Project Report
ATC-265

Airbus 320 Performance During ATC-Directed Breakouts on Final Approach

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16. Abstract

An evaluation of Airbus 320 (A320) performance during ATC-directed breakouts was conducted in a two-part study during 1995. Phase 1 tested performance given existing pilot training and ATC breakout phraseology. Phase 2 tested the combined effect of proposed ATC phraseology, pilot situational awareness training, and an A320-specific breakout procedure on performance. Pilot training included a briefing and viewing a videotape, but no simulator practice. Turn performance statistics from the Precision Runway Monitor Demonstration Program were used as the test criteria. Pilot preferences regarding procedures and the training material were also elicited. Three conclusions were: (1) breakout performance given the tested combination of pilot training and proposed ATC phraseology did meet the test criteria; (2) breakout performance given existing procedures did not meet the test criteria; and (3) the tested breakout procedure should be refined because it conflicted with other cockpit procedures and increased the transition time to a positive climb rate. Based on the results of this study, it is recommended that a combination of pilot situational awareness training, A320 breakout procedure, and modified ATC breakout phraseology equivalent to that tested in Phase 2 be employed for simultaneous parallel approach operations in instrument meteorological conditions.

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EXECUTIVE SUMMARY

During simultaneous parallel approaches, Federal Aviation Administration (FAA) regulations require air traffic controllers (ATC) to staff special radar-monitoring positions dedicated to maintaining separation between adjacent aircraft. While the monitor controller response to a deviation, or blunder, towards the adjacent approach is critical, the response of the threatened aircrew and aircraft also affects the safety of the operation.

Two studies were conducted during the Precision Runway Monitor (PRM) Demonstration Program to measure Boeing 727 (B727) and McDonnell Douglas 10 (DC10) performance during ATC-directed breakouts given then-existing pilot training and ATC breakout phraseology. A follow-on study measured B727 breakout performance given increased pilot situational awareness. The recorded B727 and DC10 simulator tracks were then incorporated into the PRM Program's risk assessment model as representative threatened-aircraft breakouts. All the B727 and DC10 tracks recorded during the breakout response studies were used in one analysis. Based on the results of the follow-on study, B727 and DC10 tracks with very slow turn performance were excluded from a second analysis. The two risk analysis results suggested that then-existing procedures were not sufficient to meet the target level of safety and that a pilot familiarization program was needed for close parallel approaches.

The PRM Demonstration Program included other simulations that incorporated remote-site McDonnell Douglas 80 (MD80) cockpit simulators. Simultaneous parallel approach studies were also conducted by the Multiple Parallel Approach Procedure (MPAP) technical working group. The latter studies incorporated newer aircraft types such as the Boeing 747-400 (B747-400). Observations made during both programs indicated that some aircrews had difficulty executing the breakout when the autopilot was connected, and that some newer aircraft types had longer breakout response times than the older, analog aircraft.

FAA commissioned two studies to evaluate the breakout performance of two advanced-avionics aircraft: the B747-400 and Airbus 320 (A320). This report documents the A320 study conducted in 1995 using a full-motion A320 cockpit simulator at Northwest Aerospace Training Corporation in Eagan, Minnesota. Subjects were qualified commercial A320 pilots. The primary purpose of the study was to evaluate A320 breakout response given current procedures and given proposed training materials. The secondary purpose was to elicit pilot preferences regarding breakout procedures and the tested training material.

TEST DESIGN

Phase 1 of the study evaluated A320 breakout performance given current procedures and pilot training. The ATC phraseology was

(Aircraft) TURN (left/right) IMMEDIATELY HEADING (degrees).
(Climb/Descend) AND MAINTAIN (altitude).

Phase 2 tested the combined effect of increased situational awareness, a written breakout procedure, and proposed ATC breakout phraseology on A320 breakout performance. The situational awareness training package included a video that explained close parallel approach operations and what is expected of the aircrew, an 11-0 Airport Information Page, and a pilot awareness training bulletin. The breakout procedure was A320-specific and encouraged "open climb" rather than take off/go-around (TOGA) thrust for climbing breakouts above 400 feet above ground level (AGL). The pilots did not practice the procedure beforehand. The ATC phraseology was

> (Aircraft) TRAFFIC ALERT. (Aircraft) TURN (left/right) IMMEDIATELY HEADING (degrees). (Climb/Descend) AND MAINTAIN (altitude).

ATC-directed climbing breakouts during manual and autopilot-coupled approaches were tested at decision altitude, 500 feet above ground level (AGL), and 1800 feet AGL. Descending breakouts at 1800 feet AGL were also tested for both approach modes. Phase 1 included an engine-out distraction at decision altitude. Phase 2 included climbing breakouts at 1000 feet AGL. The test criteria for both phases were based on the DC10 and B727 data used in the PRM risk analysis: mean time to start of turn less than or equal to 8 seconds and maximum time to start of turn of less than 17 seconds.

TEST RESULTS

Breakout performance during Phase 1 did not meet the test criteria for either approach mode. Except for two combinations of approach mode and breakout location, mean times to start of turn were greater than 8 seconds. In addition, time to start of turn was greater than 17 seconds in 16 out of 136 trials. The pilots agreed that breakout procedure training and better situational awareness would have enhanced their performance.

Mean time to start of turn was acceptable for both approach modes in Phase 2, although mean time to start of turn following manual approaches was 1 to 3 seconds less than mean time following autopilot-coupled approaches. Time to start of turn was greater than 17 seconds in three trials. Two factors were associated with these three trials: breakouts at decision altitude and individual pilot response time. Eighty-eight to 92 percent of the pilots agreed that the training aids increased their awareness of simultaneous close parallel approaches. Approval for the tested ATC phraseology was similar, with 75 percent strongly agreeing that the ATC phraseology encouraged a quicker response than the current phraseology. Based on their experience, 75 percent of the pilots preferred using the autopilot during simultaneous close parallel approaches in Category I weather but only 56 percent preferred using the autopilot during the breakout. This result did not agree with their actual performance because the autopilot remained engaged during most of the Phase 2 autopilot-coupled trials. The autopilot was disconnected before the turn in only seven percent of the trials, and all except one disconnect occurred with one crew. Several pilots commented that they did not like using "open climb" at any altitude and felt that TOGA thrust was better. Several pilots stated they did not like the procedure to call out when the aircraft was 400 feet AGL because it interfered with the callout at 200 feet above minimums.

In the Phase 1 surveys, six subject crews mentioned TOGA thrust as an aircraft limitation that could cause an inherent unwanted delay. They wrote that if heading is manually changed before the thrust levers are moved to TOGA then the avionics revert to the go-around track and the pilots have to enter the heading again. This phenomenon was observed in 14 of the autopilot-coupled tracks. The TOGA-induced roll back towards the go-around track added 4 to 18 seconds to these turn responses.

In the Phase 2 surveys, several pilots commented that the autothrottle was slow to respond during open climb. Their observations were consistent with the data analysis results. Although using open climb did not appear to affect turn performance, it significantly increased the mean time required for the aircraft to transition from descent to climb. In addition, the transition time was longer than 12 seconds for many open-climb breakouts at 1800 feet AGL. Transition times appeared to be related to engine rpm at the start of the response.

CONCLUSIONS

Three conclusions were made regarding A320 breakout performance. First, turn performance did not meet the test criteria given current training and ATC phraseology. Second, turn performance did meet the test criteria when the pilots received awareness and procedure training combined with proposed ATC breakout phraseology. There were a few long response times, but limiting breakouts below 400 feet AGL could significantly reduce the frequency of their occurrence. Third, the tested breakout procedure should be refined because it conflicted with other cockpit procedures and increased the time to transition to a positive climb rate.

Based on these conclusions, it is recommended that a combination of pilot situational awareness training, A320 breakout procedure and modified ATC breakout phraseology equivalent to that used in Phase 2 be employed for simultaneous parallel approach operations in instrument meteorological conditions.

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1. INTRODUCTION

Since 1987, the Federal Aviation Administration (FAA) has 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) 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 Program (MPAP), 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 aircrew 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 advanced avionics aircraft that the flight automation is not designed for emergency maneuvers in the terminal area. In order to evaluate breakout performance in newer aircraft, 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). This report documents the results of the A320 study. A separate report [4] documents the results of 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 A320 study. Section 3 describes the test and analysis procedures for the A320 study. Section 4 presents the breakout performance analysis, and Section 5 presents pilot survey results. Section 6 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 unexpected and 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. An ATC-directed breakout is a go-around executed by an aircraft on the adjacent approach because of the blunder.

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 ARTS radar displays depict a 2000-foot wide no transgression zone (NTZ) centered between the runways. For multiple parallel approaches and for dual parallel approaches with separations between 3400 feet and 4300 feet, 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 aircrew 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.

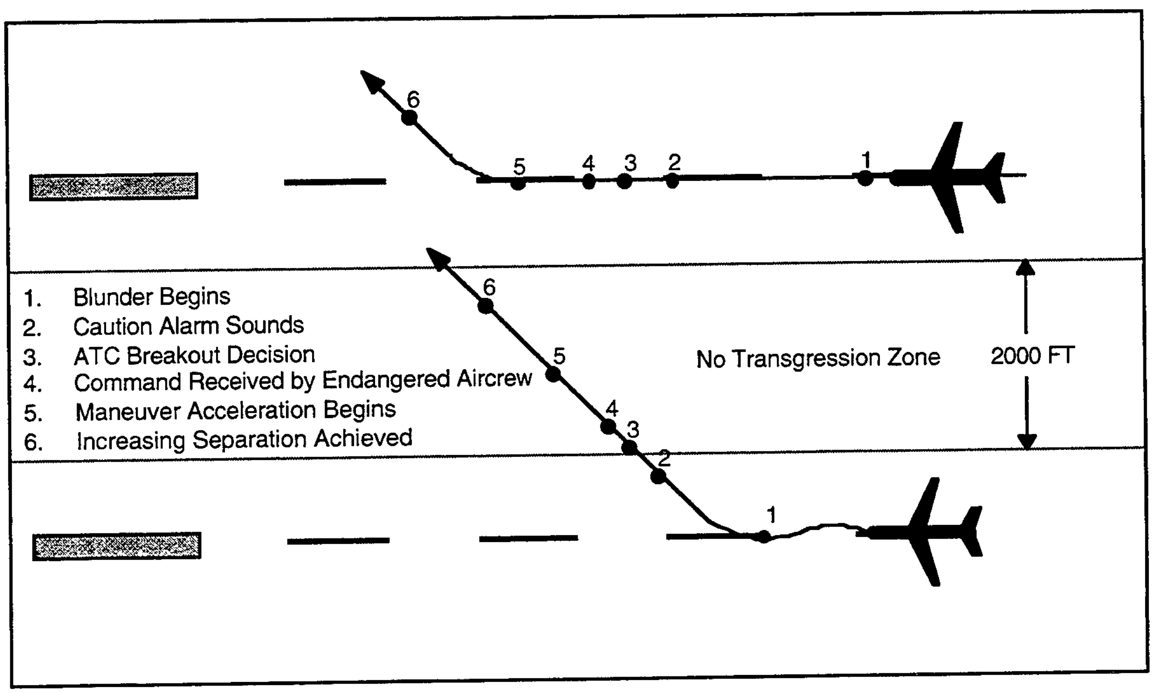

Figure 1-1. Sequence of events during an approach blunder.

1.1.2 B727 and DC10 Performance Studies

FAA Standards Development Branch conducted two studies in 1989 to measure aircrew performance during missed approaches and ATC-directed breakouts [5, 6]. These studies utilized the Boeing 727 (B727) cockpit simulator at the Mike Monroney Aeronautical Center, Oklahoma City, OK, and the Federal Express McDonnell Douglas 10 (DC10) cockpit simulator at Memphis, TN. 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 [7]. The ATC-directed breakout scenarios were also incorporated into the PRM Demonstration Program risk assessment [1].

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 might have been due to various interpretations of the meaning of the word "immediately."

Because of the long response times observed in the studies, a follow-on study was conducted using the B727 simulator [8]. In this study, the pilots were briefed that "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).

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

	B727			DC10		
Scenario	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.

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 [8].

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.

Data from the B727 and DC10 performance studies described in Section 1.1.2 were incorporated into the Monte Carlo simulation as representative threatened-aircraft breakouts. 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 increased 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].

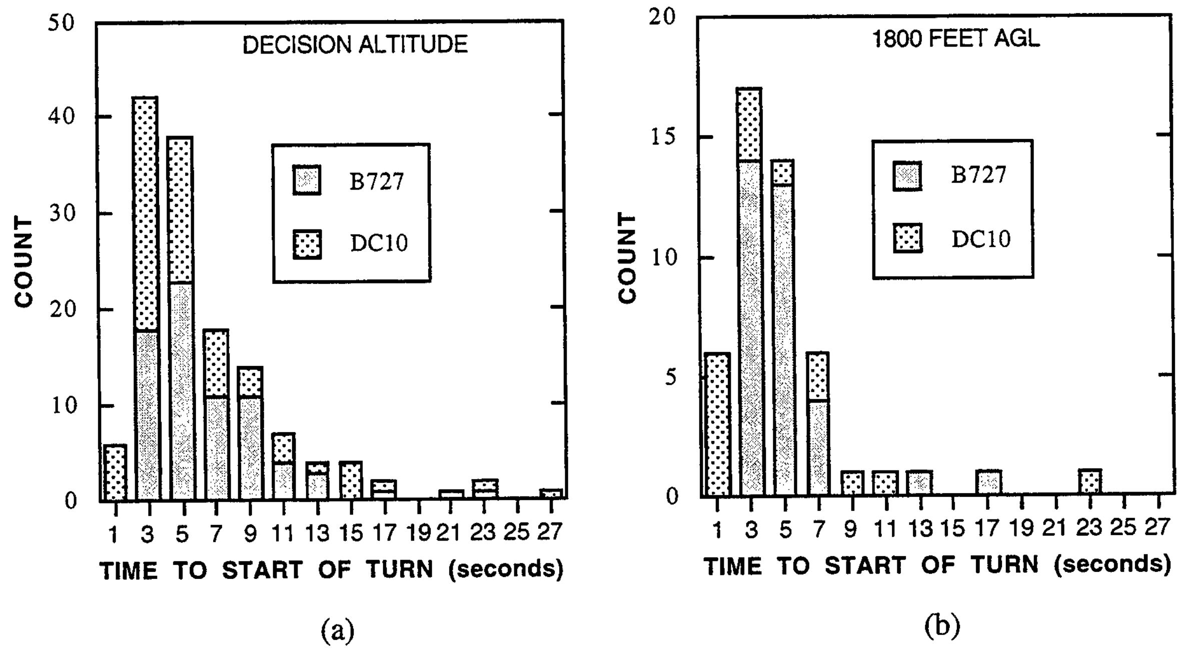

Figure 1-2. B727 and DC10 data used in the PRM risk analysis. Values are times from start of ATC breakout instruction to start of left-hand roll. (a) 100-foot DA and 200-foot DA, combined; (b) 1800 feet AGL.

During one of the PRM Demonstration Program simulations, a McDonnell-Douglas 80 (MD80) pilot had difficulty disconnecting the autoland in a MD80 cockpit simulator in order to fly a manual breakout. 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.

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 Program (MPAP) 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 [9]. 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 aircrew 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. 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 [9] and April 1996 [10]. 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 aircrew and aircraft breakout performance for newer aircraft types, given current procedures. Because of the slow responses observed during the MPAP simulation in 1994, this study was expanded to include evaluation of the effect of pilot training on breakout performance.

The primary objective of the A320 study was to determine if pilot training improved A320 breakout response. Phase 1 of the study was used as a baseline to measure A320 breakout performance given current procedures and aircrew training. Phase 2 tested the effect of a cockpit-specific breakout procedure combined with pilot situational awareness training and modified controller phraseology on the breakout maneuver.

The measure used to determine acceptable performance was time from start of the ATC breakout instruction to start of roll. Although a breakout maneuver involves pitch, thrust, and roll changes, time to start of roll was identified as the critical measure of performance. The B727 and DC10 breakout performance data that resulted in the successful PRM risk analysis were used as the criteria for acceptable breakout performance. As mentioned in Section 1.1.3, the PRM risk analysis indicated an acceptable level of safety 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.

The secondary objective of the study was to evaluate factors that can affect A320 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:

Phase 1: What is A320 breakout performance given current ATC 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 increased situational awareness combined with an aircraft-specific breakout procedure improve A320 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 referred to as a hand-flown, or manual, approach, and AP mode is 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 referred to as a hand-flown, or manual, breakout and AP mode is 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 achieved a 3-degree or greater roll to the left and maintained the roll until the final heading was reached.

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

2. EXPERIMENTAL DESIGN

This study was designed in two steps. First, Phase 1 was designed to test A320 breakout performance given current procedures. Then, Phase 2 was designed to test the effect of proposed pilot training and ATC breakout phraseology on A320 breakout performance. The experimental designs for Phase 2 was dependent on the knowledge gained from the previous phase and from the B747-400 study. Because of the dependency of the second phase on previous evaluations and because of the time frame available for initial test development, the two phases were not designed concurrently. This resulted in variations in the test scenarios and in the pilot surveys used in each of the two phases. 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. In addition, Phase 1 used the same design as used in the first phase of the B747-400 study. Since these were the first studies 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 automation transition altitude of 400 feet AGL[1]. In order to satisfy user-community concerns about the realism of the breakout scenarios, the distraction scenarios were retained. Due to time constraints, an aircraft-specific distraction could not be developed, so the right engine failure distraction used in the B727 and DC10 studies was retained. 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

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[1] The A320 automation does not accept manual heading input when the aircraft is below 400 feet radio altitude.

the other three variables: approach mode with level of distraction; approach mode with altitude of breakout; and, approach mode with 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 is 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 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

	Breakout Group				
Approach 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, proposed ATC phraseology, and an A320-specific breakout procedure on breakout performance. The training package used during the study is described in Section 3.3 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. Climbing breakouts at 1000 feet AGL (1000') were added to reduce subject anticipation of when the breakout would occur and to provide data for use in future risk assessments. The distraction scenarios were removed from the design.

2.2.1 Independent Variables

In evaluating the effect of the 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 within-subject model, with approach mode combined with each of the other two factors: approach mode with altitude of breakout; and, approach mode with 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. 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 the autopilot breakout at decision altitude was Category I weather minimum. This removed the airline policy constraint that was observed in Phase 1 and allowed for sequence assignment by crewmember: 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 crewmember, identified as subject A or B, are listed in Table 2-4. All crews experienced the same set of sequenced scenarios. One half of the crews experienced the set in the forward order, while the other crews experienced the set 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

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

2.3 RESEARCH QUESTIONS

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

1. Does A320 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 low altitudes (less than 400 feet AGL)?
3. Are pilots comfortable with executing descending 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 combined with a self-administered written A320 breakout procedure 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 effective in increasing pilot situational awareness?

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

7. Does altitude affect breakout performance?
8. Does vertical direction of the breakout affect breakout performance?
9. Does approach mode affect breakout performance?

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 A320 aircraft. Subject pilots came from Northwest Airlines, United Airlines, and America West Airlines.

3.2 FACILITY

The study was conducted at the Northwest Aerospace Training Corporation (NATCO) in Eagan, Minnesota. The subject crew and all test personnel occupied the certified full-motion A320 cockpit simulator. An observer sat behind the first officer's seat. The observer's duties were to verify that the simulator was properly configured for each test run and to record observations during each session. A Northwest Airlines pilot/instructor operated the simulator controls located behind the captain's seat. The simulation operator's duties were to configure the simulator for each test run, record data, and help the subjects with equipment-related problems. A third person sat next to the simulation operator and read the controller scripts. All test personnel who acted as controller had previous air traffic control experience. All test personnel were instructed not to provide information to the subject crews that might affect the results or to provide suggestions about cockpit procedures.

3.2.1 A320 Flight Deck Controls

Since the A320 is the first certificated commercial aircraft with fly-by-wire technology, the cockpit automation may be unfamiliar to some readers. This section describes the controls and displays that were important during the breakout maneuver and some of the differences between the A320 and conventional advanced-automation cockpits such as the B747-400. The purpose of this section is to provide the reader with an understanding of the measured data and to provide insight needed for interpreting the results. This is not intended to be a primer on A320 operations. In order to facilitate the description of the cockpit displays, the simulator is referred to as the "aircraft."

The first officer instrument panel and the pedestal of the NATCO A320 cockpit simulator are shown in Figure 3-1. One difference between the A320 and other commercial aircraft is the lack of a control wheel. Instead, the pilot uses the side stick to control pitch and roll. The side stick is outboard of the seat: to the left for the captain, and to the right for the first officer. During automated flight, pressing the button on the stick disengages the autopilot and allows the pilot to take control of the aircraft. During manual flight, pressing the button overrides the other stick; but this is not a normal procedure.

The Flight Control Unit (FCU) is the upper center section of the instrument panel, located in the upper left corner of Figure 3-1. The Flight Control Unit is comparable to the Mode Control Panel in a Boeing aircraft, and houses the speed, heading, altitude, and vertical speed knobs. The crew can enter a new value for any of these flight parameters either via the FCU knob or by entering the value into the Multipurpose Cockpit Display Unit (MCDU) located on the pedestal. During this study, manual entries were made using the FCU knobs.

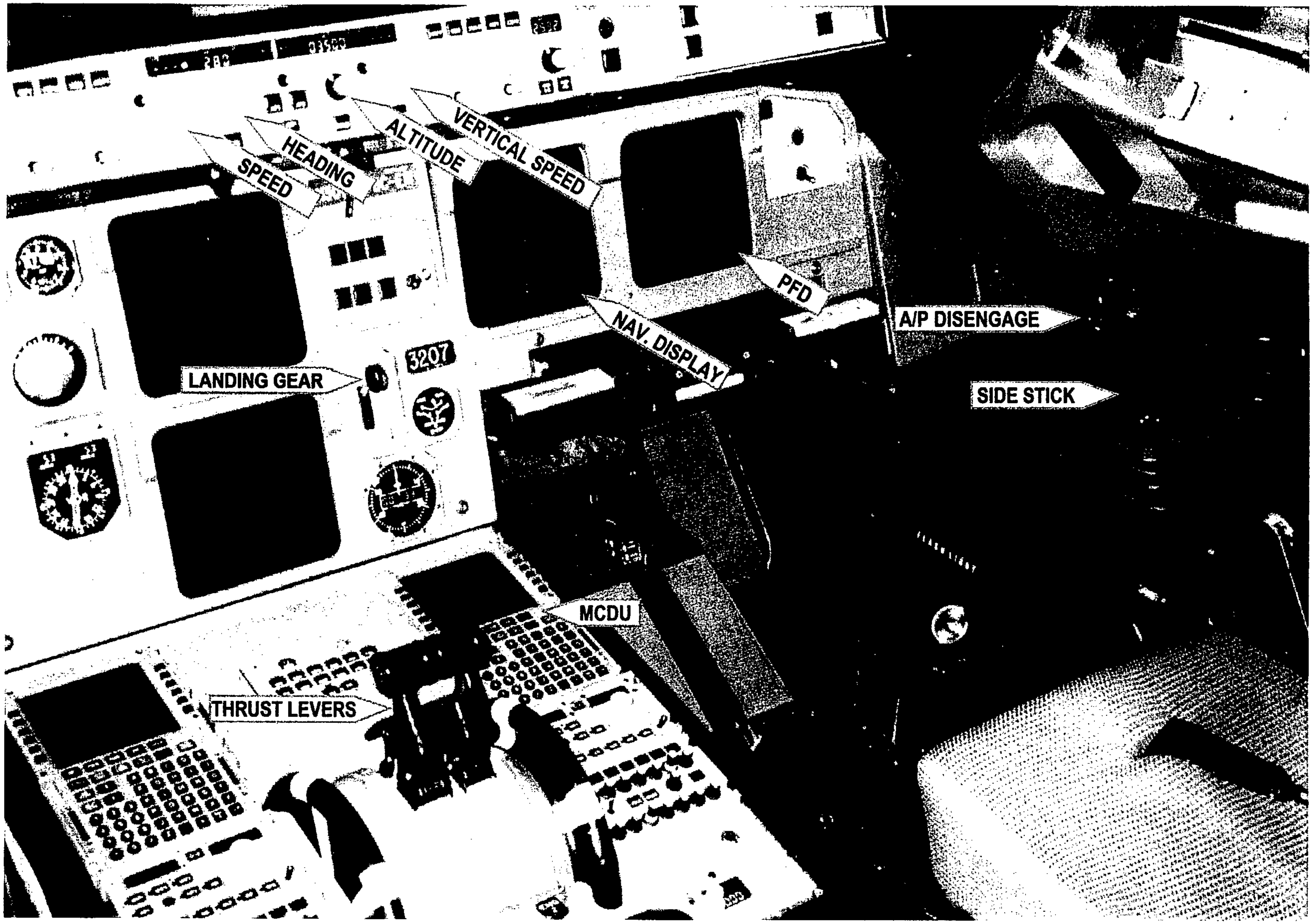

Figure 3-1. A320 flight deck. This view shows the central pedestal and the first officer's side of the instrument panel.

Instead of conventional throttles, the A320 has thrust levers that are located on the pedestal. Each thrust lever has six positions (four detents and two limits). The forward limit is TOGA (Take Off/Go Around). Next is the FLX/MCT (Flexible Reduced Thrust/ Maximum Continuous Thrust) detent, followed by the CL (climb), Forward Idle, and Reverse Idle detents. The aft limit of the thrust levers is Maximum Reverse.

Autothrust is engaged under normal operations and is typically employed by the pilot flying as follows. The A320 pilot selects either TOGA or FLX/MCT for take-off. Thrust is reduced to CL at 1500 feet AGL, the default thrust reduction altitude, and the aircraft operates at CL until just prior to landing. The pilot selects Forward Idle just prior to touch down. Once on the runway, Reverse Idle and Max Reverse are used to decrease airspeed. Although autothrust is used during normal operations, the pilot flying has the option of disconnecting autothrust and using the thrust levers as conventional throttles during non-standard procedures.

The two thrust lever positions used during this study were CL and TOGA. At the beginning of each trial, the thrust levers were set to CL and autothrust was engaged. During climbing breakouts, a positive rate of climb was achieved by using either of two procedures.

1) The pilot flying moved the thrust levers to TOGA and initiated an immediate go-around maneuver using the maximum available rated thrust. Aircraft pitch attitude immediately increased from approximately +3 degrees to a nominal +18 degrees.

2) The pilot flying left the thrust levers in the CL detent. "Open Climb" mode was selected by setting the altitude to a level higher than the existing aircraft altitude displayed in the FCU altitude window and pulling the altitude select knob. The engines smoothly advanced to climb thrust and the autopilot and/or flight directors commanded an increase in pitch attitude to maintain existing airspeed. While less dramatic than a go-around maneuver, Open Climb arrested the sink rate without an abrupt change in pitch attitude.

The Flight Management System (FMS) operates under managed guidance or under selected guidance. In managed guidance, the speed, heading, altitude, and vertical speed in the flight director and autopilot are based on the flight plan entered into the FMS via the MCDU. In selected guidance, the value for a given flight parameter is manually selected by a crewmember. The guidance mode for each flight parameter depends on the position of the respective FCU knob. When a knob is depressed (pushed), that control value is based on managed guidance and, except for altitude, the window above the knob displays three dashes. When the knob is pulled, the pilot overrides the managed-guidance value and the selected value is displayed in the corresponding window. For example, during normal operations the crew may need to override speed control if air traffic control requests a speed change. During this study, the aircrews used selected guidance for heading and altitude, if needed, during the ATC-directed breakouts.

In Figure 3-1, dashes are displayed in the speed and vertical speed windows, indicating that these values were based upon managed guidance. The heading window in Figure 3-1 displays a value, indicating that the heading knob was pulled and managed navigation was overridden. Note that the FCU always has an altitude value displayed, even in managed flight.

The flight control system provides limits on pitch, roll, speed, et cetera, to prevent the pilot flying from inadvertently exceeding the aircraft limitations. There are no company-induced limits within the flight management system; all values are set by the manufacturer. The flight control system dynamically calculates each limit based primarily on aircraft configuration. Depending on the status of the primary flight control computers, the flight control system will operate under Normal Law or under various other control laws as the system degrades. It is not possible for the pilot to override any flight control limit during manual flight when the aircraft is operating under Normal Law. However, these limits are much larger than the operating parameters for pitch and roll angles, and should not be confused with the Federal Aviation Regulation (FAR) limits. As will be described in the results section, some pilots exceeded the FAR roll limit of 30 degrees, yet remained within the flight control system's limit.

For this study, the final approaches were flown either manually with only the flight director and autothrust engaged, or automatically with the autopilot engaged. During each breakout, the pilot flying had the option of flying manually or of using the autopilot. Following manual approaches, all pilots flew manual breakouts. Following autopilot-coupled approaches, the pilot flying could disconnect the autopilot by pushing the button on the side stick, then fly a manual breakout. If the pilot flew the breakout using the autopilot, the new heading and altitude were selected in the Flight Control Unit. The new flight path was then displayed on the Navigation Display and the new flight parameters were displayed on the Primary Flight Display. Entering the new heading and altitude information into the FCU was not as critical for manual breakouts because the flight director was used only as a reference, if at all, and did not control the flight path.

If the thrust levers are at the CL detent when the new altitude is entered, pitch and thrust are based on open climb. If the thrust levers are advanced to TOGA, the flight directors and autopilot enter the Go-Around mode as follows. As soon as the thrust levers are set to the TOGA stop, the go-around mode is engaged. Lateral guidance is now in GA TRK (go-around track). For safety reasons, no action may be performed on the heading knob until the aircraft is above 400 feet radio altitude. Above 400 feet, pushing the heading knob disengages GA TRK and places the system in Managed (lateral) Navigation. In contrast, pulling the heading knob disengages GA Track and places the system in Selected (lateral) Navigation, i.e., in heading navigation.

The effect of TOGA on the autopilot breakouts conducted during this study was two-fold. First, the flight director would not accept the manually-selected heading until the aircraft was above 400 feet. Second, if the thrust levers were set to the TOGA position after the breakout heading had been selected and while the autopilot was engaged, the aircraft turned back towards GA Track (ground track at the time of TOGA selection). The crew then had to override the flight management system or disconnect the autopilot and fly a manual breakout. The effect of TOGA on descending as well as climbing breakouts was a consideration in the development of the A320 breakout procedure tested during Phase 2.

3.3 TEST PROCEDURES

Phase 1 was conducted during February 1995, and Phase 2 was conducted during June 1995. Upon arrival at the test facility, 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 (MEM) runway 36L. The approach plate to be used was given to each crewmember. For Phase 1, the current Category I and Category II NOS approach plates were used. For Phases 2, the Jeppeson approach plates for Memphis 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, 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 NATCO cockpit simulator. Each test session lasted approximately three hours. There was a half-hour break mid-way through the test sequence. 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 a gross weight of 141,900 pounds 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 crewmembers alternated who flew the aircraft. In Phases 2, the pilot flying was based on the test sequence. The approaches was flown either manually, with the flight director on, or autopilot-coupled according to the test sequence.

3.3.2 Situational Awareness Training

In Phase 2, the subjects reviewed a situational awareness-training package during the briefing. The training package consisted of a short video describing close parallel approach operations [11], 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 Cockpit Procedure Training

After the subjects reviewed the situational awareness package, they received a procedure-training package. The pilots read the 1-page breakout procedure then took an open-book test. The purpose of the test was to reinforce the concepts in the procedure-training bulletin. This was the only procedure training that the pilots received. They were not given any instructions by any test personnel nor did they practice the procedure before the test session.

For breakouts below 400 feet above ground level (AGL), the crew was to fly the normal missed approach procedure and select the heading and altitude given in the ATC breakout instruction. For breakouts above 400 feet AGL, the crew changed heading and altitude to selected guidance and configured the aircraft appropriately. The procedure mentioned using "open climb" for climbing breakouts, but did not recommend against using TOGA to achieve positive climb. For descending breakouts, the crew was to continue the descending vertical speed. The procedure bulletin and test are presented in Appendix D.

3.3.4 Air Traffic Control Phraseology

The air traffic control breakout phraseology used in Phase 1 was taken from FAA Order 7110.65H [12]:

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

The air traffic control breakout phraseology used in Phases 2 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 aircrews using the local controller frequency to expect transmission of an emergency procedure. In addition, the additional text would reduce the chance of a clipped or blocked breakout instruction.

3.4 DATA COLLECTION

Aircraft metric data from the A320 simulator were collected by a program running on the Gould computer controlling the A320 simulator at NATCO. NATCO personnel transferred the data from the Gould disks to 9-track magnetic tapes and mailed them to Lincoln Laboratory. Data were extracted from the tapes using a custom program on a VAX computer under OpenVMS.

The basic format of the data files was a header with time and date information followed by some number of data records with aircraft metric data for each track. Data records were written at a rate of 3 Hertz and 3.75 Hertz for Phases 1 and 2, respectively. Each record included a time stamp, information about test settings and the aircraft position, orientation, and configuration.

Aircraft position and orientation data included latitude and longitude, altitude and climb rate, heading, bank angle, pitch angle, and indicated airspeed. Aircraft configuration data included engine rpm (both engines), TOGA indicator, and autopilot indicator. Test settings included wind direction and speed, the ATC event marker which indicated when the ATC pressed the marker button, and a test identification string which encoded scenario number, date, and trial number.

In addition to the computer data, videotape recordings of the cockpit were made during testing using in-cockpit video recording equipment normally used in pilot training. The camera was located behind and above the first officer, near the center of the aisle. The image frame included the instrument panel, thrust levers, and both pilots.

3.5 DATA EXTRACTION

Data used in the analyses were extracted from both the digital and video data recordings. Data extraction from the videotapes 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 that were imported to Excel™ 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 of "1" and signified the time at which the breakout instruction started. 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 E 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 (the aircraft was on approach to MEM 36L), a criterion consistent with previous studies. However, 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. If the algorithms did not return the same time to start of roll, the correct value was manually selected.

The engine, pitch, and vertical speed events were determined by comparing the values of those metrics at the time of the breakout instruction 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, if vertical speed was -850 feet per second at the start of the ATC transmission, then the start of climb event was the record at which the vertical speed was greater than -700 feet per second, indicating that the aircraft was still descending but had started accelerating towards a positive climb rate.

3.5.2 Video Data

Because of the location of the video camera, only large-scale movements by the pilots were visible. The locations of the controls mentioned in Section 3.2 were visible, but not the exact settings. To illustrate, the video image in Figure 3-2 was recorded during one of the autopilot breakouts. The first officer was the pilot flying and had his hand on the thrust levers. The captain was adjusting the heading knob on the Flight Control Unit. The bright lights at the outer edges of the Flight Control Unit were flashing, indicating that the autopilot had been disconnected. The observer was taking notes. The simulator operator and the controller (not shown) were located to the left and behind the observer.

Table 3-1. Digital Data Measurements

Variable Name	Measure	Criterion
dt_roll	Time to start of aircraft roll	Roll angle of at least 3 deg to left, with restrictions
dt_engine	Time to increase in engine thrust	Increase of 500 rpm 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_toga	Time to change in TOGA status	Status changed from off (0) to engaged (1)
maximum_roll	Greatest roll angle magnitude	Largest left-hand roll angle achieved during the turn maneuver
dx_turn	Distance traveled until start of turn	Difference between ground position at start of roll and at start of ATC instruction
dt_min_altitude	Time to minimum altitude	Minimum radio altitude
dz_min_altitude	Altitude loss	Difference between altitude at start of ATC transmission and minimum altitude

* all times are referenced to start of ATC instruction

The information extracted from the videotapes included what pilots and testers did and said. 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, the sequence of pilot actions.

The times from start of ATC transmission to changes in autopilot and TOGA status were measured from the video data. Change in autopilot status was indicated by the flashing lights and by an audible warning. Change to TOGA thrust was indicated by forward movement of the thrust lever. These times were used to validate the times to event extracted from the digital data. Agreement indicated that the ATC event marker was pressed at the correct time.

3.6 DATA VALIDATION

The data for each trial were manually reviewed before the extracted performance variables were used. The review focused on three areas: result accuracy, timing accuracy, and scenario configuration. Result accuracy was checked by manually reviewing the digital data and results for each trial. If the automated process incorrectly declared the time of an event, then the time to the event was manually calculated and corrected in the Excel™ spreadsheet.

Timing accuracy was checked by manually comparing the times to autopilot disconnect and to TOGA thrust measured from the videotapes with the values extracted from the digital data. This process revealed an error during Phase 1 in the digital data collection subroutine which incremented the time stamp. The error was corrected, and the video and digital data

Figure 3-2. Videotape frame recorded during a breakout.

results for subsequent test sessions agreed. For the sessions with incorrect time stamps, the error was corrected during data extraction by incrementing the time data at the correct rate.

Scenario configuration was checked by manually verifying that the weather conditions, initial autopilot setting, subject pilot, and breakout location agreed with the test scenario. In addition, the breakout instruction was compared to the scripted text. If the configuration was correct, the trial was used in the analysis. If the configuration did not match the test scenario, then the trial was retained only if the configuration matched another test scenario. In this case, the trial identification string was changed to match the assumed scenario's identification. If the trial configuration did not match any of the test scenarios, then the data for that trial were not used in the analysis.

In some trials, the controller used the wrong call sign in the breakout instruction. During Phase 1, these events were random and unintentional. In Phase 2, the wrong call sign was deliberately used for one breakout halfway through each session. The purpose of the intentional error was to check whether the subjects were automatically reacting without paying attention to the message. In each case, the crew did not respond to the breakout instruction with the incorrect call sign and the controller had to repeat the message with the correct call sign. The data for these trials were not used in the analysis.

3.7 DATA ANALYSIS

Exploratory analysis was used to identify general trends in breakout performance. A subset of test variables representing turn and climb 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 .05 significance level. If the null hypothesis was rejected for a factor with more than two levels, then either the Tukey's b multiple range test or paired-sample t-test was used to determine which factor levels were statistically similar. If a subject experienced a given combination of approach mode and breakout group more than once, then these repeated measures were averaged and treated as a single sample. This was done to equalize the number of samples in each test cell.

The ANOVA formulas used depended on the phase. The formulas may be found in a statistical text such as [13]. For Phase 1, the assignment of subjects to each combination of test factors was assumed to be random. Although each subject experienced multiple cases for each combination of approach mode and breakout group, there were no complete sets of repeated measures. If a repeated-measure analysis had been used, then some results would have been ignored and values for missing levels would have been estimated. Therefore, it was necessary to assume a random, between-subject model for all independent variables. Collapsing the model with respect to subject (i.e., use between-subject comparisons) resulted in a more conservative analysis than if the data had been forced to fit a within-subject model.

A mixed-factor model (within and between subject) was used for the Phase 2 analysis. 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.

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 additionally required for mixed-factor 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.

Since the Phase 2 data included within-subject replicates, the analysis of variance required a complete set of data. Missing data values were replaced with the mean value for that test cell. The degree of freedom for the denominator was then reduced by the number of missing values. Any missing values are noted in the results section.

4. DATA ANALYSIS RESULTS

4.1 PILOT PARTICIPATION

Ten crews participate in each phase of the study. Twenty-eight pilots participated, with 12 acting as subjects in both phases. The subject pilots were from Northwest Airlines, United Airlines, and America West Airlines. Pilot participation by phase is listed in Table 4-1.

Table 4-1. Subject Participation by Phase of Study

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

4.2 LENGTH OF CONTROLLER BREAKOUT INSTRUCTIONS

Two controllers participated in Phase 1 and a third controller participated in Phase 2. Table 4-2 lists the group statistics for the length of the controller transmissions for each phase of the study. The breakout instructions during Phase 2 included additional words (<Aircraft>, TRAFFIC ALERT), and averaged one second longer than in Phase 1.

Table 4-2. Duration of ATC Breakout Instruction (seconds)

Phase	Count	Median	Mean	S.D.	Minimum	Maximum
1	160	4.1	4.4	0.9	3.3	7.6
2	177	5.1	5.0	0.4	4.3	6.8

4.3 PRACTICE EFFECTS

Although the Phase 1 experimental design did not assign within-subject replicates, company policies for the participating airlines dictated which pilot would fly Category II approaches: first officer for two airlines, and captain for the third airline. Because of this requirement, the replicate samples for the autopilot-coupled approaches were both flown by the same crewmember and could be used as within-subject replicates for measuring practice effects. There were also enough within-subject replicates for hand-flown approaches to include them in the analysis.

Paired-sample t tests for the mean were conducted separately for the Phase 1 hand-flown and autopilot-coupled data in case there was a difference in performance over time for one approach mode, but not for the other. Six performance variables were tested: dt_engine, dt_min_altitude, dt_pitch, dt_roll, dt_toga, and dt_vertical_speed. The null hypothesis was that there was no change in performance between the first and second replicate. If the calculated t value was larger than the critical value at the .05 level, then the null hypothesis was rejected, and the mean difference between the replicates was assumed to be significantly different from zero. No t values were significant at the .05 level, indicating that the differences between the first and second replicates in Phase 1 were due to random variability.

The Phase 2 experimental design included within-subject replicates for autopilot-coupled scenarios at 500 feet AGL and at 1800 feet AGL. The same variables as in Phase 1, except for dt_toga, were tested for each breakout altitude using the paired-sample t test. Out of ten t tests, two indicated a significant difference between the first and second replicate. The t test indicated that mean time to increasing engine speed at 500 feet was 1.8 seconds less for the second trial ($t = -2.12$, d.f. = 19, $p = .047$; $Mean_1 = 15.2$ seconds, $Mean_2 = 13.4$ seconds). In contrast, the t test indicated that mean time to minimum altitude at 1800 feet was 6.8 seconds longer for the second trial ($t = -2.62$, d.f. = 13, $p = .02$; $Mean_1 = 17.5$ seconds, $Mean_2 = 24.3$ seconds).

The Phase 2 repeated-measure data were also grouped by whether or not the pilot participated in Phase 1 to test for differences attributable to previous participation. One set of paired data included pilots who participated in Phase 1 and the other set included pilots who were new to the study. These t tests indicated no significant differences between the first and second replicate for either level of experience.

In order to search for possible practice effects not identified by the paired-sample t-tests, all data were qualitatively reviewed. First, the performance variables were grouped by crew within each phase, then ordered by scenario sequence. 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 are graphically depicted in Appendix F. No trends were identified for either phase. 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. There were fluctuations over the course of each session, but these were attributed mainly to scenario differences and to variability in subject responses.

The analysts' notes for the videotapes were also reviewed. Some Phase 1 crews discussed general procedures, but there were no specific conversations regarding how to execute the breakout. No pilot comments regarding breakout procedures were noted from the Phase 2 video data. These observations, together with the analytical results, suggest that there were no observable practice effects in either phase of the study. In general, response times did not decrease or increase over time. The pilots may have become more comfortable with the breakout procedure during the course of the test session, but the learning experience did not significantly affect the observed breakout performance.

4.4 GENERAL OBSERVATIONS

A breakout procedure is a complex set of responses to the ATC instruction. There are many ways for the crew to change altitude and direction. Similarly, the sequence of automation changes depends on the aircraft configuration. This section presents the trends that were observed in how the subjects chose to execute the breakouts and in the relative timing of the measured aircraft responses. Two pilot inputs were recorded: use of TOGA and use of autopilot. Other pilot inputs could not be measured. The analysts observed coarse pilot movements such as reaching for the heading or altitude knob on the video recordings, but the times at which the pilots entered information into the flight director could not be determined.

4.4.1 Use of Autopilot and TOGA

In both study phases, use of the autopilot during the ATC-directed breakout was at the discretion of the pilot flying. Following hand-flown approaches, the subjects always left the autopilot off during the breakout. Following autopilot-coupled approaches, the autopilot was disconnected before the start of turn in 14 out of 75 trials in Phase 1 (19 percent), and in seven out of 101 trials in Phase 2 (7 percent). In Phase 1, ten AP/HF breakouts were at decision altitude or 500 feet AGL. Although seven of the 20 pilots in Phase 1 disconnected the autopilot at least once, nine of these events occurred with two pilots. In Phase 2, six of the seven events occurred with one crew. These results suggest that a few pilots were responsible for most of the AP/HF breakouts and that the majority of the subjects preferred to leave the autopilot connected during the breakout. Because of the small number of subjects conducting AP/HF breakouts, breakout mode was not considered during the detailed analysis.

In Phase 1, the subject pilots did not receive any training, and use of TOGA thrust was at their discretion. In Phase 2, the training material discouraged the use of TOGA thrust for climbing breakouts above 400 feet AGL. In both phases, all subjects used TOGA thrust during breakouts at decision altitude, and did not use TOGA thrust during descending breakouts.

In Phase 1, TOGA thrust was not used during 9 out of 77 climbing breakouts above 400 feet AGL (12 percent). Four of these events were for one subject. Thus, pilot preference in Phase 1 was to use TOGA, and the number of trials in which it was not used was too small to allow comparison.

In Phase 2, when use of TOGA was discouraged, TOGA thrust was used in 31 out of 127 climbing breakouts above 400 feet AGL (24 percent). Of these events, 22 were for two crews from one airline. Because use of TOGA was mainly limited to four subjects in Phase 2, there was not enough between-subject variability to allow comparisons.

4.4.2 Climb Performance

Five performance variables measured A320 climb response: time to increasing engine rpm (dt_engine); time to pitch change (dt_pitch); time to vertical speed change (dt_vertical_speed); time to minimum altitude (dt_min_altitude); and, distance to minimum altitude (dz_min_altitude). In general, the subjects continued at the same speed and vertical rate during descending breakouts, so these performance variables were not calculated for descending scenarios. Group statistics for the five variables are presented in Appendix G.

Exploratory analysis indicated two trends. First, when TOGA thrust was used, the order of events was generally dt_engine, then dt_pitch, and then dt_vertical_speed. The mean time between dt_engine and dt_pitch was 0.6 second for manual approaches and 1.1 seconds for autopilot-coupled approaches. The mean time between dt_pitch and dt_vertical_speed was 0.7 second for both approach modes. For those trials that did not follow this trend, TOGA thrust was applied after the climb had been initiated.

Second, during open climb following autopilot-coupled approaches, the order of events was generally dt_pitch, then dt_vertical_speed, then dt_engine, with mean times between events of 2.1 seconds and 2.6 seconds, respectively. Those trials that did not follow the trend were at 1800 feet AGL, and the turn started before the climb. The sequence of events was random for open climb following manual approaches, meaning there were no trends observed in the relative timings of dt_engine, dt_pitch, and dt_vertical_speed for these cases.

Since the use of TOGA thrust affected the sequence of aircraft responses, it was possible that it also affected the rate of climb. In order to check for this possible effect, an additional variable, dt_transition, was calculated during the analysis. This variable was calculated as the time difference between start of vertical acceleration and the time at which the aircraft vertical speed was zero: dt_min_altitude – dt_vertical_speed. Dt_transition provided an estimate of the time required to transition from a negative to a positive vertical speed, or from a descent to a climb.

Figure 4-1 presents the dt_transition data grouped by approach mode and climb mode for climbing breakouts above 400 feet AGL. The data from Phase 1 and Phase 2 are shown separately because both climb modes were used in both phases. Data from decision altitude are not included because TOGA was always used in both phases. The results show the similarity in distributions between the two phases, although the numbers of samples in each group are different for each phase. In the majority of trials, the aircraft transitioned from descend to climb in less than 5 seconds. In those trials in which TOGA thrust was engaged and dt_transition was longer than 5 seconds, TOGA was engaged after the start of climb. The open-climb trials in which dt_transition was greater than 12 seconds were all 1800' scenarios in which pitch, engine, and vertical-speed accelerations were slow. In each of these cases, vertical speed went below 1000 feet per minute before starting to increase. Another characteristic was that engine speed was around 1600 rpm at the start of the breakout, as opposed to greater than 3000 rpm for other 500' and 1800' trials.

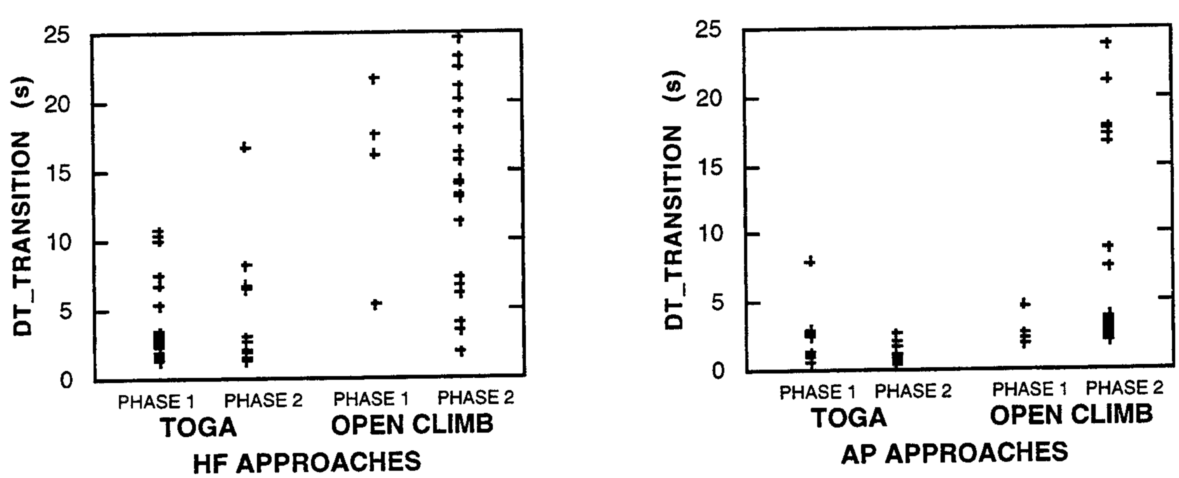

Figure 4-1. Transition time for climbing breakouts above 400 feet AGL.

4.4.3 Turn Performance

Three performance variables measured A320 turn response: time to start of roll (dt_roll); distance to start of roll (dx_turn); and, maximum roll angle magnitude (maximum_roll). Distance to start of roll was proportional to time to start of roll and true air speed, so it was not analyzed in detail. Statistics for the three variables are presented in Appendix G.

Maximum roll magnitude was consistently between 23.7 and 25.6 degrees for breakouts in which the autopilot remained engaged, except during engine-out scenarios. Maximum roll magnitude was more variable and generally smaller for the engine-out trials. There was also greater variability for hand-flown breakouts, although the mean value was similar to the mean for autopilot-coupled breakouts.

For hand-flown breakouts, maximum roll magnitude exceeded 30 degrees in 29 trials. These trials were individually reviewed to determine if there were any common traits. Except for one pilot, individual performance was not a factor: fourteen of the 28 subjects exceeded 30 degrees at least once, and subject 8 exceeded that value nine times. Fifteen events were in Phase 1, fourteen were in Phase 2. There was also equal distribution between HF/HF and AP/HF breakouts and between first and second half of the session. Most of the large roll angles occurred during climbing breakouts above 400 feet AGL (24 trials). Figure 4-2 presents the roll angle data for the nine trials in which maximum roll magnitude was greater than 35 degrees. In each case, roll rate was constant until maximum roll angle was achieved. Then the aircraft rolled back to a smaller angle. The roll angle magnitudes were greater than 30 degrees for five to seven seconds.

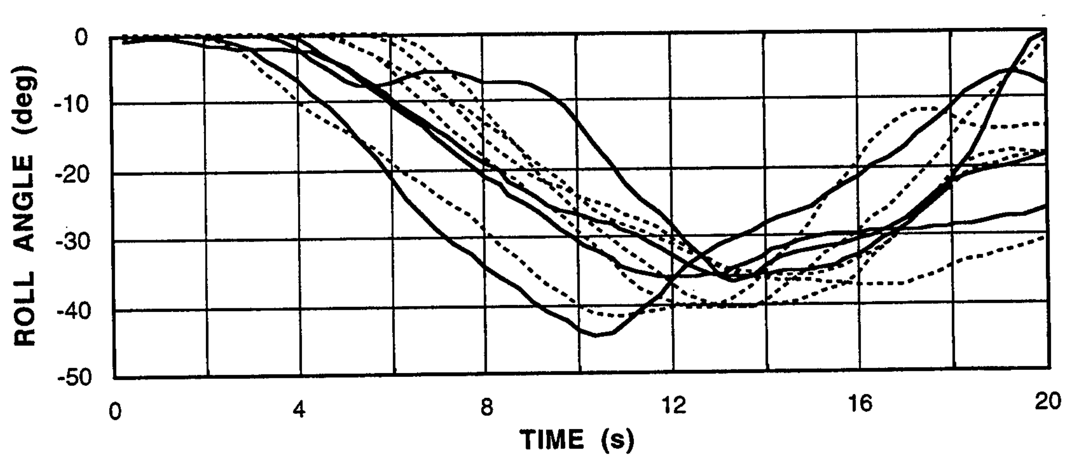

Figure 4-2. Maximum roll magnitudes greater than 35 degrees. The negative roll angle values indicate a left roll. Roll histories with dotted lines are for subject 8.

As mentioned in Section 3.5.1, two algorithms were used to measure time to start of roll. For most trials, these algorithms returned the same value for dt_roll. In 24 cases, the algorithms returned different values. These trials were individually reviewed to determine if there were any common traits. Six events were the right engine-out scenario; and the aircraft rolled right when thrust was applied. Four events were manual approaches with climbing breakouts. It was unclear whether the pilots had started the roll then rolled back slightly or if the rollback was an artifact of manual control using the side stick.

The remaining rollbacks (14 events) involved autopilot breakouts at 500 and 1800 feet AGL. These were distributed among nine pilots. There was also equal distribution between phases of study. Eleven events occurred in the second half of the session. In all 14 trials, the new heading was entered into the flight director before the thrust levers were set to TOGA. Once TOGA was engaged, the flight director reverted to the pre-programmed go-around track. The crew then had to re-enter the new heading information. In these trials, the start of turn was delayed 4 to 18 seconds. Figure 4-3 presents the roll and heading data for two of these trials as illustrations of the possible delay in turn away from the approach course because of TOGA-induced rollback.

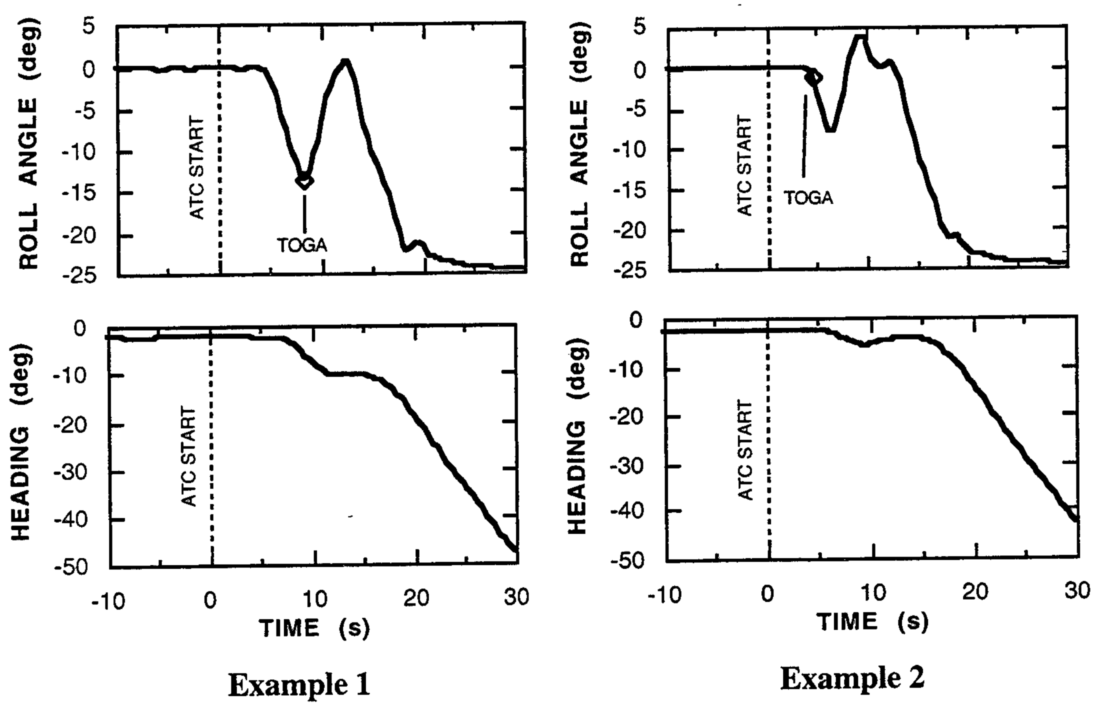

Figure 4-3. Two TOGA-induced rollbacks. Initial heading is –2.5 degrees because of crosswinds.

4.5 PHASE 1 ANALYSIS

For the statistical analysis, subject assignments in Phase 1 were assumed to be random with respect to breakout group and approach mode.[2] Replicates for the decision altitude (DA), 500 feet AGL (500'), and 1800 feet AGL (1800') breakout groups were used to test the effect of

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2 Assignments were not completely random due to compliance with company policy and to ad hoc crew assignment during each session.

altitude on turn and climb performance. Replicates for the DA and engine-out breakout groups were used to test the effect of cockpit distractions on turn and climb performance. Replicates from the 1800' and Descend breakout groups were used to test the effect of breakout direction on turn performance only. The effect of direction on climb variables was not tested because the pilots did not change vertical speed during the descending breakouts.

Five dependent variables were evaluated: time to increasing engine rpm (dt_engine); time to start of climb (dt_vertical_speed); time to TOGA engage (dt_toga); altitude loss (dz_min_altitude); and, time to start of roll (dt_roll). The first four dependent variables were associated with climb performance, and dt_roll measured turn performance.

4.5.1 Altitude by Approach Mode

Exploratory analysis indicated that the variances for the four dependent variables associated with climb performance were much smaller at decision altitude than at 500' or 1800'. These variables required transformations in order to satisfy the ANOVA assumption of equality of variances. The best transformations were the inverses: 1/dt_engine; 1/dt_vertical_speed; 1/dt_toga; and, 1/dz_min_altitude.

The analysis of variance indicated a significant main effect for altitude with all five dependent variables. As indicated by the results shown in Table 4-3, the four climb variables were smallest at decision altitude, and increased significantly with each altitude group. Turn performance exhibited the opposite trend: mean dt_roll was largest at decision altitude and smallest at 1800 feet AGL. The Tukey's b test indicated that mean time to start of turn at decision altitude was significantly larger than the 1800' mean, but that it was not significantly different from the 500' mean. The 500' mean also was not significantly different from the 1800' mean.

Table 4-3. Altitude Main Effect (Altitude by Approach-Mode ANOVA)

DEPENDENT VARIABLE	CALCULATED F VALUE [1]	MEAN VALUE DA	500'	1800'	SIGNIFICANT DIFFERENCES
dt_engine [2] (s)	13.07	3.3	5.1	7.1	DA < 500' < 1800'
dt_vertical_speed [2] (s)	16.64	4.6	6.2	8.2	DA < 500' < 1800'
dt_toga [2] (s)	14.33	3.4	4.8	7.9	DA < 500' < 1800'
dz_min_altitude [2] (ft)	34.72	67	89	152	DA < 500' < 1800'
dt_roll (s)	5.44	11.3	8.7	6.9	DA > 1800'

1 $F_{.05}(2,69) = 3.14$
2 Variable was transformed for the analysis

The analysis of variance also indicated a significant main effect for approach mode for time to start of climb and time to start of roll. As listed in Table 4-4, the mean values for hand-flown approaches were significantly smaller than the mean values for autopilot-coupled approaches. The calculated F valued for the other dependent variables were smaller than the critical value, $F_{.05}$, indicating that the differences in means for these variables were random and not significant. There was no significant interaction effect between altitude and approach mode.

Table 4-4. Approach Mode Main Effect (Altitude by Approach Mode ANOVA)

DEPENDENT VARIABLE	CALCULATED F VALUE [1]	MEAN VALUE		SIGNIFICANT DIFFERENCES
		HAND-FLOWN	AUTOPILOT	
dt_engine [2] (s)	0.07	4.8	5.6	None
dt_vertical_speed [2] (s)	5.74	5.8	6.9	HF < AP
dt_toga [2] (s)	1.19	5.1	5.4	None
dz_min_altitude [2] (ft)	0.16	103	101	None
dt_roll (s)	11.65	7.3	10.9	HF < AP

1 $F_{.05}(1,69) = 3.99$
2 Variable was transformed for the analysis

4.5.2 Direction by Approach Mode

Because there were no changes to the dependent variables associated with climb performance during descending breakouts, only turn performance was assessed. Exploratory analysis indicated unequal variances for dt_roll for this data subset. The statistics listed in Appendix G show that the mean values for the four different cases were all larger than the median values, indicating that the distributions were skewed by a few long response times. The inverse of the dependent variable, 1/dt_roll, was used in the analysis to compensate for the skewed distributions. The analysis of variance indicated no main effect for direction, meaning there was no significant difference between mean values for climbing and descending breakouts at 1800 feet AGL ($F(1,39) = 0.13$; $p > 0.05$). A main effect was indicated for approach mode ($F(1,39) = 8.54$; $p < 0.05$; $Mean_{HF} = 7.2$ s; $Mean_{AP} = 7.6$ s). The mean value for hand-flown approaches was smaller than for autopilot-coupled approaches. This result was the same as the result from the altitude by approach mode analysis. There was no interaction effect between direction and approach mode.

4.5.3 Distraction by Approach Mode

The only cockpit indications of an engine failure were flashing warning lights on the Flight Control Unit and a message on one of the displays. There was no audible alarm. One crew commented afterwards that this "isn't much indication of engine failure." The failure was not verbally acknowledged in six trials. In six other trials, the crew asked to continue at present heading because of the failure. This response was not anticipated during the experiment design phase. Although operationally significant, the straight-ahead responses did not provide data on climbing-turn breakout responses. Thus, these straight-ahead trials were not used in the analysis of variance.

Exploratory analysis indicated that all dependent variables satisfied the assumption of equal variances, so no transformations were required. The analysis of variance indicated a main effect for distraction level with dt_engine and dt_vertical_speed, with these responses occurring sooner in the engine-out scenarios. The analysis information is listed in Table 4-5. Although mean dt_roll was 1.3 seconds less for the DA scenarios, between-subject variability was large enough that the difference was not statistically significant.

Table 4-5. Distraction Main Effect (Distraction by Approach-Mode ANOVA)

DEPENDENT VARIABLE	CALCULATED F VALUE [1]	MEAN VALUE		SIGNIFICANT DIFFERENCES
		DA	ENG OUT	
dt_engine (s)	21.25	3.3	2.3	DA > ENG OUT
dt_vertical_speed (s)	5.26	4.6	4.0	DA > ENG OUT
dt_toga (s)	0.90	3.4	3.2	None
dz_min_altitude (ft)	1.99	67	62	None
dt_roll (s)	0.41	11.3	12.6	None

1 $F_{.05}(1,36) = 4.12$

The analysis of variance also indicated a significant main effect for approach mode with three dependent variables: dt_engine, dt_toga, and dz_min_altitude. These dependent variables were smaller for autopilot-coupled approaches. The results are listed in Table 4-6. Although mean dt_roll was 3.5 seconds less for hand-flown approaches between-subject variability was such that the difference was not statistically significant. There was no interaction effect between distraction level and approach mode.

Table 4-6. Approach Mode Main Effect (Distraction by Approach-Mode ANOVA)

DEPENDENT VARIABLE	CALCULATED F VALUE [1]	MEAN VALUE		SIGNIFICANT DIFFERENCES
		HAND-FLOWN	AUTOPILOT	
dt_engine (s)	21.92	3.4	2.4	HF > AP
dt_vertical_speed (s)	0.36	4.3	4.4	None
dt_toga (s)	14.70	3.8	2.7	HF > AP
dz_min_altitude (ft)	6.59	69	60	HF > AP
dt_roll (s)	2.15	10.2	13.7	None

1 $F_{.05}(1,36) = 4.12$

4.6 PHASE 2 ANALYSIS

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. The within-subject assignments were such that the climbing-breakout data were analyzed in two sets. The first set included all within-subject replicates at decision altitude (DA), 500 feet AGL (500'), and 1800 feet AGL (1800'). The second set included all within-subject replicates at 500', 1000 feet AGL (1000'), and 1800'. Within-subject replicates for the 1800' and Descend breakout groups were used to test the effect of breakout direction on time to start of turn. The effect of breakout direction on speed and climb variables was not tested because the pilots did not change vertical speed during the descending breakouts.

Four dependent variables were evaluated: time to increasing engine rpm (dt_engine); time to increasing vertical speed (dt_vertical_speed); altitude loss (dz_min_altitude); and, time to start of roll (dt_roll). Exploratory analysis indicated that dt_roll and dz_min_altitude did not satisfy the assumption of homogeneity of variances and required transformation. The best transformations were the inverses: 1/dt_roll and 1/dz_min_altitude. The other test variables were not transformed.

4.6.1 Altitude by Approach Mode

The analysis of variance using approach mode as the between-subject independent variable and the DA, 500', and 1800' breakout groups as the within-subject independent variable yielded significant main effects for both approach mode and altitude, but no significant interaction between the two independent variables. The analysis information for the main effect of approach mode is listed in Table 4-7. The calculated F value was greater than the critical value for all dependent variables, indicating that the difference between mean values was significant and not random. The conclusion was that all analyzed breakout events averaged 3 to 4 seconds less for hand-flown approaches than for autopilot-coupled approaches. Mean altitude loss for hand-flown approaches was 25 feet less than for autopilot-coupled approaches.

Table 4-7. Approach Mode Main Effect (DA-500'-1800' ANOVA)

DEPENDENT VARIABLE	CALCULATED F VALUE [1]	MEAN VALUE		SIGNIFICANT DIFFERENCES
		HAND-FLOWN	AUTOPILOT	
dt_engine (s)	7.15	7.6	10.5	HF < AP
dt_vertical_speed (s)	32.77	6.7	10.7	HF < AP
dz_min_altitude [2] (ft)	5.48	138	163	HF < AP
dt_roll [2] (s)	11.42	6.1	10.3	HF < AP

1 $F_{.05}(1,14) = 4.60$
2 Variable was transformed for the analysis

Table 4-8 lists the analysis of variance information for the altitude main effect. The calculated F values for all dependent variables were larger than the critical value, indicating that the mean for at least one level of altitude was significantly different from the other means. Because altitude was the within-subject factor, paired-sample t-tests were used to determine which levels had significantly different sample means. The t tests yielded a significant difference between decision altitude and the other two altitudes for dt_engine and dt_vertical_speed. Both events averaged 5 to 6 seconds less at decision altitude than at 500' and 1800'. There was no significant difference between 500' and 1800' for these two dependent variables. Mean distances to minimum altitude were significantly different for all three altitudes: mean altitude loss increased from 83 feet at decision altitude to 217 feet at 1800 feet AGL. The results for time to start of roll were less conclusive. Although mean dt_roll was larger at decision altitude than at the other two altitudes, it was significantly different from only the 500' mean. The t tests indicated that the 1800' results were not significantly different from either the DA or the 500' results.

Table 4-8. Altitude Main Effect (DA-500'-1800' ANOVA)

DEPENDENT VARIABLE	CALCULATED F VALUE [1]	MEAN VALUE			SIGNIFICANT DIFFERENCES
		DA	500'	1800'	
dt_engine (s)	15.60	5.0	11.2	10.9	DA < (500',1800')
dt_vertical_speed (s)	14.73	5.8	10.0	11.0	DA < (500',1800')
dz_min_altitude [2] (ft)	66.20	83	150	217	DA < 500' < 1800'
dt_roll [2] (s)	5.21	9.9	6.7	8.1	DA > 500'

1 $F_{.05}(2,28) = 3.34$
2 Variable was transformed for the analysis

Because some trials were rejected during the data validation process, two cases were missing for the 500'-1000'-1800' data set. These missing data were replaced by the appropriate means, and the denominator degree of freedom was reduced by two.

The analysis of variance using approach mode together with the 500', 1000', and 1800' breakout groups as independent variables yielded a main effect for approach mode with dt_roll and dt_vertical_speed. The analysis information is presented in Table 4-9. Although the means for dt_engine and dz_min_altitude were smaller for hand-flown approaches, the variability in responses was large enough that the null hypotheses of no significant difference between means were not rejected.

Table 4-9. Approach Mode Main Effect (500'-1000'-1800' ANOVA)

DEPENDENT VARIABLE	CALCULATED F VALUE [1]	MEAN VALUE		SIGNIFICANT DIFFERENCES
		HAND-FLOWN	AUTOPILOT	
dt_engine (s)	2.71	10.3	13.4	None
dt_vertical_speed (s)	5.46	10.5	13.2	HF < AP
dz_min_altitude [2] (ft)	0.01	204	218	None
dt_roll [2] (s)	26.65	5.1	7.2	HF < AP

1 $F_{.05}(1,12) = 4.75$
2 Variable was transformed for the analysis

The analysis of variance using the 500', 1000', and 1800' breakout groups also yielded a significant main effect for altitude with dt_vertical_speed and dz_min_altitude. The analysis information is presented in Table 4-10. The paired-sample t tests yielded a significant difference between 1800' and the other two altitudes. There was no significant different between 500' and 1000'. This is partly consistent with the DA-500'-1800' analysis, which indicated a significant difference between 500' and 1800' for dz_min_altitude but not for dt_vertical_speed. Mean time to start of roll (dt_roll) and time to engine rpm increase (dt_engine) were similar for the three altitude levels. These results are consistent with the DA-500'-1800' analysis, which indicated no significant difference between 500' and 1800' for these dependent variables.

Table 4-10. Altitude Main Effect (500'-1000'-1800' ANOVA)

DEPENDENT VARIABLE	CALCULATED F VALUE [1]	MEAN VALUE			SIGNIFICANT DIFFERENCES
		500'	1000'	1800'	
dt_engine (s)	1.30	12.4	12.4	10.7	None
dt_vertical_speed (s)	5.52	10.6	11.3	13.8	(500', 1000') < 1800'
dz_min_altitude [2] (ft)	27.52	170	182	280	(500', 1000') < 1800'
dt_roll [2] (s)	0.38	6.2	5.8	6.3	None

1 $F_{.05}(2,26) = 3.37$
2 Variable was transformed for the analysis

4.6.2 Direction by Approach Mode

The analysis of variance using direction and approach mode as independent variables was performed on the transformed turn variable, 1/dt_turn. The results indicated a significant main effect for approach mode. The mean for hand-flown approaches was 2.7 seconds smaller than for autopilot-coupled approaches ($F(1,14) = 21.77$; $Mean_{HF} = 5.2$ s; $Mean_{AP} = 7.9$ s). The results indicated no significant main effect for direction. The mean value for climbing breakouts was similar to the mean value for descending breakouts ($F(1,14) = 0.01$; $Mean_{1800'} = 6.8$ s; $Mean_{DESC} = 6.4$ s). There was no significant interaction between approach mode and direction.

4.7 COMPARISON BETWEEN PHASES

In Phase 1, TOGA thrust was used in all breakouts at decision altitude and in 88 percent of the climbing breakouts above 400 feet AGL. In Phase 2, TOGA thrust was also used in all breakouts at decision altitude, but open climb mode was employed by 16 out of 20 subject pilots during climbing breakouts above 400 feet AGL. Analysis of variance was used to test whether or not there were significant differences in turn or climb performance between the two study phases. Time from start of ATC instruction to start of roll, dt_roll, was used as the turn performance metric. The metrics for climb performance were time from start of ATC instruction to start of pitch increase (dt_pitch), time from pitch increase to increasing vertical speed (dt_vertical_speed – dt_pitch), and time from increasing vertical speed to positive rate of climb (dt_transition).

Each variable was tested for each of the breakout groups common to Phase 1 and Phase 2: DA, 500', 1800', and Descend (turn performance only). All variables satisfied the analysis of variance assumptions for each breakout group, therefore no transformations were required. Hand-flown and autopilot-coupled trials were combined (i.e., not tested separately, based on the results of Sections 4.5 and 4.6.

The analysis of variance indicated no change in turn performance between Phase 1 and Phase 2. The calculated F values for each of the four breakout groups was smaller than the $F_{.05}$ critical value, indicating no significant difference between dt_roll distributions. The group means and calculated F values are listed in Table 4-11.

Table 4-11. Effect of Phase on Dt_roll

	MEAN DT_ROLL (s)			
PHASE	DA	500'	1800'	DESCEND
1	11.3	8.7	6.9	5.7
2	10.1	6.4	7.1	6.4
Calculated F Value	F(1,41) = 0.46	F(1,62) = 2.72	F(1,60) = 0.02	F(1,32) = 0.77

The analysis of variance indicated no significant difference in dt_pitch between Phase 1 and Phase 2 at decision altitude (DA), but did indicate a significant difference between the two phases for the 500' and 1800' breakout groups. The calculated F value was less than the $F_{.05}$ critical value for the DA group, but larger than the critical values for the 500' and 1800' groups. The group means and F values are listed in Table 4-12.

A comparison between the mean values in Table 4-11 and Table 4-12 suggests that, on average, climb started before the turn during breakouts at decision altitude. The mean statistics also suggest that, on average, climb started before or at the same time as the turn in Phase 1 for breakouts above 400 feet AGL, but that the turn was initiated before climb for breakouts above 400 feet AGL during Phase 2.

Table 4-12. Effect of Phase on Dt_pitch

	MEAN DT_PITCH (s)		
PHASE	DA	500'	1800'
1	4.5	5.6	6.9
2	5.3	9.0	9.4
Calculated F Value	F(1,41) = 1.99	F(1,62) = 22.73*	F(1,60) = 9.85*

* value larger than $F_{.05}$

The analysis of variance indicated similar differences between Phase 1 and Phase 2 for the time between pitch increase and vertical speed increase. The calculated F value was less than the critical value for breakouts at decision altitude, indicating no significant difference. The calculated F value was larger than the critical value for climbing breakouts above 400 feet AGL, indicating that the time from pitch increase to increasing vertical speed was longer in Phase 2. The group means and F values are listed in Table 4-13.

Table 4-13. Effect of Phase on (Dt_vertical_speed - Dt_pitch)

	MEAN (DT_VERTICAL_SPEED - DT_PITCH) (s)		
PHASE	DA	500'	1800'
1	0.1	0.6	1.4
2	0.5	1.5	3.0
Calculated F Value	F(1,41) = 0.97	F(1,62) = 4.76*	F(1,60) = 3.80*

* value larger than $F_{.05}$

Similarly, the analysis of variance indicated no significant difference in dt_transition for breakouts at decision altitude, but did indicate a significant difference for climbing breakouts above 400 feet AGL. The mean dt_transition statistic was significantly larger in Phase 2 than in Phase 1, indicating that, on average, it took longer to transition to a positive climb rate in Phase 2 at altitudes above 400 feet AGL. The group means and F values are listed in Table 4-14.

Table 4-14. Effect of Phase on Dt_transition

	MEAN DT_TRANSITION (s)		
PHASE	DA	500'	1800'
1	1.7	1.9	4.2
2	1.6	4.4	9.7
Calculated F Value	F(1,41) = 0.00	F(1,62) = 13.80*	F(1,60) = 11.64*

* value larger than $F_{.05}$

4.8 COMPARISON 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 Precision Runway Monitor Program risk analysis. The data for each phase were grouped by breakout scenarios: climbing breakouts at decision altitude (DA); climbing breakouts above 400 feet AGL (500', 1000', and 1800'); and, descending breakouts at 1800 feet AGL. The distraction scenarios from Phase 1 were not included in this analysis. For each phase, a given approach mode was classified as acceptable if all response times were less than or equal to 17 seconds and mean time to start of roll was less than or equal to 8 seconds for the three scenario groups.

The distributions of times from start of ATC transmission to start of roll are presented in Figure 4-4 for Phase 1. The statistics for each approach mode are also presented. Mean time to start of turn was acceptable for only two conditions: hand-flown approaches followed by climbing breakouts above 400 feet AGL and autopilot-coupled approaches followed by descending breakouts. Except for descending AP mode breakouts, the mean statistics were two or more seconds larger than the medians (50^{th} percentile) because of the long response times. In Phase 1, 16 trials out of 136 had a time to start of roll greater than 17 seconds. Table 4-15 lists data for each of these events. Six were at decision altitude, two were descending breakouts, and eight were climbing breakouts above 400 feet AGL. Only two of the ten autopilot-coupled trials listed in Table 4-15 had TOGA-induced rollbacks. Seven of the long response times were for subject 6, while the other nine events were attributed to eight pilots.

The distributions and statistics for time to start of roll are presented in Figure 4-5 for Phase 2. All mean statistics were less than 8 seconds except for autopilot mode breakouts at decision altitude. There were three trials with time to start of roll greater than 17 seconds. Two were hand-flown scenarios (DA and 1800') with subject 6 as pilot flying. The other was an autopilot-coupled scenario at decision altitude. All three trials were in the middle of the session.

Table 4-15. Phase 1 Times to Start of Turn Greater Than 17 Seconds

Approach Mode	Breakout Group	Sequence Number	Pilot	DT_ROLL (s)	DT_TOGA (s)	First roll (s)
HF	DA	4	6	18.7	3.7	---
HF	500'	1	6	19.0	4.7	---
HF	500'	17	6	21.0	4.7	4.0
HF	1800'	5	6	23.7	6.3	---
HF	DESC	2	3	27.0	N/A	3.0
HF	DESC	2	9	26.3	2.7	---
AP	DA	9	6	19.0	3.3	---
AP	DA	3	6	21.3	3.3	---
AP	DA	13	11	27.0	2.0	---
AP	DA	13	14	20.0	3.3	---
AP	DA	13	18	30.3	1.0	---
AP	500'	12	4	21.0	4.7	---
AP	500'	13	6	18.0	4.0	---
AP	500'	8	16	18.3	5.0	---
AP	1800'	15	4	21.0	5.3	6.0
AP	1800'	15	19	23.3	7.3	5.0

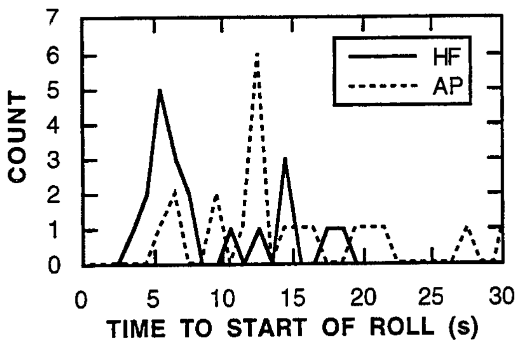
4.9 SUMMARY

Approach mode affected turn performance in both study phases, with mean times to start of turn following hand-flown approaches being 2 to 4 seconds smaller than mean times following autopilot-coupled approaches at all altitudes. Approach mode had a greater effect on climb performance in Phase 2 than in Phase 1. In Phase 1, mean time to increasing vertical speed was significantly less for hand-flown approaches; but there were no significant differences between mean values for the other three climb variables. In Phase 2, however, all four climb variables were significantly smaller for hand-flown approaches.

Altitude also affected performance in both phases. Mean values for climb variables were least at decision altitude, and increased with increasing altitude. The opposite result was observed for time to start of turn. In both phases, mean dt_roll was significantly more at decision altitude than at the altitudes above 400 feet AGL. There was no significant difference in turn performance between 500 feet AGL and 1800 feet AGL.

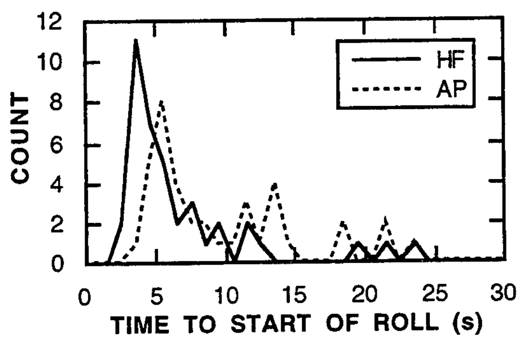
Breakout direction did not affect turn performance. In both study phases, mean time to start of turn was statistically similar for descending and climbing breakouts at 1800 feet AGL.

The engine-out distraction also had little effect on climbing-turn breakout performance. The analysis of variance indicated similar means for time to start of turn (dt_roll), time to TOGA (dt_toga), and vertical loss (dz_min_altitude). Mean time to increasing engine rpm (dt_engine) and mean time to start of climb (dt_vertical_speed) were less for the distraction scenarios. This result, however, may be an artifact of the crews responding to the engine failure rather than an indicator of performance differences. The six straight-ahead responses were not used in this analysis.



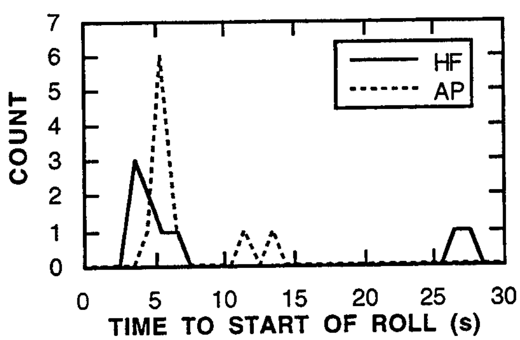
Climbing breakouts at decision altitude

Approach Mode	Count	Mean (s)	Median (s)	S.D. (s)	Max (s)
HF	20	8.7	6.4	4.7	18.7
AP	20	14.2	12.3	6.6	30.3



Climbing breakouts above 400 feet AGL

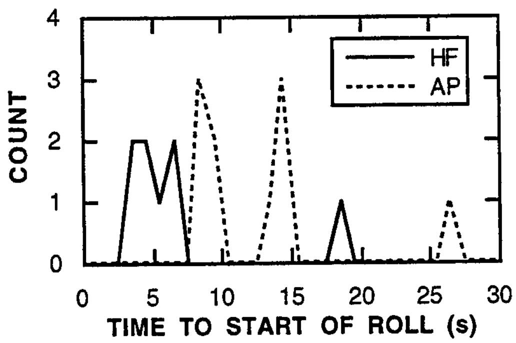
Approach Mode	Count	Mean (s)	Median (s)	S.D. (s)	Max (s)
HF	39	6.6	4.4	5.0	23.7
AP	38	9.4	7.0	5.4	23.3



Descending breakouts at 1800 feet AGL

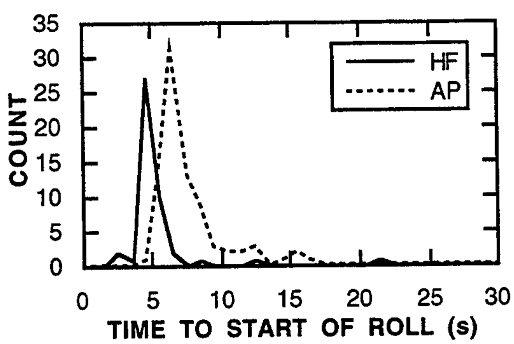
Approach Mode	Count	Mean (s)	Median (s)	S.D. (s)	Max (s)
HF	9	9.2	4.3	9.9	27.0
AP	10	6.7	5.7	3.0	13.0

Figure 4-4. Times to start of roll for Phase 1 breakouts.



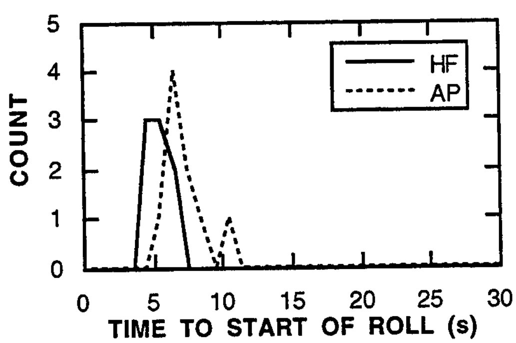
Climbing breakouts at decision altitude

Approach Mode	Count	Mean (s)	Median (s)	S.D. (s)	Max (s)
HF	8	6.6	5.1	4.8	18.1
AP	10	12.8	11.5	5.4	26.7



Climbing breakouts above 400 feet AGL

Approach Mode	Count	Mean (s)	Median (s)	S.D. (s)	Max (s)
HF	45	5.3	4.5	2.8	21.1
AP	82	7.6	6.7	2.5	16.8



Descending breakouts at 1800 feet AGL

Approach Mode	Count	Mean (s)	Median (s)	S.D. (s)	Max (s)
HF	8	5.3	5.1	0.9	6.9
AP	9	7.3	6.9	1.5	10.4

Figure 4-5. Times to start of roll for Phase 2 breakouts.

The analysis of variance comparing Phase 1 to Phase 2 indicated no change in turn performance. Mean times to start of turn were statistically similar between phases for all breakout groups. In contrast, the results indicated a significant difference between phases in climb performance for altitudes above 400 feet AGL. The dt_pitch mean statistics suggested that the pilots waited longer to initiate the climb in Phase 2. In addition, the results indicated that the aircraft response generally was more sluggish in Phase 2. The mean time used between the start of the climb response and the time at which positive climb rate was achieved was significantly longer in Phase 2 than in Phase 1. A comparison between the mean turn and climb statistics also suggests that in Phase 1, the subjects generally started the climb before the turn; whereas in Phase 2, the subjects started the turn before the climb. There were no significant differences in climb performance at decision altitude between Phase 1 and Phase 2.

Phase 1 turn performance did not satisfy either of the test requirements. Mean times to start of turn were generally larger than 8 seconds, and twelve percent of the trials had a dt_roll value of greater than 17 seconds.

Turn performance was better in Phase 2. Except for autopilot-coupled breakouts at decision altitude, all Phase 2 mean times to start of roll were less than 8 seconds. The number of long times to start of turn was also smaller. The three trials with dt_roll greater than 17 seconds had similar circumstances. Two of the three occurred at decision altitude, and two of the three were manual breakouts for one subject pilot.

Use of TOGA thrust had an apparent effect on both turn and climb performance. First, if TOGA thrust was applied after the new heading was selected during autopilot-coupled breakouts, then the flight director would revert to the pre-programmed go-around track. The crew then had to re-enter the new heading. Sometimes this event resulted in a significant delay to start of turn. Second, if TOGA thrust was not used and the aircraft remained in open-climb mode, then the transition from descend to climb sometimes took longer than expected at 1800 feet AGL. This event appeared to be related to the initial engine speed and altitude. Long transition times occurred in both manual and autopilot-coupled scenarios.

5. SURVEY RESULTS

Following participation in A320 Phase 1 and A320 Phase 2, subjects were asked to complete a survey. Each phase had its own survey that included questions consistent with the intent of that particular phase of study.

The questions in the Phase 1 Survey focused on assessing the level of difficulty of breakouts and identifying differences in the level of difficulty that may be attributable to where the breakout occurred, i.e., at decision altitude, inside the outer marker, and outside the outer marker. The Phase 1 Survey was also designed to elicit responses regarding the specific conditions that may have influenced pilot responses, including: altitude, configuration, air speed, company policy, and passenger comfort.

The primary focus of the Phase 2 Survey was to assess the potential value added by the training and materials provided to increase situational awareness. Questions were included regarding the general level of difficulty of executing breakouts but did not focus on variations on the level of difficulty as a function of where the blunder occurred or what specific conditions may have influenced pilot response.

Section 5.1 reports the results of the Phase 1 Survey and Section 5.2 reports the results of the Phase 2 Survey. In reporting results, verbatim comments made by the pilot-subjects are included. In some cases, pilots used abbreviations for commonly used terms. The translation of an abbreviation is provided in parenthesis by the data analyst the first time a particular abbreviation is used.

5.1 SURVEY RESULTS FOR PHASE 1

Ten crews, each consisting of a captain and first officer, participated in Phase 1. Each participating pilot was assigned a subject-number to assure the anonymity of his or her responses. Pilots were asked to list their total flight time and the total hours in the aircraft type A320. Table 5-1a and Table 5-1b, respectively, list the total, mean, and range for "total flight time" and "hours in type" for both captains and first officers. The values 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 5-1a. Flight Time (hours)

POSITION	TOTAL FLIGHT TIME	MEAN	RANGE
Captain (n = 8)	111,250	12,361	5,600 to 20,000
First Officer (n = 5)	78,000	8,666	2,500 to 14,000

Table 5-1b. Hours in Type (A320)

POSITION	TOTAL HOURS IN TYPE	MEAN	RANGE
Captain (n = 9)	14,450	1,605	400 to 3,000
First Officer (n = 5)	13,385	1,487	85 to 3,000

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.

<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 a descending breakout. 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>.**

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

Figure 5-1 graphically illustrates the results. These data are reported as the percentage of crews selecting each specific rating for each specific item. Of note is the fact that crews generally rated the difficulty o the breakout as "not at all" or "somewhat difficult" and never rated it as "more than moderately" or "very difficult."

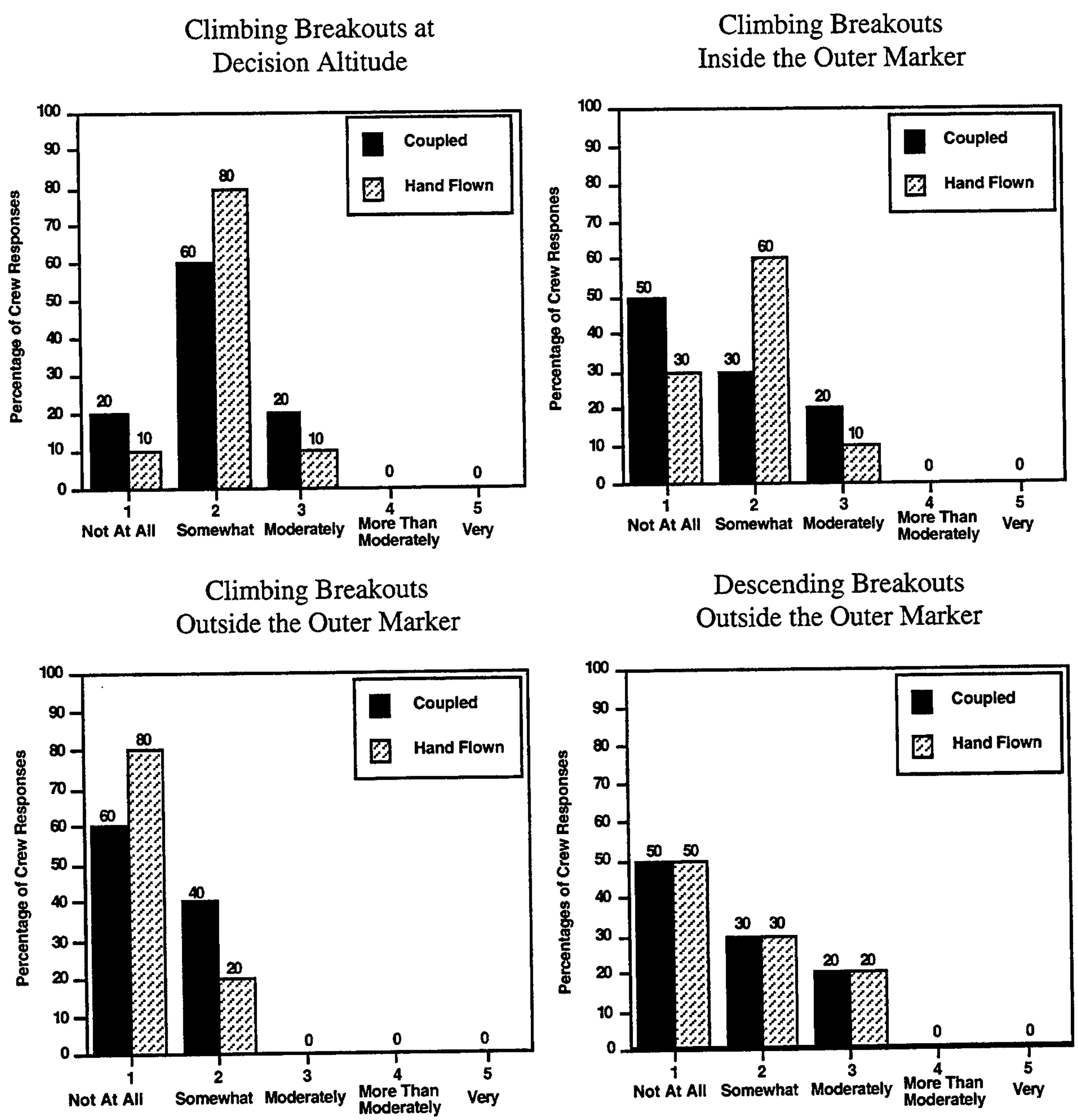


Figure 5-1. Crew ratings of difficulty of breakouts.

Following each of these four survey items, 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 with a "yes" or "no" to each of the attributes, including: altitude, aircraft configuration, air speed, company policy, and passenger comfort. Table 5-2 lists the percentage of "yes" responses, indicating that an attribute was part of the basis on which the crew decided to make the turn. For example, as seen below, 30% of the crews said that "yes," altitude was a factor in making the decision to start turning in the case of a climbing breakout at decision altitude.

Table 5-2. 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	30	20	10	20	0	30
2c.	Climbing Breakout inside the Outer Marker	20	20	0	20	0	20
3c.	Climbing Breakout outside the Outer Marker	10	10	0	10	10	20
4c.	Descending Breakout outside the Outer Marker	20	10	0	20	10	10

The number of "yes" responses does not vary for the most part, except for some differences reported regarding the consideration of altitude and air speed on climbing breakouts at decision altitude. However, the differences are small.

To elaborate on what was meant by "other" in response to Items 1c, 2c, 3c, and 4c, one crew that responded "yes" made comments indicating that a consideration was the ATC instruction to turn immediately and the sense of urgency in the voice of the controller.

As part of Item 4c one additional attribute was listed: "Obstacles/Minimum Vectoring Altitude." Two (20%) of the ten crews said "yes" that this was a consideration. A comment accompanied one of the "yes" responses:

- Questioned to ensure terrain clearance.

Item 4c also contained the following question: **Was thrust management a factor?** Six crews (60%) reported "no," while four crews (40%) reported "yes." Three of the crew reporting "yes" made the following comments:

- Decision not to use TOGA(take off/go around thrust) if not required, i.e., not low altitude.
- Cannot use TOGA, another mental step.
- No TOGA thrust.

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

Eight of the crews (80%) responded "yes," the company directs a minimum altitude for all turns. Responses were sorted by airline. The crews from Northwest Airlines reported that the company-directed minimum altitude for all turns is 500 feet, unless operationally required. One of the crews from America West responded "no" and the other responded "400 feet, unless an emergency immediate turn is needed." Of the two crews from United Airlines, one responded "no" and the other responded "400 feet."

<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 of the crews (60%) responded "yes" and four of the crews (40%) responded "no." Only one crew responding "no" commented: "no, we depend on ATC to give required vector." Comments following a "yes" response were:

- Depends on direction of turn — into or away from traffic.
- In this case, ILS (Instrument Landing System) 36L (Left), an instruction to turn right would need some thought.
- If turning into other aircraft — I'd sure ask.
- We may have clicked A/P (autopilot) off to get quicker turn.
- Especially toward parallel runway.

<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."**

Six of the crews (60%) responded "no" and four of the crews (40%) responded "yes." The crews who responded "no" did not elaborate on their responses. However, one of the pilots who responded "no" commented that even though he said "no," he thought that written procedures would be beneficial. The comments following a "yes" response were:

- Makes you more aware of the concerns of proximity to other aircraft.
- We need <u>some</u> direction and practice/training.
- Might change the priorities.

<u>Survey Item 8</u>. What, if any, A320 aircraft limitations do you think could cause an inherent unwanted delay?

Two of the crews (20%) had no comment. Eight of the crews (80%) made the following comments:

- A320 FCU (Flight Control Unit) should be modified to allow selecting a HDG (heading) without TOGA causing it to reset GA TRK (go-around track).
- TOGA thrust selects go-around NAV (navigation) track — requires pilots to select heading to comply with ATC headings — requires good auto flight management procedures.
- Too much reliance on the auto flight system. The pilot must initiate this action without depending on or waiting for autoflight response.
- When you pull HDG knob to activate HDG then go TOGA on throttles then HDG goes to RWY (runway) track — you then have to pull HDG again.
- Crews must be extremely aware of flight mode, especially "GA Track," changes. Normal law may limit roll rate.
- Autopilot is programmed for smoothness.
- When advancing thrust to GA, this wipes out all previous inputs on the FCU and may stop the turn to go to GA track.
- A320 aircraft limitation — load demand limitation of autopilot limits maneuvers. During GA tried going TOGA as well as open climb. Each way gives different initial responses which might affect the desired action of the aircraft. Might want to consider recommended action as far as using TOGA or just using FCU inputs for breakout / GA execution.

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

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

- High degree of urgency.
- Emergency turn.
- Right now, consistent with maintaining aircraft control.
- Now!
- Urgent.
- High degree.
- Very high.
- Very high degree.
- Most urgent.
- Immediate, start turn and climb for safety.

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

Eight of the crews (80%) responded "yes," while two of the crews (20%) responded "no." The crews who responded "yes" made the following comments:

- With experience you begin to see which procedures work better than others.
- TOGA thrust first, then turn.
- Decided to fly the aircraft, then turn when conditions were safe.
- When you become conditioned to the fact that you are going to do a go-around you are more mentally alert for this condition.
- Get turn going (left/right), then confirm exact clearance.
- Heading first because the autopilot is already set-up for climb.
- Responded to "immediately" – immediately.
- Start the climb or descent and direction of turn and then "fine tune" after established.

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

Nine of the crews (90%) said "yes" and one crew (10%) said "no." Comments regarding the need for training or better situational awareness were:

- Training should definitely be conducted for decreased separation and simultaneous parallel approach-type operations, should these operations become widespread and common. Without training, much more disorganization in the flight deck is likely, and safe completion is more problematic.
- Possible instruction concerning procedures for flying if directed to do a non-standard maneuver.
- This is not the typical way you are trained to do GA.
- Introduce breakouts into simulation scenarios, emphasizing aircraft configuration and mode changes, especially automated cockpits.
- Training always helps.
- If we had known impact with another aircraft was close at hand, we would have taken a/c (aircraft) off autopilot to get quicker turn.
- Knowledge of simultaneous ILS in progress, closely spaced underscores the need for immediate response.

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

Two crews commented that the simulation was a good training experience and provided the following responses:

- This was a good exercise and proved that there are limits to the immediate needs of a go-around in the autoflight system.
- Great training – got us thinking about other than training strategies.

5.2 SURVEY RESULTS FOR PHASE 2

Ten crews, each consisting of a captain and first office, participated in A320 Phase 2. The pilots of eight of the ten crews completed the Phase 2 Survey. Each participating pilot was assigned a subject-number to assure the anonymity of his or her responses. Pilots were asked to list their total flight time and the total hours in the aircraft type tested, i.e., A320. Table 5-3a and Table 5-3b, respectively, list the total, mean, and range for "total flight time" and "hours in type" for both captains and first officers. The values were calculated from the data provided by all pilots who responded to the questions. When the number of respondents (n) is less than 8, 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 sixteen survey forms for eight crews.

Table 5-3a. Flight Time (hours)

POSITION	TOTAL FLIGHT TIME	MEAN	RANGE
Captain (n=8)	107,000	13,375	11,000 to 18,000
First Officer (n=6)	57,000	9,500	6,000 to 13,000

Table 5-3b. Hour in Type (A320)

POSITION	TOTAL FLIGHT TIME	MEAN	RANGE
Captain (n=8)	11,100	1,387	150 to 2,500
First Officer (n=6)	11,680	1,946	500 to 3,000

Survey Items 1 through 4.

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, 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.

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.**

Figures 5-2 and 5-3 graphically depict the ratings of ease of executing ATC-directed breakouts when autopilot is used versus when it is not used for both climbing (Figure 5-2) and descending (Figure 5-3) breakouts. In general, the responses to each of these questions were quite similar. Whether the ATC-directed breakout (climbing or descending) was executed when using autopilot or not, the majority of pilots rated the breakout as generally easy to perform.

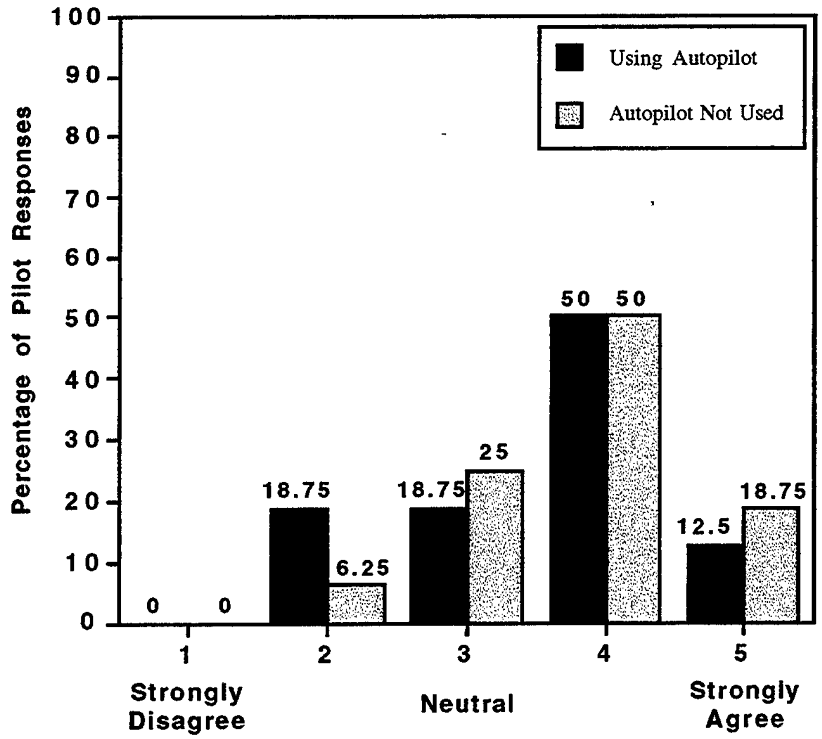


Figure 5-2. Ratings of ease of executing ATC-directed climbing breakouts.

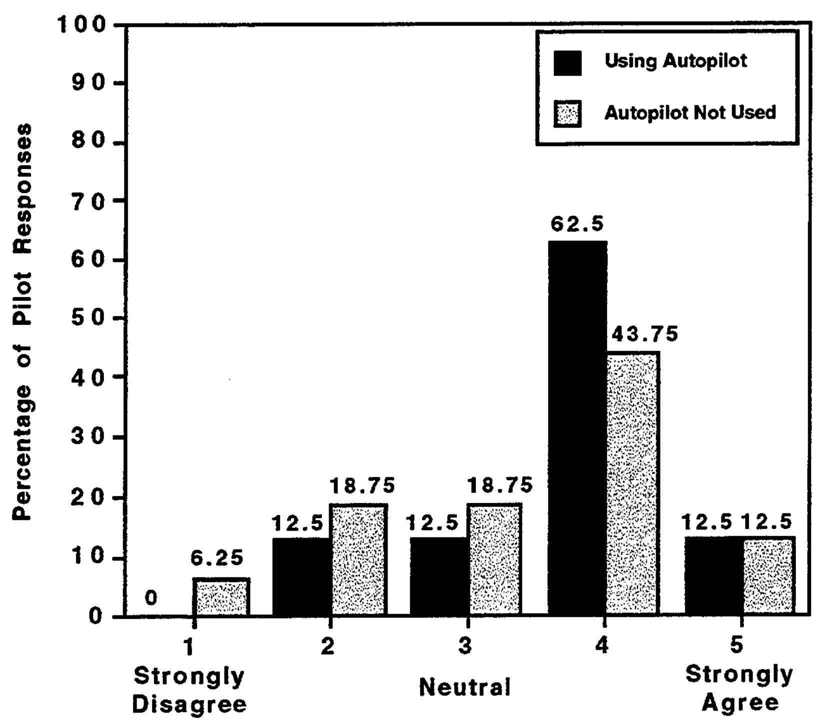


Figure 5-3. Ratings of ease of executing ATC-directed descending breakouts.

Survey Item 5. **More crew coordination is required for simultaneous close parallel approaches than for normal ILS approaches.**

Each pilot was asked to respond by using the same 5-point scale as used in the previous questions. Fourteen of the sixteen pilots (87.5%) 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 two pilots responded "2" indicating that they disagreed, i.e., more crew coordination is not required.

Following Items 1 through 5, pilots were asked to comment regarding the ATC-directed breakout procedures. Those comments were:

- Auto-throttles slow to respond to open climb / expedite mode on climbing breakout.
- Climbing breakout using autopilot is easier and quicker above 400' than below 400', but throttle response very slow when left in climb.
- I would recommend using call signs at the end of the "Alert" breakaway command due to blocked transmission. If initial call sign is blocked, either all aircraft will breakaway or none will.
- Autopilot breakouts to me were easier for the reason there is less verbal communication. PF (pilot flying) on the A320 is operating the FCU.
- New clear command for breakout may be a good idea -- ATC should inform aircraft that simultaneous close parallel approaches are in progress.
- Changing FCU requires extra vigilance especially when changing from approach to HDG/VS (heading/vertical speed). Heading selection often changes to pre-set heading and must be reset and confirmed with ATC.
- Not well suited to A320 automation.
- The descending breakout goes against normal instincts as does the "open climb." I want to go to TOGA.

Survey Items 6 through 11 concerned the use of various types of information sources and training materials. Items 6 through 9 concerned increasing situational awareness. Item 10 concerned the training bulletins and whether they aided in increasing understanding of expectations during simultaneous close parallel approaches. Item 11 concerned the training bulletins and whether they helped the pilot in executing the ATC-directed breakout. Each question is listed below. Figure 5-4 graphically illustrates the responses to each of the questions.

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

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

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

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

As shown in Figure 5-4, pilots generally reported an increase in situational awareness due to the approach plate notes, airport information page, new ATC phraseology, and video. Pilots also generally reported the positive effects of the training bulletins. Following Items 6 through 11, each pilot was asked to list comments regarding the material provided (approach plate notes, airport information page, new ATC phraseology, video, and the training bulletin). Those comments are listed below and are categorized by topic:

Approach Plate Notes

- Not powerful enough language.

Airport Information Page

- Airport Information Page is way too much "fine print" - would rather just see a clear & concise note on Approach Page.

New ATC Phraseology

- A lot easier to do the 2nd or 3rd time than the first. Good wording – Traffic Alert lets you know instantly what the breakout is for.
- Heightened need to turn quickly.
- Urgent traffic alert should be different from TCAS (Traffic Alert and Collision Avoidance System) alerts.
- It prepared me to act on the following command.

Video

- Video was informational and self explaining.
- Good video.
- Good video.

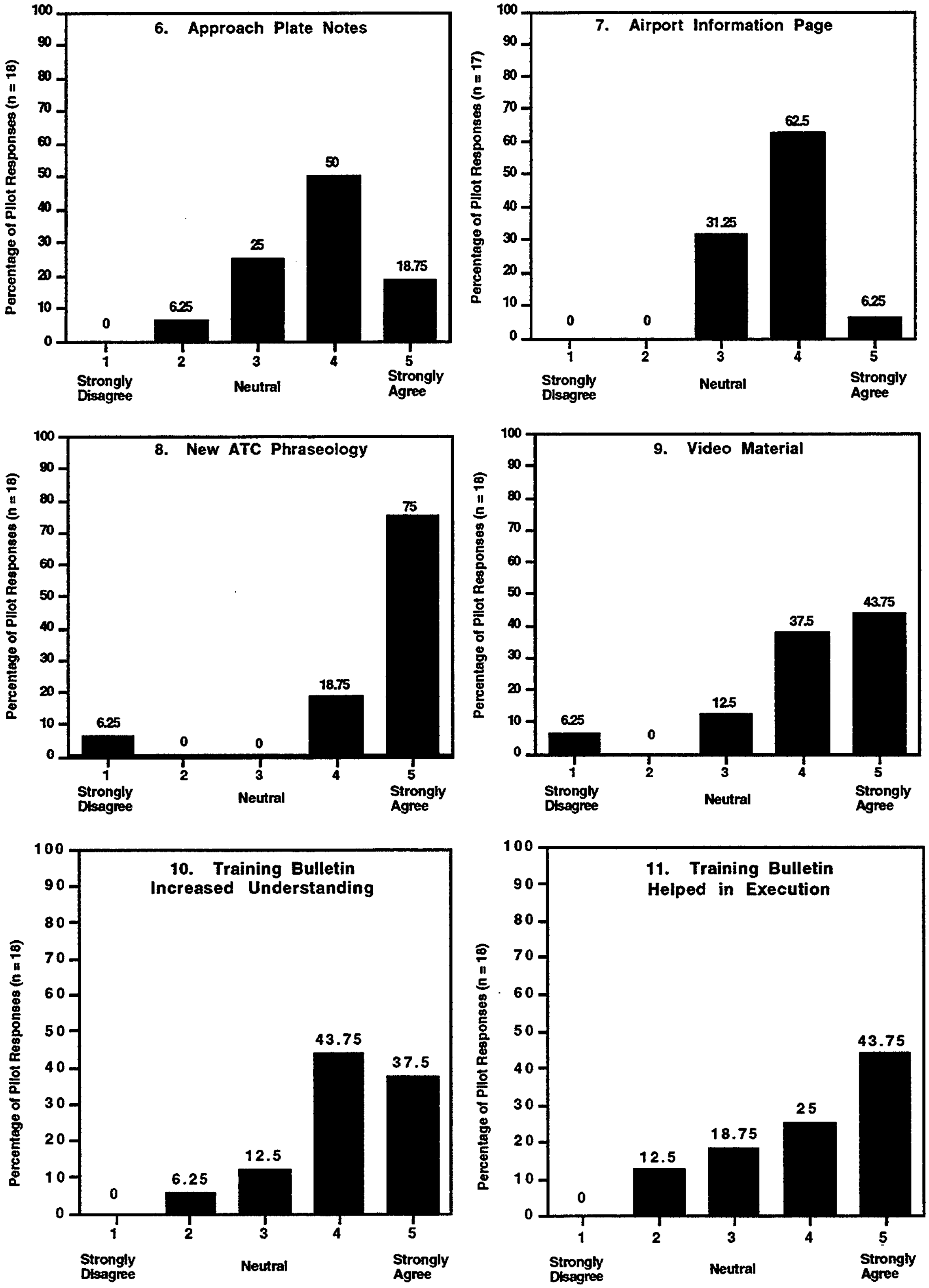


Figure 5-4. Ratings of the information sources and training materials.

Training Bulletins

- I would strongly recommend against doing this by bulletin. Hands-on is best.
- Training video was good, made me more aware of aircraft locations and distances.

Other Comments

- Good material.
- The material prepared me for the heightened awareness necessary for the breakout.
- Simulation training should be required for this procedure during normal SVT (a term for simulator six-month check).

Survey Item 12. **Based on the information presented, how would you choose to fly simultaneous close parallel approaches in IMC weather with CAT I minima?**

Pilots responded by selecting from the following choices:

1	2	3
Coupled Autopilot	Hand Flown/ Flight Director	No Preference

The distribution of responses is seen in Figure 5-5. Twelve (75%) of the sixteen pilots chose "coupled autopilot." Of the remaining four pilots, three (18.75%) chose "hand flown/flight director" and one (6.25%) indicated "no preference."

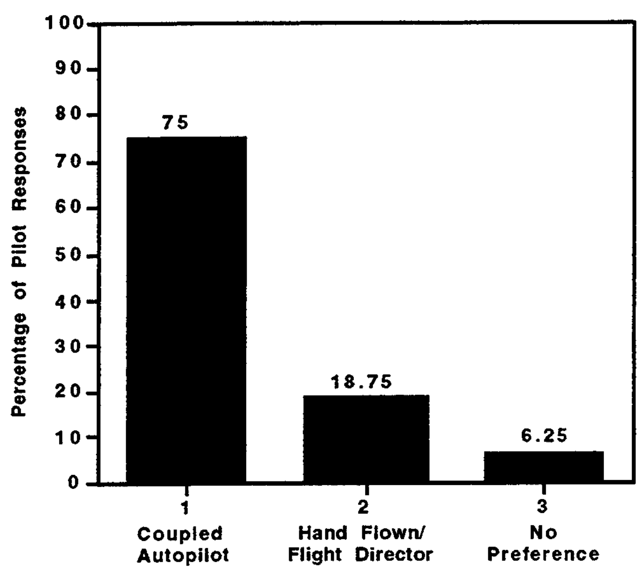


Figure 5-5. Mode preference for flying simultaneous close parallel approaches in IMC weather with CAT I minima.

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

Pilots responded by selecting from the following choices:

1	2	3
Autopilot	Hand Flown	No Preference

The distribution of responses is seen in Figure 5-6. Nine of the sixteen pilots (56.25%) chose "autopilot." Six pilots (37.5%) chose "hand flown" and one pilot (6.25%) indicated "no preference."

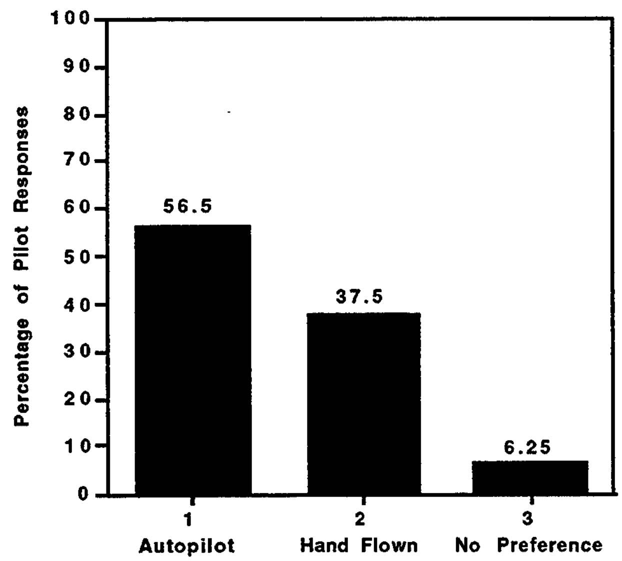


Figure 5-6. Mode preference for executing the ATC-directed breakout.

<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?

Fourteen (87.5%) of the sixteen pilots responded "yes." One pilot (6.25%) responded "no," and one pilot (6.25%) did not respond. No comments were given.

<u>Survey Item 15</u>. What additional information or training would you like to have for simultaneous close parallel approach procedures?

The following comments were made:

- Include one during SVT simulator period.
- More emphasis on who operates autopilot when given breakaway. Emphasize crew coordination and duties.

- Know in advance the likely procedure to be flown in the event of a climbing/descending breakout.
- Video and simulation training.
- Maybe one standard way of doing the approach.
- Procedures for breakoff with autopilot "on" as going to TOGA causes loss of heading select.
- A320 breakout above 400' (no TOGA) slow on climb performance.
- Procedures specific to aircraft, which should be essentially the same for all a/c at NWA (Northwest Airlines).
- Would need simulation training for approaches and missed approaches.
- During training or SVT practice a few parallel approaches.
- ATC should advise each aircraft of close approaches prior to commencement.

Survey Item 16. **Additional comments:**

- I am uncomfortable with the 400' call and additional duties associated with it. How about all breakaways be done at TOGA power?
- I am more comfortable using TOGA power on all climbing breakouts regardless of above or below 400!
- On A320 400' (part of training procedure) and 200' above minimum (decision altitude) call is simultaneous – this is a problem that would have to be worked out if this system becomes reality.
- 400' call-out is same altitude as 200' above minimum (decision altitude) for CAT I. This becomes confusing - most crews will miss one or the other.
- For A320 and other automated a/c need to specify which pilot will operate "panel" during autopilot approach.
- Good period, thanks!
- The A320 should go to TOGA power. The aircraft was designed that way.

5.3 SUMMARY OF PHASE 1 AND PHASE 2 SURVEY RESULTS

In Phase 1, pilots received no special training or materials to make them aware that closely spaced simultaneous approaches were in operation. They were told to fly the approach in the simulation as they normally would fly during actual conditions. In Phase 2 pilots were given specific training and informational materials regarding simultaneous approaches to closely spaced parallel runways.

Results of Phase 1 indicated the need for specific training and materials to heighten the awareness of pilots regarding the conduct of simultaneous approaches to closely spaced parallel runways. In Phase 1 Survey Item 10, responses indicated that most crews reported developing a strategy for making a decision to turn and then to execute the turn. This indicates the potential for training on the procedure to affect future performance. Phase 1 Survey Item 11 responses indicated that 90% of the crews thought that training or better situational awareness would have enhanced performance during the ATC-directed breakout. Comments to many of the questions indicated that training involving awareness of the situation and practice through the use of simulation would be desirable. These findings confirmed the need for A320 Phase 2, in which specific training and materials were provided to heighten situational awareness and to potentially affect pilot performance.

Responses to study Phase 2 Survey Item 5 indicated that the majority of pilots felt that more crew coordination is required for simultaneous close parallel approaches than for normal ILS approaches. In the Phase 2 Survey, Items 6 through 11 concerned the use of various types of information sources and training materials and their ability to help in increasing situational awareness. Figures 5-2 and 5-3 show that the majority of responses indicated that pilots "agree" or "strongly agree" that awareness is increased by use of informational materials, including: approach plate notes, airport information page, video material, and training bulletins. Pilot responses also indicated that the new ATC phraseology used, i.e., "Traffic Alert" coupled with the word "immediately," helped to foster a quick response.

Phase 2 Survey responses indicated that 75% of pilots would choose to fly simultaneous close parallel approaches in IMC weather CAT I minima using coupled autopilot rather than hand flown/flight director. Based on their experience in Phase II, the majority of pilots chose autopilot versus hand flown in executing the ATC-directed breakout.

6. DISCUSSION

6.1 RESEARCH QUESTIONS

The testable questions posed in Section 1.2 asked about the A320 breakout performance in each phase and how the turn performance compared to that observed in the DC10 and B727 studies. These questions were further refined into the nine research questions listed in Section 2.3.

Research questions 1 and 5 asked if either the Phase 1 or Phase 2 turn performance met the test criteria for mean and maximum time from start of ATC breakout instruction to start of turn. Except for two combinations of approach mode and breakout group, Phase 1 mean values were greater than the 8-second criterion. In addition, twelve percent of the times to start of turn were greater than the 17-second criterion. The data in Table 4-11 indicate that the long response times were not limited to one approach mode or to one breakout group. In Phase 2, mean time to start of turn was less than 8 seconds for all combinations of approach mode and breakout group. A comparison between the Phase 1 distributions in Figure 4-4 and the Phase 2 distributions in Figure 4-5 indicated that the smaller mean values in Phase 2 were mainly due to the reduction in the frequency of long response times rather than a general decrease in response times. Although the number of long response times decreased in Phase 2, there were three trials with times to start of turn of greater than 17 seconds. Two factors were associated with these three trials: breakouts at decision altitude and individual pilot performance. The pilot associated with two of the long response times was also associated with seven of the long response times in Phase 1.

Statistical comparisons between the Phase 1 and Phase 2 turn data confirmed that the smaller mean time-to-turn values in Phase 2 were not due to a shift in the response distributions. The analysis of variance results indicated that the mean values were not significantly different between the two phases.

Research questions 2 and 3 asked about pilot comfort executing climbing breakouts below 400 feet AGL and descending breakouts outside the outer marker in Phase 1. The pilots rated these breakouts as being "not at all" to "moderately" difficult. The distributions of responses were similar to those for climbing breakouts inside and outside the outer marker. The ratings were also similar for hand-flown and autopilot-coupled approach modes.

Research question 6 asked which situational awareness aids were helpful to the pilots in Phase 2. At least 88 percent of the responses were "neutral" to "strongly agree" for each of the four aids: approach plate modifications; airport information page; video material; and, breakout training bulletin. Ninety-two percent agreed that the new ATC phraseology was helpful. Of these, seventy-five percent strongly agreed that the new ATC phraseology encouraged them to respond more quickly than the current phraseology.

Research questions 4, 7, 8, and 9 asked if any of the test conditions (independent variables) affected breakout performance. Similar results were observed in both phases of the study. First, altitude affected both climb and turn performance, although the trends were opposite. Mean times from start of ATC instruction to start of engine, pitch, and vertical speed responses were smallest at decision altitude and increased with increasing altitude. Similarly, mean altitude loss was smallest at decision altitude, and increased with increasing altitude. In contrast, mean time from start of ATC instruction to start of turn was largest at decision altitude but similar for the 500', 1000', and 1800' scenarios. Second, approach mode affected both turn and climb performance. In general, the measured dependent variables were smaller for hand-flown scenarios than for autopilot-coupled scenarios. Based on the data in Figures 4-4 and 4-5, median time to start of turn was 1 to 3 seconds less for hand-flown scenarios at altitudes above 400 feet AGL and 6 seconds less for hand-flown scenarios at decision altitude. Third, direction of the turn did not affect turn performance in either phase. Mean times to start of turn were similar for climbing and descending breakouts at 1800 feet AGL.

The engine-out scenarios were intended to measure the effect of cockpit distractions on A320 breakout performance. Instead, they tested breakout performance during an aircraft emergency. During six engine out trials (30 percent), the pilot flying elected to continue straight ahead rather than turn. This result indicates that these scenarios were not appropriate as distractors and that a more-common distraction scenario should be developed for future studies.

When only these trials in which the crew complied with the ATC instruction were considered, the engine-out event in Phase 1 had little or no effect on breakout performance at decision altitude. Mean times to start of turn and to TOGA were statistically similar for the two levels of distraction. However, mean times to engine rpm increase and to start of climb were significantly smaller for the engine-out scenarios. These shorter response times may have been a result of the pilots responding to the engine failure, which occurred before the breakout instruction, rather than a response to the breakout instruction.

6.2 ANCILLARY ISSUES

Survey questions elicited pilot opinion regarding other aspects of ATC-directed breakouts. Based on their experience in Phase 1, the subjects pilots felt there was a need for training and heightened situational awareness. Six crews felt their response would have been different at low altitude if they had received the additional training. Eight crews replied that they developed a strategy for executing the breakout. These responses suggest that practicing a specific breakout procedure would increase pilot comfort with the maneuver. Phase 2 subjects pilots also commented on the need for simulator training.

When asked what, if any, aircraft limitations they thought caused an inherent unwanted delay, the most frequent response was the problem with TOGA thrust reverting to the go-around track. These pilot observations agreed with the observed rollbacks in the aircraft data. In fourteen autopilot-coupled trials, the rollback lasted long enough to add 4 to 18 seconds to the turn response.

In Phase 2, some subject pilots commented on the tested breakout procedure. Several did not like the altitude callout at 400 feet AGL because it interfered with the callout procedure at 200 feet above minimums. There were also comments about using open climb instead of TOGA thrust. One concern was that leaving the thrust levers at the Climb detent is counter-intuitive because the pilots are trained to use TOGA thrust. The other concern was the sluggish autothrottle response during open climb. The latter concern agreed with the observed climb performance. Mean time difference between pitch increase and vertical speed increase was longer in Phase 2 than in Phase 1. In addition, the mean time to transition from a negative to a positive climb rate was longer in Phase 2. In Phase 1, TOGA thrust was used in 88 percent of the climbing breakouts above 400 feet AGL, whereas TOGA thrust was used in only 24 percent of the climbing breakouts above 400 feet AGL in Phase 2. Open climb mode was used in the remainder of the trials.

It is not known if a delay in climb response would affect the safety of close parallel approach operations. The emphasis to-date has been on turn performance, and little is known about the effect of climb performance on blunder safety analyses. We recommend further research on the role of climb response in breakout performance.

6.3 CONCLUSIONS

Three conclusions were made concerning A320 breakout performance in this study. First, turn performance in Phase 1 did not meet the best criteria for either manual or autopilot-coupled approach modes. This suggests that the existing combination of pilot training and ATC phraseology is not sufficient to guarantee a satisfactory distribution of A320 breakout responses.

Second, turn performance in Phase 2 did meet the test criteria for most combinations of breakout group and approach mode. This suggests that the proposal ATC breakout phraseology combined with pilot situational awareness training and a breakout procedure is sufficient to achieve a satisfactory distribution of A320 breakout responses. Mean time to start of turn was less than 8 seconds for all breakout groups and approach modes. There were 3 times to start of turn greater than 17 seconds. However, the effect of this small percentage could be mitigated if breakouts were limited below 400 feet AGL. The results also illustrated that some pilots will respond more slowly than expected even with increased situational awareness.

Third, the tested breakout procedure should be refined because it conflicted with other cockpit procedure and increased the average time to transition from a negative to a positive climb rate. The pilots were trained to use TOGA thrust, and were not comfortable with leaving the thrust levers at the climb detent. They also were not comfortable with the altitude callout at 400 feet AGL. In addition, open-climb performance was sluggish at higher altitudes.

Based on the above conclusions, it is recommended that a combination of pilot awareness training, A320 breakout procedure, and ATC breakout phraseology equivalent to that used in Phase 2 be employed for simultaneous parallel approach operations in instrument meteorological conditions. The implemented A320 breakout procedure should account for the effects of thrust management (TOGA or open climb) on turn and climb performance during autopilot-coupled breakouts.

GLOSSARY

A320	Airbus 320
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
ARTS	Automated Radar Terminal System
ATC	Air Traffic Control
ATIS	Automatic Terminal Information System
B727	Boeing 727
B747-400	Boeing 747-400
CAT	category
CL	climb
DA	decision altitude
DC10	McDonnell Douglas 10
DH	decision height
DME	Distance Measuring Equipment
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FCU	flight control unit
FD or F/D	flight director
FMS	flight management system
GA or G/A	go around
GS	glide slope
GA TRK	go around track
HDG	heading
HDG SEL	heading select
HF	hand-flown
HF/HF	hand-flown approach / hand-flown breakout
ILS	instrument landing system

IMC	instrument meteorological conditions
LNAV	localizer navigation mode
LOC	localizer
MA	missed approach
MCDU	multipurpose cockpit display unit
MD80	McDonnell Douglas 80
MEM	Memphis International Airport
MPAP	Multiple Parallel Approach Procedure
MVA	minimum vectoring altitude
NATCO	Northwest Aerospace Training Corporation
NAV	navigation
ND	navigational display
NOS	National Ocean Service
NTZ	no transgression zone
NWA	Northwest Airlines
PF	pilot flying
PFD	primary flight display
PNF	pilot not flying
PRM	Precision Runway Monitor
SVT	Simulator training
TCAS	Traffic Alert and Collision Avoidance System
TOGA or 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
VS	vertical speed

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APPENDIX A. SCENARIO SEQUENCES

The following sub-sections list the information for each test scenario in Phases 1 and 2 in the order in which they were conducted. Breakout DME was the range (nautical miles) from the runway threshold at which the air traffic controller started the breakout instruction. Breakout heading, direction, and altitude were the values used in the Air Traffic Control 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). Whether or not the breakout was conducted using the autopilot was at the discretion of the pilot flying. All approaches were Category I except for an autopilot breakout at decision altitude and an autopilot missed approach (MA). Pilot flying was assigned to either the captain (C) or first officer (F). Scenario order and pilot assignments were rotated among the four sequence sheets listed in Section A.2.

Table A-1. Weather Conditions

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

Table A-2. A320 Phase 1 Run Sequence

Scenario Number	Approach Mode	Simulator Scenario	Weather Card	Breakout DME	Breakout Heading	Breakout Direction	Breakout Altitude
100	HF	001	1	lands	---	---	---
111	HF	002	1	1.7	300	Climb	3500
116	HF	003	3	5.6	285	Descend	1800
105	AP	001	1	lands	---	---	---
103	AP	002	2	0.5	290	Climb	3000
108	HF	005	1	0.8	290	Climb	3000
109	HF	003	3	5.6	280	Climb	4000
100	HF	001	1	lands	---	---	---
115	HF	003	3	5.6	285	Climb	4200
113	HF	003	3	0.8	285	Climb	3000
112	HF	002	1	MA	---	---	---
110	AP	002	2	MA	---	---	---
106	AP	002	2	1.8	300	Climb	3000
107	AP	004	2	0.5	270	Climb	4000
117	AP	002	2	5.6	300	Descend	1800
104	AP	002	2	5.6	290	Climb	5000
100	HF	001	1	lands	---	---	---
114	AP	002	2	1.7	280	Climb	4000
103	AP	002	2	0.5	290	Climb	3000
113	HF	003	3	0.8	285	Climb	3000
101	AP	002	2	5.6	280	Climb	4000
102	HF	003	3	1.8	290	Climb	3700

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

A.2 PHASE 2

Table A-3. A320 Phase 2 Sequence 1 (Crews 1, 5, 9)

Scenario Number	Approach Mode	Pilot Flying	Simulator Scenario	Weather Card	Breakout DME	Breakout Heading	Breakout Direction	Breakout Altitude
201	AP	C	002	1	6.0	280	Climb	4000
211	HF	F	002	1	2.0	300	Climb	3500
200	HF	C	001	1	lands	---	---	---
220	AP	F	002	1	6.0	300	Climb	4000
218	AP	C	002	1	3.3	285	Climb	3500
206	AP	C	002	1	1.9	300	Climb	3000
216	HF	F	003	3	6.3	285	Descend	1400
209	HF	F	003	3	6.1	280	Climb	3500
213	HF	C	003	3	0.9	285	Climb	3000
221	AP	F	003	3	1.9	270	Climb	3000
212	HF	C	002	1	MA	---	---	---
217	AP	C	002	1	6.2	300	Descend	1500
222	AP	F	003	3	1.9	290	Climb	4000
203	AP	F	002	2	0.6	290	Climb	3000
215	HF	C	003	3	5.8	285	Climb	4200
210	AP	F	002	2	MA	---	---	---
214	AP	C	002	1	1.9	280	Climb	4000
219	HF	F	003	3	3.5	285	Climb	3000
223	AP	F	002	1	5.9	280	Climb	4000
205	AP	F	001	1	lands	---	---	---
202	HF	C	003	3	1.8	290	Climb	3700
204	AP	C	002	1	5.9	290	Climb	5000

Table A-4. A320 Phase 2 Sequence 2 (Crews 2, 6)

Scenario Number	Approach Mode	Pilot Flying	Simulator Scenario	Weather Card	Breakout DME	Breakout Heading	Breakout Direction	Breakout Altitude
201	AP	F	002	1	6.0	280	Climb	4000
211	HF	C	002	1	2.0	300	Climb	3500
200	HF	F	001	1	lands	---	---	---
220	AP	C	002	1	6.0	300	Climb	4000
218	AP	F	002	1	3.3	285	Climb	3500
206	AP	F	002	1	1.9	300	Climb	3000
216	HF	C	003	3	6.3	285	Descend	1400
209	HF	C	003	3	6.1	280	Climb	3500
213	HF	F	003	3	0.9	285	Climb	3000
221	AP	C	003	3	1.9	270	Climb	3000
212	HF	F	002	1	MA	---	---	---
217	AP	F	002	1	6.2	300	Descend	1500
222	AP	C	003	3	1.9	290	Climb	4000
203	AP	C	002	2	0.6	290	Climb	3000
215	HF	F	003	3	5.8	285	Climb	4200
210	AP	C	002	2	MA	---	---	---
214	AP	F	002	1	1.9	280	Climb	4000
219	HF	C	003	3	3.5	285	Climb	3000
223	AP	C	002	1	5.9	280	Climb	4000
205	AP	C	001	1	lands	---	---	---
202	HF	F	003	3	1.8	290	Climb	3700
204	AP	F	002	1	5.9	290	Climb	5000

Table A-5. A320 Phase 2 Sequence 3 (Crews 3, 7, 10)

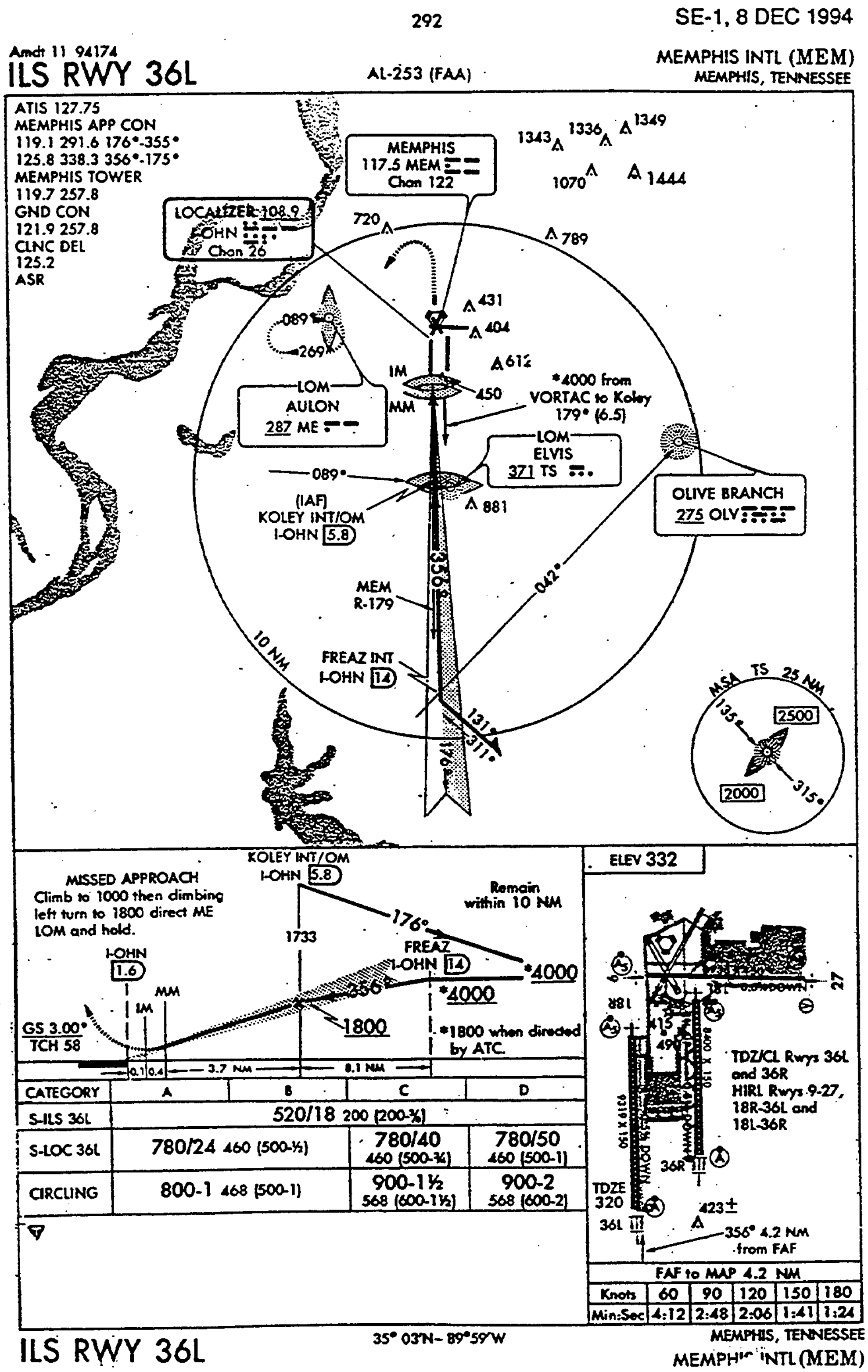
Scenario Number	Approach Mode	Pilot Flying	Simulator Scenario	Weather Card	Breakout DME	Breakout Heading	Breakout Direction	Breakout Altitude
204	AP	C	002	1	5.9	290	Climb	5000
202	HF	C	003	3	1.8	290	Climb	3700
205	AP	F	001	1	lands	---	---	---
223	AP	F	002	1	5.9	280	Climb	4000
219	HF	F	003	3	3.5	285	Climb	3000
214	AP	C	002	1	1.9	280	Climb	4000
210	AP	F	002	2	MA	---	---	---
215	HF	C	003	3	5.8	285	Climb	4200
203	AP	F	002	2	0.6	290	Climb	3000
222	AP	F	003	3	1.9	290	Climb	4000
217	AP	C	002	1	6.2	300	Descend	1500
212	HF	C	002	1	MA	---	---	---
221	AP	F	003	3	1.9	270	Climb	3000
213	HF	C	003	3	0.9	285	Climb	3000
209	HF	F	003	3	6.1	280	Climb	3500
216	HF	F	003	3	6.3	285	Descend	1400
206	AP	C	002	1	1.9	300	Climb	3000
218	AP	C	002	1	3.3	285	Climb	3500
220	AP	F	002	1	6.0	300	Climb	4000
200	HF	C	001	1	lands	---	---	---
211	HF	F	002	1	2.0	300	Climb	3500
201	AP	C	002	1	6.0	280	Climb	4000

Table A-6. A320 Phase 2 Sequence 4 (Crews 4, 8)

Scenario Number	Approach Mode	Pilot Flying	Simulator Scenario	Weather Card	Breakout DME	Breakout Heading	Breakout Direction	Breakout Altitude
204	AP	F	002	1	5.9	290	Climb	5000
202	HF	F	003	3	1.8	290	Climb	3700
205	AP	C	001	1	lands	---	---	---
223	AP	C	002	1	5.9	280	Climb	4000
219	HF	C	003	3	3.5	285	Climb	3000
214	AP	F	002	1	1.9	280	Climb	4000
210	AP	C	002	2	MA	---	---	---
215	HF	F	003	3	5.8	285	Climb	4200
203	AP	C	002	2	0.6	290	Climb	3000
222	AP	C	003	3	1.9	290	Climb	4000
217	AP	F	002	1	6.2	300	Descend	1500
212	HF	F	002	1	MA	---	---	---
221	AP	C	003	3	1.9	270	Climb	3000
213	HF	F	003	3	0.9	285	Climb	3000
209	HF	C	003	3	6.1	280	Climb	3500
216	HF	C	003	3	6.3	285	Descend	1400
206	AP	F	002	1	1.9	300	Climb	3000
218	AP	F	002	1	3.3	285	Climb	3500
220	AP	C	002	1	6.0	300	Climb	4000
200	HF	F	001	1	lands	---	---	---
211	HF	C	002	1	2.0	300	Climb	3500
201	AP	F	002	1	6.0	280	Climb	4000

* Scenarios 203 and 210 were Category II approaches.

APPENDIX B. PHASE 1 APPROACH PLATES

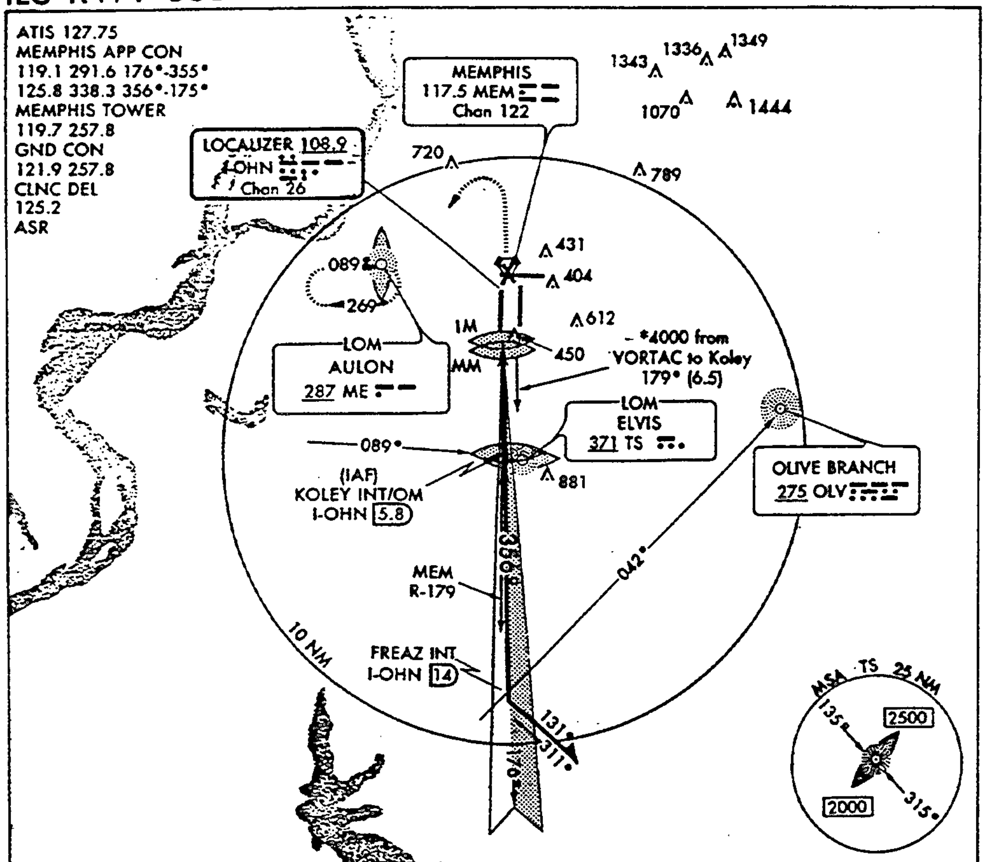


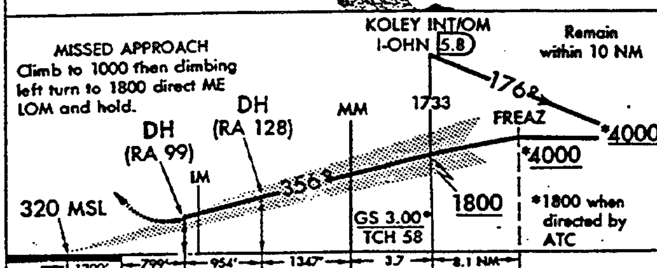
Amdt 11 94174 (CAT II) SE-1, 13 OCT 1994

ILS RWY 36L

AL-253 (FAA)

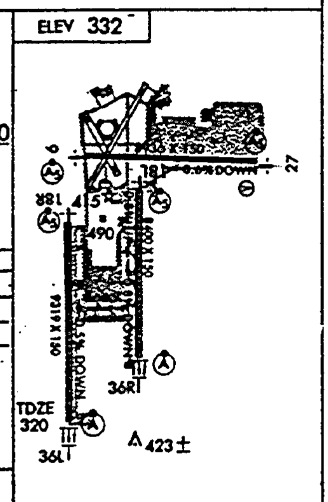
MEMPHIS INTL (MEM)
MEMPHIS, TENNESSEE





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.

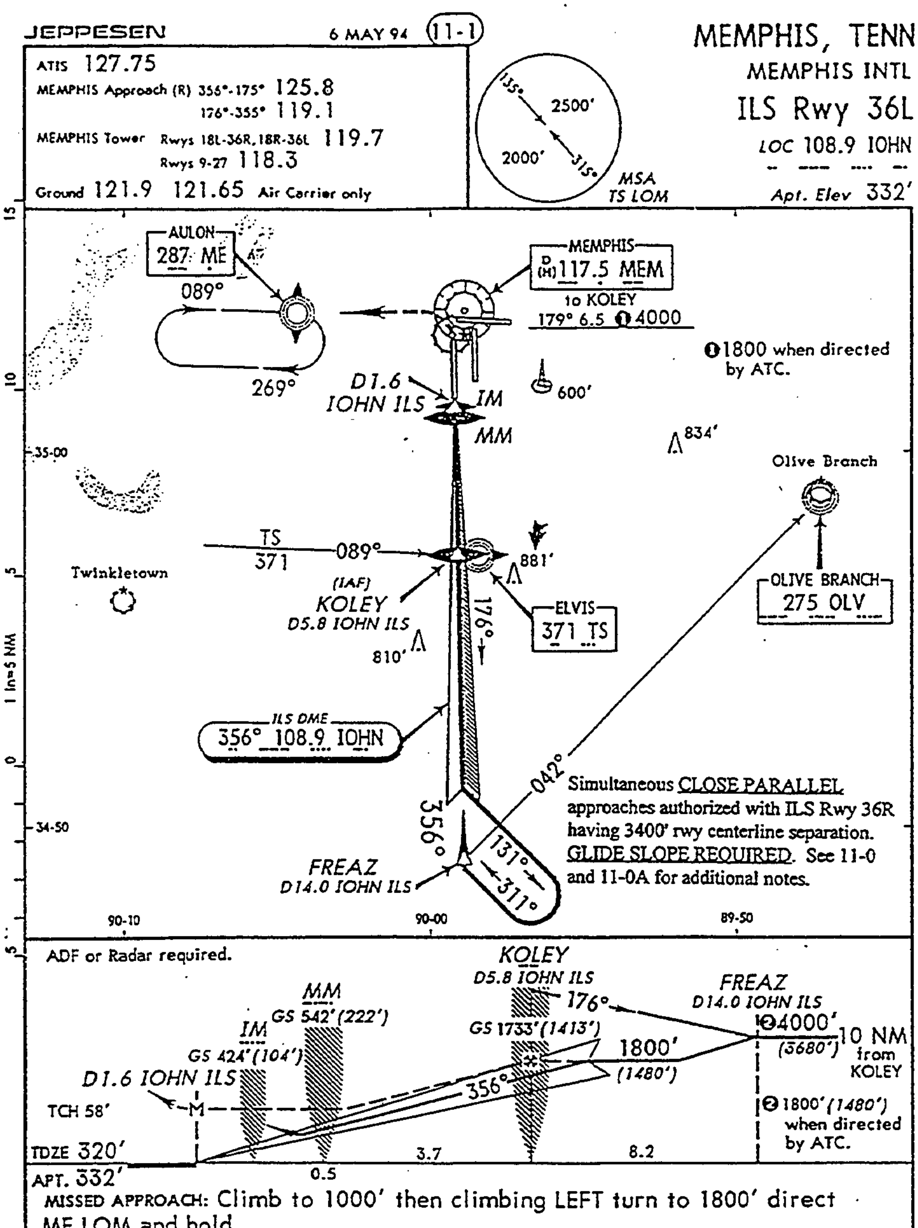


CATEGORY II ILS–SPECIAL AIRCREW & AIRCRAFT CERTIFICATION REQUIRED

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. PHASE 2 APPROACH PLATES



	STRAIGHT-IN LANDING RWY 36L ILS DA(H) 520'(200') FULL	TDZ or CL out	ALS out	LOC (GS out) MDA(H) 780'(460')	ALS out	CIRCLE-TO-LAND Max Kts	MDA(H)
A	RVR 18 or 1/2	RVR 24 or 1/2	RVR 40 or 3/4	RVR 24 or 1/2	RVR 50 or 1	90	800'(468')-1
B						120	
C				RVR 40 or 3/4	RVR 60 or 1 1/4	140	900'(568')-1 1/2
D				RVR 50 or 1	1 1/2	165	900'(568')-2

Gnd speed-Kts		70	90	100	120	140	160
GS	3.00°	377	485	539	647	755	862
MAP at D1.6 IOHN ILS or KOLEY to MAP	4.2	3:36	2:48	2:31	2:06	1:48	1:34

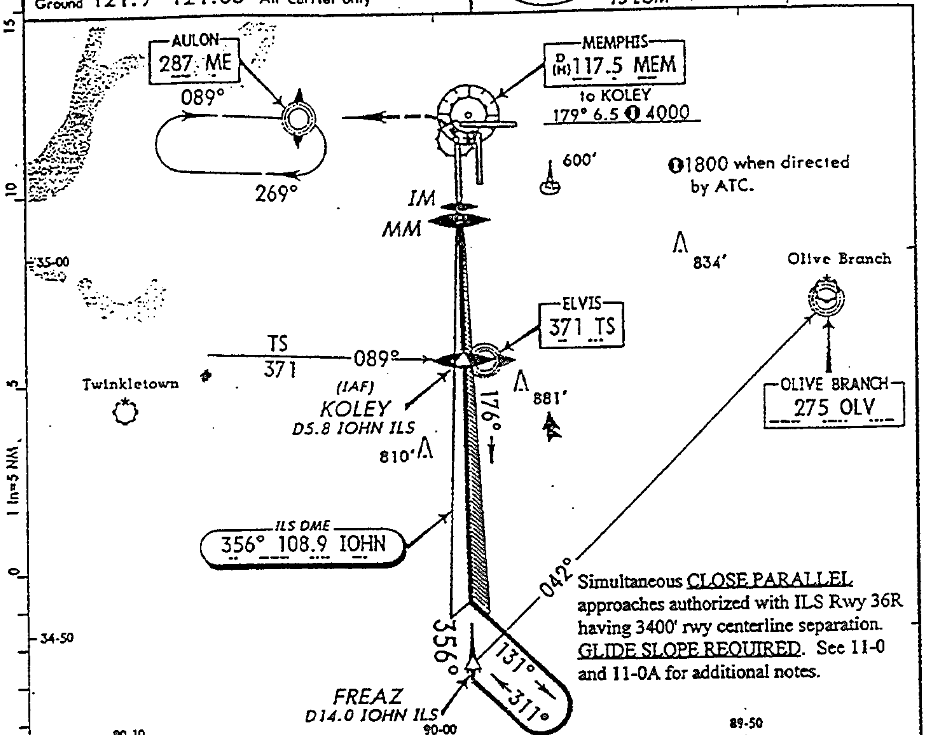
CHANGES: ATIS frequency.

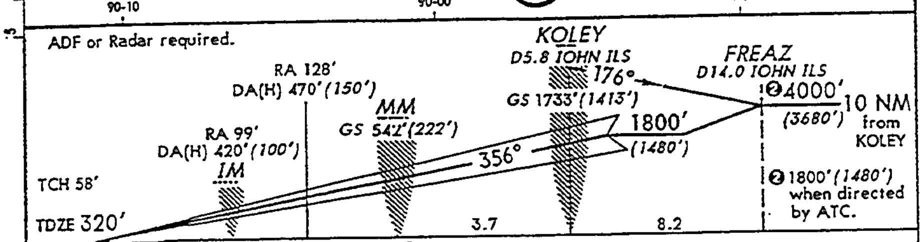
JEPPESEN 6 MAY 94 (11-1A)

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

MSA TS LOM: 2500' / 2000'





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')	CAT II ILS RA 128' DA(H) 470' (150')
RVR 6	RVR 7	RVR 12	RVR 16

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 WRITTEN TRAINING MATERIALS

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 [11] 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 subject 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 crews also received a written breakout procedure designed specifically for the A320. The crews read the procedure, then took a second self-administered test which was designed to reinforce the concepts presented in the written procedure bulletin. The crews were required to follow the breakout procedure during the test session. There was no other procedure training, and the pilots did not practice the breakout procedure before the test session. The test personnel were directed to not provide any information about how to execute the procedure.

The following pages present the written training package in the following order: the 11-0 Information Page; the Pilot Awareness Training Bulletin; the Pilot Awareness Open Book Test; the A320 Breakout Procedure Training Bulletin; and, the A320 Breakout Procedure Open Book Test.

D.1 11-0 INFORMATION PAGE

(INFORMATION PAGE)

11-0

MEMPHIS,TENN

MEMPHIS INTL

*********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:

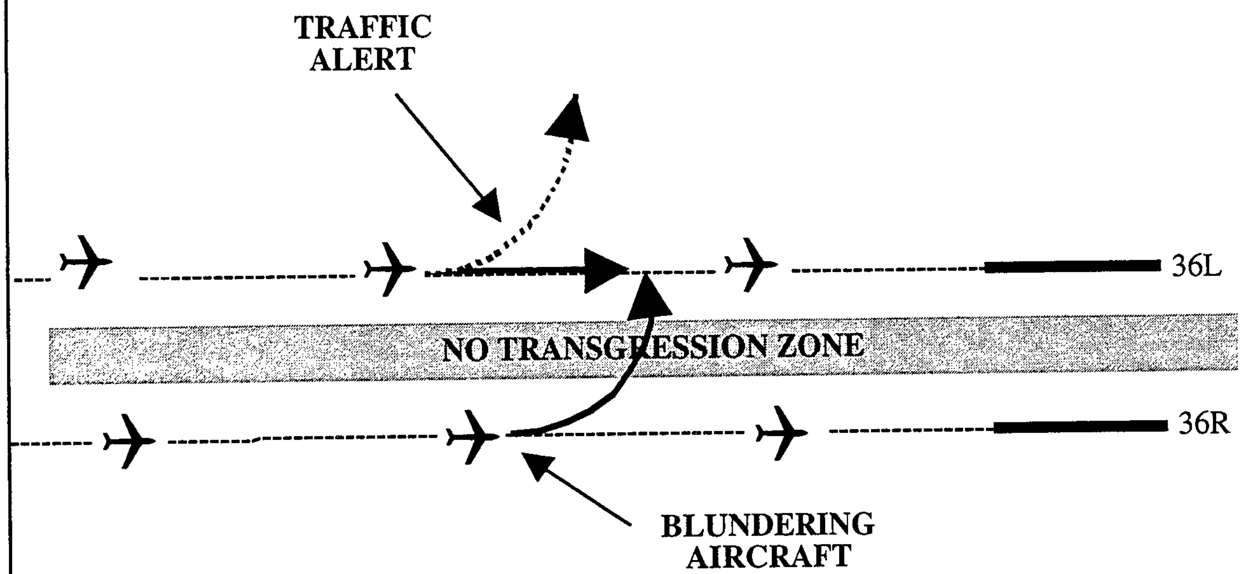
"(Aircraft callsign) TRAFFIC ALERT (aircraft callsign) turn (left/right) IMMEDIATELY heading (degrees). (Climb/desc)end and maintain (altitude)".

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

D.2 PILOT AWARENESS TRAINING BULLETIN

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)L/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.

D.3 PILOT AWARENESS OPEN BOOK TEST

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.

PAGE 2
OPEN BOOK TEST

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.

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]

D.4 A320 BREAKOUT PROCEDURE

A320 BREAKOUT PROCEDURE
TRAINING BULLETIN

With the advent of closely spaced simultaneous approaches, it has become apparent that there needs to be a procedure established for breaking off from an ILS before reaching the D/H. The present procedures for "going around" or "conducting a miss" prior to the D/H require the pilot to continue to the missed approach point before starting the missed approach procedure unless ATC directs otherwise. An ATC directed breakout from a simultaneous ILS usually is the result of an aircraft from the adjoining approach course blundering into the breakout aircraft's path. The breakout instructions from ATC can include a climbing turn, a level turn, a descending turn or a climb out straight ahead. Any "breakout" procedure must allow for these eventualities. For example, engaging TOGA results in a climbout straight ahead, something a pilot would not want to do if ATC wanted him to descend in order to avoid the blundering aircraft. The following procedure was designed by taking into consideration all the breakout possibilities.

1. Modify existing approach callouts to include **PNF** calling "400 feet" as a crew awareness advisory when **FMA** annunciates "LAND".

2. Use the following procedure in the event of an ATC breakout:

A. Above 400 feet AGL:

- Pull heading select knob, confirm "HDG" and "V/S" annunciations on FMA. Set new ATC assigned heading.

- Set new ATC assigned altitude in FCU.

- If new assigned altitude is above current altitude, pull FCU Altitude knob and confirm "OPEN CLIMB" annunciation on FMA.

- If new assigned altitude is below current altitude, continue descent in "V/S" and confirm "ALT *" and "ALT" annunciate on FMA as aircraft levels off at assigned altitude.

- Configure the aircraft appropriately.

B. Below 400 feet AGL:

- Fly normal missed approach procedure.

NOTE: When the aircraft is established on the ILS and the LOC and G/S are annunciated, pulling either the HEADING or VERTICAL SPEED knob above 400 feet radio altimeter causes the FMA to annunciate "HDG" and "V/S." The vertical speed commanded will be the existing rate at the time either knob is pulled. *Once the FMA annunciates "LAND"*, no change can be effected with the autopilot engaged except "GO AROUND."

D.5 A320 BREAKOUT PROCEDURE OPEN BOOK TEST

A320 BREAKOUT PROCEDURE
OPEN BOOK TEST

1. When the aircraft is established on the ILS and LOC and G/S are annunciated, the pilot not flying should call "400 feet" because

    a) It is a good call before reaching decision height.

    b) It will alert the pilot flying that the aircraft is the "LAND" mode.

    c) This is the time to go "heads up".

2. When the aircraft is above 400 feet, pulling the heading select knob will cause the FMA to annunciate which of the following?

    a) "LOC" and "G/S".

    b) Climb.

    c) "HDG" and "V/S".

3. The pilot should use TOGA for all descending breakouts.

    a) False

    b) True

4. When the aircraft is below 400 feet radio altimeter, and on the autopilot

    a) The heading knob can be used to change heading at any time.

    b) Any mode can be changed.

    c) Only after "TOGA" is selected, can the heading knob be pulled and a new heading set.

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

APPENDIX E. 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 to locate the marker record, which was the first record with an event marker status flag of "on" and which signified 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 track file was not used in the analysis.

The algorithms to measure time-to-event values then operated on the 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 the tracks were processed, analysts reviewed 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.

E.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 E-1.

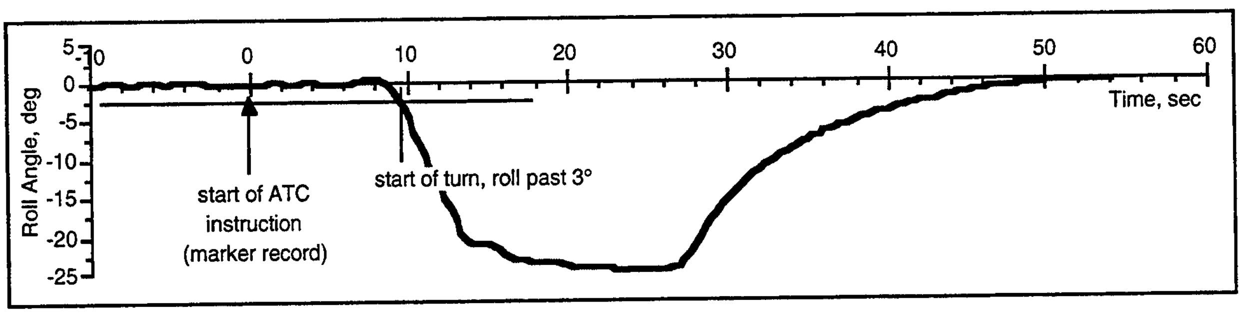


Figure E-1. Roll angle data for a breakout with nominal roll characteristic.

However, some tracks were not nominal and showed a "double roll" as illustrated in Figure E-2. This sometimes occurred when the pilots started the roll maneuver before engaging TOGA thrust during autopilot-coupled scenarios. In this case, the flight director returned the aircraft to the stored missed-approach course. The pilot then had to override the flight director and reinitiate the roll for the breakout maneuver.

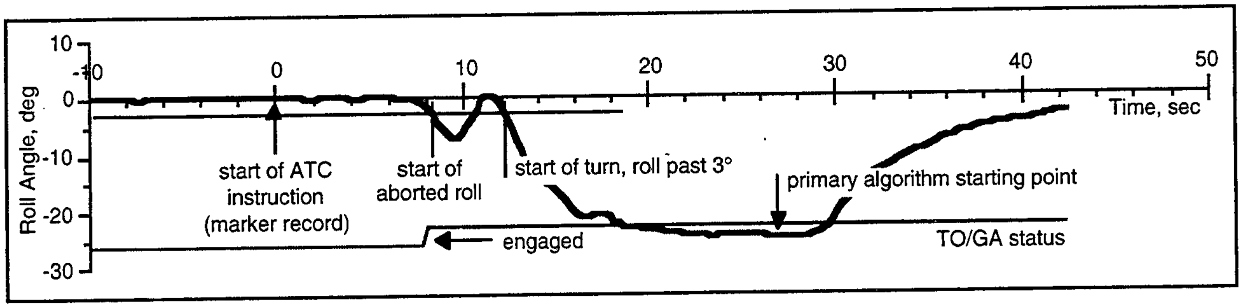


Figure E-2. Roll angle data for a breakout with a double roll. Note return to center after TOGA thrust was engaged.

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 8.3 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 E-2, the algorithm started working backwards from the primary starting point near 27 seconds and returned a time to start of roll of 12.3 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.

E.2 TIMES TO OTHER EVENTS

E.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 TOGA status. The events of interest were the disengagement of the autopilot and the engagement of TOGA thrust. There is an example of the TO/GA status values at the bottom of the plot in Figure E-2.

E.2.2 Pitch, Vertical Speed, and Engine Speed

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 E-1 lists the parameters. Although delta-value parameters were assigned for descending breakouts, most pilots did not change the vertical speed or air speed values in the flight director. As a result, there were no pitch, vertical speed, or engine speed events for the majority of descending breakouts.

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

Metric	Climbing Breakout	Descending Breakout
pitch	+1.2 degrees	-1.2 degrees
vertical speed	+150 feet/minute	-100 feet/minute
engine speed	+300 rpm	N/A

Examples of pitch and vertical speed event determinations are depicted in Figure E-3. The data were from the same track illustrated in Figure E-1. Figure E-4 illustrates engine speed from a scenario (108) with a simulated engine failure. Note that the right engine speed started decreasing shortly before the breakout instruction. This phenomenon was used to verify that there was a simulated right engine failure.

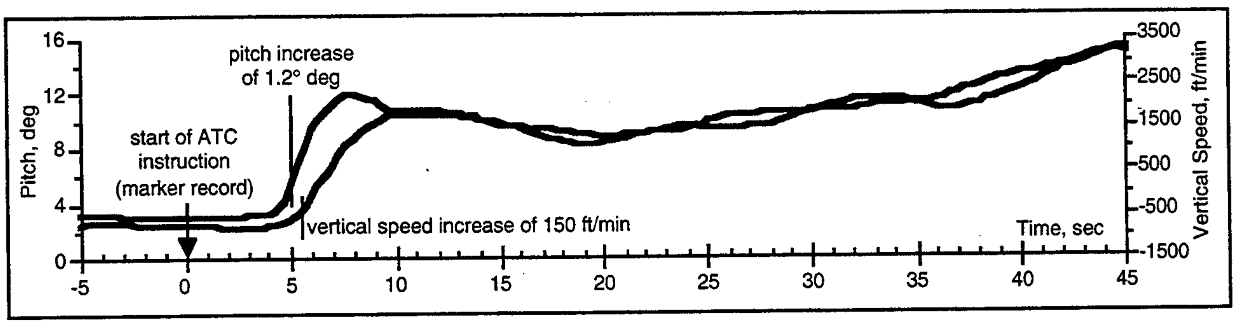


Figure E-3. Pitch and vertical speed data during a breakout.

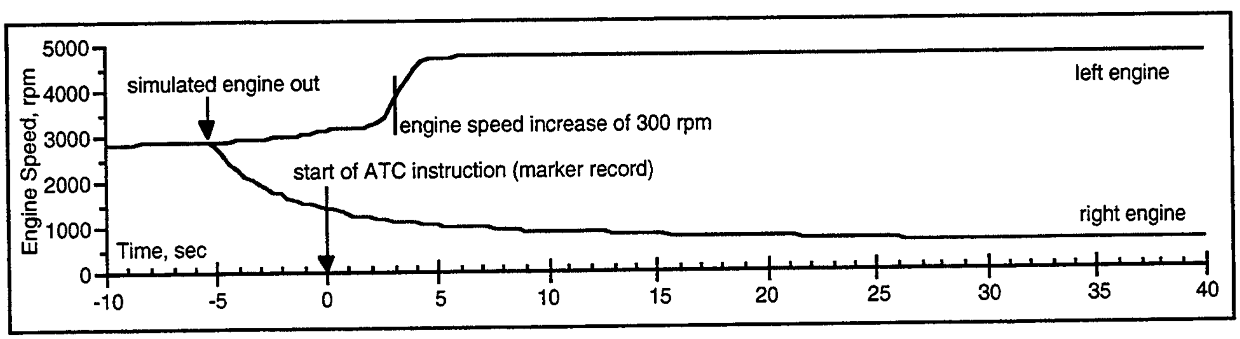


Figure E-4. Engine speed data during a breakout with simulated engine failure.

APPENDIX F. SCENARIO-ORDERED RESULTS

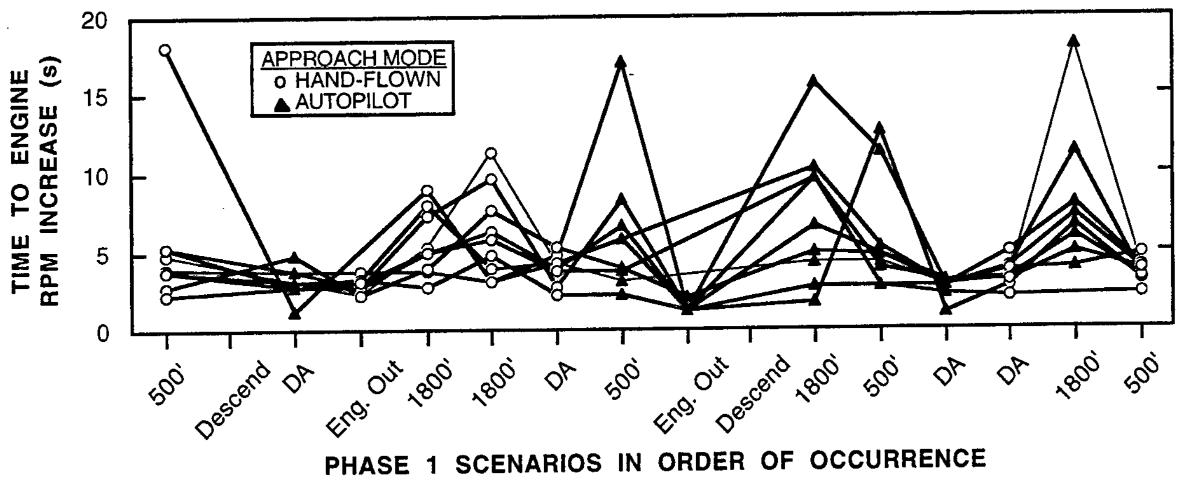
The following sections present raw results for representative performance variables. The results are graphically depicted in the order of occurrence. The first (left-hand) values were from the first trial in the session, and the last (right-hand) values were from the last trial in the session. The lines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

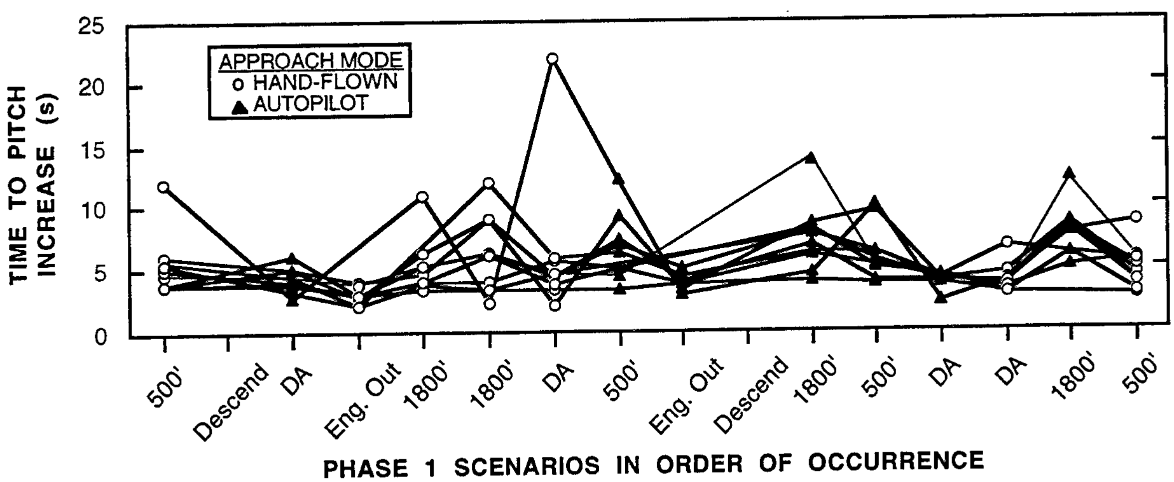
Seven performance variables are presented for each phase of the study: time to engine speed increase (dt_engine); time to pitch increase (dt_pitch); time to increasing vertical speed (dt_vertical_speed); time to min altitude (dt_min_altitude); altitude loss for climbing breakouts only (dz_min_altitude); maximum roll angle (maximum_roll); and time to start of roll (dt_roll). Time to TOGA thrust input (dt_toga) is also presented for Phase 1. 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.

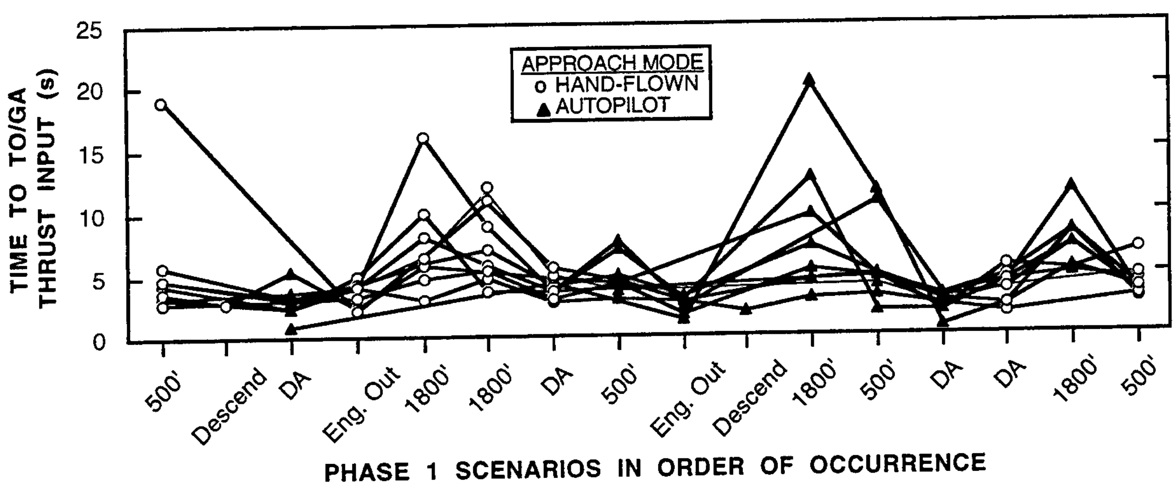
The data are coded as either having been a hand-flown (HF) approach or an autopilot-coupled (AP) approach. The codes along the horizontal axis represent the breakout groups. The code key is:

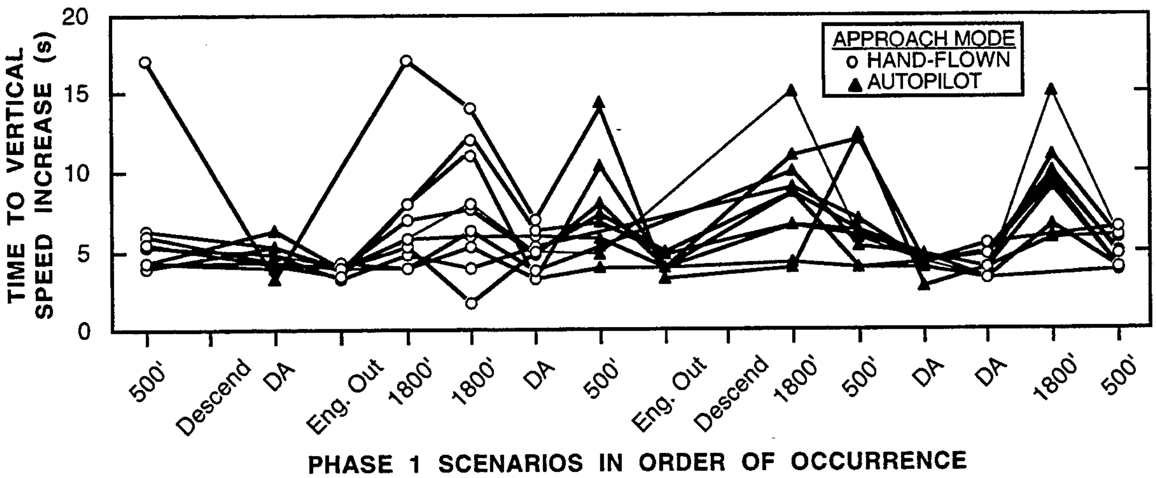
Code	Breakout Group
DA	Climbing breakout at decision altitude
500'	Climbing breakout at 500 feet AGL
1000'	Climbing breakout at 1000 feet AGL
1800'	Climbing breakout at 1800 feet AGL
Descend	Descending breakout at 1800 feet AGL
Eng. Out	Climbing breakout at DA, with engine out distraction

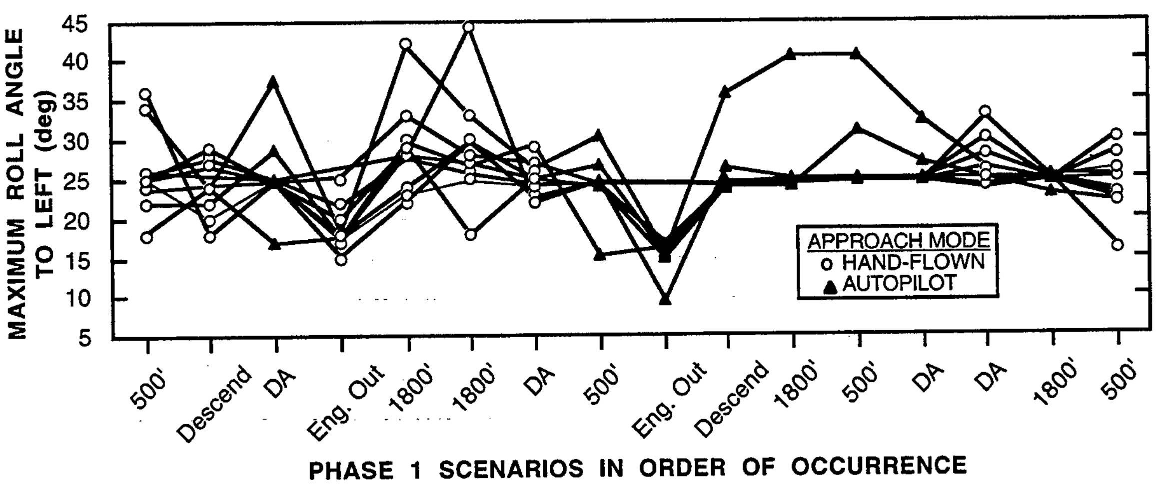
F.1 PHASE 1

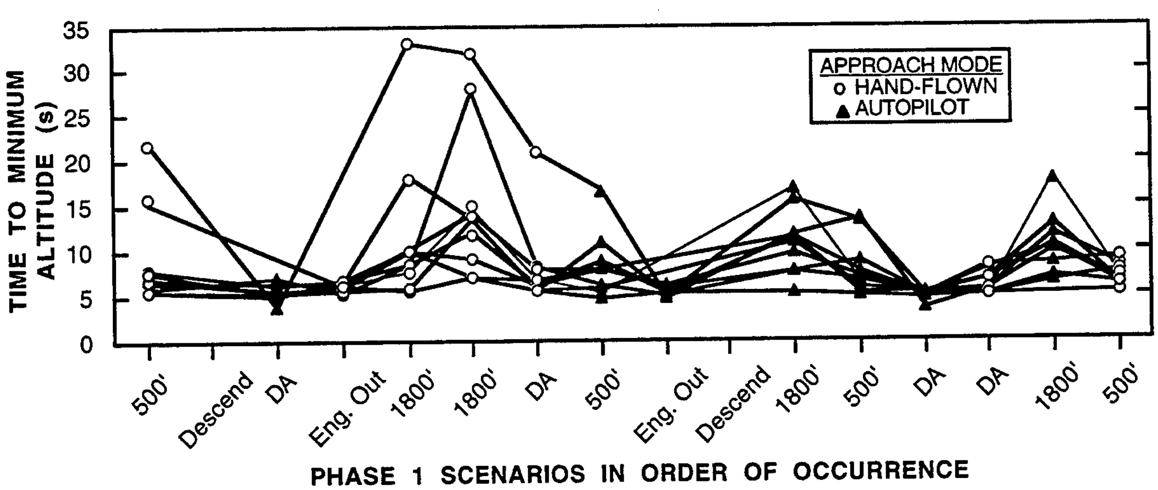

APPROACH MODE
o HAND-FLOWN
▲ AUTOPILOT
TIME TO ENGINE RPM INCREASE (s)
20
15
10
5
0
500'
Descend
DA
Eng. Out
1800'
1800'
DA
500'
Eng. Out
Descend
1800'
500'
DA
DA
1800'
500'
PHASE 1 SCENARIOS IN ORDER OF OCCURRENCE

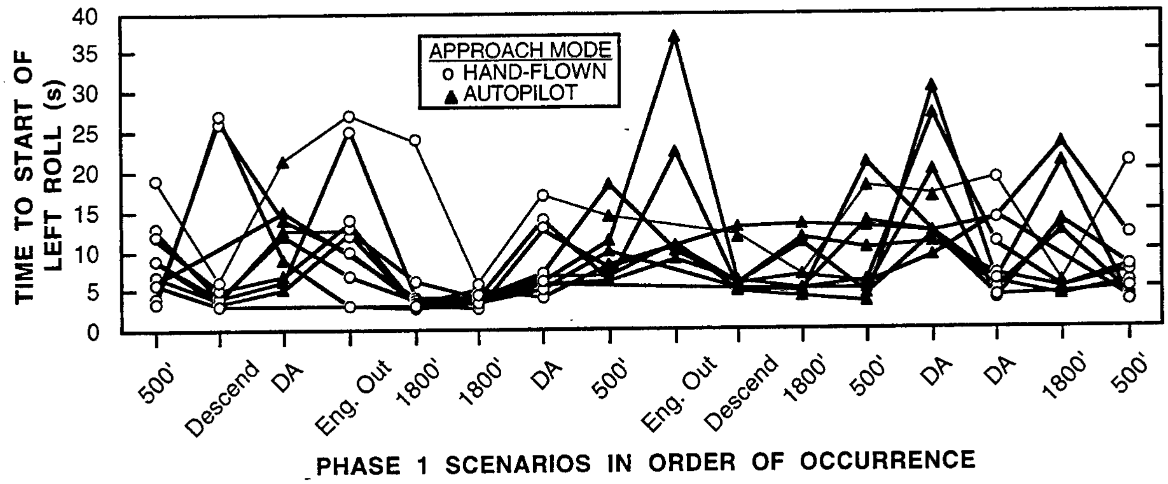

APPROACH MODE
o HAND-FLOWN
▲ AUTOPILOT
TIME TO PITCH INCREASE (s)
25
20
15
10
5
0
500'
Descend
DA
Eng. Out
1800'
1800'
DA
500'
Eng. Out
Descend
1800'
500'
DA
DA
1800'
500'
PHASE 1 SCENARIOS IN ORDER OF OCCURRENCE

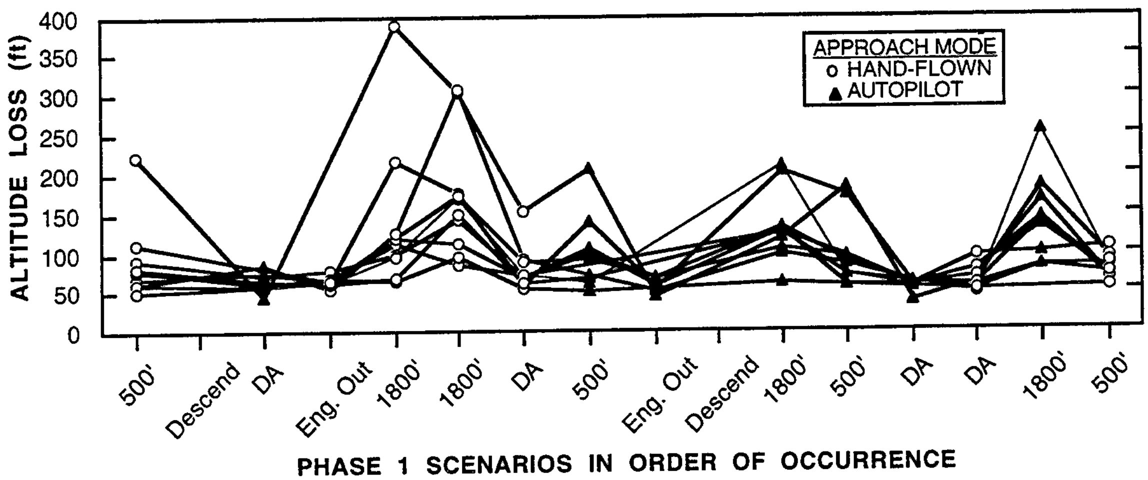

APPROACH MODE
o HAND-FLOWN
▲ AUTOPILOT
TIME TO TO/GA THRUST INPUT (s)
25
20
15
10
5
0
500'
Descend
DA
Eng. Out
1800'
1800'
DA
500'
Eng. Out
Descend
1800'
500'
DA
DA
1800'
500'
PHASE 1 SCENARIOS IN ORDER OF OCCURRENCE


TIME TO VERTICAL SPEED INCREASE (s)
20
15
10
5
0
APPROACH MODE
o HAND-FLOWN
▲ AUTOPILOT
500'
Descend
DA
Eng. Out
1800'
1800'
DA
500'
Eng. Out
Descend
1800'
500'
DA
DA
1800'
500'
PHASE 1 SCENARIOS IN ORDER OF OCCURRENCE

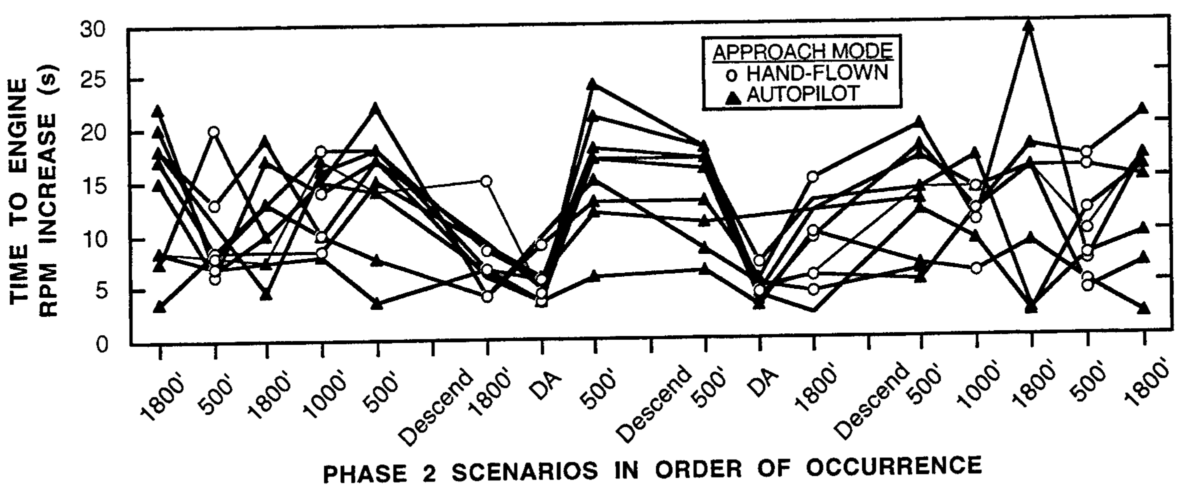

MAXIMUM ROLL ANGLE TO LEFT (deg)
45
40
35
30
25
20
15
10
5
APPROACH MODE
o HAND-FLOWN
▲ AUTOPILOT
500'
Descend
DA
Eng. Out
1800'
1800'
DA
500'
Eng. Out
Descend
1800'
500'
DA
DA
1800'
500'
PHASE 1 SCENARIOS IN ORDER OF OCCURRENCE

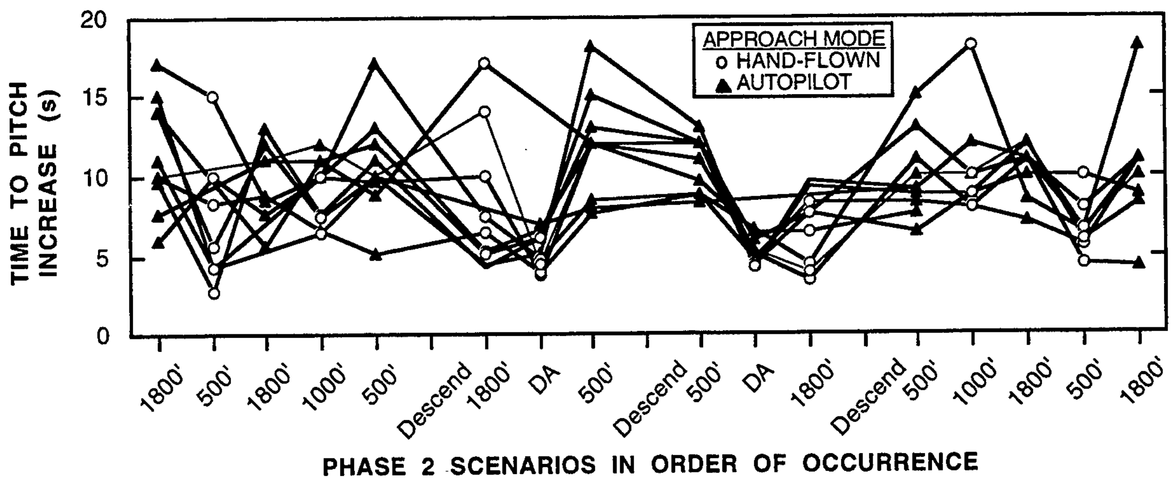

TIME TO MINIMUM ALTITUDE (s)
35
30
25
20
15
10
5
0
APPROACH MODE
o HAND-FLOWN
▲ AUTOPILOT
500'
Descend
DA
Eng. Out
1800'
1800'
DA
500'
Eng. Out
Descend
1800'
500'
DA
DA
1800'
500'
PHASE 1 SCENARIOS IN ORDER OF OCCURRENCE


APPROACH MODE
o HAND-FLOWN
▲ AUTOPILOT
TIME TO START OF LEFT ROLL (s)
0
5
10
15
20
25
30
35
40
500'
Descend
DA
Eng. Out
1800'
1800'
DA
500'
Eng. Out
Descend
1800'
500'
DA
DA
1800'
500'
PHASE 1 SCENARIOS IN ORDER OF OCCURRENCE

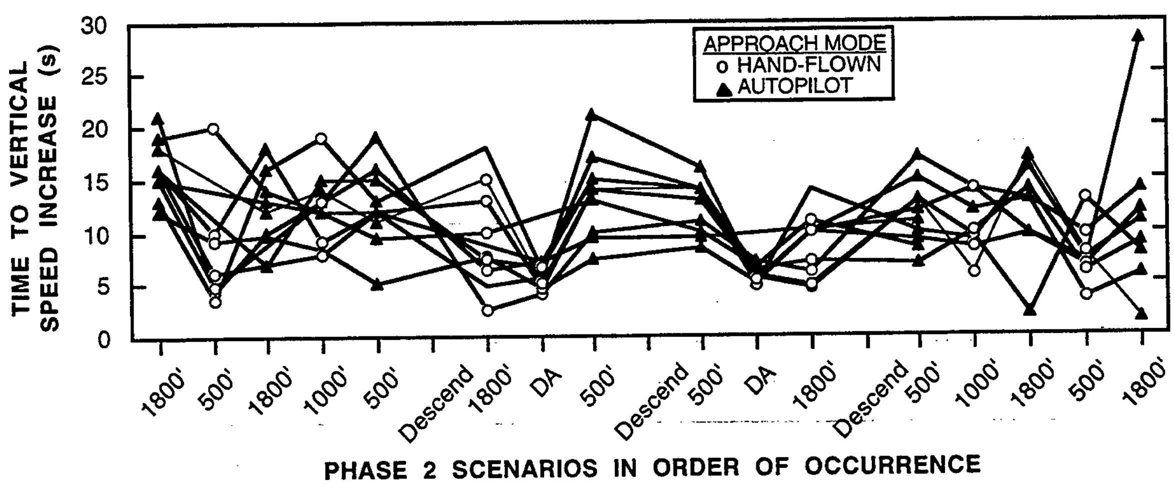

APPROACH MODE
o HAND-FLOWN
▲ AUTOPILOT
ALTITUDE LOSS (ft)
0
50
100
150
200
250
300
350
400
500'
Descend
DA
Eng. Out
1800'
1800'
DA
500'
Eng. Out
Descend
1800'
500'
DA
DA
1800'
500'
PHASE 1 SCENARIOS IN ORDER OF OCCURRENCE

F.2 PHASE 2

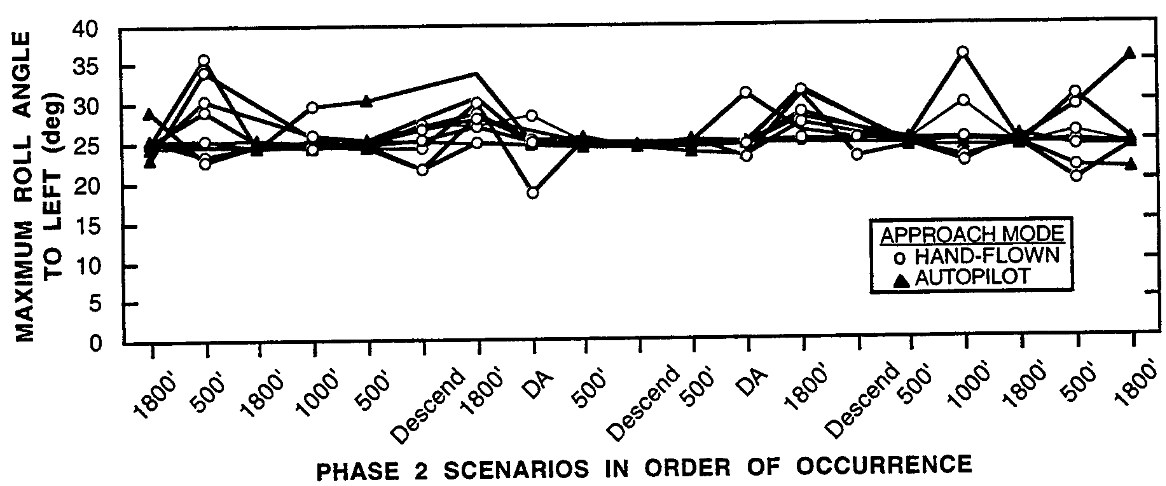

APPROACH MODE
o HAND-FLOWN
▲ AUTOPILOT
TIME TO ENGINE RPM INCREASE (s)
0
5
10
15
20
25
30
1800'
500'
1800'
1000'
500'
Descend
1800'
DA
500'
Descend
500'
DA
1800'
Descend
500'
1000'
1800'
500'
1800'
PHASE 2 SCENARIOS IN ORDER OF OCCURRENCE



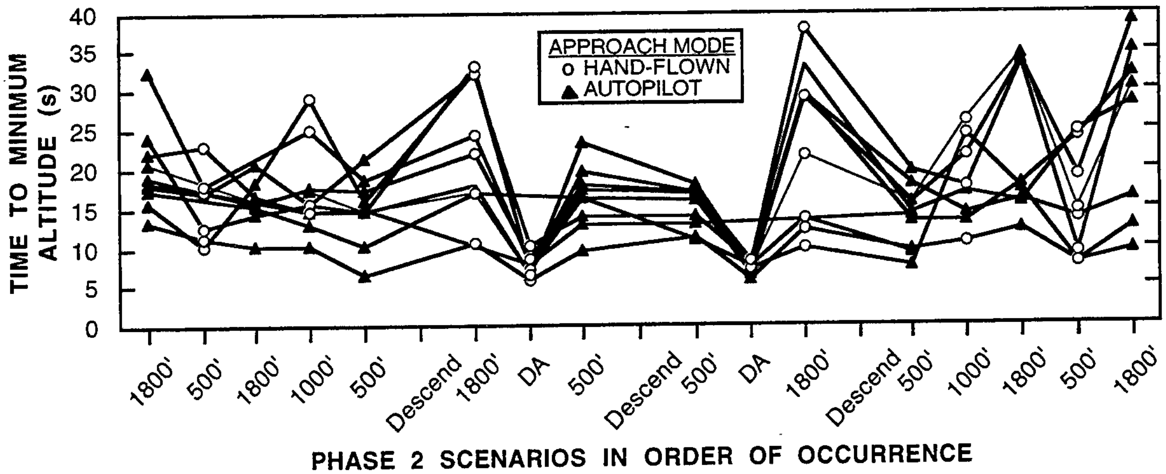
TIME TO PITCH INCREASE (s)
APPROACH MODE
o HAND-FLOWN
▲ AUTOPILOT
1800' 500' 1800' 1000' 500' Descend 1800' DA 500' Descend 500' DA 1800' Descend 500' 1000' 1800' 500' 1800'
PHASE 2 SCENARIOS IN ORDER OF OCCURRENCE

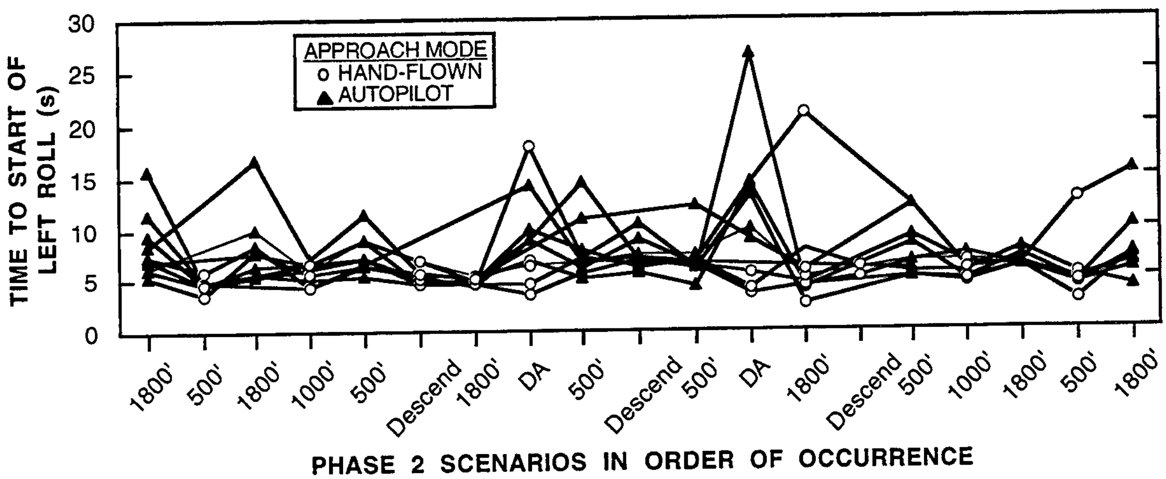


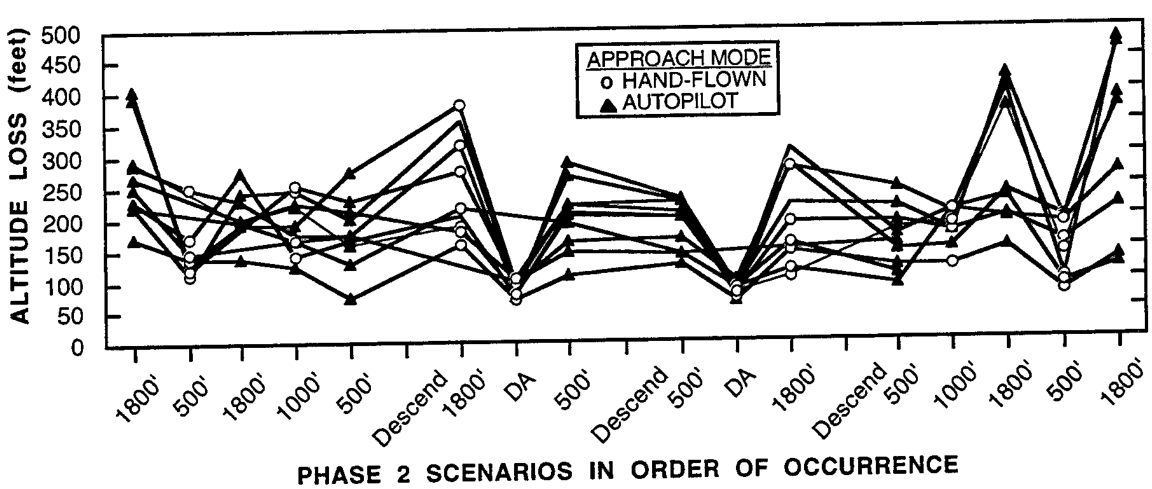
TIME TO VERTICAL SPEED INCREASE (s)
APPROACH MODE
o HAND-FLOWN
▲ AUTOPILOT
1800' 500' 1800' 1000' 500' Descend 1800' DA 500' Descend 500' DA 1800' Descend 500' 1000' 1800' 500' 1800'
PHASE 2 SCENARIOS IN ORDER OF OCCURRENCE



MAXIMUM ROLL ANGLE TO LEFT (deg)
APPROACH MODE
o HAND-FLOWN
▲ AUTOPILOT
1800' 500' 1800' 1000' 500' Descend 1800' DA 500' Descend 500' DA 1800' Descend 500' 1000' 1800' 500' 1800'
PHASE 2 SCENARIOS IN ORDER OF OCCURRENCE


TIME TO MINIMUM ALTITUDE (s)
APPROACH MODE
o HAND-FLOWN
▲ AUTOPILOT
1800' 500' 1800' 1000' 500' Descend 1800' DA 500' Descend 500' DA 1800' Descend 500' 1000' 1800' 500' 1800'
PHASE 2 SCENARIOS IN ORDER OF OCCURRENCE


TIME TO START OF LEFT ROLL (s)
APPROACH MODE
o HAND-FLOWN
▲ AUTOPILOT
1800' 500' 1800' 1000' 500' Descend 1800' DA 500' Descend 500' DA 1800' Descend 500' 1000' 1800' 500' 1800'
PHASE 2 SCENARIOS IN ORDER OF OCCURRENCE


ALTITUDE LOSS (feet)
APPROACH MODE
o HAND-FLOWN
▲ AUTOPILOT
1800' 500' 1800' 1000' 500' Descend 1800' DA 500' Descend 500' DA 1800' Descend 500' 1000' 1800' 500' 1800'
PHASE 2 SCENARIOS IN ORDER OF OCCURRENCE

APPENDIX G. SUMMARY STATISTICS FOR ALL TEST VARIABLES

Table G-1. DT_ROLL
Time from start of ATC instruction to start of roll (seconds)

PHASE 1						
HAND-FLOWN APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
Engine Out	12.3	12.6	8.6	3.0	27.0	9
DA	6.4	8.7	4.7	3.7	18.7	20
500'	7.2	8.3	4.9	3.3	21.0	20
1800'	3.7	4.9	4.6	2.7	23.7	19
Descend	4.3	9.2	9.9	3.1	27.0	9
AUTOPILOT-COUPLED APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
Engine Out	10.7	16.5	11.1	8.7	36.8	6
DA	12.3	14.2	6.6	5.3	30.3	20
500'	8.3	10.0	5.1	3.3	21.0	19
1800'	5.7	8.9	5.8	4.0	23.3	19
Descend	5.7	6.7	3.0	4.7	13.0	10
PHASE 2						
HAND-FLOWN APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
DA	5.1	6.6	4.8	3.5	18.1	8
500'	4.5	5.1	2.2	2.9	12.8	16
1000'	4.8	5.2	1.0	4.3	6.7	10
1800'	4.5	5.6	3.9	2.7	21.1	19
Descend	5.1	5.3	0.9	4.5	6.9	8
AUTOPILOT-COUPLED APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
DA	11.5	12.9	5.4	8.8	26.7	10
500'	6.7	7.5	2.3	4.3	14.4	40
1000'	6.4	6.3	0.8	5.1	7.5	9
1800'	7.2	8.0	2.9	5.3	16.8	33
Descend	6.9	7.3	1.5	5.6	10.4	9

Table G-2. MAXIMUM_ROLL
Maximum roll angle (degrees)

PHASE 1						
HAND-FLOWN APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
Engine Out	17.8	19.0	3.0	15.3	25.4	9
DA	25.0	25.8	2.6	21.8	32.7	20
500'	25.0	25.1	4.7	16.1	36.4	20
1800'	28.1	28.7	6.2	18.0	44.2	19
Descend	23.9	23.9	3.6	17.9	29.0	9
AUTOPILOT-COUPLED APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
Engine Out	15.4	14.9	2.5	9.4	16.5	7
DA	24.8	25.7	3.9	17.0	37.5	20
500'	24.7	25.7	4.7	15.3	40.6	19
1800'	24.7	25.5	3.7	23.0	40.5	19
Descend	24.4	25.6	3.7	23.7	35.8	10
PHASE 2						
HAND-FLOWN APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
DA	24.9	25.1	3.7	18.6	31.2	8
500'	25.7	26.8	4.4	20.0	35.8	16
1000'	25.9	27.1	4.1	22.2	35.8	10
1800'	28.4	28.9	2.9	24.9	35.3	19
Descend	25.0	24.5	2.2	21.5	27.4	8
AUTOPILOT-COUPLED APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
DA	24.9	24.7	0.5	23.3	25.1	10
500'	24.9	25.0	1.0	23.8	30.4	40
1000'	24.9	24.9	0.3	24.4	25.4	9
1800'	24.6	24.7	1.1	21.2	28.9	33
Descend	24.5	24.5	0.1	24.2	24.6	9

Table G-3. DX_TURN

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

Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
PHASE 1						
HAND-FLOWN APPROACHES						
Engine Out	2800.3	2844.7	1879.4	695.8	5793.5	9
DA	1537.6	2113.8	1149.5	881.1	4462.8	20
500'	1729.2	2052.7	1232.3	784.1	5342.9	20
1800'	890.8	1210.8	1152.0	640.6	5868.6	19
Descend	1050.8	2348.8	2613.0	746.4	7364.6	9
AUTOPILOT-COUPLED APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
Engine Out	2436.9	3488.2	2434.5	1763.3	8407.1	7
DA	2977.1	3436.7	1625.8	1263.3	7669.3	20
500'	2551.0	3095.3	1860.3	1059.3	8713.7	19
1800'	1508.4	2352.6	1533.6	1006.5	5770.5	19
Descend	1361.3	1611.4	692.3	1182.0	3110.9	10
PHASE 2						
HAND-FLOWN APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
DA	1220.9	1602.8	1201.3	826.9	4475.1	8
500'	1104.4	1220.0	541.7	707.3	3170.9	16
1000'	1167.7	1256.9	238.0	1026.8	1654.4	10
1800'	1129.8	1435.8	1015.8	725.3	5472.1	19
Descend	1284.6	1356.3	268.2	1123.6	1916.3	8
AUTOPILOT-COUPLED APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
DA	2758.2	3080.3	1312.0	2080.9	6420.5	10
500'	1607.5	1806.5	559.7	1027.9	3466.4	40
1000'	1518.2	1784.2	904.5	1195.0	4156.2	9
1800'	1791.4	2018.8	738.4	1282.2	4198.9	33
Descend	1976.3	1897.7	405.7	1353.3	2744.7	9

Table G-4. DT_ENGINE

Time from start of ATC breakout instruction to rpm increase (seconds)

PHASE 1						
HAND-FLOWN APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
Engine Out	2.8	2.9	0.5	2.3	3.7	8
DA	3.8	3.7	0.9	2.0	5.3	18
500'	3.7	4.5	3.5	2.3	18.0	18
1800'	5.2	5.9	2.5	2.7	11.3	18
Descend	N/A	N/A	N/A	N/A	N/A	9
AUTOPILOT-COUPLED APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
Engine Out	1.3	1.4	0.3	1.3	2.0	6
DA	2.7	2.8	0.8	1.0	4.7	19
500'	4.7	6.1	4.1	2.3	17.0	17
1800'	6.7	7.8	4.4	1.7	18.0	17
Descend	N/A	N/A	N/A	N/A	N/A	10
PHASE 2						
HAND-FLOWN APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
DA	4.3	5.2	1.9	3.7	8.8	8
500'	7.9	9.6	4.5	4.3	20.0	16
1000'	11.2	11.3	3.2	6.1	17.6	10
1800'	6.7	8.1	3.7	2.4	14.9	19
Descend	N/A	N/A	N/A	N/A	N/A	8
AUTOPILOT-COUPLED APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
DA	4.8	4.7	0.9	3.2	5.9	10
500'	15.6	14.3	4.8	3.7	23.7	40
1000'	15.2	13.5	3.5	8.0	16.8	9
1800'	14.9	12.8	5.7	2.1	21.6	31
Descend	N/A	N/A	N/A	N/A	N/A	9

Table G-5. DT_PITCH

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

PHASE 1						
HAND-FLOWN APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
Engine Out	3.0	2.9	0.7	2.0	4.0	9
DA	3.8	5.0	4.2	2.0	22.0	20
500'	4.8	5.1	2.1	2.7	12.0	20
1800'	5.3	5.8	2.7	2.3	11.9	19
Descend	N/A	N/A	N/A	N/A	N/A	9
AUTOPILOT-COUPLED APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
Engine Out	3.7	3.9	0.7	3.0	5.0	7
DA	4.0	4.1	0.8	2.3	6.0	20
500'	5.7	6.4	2.4	3.3	12.3	19
1800'	7.7	7.6	2.4	4.0	13.7	19
Descend	N/A	N/A	N/A	N/A	N/A	10
PHASE 2						
HAND-FLOWN APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
DA	4.4	4.5	0.7	3.7	6.1	8
500'	6.5	6.9	3.0	2.7	14.9	16
1000'	8.0	9.1	3.2	6.4	17.6	10
1800'	6.4	7.4	3.6	3.5	17.3	19
Descend	N/A	N/A	N/A	N/A	N/A	8
AUTOPILOT-COUPLED APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
DA	6.0	5.9	0.8	4.8	6.9	10
500'	10.5	10.7	2.7	5.1	18.1	40
1000'	10.1	10.1	1.6	6.7	12.0	9
1800'	10.7	11.1	3.0	5.6	18.5	33
Descend	N/A	N/A	N/A	N/A	N/A	9

Table G-6. DT_VERTICAL_SPEED

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

PHASE 1						
HAND-FLOWN APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
Engine Out	4.0	3.9	0.3	3.3	4.3	9
DA	4.7	4.6	1.1	3.3	7.0	20
500'	5.2	5.6	2.8	3.7	17.0	20
1800'	6.0	7.3	3.9	1.7	17.0	19
Descend	N/A	N/A	N/A	N/A	N/A	9
AUTOPILOT-COUPLED APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
Engine Out	4.0	4.2	0.6	3.3	5.0	7
DA	4.3	4.5	0.7	2.7	6.3	20
500'	6.3	7.1	3.0	4.0	14.3	19
1800'	9.0	8.8	3.0	4.0	15.0	19
Descend	N/A	N/A	N/A	N/A	N/A	10
PHASE 2						
HAND-FLOWN APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
DA	4.9	5.0	0.8	4.0	6.7	8
500'	7.3	8.2	3.8	3.7	19.5	16
1000'	9.2	10.6	3.9	5.9	19.2	10
1800'	9.9	9.8	4.5	4.5	20.0	19
Descend	N/A	N/A	N/A	N/A	N/A	8
AUTOPILOT-COUPLED APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
DA	6.4	6.3	0.8	5.1	7.2	10
500'	12.8	2.4	3.3	5.1	20.5	40
1000'	12.3	12.1	2.2	8.3	14.9	9
1800'	13.9	14.6	4.6	6.9	27.7	33
Descend	N/A	N/A	N/A	N/A	N/A	9

Table G-7. DT_TOGA

Time from start of ATC breakout instruction to TOGA thrust engaged (seconds)

PHASE 1						
HAND-FLOWN APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
Engine Out	4.0	3.7	0.9	2.2	5.0	9
DA	3.8	3.8	1.0	1.7	5.5	20
500'	3.7	4.8	3.7	2.7	19.3	19
1800'	6.2	7.3	3.4	3.0	16.0	16
Descend	2.7	2.7	N/A	2.7	2.7	1
AUTOPILOT-COUPLED APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
Engine Out	2.7	2.5	0.7	1.3	3.3	7
DA	2.8	2.7	1.0	.7	5.3	20
500'	4.7	5.3	2.5	2.0	11.7	18
1800'	7.3	8.1	4.3	3.0	20.3	15
Descend	2.0	2.0	N/A	2.0	2.0	1
PHASE 2						
HAND-FLOWN APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
DA	3.7	4.8	2.1	3.2	9.1	8
500'	5.9	5.7	1.0	4.0	6.9	7
1000'	8.3	8.3	3.8	5.6	10.9	2
1800'	6.5	7.1	2.1	5.3	10.9	6
Descend	N/A	N/A	N/A	N/A	N/A	9
AUTOPILOT-COUPLED APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
DA	4.4	4.2	0.9	2.7	5.3	10
500'	5.9	5.9	1.4	3.5	8.0	8
1000'	8.7	8.7	1.3	7.7	9.6	2
1800'	8.8	8.5	1.7	6.7	10.7	5
Descend	N/A	N/A	N/A	N/A	N/A	9

Table G-8. DT_MIN_ALTITUDE

Time from start of ATC breakout instruction to minimum altitude (seconds)

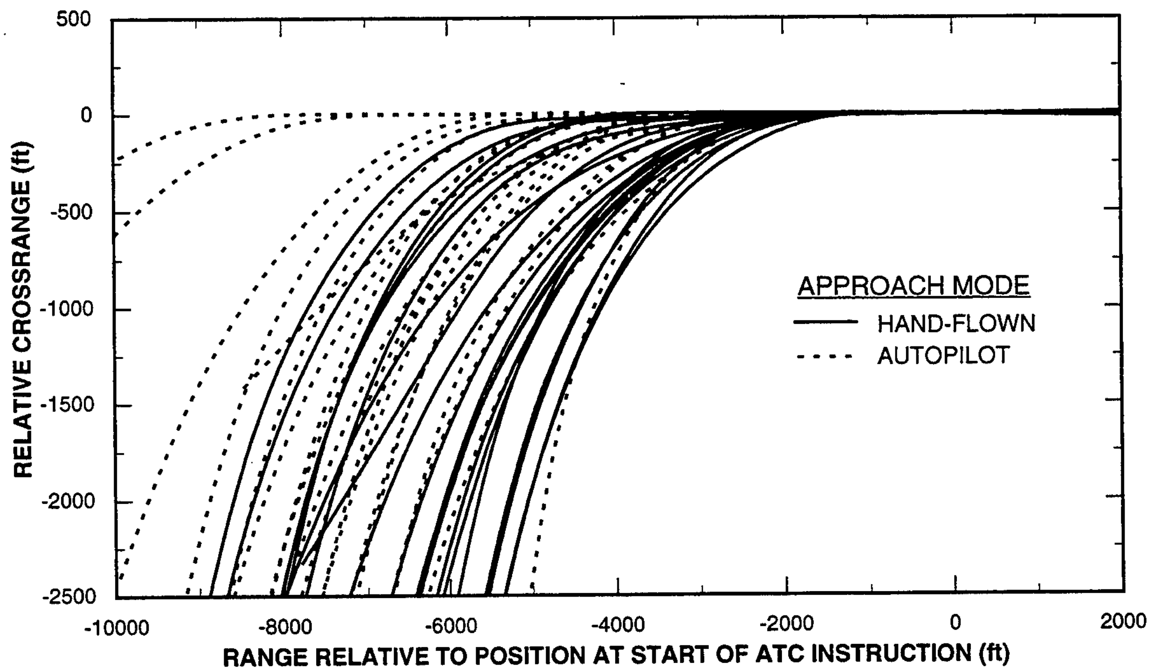
PHASE 1						
HAND-FLOWN APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
Engine Out	6.3	6.3	0.6	5.3	7.0	9
DA	6.3	7.1	3.5	5.0	21.0	20
500'	6.9	8.1	4.0	5.3	22.3	20
1800'	10.0	13.7	8.4	5.7	33.3	19
Descend	N/A	N/A	N/A	N/A	N/A	9
AUTOPILOT-COUPLED APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
Engine Out	5.3	5.4	0.6	4.7	6.3	7
DA	5.3	5.3	0.8	3.7	7.3	20
500'	7.3	8.2	3.3	4.7	16.7	19
1800'	10.7	10.8	3.4	5.3	17.7	19
Descend	N/A	N/A	N/A	N/A	N/A	10
PHASE 2						
HAND-FLOWN APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
DA	7.2	7.6	1.3	5.9	10.1	8
500'	14.2	15.0	5.6	7.7	24.8	16
1000'	23.0	21.2	6.3	10.4	29.1	10
1800'	24.5	23.8	8.7	9.9	37.9	19
Descend	N/A	N/A	N/A	N/A	N/A	8
AUTOPILOT-COUPLED APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
DA	7.2	7.1	0.8	5.9	8.0	10
500'	15.5	15.0	3.6	6.4	23.2	40
1000'	14.7	14.7	2.4	10.1	17.6	9
1800'	17.9	20.7	8.2	9.6	38.7	33
Descend	N/A	N/A	N/A	N/A	N/A	9

Table G-9. DZ_MIN_ALTITUDE

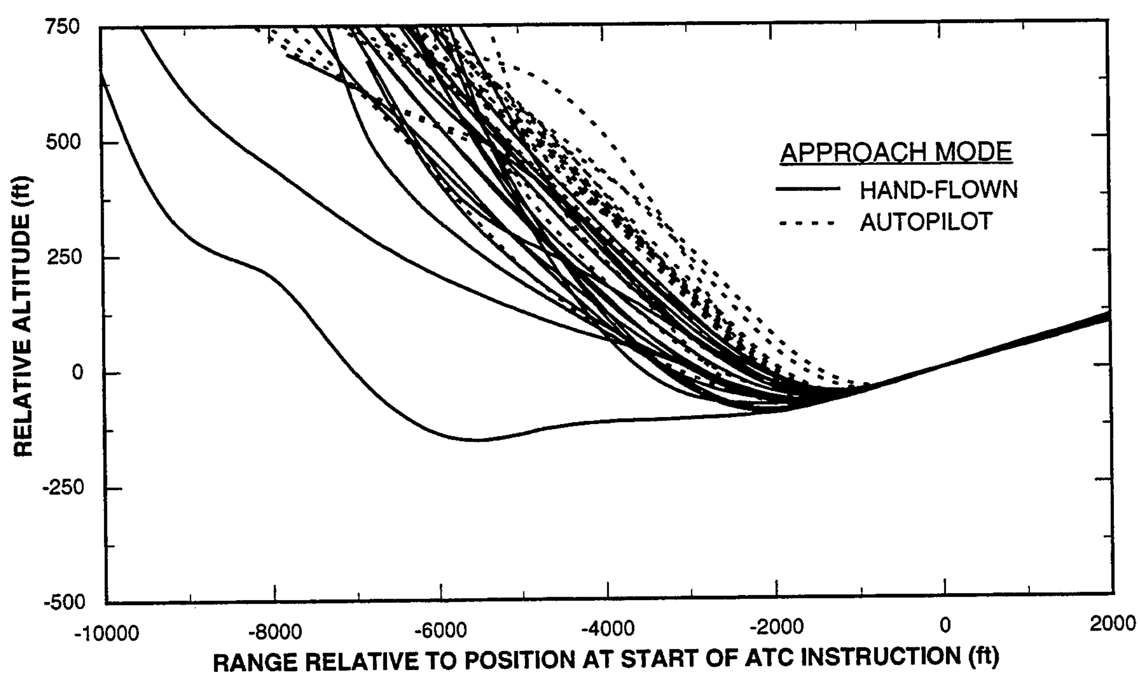
Altitude loss from start of ATC breakout instruction to minimum altitude (feet)

PHASE 1						
HAND-FLOWN APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
Engine Out	65.0	65.6	6.2	55.0	77.0	9
DA	68.5	71.9	23.1	49.0	152.0	20
500'	75.0	83.7	36.0	52.0	222.0	20
1800'	125.0	158.0	88.6	64.0	387.0	19
Descend	N/A	N/A	N/A	N/A	N/A	9
AUTOPILOT-COUPLED APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
Engine Out	56.0	56.9	8.6	45.0	69.0	7
DA	59.0	60.7	9.8	39.0	85.0	20
500'	87.0	98.8	44.8	53.0	206.0	19
1800'	130.0	136.3	48.5	60.0	252.0	19
Descend	N/A	N/A	N/A	N/A	N/A	10
PHASE 2						
HAND-FLOWN APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
DA	76.5	80.8	11.8	67.0	101.0	8
500'	139.5	144.3	45.2	77.0	248.0	16
1000'	195.5	191.0	42.1	120.0	253.0	10
1800'	215.0	228.5	79.9	104.0	382.0	19
Descend	N/A	N/A	N/A	N/A	N/A	8
AUTOPILOT-COUPLED APPROACHES						
Breakout Group	Median	Mean	Std Dev	Minimum	Maximum	Count
DA	86.0	84.2	10.6	66.0	98.0	10
500'	184.0	181.4	49.8	74.0	286.0	40
1000'	174.0	180.8	33.6	122.0	223.0	9
1800'	230.0	265.8	100.7	120.0	477.0	33
Descend	N/A	N/A	N/A	N/A	N/A	9

APPENDIX H. PHASE 1 BREAKOUT TRAJECTORIES

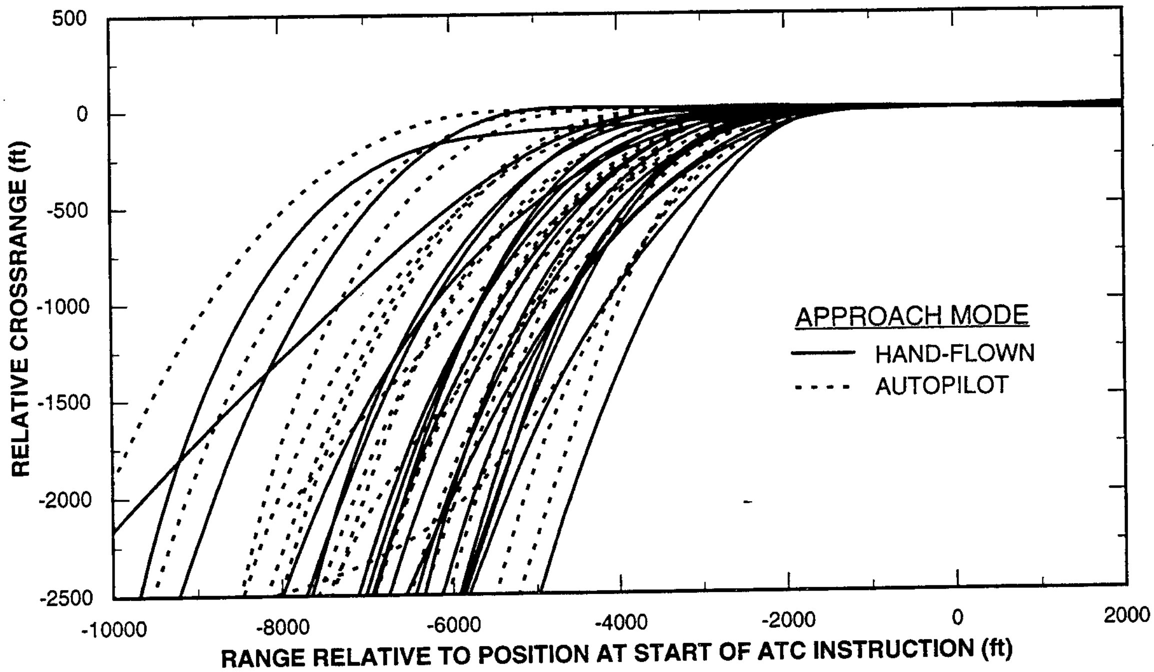


(a)

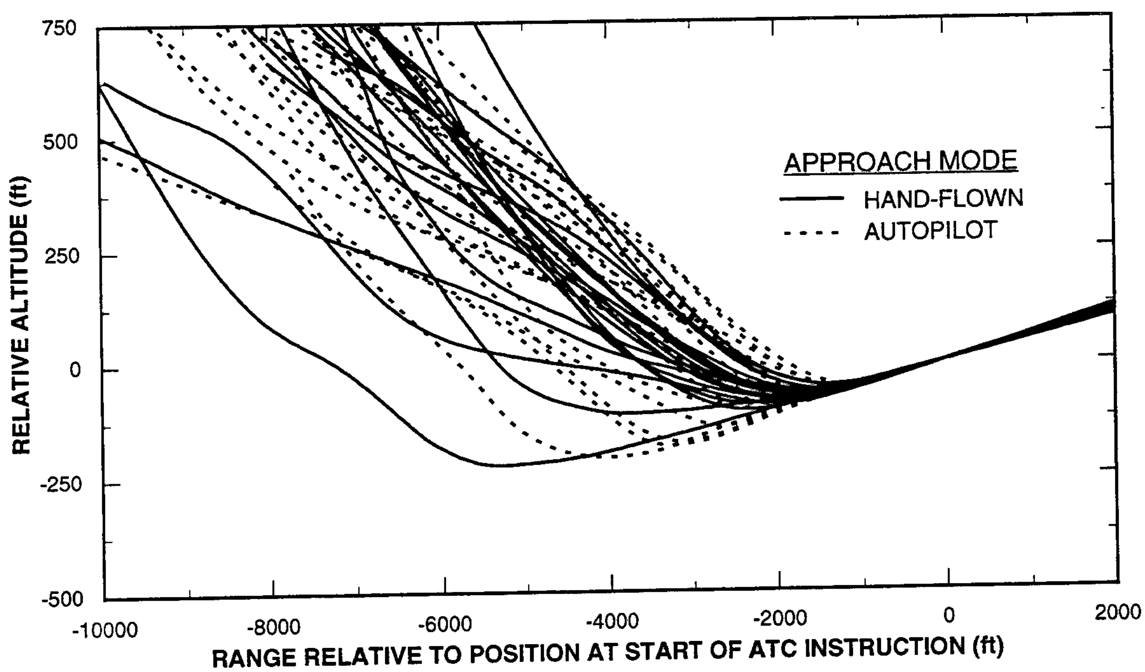


(b)

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

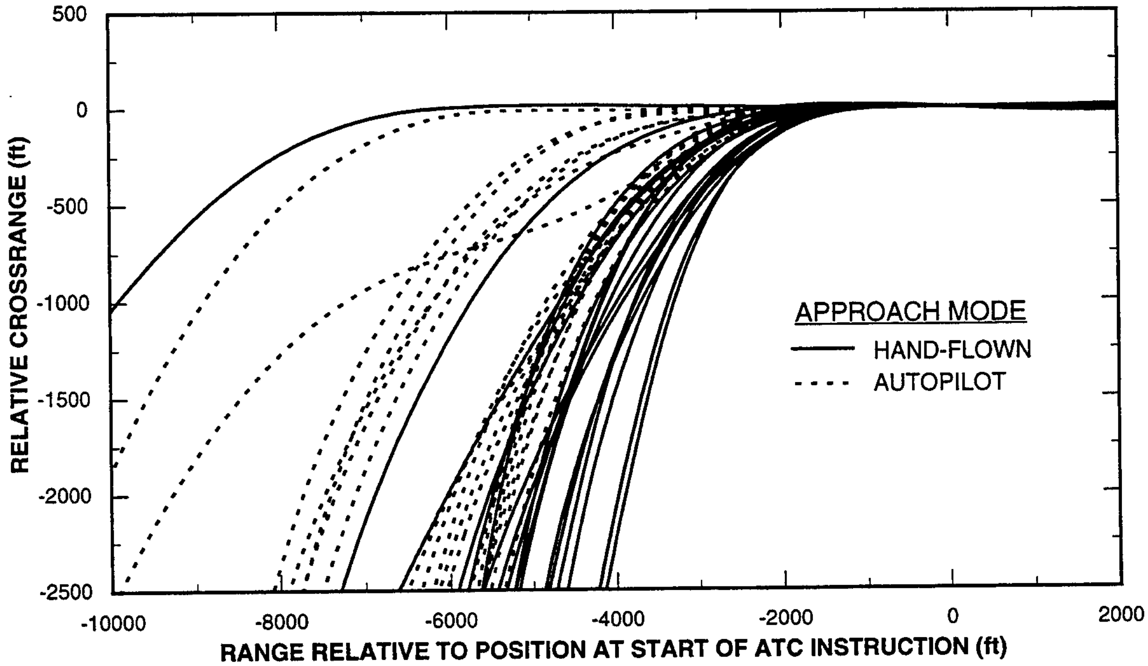


(a)

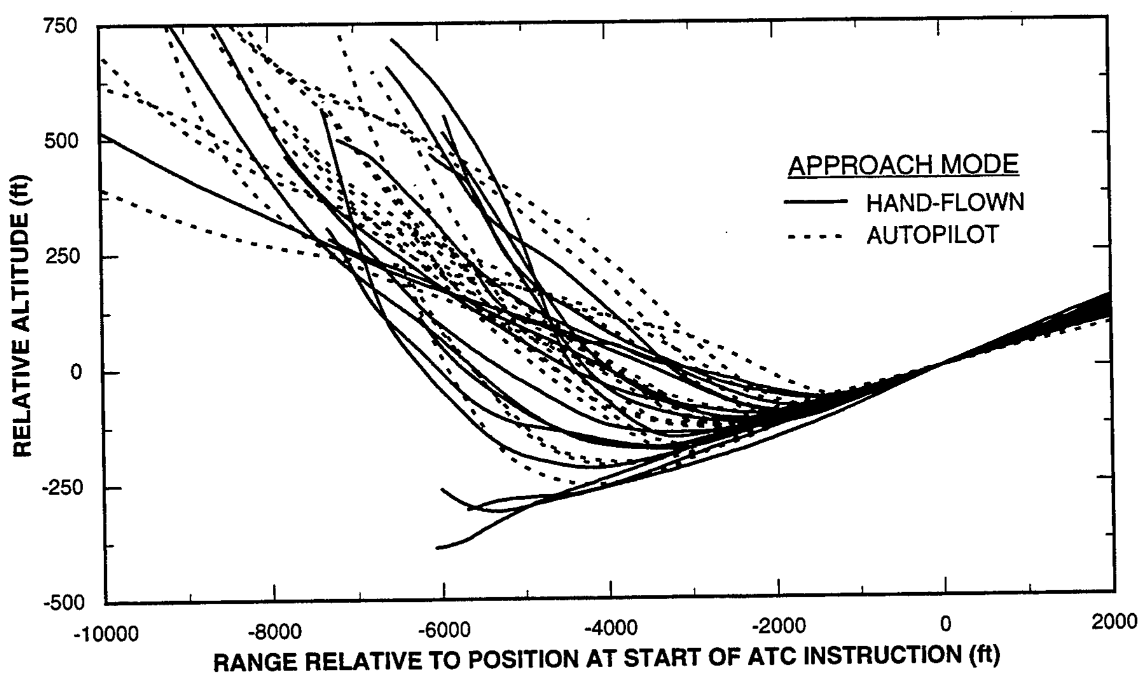


(b)

Figure H-2. Phase 1 climbing breakouts at 500 feet above ground level.
(a) Ground track. (b) Vertical profile.

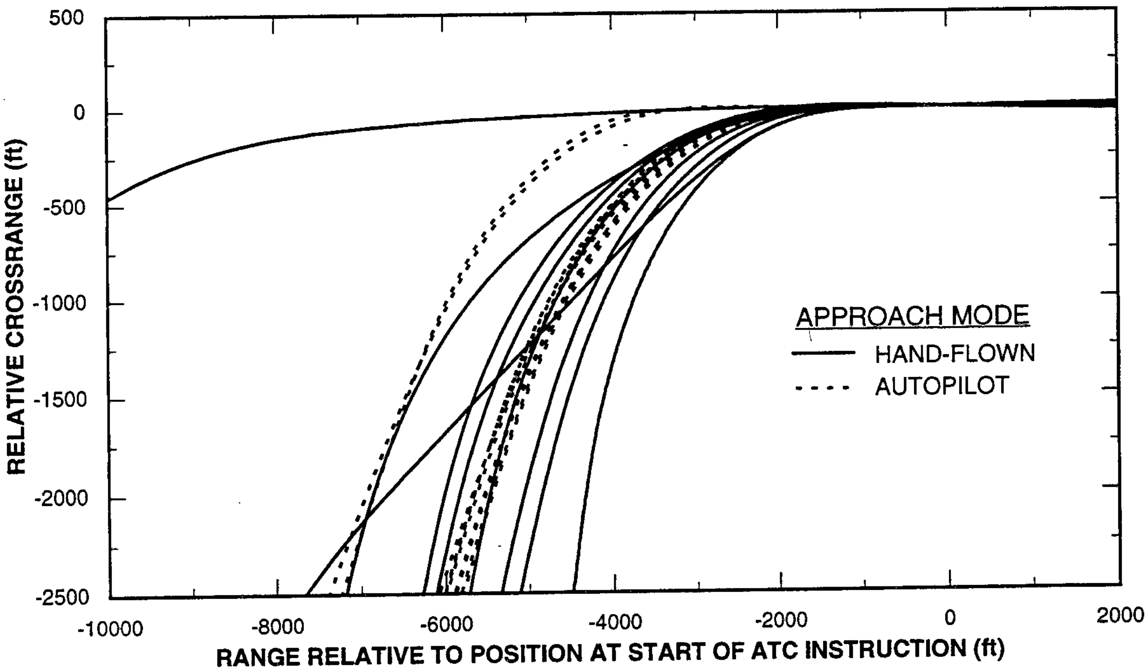


(a)

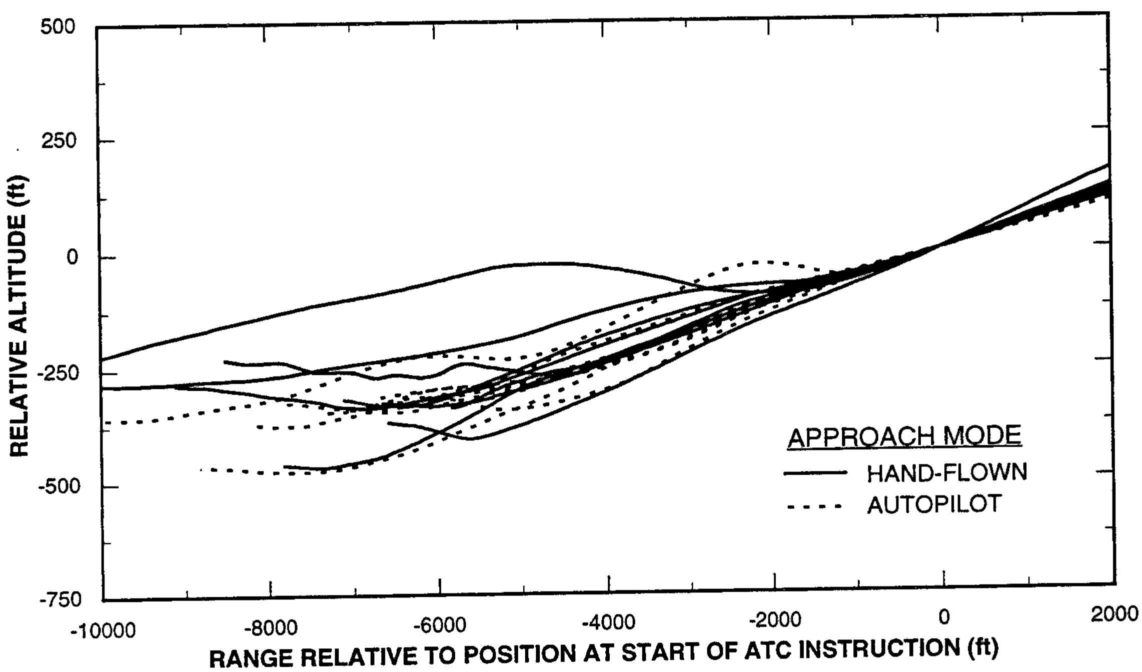


(b)

Figure H-3. Phase 1 climbing breakouts at 1800 feet above ground level. (a) Ground track. (b) Vertical profile.



(a)



(b)

Figure H-4. Phase 1 descending breakouts at 1800 feet above ground level. (a) Ground track. (b) Vertical profile.

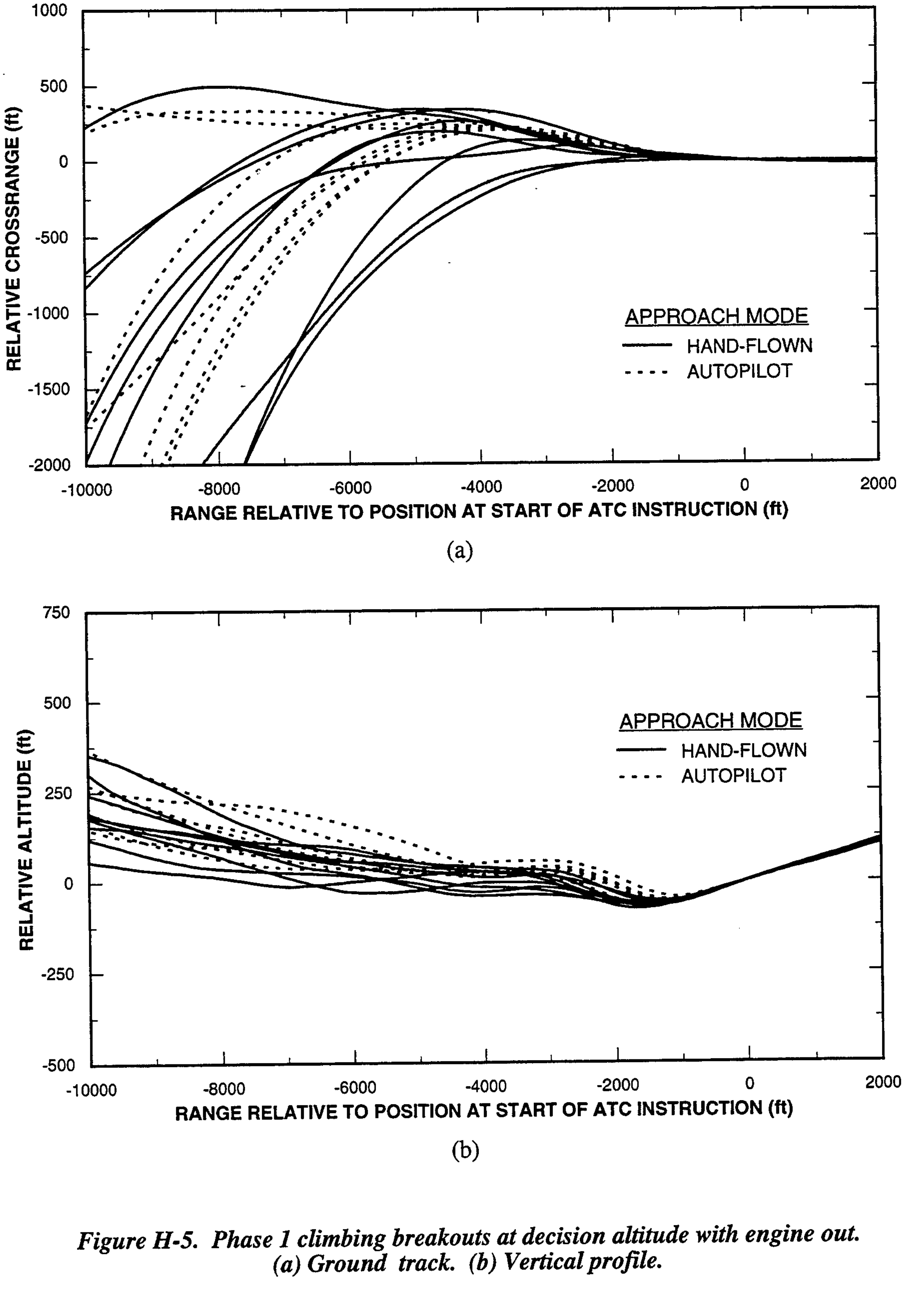
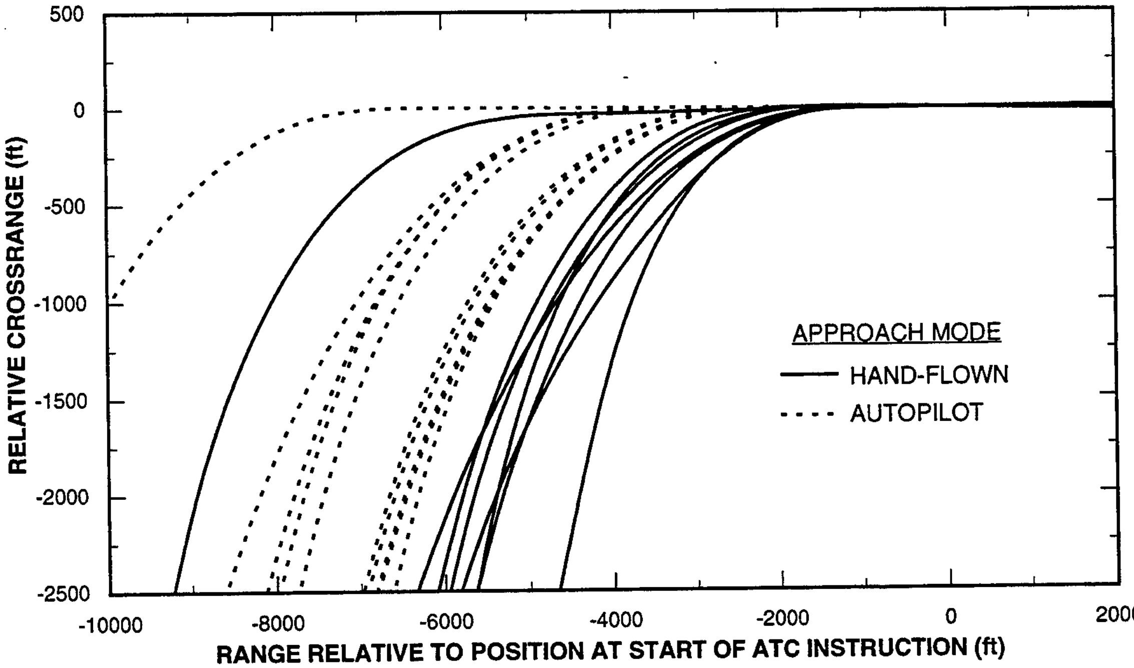
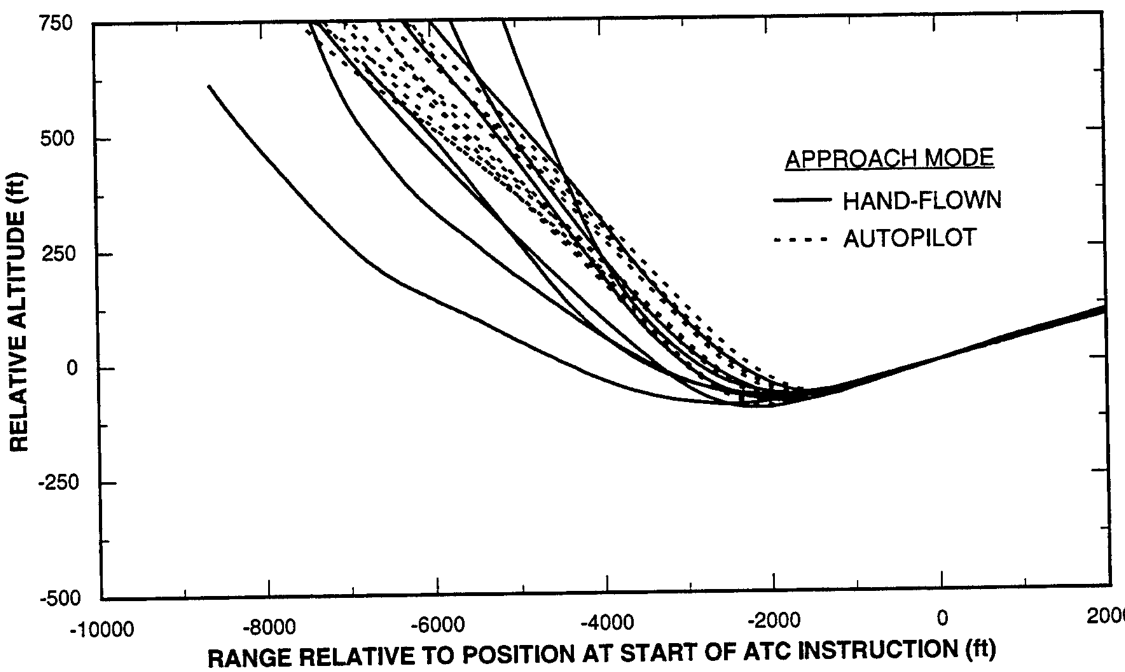


Figure H-5. Phase 1 climbing breakouts at decision altitude with engine out. (a) Ground track. (b) Vertical profile.

APPENDIX I. PHASE 2 BREAKOUT TRAJECTORIES

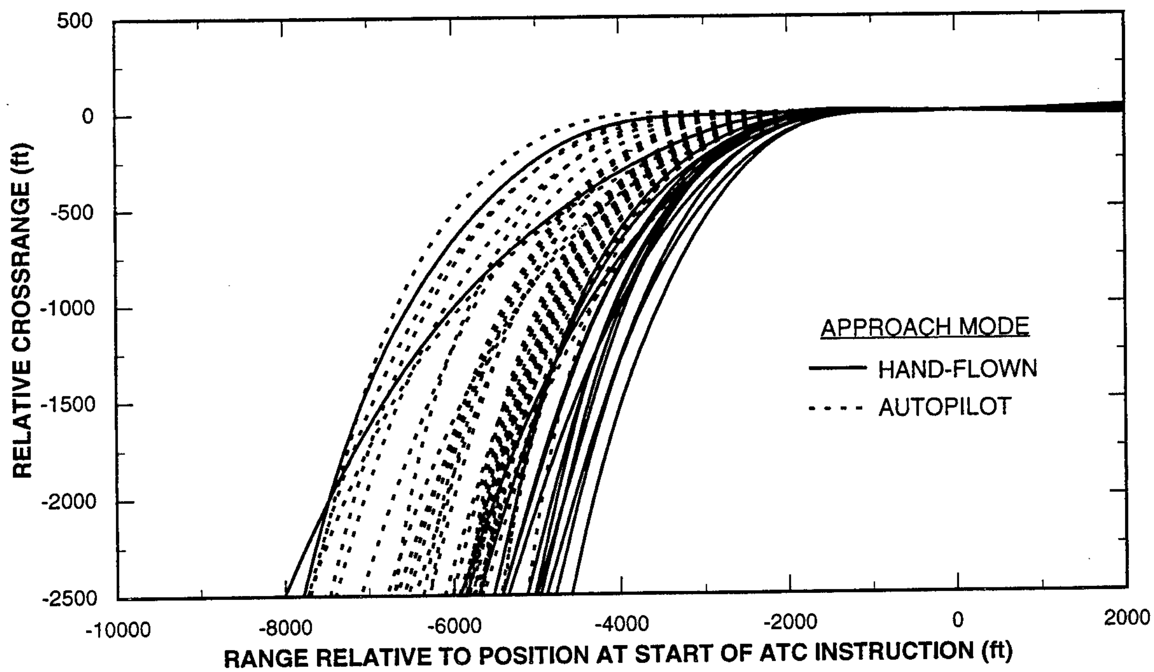


(a)

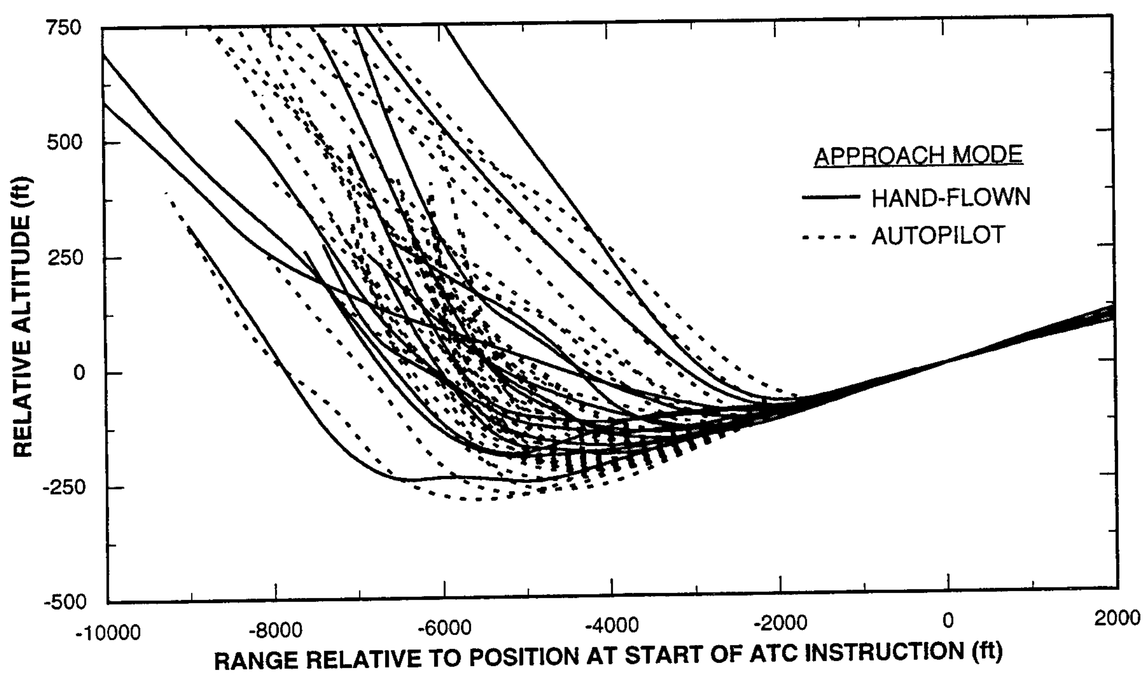


(b)

Figure I-1. Phase 2 climbing breakouts at decision altitude.
(a) Ground track. (b) Vertical profile.



(a)



(b)

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

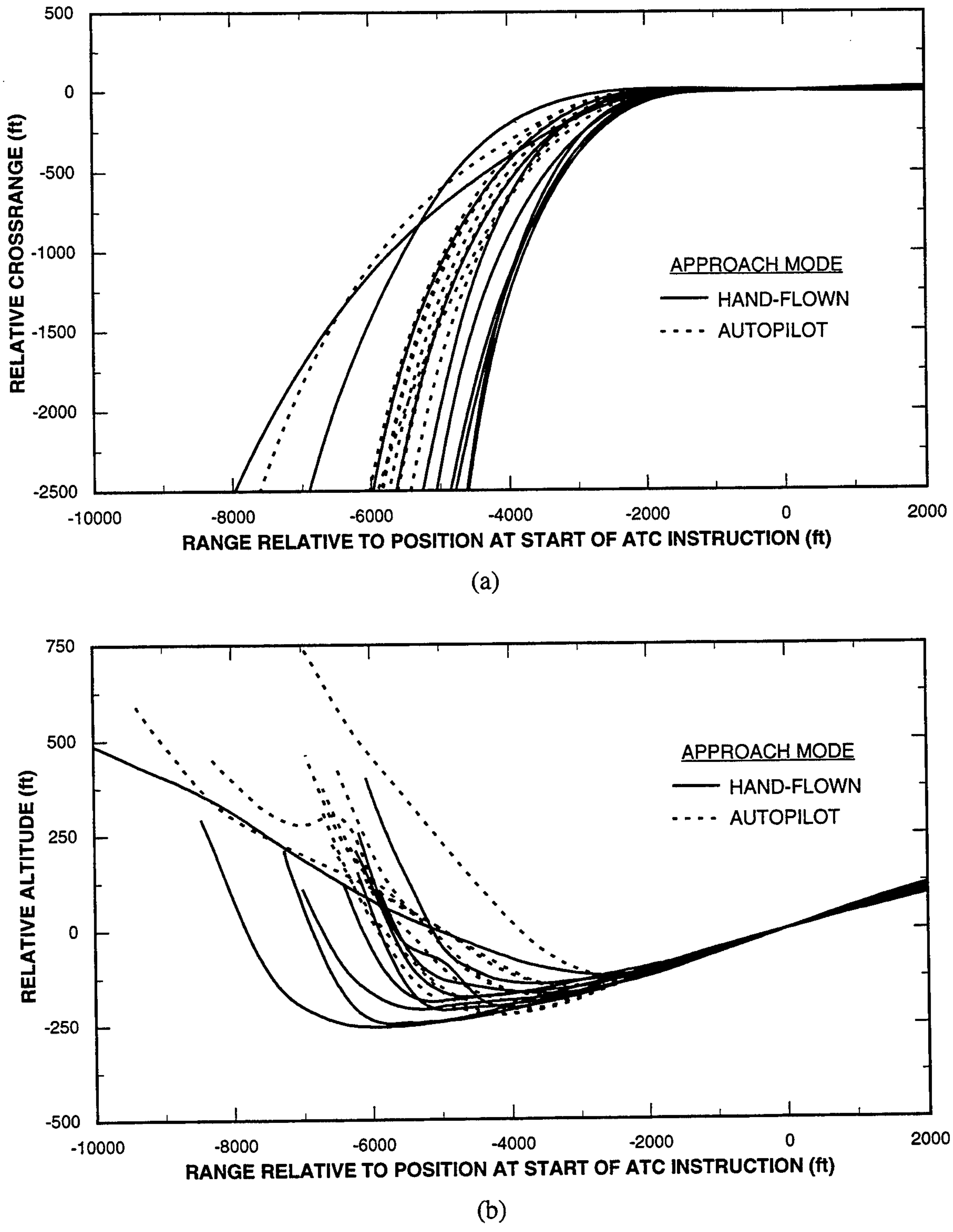
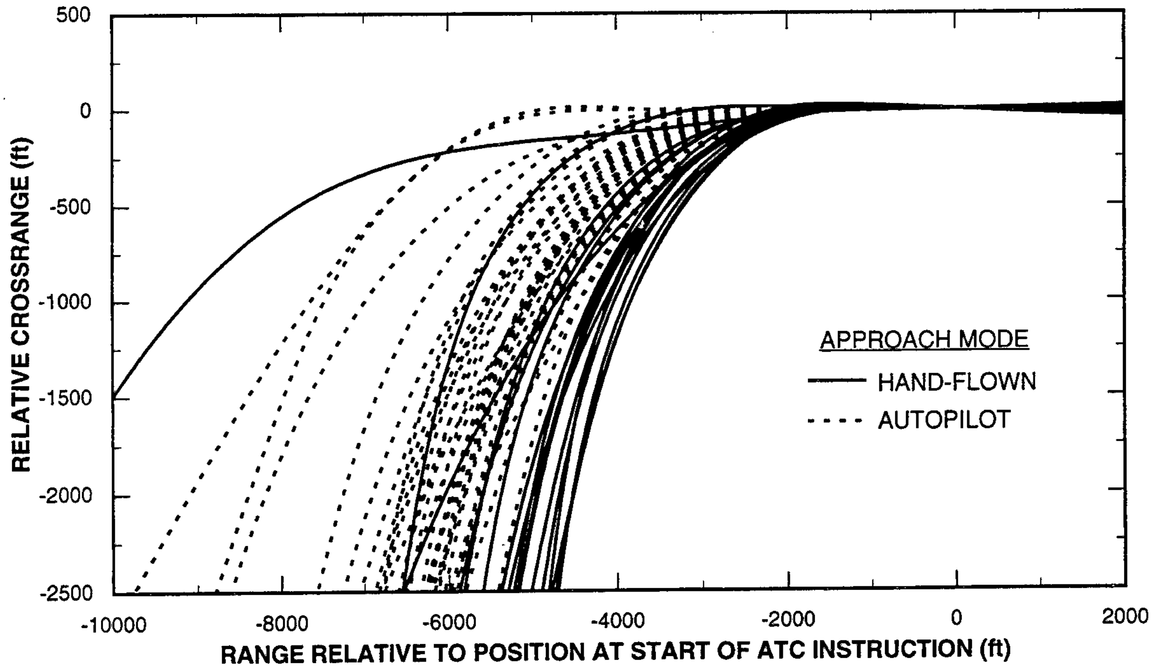
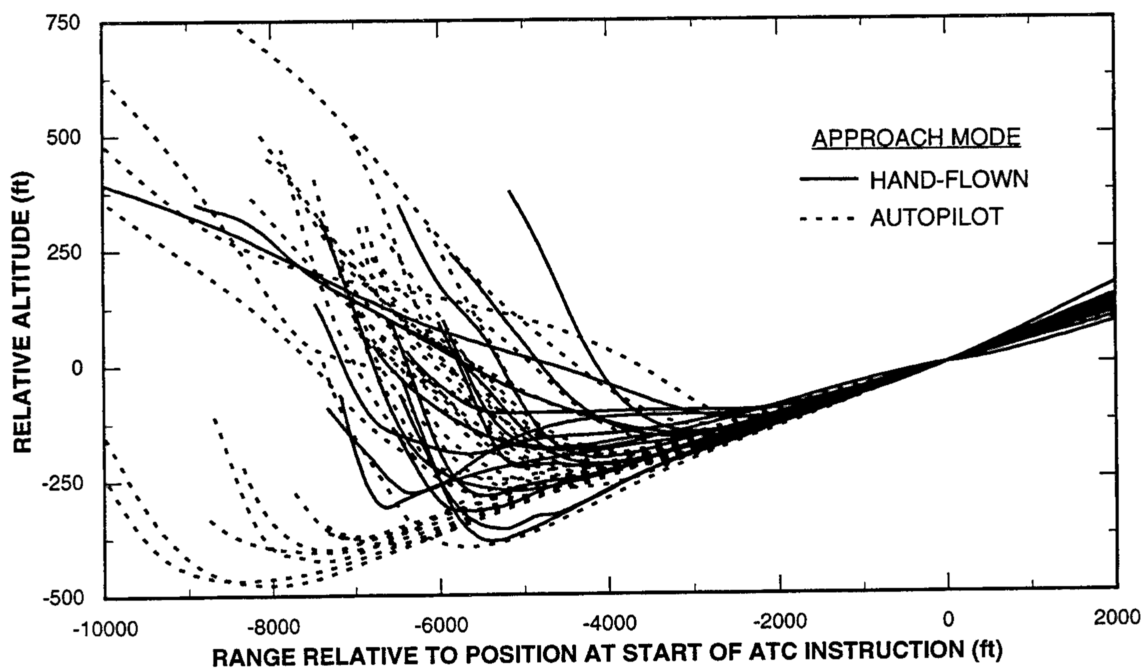


Figure I-3. Phase 2 climbing breakouts at 1000 feet above ground level. (a) Ground track. (b) Vertical profile.

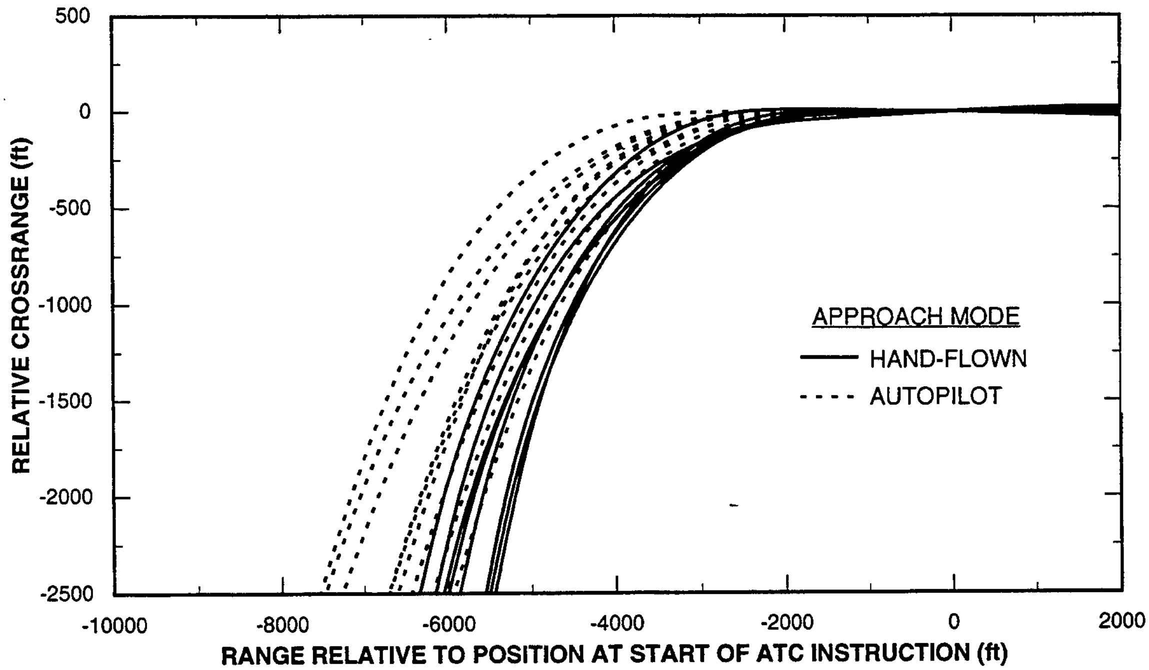


(a)

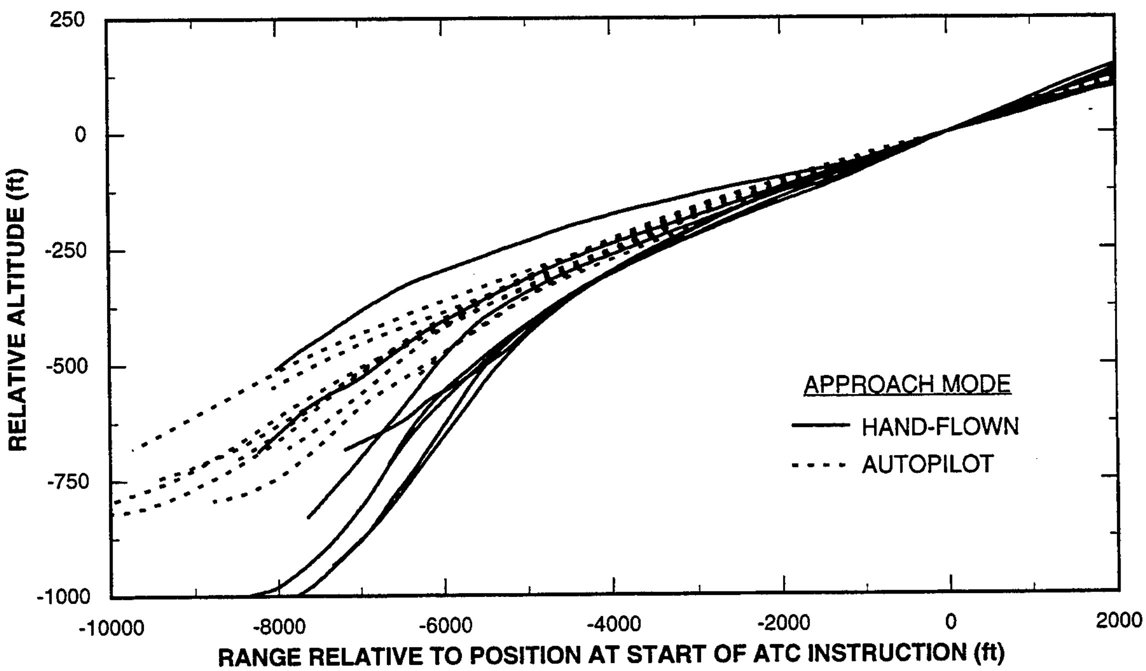


(b)

Figure I-4. Phase 2 climbing breakouts at 1800 feet above ground level. (a) Ground track. (b) Vertical profile.



(a)



(b)

Figure I-5. Phase 2 descending breakouts at 1800 feet above ground level.
(a) Ground track. (b) Vertical profile.