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End-Around Taxiway (EAT) Analysis—East Traffic Arrivals (Runways 17C and 17R) at Dallas/Fort Worth International Airport (DFW)

Flight Systems Laboratory
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Flight Operations Simulation Branch
Flight Technologies and Procedures Division
Flight Standards Service

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12. Abstract

The Dallas/Fort Worth International Airport (DFW) proposes the construction and operation of End-Around Taxiways (EATs) for runways in both east and west traffic. While FAA Advisory Circular 5300-13, “Airport Design,” establishes design and/or operational criteria for EATs at departure ends of runways, it is significant to note that there are presently no regulatory criteria or standards that specifically address the use of EATs at approach ends. To address this issue, the FAA conducted this research as a potential supplement to previously developed End-Around Taxiway national standards for aircraft departures over EATs.

Pilot performance (as it relates to aircraft performance) was evaluated from a human-in-the-loop standpoint through elicited subjective responses and comments from aircrews, as well as objective observation of crew performance during closely scripted scenarios. Pilot performance, subjective post-run responses, and debriefing comments corroborate the pilots’ relative comfort with limited workload changes attributed to EATs. The primary criterion for pilot success was predicated on a crew’s ability to fly the glide slope within stabilized flight criteria and all crews were successful in all scenarios with very few exceptions. From a human factors perspective, there were no appreciable changes in physical or mental workload that would compromise the current levels of safety. Pilots did indicate a reluctance to fly directly over aircraft on the active EATs during marginal meteorological or aircraft performance conditions (e.g., engine malfunction) when precise glide slope integrity might be compromised.

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Executive Summary

The Dallas/Fort Worth International Airport (DFW) proposes the construction and operation of End-Around Taxiways (EATs) for runways in both east and west traffic. While FAA Advisory Circular 5300-13, "Airport Design," [4] establishes design and/or operational criteria for EATs at departure ends of runways, it is significant to note that there are presently no regulatory criteria or standards that specifically address the use of EATs at approach ends. To address this issue, the FAA conducted this research to supplement previously developed End-Around Taxiway national standards contained in FAA Advisory Circular 5300-13 for aircraft departures over EATs.

This evaluation was conducted in a B747-400 Level D Full Flight Simulator to evaluate EAT procedures for aircraft arriving at DFW Runways 17C and17R. An Instrument Landing System approach was used for each arrival. Pilot performance (as it relates to aircraft performance) was evaluated from a human-in-the-loop standpoint through elicited subjective responses and comments from aircrews, as well as objective observation of crew performance during closely scripted scenarios. Pilot comments varied slightly across all crews, with the predominant responses from pilots being those of relative comfort and limited workload changes directly attributable to the EATs themselves. Both pilot performance and subjective post-run responses corroborate this finding.

The primary criterion for pilot success was predicated on a crew's ability to fly the glide slope within stabilized flight criteria. For the purposes of this evaluation stabilized flight is achieved when pilots have final checklists complete, the aircraft is in final landing configuration and the crew does not exceed 1000 foot per minute rate of descent below 1000' AGL, for more than 3 seconds. With very few exceptions, all crews were successful in all of the scenarios. Pilot debriefing remarks indicated that pilots were very reluctant to fly directly over aircraft on the active EATs during marginal meteorological or aircraft performance conditions (e.g., engine malfunction) when precise glide slope integrity might be compromised.

From a human factors perspective, there were no appreciable changes in physical workload, mental workload, or comfort levels that would compromise current levels of safety. Based upon the evaluation of the objective and subjective data collected, arrival operations should be approved in the current operational design. EAT operations may increase safety levels for the reasons mentioned. Pilot crews felt that this operation might increase safety through the reduction of runway crossings and reduced aircraft/ATC communications. Furthermore, there do not appear to be any additional human factors, Crew Resource Management, or operational issues that should preclude approach operations over EATs.

Additional comments from all crews during the debriefing pointed out a potential problem with both crews and passengers aboard aircraft that are negotiating an EAT, especially those that might be perpendicular to the final flight path of an approaching aircraft. Pilots almost universally indicated that they would adjust their own taxi speeds to ensure that they would not be directly under an arriving aircraft while they were on the EAT. Although this phenomenon

was not specifically addressed in this test, enough concern was expressed that it may warrant further evaluation. Additionally, as in the departure case, further investigation may be needed to: (1) identify crew training requirements, and (2) identify and establish EAT-specific aircrew operational procedures. Conclusions drawn from this data, analysis, and evaluation potentially may be generalized to other runways or other locations with or without further evaluation.

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1.0 Introduction

This report presents the results of an End-Around Taxiway (EAT) analysis conducted on east traffic arrivals at Dallas/Fort Worth International Airport (DFW). This evaluation was conducted by the FAA Flight Operations Simulation and Analysis Branch (AFS-440) using a B737-400 Level D Full Flight Simulator located at the NASA-Ames Crew-Vehicle Systems Research Facility.

1.1 Purpose and Structure of This Report

The purpose of this evaluation was to gather human factors and operational information, potentially leading to the development, application, and approval of procedures for aircraft arriving at DFW Runways 17C and 17R while simultaneous EAT operations are being conducted at both the approach and departure ends of those runways. An Instrument Landing System approach was used for each arrival. This report provides background information and describes the evaluation processes and methodologies used in the study. Conclusions drawn from this data, analysis, and evaluation potentially may be generalized to other runways or other locations with or without further evaluation.

1.2 Background

DFW proposes the construction and operation of EATs at the departure and arrival ends of runways in all four quadrants (see Figure 1). While FAA Advisory Circular 5300-13, "Airport Design," [4] establishes design and/or operational criteria for EATs at departure ends of runways, it is significant to note that there are presently no regulatory criteria or standards that specifically address the use of EATs at approach ends. To address this issue, the FAA conducted this research to supplement previously developed End-Around Taxiway national standards for aircraft departures over EATs (References 1-4).

Prior to the development of national EAT criteria for arrival procedures, site-specific proposals, such as DFW, had to be evaluated on a case-by-case basis. Extensive discussion and analysis of the DFW case with DFW officials, American Airlines, Airline Pilots Association, National Aeronautics and Space Administration (NASA), FAA (Flight Standards, Air Traffic, Airports), the Center for Advanced Aviation System Development/MITRE, and others reflected that this unique proposal warranted further risk assessment and safety analysis, particularly regarding human factors issues.

This evaluation was coordinated at, and in conjunction with, the NASA Ames Research Center. Appendix A contains a chronology of events, background information, milestones, and depictions of demonstrations and evaluations conducted since the EAT concept was proposed.

1.3 DFW Airport and End-Around Taxiway Concept

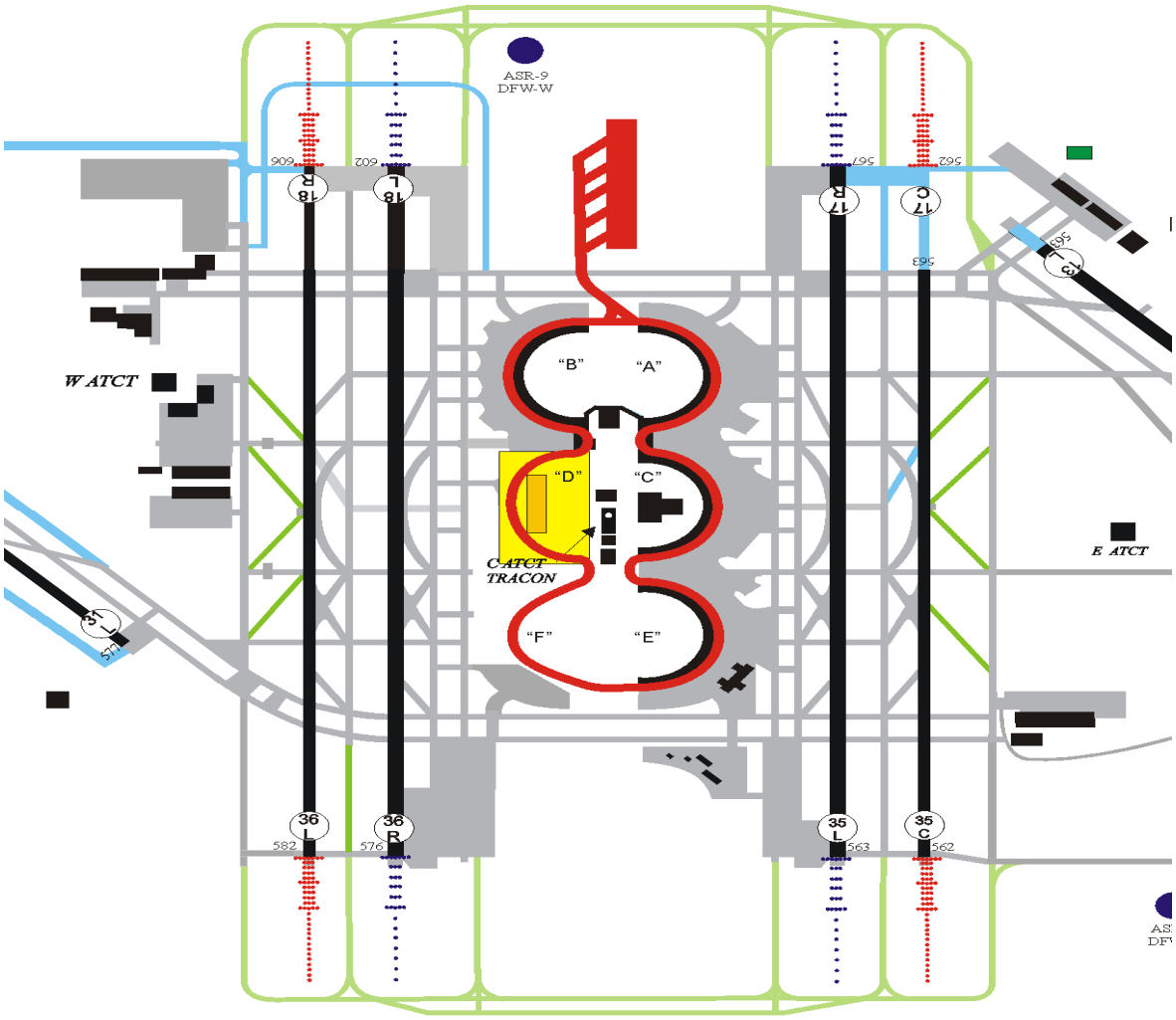

Figure 1: Dallas/Fort Worth International Airport EAT Design Plan

The DFW design plan features (see Figure 2 and Figure 3):

- EATs cross under final approaches and takeoff paths 2,650 feet from the ends of the runways.
- There are no penetrations of IFR approach surfaces.
- The IFR departure surface is penetrated only if it begins at the runway elevation (35 feet is acceptable).
- EATs are free-flowing without routine tower intervention.
- They are used for taxiing aircraft under aircraft that are both landing and taking off in both VFR and IFR conditions.

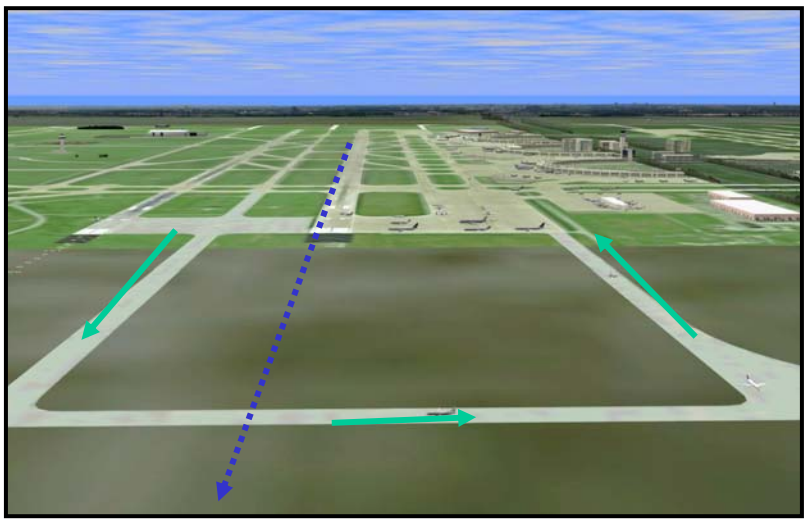

Figure 2: EAT Departures

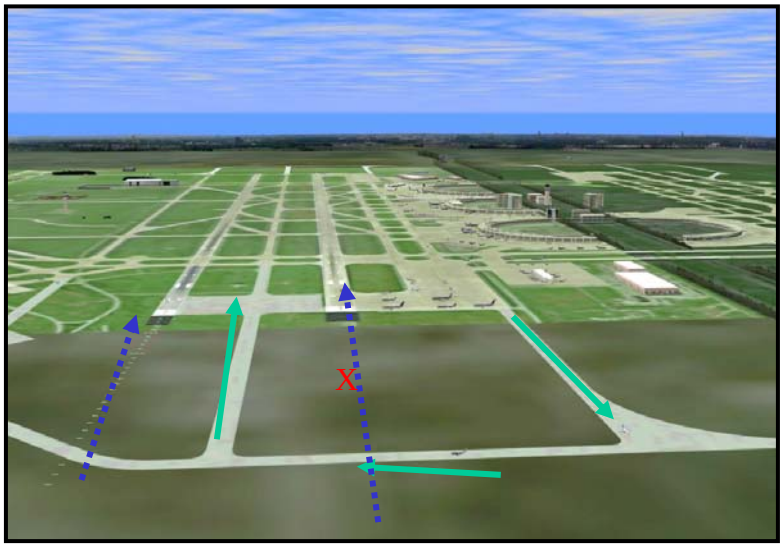

Figure 3: EAT Arrivals

2.0 Human Factors Evaluation

This evaluation was conducted using a B747-400 Level D Full Flight Simulator to evaluate EAT procedures for aircraft arriving at DFW Runways 17C and Runway 17R. Pilot performance (as it relates to aircraft performance) was evaluated from a human-in-the-loop standpoint through elicited subjective responses and comments from aircrews and objective observation of crew performance during closely scripted scenarios. Pilot comments varied slightly across all crews, with the predominant responses from pilots being those of relative comfort and limited workload changes directly attributable to the EATs themselves. Both pilot performance and responses from subjective post-run questionnaires corroborate this finding.

The primary criterion for pilot success was predicated on a crew's ability to fly the glide slope within stabilized flight criteria commensurate with their training, experience, and company standard operating procedures. For the purposes of this evaluation, stabilized flight was achieved when the aircraft was in final landing configuration and the crew did not exceed 1000 foot per minute rate of descent below 1000 feet above ground level for more than 3 seconds. With very few exceptions, all crews were successful in all of the scenarios. Pilot debriefing remarks indicated that pilots were very reluctant to fly directly over aircraft on the active EATs during meteorological or aircraft performance conditions (e.g., engine malfunction) when precise glide slope tracking might be compromised.

2.1 B737-400 Flight Simulator Operational Runs

Ten different crews each flew 24 distinct scenarios per the approved plan. Note that ceiling and visibility variables (e.g. 400'/6000RVR) were predicated on a crew's ability to visually acquire and react to EAT aircraft. The captain and first officer alternated flying each scenario. Table 1 displays the operational runs. Scenario sets were randomized across all crews (see Table 2). After completing the 24-scenario set, each crew conducted two additional scenarios (one day and one night) performing an Air Traffic Control (ATC)-directed sidestep maneuver from Runway 17C to Runway 17R. The sidestep maneuver scenarios were evaluated independently of the previous 24 scenarios. As such, the success or failure of arrival procedures was not predicated on the success or failure of the crew's performance during the sidestep maneuvers.

Table 1: Operational Scenarios

Scenario	Pilot Flying	Wind (Knots)	Ceiling (Feet AGL)	Visibility (SM/RVR)	Day/ Night	Autopilot Engaged/ Disengaged	EAT Traffic Density
1 Approach & Landing	CP/FO	215/10	Unlimited	Clear	Day	Engaged	None
2 Approach & Landing	CP/FO	125/10	Unlimited	Clear	Day	Engaged	One
3 Approach & Landing	CP/FO	215/10	Unlimited	Clear	Day	Engaged	Multiple
4 Approach & Landing	CP/FO	125/10	Unlimited	Clear	Day	Disengaged	None
5 Approach & Landing	CP/FO	215/10	Unlimited	Clear	Day	Disengaged	One
6 Approach & Landing	CP/FO	125/10	Unlimited	Clear	Day	Disengaged	Multiple
7 Approach & Landing	CP/FO	215/10	400	6,000	Day	Engaged	None
8 Approach & Landing	CP/FO	125/10	400	6,000	Day	Engaged	One
9 Approach & Landing	CP/FO	215/10	400	6,000	Day	Engaged	Multiple
10 Approach & Landing	CP/FO	125/10	400	6,000	Day	Disengaged	None
11 Approach & Landing	CP/FO	215/10	400	6,000	Day	Disengaged	One
12 Approach & Landing	CP/FO	125/10	400	6,000	Day	Disengaged	Multiple
13 Approach & Landing	CP/FO	215/10	Unlimited	Clear	Night	Engaged	None
14 Approach & Landing	CP/FO	125/10	Unlimited	Clear	Night	Engaged	One
15 Approach & Landing	CP/FO	215/10	Unlimited	Clear	Night	Engaged	Multiple
16 Approach & Landing	CP/FO	125/10	Unlimited	Clear	Night	Disengaged	None
17 Approach & Landing	CP/FO	215/10	Unlimited	Clear	Night	Disengaged	One
18 Approach & Landing	CP/FO	125/10	Unlimited	Clear	Night	Disengaged	Multiple

Table 1: Operational Scenarios (Continued)

Scenario	Pilot Flying	Wind (Knots)	Ceiling (Feet AGL)	Visibility (SM/RVR)	Day/ Night	Autopilot Engaged/ Disengaged	EAT Traffic Density
19 Approach & Landing	CP/FO	215/10	400	6,000	Night	Engaged	None
20 Approach & Landing	CP/FO	125/10	400	6,000	Night	Engaged	One
21 Approach & Landing	CP/FO	215/10	400	6,000	Night	Engaged	Multiple
22 Approach & Landing	CP/FO	125/10	400	6,000	Night	Disengaged	None
23 Approach & Landing	CP/FO	215/10	400	6,000	Night	Disengaged	One
24 Approach & Landing	CP/FO	125/10	400	6,000	Night	Disengaged	Multiple
25 Approach & Sidestep Landing	CP/FO	215/10	Unlimited	Clear	Day	Engaged	Multiple
26 Approach & Sidestep Landing	CP/FO	125/10	Unlimited	Clear	Night	Engaged	Multiple

Table 2: Randomized Operational Scenarios Schedule

Crew 1	Run 1 CP	Run 2 FO	Run 3 CP	Run 4 FO	Run 5 CP	Run 6 FO	Run 7 CP	Run 8 FO	Run 9 CP	Run 10 FO	Run 11 CP	Run 12 FO	Run 13 CP
Scenario	11	4	16	17	3	6	20	21	22	10	24	19	5
Crew 1	Run 14 FO	Run 15 CP	Run 16 FO	Run 17 CP	Run 18 FO	Run 19 CP	Run 20 FO	Run 21 CP	Run 22 FO	Run 23 CP	Run 24 FO	Run 25 CP	Run 26 FO
Scenario	2	14	8	18	13	7	15	9	23	1	12	25	26
Crew 2	Run 1 FO	Run 2 CP	Run 3 FO	Run 4 CP	Run 5 FO	Run 6 CP	Run 7 FO	Run 8 CP	Run 9 FO	Run 10 CP	Run 11 FO	Run 12 CP	Run 13 FO
Scenario	11	4	16	17	3	6	20	21	22	10	24	19	5
Crew 2	Run 14 CP	Run 15 FO	Run 16 CP	Run 17 FO	Run 18 CP	Run 19 FO	Run 20 CP	Run 21 FO	Run 22 CP	Run 23 FO	Run 24 CP	Run 25 FO	Run 26 CP
Scenario	2	14	8	18	13	7	15	9	23	1	12	25	26
Crew 3	Run 1 CP	Run 2 FO	Run 3 CP	Run 4 FO	Run 5 CP	Run 6 FO	Run 7 CP	Run 8 FO	Run 9 CP	Run 10 FO	Run 11 CP	Run 12 FO	Run 13 CP
Scenario	14	8	18	13	16	23	11	17	24	4	29	15	7
Crew 3	Run 14 FO	Run 15 CP	Run 16 FO	Run 17 CP	Run 18 FO	Run 19 CP	Run 20 FO	Run 21 CP	Run 22 FO	Run 23 CP	Run 24 FO	Run 25 CP	Run 26 FO
Scenario	10	3	6	22	2	5	12	1	19	9	21	25	26
Crew 4	Run 1 FO	Run 2 CP	Run 3 FO	Run 4 CP	Run 5 FO	Run 6 CP	Run 7 FO	Run 8 CP	Run 9 FO	Run 10 CP	Run 11 FO	Run 12 CP	Run 13 FO
Scenario	14	8	18	13	16	23	11	17	24	4	29	15	7
Crew 4	Run 14 CP	Run 15 FO	Run 16 CP	Run 17 FO	Run 18 CP	Run 19 FO	Run 20 CP	Run 21 FO	Run 22 CP	Run 23 FO	Run 24 CP	Run 25 FO	Run 26 CP
Scenario	10	3	6	22	2	5	12	1	19	9	21	25	26
Crew 5	Run 1 CP	Run 2 FO	Run 3 CP	Run 4 FO	Run 5 CP	Run 6 FO	Run 7 CP	Run 8 FO	Run 9 CP	Run 10 FO	Run 11 CP	Run 12 FO	Run 13 CP
Scenario	16	21	9	6	5	8	20	12	18	4	22	23	7
Crew5	Run 14 FO	Run 15 CP	Run 16 FO	Run 17 CP	Run 18 FO	Run 19 CP	Run 20 FO	Run 21 CP	Run 22 FO	Run 23 CP	Run 24 FO	Run 25 CP	Run 26 FO
Scenario	17	24	10	3	19	11	15	1	13	14	2	25	26

Table 2: Randomized Operational Scenarios Schedule (Continued)

Crew 6	Run 1 FO	Run 2 CP	Run 3 FO	Run 4 CP	Run 5 FO	Run 6 CP	Run 7 FO	Run 8 CP	Run 9 FO	Run 10 CP	Run 11 FO	Run 12 CP	Run 13 FO
Scenario	16	21	9	6	5	8	20	12	18	4	22	23	7
Crew 6	Run 14 CP	Run 15 FO	Run 16 CP	Run 17 FO	Run 18 CP	Run 19 FO	Run 20 CP	Run 21 FO	Run 22 CP	Run 23 FO	Run 24 CP	Run 25 FO	Run 26 CP
Scenario	17	24	10	3	19	11	15	1	13	14	2	25	26
Crew 7	Run 1 CP	Run 2 FO	Run 3 CP	Run 4 FO	Run 5 CP	Run 6 FO	Run 7 CP	Run 8 FO	Run 9 CP	Run 10 FO	Run 11 CP	Run 12 FO	Run 13 CP
Scenario	7	12	14	17	22	2	20	10	3	13	5	4	18
Crew 7	Run 14 FO	Run 15 CP	Run 16 FO	Run 17 CP	Run 18 FO	Run 19 CP	Run 20 FO	Run 21 CP	Run 22 FO	Run 23 CP	Run 24 FO	Run 25 CP	Run 26 FO
Scenario	6	9	21	1	15	11	19	16	8	24	23	25	26
Crew 8	Run 1 FO	Run 2 CP	Run 3 FO	Run 4 CP	Run 5 FO	Run 6 CP	Run 7 FO	Run 8 CP	Run 9 FO	Run 10 CP	Run 11 FO	Run 12 CP	Run 13 FO
Scenario	7	12	14	17	22	2	20	10	3	13	5	4	18
Crew 8	Run 14 CP	Run 15 FO	Run 16 CP	Run 17 FO	Run 18 CP	Run 19 FO	Run 20 CP	Run 21 FO	Run 22 CP	Run 23 FO	Run 24 CP	Run 25 FO	Run 26 CP
Scenario	6	9	21	1	15	11	19	16	8	24	23	25	26
Crew 9	Run 1 CP	Run 2 FO	Run 3 CP	Run 4 FO	Run 5 CP	Run 6 FO	Run 7 CP	Run 8 FO	Run 9 CP	Run 10 FO	Run 11 CP	Run 12 FO	Run 13 CP
Scenario	5	23	11	12	3	19	9	21	7	10	1	17	16
Crew 9	Run 14 FO	Run 15 CP	Run 16 FO	Run 17 CP	Run 18 FO	Run 19 CP	Run 20 FO	Run 21 CP	Run 22 FO	Run 23 CP	Run 24 FO	Run 25 CP	Run 26 FO
Scenario	13	18	15	14	8	22	2	20	6	24	4	25	26
Crew 10	Run 1 FO	Run 2 CP	Run 3 FO	Run 4 CP	Run 5 FO	Run 6 CP	Run 7 FO	Run 8 CP	Run 9 FO	Run 10 CP	Run 11 FO	Run 12 CP	Run 13 FO
Scenario	5	23	11	12	3	19	9	21	7	10	1	17	16
Crew 10	Run 14 CP	Run 15 FO	Run 16 CP	Run 17 FO	Run 18 CP	Run 19 FO	Run 20 CP	Run 21 FO	Run 22 CP	Run 23 FO	Run 24 CP	Run 25 FO	Run 26 CP
Scenario	13	18	15	14	8	22	2	20	6	24	4	25	26

2.2 Subject Pilots

A total of ten aircrews (i.e., one captain and one first officer) participated in this study. The crews were a mix of line pilots from various commercial airlines. All crew members were current or former (recently retired) captains or first officers with experience in either the Boeing 747-400 or similarly large type aircraft. Each crew had at least one pilot who was type-rated in the Boeing 747-400. Pilot ages ranged from 38 to 66 years, with pilot experience ranging from 25 to 50 years. Total flight time for subject pilots ranged between 7,000 and 37,000 total hours.

2.3 Subjective Questionnaire

A total of three questionnaires were distributed during the study. After each of the 26 scenarios/runs, both crew members (regardless of pilot flying [PF] or pilot monitoring [PM]) completed a subjective questionnaire, resulting in 520 total questionnaires collected. It was stressed that each questionnaire was designed to capture pilot reaction to that particular stand-alone scenario. Appendix B contains a copy of the post-run questionnaire

Following the simulator session, both the captain and first officer were given a final post-simulation questionnaire to gather their overall view of the operation and encompassing all scenarios/runs. Appendix C contains the post-simulation questionnaire. After completing the final questionnaire, the crew and evaluators/observers conducted a verbal post-simulation debriefing, which is contained in Appendix D.

All evaluators and observers briefed crews from a scripted briefing sheet and debriefed crews in the same manner to preserve data/test continuity and integrity.

2.4 Responses from Subjective Questionnaires

Pilots' responses to the questionnaires provided data on (1) their ability to visually acquire aircraft taxiing on the EAT, (2) their comfort level while flying approaches, and (3) their perceived workload during the operations. In addition, observers and evaluators also monitored the pilots during the scenarios to provide additional information regarding pilots' ability to perform final approach procedures with simultaneous EAT operations in effect.

2.4.1 Visual Acquisition of Taxiing Aircraft

Question 1 simply asked pilots if they visually acquired one, multiple, or no aircraft taxiing on the EAT. Eighty total scenarios contained no EAT aircraft at all and 160 scenarios contained either one or two EAT aircraft. The intent of this question was to determine if pilots remained focused on the intended point of landing or were partially distracted by EAT aircraft. Responses indicated that in most scenarios, they did detect and track aircraft on the EAT in the scenarios

containing one or multiple aircraft on the EAT. There was some confusion about whether an aircraft was present; however, this may have been due to aircraft on the EAT at the departure end of the runway. Some pilots reported seeing the aircraft on the EAT at the departure end of the runway, as well as on the arrival end. Eleven participants reported seeing an aircraft on the EAT when there was none and 16 participants reported not seeing an aircraft on the EAT when there was at least one.

2.4.2 Pilot Comfort Level and Workload

The questionnaires also surveyed pilot comfort level and workload while over flying the EAT. Generally, all crews consistently reported scores in the mid-range across comfort and workload scales. However, the first officer of Crew 6 misinterpreted Question 3 and Question 4 ("…comfort level prior to and directly flying over the EAT…") and took a different approach to answering those questions (i.e., he interpreted the questions to ask whether he was comfortable without taking into account each particular run's comparability to typical operations). Since he misinterpreted the questions, his responses were dropped from the analysis.

Question 2 dealt with a comparative analysis between approaches while EAT operations were ongoing and other approach procedures that the crew members had flown. Analysis found that there were no significant differences in reported difficulty of flying the approaches over the EAT as compared to typical operations. Generally, both the PFs and the PMs reported that the EAT operations were about the same difficulty as their normal operations (see Figure 4).

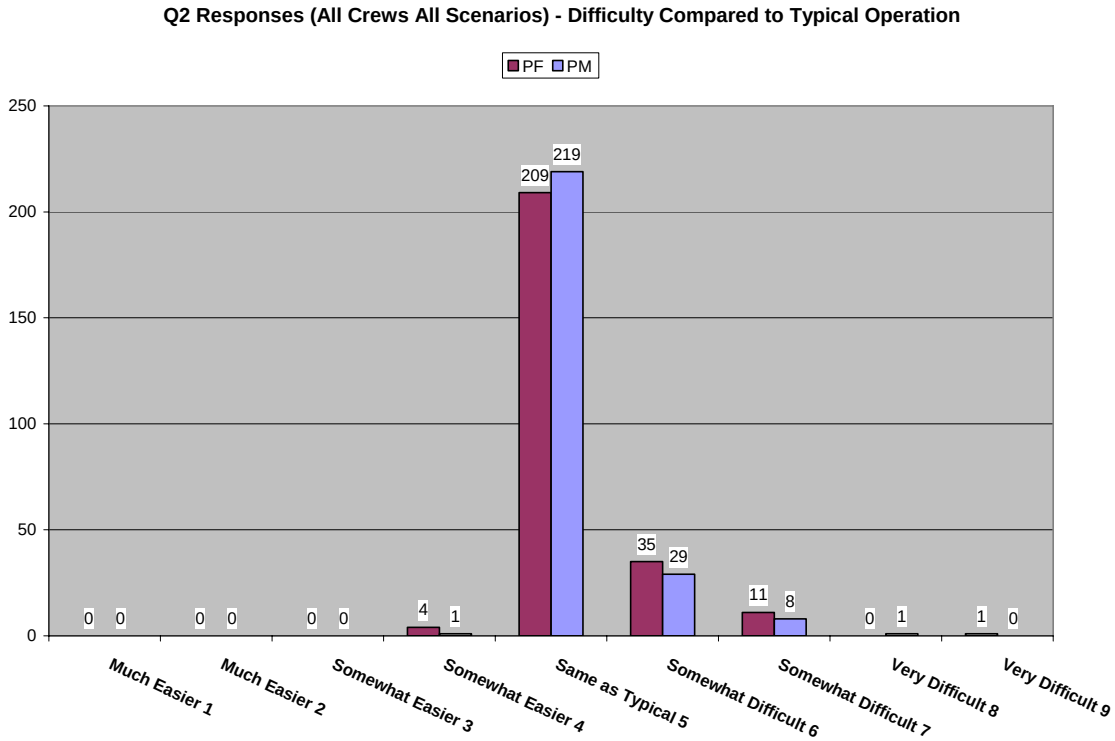

Figure 4: Responses to Question 2:
Difficulty Compared to Typical Operation

Table 3 shows the average (mean) PF responses to Questions 2 through 6 by number of aircraft on EAT. Question 3 and Question 4 were intended to derive information concerning crew member comfort level both before flying over the EAT and while flying directly over the top of the EAT. Question 3 asked pilots to rate their comfort level prior to over flying the EAT. (See Figure 5.) Recalling that a lower response correlates to greater comfort, the averages imply greater comfort levels in those scenarios that did not have any aircraft on the EAT. A 2 (visibility) x 2 (day/night) x 3 (number of aircraft on the EAT) Analysis of Variance (ANOVA) showed a statistically significant difference in the means for Question 3 by number of aircraft on the EAT at $p < 0.05$ ($F(2, 8) = 6.079$). (See Figure 6.)

Table 3: Average Subjective Questionnaire Responses by Number on Aircraft on EAT (5=Same as Typical)

Question	Zero EAT	One EAT	Multiple EAT
2	5.01	5.1	5.09
3	4.8	5.08	5.4
4	4.9	5.58	5.75
5	5.14	5.39	5.34
6	5.08	5.25	5.26

Note: Scenarios 25 and 26 were not included in the averages.

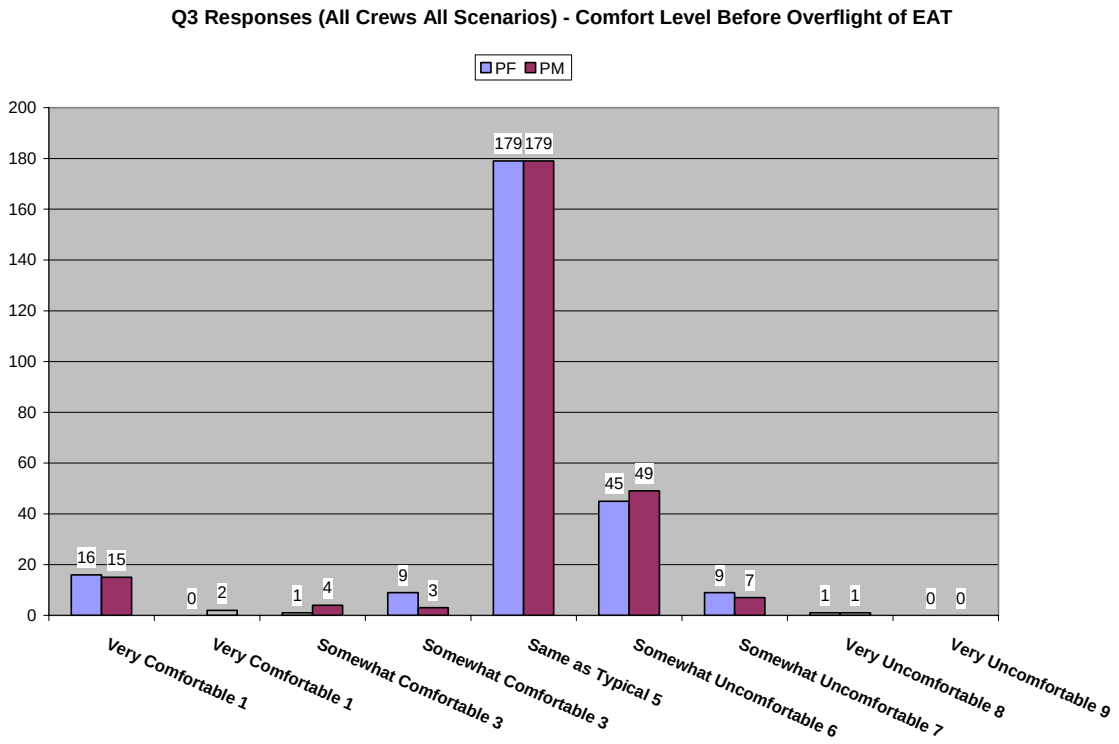

Figure 5: Responses to Question 3: Comfort Level Before Overflight of EAT

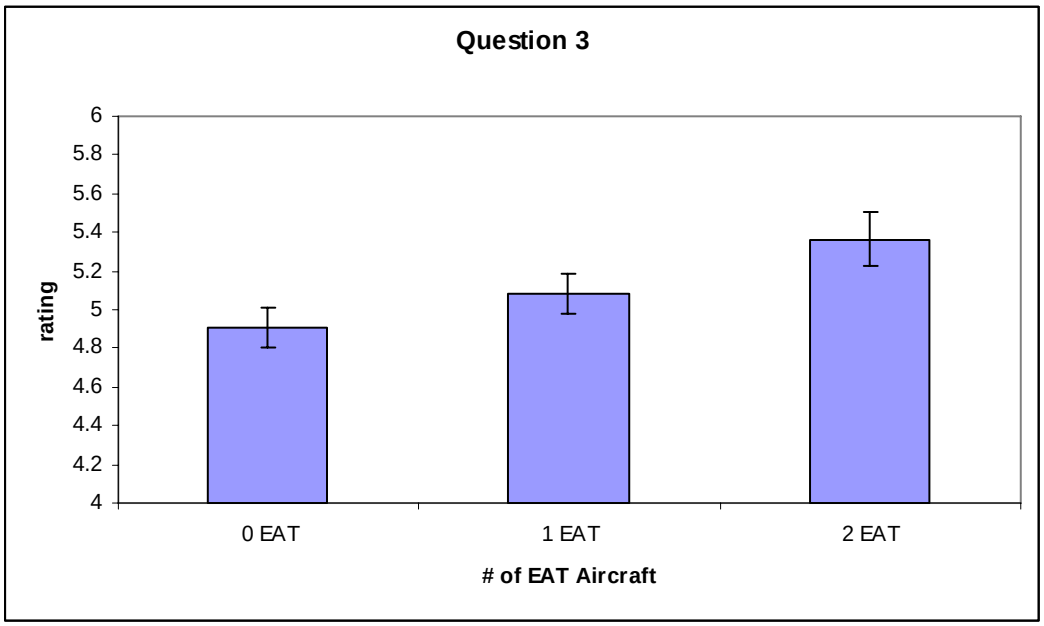

Figure 6: Responses to Question 3 by Number of Aircraft on the EAT

Question 4 asked pilots to rate their comfort levels when directly over the EAT. (See Figure 7 and Figure 8.) As in Question 3, pilots reported a greater level of comfort when there were no aircraft on the EAT. This was a statistically significant difference in means at $p < 0.01$ ($F(2, 8) = 12.704$). Responses to Question 4 also showed a main effect of visibility at $p < 0.05$ ($F(1, 9) = 5.309$), with a decrease in comfort level in the lower visibility condition (see Figure 9).

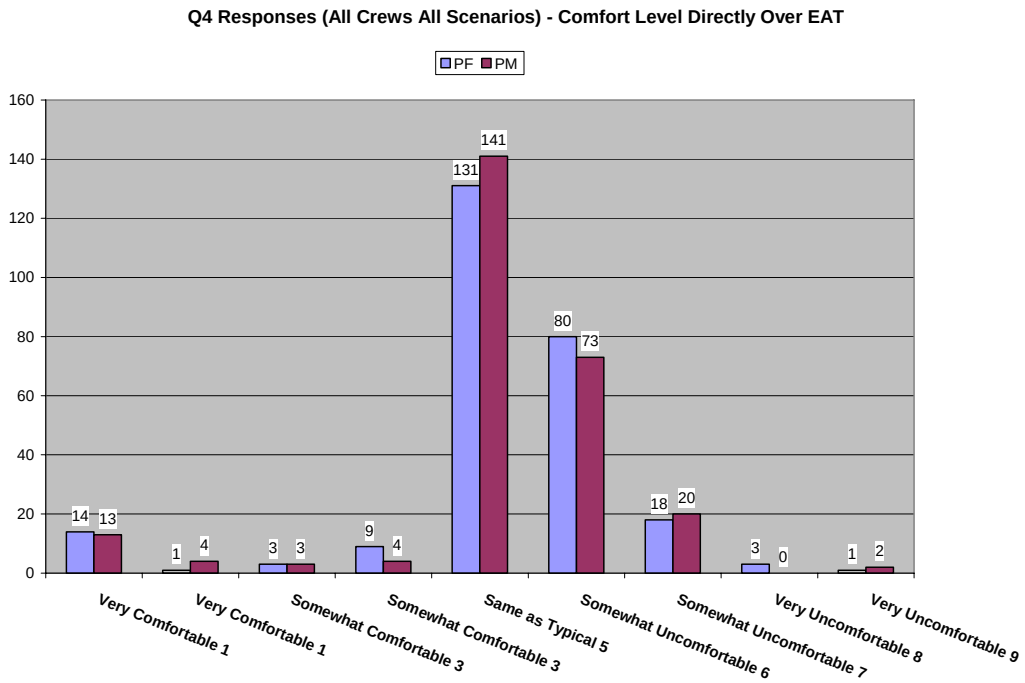

**Figure 7: Responses to Question 4:
Comfort Level Directly Over EAT**

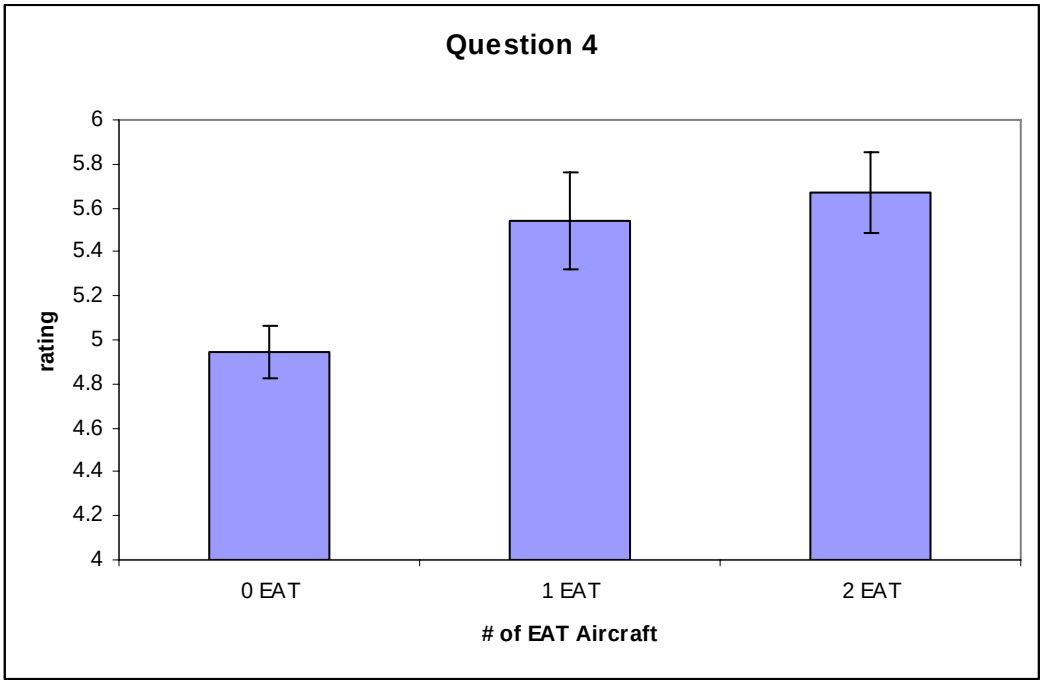

**Figure 8: Responses to Question 4
by Number of Aircraft on the EAT**

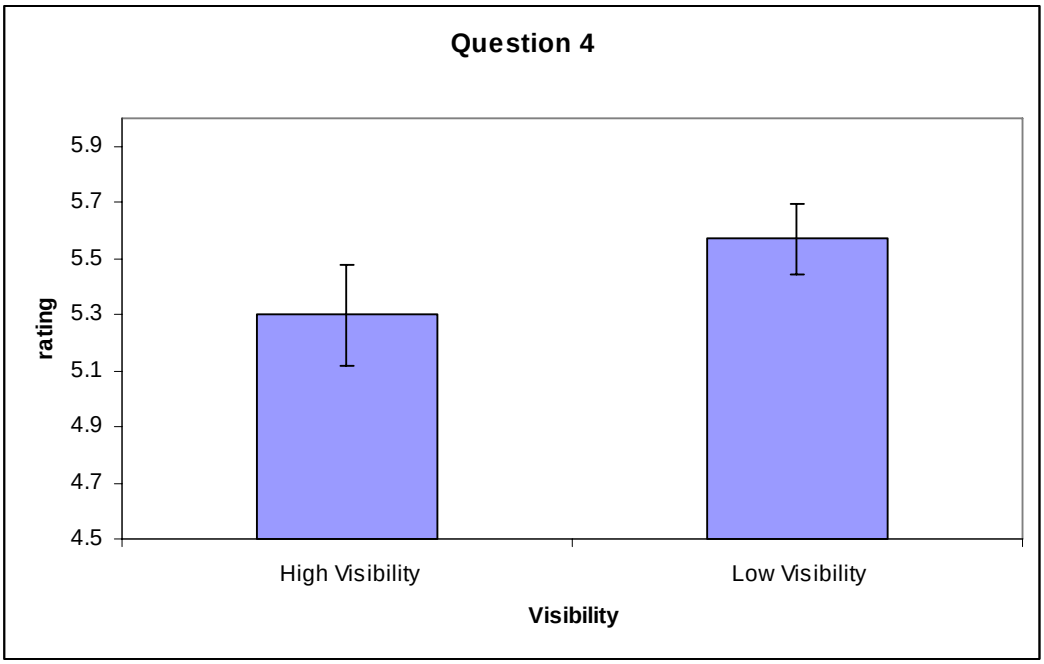

Figure 9: Responses to Question 4 by Visibility

In both Question 3 and Question 4, while there was a statistically significant decrease in the rated levels of comfort with an increasing number of aircraft on the EAT, it is not a practical difference. The ratings in the uncomfortable range tended to be "slightly uncomfortable" and differed from the "same as typical operations" by a relatively small amount. Pilot comments during the debriefing indicated an increase in comfort levels with increased experience and familiarity with EAT operations in the simulator.

Pilot comments, as well as subjective ratings, generally indicated that the sidestep maneuver scenarios (Scenarios 25 and 26) were the least comfortable scenarios of the simulation. Since these two scenarios were flown during the same period as the nominal approach conditions, pilots commented on them in comparison with the entire scenario set. Note that as a result, the averages in Table 3 and ANOVA results do not include the sidestep maneuver.

Question 5 and Question 6 asked crew members about their perceived levels of individual and crew workload (i.e., any change in level of workload that can specifically be attributed to EAT operations). There were no statistically significant differences in reported individual or crew workload between scenarios. Pilots reported that both individual and crew workload levels were consistent with workload experienced during their normal piloting duties. Figure 10 and Figure 11 display perceived individual and crew workloads, respectively.

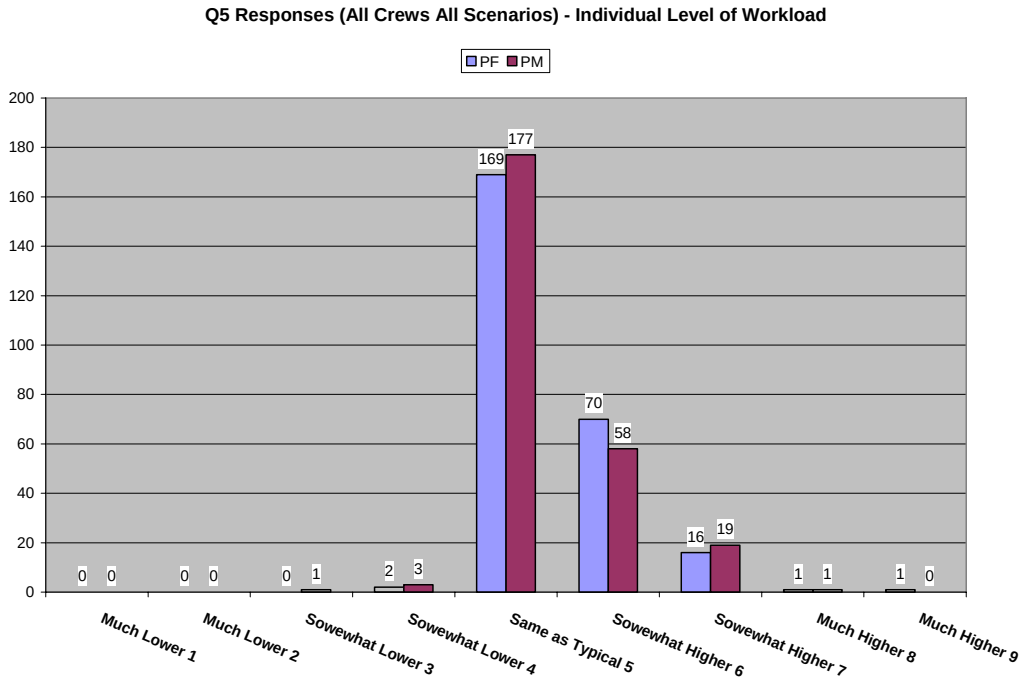

Figure 10: Responses to Question 5: Individual Workload

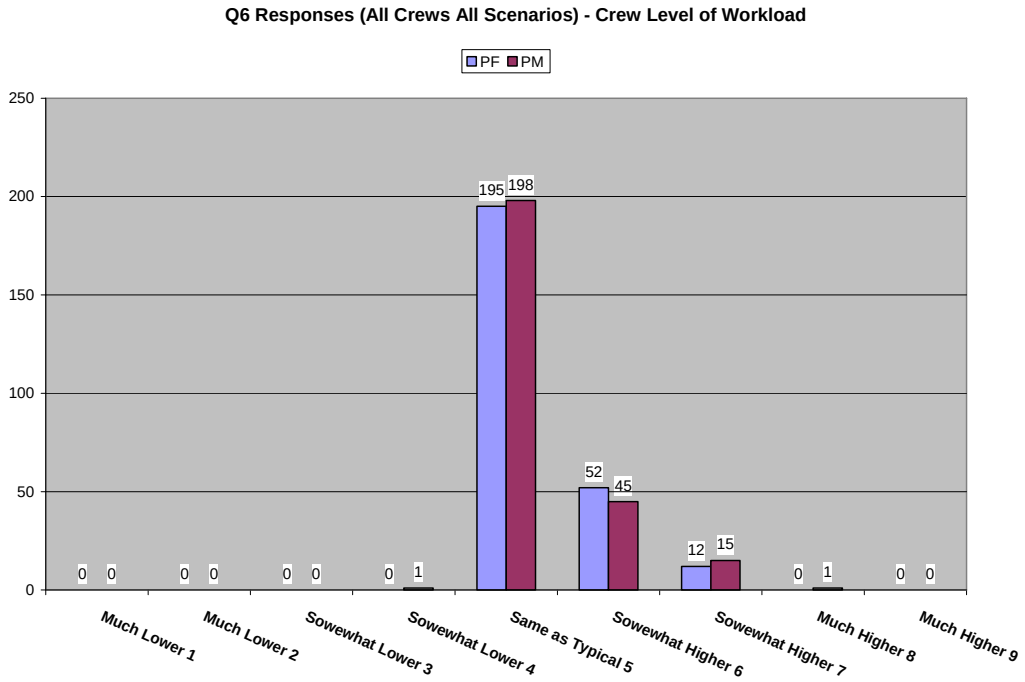

Figure 11: Responses to Question 6: Crew Workload

2.5 Objective (in-the-Cockpit) Observations

Objective crew performance measures were accomplished through simple observation of pilot/crew performance. Observers, which included pilots who were familiar with commercial aircraft pilot procedures and techniques, were unobtrusively positioned directly behind the pilot stations in the simulators. All flight scenarios were carefully scripted. During those periods in a given flight sequence when a pilot or crew member performed a task out of the norm, the observers monitored both primary and secondary task completion. That is, task performance was monitored during those times pilots might have been required to do more things or different things within the scope of their duties to safely maneuver the aircraft. As such, mental or physical workload might have increased, tasks may have been perceived as more difficult, reactions to external stimuli might have changed, or task shedding may have taken place. Such changes were observed and recorded; however, reaction times, visual scan patterns, and instrument/system monitoring were not measured.

For the purposes of this evaluation, primary tasks were those that included the approach and arrival sequence when EAT operations were ongoing (e.g., visually scanning the area near or around the end of the runway, visually acquiring aircraft that were either operating on the EAT or crossing at some point on the arrival runway or at the departure end of that runway, and taking appropriate action). Secondary tasks included those measures that occur during normal flight operations (e.g., properly configuring the airplane, communications calls, crew cockpit coordination, and checklist completion items).

Generally, pilots had no difficulty physically performing final approach procedures with simultaneous EAT operations in effect. There did not appear to be any appreciable increase in physical demands based upon the EAT scenario. During those times when other large aircraft were operating on the EAT, pilots might have been required to accomplish more or different actions within the scope of their duties to safely maneuver the aircraft (e.g., visual acquisition strategies, scanning techniques, and crew cockpit coordination). No primary or secondary task shedding was observed.

During arrival operations, pilots were only minimally distracted by aircraft on any part of the EAT. Both the PF and PM remained on task during the final approach. Infrequently, the PF/PM was observed leaning forward to gain visual acquisition of EAT aircraft or to enhance greater visibility of the visual scene. Those crew members indicated this was done more out of curiosity than out of operational necessity, and this behavior would likely subside as they gained operational exposure and experience with these procedures. Several pilots stated that they had visually acquired aircraft on the EAT at the approach and/or departure ends of the landing runway. Pilots did not deviate from the nominal flight path due to this. Note that one-third of all scenarios did not have any EAT aircraft in the visual scene at all. The remaining two-thirds had either one or multiple aircraft on the EAT.

2.6 Pilot Comments/Debriefing Remarks

After each crew completed all scenarios, a very short debriefing was conducted to gather crew comments, concerns, and recommendations. A summary of the most frequent crew comments is listed below:

- All crews felt comfortable flying over the top of EAT aircraft as long as they were assured of glide slope integrity. While the use of Precision Approach Path Indicator/Visual Approach Slope Indicator lights might be sufficient, EATs should not be conducted unless the electronic glide slope is operational. Any potential compromise of an aircraft's ability to maintain the glide slope (wind shear, turbulence, mechanical problem, etc.), given the proximity of their own ship's landing gear to the tail of a Group IV aircraft on the EAT, would be grounds for a go-around or even suspending EAT operations.

- Approximately half the crews felt more comfortable when ceiling and visibility conditions were very low, so that they did not visually acquire aircraft on the EAT. While they knew those aircraft were (or could be) taxiing, they felt secure knowing that the system was properly vetted for Terminal Instrument Procedures (TERPS) and operational clearances and did not have the added requirement of searching for and acquiring the EAT aircraft. The same group felt that during good ceiling and visibility conditions, when visual acquisition of the EAT could be made from farther away, the pilots felt the need to include the EAT aircraft in their scan pattern, which potentially increased workload. The other half of the subjects indicated that they were more comfortable when they could visually acquire the EAT aircraft as far out as possible and maintain visual contact with both EAT and crossing aircraft.

- There was no appreciable increase in mental or physical workload during arrivals when EAT operations were in effect, whether pilots had visual acquisition of an EAT aircraft or not.

- Comfort levels increased with more flights flown.

- All crews universally commented on an increase in anxiety levels during the sidestep maneuver from Runway 17C to Runway 17R. This was in large part due to the loss of a dedicated localizer and glide slope on Runway 17R. They were less comfortable having to fly this short final approach visually without electronic vertical guidance.

- When queried about any previous experience with or knowledge of EAT operations on the line, pilots almost universally indicated only a passing knowledge of the concept. Most of the pilots had neither experience with nor knowledge of the concept. The pilot viewpoints on EAT operations were perceived to be unbiased prior to this demonstration.

- Two crews felt that they had climbed slightly at the point of over flying an aircraft on the EAT. The observers' recording and the aircraft performance data do not corroborate this as glide slope tracks show that they maintained a constant rate of descent and did not violate stabilized flight criteria at any time. Most likely, the pilots experienced a minor perceptual anomaly, which was not supported by the data analysis.

- Future notification media is critical to alerting pilots of EAT use. Some of the potential systems included Notices to Airmen, Attention All Users Pages, notes on the approach charts, Automatic Terminal Information Service, and/or ATC calls.

- Crew training in the form of a video or even in a simulator would be extremely beneficial prior to landing or departing at a site with EATs in use.

- While the pilots did not experience any trials in which they were over flown by an arrival aircraft while transiting the EAT, the flight crews all expressed concern about being the aircraft on the EAT that was being flown over. The pilots indicated that they would likely slow down or speed up to avoid being directly under an arrival aircraft while transiting the EAT. Some of the pilots thought that it might be appropriate to make a passenger call to notify the cabin that the over flight was normal.

3.0 Aircraft/Pilot Performance Evaluation

Aircraft performance and position data were gathered during the entire simulation. The purpose for such data collection was to verify that pilots were able to maintain stabilized flight throughout each scenario and to measure their tracking performance. Data used in the following analysis included:

- Touchdown location
- Flight path tracking (localizer and glide slope deviations)

The tracking data were collected to evaluate each crew's ability to maintain precise tracking on the glide slope from the time the aircraft began its descent on a 3-degree glide slope and landing the aircraft at the intended point of touchdown while maintaining the aircraft within stabilized flight criteria. The glide slope and localizer tracking data were reduced to Average Error (AveE) values across each trial. The AveE values were used as the dependent variable for the following statistical analyses.

The tracking data were essentially measuring only the PF's performance. Therefore, if the PF did not see an EAT aircraft when one was present, these trials were removed from the analysis and replaced with the series mean. There were 11 trials (7%) in which the PF did not see the EAT aircraft. In addition, a data collection error resulted in missing data for one trial, which was also replaced with the series mean. As a result, a total of 228 trials were included in the analysis.

3.1 Glide Slope Tracking

Generally, crews maintained stabilized flight along the glide slope and touched down within the intended landing zone. Of the 239 recorded runs there was one missed approach, and 3 aircraft landed greater than 3000 feet from threshold (3018 feet,3168 feet and 3240feet).
Figure 12 depicts the glide slope of all ten crews for a representative scenario with the autopilot disengaged; Figure 13 shows the glide slope with autopilot engaged. As predicted, flight path tracking was less precise with the autopilot disengaged but still well within stabilized flight criteria. In the autopilot off condition, pilots tended to fly slightly above the glide slope, although not appreciably.

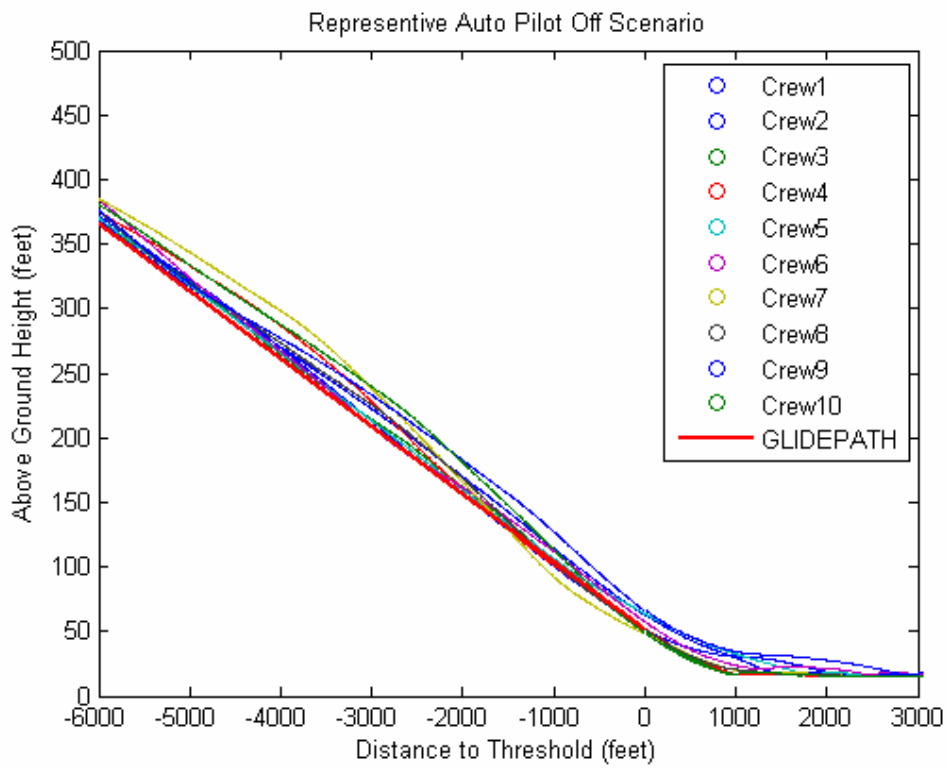

Figure 12: Glide Slope: All Crews Scenario with Autopilot Off

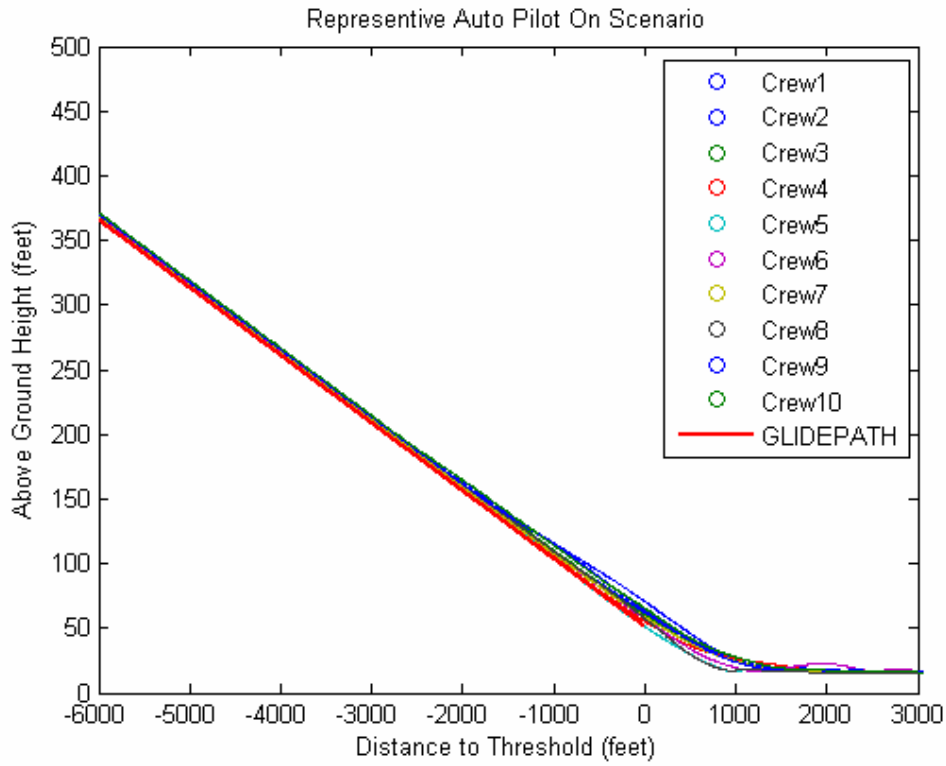

Figure 13: Glide Slope: All Crews Scenario with Autopilot On

Using the glide slope AveE data, a 2 (visibility) x 2 (day/night) x 2 (auto/hand fly) x 3 (number of aircraft on the EAT) ANOVA showed a significant main effect of visibility at $p < 0.05$; (F (1, 9) = 6.15), and autopilot condition at $p < 0.01$; (F (1, 9) = 29.59). Figure 14 and Figure 15 show that the glide slope tracking errors increased with clear visibility and with hand flying, respectively. This result was expected as more deviations were anticipated while hand flying and in clear visibility (when pilots spend more time scanning out the window). There were no main effects across the day/night and number of EAT aircraft independent variables.

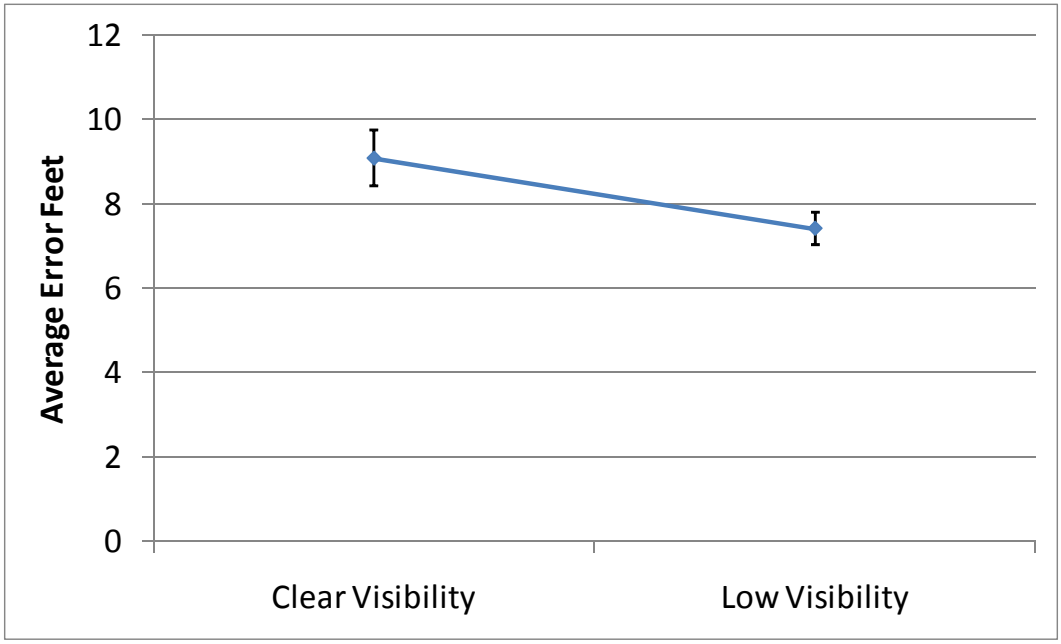

Figure 14: Average Glide Slope Tracking Errors by Visibility

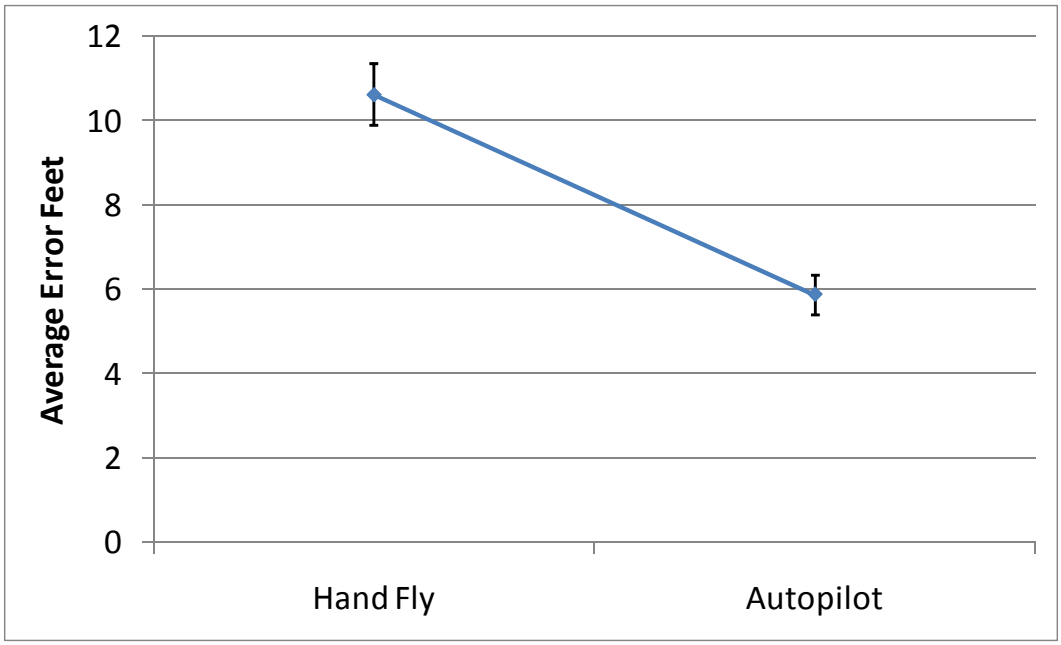

Figure 15: Average Glide Slope Tracking Errors by Autopilot Condition

There was a significant three-way interaction between visibility, autopilot condition, and number of aircraft on the EAT at $p < 0.05$; (F (2, 18) = 4.95). Figure 16 shows that in good visibility, the glide slope AveE tended to decrease when there were EAT aircraft present and pilots were hand flying the approach. The glide slope AveE tended to slightly increase when the pilots were using the autopilot. This suggests that the pilots may have been more focused on the tracking task when EAT aircraft were present.

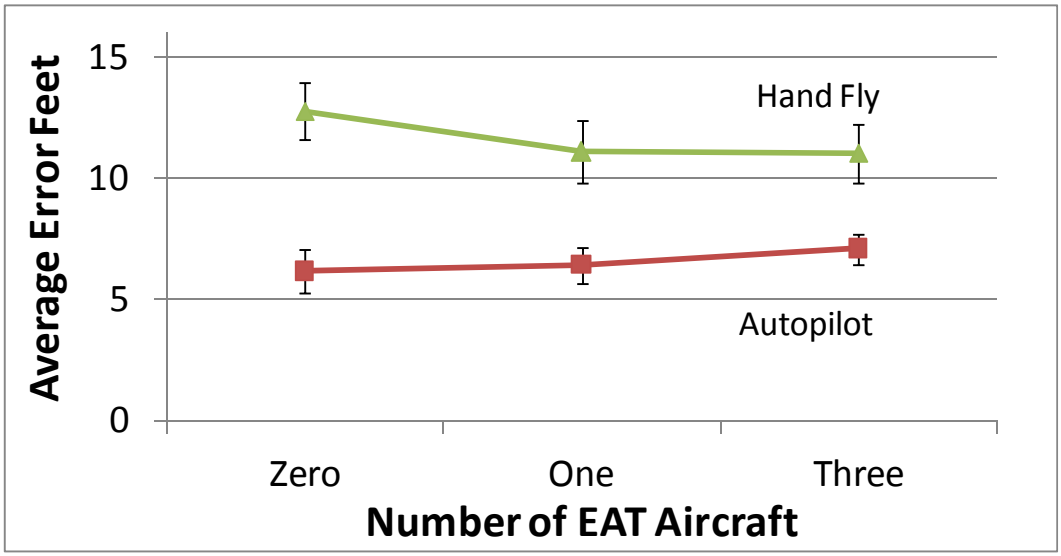

Figure 16: Average Glide Slope Tracking Errors in Clear Visibility by Autopilot Condition and Number of EAT Aircraft

Figure 17 shows that in reduced visibility conditions, the tracking errors were less affected by the EAT aircraft. This was expected, as the EAT aircraft were not visible until the very end of the reduced visibility trials.

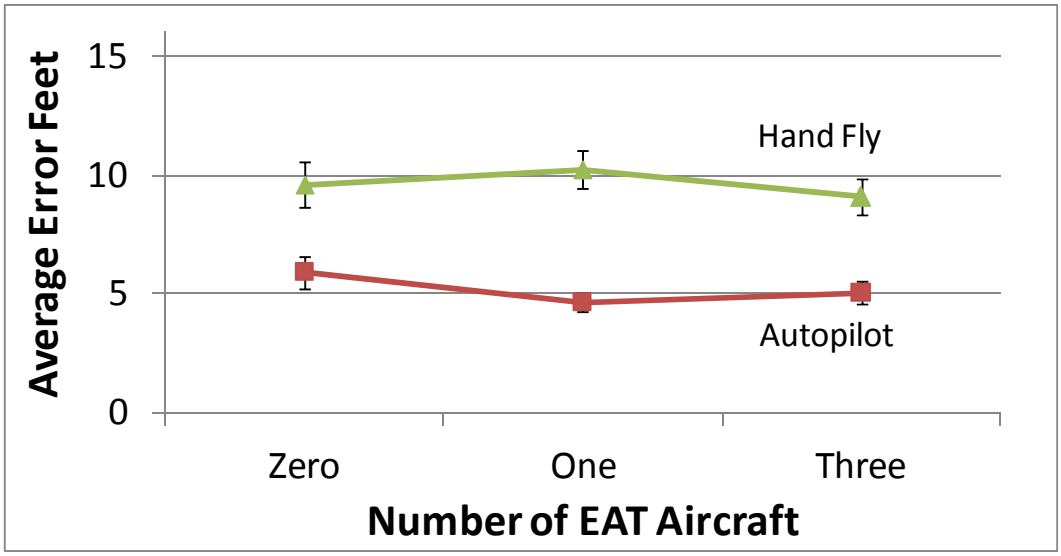

Figure 17: Average Glide Slope Tracking Errors in Reduced Visibility by Autopilot Condition and Number of EAT Aircraft

Another parameter that was critical to the evaluation was the crossing height of the aircraft above the EAT (feet AGL), assuming precise tracking on the glide slope. For evaluation purposes, the EAT crossing height dependent variable can be broken down into the following variables: autopilot on/off and one/multi/no EAT aircraft, accounting for six categories shown in Table 4.

In the first five of the six categories, the average EAT crossing height fell within less than three feet of each other. In the sixth category (autopilot off/no EAT aircraft), the average EAT crossing height was highest by approximately three feet. In 1.5% of the total runs, aircraft crossed below two standard deviations of the mean (autopilot on and off). In 3.0% of the total runs, aircraft crossed above two standard deviations of the mean (autopilot on and off).

Table 4 shows that pilots crossed over the top of the EAT within close tolerance of the glide slope with few exceptions. Under nominal conditions, the glide slope crossed the EAT at approximately 191 feet AGL.

Table 4: Average Height at Crossing End-Around Taxiway (Feet)

Autopilot	Zero EAT	One EAT	Multi EAT
On	192.8	191.7	191.7
Off	196.6	190.7	193.0

The third dependent variable that was critical to the evaluation was the average touchdown point from threshold. (See Table 5.) There were no runs with autopilot on that landed outside of two standard deviations of the mean. There were four total runs (1.5 %) with autopilot off that landed farther than two standard deviations from the mean with the greatest being 3240 feet.

Table 5: Average Touchdown Point From Threshold (Feet)

Autopilot	Zero EAT	One EAT	Multi EAT
On	1,708.1	1,752.8	1,744.9
Off	1,839.5	1,744.5	1,868.2

3.2 Localizer Tracking

The lateral tracking analysis yielded results similar to the results of the glide slope tracking. Using the localizer AveE data, a 2 (visibility) x 2 (day/night) x 2 (auto/hand fly) x 3 (number of aircraft on the EAT) ANOVA showed a significant main effect of visibility at $p < 0.01$; (F (1, 9) = 20.28), and auto/hand fly at $p < 0.01$; (F (1, 9) = 54.02). Figure 18 and Figure 19 show that localizer tracking errors increased with clear visibility and with hand flying, respectively. Similar to the glide slope analysis above, this result was expected as more deviations were anticipated while hand flying and in clear visibility (when pilots spend more time scanning out the window). There were no main effects across the day/night and number of EAT aircraft independent variables.

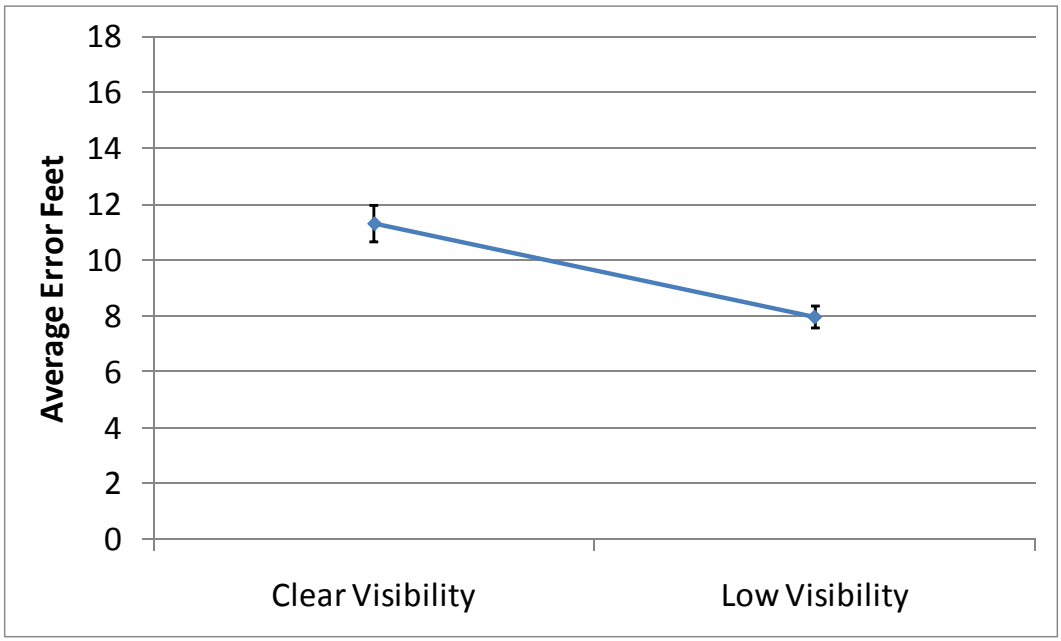

Figure 18: Average Localizer Tracking Errors by Visibility

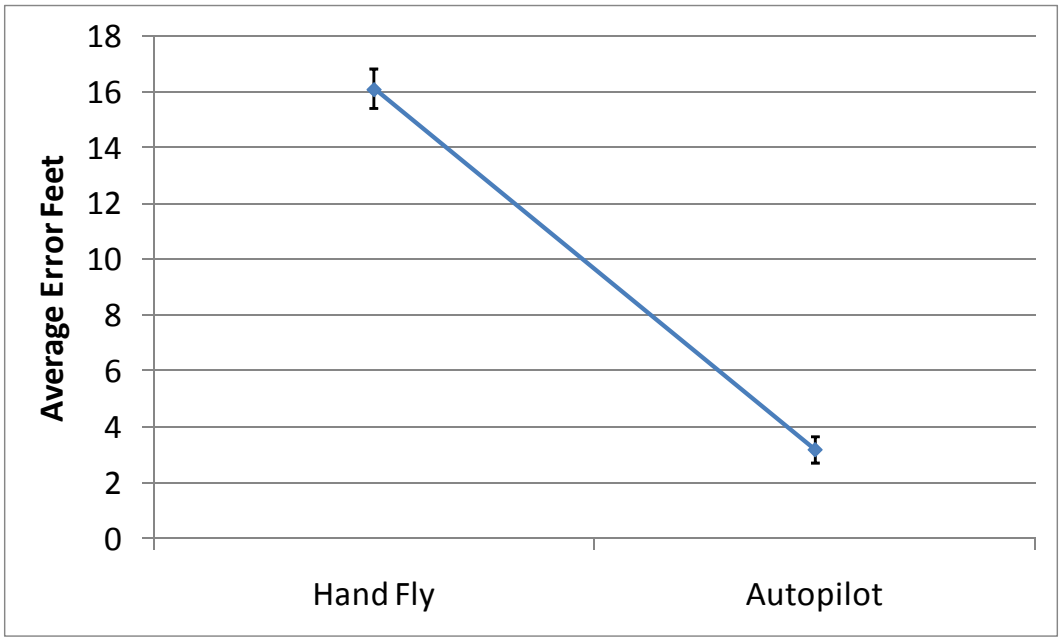

Figure 19: Average Localizer Tracking Errors by Autopilot Condition

There were significant two-way interactions between day/night and visibility at $p < 0.05$; (F (1, 9) = 6.53) and also between visibility and auto/hand fly at $p < 0.01$; (F (1, 9) = 18.26). Figure 20 and Figure 21 show that localizer tracking errors increased in clear visibility at night and in clear visibility when hand flown. This result is not surprising as pilots spend more time scanning out the window in good visibility conditions and tracking errors were expected to increase with hand flying.

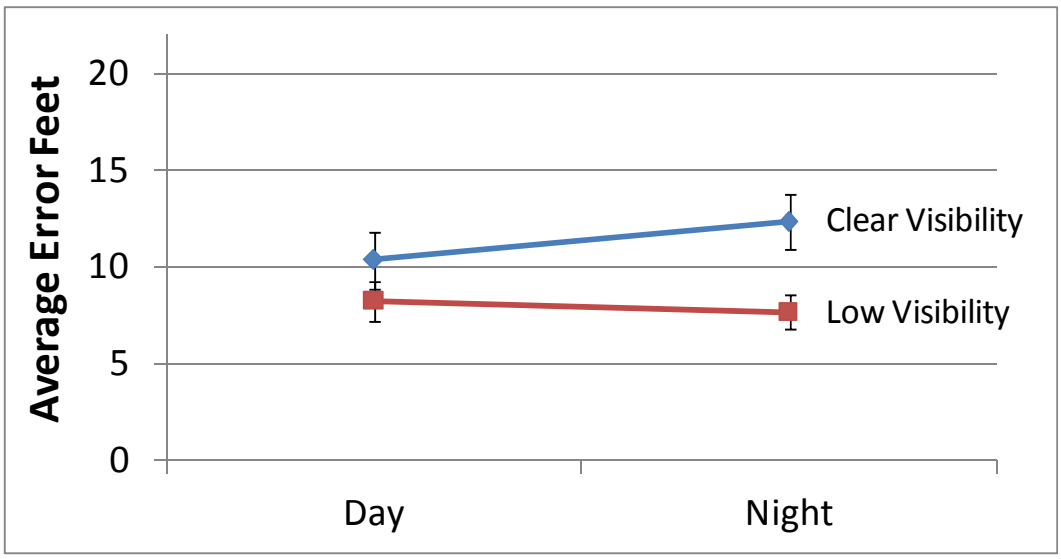

Figure 20: Average Localizer Tracking Errors by Visibility and Time of Day

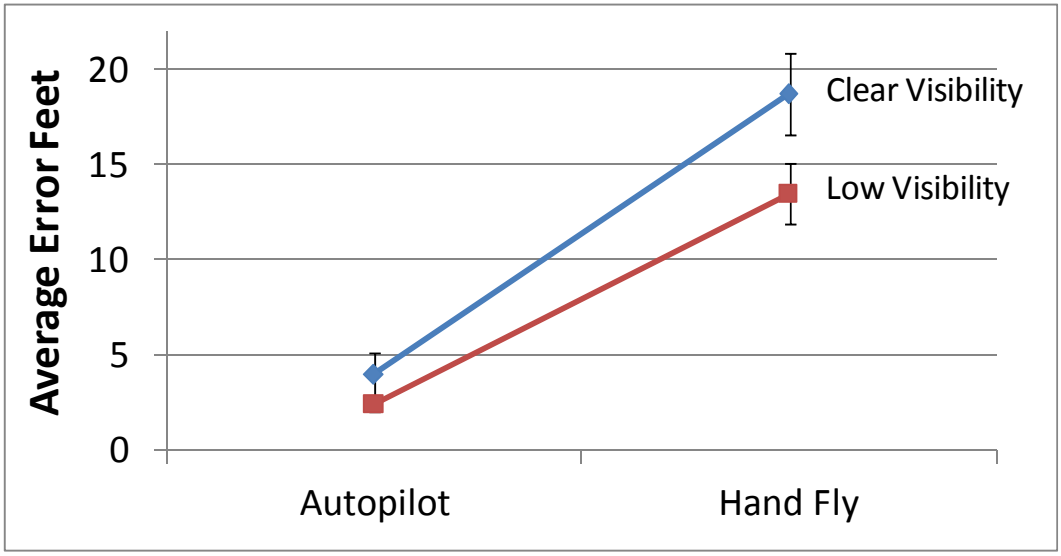

Figure 21: Average Localizer Tracking Errors by Visibility and Autopilot Condition

There was a significant three-way interaction between visibility, autopilot condition, and number of aircraft on the EAT at $p < 0.05$; (F (2, 18) = 6.25). Figure 22 shows that in good visibility the localizer AveE tended to decrease when there were EAT aircraft present and pilots were hand flying the approach and tended to slightly increase when the pilots were using the autopilot. This suggests that the pilots may have been more focused on the tracking task when EAT aircraft were present. Figure 23 shows that in reduced visibility conditions, the tracking errors were less affected by the EAT aircraft. This was expected, as the EAT aircraft were not visible until the very end of the scenario.

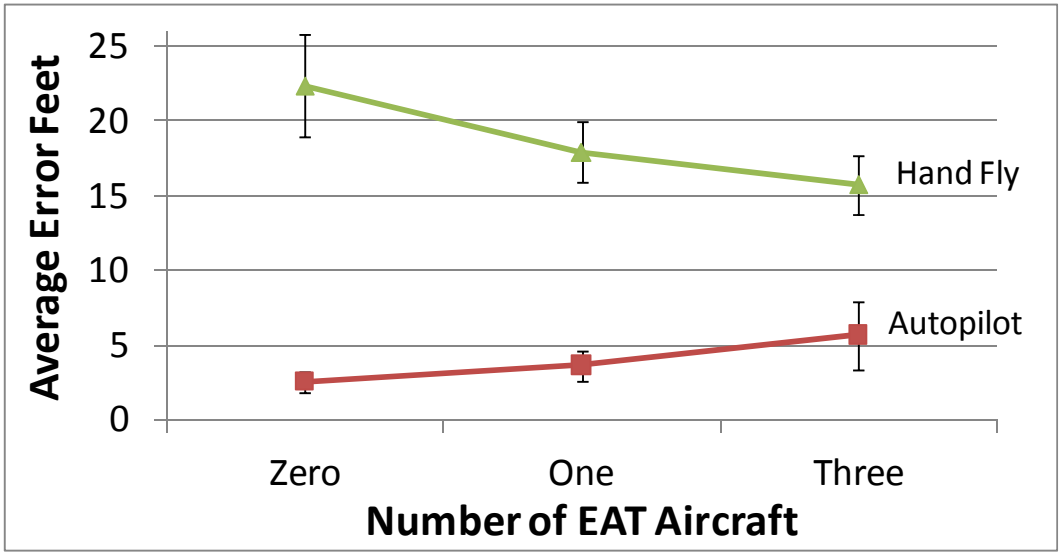

Figure 22: Average Localizer Tracking Errors in Clear Visibility by Autopilot Condition and Number of EAT Aircraft

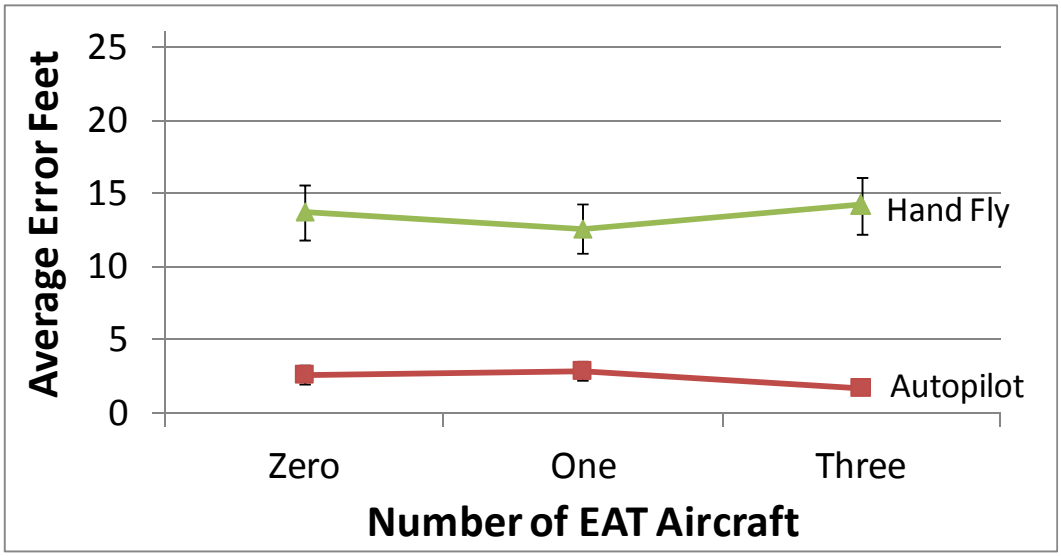

Figure 23: Average Localizer Tracking Errors in Reduced Visibility by Autopilot Condition and Number of EAT Aircraft

4.0 Conclusions

Conclusions drawn from this data, analysis, and demonstration can be modestly generalized to other runways or other locations, assuming similar geometries, elevations, runway configurations, etc.

4.1 Human Factors

The DFW proposal for an EAT system would certainly reduce the frequency of runway crossings of conventional crossing taxiways. It may also significantly reduce the amount of communications between ATC and aircraft on the ground. Furthermore, from a human factors perspective, there was no appreciable increase in mental or physical workload for the pilot or crew of final approach aircraft that would compromise current levels of safety.

In general, subjective data from crew responses and observations and objective data from aircraft performance indicate that pilots had no difficulty maintaining aircraft control within stabilized flight criteria across all variables and all scenarios (except for scenarios with sidestep maneuvers). Pilots clearly acquired aircraft on or near the EAT structure, maintained visual contact, and performed their normal duties with limited or no degradation to performance.

Beyond the expected differences associated with the autopilot and reduced visibility trials, the objective aircraft performance data indicated that when EAT aircraft were present, and when pilots were hand flying, both vertical and lateral tracking errors were less. The presence of EAT aircraft appears to have caused the pilots to allocate more attention to the tracking task (i.e. visually tracking and flying the aircraft to the intended point of landing). This resulted in reduced tracking errors. However, the subjective data did not indicate any increase in perceived workload associated with the additional attention devoted to the tracking task when EAT aircraft were present.

The pilots' responses on the subjective questionnaire resulted in a statistically significant decrease in the rated levels of comfort with increasing aircraft on the EAT. However, their comfort ratings tended to be "slightly uncomfortable," and only slightly differed from the "same as typical operations." In addition, during the debriefing, pilots indicated they became more comfortable with EAT operations after more experience with them. Pilot comments, as well as subjective ratings, generally indicated that the sidestep maneuver scenarios were the least comfortable phases of the simulation.

Finally, during the debriefing, the pilots expressed some concern about being on the EAT while another aircraft was approaching. Although the pilots did not experience this condition, they speculated that they might adjust their taxi speed to avoid being directly under the approaching aircraft when it crossed over the EAT. The pilots provided several other comments concerning aircraft on the EAT or crossing near the departure end of the landing runway. However, these

comments are consistent with comments and concerns already discussed, examined, and vetted in other studies.

4.2 Operations

The implementation of EAT requires the development of airfield and flight operational procedures to ensure that the appropriate level of safety is maintained while promoting capacity goals. All operational issues have been identified, and feasible recommendations and mitigations have been suggested. This would include a proper aircrew notification and training program to familiarize flight crews with EAT operations.

5.0 Recommendations

Based upon the evaluation of the data collected, arrival operations with EATs should be approved in the current operational design. EAT operations may increase safety levels for the reasons mentioned. Pilot crews felt that this operation might increase safety through the reduction of runway crossings and reduced aircraft/ATC communications. Furthermore, there do not appear to be any human factors, Crew Resource Management, or operational issues that should preclude approach operations over EATs.

As is the case in similar evaluations of this type, further investigation may be needed to: (1) identify crew training requirements, (2) develop crew notification procedures that EAT are in effect at arriving/departing airports, and (3) evaluate the impact on both the crew and passengers of actual EAT aircraft when another aircraft is on short final, on a perpendicular course or over flying the EAT.

We did not evaluate (3) above in this study. Although we feel that safety concerns for aircraft that are on the EAT are not expected, the frequency of pilot debriefing comments may warrant a follow-up study to evaluate the effect on a crew/passengers, in an EAT aircraft, with an aircraft over-flying them. The methodology for such an evaluation needs further development. Perhaps, this subsequent study might involve the use of two interactive simulators, one flying as the arriving aircraft and the other as the EAT aircraft. Regardless of the methodology, a rigorous experimental design is not warranted as nothing out of the ordinary is expected.

Appendix A: Background Information and Chronology of EAT Evolution

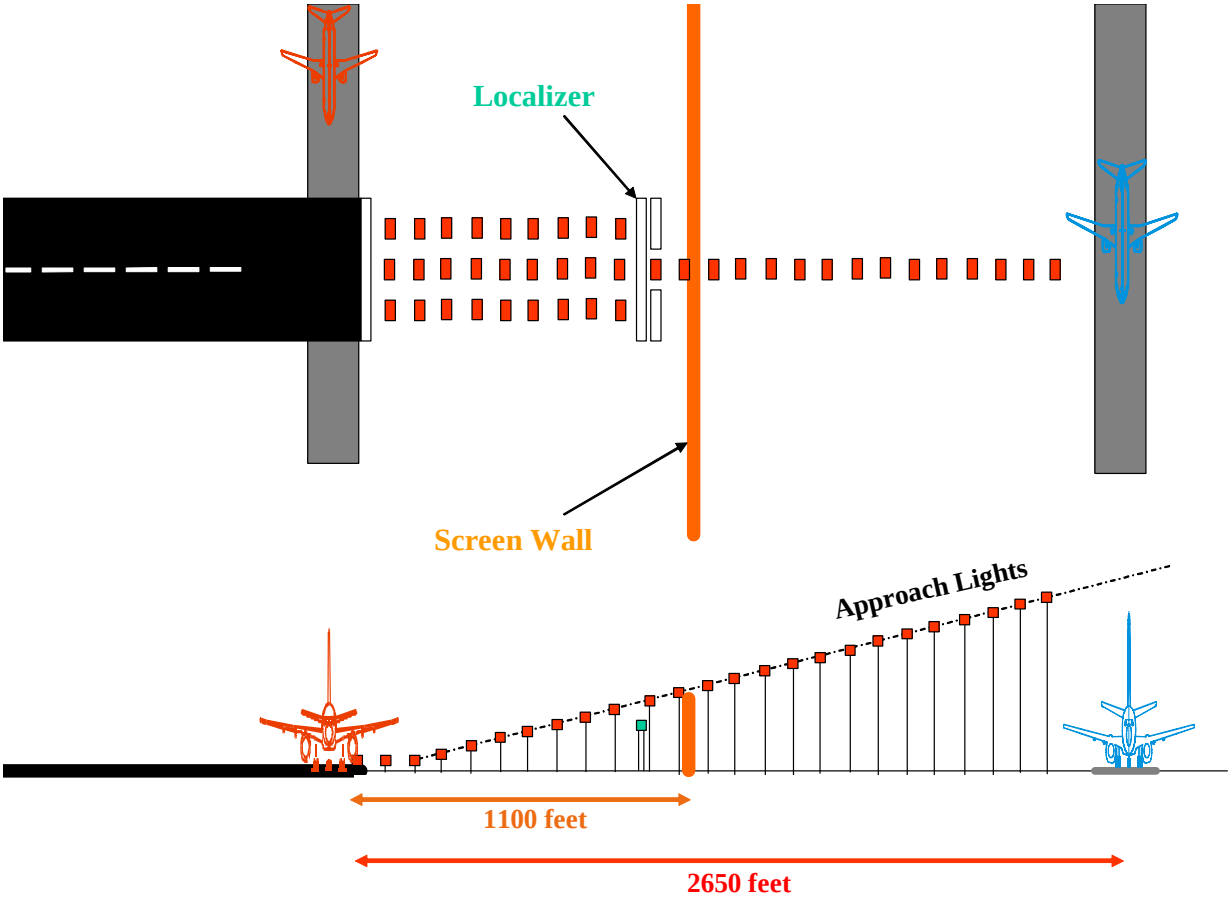

Figure A1: EAT Geometry

Figure A2: KATL-Atlanta EAT Proof-of-Concept Demonstration
May 2004

Figure A3: PC-Based Simulation – January 2005

Figure A4: Masking Screen Prototype (6,000 Feet) – April 2006

Figure A5: Masking Screen Prototype (Boeing 737 Masking Aircraft – Front) – April 2006

Figure A6: Masking Screen Prototype (Boeing 737 Masking Aircraft – Behind) – April 2006

Figure A7: Masking Screen Prototype (ARFF Vehicle) – April 2006

Figure A8: Masking Screen Prototype (ARFF Vehicle – 2,000 Feet) – April 2006

Appendix B: Post-Run Questionnaire

DATE: _____ CREW #: _____ RUN # _____ SCENARIO _____ PF/PNF

Post-Run Questionnaire

1. Did you see any aircraft on the EAT during this approach? YES ☐ NO ☐

2. How does the difficulty of this procedure compare to your typical company operations?

Much Easier		Somewhat Easier		**Same as Typical Operation**	Somewhat Difficult		Very Difficult	
1	2	3	4	5	6	7	8	9

3. Rate your level of comfort while on the visual segment of the final approach <u>before</u> passing over the EAT.

Very Comfortable		Somewhat Comfortable		**Same as Typical Operation**	Somewhat Uncomfortable		Very Uncomfortable	
1	2	3	4	5	6	7	8	9

4. Rate your level of comfort when your aircraft was <u>directly over</u> the EAT.

Very Comfortable		Somewhat Comfortable		**Same as Typical Operation**	Somewhat Uncomfortable		Very Uncomfortable	
1	2	3	4	5	6	7	8	9

5. Rate your **individual workload** for this procedure from the standpoint of thinking, deciding, calculating, remembering, looking, searching, etc.

Much Lower Workload		Somewhat Lower Workload		**Same as Typical Operation**	Somewhat Higher Workload		Much Higher Workload	
1	2	3	4	5	6	7	8	9

6. Rate the **crew workload** for this procedure from the standpoint of thinking, deciding, calculating, remembering, looking, searching, communicating, coordinating, etc.

Much Lower Workload		Somewhat Lower Workload		**Same as Typical Operation**	Somewhat Higher Workload		Much Higher Workload	
1	2	3	4	5	6	7	8	9

7. Any additional comments about this trial?

_____

_____

Appendix C: Post-Simulation Questionnaire

DATE: _____CREW #:_____ RUN #_____SCENARIO_____PF/PNF

Post-Simulation Questionnaire

1. In general, compared to other approach procedures that your company performs, characterize the overall procedure flown in the test.

Easy			Moderate			Difficult		
1	2	3	4	5	6	7	8	9

2. Rate your overall level of comfort with this procedure.

Very Comfortable			Moderately Comfortable			Uncomfortable		
1	2	3	4	5	6	7	8	9

3. Compared to other approach procedures, rate the overall level of effort required to perform this one.

Lower			No Different			Higher		
1	2	3	4	5	6	7	8	9

4. Rate your perceived level of **individual situational awareness** for this procedure.

Low			Moderate			High		
1	2	3	4	5	6	7	8	9

5. Rate the overall level of **crew situational awareness** for this procedure.

Low			Moderate			High		
1	2	3	4	5	6	7	8	9

Appendix D: Post-Simulation Debrief

DATE: _____CREW #:_____ PF/PNF

Post-Simulation De-Brief

1. Overall, did you feel comfortable with this procedure (i.e. as the arriving aircraft with another aircraft on the End-Around Taxiway)? _____ Why? Why Not? _____

_____

_____

2. What additional mental or physical requirements were imposed on you during this procedure? Were there any changes to your workload due to over flying the EAT aircraft?

_____

_____

3. Which phase of the procedure was most difficult? _____ Why? _____

_____

_____

4. In actual operations, how comfortable would you be over flying an aircraft on the EAT with **good** visibility?

_____

_____

5. In actual operations, how comfortable would you be over flying an aircraft on the EAT with **poor** visibility?

_____

_____

6. Did you have any problems discriminating between aircraft that were on the EAT and aircraft that may have been holding short at any point on the runway? _____

_____

_____

7. Have you ever been to any other location where End-Around Taxiways or similar operations are in effect? _____
Where?_____

What were your impressions?

_____

_____

8. Do you have any suggestions for this procedure in the future?

_____

_____

References

[1] Reisweber, Mark, et.al. *Proof-of-Concept Demonstration for the Proposed Runway 8R End Around Taxiway (EAT) at Hartsfield-Jackson Atlanta International Airport (KATL),* DOT-FAA-AFS-440-5, November 2004

[2] Reisweber, Mark, et.al. *Proof-of-Concept Demonstration for the Proposed Runway 17R End Around Taxiway (EAT) at Dallas/Fort Worth International Airport (DFW),* DOT-FAA-AFS-440-6, November 2004

[3] Reisweber, Mark, et.al. *Safety Study Report On Aircraft Discrimination And Masking Evaluation For The Proposed Runway 17R End Around Taxiway (Eat) At Dallas/Fort Worth International Airport* DOT-FAA-AFS-440-12, June 2005

[4] FAA Advisory Circular 150/5300-13, "Airport Design." Change 10. September 9, 2006