14.40	14.13	3.87	9.60	20.40	9
DESCEND	24.50	24.50	N/A	24.50	24.50	1
DISTRACTION	24.90	24.90	N/A	24.90	24.90	1
PHASE 2						
HAND-FLOWN APPROACHES, HAND-FLOWN BREAKOUTS						
500'	N/A	N/A	N/A	N/A	N/A	14
700'	N/A	N/A	N/A	N/A	N/A	7
1800'	N/A	N/A	N/A	N/A	N/A	10
DESCEND	N/A	N/A	N/A	N/A	N/A	6
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
500'	N/A	N/A	N/A	N/A	N/A	19
700'	N/A	N/A	N/A	N/A	N/A	5
1800'	N/A	N/A	N/A	N/A	N/A	18
DESCEND	N/A	N/A	N/A	N/A	N/A	6
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
500'	N/A	N/A	N/A	N/A	N/A	9
700'	N/A	N/A	N/A	N/A	N/A	2
1800'	N/A	N/A	N/A	N/A	N/A	10
DESCEND	N/A	N/A	N/A	N/A	N/A	1
PHASE 3						
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
DA	22.80	21.97	5.70	15.90	27.20	11
500'	21.70	25.96	10.29	17.80	43.40	26
1000'	N/A	N/A	N/A	N/A	N/A	8
1800'	21.30	26.69	10.50	17.60	48.10	29
DESCEND	26.10	26.10	5.94	21.90	30.30	8
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
DA	18.30	18.89	2.32	16.30	22.10	8
500'	8.90	9.30	2.64	5.20	15.90	27
1000'	7.40	8.52	5.61	3.90	21.80	8
1800'	9.90	11.67	4.91	7.20	24.60	24
DESCEND	13.80	14.90	6.01	7.80	26.90	9

DX_TURN: Ground distance traveled from start of ATC breakout instruction to start of roll (feet)

	MEDIAN	MEAN	S.D.	MINIMUM	MAXIMUM	COUNT
PHASE 1						
HAND-FLOWN APPROACHES, HAND-FLOWN BREAKOUTS						
DA	1388.10	1886.65	1312.44	742.20	5355.40	17
500'	1167.70	1600.69	1019.01	690.10	4029.80	17
1800'	1151.95	1206.39	286.23	845.40	2020.80	18
DESCEND	1287.70	1358.60	265.18	1089.10	1873.20	7
DISTRACTION	3433.90	3563.30	1510.56	1175.50	5807.00	9
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
DA	2272.30	3380.03	2034.08	1243.80	8301.70	13
500'	2294.40	2393.19	822.04	1177.50	3591.50	12
1800'	2172.70	2319.07	620.38	1637.10	3429.60	8
DESCEND	3216.20	3575.32	1516.46	2139.70	6264.90	6
DISTRACTION	7307.00	7242.54	2748.96	3775.20	11194.70	7
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
DA	6716.70	6675.59	756.35	5796.20	7848.70	7
500'	3384.50	3656.90	1027.30	2143.50	4898.20	9
1800'	4518.50	4371.50	1307.75	2309.80	6429.80	9
DESCEND	7372.40	7372.40	N/A	7372.40	7372.40	1
DISTRACTION	8593.30	8593.30	N/A	8593.30	8593.30	1
PHASE 2						
HAND-FLOWN APPROACHES, HAND-FLOWN BREAKOUTS						
500'	1472.50	1713.99	419.01	1271.60	2459.70	14
700'	2089.10	2724.23	2001.61	1228.30	7046.40	7
1800'	1491.85	1715.89	480.69	1299.60	2558.20	10
DESCEND	1456.20	2093.50	1341.86	790.20	3830.80	6
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
500'	1880.40	2280.95	1148.38	1475.40	5362.90	19
700'	1810.00	1866.42	253.62	1650.60	2264.00	5
1800'	1793.90	2198.43	923.53	1144.10	4508.40	18
DESCEND	3591.90	4780.07	4021.41	1726.80	12448.00	6
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
500'	3528.70	3419.04	662.13	2305.90	4453.10	9
700'	3864.15	3864.15	1351.49	2908.50	4819.80	2
1800'	3635.05	4182.27	1520.84	3062.60	7985.60	10
DESCEND	2820.50	2820.50	N/A	2820.50	2820.50	1
PHASE 3						
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
DA	1964.70	2241.75	759.26	1386.20	3640.10	11
500'	1753.60	1954.05	516.90	1406.30	3309.10	26
1000'	1820.70	2152.96	624.96	1543.60	3107.10	8
1800'	1969.30	2115.73	608.56	1485.90	3990.50	29
DESCEND	1843.70	2058.64	677.81	1589.80	3636.60	8
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
DA	5670.45	5920.91	539.16	5390.20	6765.70	8
500'	3339.40	3501.89	663.41	2421.70	5055.10	27
1000'	3072.05	3702.90	1626.33	2379.70	6593.40	8
1800'	3875.80	4415.69	1434.63	2955.30	8249.90	24
DESCEND	4701.60	4945.28	1355.22	3246.70	7078.80	9

DT_THROTTLE: Time from start of ATC breakout instruction to throttle increase (seconds)

	MEDIAN	MEAN	S.D.	MINIMUM	MAXIMUM	COUNT
PHASE 1						
HAND-FLOWN APPROACHES, HAND-FLOWN BREAKOUTS						
DA	3.96	3.93	.88	2.23	5.07	17
500'	4.84	5.06	1.45	2.84	8.51	17
1800'	5.74	6.00	2.44	2.88	13.34	18
DESCEND	N/A	N/A	N/A	N/A	N/A	7
DISTRACTION	4.13	4.05	1.20	2.01	5.39	9
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
DA	3.97	4.41	1.61	2.83	9.17	13
500'	4.83	5.90	2.48	3.94	12.11	12
1800'	6.40	6.57	2.21	4.40	10.98	8
DESCEND	N/A	N/A	N/A	N/A	N/A	6
DISTRACTION	5.07	4.74	1.08	3.10	5.83	7
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
DA	4.50	4.17	1.11	2.84	5.34	7
500'	5.95	6.07	1.33	3.74	7.96	9
1800'	7.65	7.78	1.43	5.82	10.49	9
DESCEND	N/A	N/A	N/A	N/A	N/A	1
DISTRACTION	3.69	3.69	N/A	3.69	3.69	1
PHASE 2						
HAND-FLOWN APPROACHES, HAND-FLOWN BREAKOUTS						
500'	5.73	5.62	1.07	3.77	7.97	14
700'	5.29	5.27	.95	3.74	6.33	7
1800'	7.38	6.75	1.74	3.86	8.64	10
DESCEND	N/A	N/A	N/A	N/A	N/A	6
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
500'	6.97	6.82	1.29	4.26	8.70	19
700'	6.57	7.10	2.09	4.54	9.63	5
1800'	7.31	7.40	2.56	5.04	15.79	18
DESCEND	N/A	N/A	N/A	N/A	N/A	6
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
500'	6.50	6.55	1.32	4.77	9.34	9
700'	6.49	6.49	.40	6.20	6.77	2
1800'	8.27	8.43	1.90	6.23	12.47	10
DESCEND	N/A	N/A	N/A	N/A	N/A	1
PHASE 3						
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
DA	5.30	5.45	.77	4.40	7.24	11
500'	6.63	6.70	1.38	4.70	10.93	26
1000'	6.60	7.23	1.51	5.83	10.34	8
1800'	8.20	8.60	1.90	5.43	14.93	29
DESCEND	N/A	N/A	N/A	N/A	N/A	8
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
DA	5.01	5.14	.78	4.44	6.73	8
500'	5.63	5.84	1.23	3.90	9.47	27
1000'	6.03	6.14	1.64	3.93	9.33	8
1800'	8.08	8.57	3.21	4.77	18.77	24
DESCEND	7.36	7.36	N/A	7.36	7.36	9

DT_ENGINE: Time from start of ATC breakout instruction to EPR increase (seconds)

BREAKOUT GROUP	MEDIAN	MEAN	S.D.	MINIMUM	MAXIMUM	COUNT
PHASE 1						
HAND-FLOWN APPROACHES, HAND-FLOWN BREAKOUTS						
DA	5.24	4.90	.90	3.10	6.20	17
500'	5.70	5.84	1.53	3.46	9.65	17
1800'	6.63	7.42	3.72	4.02	21.29	18
DESCEND	N/A	N/A	N/A	N/A	N/A	7
DISTRACTION	4.77	4.64	1.27	2.59	6.52	9
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
DA	4.60	5.13	1.59	3.66	9.74	13
500'	5.85	6.85	2.47	4.50	12.95	12
1800'	7.39	7.39	2.09	5.30	11.55	8
DESCEND	13.65	13.65	11.81	5.30	22.00	6
DISTRACTION	5.40	5.23	1.04	3.67	6.41	7
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
DA	5.34	5.07	1.17	3.69	6.24	7
500'	6.80	6.86	1.23	4.61	8.57	9
1800'	8.22	8.48	1.49	6.41	11.34	9
DESCEND	N/A	N/A	N/A	N/A	N/A	1
DISTRACTION	4.25	4.25	N/A	4.25	4.25	1
PHASE 2						
HAND-FLOWN APPROACHES, HAND-FLOWN BREAKOUTS						
500'	6.61	6.38	1.16	4.36	8.50	14
700'	6.16	6.16	.88	4.84	7.30	7
1800'	8.07	7.58	1.79	4.42	9.77	10
DESCEND	N/A	N/A	N/A	N/A	N/A	6
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
500'	7.81	7.69	1.40	4.79	9.86	19
700'	6.87	7.84	2.29	5.07	10.47	5
1800'	7.84	8.18	2.64	5.40	16.93	18
DESCEND	N/A	N/A	N/A	N/A	N/A	6
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
500'	7.60	7.39	1.39	5.30	10.20	9
700'	7.49	7.49	.62	7.06	7.93	2
1800'	9.04	9.16	1.85	6.53	13.00	10
DESCEND	N/A	N/A	N/A	N/A	N/A	1
PHASE 3						
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
DA	6.20	6.24	.83	5.10	8.11	11
500'	7.52	7.52	1.38	5.64	11.50	26
1000'	7.32	7.93	1.58	6.37	11.17	8
1800'	9.10	9.43	1.92	6.54	15.80	29
DESCEND	36.50	36.50	N/A	36.50	36.50	8
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
DA	5.87	6.01	.74	5.33	7.57	8
500'	6.46	6.69	1.25	4.70	10.31	27
1000'	6.90	6.93	1.61	4.80	10.14	8
1800'	8.95	9.32	3.25	5.33	19.33	24
DESCEND	8.62	8.09	2.20	5.00	10.80	9

DT_PITCH: Time from start of ATC breakout instruction to increasing pitch angle (seconds)

	MEDIAN	MEAN	S.D.	MINIMUM	MAXIMUM	COUNT
PHASE 1						
HAND-FLOWN APPROACHES, HAND-FLOWN BREAKOUTS						
DA	4.07	4.11	1.21	1.16	5.96	17
500'	4.51	4.77	1.50	2.59	8.15	17
1800'	5.91	5.79	2.08	2.06	9.31	18
DESCEND	2.50	2.50	N/A	2.50	2.50	7
DISTRACTION	3.69	3.91	1.10	2.59	6.17	9
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
DA	5.18	5.14	.76	4.10	6.20	13
500'	6.00	6.70	2.08	4.50	11.83	12
1800'	7.50	7.95	2.39	5.03	12.39	8
DESCEND	12.80	12.80	10.89	5.10	20.50	6
DISTRACTION	5.63	5.84	1.24	4.23	7.47	7
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
DA	5.34	5.19	1.14	3.69	6.54	7
500'	7.20	7.05	1.27	4.89	8.87	9
1800'	8.26	8.77	1.33	6.70	10.53	9
DESCEND	N/A	N/A	N/A	N/A	N/A	1
DISTRACTION	4.81	4.81	N/A	4.81	4.81	1
PHASE 2						
HAND-FLOWN APPROACHES, HAND-FLOWN BREAKOUTS						
500'	5.86	5.97	2.14	2.33	9.63	14
700'	4.83	5.01	.78	3.70	5.87	7
1800'	5.65	5.86	1.95	3.07	8.96	10
DESCEND	7.03	7.03	N/A	7.03	7.03	6
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
500'	7.33	7.14	.96	5.13	9.27	19
700'	7.40	7.79	1.10	6.47	9.06	5
1800'	7.05	7.97	2.92	4.44	17.50	18
DESCEND	24.57	24.57	18.29	11.63	37.50	6
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
500'	7.08	7.33	1.42	5.86	10.20	9
700'	7.22	7.22	.22	7.06	7.37	2
1800'	9.10	9.30	1.79	7.37	13.30	10
DESCEND	N/A	N/A	N/A	N/A	N/A	1
PHASE 3						
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
DA	6.10	6.31	.69	5.60	7.87	11
500'	6.99	7.19	1.47	5.56	11.20	26
1000'	7.92	8.42	1.88	6.20	12.31	8
1800'	9.00	9.40	2.00	6.27	15.00	29
DESCEND	8.09	8.09	N/A	8.09	8.09	8
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
DA	5.85	6.02	.75	5.27	7.57	8
500'	6.44	6.70	1.26	4.70	10.31	27
1000'	6.76	6.97	1.45	4.80	9.60	8
1800'	9.45	10.00	3.84	5.64	20.50	24
DESCEND	8.02	7.76	1.33	6.00	9.00	9

DT_VERTICAL_SPEED: Time from start of ATC breakout instruction to start of climb (seconds)

	MEDIAN	MEAN	S.D.	MINIMUM	MAXIMUM	COUNT
PHASE 1						
HAND-FLOWN APPROACHES, HAND-FLOWN BREAKOUTS						
DA	4.82	4.94	1.14	2.02	7.00	17
500'	5.14	5.43	1.54	3.13	8.50	17
1800'	7.87	7.50	1.98	4.60	11.00	18
DESCEND	3.36	3.36	N/A	3.36	3.36	7
DISTRACTION	4.78	5.01	1.35	2.59	7.00	9
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
DA	5.64	5.38	.72	4.23	6.20	13
500'	6.89	7.47	2.19	5.11	12.67	12
1800'	7.62	8.31	2.45	5.60	13.24	8
DESCEND	13.35	13.35	11.10	5.50	21.20	6
DISTRACTION	6.47	6.04	1.14	4.51	7.47	7
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
DA	5.62	5.36	1.09	3.97	6.54	7
500'	7.65	7.62	1.27	5.46	9.46	9
1800'	8.87	9.05	1.20	7.29	11.06	9
DESCEND	N/A	N/A	N/A	N/A	N/A	1
DISTRACTION	4.81	4.81	N/A	4.81	4.81	1
PHASE 2						
HAND-FLOWN APPROACHES, HAND-FLOWN BREAKOUTS						
500'	6.20	5.99	2.19	1.13	10.21	14
700'	5.66	5.97	1.05	4.84	8.07	7
1800'	6.46	6.33	2.68	2.77	10.69	10
DESCEND	7.33	7.33	N/A	7.33	7.33	6
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
500'	7.83	7.97	.94	5.70	9.83	19
700'	7.97	8.40	1.54	6.47	10.46	5
1800'	8.86	9.16	2.64	6.54	18.06	18
DESCEND	16.77	16.77	6.74	12.00	21.53	6
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
500'	7.64	7.90	1.35	6.46	10.76	9
700'	7.91	7.91	.40	7.63	8.20	2
1800'	9.75	9.76	1.92	7.64	13.87	10
DESCEND	N/A	N/A	N/A	N/A	N/A	1
PHASE 3						
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
DA	6.67	6.85	.49	6.16	7.84	11
500'	7.45	8.00	1.56	6.13	12.37	26
1000'	8.53	9.16	2.22	7.07	14.24	8
1800'	9.77	10.19	1.95	7.10	15.83	29
DESCEND	7.92	7.92	.69	7.43	8.40	8
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
DA	6.29	6.52	.79	5.80	8.13	8
500'	6.93	7.20	1.22	5.30	10.60	27
1000'	7.62	7.64	1.60	5.37	10.70	8
1800'	10.15	10.52	3.86	6.20	21.00	24
DESCEND	8.82	8.78	1.45	7.00	10.50	9

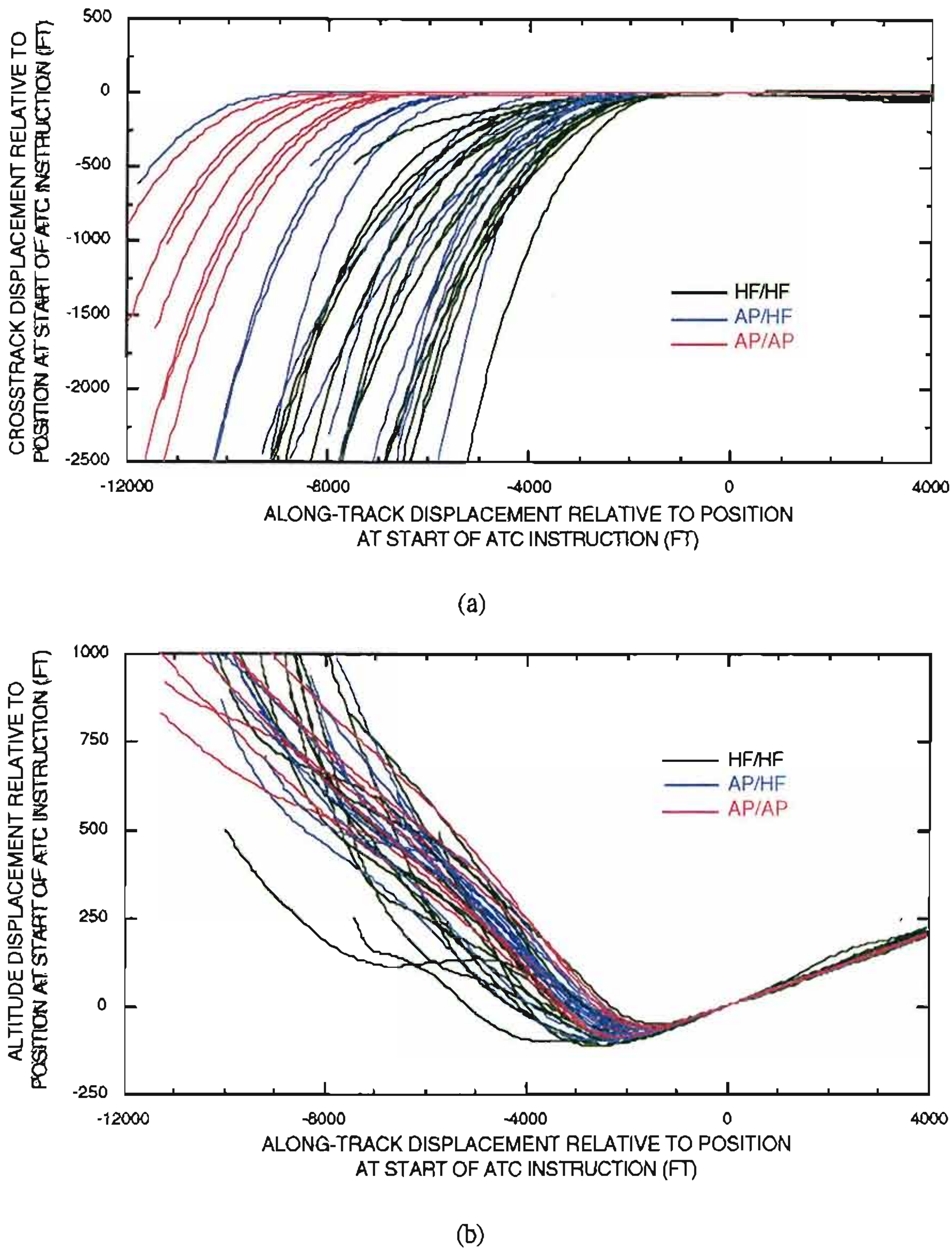
DT_FLAPS: Time from start of ATC breakout instruction to change in flap angle (seconds)

	MEDIAN	MEAN	S.D.	MINIMUM	MAXIMUM	COUNT
PHASE 1						
HAND-FLOWN APPROACHES, HAND-FLOWN BREAKOUTS						
DA	14.47	16.14	7.80	7.78	41.57	17
500'	15.77	17.21	5.70	7.67	33.79	17
1800'	17.54	21.11	8.28	12.96	38.87	18
DESCEND	39.60	39.21	3.00	36.03	41.99	7
DISTRACTION	19.63	19.48	6.18	10.77	27.80	9
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
DA	14.64	17.67	7.76	9.20	34.53	13
500'	15.58	17.54	5.93	11.14	31.00	12
1800'	16.70	19.68	6.70	13.80	33.00	8
DESCEND	45.43	44.92	15.15	30.08	64.64	6
DISTRACTION	34.63	34.64	23.97	6.75	70.83	7
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
DA	12.71	13.68	4.71	9.00	22.54	7
500'	17.41	16.82	4.68	10.13	24.39	9
1800'	17.07	17.10	4.39	12.39	23.83	9
DESCEND	22.23	22.23	N/A	22.23	22.23	1
DISTRACTION	14.75	14.75	N/A	14.75	14.75	1
PHASE 2						
HAND-FLOWN APPROACHES, HAND-FLOWN BREAKOUTS						
500'	17.29	17.11	3.31	12.37	26.00	14
700'	16.86	17.49	2.62	14.23	21.66	7
1800'	19.35	29.63	19.43	12.89	62.37	10
DESCEND	50.90	45.91	15.48	23.77	62.53	6
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
500'	17.50	18.60	6.29	11.70	33.17	19
700'	17.70	18.27	1.69	16.94	20.74	5
1800'	16.40	20.70	13.45	10.73	66.23	18
DESCEND	29.70	28.41	5.35	22.53	33.00	6
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
500'	17.31	17.28	1.59	14.33	19.63	9
700'	20.22	20.22	2.57	18.40	22.03	2
1800'	18.40	19.22	3.18	16.47	25.53	10
DESCEND	25.33	25.33	N/A	25.33	25.33	1
PHASE 3						
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
DA	29.94	29.21	11.00	15.40	49.46	11
500'	23.73	24.91	11.15	12.06	56.56	26
1000'	22.22	25.86	11.15	14.29	46.73	8
1800'	24.90	28.77	11.49	13.07	48.53	29
DESCEND	35.51	35.17	14.37	18.40	54.07	8
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
DA	24.25	20.95	6.48	9.56	27.33	8
500'	18.50	19.32	6.06	11.83	39.20	27
1000'	22.17	25.97	10.11	15.66	43.27	8
1800'	25.91	31.91	14.05	16.47	59.30	24
DESCEND	46.62	50.56	12.19	37.77	72.83	9

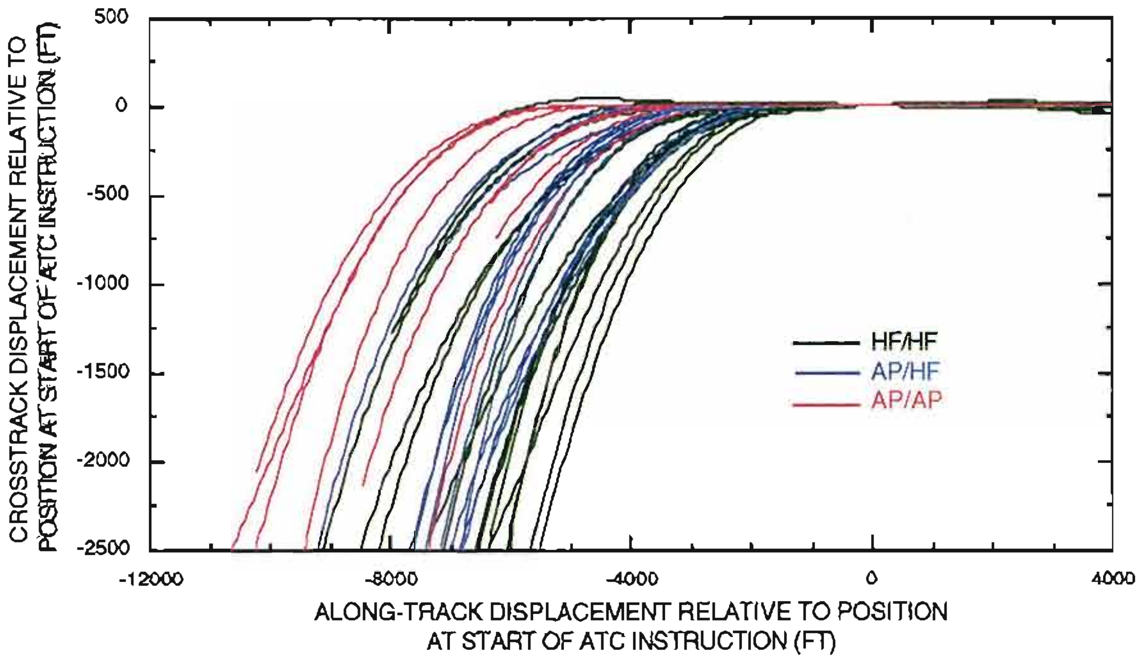
DT_GEAR: Time from start of ATC breakout instruction to change in gear position (seconds)

BREAKOUT GROUP	MEDIAN	MEAN	S.D.	MINIMUM	MAXIMUM	COUNT
PHASE 1						
HAND-FLOWN APPROACHES, HAND-FLOWN BREAKOUTS						
DA	20.38	22.64	7.36	16.46	45.00	17
500'	24.19	22.87	3.68	15.84	28.25	17
1800'	22.14	25.23	7.87	15.78	40.63	18
DESCEND	40.53	42.75	8.28	35.81	51.92	7
DISTRACTION	28.69	29.13	6.48	21.01	37.98	9
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
DA	30.22	26.63	8.12	14.96	38.93	13
500'	19.81	21.84	4.56	18.33	33.81	12
1800'	20.72	24.16	6.71	18.93	35.83	8
DESCEND	44.98	46.08	11.70	36.04	58.33	6
DISTRACTION	41.36	41.21	21.47	16.27	74.17	7
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
DA	19.80	22.99	8.86	15.91	40.85	7
500'	22.74	23.02	4.33	16.42	29.50	9
1800'	22.83	23.55	5.21	17.66	31.20	9
DESCEND	40.80	40.80	N/A	40.80	40.80	1
DISTRACTION	24.11	24.11	N/A	24.11	24.11	1
PHASE 2						
HAND-FLOWN APPROACHES, HAND-FLOWN BREAKOUTS						
500'	23.86	22.96	5.25	9.87	33.17	14
700'	24.70	24.63	5.08	18.13	34.47	7
1800'	32.24	36.91	16.72	16.69	59.50	10
DESCEND	42.56	44.65	4.48	41.60	49.80	6
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
500'	22.17	26.82	13.53	12.33	67.47	19
700'	25.32	27.61	8.11	20.90	38.90	5
1800'	24.11	27.59	11.83	13.93	60.36	18
DESCEND	37.33	42.24	22.47	15.83	73.29	6
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
500'	21.40	22.40	3.35	18.27	28.43	9
700'	23.90	23.90	1.36	22.93	24.86	2
1800'	23.39	23.65	3.63	18.80	30.33	10
DESCEND	29.83	29.83	N/A	29.83	29.83	1
PHASE 3						
AUTOPILOT-COUPLED APPROACHES, HAND-FLOWN BREAKOUTS						
DA	33.23	33.69	10.45	23.00	57.80	11
500'	27.87	30.70	11.13	17.17	61.80	26
1000'	28.56	31.36	10.00	19.83	50.77	8
1800'	34.50	34.36	12.78	18.40	68.07	29
DESCEND	48.66	42.76	15.71	21.46	60.40	8
AUTOPILOT-COUPLED APPROACHES, AUTOPILOT-COUPLED BREAKOUTS						
DA	30.26	29.02	6.22	19.73	38.50	8
500'	24.10	27.86	11.99	17.13	70.73	27
1000'	34.15	33.57	9.26	22.89	45.54	8
1800'	32.77	36.87	13.92	19.67	63.30	24
DESCEND	56.36	55.80	6.49	46.77	64.84	9

APPENDIX I. PHASE 1 BREAKOUT TRAJECTORIES



Phase 1 climbing breakouts at decision altitude.
(a) Ground track. (b) Vertical profile.



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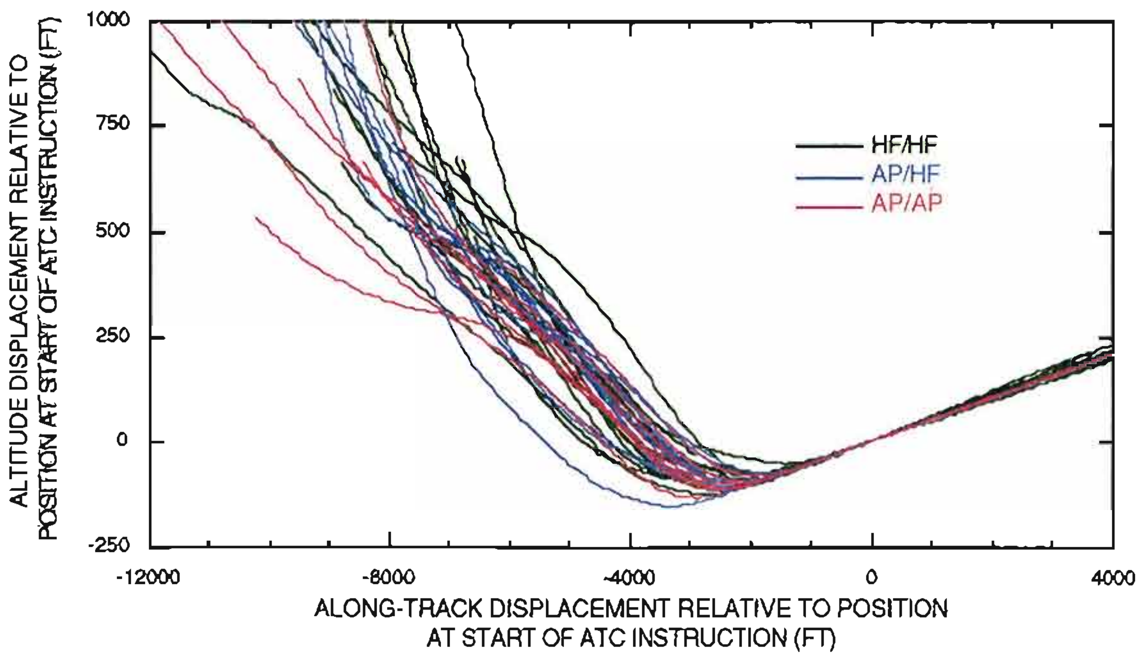
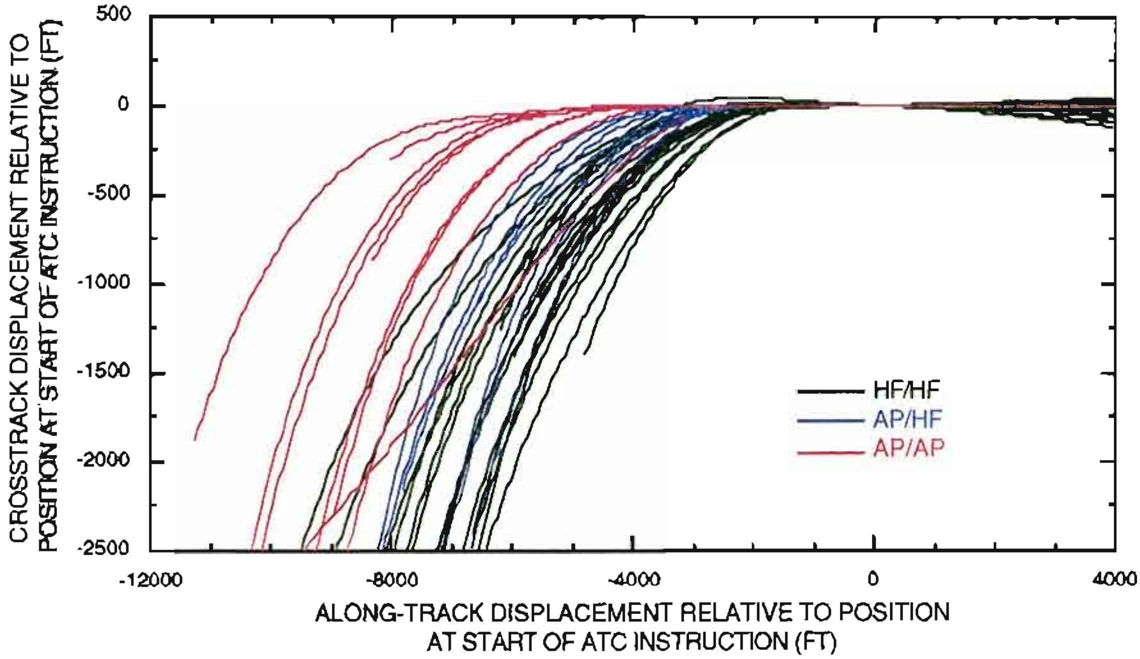


(b)

Phase 1 climbing breakouts at 500 feet above ground level.
(a) Ground track. (b) Vertical profile.



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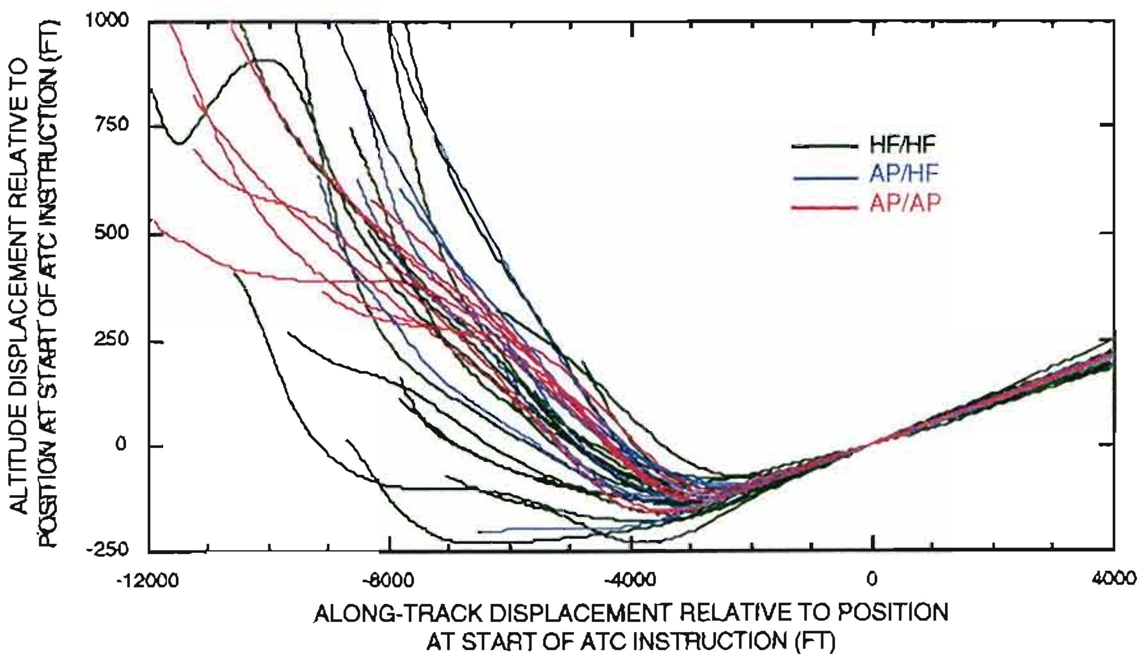
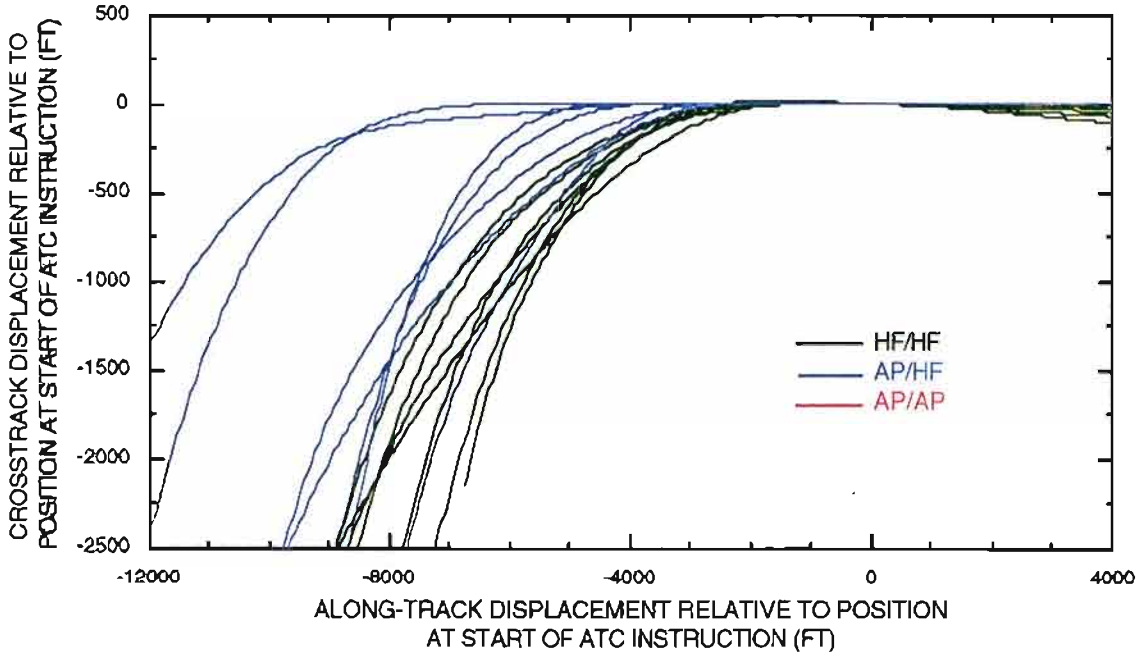


(b)

Phase 1 climbing breakouts at 1800 feet above ground level.
(a) Ground track. (b) Vertical profile.



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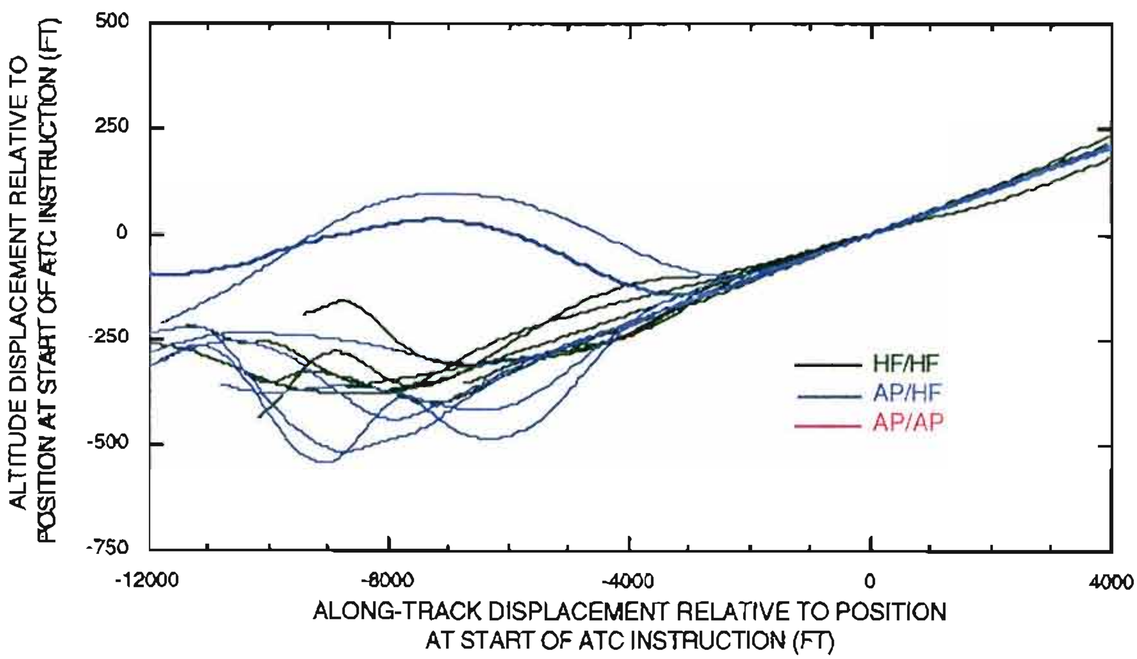
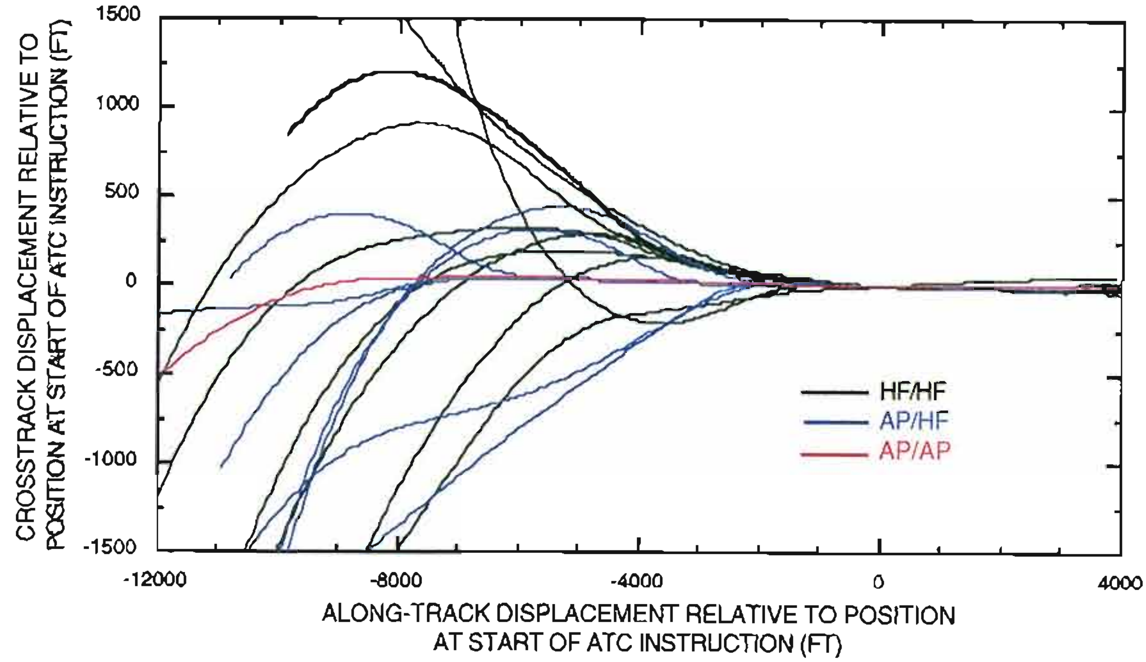
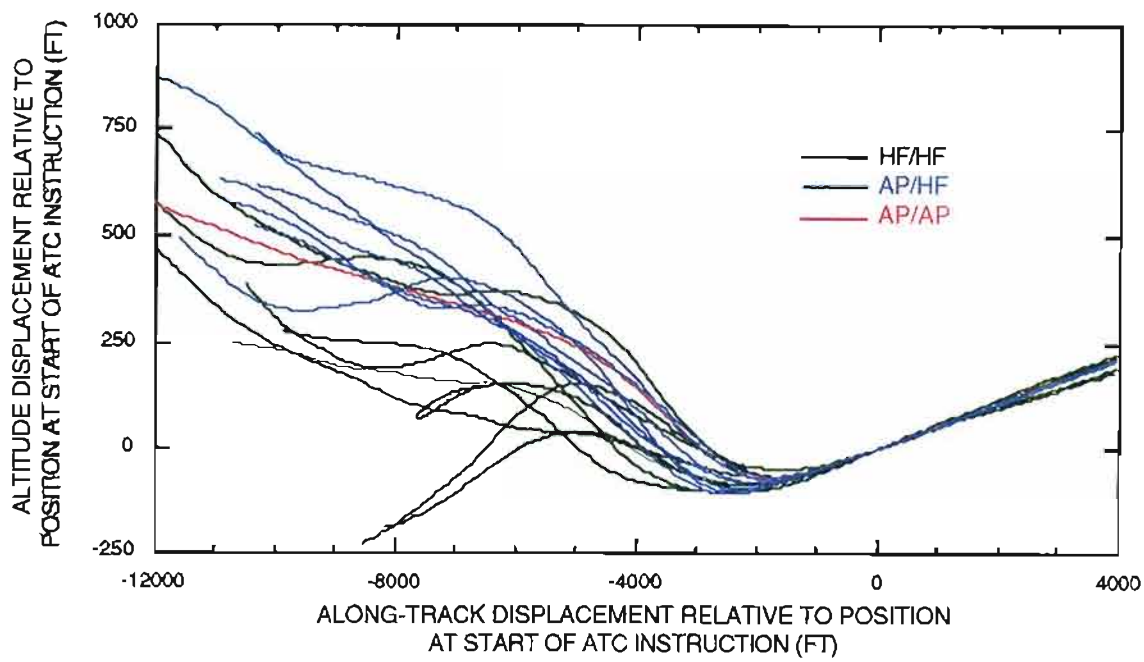


(b)

Phase 1 descending breakouts at 1800 feet above ground level.
(a) Ground track. (b) Vertical profile.



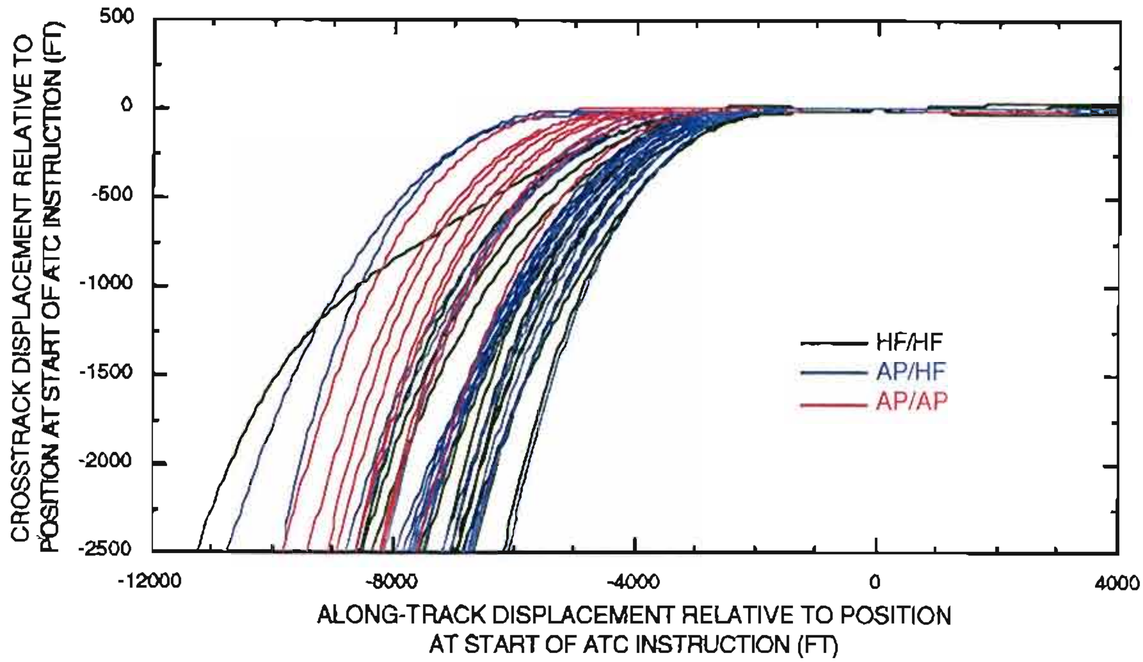
(a)



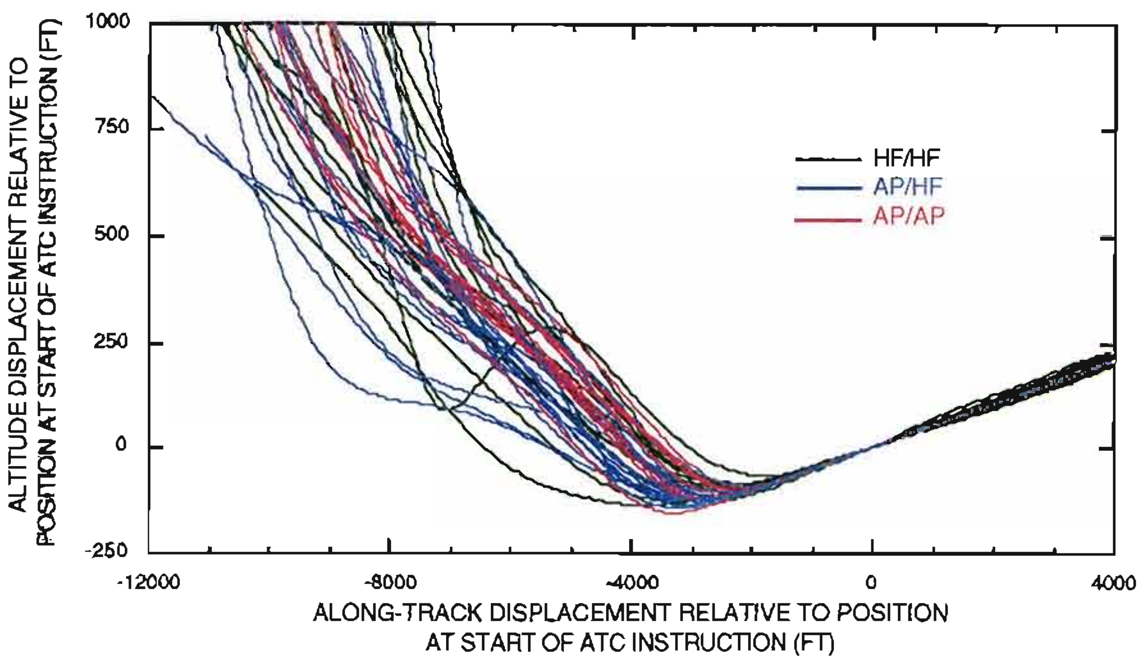
(b)

Phase 1 climbing breakouts at decision altitude, with engine out.
(a) Ground track. (b) Vertical profile.

APPENDIX J. PHASE 2 BREAKOUT TRAJECTORIES

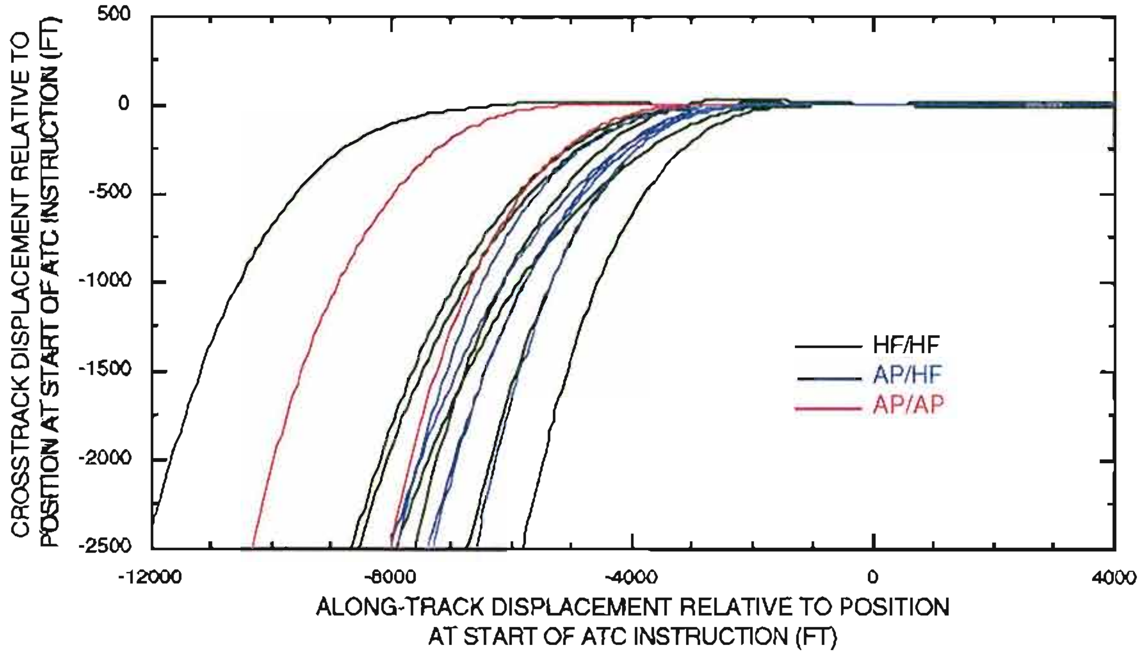


(a)

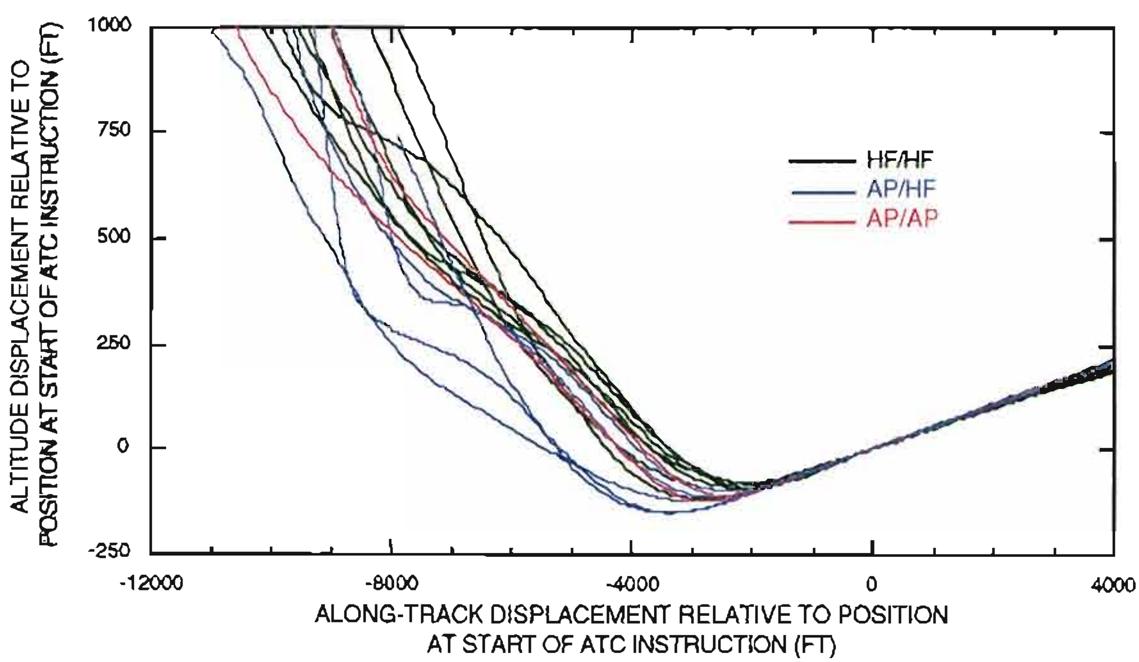


(b)

Phase 2 climbing breakouts at 500 feet above ground level.
(a) Ground track. (b) Vertical profile.

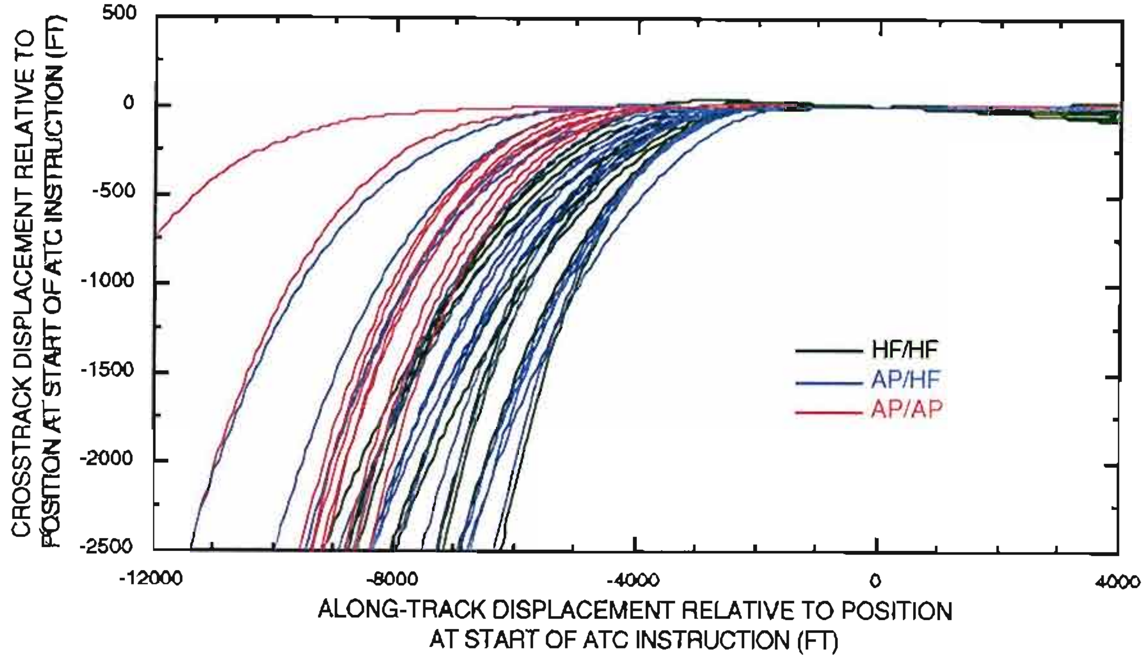


(a)

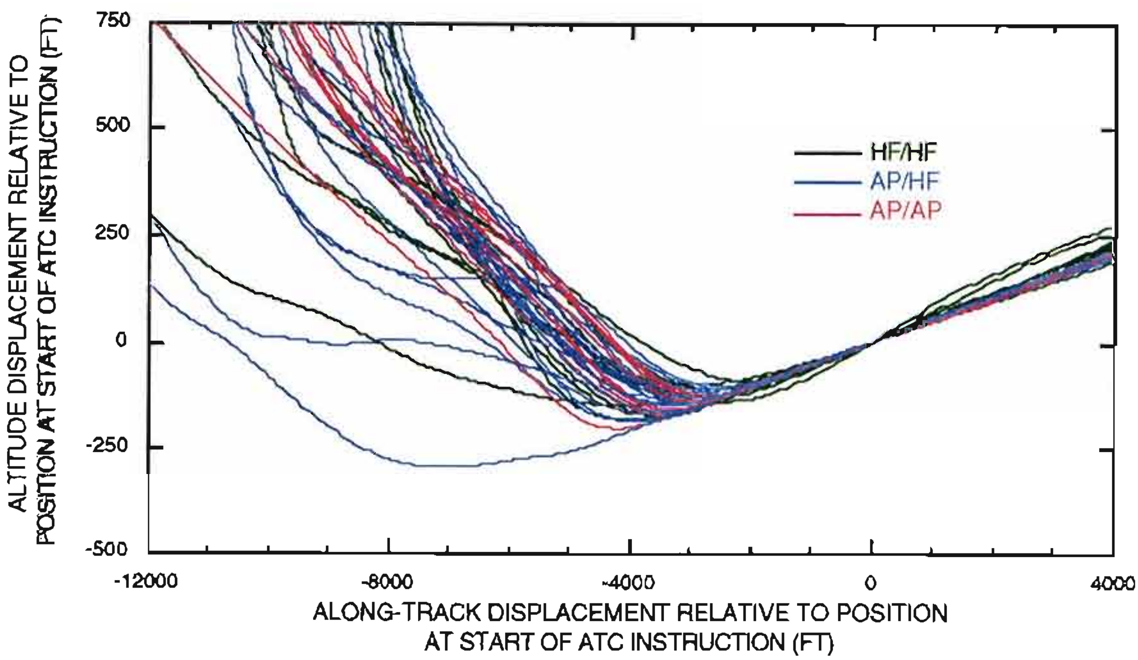


(b)

Phase 2 climbing breakouts at 700 feet above ground level.
(a) Ground track. (b) Vertical profile.

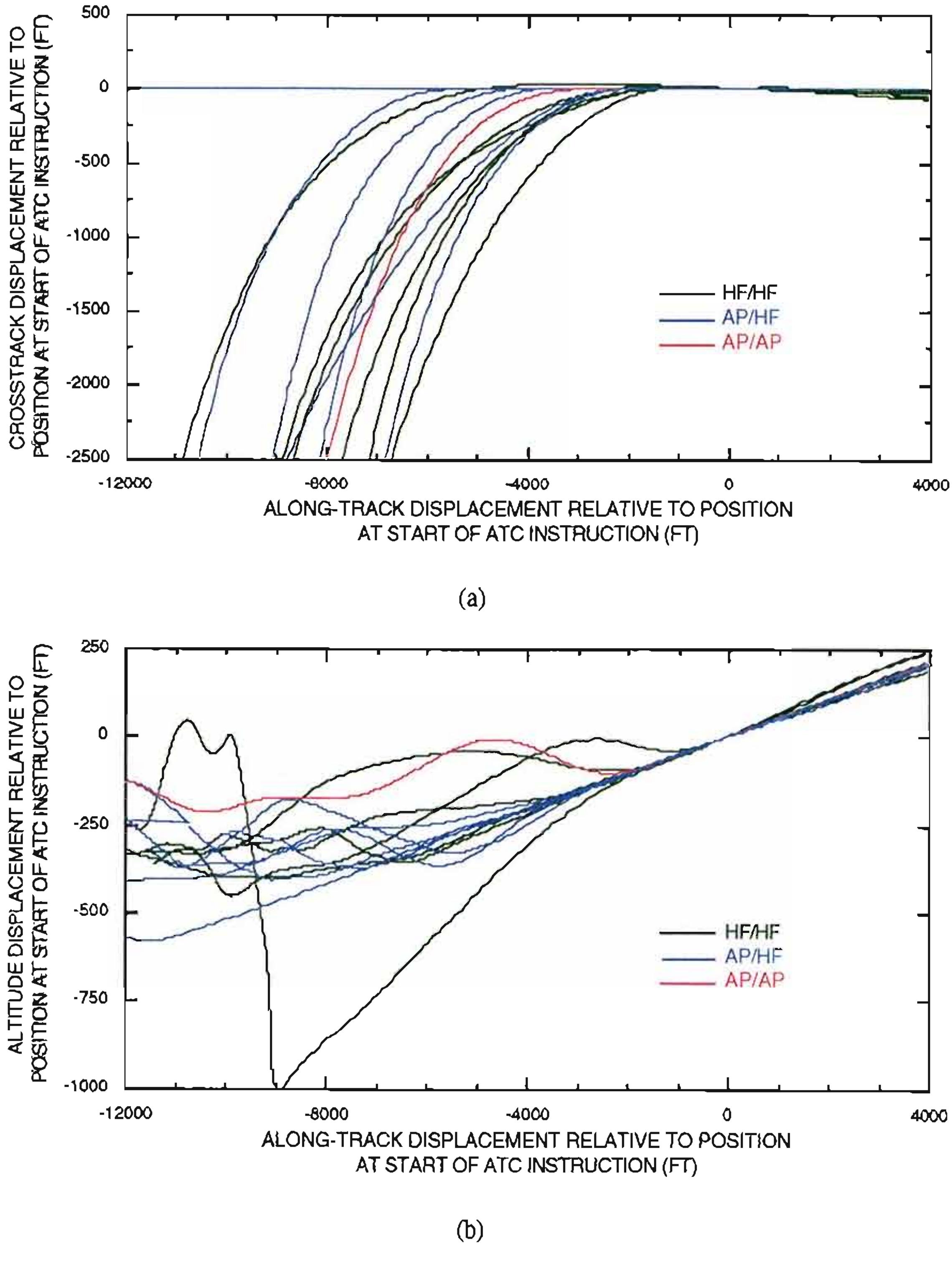


(a)



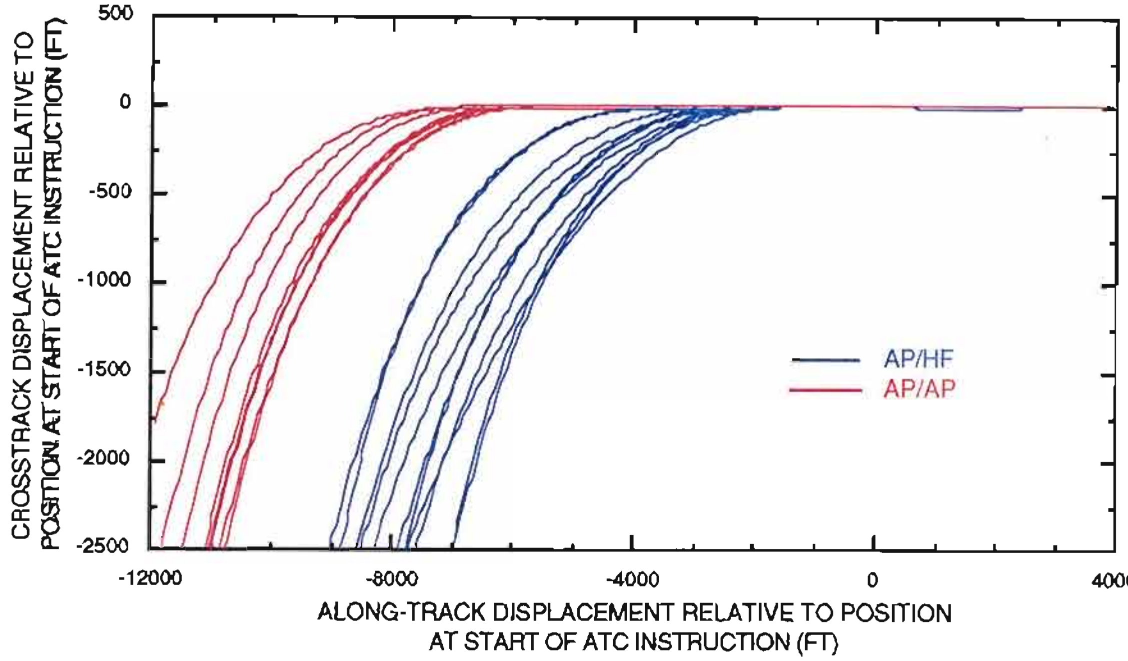
(b)

Phase 2 climbing breakouts at 1800 feet above ground level.
(a) Ground track. (b) Vertical profile.

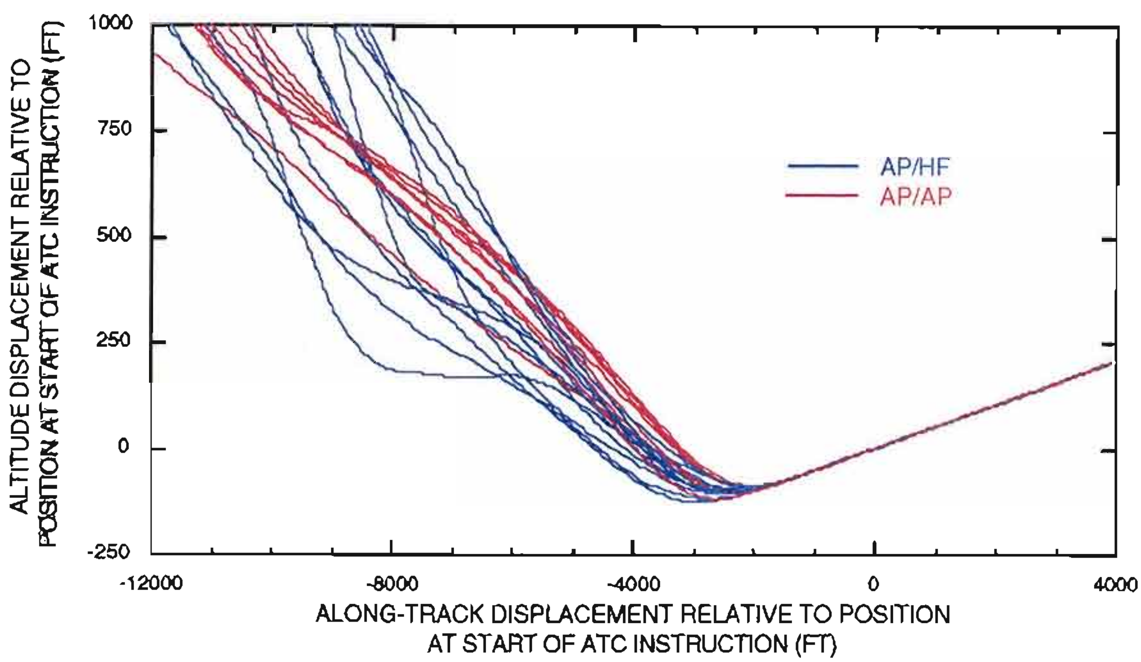


Phase 2 descending breakouts at 1800 feet above ground level.
(a) Ground track. (b) Vertical profile.

APPENDIX K. PHASE 3 BREAKOUT TRAJECTORIES

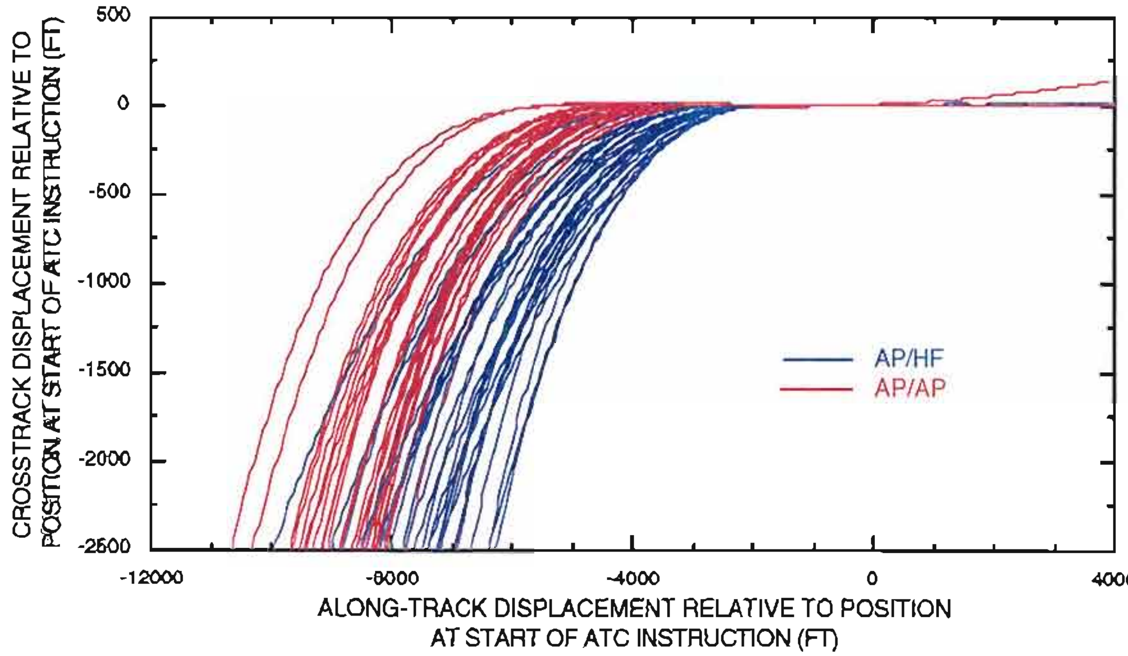


(a)

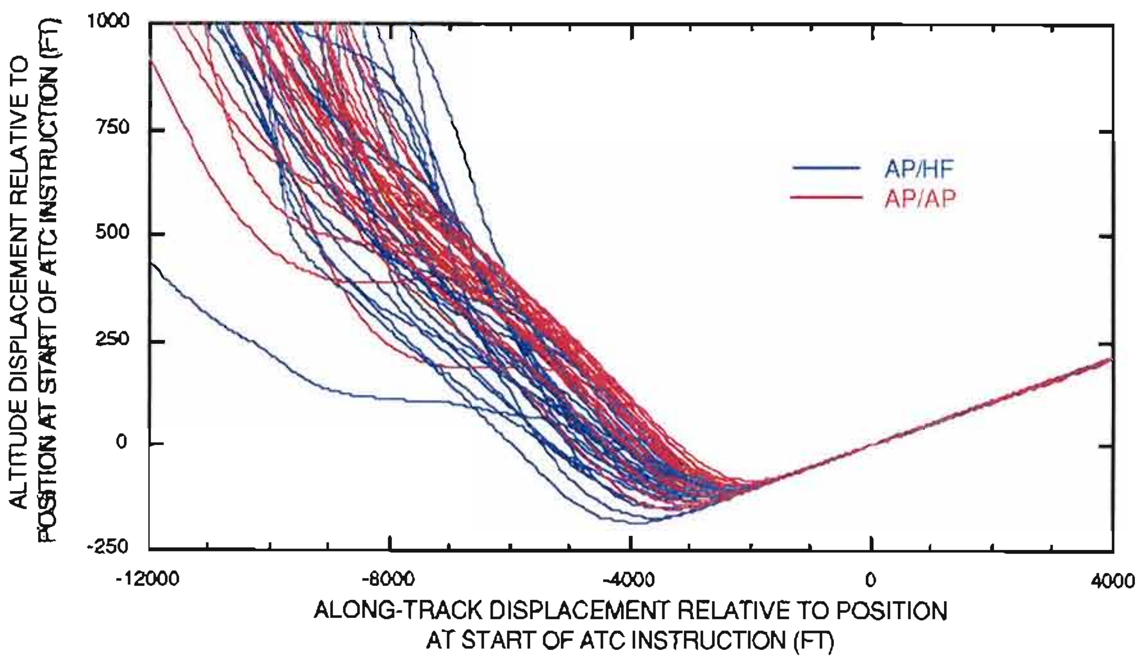


(b)

Phase 3 climbing breakouts at decision altitude.
(a) Ground track. (b) Vertical profile.

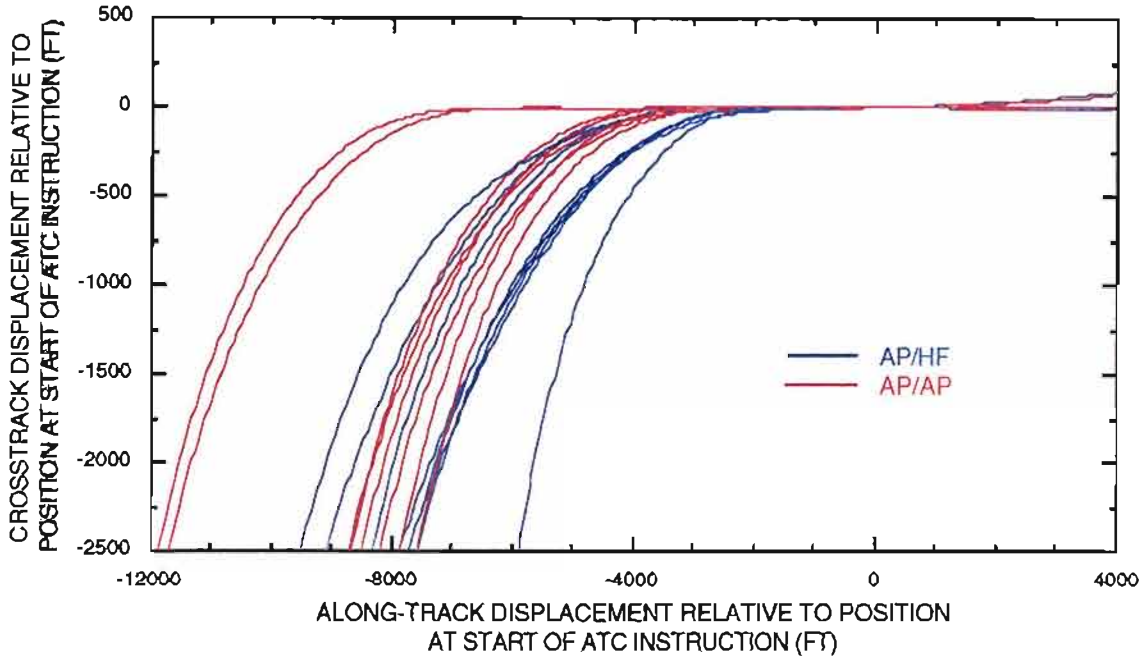


(a)

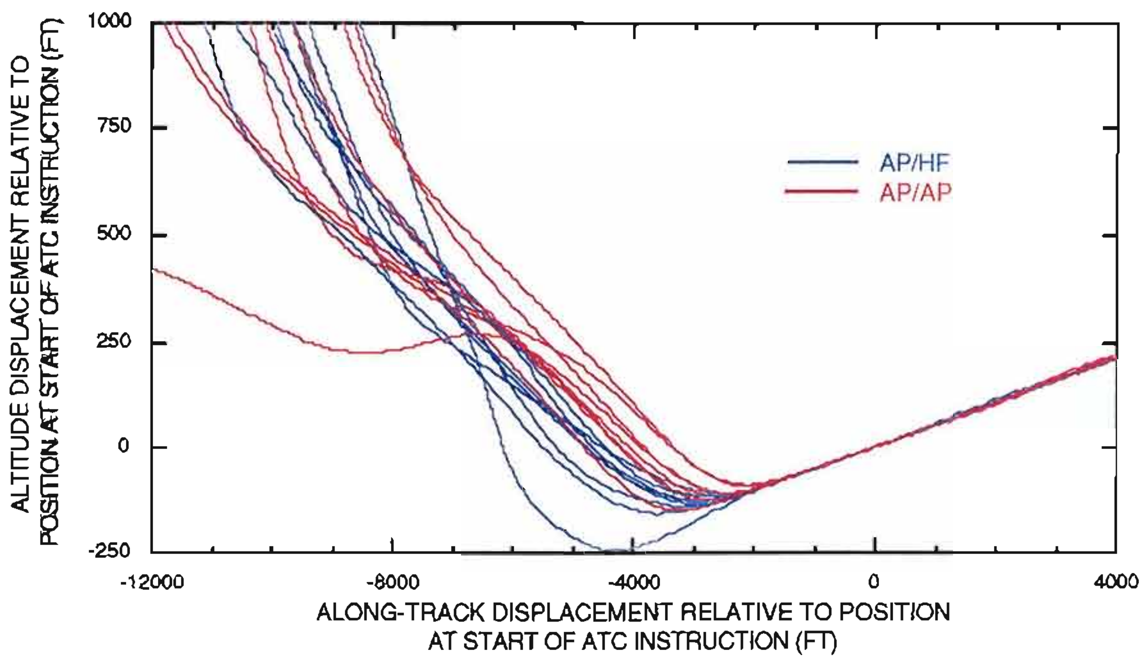


(b)

Phase 3 climbing breakouts at 500 feet above ground level.
(a) Ground track. (b) Vertical profile.

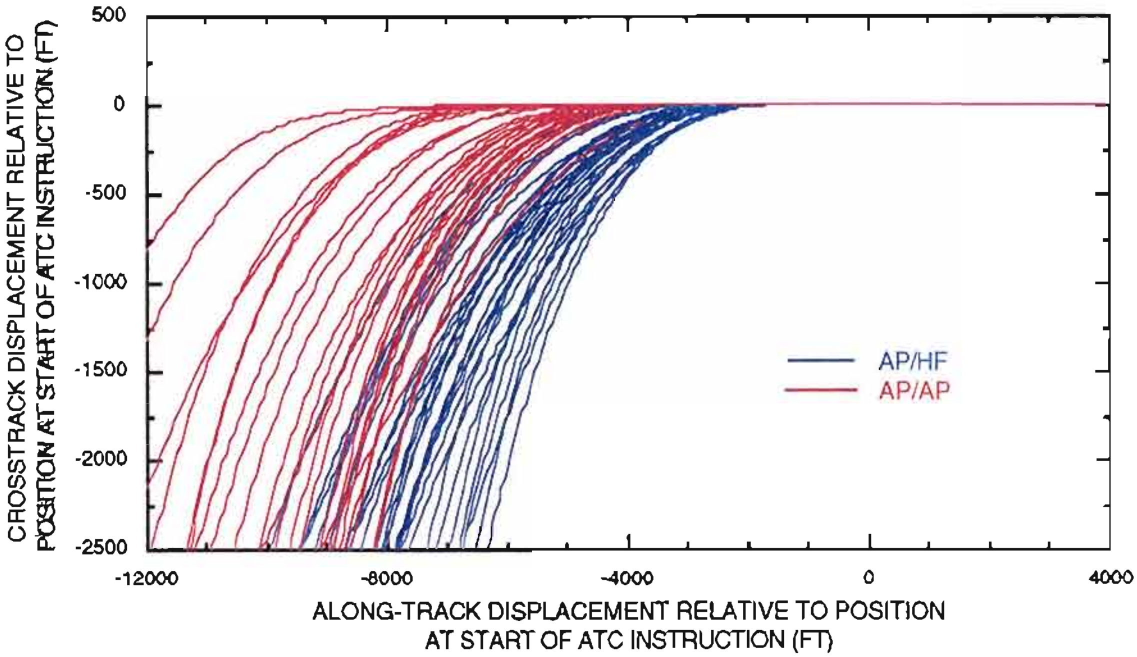


(a)



(b)

Phase 3 climbing breakouts at 1000 feet above ground level.
(a) Ground track. (b) Vertical profile.



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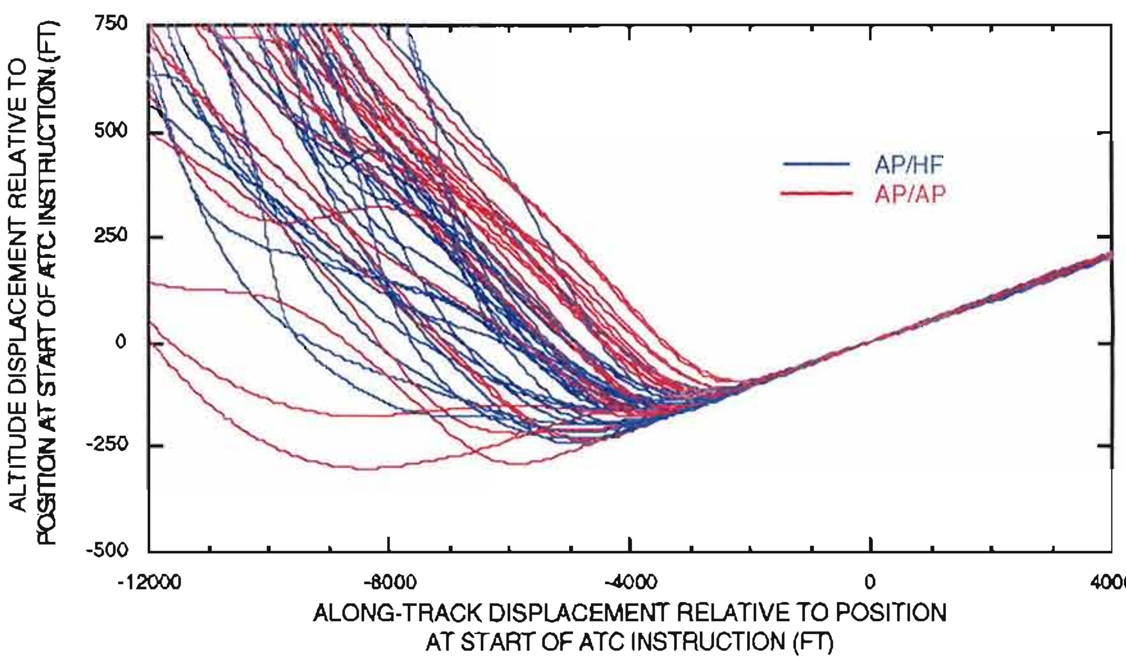
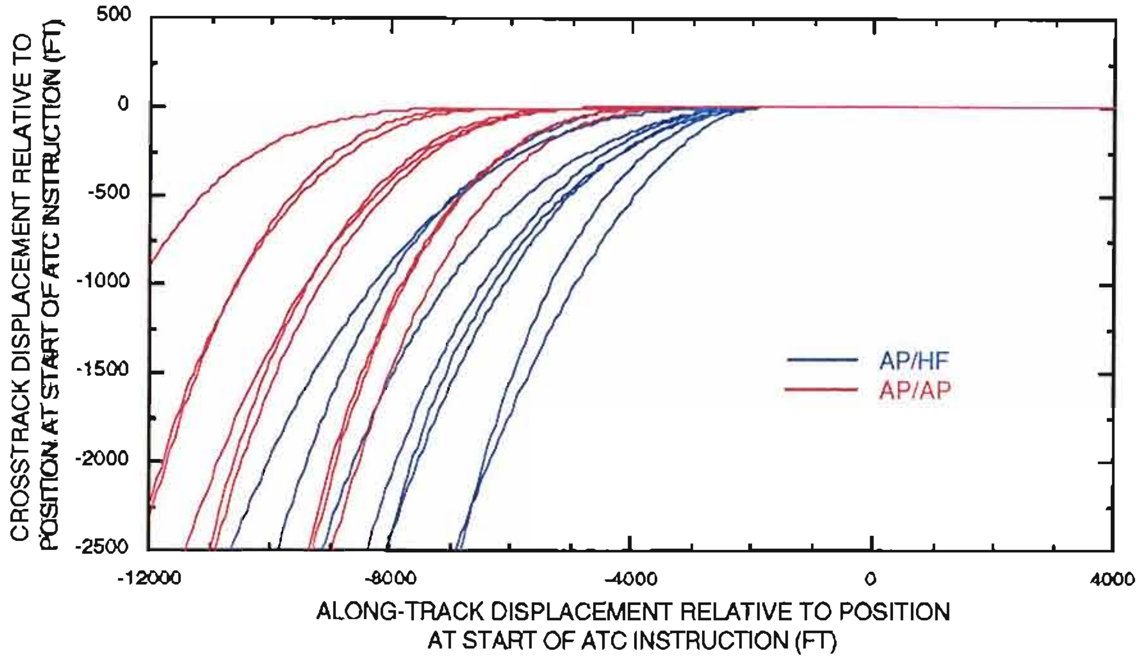


(b)

Phase 3 climbing breakouts at 1800 feet above ground level.
(a) Ground track. (b) Vertical profile.



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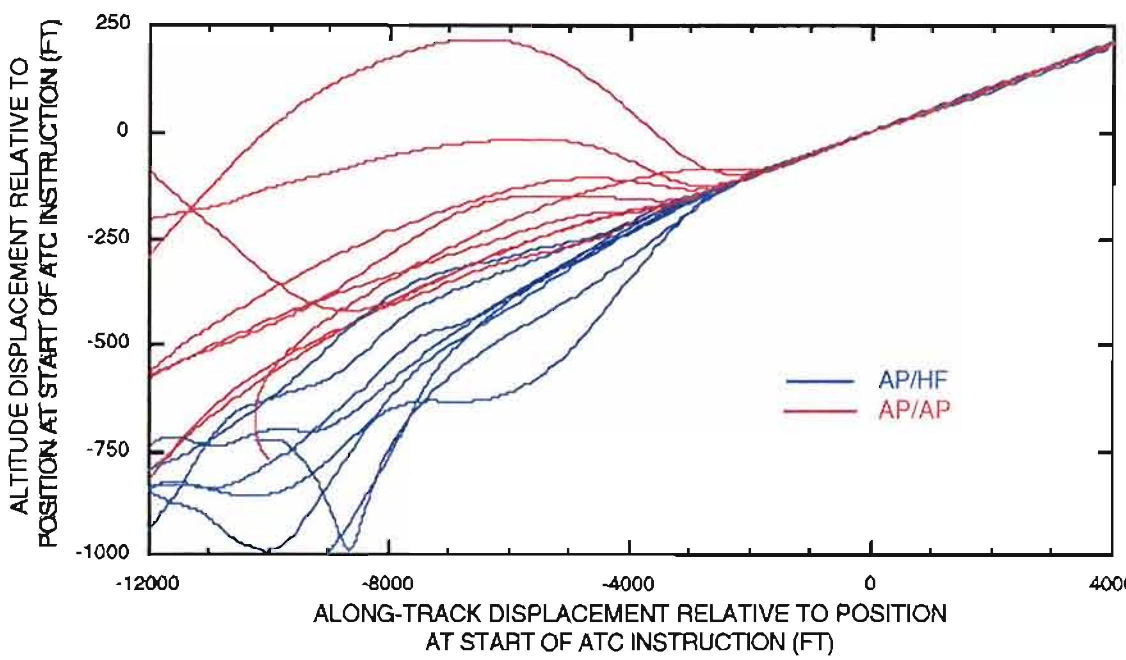

(b)

Phase 3 descending breakouts at 1800 feet above ground level.
(a) Ground track. (b) Vertical profile.

GLOSSARY

A/T	auto thrust
A320	Airbus 320
AFDS	autopilot flight director system
AGL	above ground level
ALPA	Air Line Pilots Association
ALT	altitude
ANOVA	analysis of variance
AP or A/P	autopilot
AP/AP	autopilot approach / autopilot breakout
AP/HF	autopilot approach / hand-flown breakout
APS	autopilot system
ART	annual recurrency training
ATC	Air Traffic Control
ATIS	Automatic Terminal Information System
B747-400	Boeing 747-400
CAT	category
DA	Decision Altitude
DC10	Douglas DC-10
DME	Distance Measuring Equipment
EICAS	engine indication and crew alerting system
EPR	exhaust pressure ratio
FAA	Federal Aviation Administration
FD or F/D	flight director
FDS	flight director system
FLCH	flight level change
FMC	flight management computer
FMS	flight management system
GA	go around
GS	glide slope
HDG	heading
HDG SEL	heading select
HF	hand-flown
HF/HF	hand-flown approach / hand-flown breakout

IAS	indicated air speed
ILS	instrument landing system
IMC	instrument meteorological conditions
LNAV	localizer navigation mode
LOC	localizer
MA	missed approach
MAP	missed approach point
MCP	mode control panel
MD80	McDonnell Douglas 80
MLS	microwave landing system
MPAP	Multiple Parallel Approach Procedure
MVA	minimum vectoring altitude
ND	navigational display
NOS	National Ocean Service
NTZ	no transgression zone
NWA	Northwest Airlines
ORD	Chicago O'Hare
PF	pilot flying
PFD	primary flight display
PNF	pilot not flying
PRM	Precision Runway Monitor
RA	resolution advisory
RA	radio altitude
SOP	Standard Operating Procedure
TCAS	Traffic Alert and Collision Avoidance System
TO/GA	take off/go around thrust
TRACON	Terminal Radar Approach Control
TWG	technical working group
UAL	United Airlines
VMC	visual meteorological conditions
VNAV	vertical navigation mode

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