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Flight Crew Performance Study for Paired Approach Operations

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NOTICE

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12. Abstract

The Federal Aviation Administration Flight Technologies and Procedures Division (AFS-400) conducted a feasibility study of the paired approach concept to parallel runways with centerlines spaced at 750 feet apart. The paired approach concept uses Automatic Dependent Surveillance – Broadcast (ADS-B) technology to reduce flight delays that are caused by poor weather conditions. The paired approach concept is designed to protect the trailing aircraft of the pair from a collision with the lead aircraft, if the lead aircraft blunders into its path. The paired approach concept also protects the trailing aircraft from the wake of the lead aircraft during nominal operations. Data were collected from a pilot human in the loop simulation conducted in the AFS-400 Airbus 330 (A330) flight simulator and the Air Traffic Control lab simulator located at the Mike Monroney Aeronautical Center in Oklahoma City, OK. MITRE Center for Advanced Aviation System Development (CAASD) Paired Approach experimental avionics were integrated into the A330 flight simulator for use during the study.

13. Key Words	14. Distribution Statement
ADS-B Guidance Display (AGD) Aircraft Identification (ACID) Area Navigation (RNAV) Automatic Dependent Surveillance – Broadcast (ADS-B) Blunder Cockpit Display of Traffic Information (CDTI) Data Collection Effort (DCE) Desired Spacing Goal (DSG) First Officer (FO) Flight-deck Interval Management (FIM) Human Factors (HF) Human in the Loop (HITL) Instrument Landing System (ILS) Localizer Paired Approach (PA) Performance-Based Navigation Planned Final Approach Speed (PFAS) Simulation Model ATC Research and Training (SMART) Traffic Collision Avoidance System Wake	Uncontrolled
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Executive Summary

The purpose of this report is to address the findings of the pilot human in the loop (HITL) feasibility study of the paired approach concept which was conducted at the Mike Monroney Aeronautical Center in Oklahoma City, OK from June 9th through June 20th, 2014.

The paired approach concept endeavors to increase runway capacity in instrument meteorological conditions (IMC) by enabling properly equipped aircraft to fly dependent approaches to parallel runways spaced 700 to 2,500 feet (ft) apart with a category I decision altitude. The concept was originally proposed by United Airlines. The MITRE Center for Advanced Aviation System Development (CAASD) began developing the concept in 1998 under the Federal Aviation Administration's (FAA) Safe Flight program. Over the last six years, work has continued with direct FAA sponsorship under the National Airspace System Segment Implementation Plan, through the Improved Multiple Runway Operations Portfolio, and operational improvement increments that pertain to the Closely Spaced Parallel Operations program. [1]

The objectives of this study were (1) to determine if flight crews can effectively operate the paired approach avionics under changing workload conditions, (2) to determine if they can acquire and maintain the desired spacing goal (DSG), and (3) to evaluate subject flight crew performance when confronted with nominal and off-nominal situations.

The assumptions used for this study were (1) an aircraft fleet mix that represented traffic at San Francisco International Airport (SFO), (2) weather conditions that were slightly above approach minimums for the area navigation RNAV (Required Navigation Performance (RNP)) PA RWY 28R San Francisco International approach procedure, (3) surface winds that were at the paired approach limit speed (maximum crosswind of 5 knots for SFO) and increasing with altitude, and (4) a descent checklist and approach briefing completed prior to commencing each simulated run.

The HITL data collection effort (DCE) was conducted in the Flight Technologies and Procedures Division (AFS-400) Airbus 330-200 (A330) flight simulator. The experimental paired approach avionics developed by MITRE CAASD were integrated into the simulator for this study. The study found that use of the paired approach concept is feasible, based on the performance of the subject flight crews. With only a brief introduction to the MITRE CAASD experimental paired approach avionics functions, operation, and symbology, the crews were able to operate the avionics under all conditions evaluated. They were able to acquire and maintain the DSG both with and without the assistance of the DSG symbology displayed on the paired approach avionics. When confronted with nominal and off-nominal situations, the crew complied with the breakout command that was issued by the paired approach avionics in every case.

The DCE was specifically designed to collect subjective and objective data to be used as a baseline for assessing the feasibility of the paired approach concept and for future paired approach studies. Further evaluation and testing will be necessary prior to operational consideration and implementation.

1 Introduction

The initiative for performance-based navigation dependent approaches in less than visual conditions to closely spaced parallel runways, is identified in the FAA's Automatic Dependent Surveillance-Broadcast (ADS-B) Application Integrated Work Plan. The paired approach concept endeavors to increase airport capacity in IMC by enabling properly equipped aircraft to fly dependent approaches to parallel runways spaced 700 to 2,500 ft apart to a category I decision altitude. AFS-400 conducted a pilot HITL DCE to assess the feasibility of the paired approach concept to parallel runways with runway centerlines spaced at 750 ft apart. Experimental paired approach avionics developed by MITRE CAASD were integrated into the A330 Level D qualified flight simulator for the HITL DCE. The DCE was specifically designed to collect subjective and objective data to be used as a baseline for assessing the feasibility of the paired approach concept and for future paired approach studies. The data were collected in the AFS-400 A330 flight simulator and Air Traffic Control (ATC) lab simulator, located at the Mike Monroney Aeronautical Center in Oklahoma City, OK. The data parameters collected and the resulting analysis of that data are contained in this report. No certified professional controllers were included in the test and no controller data were collected.

1.1 Background

Paired approach procedures are intended to facilitate IMC approaches to closely-spaced parallel runways (with spacing from 700 to 2,500 ft apart) and to increase runway capacity where simultaneous independent parallel approaches cannot be conducted in IMC. The procedures are enabled by advanced avionics, including ADS-B Out on the lead aircraft and ADS-B In on the trailing aircraft. The trailing aircraft must be equipped with a Cockpit Display of Traffic Information (CDTI), an ADS-B Guidance Display (AGD), and software algorithms that assist the trailing aircraft in maintaining a safe position with respect to the lead aircraft. The trailing aircraft must maintain a position behind a front gate, such that it is protected from collision in the event of a blunder by the lead aircraft, and in front of a rear gate, such that it is protected against wake encounters associated with a non-blundering lead aircraft. The desired position lies between these two gates and is referred to as the DSG. The conceptual paired approach geometry is depicted in figure 1-1.

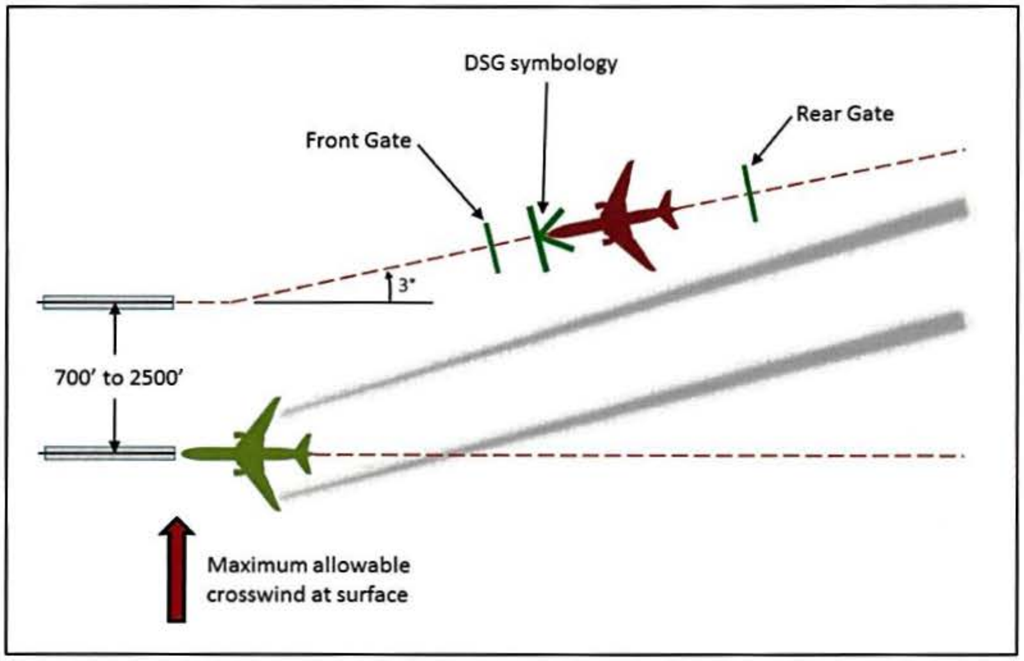

Figure 1-1: Paired Approach Operations Concept and Approach Geometry

As illustrated in Figure 1-1, the paired approach concept and geometry is comprised of simultaneous dependent approaches to parallel runways. There is an instrument landing system (ILS) approach for the leading aircraft to one runway and a converging approach course on a RNAV RNP instrument approach procedure (IAP) with authorization required for the trailing aircraft to the adjacent, parallel runway. Controllers vector the trailing aircraft to pair with the leader and join the approach approximately 15 to 20 nautical miles (NM) from the threshold. The paired approach algorithm computes speed commands required to reach and maintain the DSG which is a fixed distance behind the lead aircraft. The DSG is a function of the planned final approach speed (PFAS) of both aircraft as described by equation 1-1.

$$DSG = 5400\,ft + 120\frac{ft}{kt}\cdot\left(PFAS_{lead} - PFAS_{trail}\right) \qquad (1\text{-}1)$$

To set up the aircraft pairs, Terminal Radar Approach Control controllers request the PFAS of each aircraft. The controllers assess the incoming air traffic and choose aircraft to pair based on aircraft equipage and the PFAS of each aircraft. ATC will then advise the trailing aircraft in the pair of the lead aircraft's PFAS and aircraft identification (ACID). The flight crew of the trailing aircraft utilizes this information to properly configure their paired approach avionics. Controllers then vector each aircraft to their respective starting positions and issue clearance to the trailing aircraft to initiate pairing procedures. The trailing aircraft pilots use the paired approach avionics to assist in achieving the DSG prior to reaching the final approach fix (FAF).

MITRE CAASD conducted a HITL DCE for pilots in May, 2012, and a HITL DCE for controllers in May, 2013. Pilots from four major airlines rated the cockpit workload of the operation to be acceptable and offered several suggestions for modifications to the display functions. Certified professional controllers from the North California Terminal Radar Control Facility indicated the tasks required of the operation were feasible, acceptable, and could be performed by the average controller at the facility.

1.2 Purpose

The purpose of this DCE was to assess the safety, workload, and feasibility of paired approach operations from the flight crew viewpoint, as well as the effectiveness of the paired approach avionics to assist the flight crew in acquiring and maintaining the DSG.

2 Objectives and Scope

There were three objectives to this feasibility study:

- Objective 1: Determine if the subject flight crews can effectively operate the paired approach avionics under changing workload conditions;
- Objective 2: Determine if the subject flight crews can acquire and maintain the DSG; and
- Objective 3: Evaluate subject flight crew performance when confronted with one nominal and four off-nominal situations during the final approach.

The scope of this study incorporated the overall paired approach objectives that support the tasks identified in the FY14 Project Level Agreement listed below. Although, this study was specifically designed to meet objectives 1 through 3 as defined above, the analysis provided information to support the following project objectives:

- Provide input to paired approach concept of operations;
- Provide input to the determination of pilot and controller roles and responsibilities;
- Evaluate the effectiveness of the breakout alert and the associated breakout procedure to enable a safe and effective maneuver;
- Evaluate the effect of the presence or absence of the DSG symbology on the paired approach avionics on the crew ability to acquire and maintain the DSG;
- Evaluate the closest points of approach (CPA), specifically during blunder events; and
- Evaluate the potential for a wake encounter during the paired approach procedure.

3 Methodology

The test was scheduled over a 10 day testing period and included a four hour session each day separated by a short break at the midpoint of the session.

The typical simulation day included:

- Flight crew briefing;
- 26 scenarios, included;
  - 2 for training and familiarization; and
  - 24 for data collection.
- Post-run questionnaires, see appendix F;
- Post-simulation questionnaires, see appendix C; and
- Post-simulation debrief.

The simulation was configured to utilize runways 28L and 28R at SFO which have a runway centerline spacing of 750 ft. An ILS approach to runway 28L was flown by the simulated lead aircraft, and an RNAV (RNP) approach to runway 28R was flown by subject crews in the trailing A330 aircraft. The approach to 28R was developed specifically for paired approach operations and was not designed in accordance with simultaneous offset IAP criteria. The runway 28R final approach course was offset 3 degrees from the extended centerline of runway 28R and intersected the extended runway centerline 0.5 NM prior to the threshold. The MITRE CAASD paired approach experimental avionics consisted of a CDTI and an ADS-B AGD. As shown in image 3-1, the CDTI was displayed on an electronic flight bag for each crewmember with one AGD in the center. A detailed description of the features of the CDTI and the AGD are shown in figures 3-1 and 3-2, respectively.

Image 3-1: A330 Simulator Installation of Paired Approach Avionics

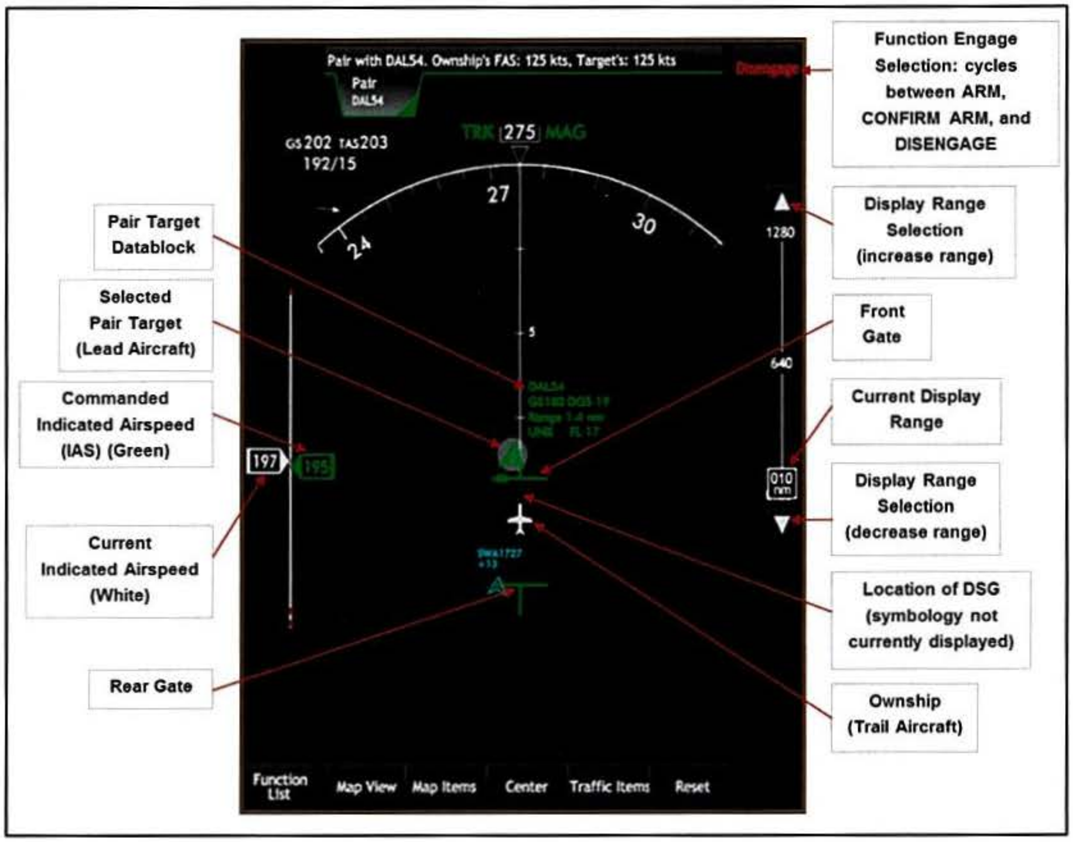

Figure 3-1: CDTI Display after Pairing

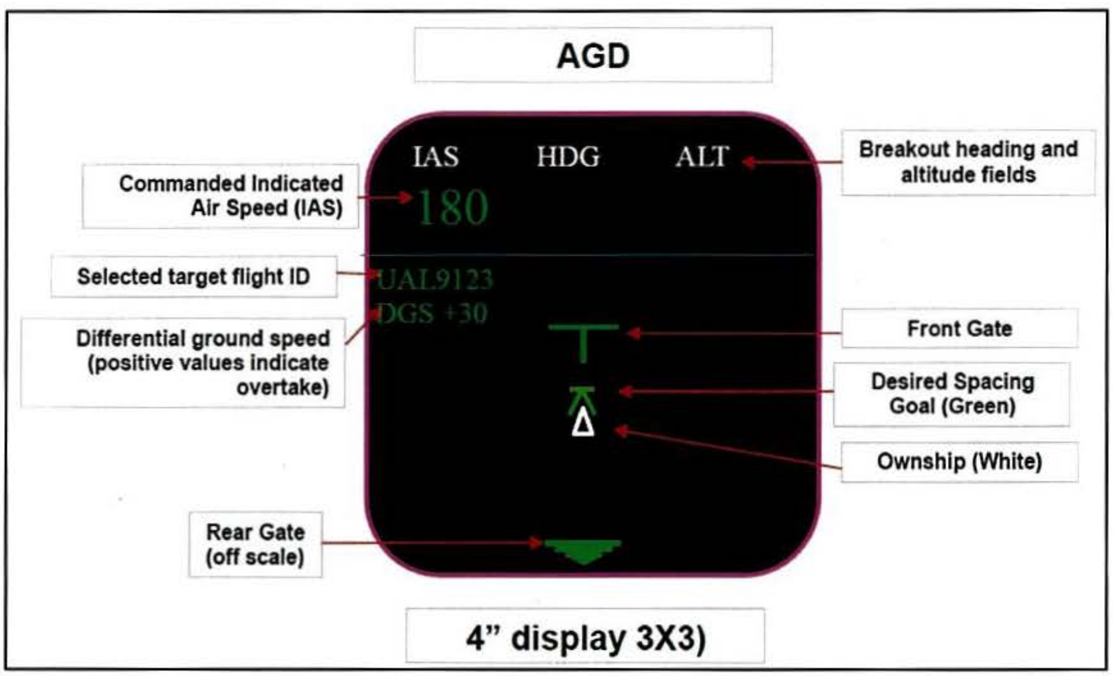

Figure 3-2: AGD Display after Pairing

Set-up Conditions:

- Ceiling was set to 463 ft (i.e. 100 ft above decision altitude) for the paired approach instrument approach procedure (RNAV (RNP) PA RWY 28R), and visibility was set to one statute mile;
- Surface wind was at paired approach limit speed (maximum surface crosswind of 5 knots for SFO) and increased to 15 knots at the FAF altitude;
- The trailing aircraft release point was on a 30° intercept to the final approach course at 5 NM from the intercept point;
- The lead aircraft was either established on the final approach course or on an intercept course; and
- Initial spacing between the lead and trailing aircraft was between 4 NM and 6 NM, and the lead aircraft was at the 10 o'clock position from the trailing aircraft at the beginning of each scenario.

3.1 Test Design and Scenarios

There was one baseline familiarization profile and five paired approach test profiles. At the beginning of each profile run, the flight simulator was positioned in accordance with the scenario requirements. The simulator operator released the A330 simulator when the ATC lab simulator, subject aircrew, and all observers indicated ready. The run continued until a successful landing was made, a missed approach or breakout was initiated, or the missed approach/breakout altitude was reached. The profile descriptions are as follows:

- **Profile 1 (Baseline)** consisted of subject pilots flying the RNAV (RNP) paired approach to 28R at SFO one time each without using paired approach procedures;
- **Profile 2 (Nominal Case)** consisted of paired approaches with no off-nominal situations introduced;
- **Profile 3 (Blunder)** consisted of off-nominal situations in the form of the lead aircraft flying across the flight path of the trailing aircraft;
- **Profile 4 (Front Gate)** consisted of off-nominal situations which placed the trailing aircraft near or in violation of the front gate. The lead aircraft approach airspeed was manipulated in order to present a front gate challenge to the trailing aircraft;
- **Profile 5 (Rear Gate)** consisted of off-nominal situations which placed the trailing aircraft near or in violation of the rear gate. The lead aircraft approach airspeed was manipulated in order to present a rear gate challenge to the trailing aircraft; and
- **Profile 6 (Missed Approach)** consisted of off-nominal situations which resulted in the lead aircraft performing a missed approach. This profile collected data to analyze the decisions and actions of the aircrew of the trailing aircraft from various positions within the paired approach safe zone (i.e. between the front and rear gates) upon execution of a missed approach by the lead aircraft.

General simulation procedures were as follows:

- The subject crew was always the trailing aircraft;
- In each scenario, the controller provided the subject crew with the lead aircraft's ACID and PFAS prior to issuing clearance to pair;
- Subject crews manually programmed the paired approach avionics to fly the paired approach procedure;
- The lead aircraft was always a large or heavy category aircraft; and
- The lead aircraft maintained 180 knots of indicated airspeed (KIAS) until the FAF, where it began its deceleration to its PFAS. After final configuration for landing, lead aircraft speeds were representative of normal operations. However, when the test matrix called for a front or rear gate off-nominal situation, there were two exceptions:
    - Depending on the subject crew's positional relationship to the front gate, the simulated lead aircraft's speed would be manipulated to an abnormally slow airspeed to induce a front gate off-nominal situation; and
    - Depending on the subject crew's positional relationship to the rear gate, the simulated lead aircraft's speed would be manipulated to an abnormally high airspeed to induce a rear gate off-nominal situation.

  These speed manipulations occurred after the subject crew had passed the FAF and were no longer receiving speed guidance from the AGD.

3.2 Test Assumptions

Each session contained a familiarization scenario and five data collection scenarios. The following assumptions apply to the operational scenario used during the data collection sessions:

- After the pilot briefing with the test director and one in-simulator familiarization run per crew member, crews would be able to operate the paired approach avionics; and
- Descent checklist and approach briefings would be considered complete prior to release.

3.3 Independent and Dependent Variables

The following variables applied to the operational scenarios used during the data collection sessions:

Independent Variables:

- Aircraft gross weight reflected either heavy or light aircraft gross weight scenarios; and
  - Heavy (396,800 lbs.) with a PFAS of 141 knots; and
  - Light (308,600 lbs.) with a PFAS of 125 knots.
- CDTI display elements.
  - The DSG symbol was displayed on half the approaches; and
  - Front and rear gates were always displayed.

Dependent Variables:

- Response to speed commands;
- Adherence to stabilized flight criteria;
- Response to nominal scenarios;
- Response to off-nominal scenarios;
- Post-run subjective responses; and
- Physiological eye track data.

3.4 Gates as Tested

The front and rear gates are site-specific and are a function of runway spacing, ambient wind conditions, airport elevation, fleet mix, navigation systems, wake vortex transport, and the trailing aircraft's position relative to the lead aircraft. MITRE CAASD conducted several Monte Carlo simulations of the paired approach procedure at SFO to determine the front and rear gate values to be programmed into the paired approach avionics.

When preparing the paired approach avionics for these HITL data collection runs, MITRE CAASD programmed the gates as shown in figure 3-3. The gate values relative to the lead aircraft distance to the runway threshold are shown in table 3-1.

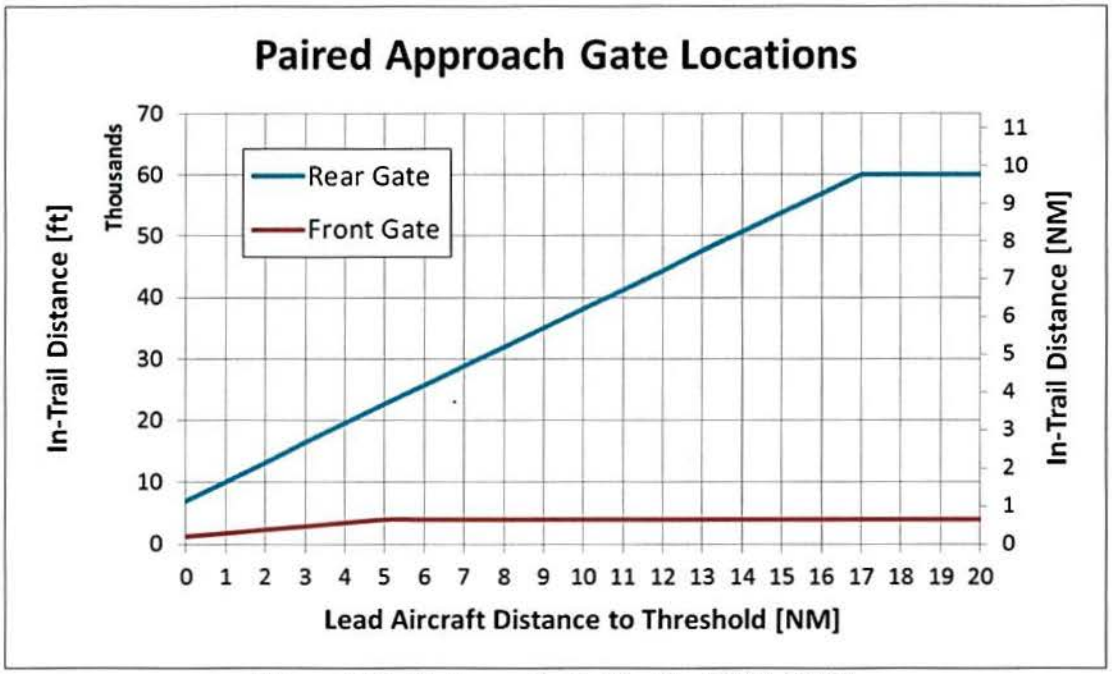

Figure 3-3: Gates as Tested in the HITL DCE

Table 3-1: Tabulated Gate Values

Gate	THR	4NM	5NM	6NM	17 NM	18 NM	20 NM	Description
Tested Front Gate [ft]	1,250	3,450	4,000	4,000	4,000	4,000	4,000	Linear from 0-5 NM
Tested Rear Gate [ft]	7,000	19,471	22,588	25,706	60,000	60,000	60,000	Linear from 0-17 NM

The wake encounter risk to be assessed and mitigated in nominal operations is only relevant when the approach courses are within 2,500 ft of each other laterally, see section 6.4.2.3. For the SFO approach courses tested, this point occurs at 6 NM from the runway threshold. The significantly displaced rear gate locations outside of 6 NM had no impact on the DCE and resulted in the rear gate always being off scale, until forced on scale by the off-nominal situations. The FAF for the ILS approach was located 5.8 NM from the runway 28L threshold. The FAF for the offset paired approach was located at 5.0 NM from the runway 28R threshold. No gate violations occurred outside the FAF.

Front and rear gate violations were induced by the test administrators. In order to induce rear gate violations, the large displacement of the rear gate required the lead aircraft to fly at significantly faster speeds than the PFAS that had been provided to the trailing aircraft. Conversely, in order to force front gate violations, the location of the front gate required the lead aircraft to fly at significantly slower speeds than the PFAS reported to the trailing aircraft.

The flight crews were instructed to breakout in response to a gate violation. The data of interest for these scenarios were pilot response times (PRT) to a breakout command as well as CPAs, see section 6.

Figures 3-4, 3-5, and 3-6 are composite images of the CDTI display, the AGD display, the view out of the captain's windscreen, and the controller's display. They show the cockpit avionics displays for a front gate violation, a rear gate violation, and a blunder respectively. In figure 3-4, the lead aircraft is flying 60 knots slower than the trailing aircraft to induce a front gate violation. In figure 3-5, the lead aircraft is flying 51 knots faster than the trailing aircraft to induce a rear gate violation. In figure 3-6, as the blundering lead crosses the path of the trailing aircraft, the difference in speed is indicated to the trailing aircraft as zero.

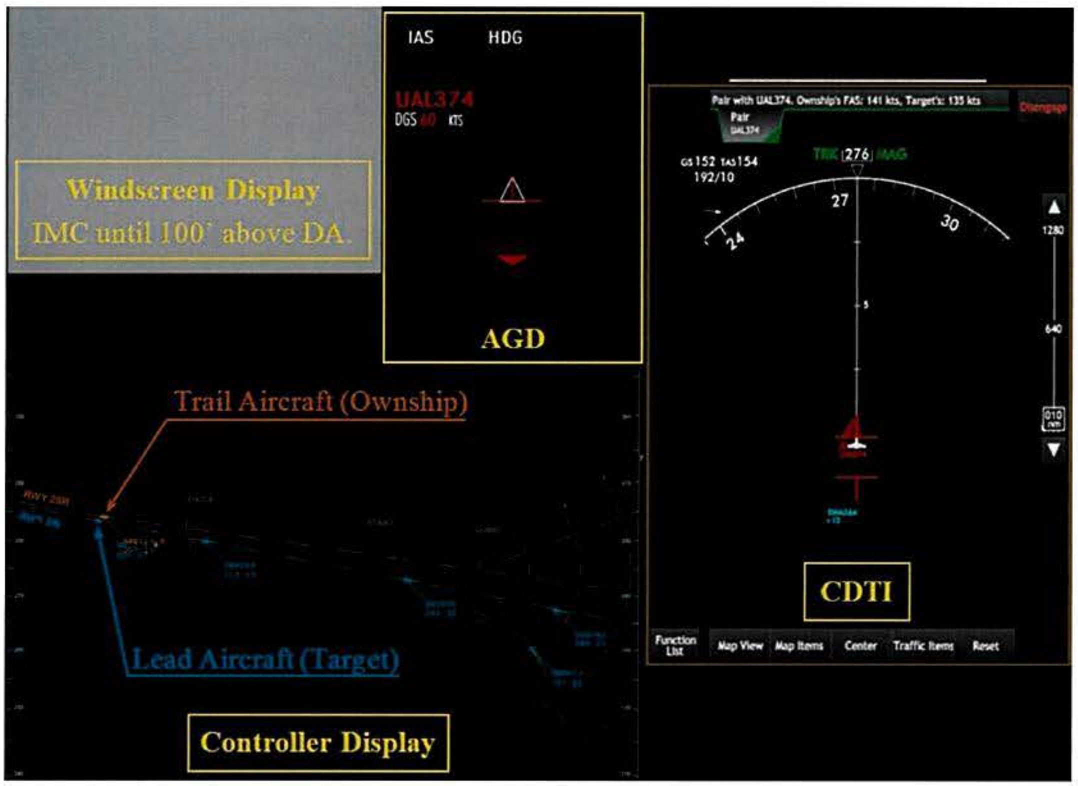

Figure 3-4: Front Gate Violation

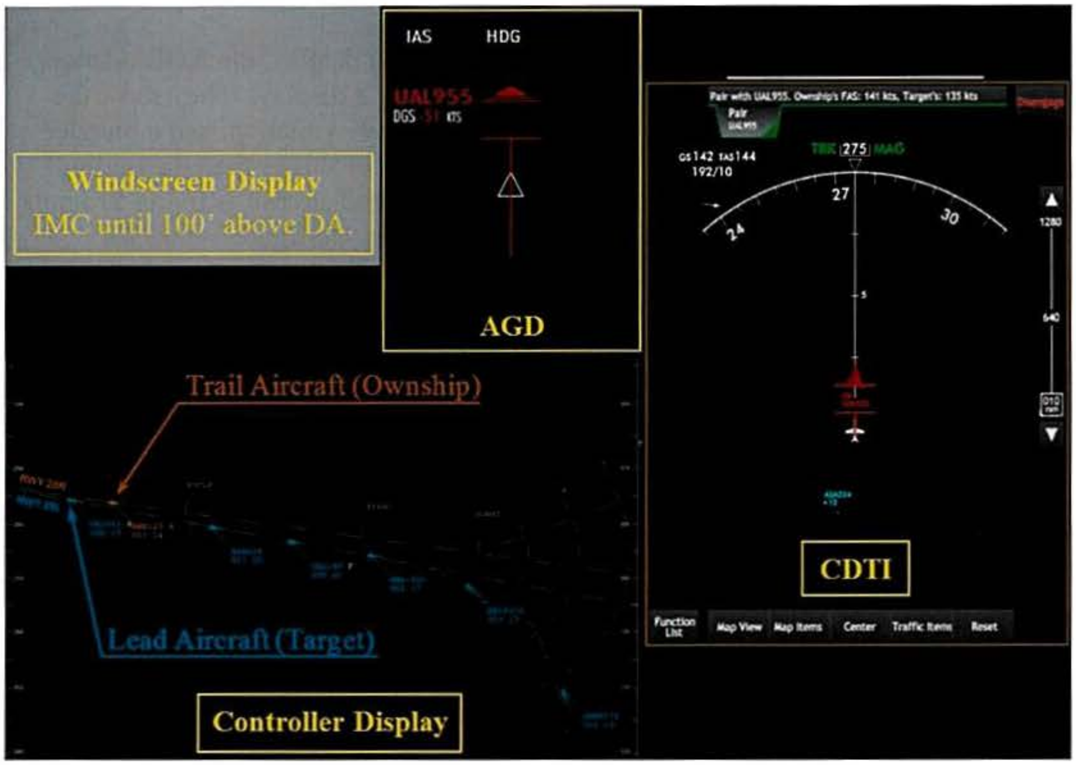

Figure 3-5: Rear Gate Violation

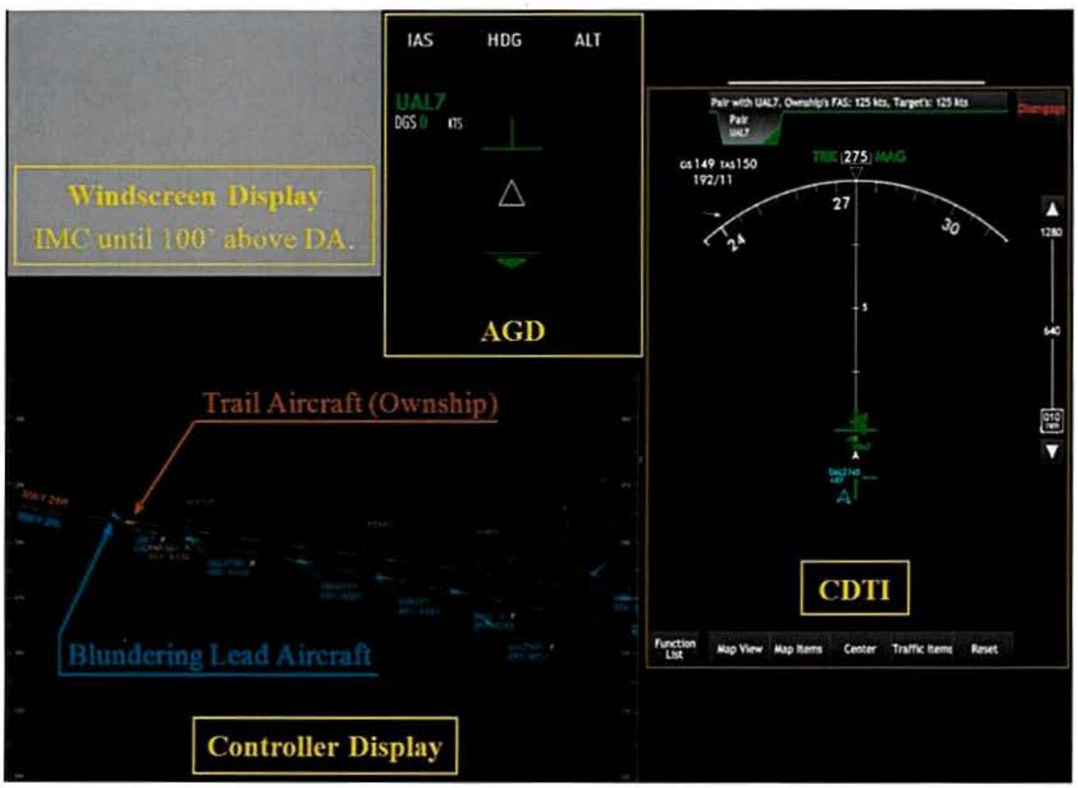

Figure 3-6: Lead Aircraft Blunder

4 Test Support Requirements

4.1 Resources, Logistics, Setup, and Requirements

4.1.1 Subject Pilots

Active Part 121 air carrier line pilots, current, and qualified in the A330, were used for this study. On two occasions, A320 pilots were utilized in lieu of A330 pilots due to crew availability. All crews were assembled from the same company, except for one crew which utilized pilots from different companies and one crew which utilized an FAA A330 qualified pilot as the first officer (FO). Most of the pilots had ADS-B and CDTI display experience, but all were unfamiliar with the paired approach concept.

4.1.2 Subject Controllers

No certified professional controllers were included in this study. The ATC lab simulator was staffed with controllers provided by Air Traffic Simulation, Inc.

4.1.3 Aircraft Simulator

The A330 simulator was prepared for the DCE by installing the MITRE CAASD paired approach experimental avionics. The installation was accomplished by AFS-400 simulation engineers with the assistance of MITRE CAASD simulation engineers who had previously designed, programmed, and installed the avionics into the MITRE CAASD fixed base flight simulator. Autopilot and autothrottles were required for the approach and operated in accordance with aircrew company policy. The airspeed was selected by the crew, via the speed selector knob located on the Flight Control Unit (FCU). The flight simulator conformed to level D qualification and was configured to conduct high level architecture at the highest design fidelity. The experimental SFO paired approach IAP, RNAV (RNP) PA RWY 28R, was developed by AFS-400 and coded into the navigation database for extraction and execution by the subject flight crews. The flight simulator had fully functional voice communications that included one headset for each pilot and one for each observer. The CDTI and AGD were fully functional. No intentional errors were introduced. The simulator visual system was operating at its highest design fidelity. Simulated (out-the-window) visibility was set at 1.0 statute mile. The data parameters collected are listed in appendix H.

4.2 ATC Lab Simulator

The Simulation Model ATC Research & Training (SMART) system was the ATC lab simulator's operating system that collected, processed, and provided the data for analysis by AFS-400. Air Traffic Simulation, Inc. provided personnel for staffing the controller positions, and Digital iBiz provided personnel for staffing and operating the pseudo-pilot positions.

4.2.1 ATC Lab Operational Requirements

The lab was required to simulate the SFO Terminal Radar Approach Control facility, local tower facility, and ground control. The lab also required communication capabilities between controllers, flight simulator subject pilots, laboratory pseudo-pilots, all members of laboratory positions, and the subject pilot observers.

4.2.2 Video and Audio Recording

Video recordings were made of the AGD, the FO's CDTI, and the view out of the captain's windscreen. A video was also made of the Standard Terminal Automation Replacement System terminal controller workstation showing the plan view of the traffic and runways. These were combined into one video for situational display and post review. Due to modifications being made to the audio system, no interphone communications between the pilots were captured.

4.2.3 Human Factors Observers

The human factors observers were responsible for observing, interpreting, and capturing the essential elements of individual pilot and flight crew interaction as it directly affects performance and potential changes in comfort or workload. The pilot observer was a current A330 airline pilot. All observers, including the flight simulator operator, made notes of events, activities, conditions, actions, and communications that were significant to the data collection. Each observer determined the significance of any event that warranted particular note and did not take any active role during the actual flight sessions.

5 Human Factors Analysis

The team evaluated nine separate flight crews. One flight crew was evaluated each day with each crew consisting of a captain and a FO. The crews were qualified and current line pilots, with each crew from the same air carrier, see table 5-1. Two different air carriers were represented. There are two exceptions to the previous two statements; crew number 5 consisted of a captain and FO from different airlines and crew number 8 had a subject pilot that was unable to attend. An A330 current and qualified FAA pilot performed duties as the missing crewmember for crew number 8. The FAA pilot was not completely familiar with the company techniques and procedures of the subject crewmember with whom he was flying, but the crewmember was instructed to perform as he normally would on the line. The FAA pilot did not divulge any of the specifics of the test beyond the information shared in the pilot briefing.

Table 5-1: Crew Demographics

Crew Number	Crew Aircraft Experience	Captain Flight Hours	FO Flight Hours	CDTI Experience
1*	NA	NA	NA	NA
2	A330	60	<1 yr	Y/Y
3	A330	700	6,000	Y/Y
4	A330	250	1,500	N/N
5**	A330	NC	NC	NC
6	A330	1,500	8,000	Y/Y
7	A320	7,800	6,000	N/N
8***	A330	4,000	FAA	Y
9	A330	4,000	1,600	Y/Y
10	A320	5,000	200	N/N

*Due to technical malfunctions, the entire day was canceled.
**Demographic data was not collected (NC).
***FO subject pilot was unable to participate.

The evaluation team consisted of a test director, pilot observer, and a human factors observer. At various times, several industry subject matter experts also observed from either the ATC lab simulator or in the cab of the A330 flight simulator. Prior to the start of each evaluation session, the test director and lead human factors observer presented a briefing to the participants. Each session lasted approximately four hours and was followed by a debriefing of the subject pilots, conducted by the lead human factors observer, with participation from the other evaluation team members.

5.1 Subjective Questionnaire Response

After each run, pilots were given a post-run questionnaire to be completed while the evaluation team reconfigured the simulator for the next run; see appendix F. [2] A multidimensional rating procedure was used. These questions solicited pilot feedback on their perception of difficulty, comfort, and workload, as it related to their normal duties and functions. Given the intrusive nature of any data-gathering procedure of this type, the number of questions, and the time required to complete them were both minimized. Questions were limited in scope so as not to reveal to the subject pilots the test objectives, which might have biased pilot responses. The results are graphically portrayed in figures 5-1 through 5-4. Discussion of test objectives 1 and 2 is not applicable within the scope of the subjective response data; only discussion of objective 3 is applicable. Subjective response data as it relates to objective 3 is portrayed in figure 5-4 with additional response data in appendix G. Subject pilots were instructed to base their responses upon their normal workload.

With the exception of the FAA stand-in pilot, post-run questionnaire responses were collected from all participants. Each pilot provided responses to all six questions after each run. A total of 364 responses were recorded for each of questions 1, 2, 5, and 6. Question 3 applied only to blunder events, and provided 48 responses. Question 4 applied only to breakout events, which provided 155 responses.

5.1.1 Approach to Subjective Data Analysis

Data analysis is first viewed from an overall perspective which allows for the confirmation of integrity and validity of the responses. Data are then parsed further by pilot seat position (captain or FO), pilot function (pilot flying or pilot monitoring), and scenario profile. The level of discrimination of the data was determined by two primary themes. The first theme was the main DCE objective that was stated in the test plan and the second was by emergent aspects discovered from the first notion analysis.

5.1.2 Figure Presentation Properties

Several presentation properties remain consistent throughout the figures. The vertical axis corresponds to a 9 point scale with 1 on the bottom, 9 at the top, and 5 in the center representing "typical." Questions are arrayed consistently in order from left to right on the horizontal axis. For the purposes of this subjective analysis, the order of the questions has been rearranged from the original order on the post-run questionnaire. The first four positions are occupied by response data from questions 1, 2, 5, and 6, which applied to every scenario profile. Because questions 4 and 3 apply only to the event occurrences of breakouts and blunders, respectively, which did not take place on every run, they were moved to the last two positions on the far right in the subjective analysis figures. The questions are listed below as they appear in the figures from left to right. For additional post-run questionnaire response figures, see appendix G.

- **Approach Difficulty:** Compared to a typical instrument approach, rate the level of difficulty performing this approach (post-run question 1);
- **Ind Workload:** Rate your perceived level of **individual workload** for this procedure from the standpoint of communication, coordination, and procedural habit patterns throughout the approach (post-run question 5);
- **Crew Workload:** Rate your perceived level of **crew workload** for this procedure from the standpoint of communication, coordination, and procedural habit patterns throughout the approach (post-run question 6);
- **Paired (Lead) Aircraft Comfort:** Rate your comfort level with the lead aircraft on its normal flight path (post-run question 2);
- **Breakout Comfort:** Rate your comfort level with having to conduct a breakout maneuver (post-run question 4); and
- **Blunder Comfort:** Rate your comfort level after recognizing the lead aircraft has blundered (post-run question 3).

5.1.3 Conceptual Set of Questions from Post-Run Questionnaire

It will be useful to keep in mind the conceptual sets of information directed for use by the subject pilot when answering the six conceptual questions on the post-run questionnaire. The conceptual sets of information directed for use by the subject pilots differ for each question. Refer to figure 5-1 for the questions below:

- **Approach Difficulty: Compared to a typical instrument approach, rate the level of difficulty performing this approach;**
  This question directs the pilots to use a conceptual set of "typical" IAPs which can include a broad number of aspects. As presented in figure 5-1, the mean is slightly below a score of 5 in the figure indicating "typical." This indicates a slight bias of the distribution towards lower difficulty across the subject pilots. While the question allows for many aspects to be included, it does not necessarily prompt the pilot to analytically think about what is specifically included in a "typical" instrument approach. One pilot's view of a "typical" instrument approach may be much different than that of another. This is the nature of human factors subjective questions and is the reason to limit inferential deduction to the threshold implicit in the question. In other words, since this question is broad in scope, it is only appropriate to make equally broad inferences regarding the data.

- **Ind Workload: Rate your perceived level of individual workload for this procedure from the standpoint of communication, coordination, and procedural habit patterns throughout the approach;**
  This question directs the pilots to use a conceptual set of personal (individual) workload influencers to include communication, coordination, and procedural habit patterns. The mean value for the responses to this question is slightly above 5, indicating an even distribution about typical individual workload across subject pilots.

- **Crew Workload: Rate your perceived level of crew workload for this procedure from the standpoint of communication, coordination, and procedural habit patterns throughout the approach;**
  Although this question is similar to that of individual workload, it asks the pilots to adjust the conceptual set of personal workload influencers to one of collective

(crew) workload influencers. The mean value for the responses to this question is slightly above 5, indicating an even distribution about typical crew workload across subject pilots.

- **Paired (Lead) Aircraft Comfort: Rate your comfort level with the paired aircraft on its normal flight path;**
  This question specifically directed the pilots to use a conceptual set of influencers consisting of comfort with the relational position of the lead aircraft to their aircraft, referred to as "ownship," while on the paired approach. The mean value is slightly below 5, indicating a slight bias of distribution towards greater comfort across the subject pilots.

- **Breakout Comfort: Rate your comfort level with having to conduct a breakout maneuver; and**
  This question directs the pilots to use a conceptual set of influencers tied to performing a breakout from the approach. The mean value for the responses to this question is slightly above 5, indicating an even distribution about typical comfort across subject pilots. However, there were only 155 responses to this question which limited its analysis.

- **Blunder Comfort: Rate your comfort level after recognizing the paired aircraft has blundered.**
  This question directs the pilots to use a conceptual set of influencers regarding comfort when the lead aircraft blundered towards the ownship. The mean value for this question is above 5, indicating a bias towards elevated discomfort across subject pilots.

5.1.4 Figures of Post-Run Questionnaire Data

5.1.4.1 All Questions – Distributions of Post-Run Questionnaire Responses

Figure 5-1 is a box-and-whisker plot which represents the distribution of responses. These plots show minimum, maximum, lower quartile (25%), upper quartile (75), and the mean. For example, approach difficulty responses have a minimum value of 1, a maximum value of 9, a lower quartile of 5, an upper quartile of 6, and a mean of 4.893. Given the unlikelihood of a blunder occurrence, pilot response to, "comfort with the blunder scenario," was to be expected. Observer records and debriefing responses both indicate that pilots did not have a problem initiating the appropriate action in response.

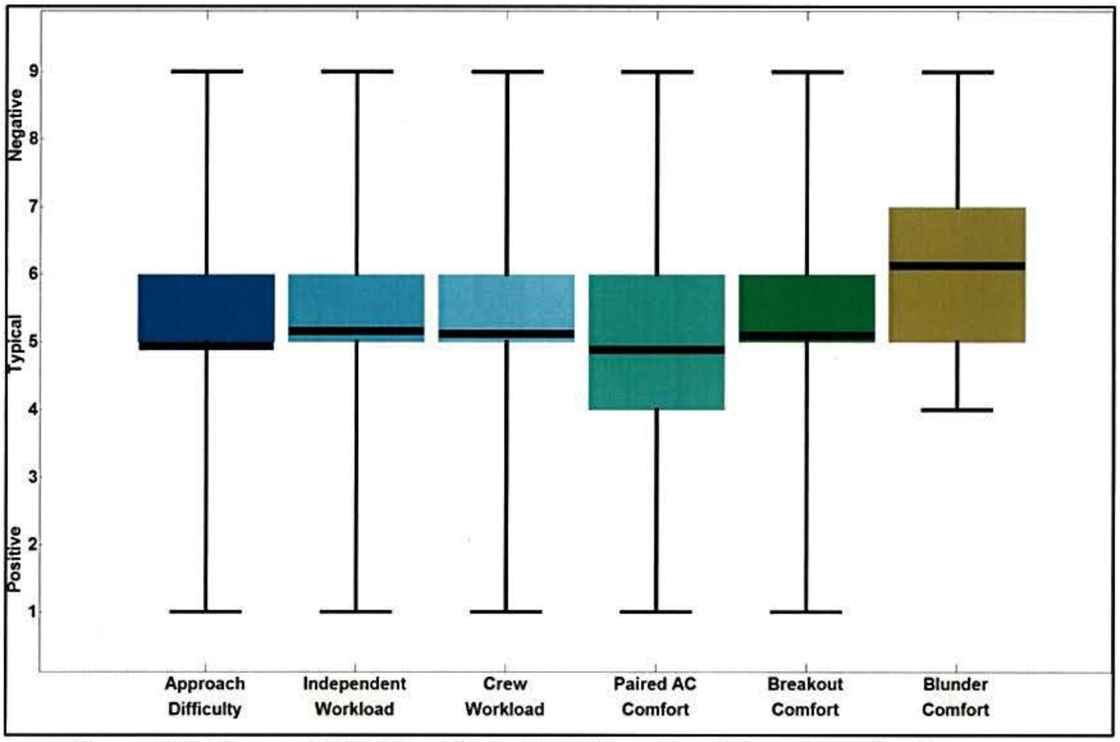

Figure 5-1: Box and Whisker Plot of All Post-Run Questionnaire Responses

5.1.4.2 Captain vs First Officer – Distributions of Post-Run Questionnaire Responses

Figure 5-2 shows the distribution of responses by each captain and FO. With the exception of responses to the question regarding blunder comfort, the values are distributed near the median value, indicating that these procedures were perceived as relatively benign when compared to the normal activities of the flight crews. Furthermore, the relatively tight distribution of responses between the two crew positions indicates that neither crew position skewed the weight of the mean values in figure 5-1.

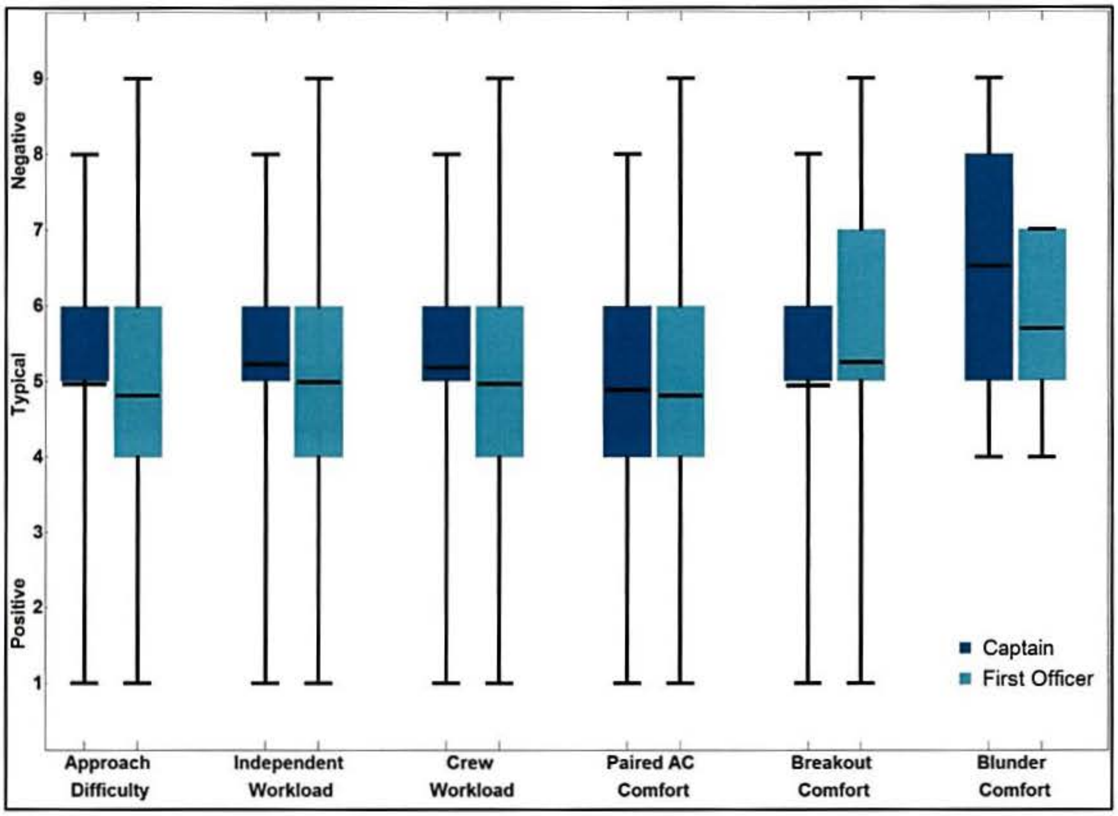

Figure 5-2: Captain vs FO – Box and Whisker Plot of Post-Run Questionnaire Responses

5.1.4.3 Pilot Flying vs Pilot Monitoring – Distributions of Post-Run Questionnaire Responses

Figure 5-3 shows the distribution of responses by pilot flying and pilot monitoring. The mean values of responses to the first five questions are distributed around the midpoint, "typical." Response data for the question of blunder comfort, far right, indicates elevated discomfort in response to this event regardless of pilot duties.

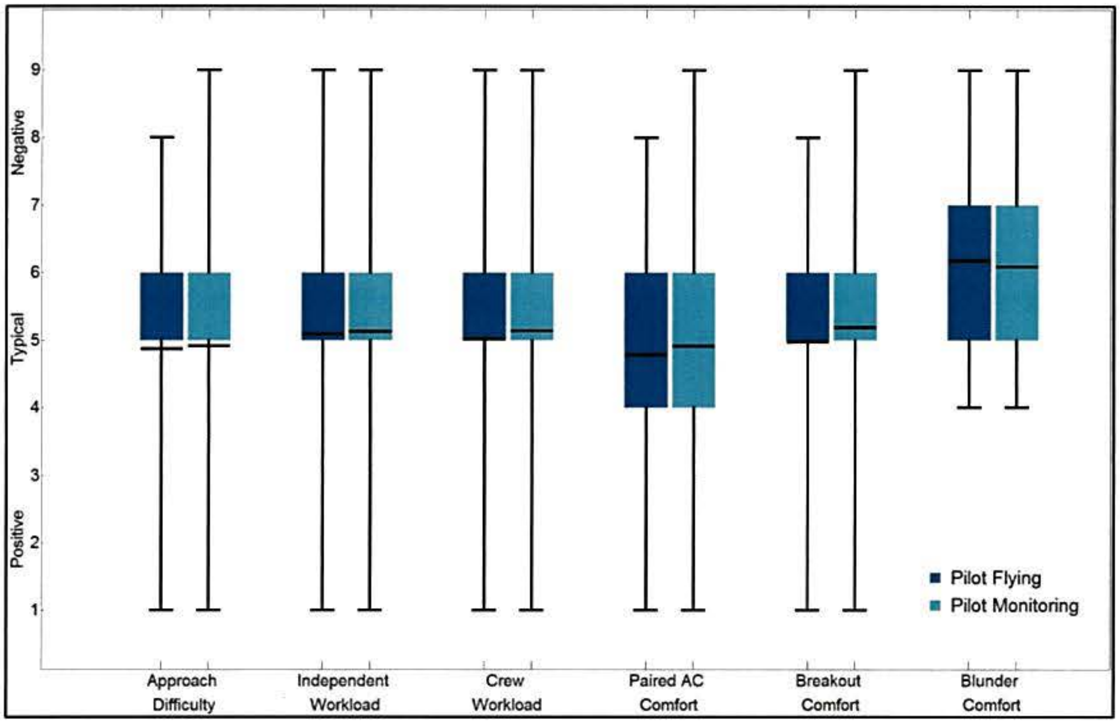

Figure 5-3: Pilot Flying vs Pilot Monitoring – Box and Whisker Plot of Post-Run Questionnaire Responses

5.1.4.4 All Scenario Profiles – Distributions of Post-Run Questionnaire Responses

Figure 5-4 shows distribution of responses to each scenario and describes the flight crew level of comfort in regards to ownship's proximity to the lead aircraft. The baseline scenarios were standard approaches without pairing. Due to time and resource constraints, a total of only 29 baseline scenarios were performed. Mean response values fall in the ranges of what might be expected, i.e., baseline and nominal run scores are lower than the off-nominal scores.

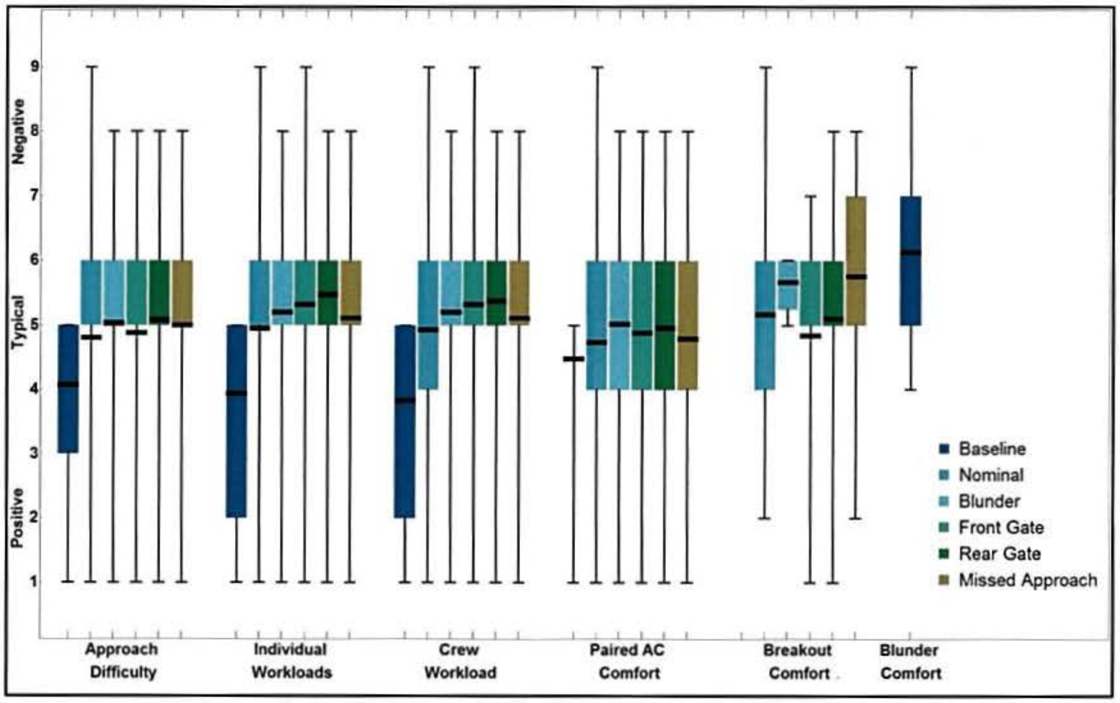

Figure 5-4: All Scenario Profiles – Box and Whisker Plot of Post-Run Questionnaire Responses

5.2 Direct Observation

Objective crew performance measures were limited in scope. This was accomplished through simple observation of pilot and crew performance, as well as in-depth, post-data collection debriefings. Observation data were taken by in-the-cockpit observers (both pilot and human factors specific). All flight scenarios were carefully scripted. During those periods in a given flight sequence, when a crewmember might have had to perform a function out of the norm from what is either expected or planned, both primary and secondary task completions were monitored. Specifically, during periods of heightened activity, heightened workload, or when task shedding may have taken place, reaction times and latency of task completion were monitored. When observed, those events were recorded and analyzed commensurate with aircraft performance metrics. Examples of such events are listed below:

- Missed radio calls;
- Query controller for a clearance repeat;
- Inappropriate response to a radio call to another aircraft;
- Misunderstood clearance and/or corresponding incorrect reaction;
- Error in the use of aircraft flight management computer and navigation system;
- Missed or incomplete checklist;
- Latency in radio response; and
- Deviations in airspeed, altitude, or course.

Observers identified major themes, issues, or problems from which the analysis and discussion were generated. Any possible connection to subjective, physiological, and aircraft performance was made, establishing a potential chain of causation, pointing directly to the impact of the paired approach procedure.

5.2.1 Objective 1 – Effective Operation of Paired Approach Avionics

Subject pilots were given only a brief explanation of the basic operations of the CDTI and AGD during the briefing. This only provided them with adequate proficiency in order to conduct the DCE. Observers noted that collective crew procedure/monitoring for use of the CDTI evolved very quickly. Procedures and monitoring were not consistent across all crews, but the effectiveness of the crew performance appeared to be so. With this in mind, the following display issues were identified:

- **Misinterpretation of the Indicated Air Speed/CDTI commanded speed scale:** There was some misinterpretation of the speed scale on the left side of the CDTI (white and green speeds shown on the left side of figure 3-1), which showed ownship's current indicated air speed and the CDTI commanded speed. Subject pilots noted several times that they misinterpreted the two displayed speeds as target (paired) aircraft speed and their own aircraft speed. Although both instruments showed the commanded airspeeds, on several occasions pilots chose to refer to the CDTI, rather than the AGD (which clearly showed the commanded speed in the upper left corner, see figure 3-2) for input guidance. As a result of their misinterpretation of speeds on the CDTI, they did not make timely airspeed changes on the FCU. Two pilots recommended that an audio or additional visual alert might decrease reaction time to the commanded airspeed changes. This is referred to as redundant coding and might be a signal that facilitates an airspeed change (e.g. an audio "beep" associated with the visual number change);
- **Counter-intuitive range scaling function:** Scaling in (decreasing range) was done at the bottom of the scale and scaling out (increasing range) was done at the top (shown on the right side of figure 3-1). Several pilots commented that this seemed opposite of what they are used to and was counter-intuitive. This was also noted by both pilot and human factors observers during simulator sessions; and
- **Data entry sequence:** A sequence of pressing buttons is required, but some button presses may be made prior to others. It should be noted that the sequence of pressing buttons demonstrated in the training video presented during the pilot briefing was different than what was used during actual testing. The conflict between the laws of primacy (training video) and recency (test) must be taken into account. Although pairing information provided by the controllers to the trailing aircraft was consistent, the order of CDTI inputs required for successful pairing varied in sequence from the way pilots were exposed to them in the introductory video. Controllers were instructed to give lead ACID and its PFAS elements required for pairing in one transmission. Observers noted that this presented difficulty to some pilots, primarily in the form of incorrect CDTI data entries and requests to the controller to clarify instructions.

5.2.2 Objective 2 – Acquiring and Maintaining the DSG

Crew perception of the utility of the DSG symbol varied. Some pilots never appeared to notice the lack of a DSG symbol, while other pilots actively manipulated airspeed to fine tune their position relative to the DSG symbol. Some pilots consciously disregarded the commanded airspeed for this and other reasons, including referring to the CDTI rather than the AGD in order to determine the necessary speed. In addition, at least one captain stated he did not trust the equipment or controllers and used his own experience to determine the required speed. Several crews noted the DSG, either on the CDTI or the AGD, as particularly useful in determining closure to the lead aircraft.

Subjective human factors and performance data, shown in appendix G (figures G-4 through G-7), points to higher workload and discomfort values with the presence of the DSG symbol "ON."

5.2.3 Objective 3 – Evaluation of Flight Crew Performance

IMC stabilized approach criteria for both carriers were similar. No later than 1,000 ft above ground level, the aircraft must be:

- Fully configured for the desired landing configuration (in this data collection flaps were FULL);
- On target final approach speed (FAS) (-5 to +10 KIAS) for one carrier or on target FAS by 500 ft above ground level for the other carrier;
- On path, within allowable lateral and/or vertical tolerances;
- At approach throttle settings; and
- At a maximum vertical descent rate of 1,000 ft per minute, unless previously briefed due to special approach considerations.

Under normal conditions, most of the subject pilots noted the A330 is a very low drag aircraft, therefore, speed and configuration changes must be carefully managed in order to achieve a stabilized approach. They routinely noted that this is emphasized to all A330 crews during training. They felt the flight profile, based on the test methodology, was very challenging (e.g. higher approach airspeed based on the higher aircraft gross weight as well as higher than normal commanded speeds to the FAF) and perhaps unrealistic for A330 operations. This resulted in deviations from habit patterns and in some instances near or actual flap overspeeds and unstable approaches, based on current stabilized approach criteria, as defined by each airline in accordance with FAA Advisory Circular 120-71A, *Standard Operating Procedures for Flight Deck Crewmembers*. [3] Flap overspeeds or near overspeeds were based on observed overspeeds or when pilots were observed selecting the next lower flap setting while within 10 KIAS of $V_{FE\ NEXT}$, i.e., the next airspeed with flaps extended. Crews should not move to $V_{FE\ NEXT}$ until the current indicated air speed is at or below the $V_{FE\ NEXT}$ symbol on the primary flight display (PFD). While there is some flap overspeed protection built into the aircraft system, any significant turbulence can easily result in the flap limit being exceeded. Most airline operators teach pilots to be at least 10 KIAS below $V_{FE\ NEXT}$ before selecting the next lower flap setting in order to avoid an inadvertent flap overspeed. In addition, according to the pilots participating in this DCE, both of the airline operators participating in this study encourage pilots to slow near the S (slat) or F (flap) speeds on the PFD, which represent the best lift to drag ratio (L/D max) speeds for that flap configuration, prior to selecting the next lower flap configuration. When combined with the higher commanded speeds, this required the aircraft to be configured early and necessitated the aggressive use of drag devices which demanded a high degree of vigilance. While some pilots were equipped to do this by virtue of their air carrier's procedures or prior experience, others were not. Still others evolved these techniques during the test.

Subject pilots were briefed that the paired approach algorithms solved for both collision risk (front gate) and wake turbulence (rear gate). Perhaps as a result, observers often noted blunder recognition and urgency of reaction was less than expected, given the close proximity of the blundering aircraft. Most subject pilots seemed to be comfortable with the proximity of blundering aircraft on the CDTI and the Traffic Collision Avoidance System (TCAS). Out of nine flight crews, two did not recognize blunders had even taken place. Of the remaining seven crews, two felt that it was safer to execute a go-around rather than continue during observed blunders. The remaining five crews always continued the approach to landing, often noting afterwards, they trusted the system to keep them safe. It should be noted that on several runs the pilot monitoring queried the controller regarding the blunder and was subsequently informed that it was safe to continue. It should also be noted, no crew ever "disengaged" the pairing software, even though it was mentioned during the pilot briefing that this option was available. The briefing intentionally did not dwell on the "disengage" feature of the paired approach avionics.

The use of the term "breakout maneuver" caused initial confusion on several occasions. Those pilots noted that "breakout" implies a precision runway monitor maneuver, which requires specific crew actions such as shutting off the flight directors. Pilots recommended a different term be used since this was simply a hand flown go-around maneuver and not a precision-runway-monitor-style of breakout. Additionally, controllers preferred a radar vector missed approach or go-around, rather than the published right hand turn to the OAK VOR. It is somewhat incompatible with the required crew callout of, "go around, LNAV," or, "go around, MANAGED NAV." Several crews noted they are all trained to immediately re-engage NAV during any missed approach or go-around to ensure lateral path and terrain avoidance compliance.

Several crews noted they preferred that the autopilot be allowed as soon as the initial breakout maneuver was completed. They noted that the Airbus aircraft are designed for maximum autopilot use and were much more comfortable when performing an autopilot go-around rather than a hand flown go-around.

5.3 Physiological Data Analysis

AFS-400 has the capability to provide a human interface in the form of non-invasive video-based glasses with audio recording capability. There were two pairs of these glasses available during the DCE, one for each crewmember. The device is worn like a normal pair of glasses and includes a high definition scene camera and special eye tracking technology that captures the eye movement of the participant wearing it as the participant looks at each Area of Interest (AOI) in the study. The eye trackers can be used to record subject pilot point-of-regard, saccade rates, dwell time, head movement, and blink rate, which are all potential correlates to workload, task efficiency, and deficiency. After the initial data collection analysis, eye fixations were measured at a rate of once per 80 milliseconds (ms) and were mapped onto a reference image of the A330 cockpit for further analysis. An example of the A330 reference image showing the approximate primary field of view (FOV) of the pilot flying, taken from the FO's side of the cockpit, is shown in image 5-1.

Image 5-1: Eye-Track Mapping Reference Image (A330) with Approximate Primary FOV

The reference image was created from ten separate images merged into a single clear, comprehensive representation. It is not to scale and is depicted in a manner to accommodate all instruments and controls in one single picture. This facilitates mapping of all scans and saccades during the entirety of each run.

The eye-tracking technology captured both eye pupil and head movement. The data mapping does not adequately display the distinction between head and individual pupil fixations or saccades. Each fixation is a snapshot in time. The system captures the number of each fixation and saccade separately. The duration of these separate instances are also recorded. Semantic gaze mapping allows for the subject pilots' eye fixations to be mapped onto the corresponding cockpit reference images for analysis.

Since post-data collection mapping is extremely time consuming, analysts chose a representative sample of crew runs from which to perform semantic gaze mapping, as shown in table 5-2. This table identifies the randomly selected sample from seven crews with an even mix of captains and FOs as pilot flying, light- and heavy-weight profiles flown, and whether DSG symbology was visible.

Table 5-2: Runs Chosen for Semantic Gaze Mapping

Date	Crew	Run	Scenario	Pilot Flying	Weight	Profile	Visible DSG Symbol
6/11/14	3	8	6	FO	Light	3-Blunder	Yes
6/11/14	3	11	12	FO	Heavy	4-Front Gate	No
6/12/14	4	13	1	Captain	Heavy	2-Nominal	Yes
6/12/14	4	10	16	FO	Heavy	5-Rear Gate	No
6/13/14	5	10	17	Captain	Heavy	6-Missed Approach	Yes
6/16/14	6	15	2	FO	Light	2-Nominal	Yes
6/16/14	6	16	11	Captain	Light	4-Front Gate	No
6/17/14	7	10	18	FO	Light	6-Missed Approach	Yes
6/17/14	7	4	24	FO	Light	1-Baseline	No
6/19/14	9	1	5	Captain	Heavy	3-Blunder	Yes
6/19/14	9	11	15	Captain	Light	5-Rear Gate	No
6/20/14	10	10	22	FO	Heavy	1-Baseline	No

In accordance with FAA Advisory Circular 90-101A, a pilot's primary FOV is defined as the area where the pilot should be able to use all the required instruments with minimum head and eye movement. [4] Primary optimum FOV is based on the vertical and horizontal visual fields from the design eye reference point. It is a single reference point in space selected by the designer (where the midpoint between the pilot's eyes is assumed to be located when the pilot is properly seated at the pilot's station) that can be accommodated with eye rotation only.

With the normal line-of-sight established at 15 degrees below the horizontal plane, the values for the vertical and horizontal (relative to the normal line-of-sight forward of the aircraft) are ±15°, as shown in figure 5-5. This area is normally reserved for primary flight information and high priority alerts. Naturally, information in this area will be detected more quickly than if placed outside this area.

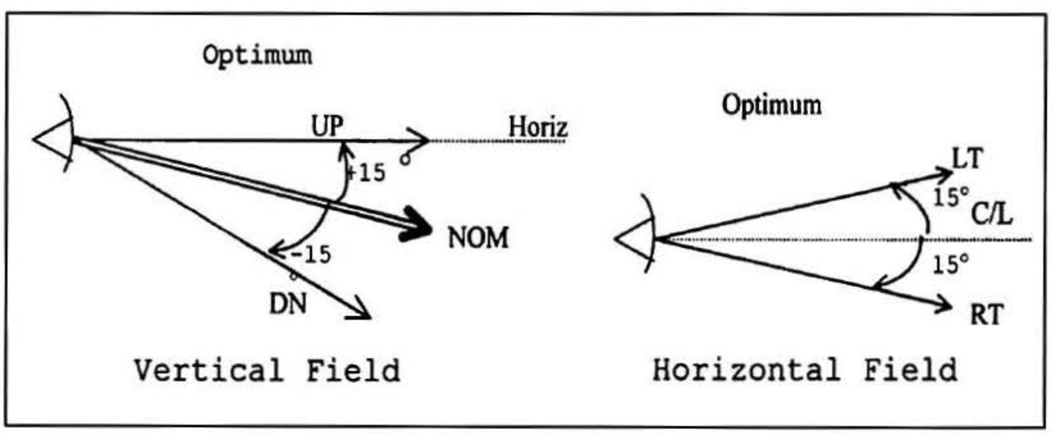

Figure 5-5: Normal Line of Sight

The AGD was canted slightly off center, facing approximately 15 degrees towards the captain. The FO's dwell time, per fixation on the AGD, was slightly less than the captain's. The difference would not account for any artifact in the eye-tracking results.

Baseline runs could not be used for representative mapping since pilots were biased to include both the AGD and CDTI in their scans, despite not needing them for these approaches. Depending upon the segment of the approach and whether the pilot was flying or monitoring, eye-track mapping analysis revealed time that was normally available for monitoring primary instruments was spent monitoring the CDTI and the AGD, as depicted in images 5-2 through 5-4. Logically, that time would otherwise be devoted to the primary instruments.

All semantic gaze maps, heat maps, figures, and accompanying key performance indicator (KPI) figures are depicted as averages of all the representative runs in that particular category. Descriptions of all the KPIs are given in table 5-3. [5] Images 5-2 and 5-3 represent heat maps overlaid onto the reference image for fixations during the actual pairing process when pilots input the required information into the CDTI.

Table 5-3: KPI Descriptions

KPI Name	Unit	Description
Sequence	count	Order of gaze hits into the AOIs based on entry time; lowest entry time = first in Sequence
Entry Time	ms	Average duration for the first fixation into the AOI
Dwell Time	ms *and* %	$\text{Dwell Time Average (ms)} = \frac{\text{Sum of Fixations \& Saccades Within AOI}}{\text{Number of Selected Subjects}}$ $\text{Dwell Time Average (\%)} = \frac{\text{(Dwell Time Average) x 100}}{\text{Current Time} - \text{Start Time}}$
Hit Ratio	%	The number of selected subjects that looked at least one time into the AOI: $\text{Hit Ratio} = \frac{\text{Total Hit Count}}{\text{Number of Selected Subjects}}$
Revisits	count	$\text{Average Revisits} = \frac{\text{Number of Revisits}}{\text{Number of Selected Subjects With At Least 1 Visit}}$ *NOTE: Glances were determined by the counter which was incremented each time a fixation hit the AOI, if not hit before.*
Revisitors	count	Number of subjects with more than one visit in an AOI
Average Fixation	ms *and* %	$\text{Average Fixation} = \frac{\text{Sum of Average Fixation Time Per Subject in AOI}}{\text{Number of Selected Subjects}}$ *NOTE: 80 (ms) is the minimum fixation time for perception to occur according to current accepted field science.*
First Fixation	ms	$\text{First Fixation} = \frac{\text{Sum of All First Fixations for Selected Subjects}}{\text{Number of Selected Subjects}}$
Fixation Count	count	$\text{Fixation Count} = \frac{\text{Sum of All Fixations for Selected Subjects}}{\text{Number of Selected Subjects}}$

The pilot monitoring was responsible for the execution of the pairing process. The heat mapping between the two figures is distinctly different, reflecting that the pilot monitoring is logically spending more time fixating on the respective CDTI than the pilot flying. However, the pilot flying consistently scanned cross-cockpit to the CDTI of the pilot monitoring to monitor the pairing process. This is evident in image 5-2, when both captain and FO consistently did this.

Image 5-2: Heat Map All, During Setup Only, Captain Flying

Image 5-3: Heat Map All, During Setup Only, FO Monitoring

While the pilot monitoring was actively entering paired approach data into one CDTI, the CDTI of the pilot flying did not display the actions of the pilot monitoring as they happened in real time, but instead displayed the message, "pair function is currently being edited," which supports the reason for cross-cockpit scanning by the pilot flying.

Although the captain and FO took turns flying the paired approach, the following images are examples of heat maps for runs where the captain was the pilot flying and the FO was the pilot monitoring.

Each physiological (eye-tracking) dataset was parsed into five time phases:

- Start of run to time of pairing;
- Pairing to FAF;
- FAF to end of run;
- FAF to aural alert for altitude of 1,000 ft; and
- Aural alert for altitude of 1,000 ft to end of run.

The captain and FO runs were all parsed out by:

- Captain/FO; and
- Pilot flying/pilot monitoring.

The most critical portion of the paired approach is the segment from the FAF through the landing, missed approach, or breakout. In this segment, the crew workload increases as the requirements for modification of the aircraft configuration and attention to aircraft control are added to that of monitoring the CDTI and AGD. In that segment, inside the point at which the 1,000 ft aural alert is announced, workload is the highest as the crew begins to prepare to execute a missed approach, transition to visual conditions and land, or to execute a breakout if commanded. In images 5-4 through 5-11, these segments are presented with the captain as the pilot flying and the FO as the pilot monitoring.

Image 5-5 depicts the eye-tracking data for each AOI from the FAF through the end of all runs in table 5-2 for the captain. Each of the most critical cockpit AOIs such as the PFD, Navigational Display, CDTI, AGD, etc., is highlighted and annotated with a breakdown of the KPIs listed in table 5-3. Similarly, figure 5-7 depicts the same information for the FO.

During the critical phase of flight in accordance with the scenario make-up (FAF through the end of the run), a comparison between the pilot flying and the pilot monitoring reveals a similar pattern of eye-tracking. Pilot comments revealed that they were not so concerned about including the CDTI in their scan as much as they were about focusing away from the primary FOV at a critical juncture in the final approach. While instruments and outside view within the primary FOV require only eye movement, the placement of the CDTI necessitated head and eye movement to acquire information.

Image 5-4: Heat Map, All Runs, Captain Flying, FAF to End of Run

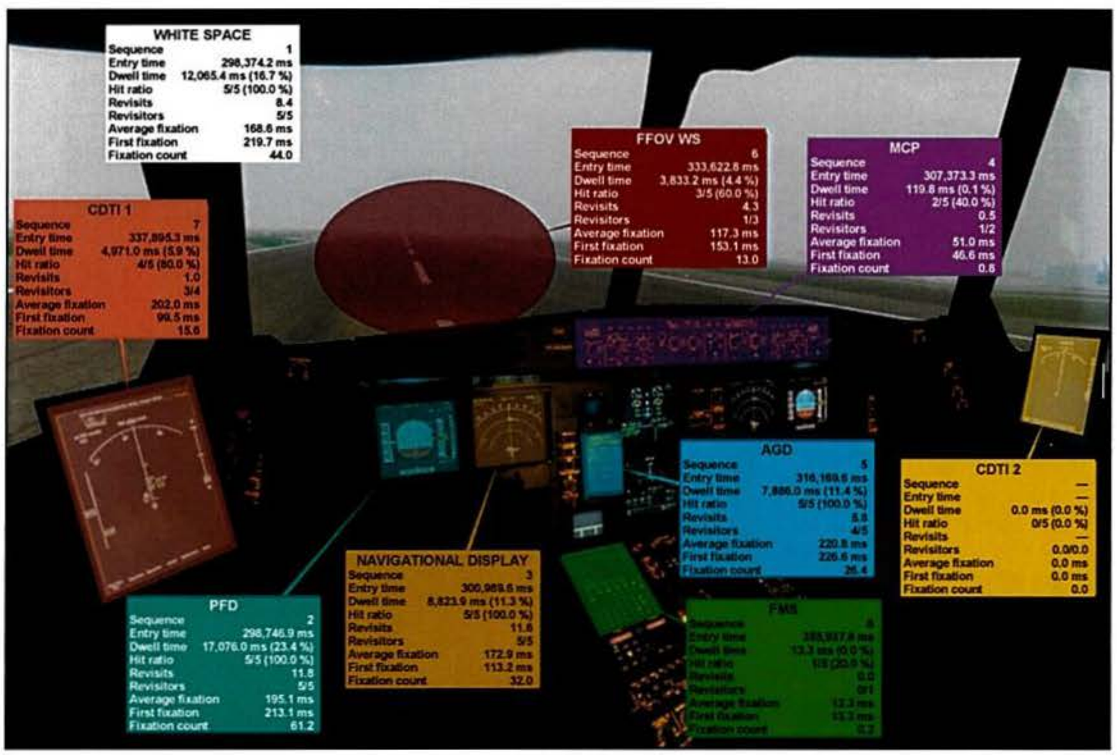

Image 5-5: KPIs, All Runs, Captain Flying, FAF to End of Run

Image 5-6: Heat Map, All Runs, FO Monitoring, FAF to End of Run

Image 5-7: KPIs, All Runs, FO Monitoring, FAF to End of Run

A subset of the data depicted in images 5-5 and 5-7 is depicted in images 5-9 and 5-11. Image 5-9 depicts eye-tracking data for the approach segment from the 1,000 ft aural alert to the end of the run. During this critical phase of flight, the eye-track data reveals that a considerable amount of time is spent by the captain looking at the AGD and CDTI. Analysis of the KPI data for the captain shows the combined AGD/CDTI percentage to be 16.5%, while the PFD time is 14.5%. Analysis of the KPI data from the AGD and CDTI for the FO is 6.0% and the PFD time is 36.2%. The heat maps in images 5-8 and 5-10 show the focus of the PFD fixations of the captain flying and the FO monitoring, respectively. As shown in these images, the eye-track data revealed that the CDTI consumed an extended portion of the total scan time during this stage of the approach where altitude monitoring is a primary function of both pilots. This observation was further corroborated during the post-simulation debriefing where the pilots expressed concern with having to look away from their primary FOV during a critical phase of the approach to use the CDTI.

In the examination of the data for both the pilot flying and the pilot monitoring, the CDTI and AGD have been integrated into the visual scan. While both instruments represent a relatively short total dwell time (between 1.2 and 8.0 seconds), they do scavenge some pilot resources that would otherwise be devoted to the instruments in the primary FOV.

Image 5-8: Heat Map, All Runs, Captain Flying, 1,000ft Aural Alert to End of Run

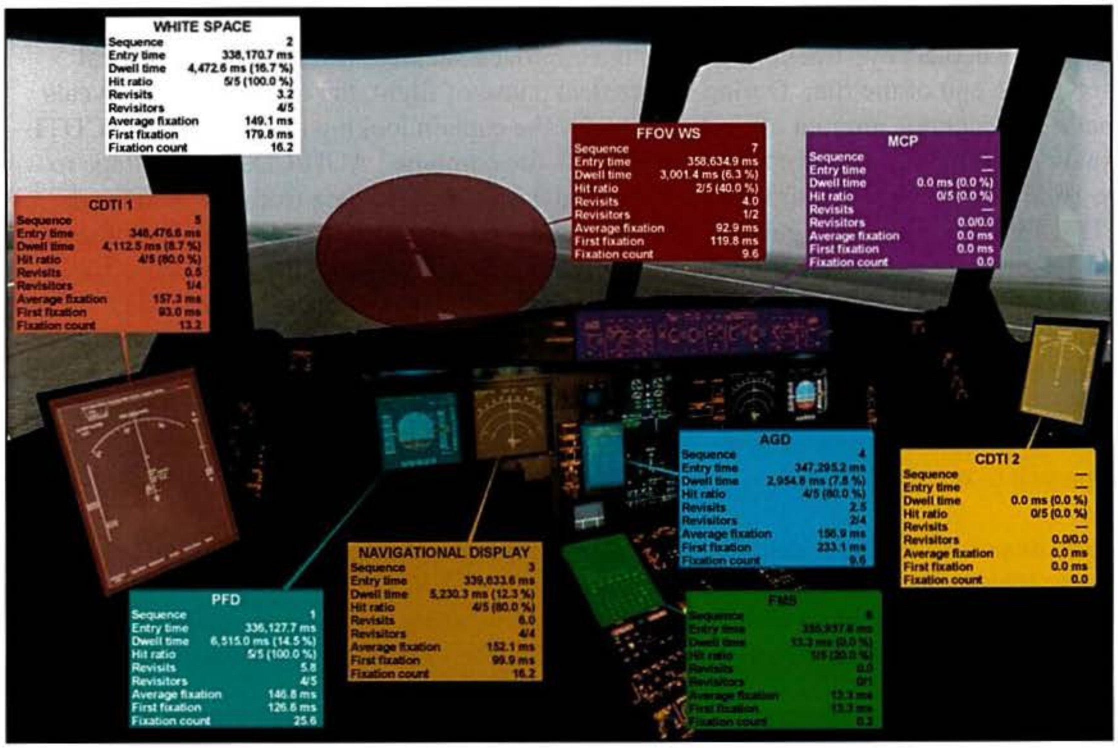

Image 5-9: KPIs, All Runs, Captain Flying, 1,000ft Aural Alert to End of Run

Image 5-10: Heat Map, All Runs, FO Monitoring, 1,000ft Aural Alert to End of Run

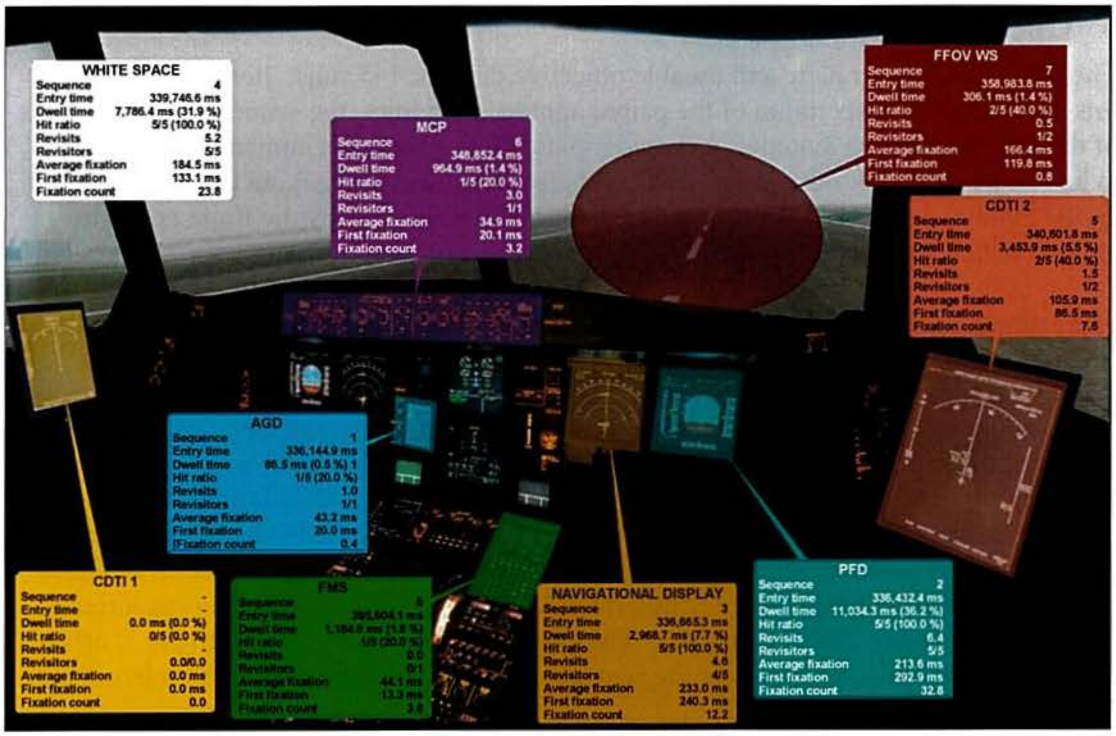

Image 5-11: KPIs, All Runs, FO Monitoring, 1,000ft Aural Alert to End of Run

6 Objective Data Analysis

The DCE yielded complete and useable objective data for 145 runs. Items of interest in this analysis are the operation of the paired approach avionics, the sequence of operations of the paired approach avionics, airspeed inputs, PRTs to speed commands given by the avionics, aircraft proximity to the DSG, and crew reactions to breakout commands given by the avionics. Also of interest are any independent decisions by the flight crews to have executed a missed approach.

The primary analysis tool utilized was the SMART Post-Processing and Analysis (SPA) software. The SPA program allows the end user to visually and audibly examine the events that were recorded by the SMART system. This multifaceted approach allows for close examination of the quality of the data recorded, testing parameters, conditions, and effects of the selected simulation elements. Figure 6-1 shows the plan view of an entire paired approach (from beginning to end) as displayed in SPA and shows the actual lead and trailing aircraft flight paths of a blunder scenario from the DCE. It also shows the points along the paths at which certain events occurred. The aircraft movement is from right to left with the leader approaching runway 28L (blue line) and the trailing aircraft approaching runway 28R (green line). The approach paths converge due to the 3° offset path to runway 28R. As they near the runway threshold, the lead aircraft blunders across the path of the trailing aircraft.

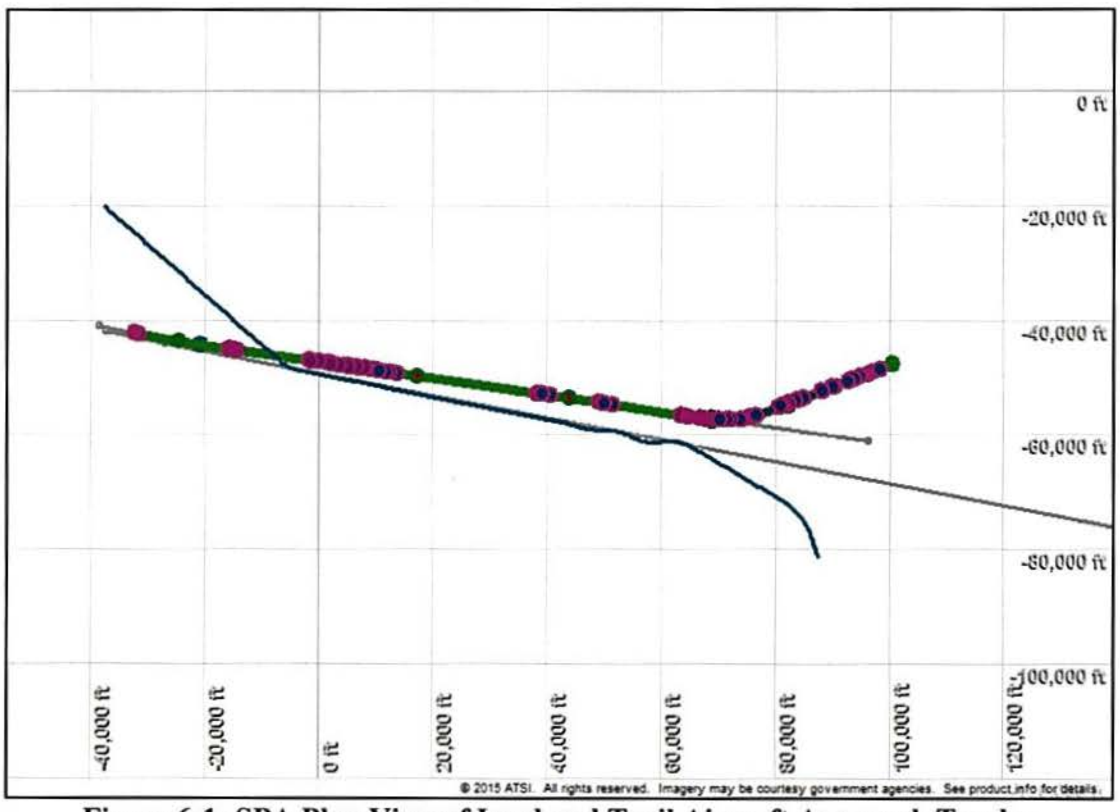

Figure 6-1: SPA Plan View of Lead and Trail Aircraft Approach Tracks

6.1 Flight Crew Operation of the Paired Approach Avionics

The first objective of the study was to determine if the flight crew was able to successfully operate the paired approach avionics. All flight crews were able to engage the avionics on every run, indicating that they were able to successfully operate the avionics.

6.2 Attaining and Maintaining the DSG

The second objective of the study was to determine if the flight crew could acquire and maintain the DSG. The trailing aircraft began each run between 15 and 20 NM from the threshold and approximately 2 NM behind the lead aircraft. Depending on the PFAS speed difference in the two aircraft, the DSG location varied between 200 ft to 580 ft behind the front gate. Without the symbology, only a commanded airspeed was displayed, and attainment of the DSG was accomplished through adherence to the commanded airspeed. The objective analysis focuses on the minimum proximity to the DSG that the flight crews were able to attain as shown in table 6-1. This table also shows that greater than 98% of the flight crews were able to get within 0.25 NM of the DSG and no flight crews failed to get within 0.5 NM of the DSG. The last two columns exhibit the effectiveness of the DSG symbology. By comparison, those runs with the DSG symbology were statistically indifferent from those runs without the symbology.

Table 6-1: Proximity to the DSG by the Flight Crew

≤ NM	≤ ft	Total Number of Runs	Percent of Total Runs	Percent of Runs with DSG Symbology	Percent of Runs without DSG Symbology
0.50	3,038	145	100.0%	100.0%	100.0%
0.25	1,519	143	98.6%	97.2%	98.7%
0.16	1,000	117	80.7%	81.9%	78.4%
0.08	500	83	57.2%	54.2%	59.5%
0.02	100	76	52.4%	48.6%	55.4%
0.01	50	74	51.0%	47.2%	54.1%

Table 6-2 shows the number of paired approach speed commands that were issued and achieved for all of the paired approach runs. It is interesting to note that 98.6% of flight crews were able to get within 0.25 NM of the DSG while successfully achieving 54.9% of the issued speed commands. This may indicate that the experimental avionics issued speed commands with greater frequency than was required. The results in table 6-2 also compares the number of speed commands achieved between those runs having the DSG symbology as compared to those runs without the symbology. The most notable effect is a decrease of 1.4 seconds on the pilot's average response time when the DSG symbology is not available.

Table 6-2: CDTI Speed Commands Issued and Achieved

Item	All	DSG Symbology Available	DSG Symbology NOT Available
Runs	145	71	74
Speed Commands Issued	1403	670	733
Speed Command Achieved	770	359	411
Percentage Achieved	54.9%	53.6%	56.1%
Average PRT [sec]	10.9	11.6	10.2

In the interest of further illustration, two runs were selected to highlight the effectiveness of the speed guidance algorithm. Figures 6-2 and 6-3 each show an example of a pilot responding to speed commands from the paired approach avionics and their corresponding distance to the DSG along the approach. The speed commands given by the paired approach avionics are depicted by the dots and the red line depicts the airspeed selected by the crew using the speed control knob on the FCU.

The pilot actions in figure 6-2 are those of a pilot adhering to the speed commands and the resulting performance in reaching and maintaining the DSG. The two graphs within the figure depict data ranging from the time of paired approach engagement up to the point at which the FAF is reached, (5.0 NM from the threshold) which is when all speed guidance ceased. In this particular run, at the time of engagement, the trailing aircraft is approximately 4,500 ft behind the DSG. Through responsive adherence to the speed commands, the pilot flying steadily decreased the distance to the DSG. This continuous improvement throughout the approach illustrates the benefit of adherence to the speed guidance of the paired approach avionics.

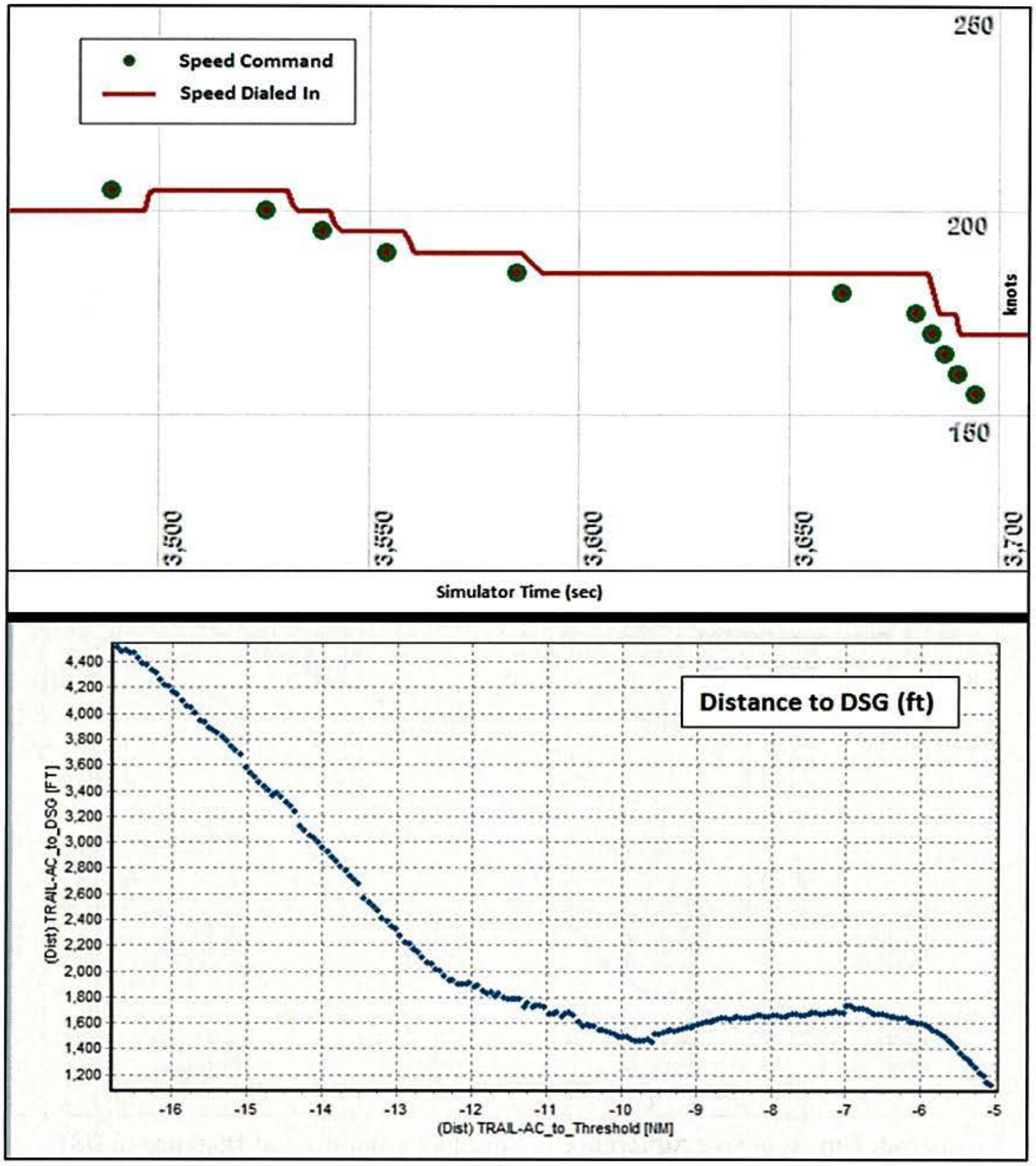

Figure 6-2: Responsive Adherence to Speed Commands and Distance to DSG

The pilot actions in figure 6-3 are those of a pilot deliberately ignoring the speed commands and the resultant performance in reaching and maintaining the DSG. In this particular run, at the time of engagement, the trailing aircraft is approximately 300 ft behind the DSG. By ignoring the speed commands, the pilot flying steadily increased the distance to the DSG. This continuous deterioration of position throughout the approach illustrates the consequence of not adhering to the speed guidance of the paired approach avionics.

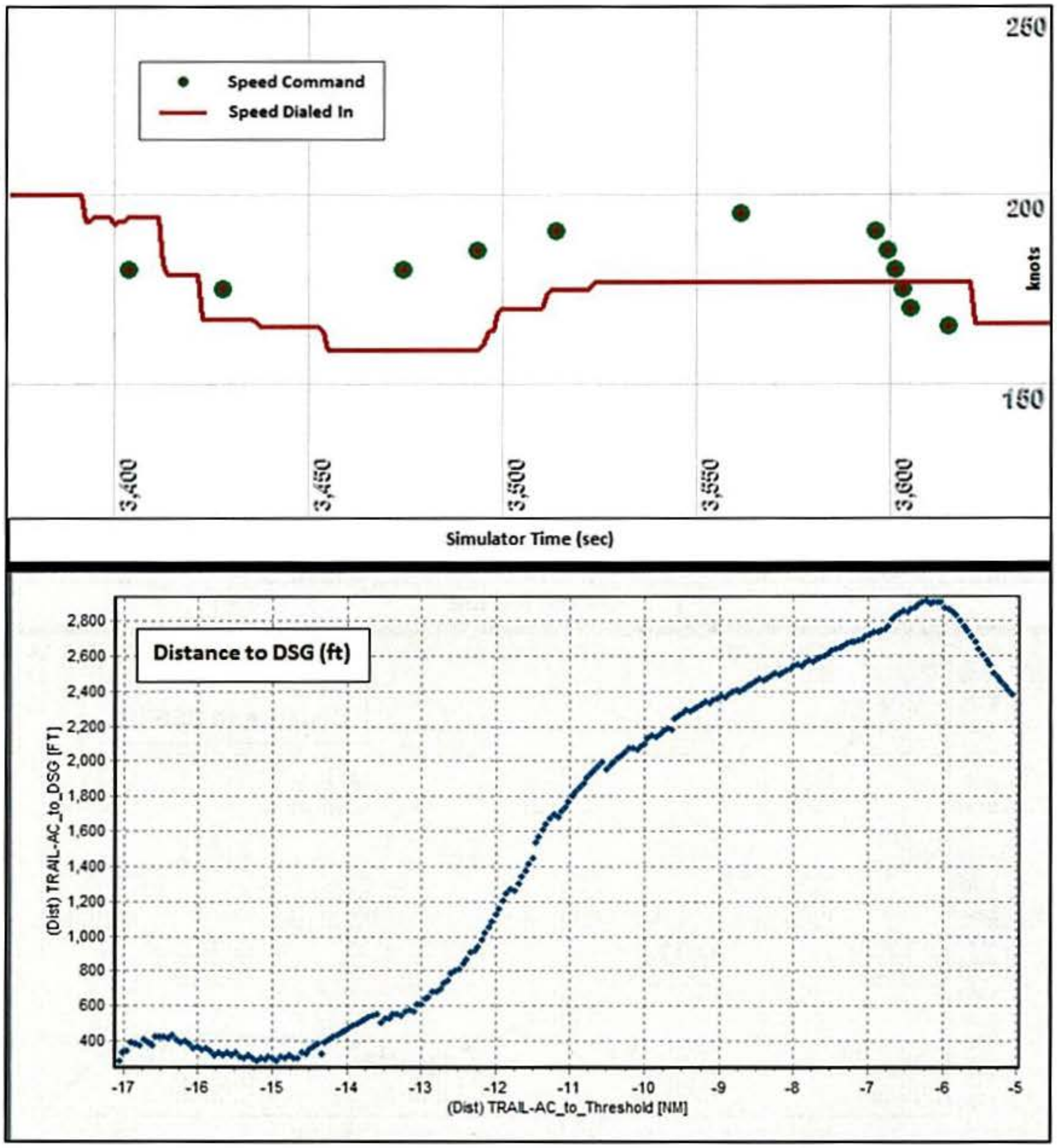

Figure 6-3: Unresponsive Adherence to Speed Commands and Distance to DSG

Comparison of figures 6-3 and 6-4 demonstrate that the subject flight crews in this test could acquire and maintain the DSG with better effectiveness by following the speed commands that were generated by the experimental paired approach avionics.

6.3 Commanded Breakouts and Decisions to Execute Missed Approach

The third objective was to evaluate subject flight crew performance when confronted with one nominal and four off-nominal situations during the final approach. All off-nominal scenario profiles had the potential for a breakout or missed approach as a necessary corrective action by the flight crew of the trailing aircraft. These breakouts and missed approaches were objectively tracked along with the reason for each occurrence.

In every case, the pilot complied with the breakout command that was issued by the paired approach avionics. The time required for the pilot to increase the throttle in response to the breakout command was recorded. The average PRT to the breakout command was 12.7 seconds, see table H-4. This may intuitively seem to be a higher reaction time than expected from a pilot. However, because the average is raised by a few very high PRT values, a more representative number for PRTs might be taken from the median which was 5.7 seconds. Table 6-3 shows the results from the study, with regard to breakouts commanded, as well as missed approaches determined to be required by the flight crew. In total, there were 70 breakouts and 8 missed approaches. By isolating only the 118 off-nominal runs (row 3 of table 6-3), it can be seen that 68 were breakouts, 8 were missed approaches, and the other 42 landed.

Table 6-3: Paired Approach Commanded Breakouts and Missed Approaches

Scenario Type	Total Runs	Breakouts Commanded	Decisions to Execute Missed Approach	Percentage of Departures from Paired Approach
All Types	145	70 (48.3%)	8 (5.5%)	53.8%
Nominal	27	2 (7.4%)	0 (0.0%)	7.4%
Off-Nominal	118	68 (57.6%)	8 (6.8%)	64.4%
Blunder	30	3 (10.0%)	8 (26.7%)	36.7%
Front Gate	28	28 (100.0%)	0 (0.0%)	100.0%
Rear Gate	29	29 (100.0%)	0 (0.0%)	100.0%
Missed Approach	31	8 (25.8%)	0 (0.0%)	25.8%

6.4 Scenario-Specific Analysis

6.4.1 Nominal

Nominal scenarios were used in this study to determine how the flight crews handled a normal paired approach procedure. These runs were meant to be used as a comparison against the off-nominal runs.

There were 27 nominal runs, two of which resulted in breakouts. In the first case, the pilot flew past the front gate, and in the second case the pilot was overtaken by the rear gate. In each case, the pilot properly complied with the breakout command provided by the paired approach avionics.

6.4.2 Off-Nominal

6.4.2.1 Blunder

All blunder scenarios were deliberately induced by the test administrators by steering the lead aircraft across the path of the trailing aircraft and were intended to result in either a commanded breakout or a missed approach executed decisively by the flight crew. The flight crews' reactions to the lead aircraft crossing in front of them were varied. Some did not notice the blundering aircraft at all, while others noticed the blunder and discussed what their action should be. Most crews that became aware of the blunder chose to continue to land since they were behind the front gate, and hence, protected from collision with the blundering aircraft. A few crews expressed discomfort with the situation and chose to execute a missed approach.

As shown in table 6-3, out of 30 blunder scenario runs, there were 3 commanded breakouts and 8 decisions to execute a missed approach making a total of 36.7% departures from the paired approach. The other 19 runs resulted in the trailing aircraft landing normally. More breakouts and missed approaches were expected since the lead aircraft blundered across the path of the trailing aircraft. This, however, was an intended part of the study, which was to gain a better understanding of how the paired approach avionics might influence pilot decision-making in the event of a blunder. The IMC likely played a role in such an outcome. Most crews, unable to visually acquire the blundering aircraft, continued the approach uninterrupted with the assumed collision protection behind the front gate.

Table 6-4 shows the smallest values of CPA recorded during the blunder scenarios for both two dimensional (2D) and three dimensional (3D) distances. The closest (2D or 3D) distance in a blunder scenario run was just over half a NM. These minimum distances exhibit the effectiveness of the front gate algorithm in preventing collisions in the event of a blundering lead aircraft.

Table 6-4: Smallest CPA for Blunder Scenarios

CPA	ft	NM
2D CPA Min:	3,345	0.55
3D CPA Min:	3,399	0.56

6.4.2.2 Front Gate

Front gate encounters were deliberately induced by the test administrators through dramatically slowing the lead aircraft which presented the trailing aircraft with a front gate challenge. The goal was to capture the flight crew response to a front gate violation. As shown in table 6-3, there were 28 front gate encounters, and the flight crews complied with every breakout command.

6.4.2.3 Rear Gate

Rear gate encounters were deliberately induced by the test administrators by increasing the speed of the lead aircraft to the point of presenting the trailing aircraft with a rear gate challenge. As indicated in table 6-3, all 29 runs resulted in a breakout. With the DCE set at SFO, the rear gate only serves a purpose within 6.0 NM of the runway threshold. This is due to two facts: 1) the rear gate is meant to protect the trailing aircraft from a wake vortex encounter, and 2) wake is only relevant when the approach paths are laterally within 2,500 ft of each other. As described in figure 6-4, the proximity of the two approach paths at SFO only meet this criteria beginning at 6.0 NM from the threshold.

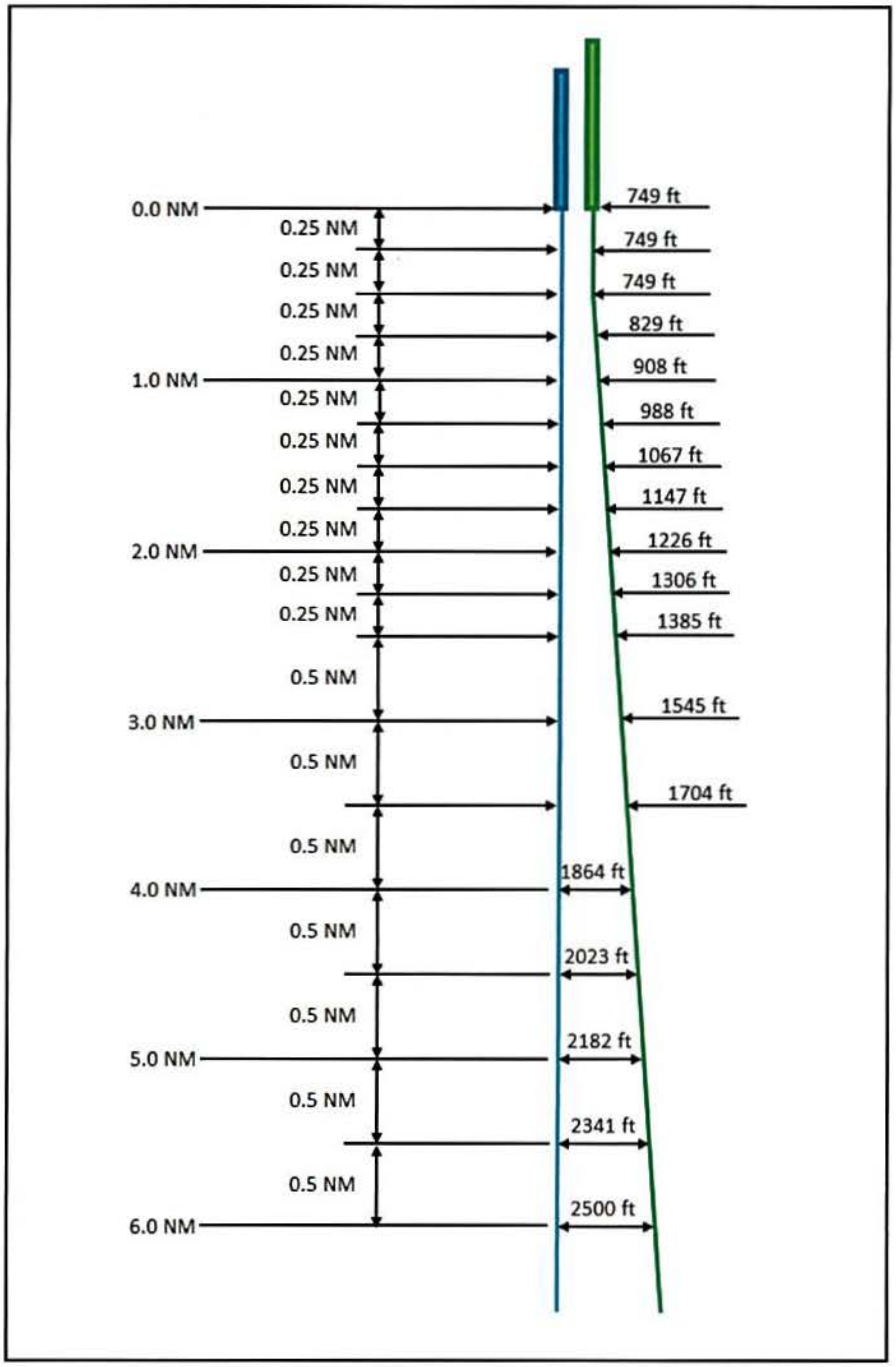

Figure 6-4: Lateral Distances between Paired Approach Paths of Runways 28L and 28R at SFO

6.4.2.4 Missed Approach

Missed approach situations were induced by the lead aircraft initiating a missed approach procedure. As indicated in table 6-3, there were 8 commanded breakouts in 31 runs, all others landed. More departures from the paired approach were expected from the subject flight crews since the lead aircraft was executing a missed approach procedure. However, because the IMC prevented the flight crews from visually acquiring the other aircraft, the only other way to see the lead aircraft was via the paired approach avionics. If the crew was not commanded to breakout and failed to notice the actions of the lead aircraft, they kept on their normal approach path and landed as if nothing happened. Also in every case where they were not commanded to breakout and did notice that the lead aircraft was executing a missed approach, they continued the approach to landing. In these cases, the pilots stated they were comforted by the premise of the paired approach technique that as long as they were positioned behind the front gate, there was theoretically no risk of a collision. Table 6-5 shows the minimum 2D and 3D CPA values during all missed approach runs. At approximately 0.63 NM, the minimum distance is similar for both 2D and 3D.

Table 6-5: Smallest CPAs for Missed Approach Runs

CPA	Feet	NM
2D CPA Min:	3,813	0.63
3D CPA Min:	3,816	0.63

6.5 Traffic Collision Avoidance System

TCAS was evaluated during the setup of the flight simulator and ATC lab simulator in preparation for the DCE. It was operated in full traffic alert and resolution advisory mode. There were traffic alerts issued to the crews which they used for situational awareness. There were no resolution advisories issued by the system.

7 Conclusions

The subject flight crews were able to effectively operate the paired approach avionics, i.e. the CDTI and the AGD, under changing workload conditions. All pilots also successfully paired with the lead aircraft in accordance with the pre-established scenarios and were able to acquire and maintain the DSG regardless of the DSG symbology being displayed. In each of the off-nominal scenarios, the pilot complied with the breakout command that was issued by the paired approach avionics.

The experimental avionics provided speed guidance that effectively minimized the proximity to the DSG, and the calculated front gate location was shown to protect the trailing aircraft from the risk of collision.

The CDTI was displayed on electronic flight bags mounted on each side of the cockpit and out of the pilot's primary FOV. As shown by the CDTI dwell time, this location of the CDTI increased the time required to consistently validate common information between the CDTI and primary instruments. This is potentially a problem area with eye accommodation, focus, and cognitive processing issues, which could lead to increased workload. Eye-track data revealed that at least one pilot monitoring was looking at the CDTI at 200 ft above approach minimums. This data supports either the placement of the CDTI into the pilot's primary FOV or the use of the AGD as the only cockpit display for the paired approach avionics. The AGD was located on the instrument panel between the two crewmembers and this location was found to be satisfactory with sufficient information displayed to attain the DSG.

During a nominal paired approach, the front gate protected the trailing aircraft from collision when the lead aircraft blundered. Additionally, the rear gate protected the trailing aircraft from the wake generated by the lead aircraft during a nominal paired approach. No analysis has been accomplished to determine the effects of a blundering lead aircraft's wake turbulence on the trailing aircraft. Thus, the level of this risk is unknown.

8 References

1. NAS Lifecycle Planning (NLP) Project Level Agreement (PLA), Improved Multiple Runway Operations (IMRO) – Closely Spaced Parallel Runway Operation (CSPO), FY14.

2. Rohrmann, Bernd. *Verbal qualifiers for rating scales: Sociolinguistic considerations and psychometric data.* Project Report, University of Melbourne, Australia, January 2007.

3. Department of Transportation, Federal Aviation Administration, Advisory Circular 120-71A, *Standard Operating Procedures for Flight Deck Crewmembers,* AFS-210, February 2003.

4. Department of Transportation, Federal Aviation Administration, Advisory Circular 90-101A, *Approval Guidance for RNP Procedures with AR*, AFS-400, February 2011.

5. *BeGaze Manual.* Computer Hardware and Software. SensoMotoric Instruments, Version 3.3, March 2013.

Appendix A: Description of Paired Approach Avionics

The paired approach concept is intended to enable properly equipped aircraft to fly dependent approaches to parallel runways spaced 700 to 2,500 ft apart. The lead aircraft communicates its relative speed and position information to the trailing aircraft, using a data link. This information is then used by the paired approach avionics in the trailing aircraft to calculate, display, and command the required speeds to fly in order to maintain a prescribed lateral and longitudinal geometry relative to the lead aircraft. See figures A-1 through A-3. Adhering to the speed commands then keeps the trailing aircraft between the front and rear gates, thus avoiding the risk of a collision or wake vortex encounter. Figure A-4 shows an image of the AGD in the event of a front gate violation and a resultant breakout command. The paired approach concept is illustrated in figure 1-1. This National Airspace System Segment Implementation Plan operational improvement builds upon ongoing flight-deck interval management initiatives. The concept requires ADS-B In for the trailing aircraft, ADS-B Out for the lead aircraft, autopilot coupling-to-approach guidance, CDTI, and flight-deck interval management capabilities, in concert with pilot and controller procedures, to enable the required interval on approach.

All menus were presented at the top of the CDTI (figure A-1) in this DCE. The pilot monitoring programmed the paired approach avionics, and the pilot flying confirmed all entries were correct prior to arming the pairing software. The CDTI screen in this DCE was touch sensitive, and the crews selected menu items by touching the screen. Crews operate and utilize the avionics as follows:
Step 1: Touch "Operations Menu";
Step 2: From next menu, touch "Pair";
Step 3: Select the lead aircraft by touching on it on the CDTI;
Step 4: Touch "Ownship's FAS";
Step 5: When the keypad appears, touch in "own ship" FAS and touch "Enter";
Step 6: Touch "Target's ACID FAS";
Step 7: When the keypad appears, touch inside the box "ACID FAS" and touch "Enter";
Step 8: "Confirm Arm" appears. Crew verifies correct entries - touch "Confirm Arm";
Step 9: "Arm" appears. When ready to engage, touch "Arm";
Step 10: "Disarm" appears, paired symbology is displayed in magenta until engaged;
Step 11: Once the pairing algorithm is satisfied paired symbology is displayed in green, "Disengage" appears, and speed commands begin; and
Step 12: Adhere to Speed Commands.

All speed guidance (picnic table & speed commands) disappears at FAF, which at SFO is 5 NM from the threshold. Even though speed commands are gone past this point, front and rear gates are displayed and active until the lead aircraft is no longer a factor.

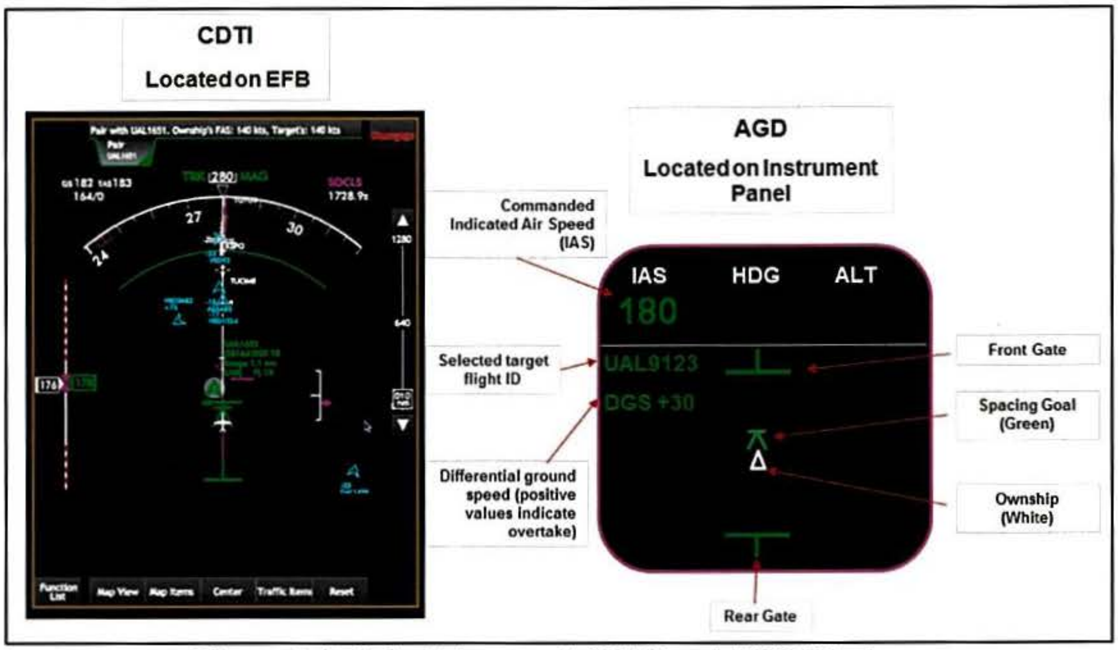

Figure A-1: Paired Approach CDTI and AGD Displays

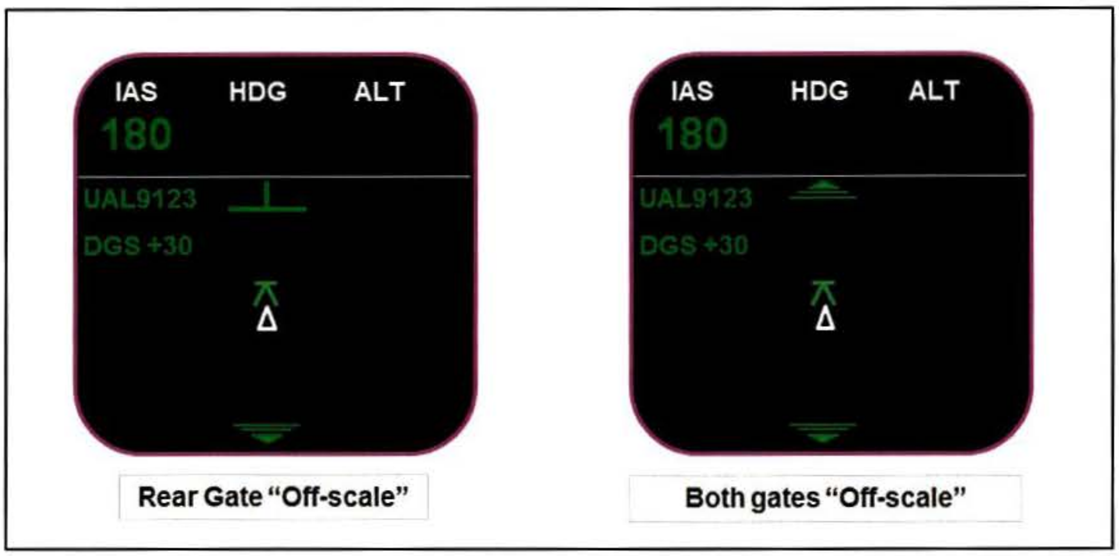

Figure A-2: AGD Off-Scale Indications

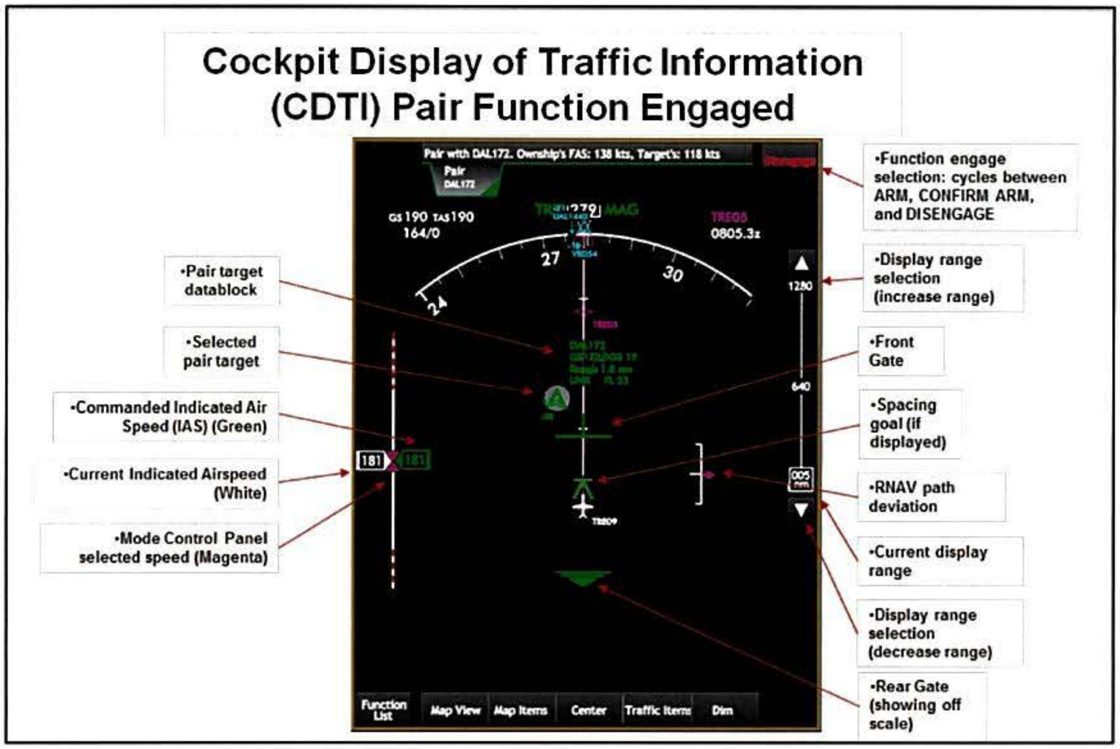

Figure A-3: CDTI Description

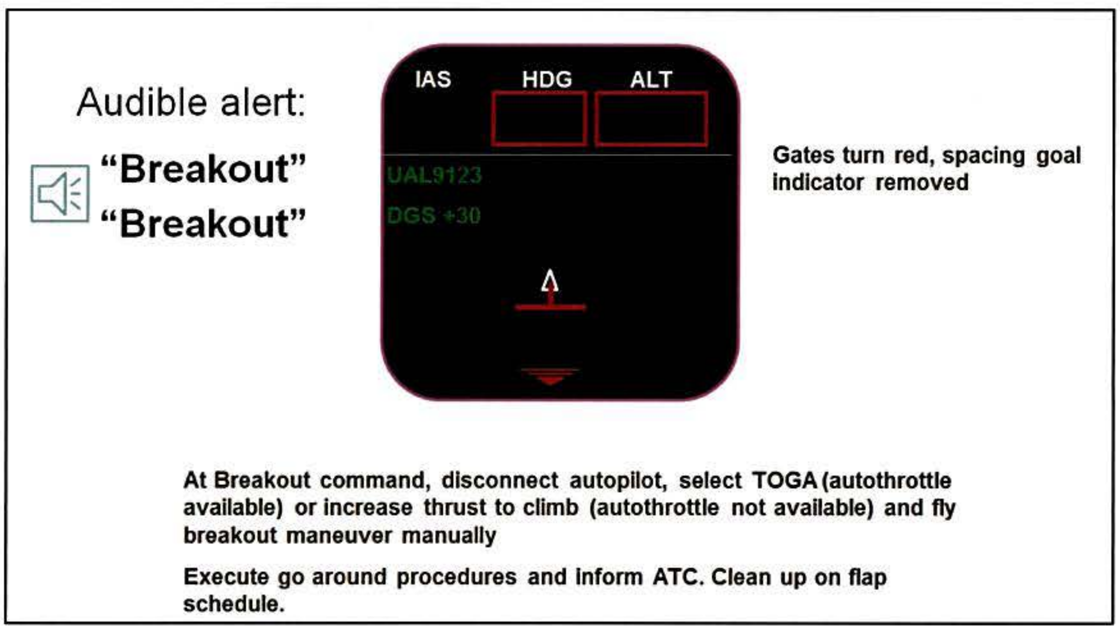

Figure A-4: AGD at Breakout

Appendix B: Paired Approach Instrument Procedures & Attention All Users Page

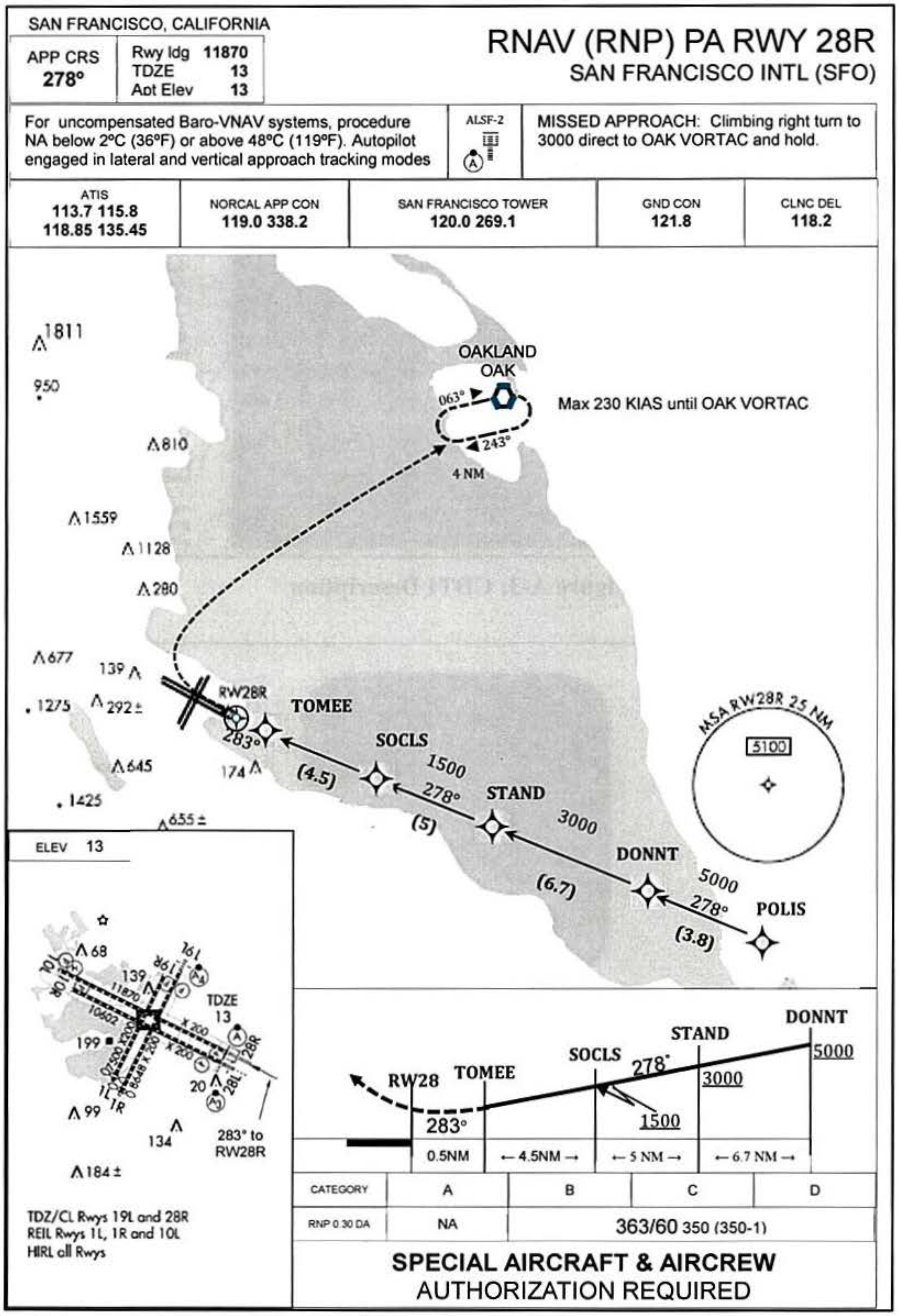

Figure B-5: IAP for Trail aircraft to Runway 28R

RNAV (RNP) PA RWY 28R

SAN FRANCISCO INTL (SFO)

ATTENTION ALL USERS PAGE (AAUP)

Condensed Briefing Points:

The Lead aircraft ID and its planned Final Approach Speed will be provided to the Trail aircraft by ATC.

Initialize paired approach avionics with flight identification and planned final approach speed of lead aircraft once this information has been provided by ATC.

Once cleared for the approach, do not descend below 5,000 feet MSL unless paired approach guidance equipment indicates that a position between the front and aft gates has been achieved.

Operate with autopilot engaged in lateral and vertical approach tracking modes until arrival at DA. Do not disengage autopilot prior to reaching DA, even if visual references are established.

1. ATIS. When the ATIS broadcast advises that paired approaches are in progress, pilots of aircraft capable of conducting paired approaches as the trail aircraft should brief to fly the RNAV (RNP) PA RWY 28R approach. If the approach clearance includes the phrase "no lead aircraft," and for aircraft unable to conduct paired approaches, the approach may still be flown. Minimums and missed approach procedures are unchanged.

2. Breakouts / Missed Approaches All Breakouts will be hand flown.

1. The breakout maneuver is a climbing right turn to 3000 feet direct to OAKLAND VORTAC, or as otherwise instructed by ATC..
2. The missed approach point is the RWY 28R Threshold.

3. Glide Path Navigation. Monitor descent path to ensure that fix crossing requirements are adhered to. Descending on the glide path provides augmented protection from wake turbulence encounters.

4. Speed Control. Paired approach speed guidance avionics provide guidance to achieve an in-trail position at SOCLS that will guarantee adequate separation for the remainder of the approach assuming that both aircraft reduce to their planned final approach speeds promptly and accurately. Follow speed guidance to the point of configuring at SOCLS. Do not delay configuration and deceleration after passing SOCLS.

5. Final Approach Speed. The successful outcome of paired operations depends on accurate maintenance of the planned final approach speed. Advise ATC promptly of any change in the planned final approach speed.

Paired approaches will be offered/conducted when weather conditions meet or exceed the RNAV (RNP) PA RWY 28R approach minima.

(PAIRED APPROACH)
RNAV (RNP) PA RWY

SAN FRANCISCO, CALIFORNIA
SAN FRANCISCO INTL

Figure B-6: Attention All Users Page for Trail Aircraft to Runway 28R

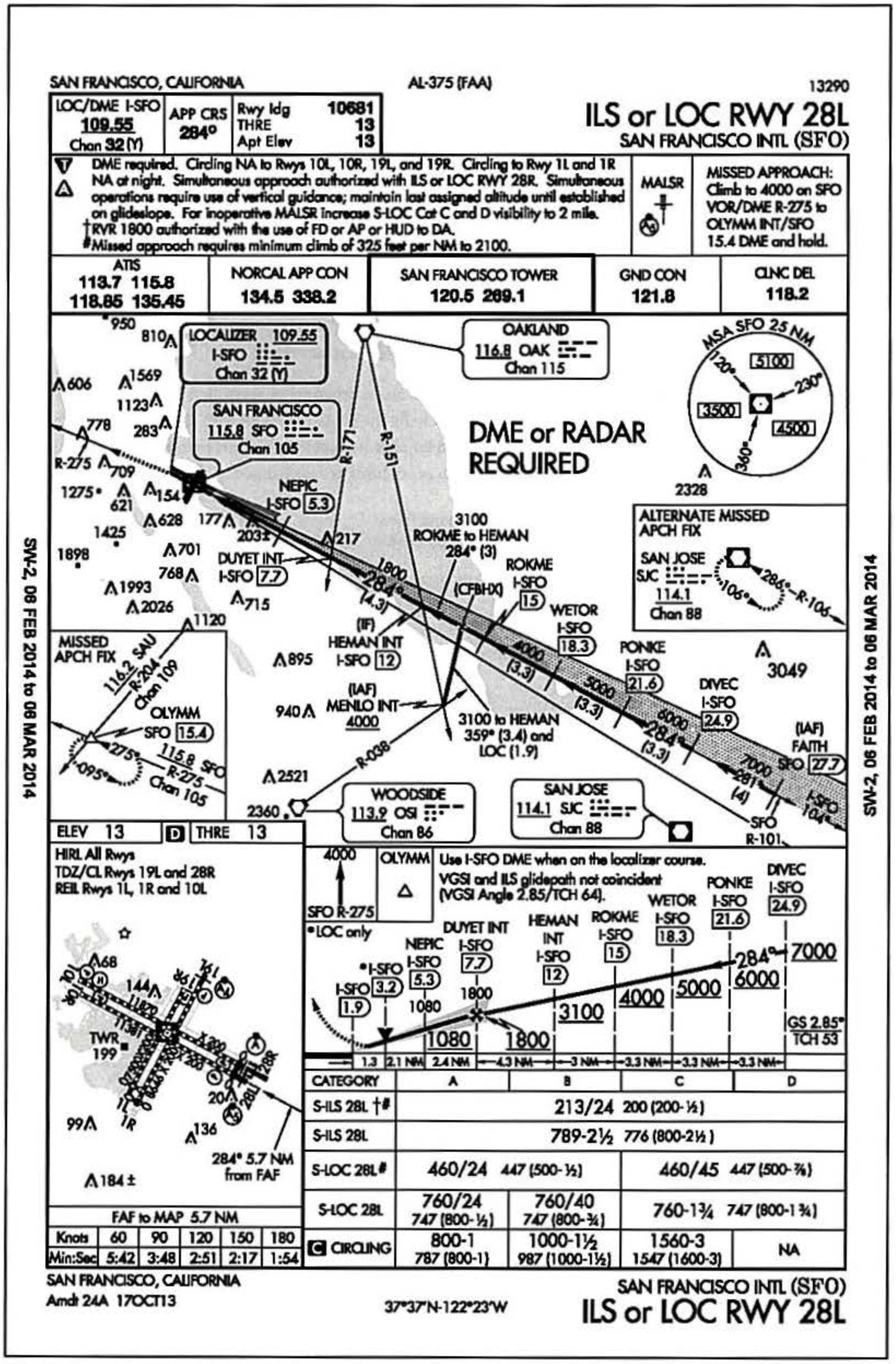

Figure B-7: IAP for Lead Aircraft to Runway 28L

Appendix C: Pilot Demographic and Post-Simulation Questionnaire

DATE: ___________________CREW #:_______________ CP/FO

1. What airline are you currently employed by?___________________________

2. Are you current and qualified (have landing currency) in the aircraft you flew in the simulation?_______________

3. Are you currently flying line operations for your company? _________

4. If you are not current and qualified in the aircraft of question 2, what aircraft are you currently flying for your employer? ________________________________
Approximately how many hours do you have in the aircraft in which you are currently qualified? _____________________

5. Were there significant differences between this simulator compared to the aircraft you fly for your company and did it impact your performance?

____

6. Did you have prior experience in the use of the AGD and CDTI prior to this evaluation?_________

7. Overall, did you feel comfortable with this procedure and the equipment we asked you to use? ________________ Why or Why Not? _________________________________

8. What additional mental or physical requirements were imposed on you during this procedure? Were there any changes to your workload (mental or physical)?

____

9. Did you have any trouble understanding and interpreting the information provided on the displays, including visual information leading to a breakout?

____

10. Were you comfortable with executing a breakout, even at lower altitudes?

____

11. Did your performance change significantly with varying aircraft weights (heavy versus light)?

____

12. What is your sense of the roles and responsibilities of each crew member with this equipement (i.e. delineation of duties)?

____

13. Do you have any suggestions for this procedure in the future? Training? Equipment?

Appendix D: Flight Crew Briefing

As part of the pilot briefing, the pilots reviewed the AAUP and approach charts. Special attention was paid to the communication and breakout requirements for these approaches. The following outline was utilized to form the pilot briefing:

- Welcome and thanks;
- No harm/no foul/no certificate action policy;
- Reason for the data collection: to study stabilized approach criteria during closely spaced paired approaches;
- Brief the paired approach concept;
- Assess the safety, workload, and feasibility of paired approach operations for the flight crew;
- Distribute AAUP and approach charts;
- Discuss hardware setup in the simulator laboratory;
- Discuss simulator set up prior to release;
    - Communication and navigation radios pre-set;
    - Aircraft positioned prior to release per each scenario;
    - Configured for the approach;
        - Speed will vary;
        - Approach flaps commensurate with that speed; and
        - Landing gear up.
    - Assume aircraft was just instructed to contact the tower. Check in with tower when simulator is released; and
    - Weather conditions will be at or near the minimums for the RNP RNAV Paired Approach to runway 28R.
- Discuss paired approach avionics and terminology;
- Discuss autopilot and autothrottle only usage;
- Overall flow (include break times);
- Human factors briefing;
- Questions;
- Allow crew briefing time;
- Tell them when to be in the flight simulator; and
- Coffee and a break.

NOTE: There was no pass/fail, no names were recorded, and all information collected was only used for risk analysis of these specific operations.

Appendix E: Pilot Scenarios

Table E-1: Pilot Scenarios

Scenario	Pilot Flying	Weight	Profile	DSG Symbology
1	Captain	Heavy	2-Nominal	Yes
2	First Officer	Light	2-Nominal	Yes
3	Captain	Light	2-Nominal	No
4	First Officer	Heavy	2-Nominal	No
5	Captain	Heavy	3-Blunder	Yes
6	First Officer	Light	3-Blunder	Yes
7	Captain	Light	3-Blunder	No
8	First Officer	Heavy	3-Blunder	No
9	Captain	Heavy	4-Front Gate	Yes
10	First Officer	Light	4-Front Gate	Yes
11	Captain	Light	4-Front Gate	No
12	First Officer	Heavy	4-Front Gate	No
13	Captain	Heavy	5-Rear Gate	Yes
14	First Officer	Light	5-Rear Gate	Yes
15	Captain	Light	5-Rear Gate	No
16	First Officer	Heavy	5-Rear Gate	No
17	Captain	Heavy	6-Missed Approach	Yes
18	First Officer	Light	6-Missed Approach	Yes
19	Captain	Light	6-Missed Approach	No
20	First Officer	Heavy	6-Missed Approach	No
21	Captain	Heavy	1-Baseline	No
22	First Officer	Heavy	1-Baseline	No
23	Captain	Light	1-Baseline	No
24	First Officer	Light	1-Baseline	No

Appendix F: Post-Run Questionnaire

DATE: _______ CREW #: _______ RUN ________ SCENARIO ___ PF/PM

1. Compared to a typical instrument approach, rate the level of difficulty performing this approach.

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

2. Rate your comfort level with the paired aircraft on its normal flight path.

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

3. Rate your comfort level after recognizing the paired aircraft has blundered.

Much Easier		Somewhat Easier		**Same as Typical Operation**	Somewhat More Difficult		Much More Difficult		
1	2	3	4	5	6	7	8	9	N/A

4. Rate your comfort level with having to conduct a breakout maneuver.

Much Easier		Somewhat Easier		**Same as Typical Operation**	Somewhat More Difficult		Much More Difficult		
1	2	3	4	5	6	7	8	9	N/A

5. Rate your perceived level of **individual workload** for this procedure from the standpoint of communication, coordination, and procedural habit patterns throughout the approach.

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

6. Rate your perceived level of **crew workload** for this procedure from the standpoint of communication, coordination, and procedural habit patterns throughout the approach.

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

Appendix G: Additional Post-Run Questionnaire Responses

Figure G-1 shows the distribution of response values of the post-run questionnaire when comparing the heavy and light profiles. Since subject pilots and observers noted the heavy gross weight scenarios increased workload, the figures that follow reference the "heavy/light" variable that are representative aircraft gross weights. Figures G-2 through G-7 reflect a subset of the response data from figure G-1.

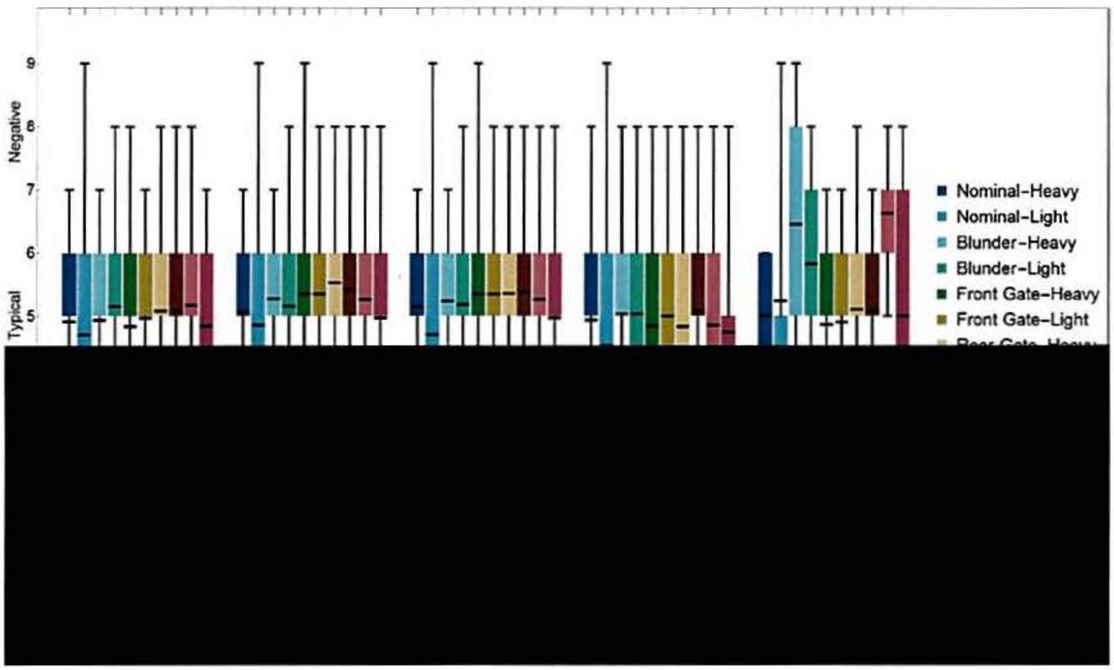

Figure G-1: All Profiles Heavy vs Light – Box & Whisker Plot of Post-Run Questionnaire Responses

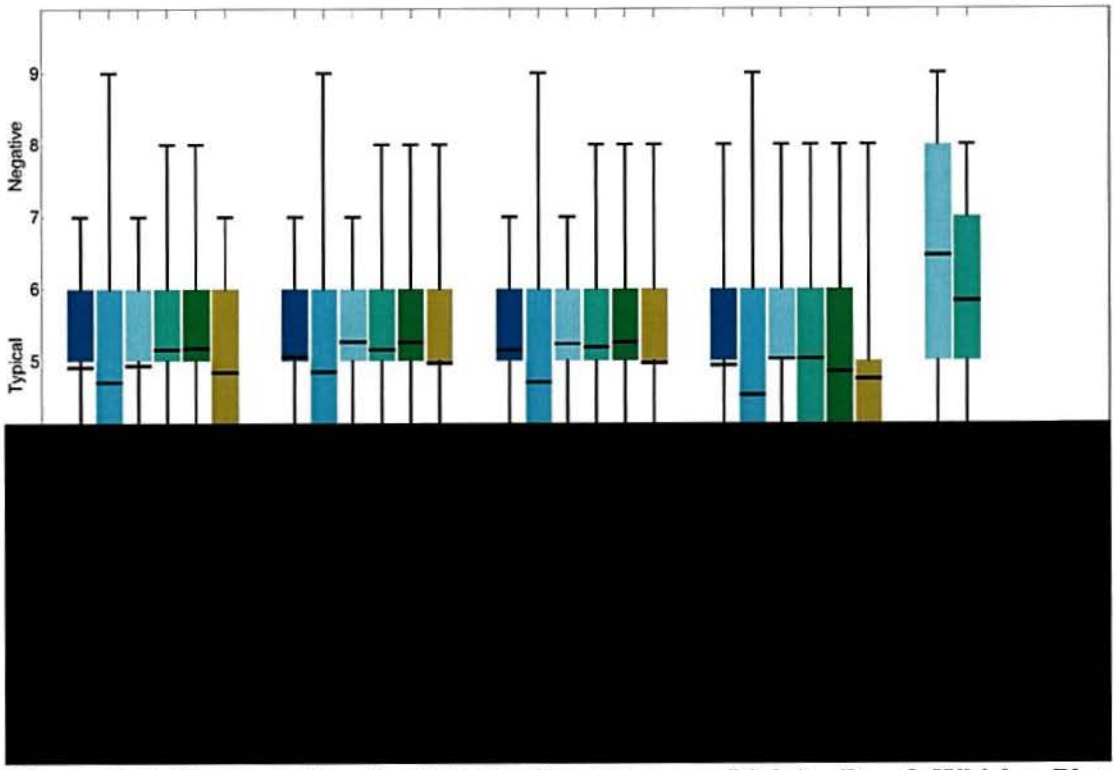

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Figure G-2: Nominal, Blunder, MA Profiles (Heavy vs Light) – Box & Whisker Plot of Post-Run Questionnaire Responses

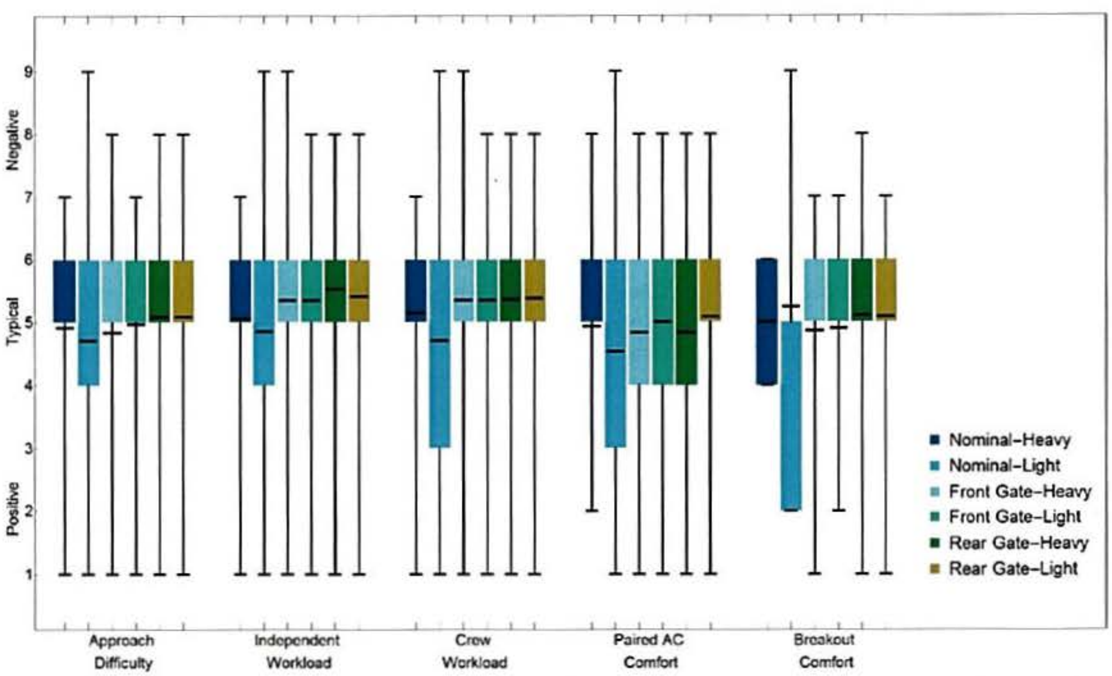


Figure G-3: Nominal, Front, & Rear Gate (Heavy vs Light) – Box & Whisker Plot of Post-Run Questionnaire Responses

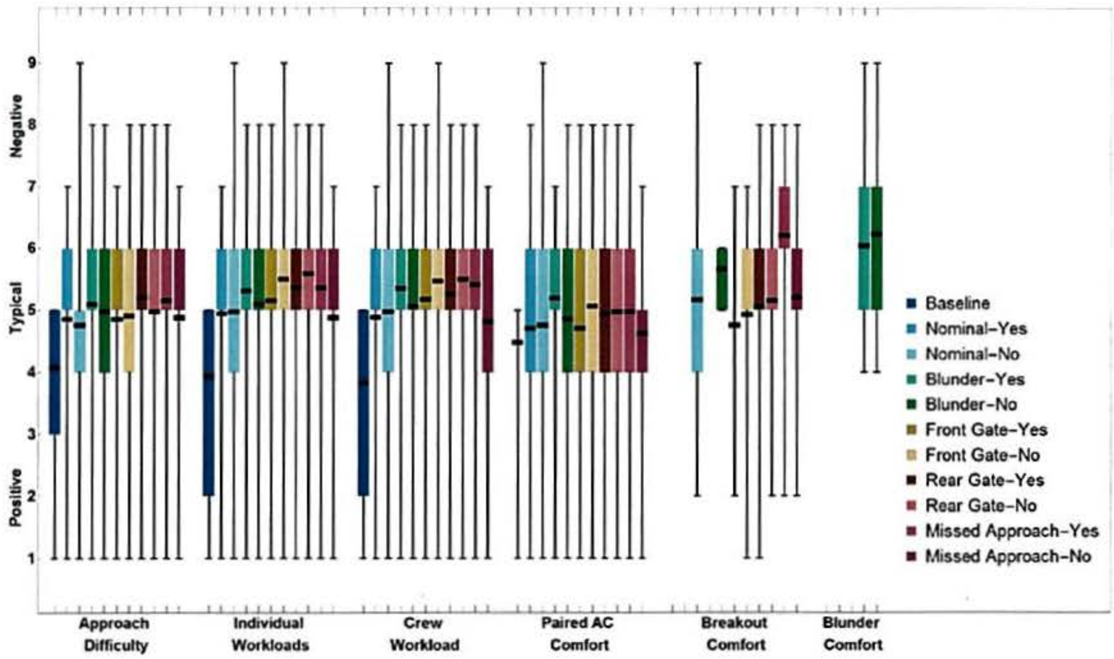


Figure G-4: All Profiles DSG Symbol ON/OFF – Box & Whisker Plot of Post-Run Questionnaire Responses

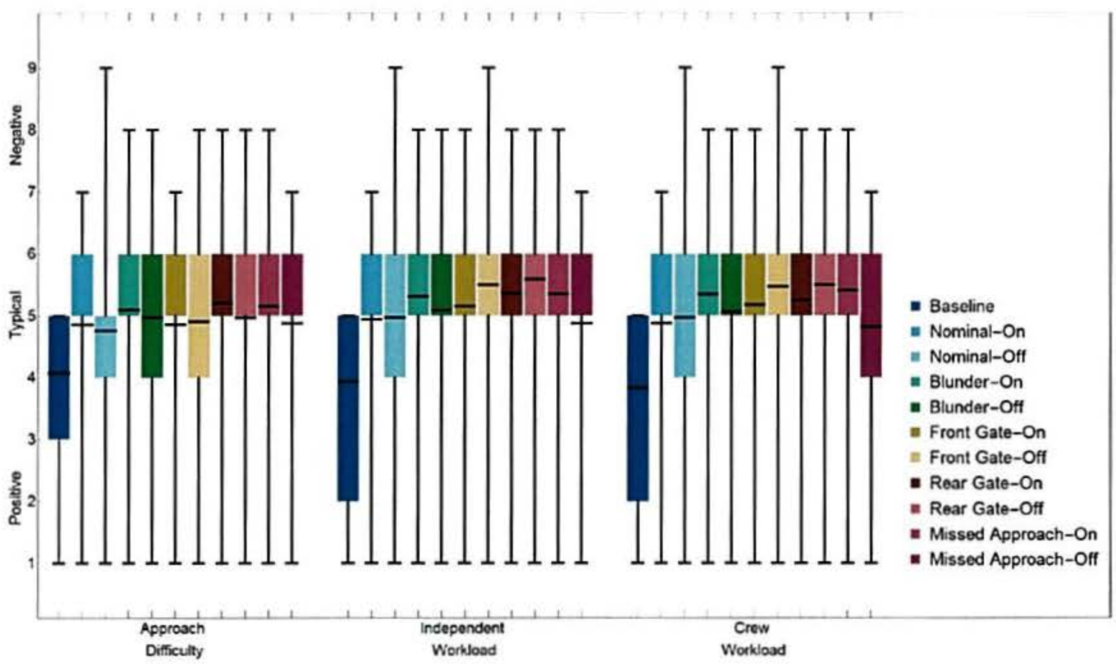
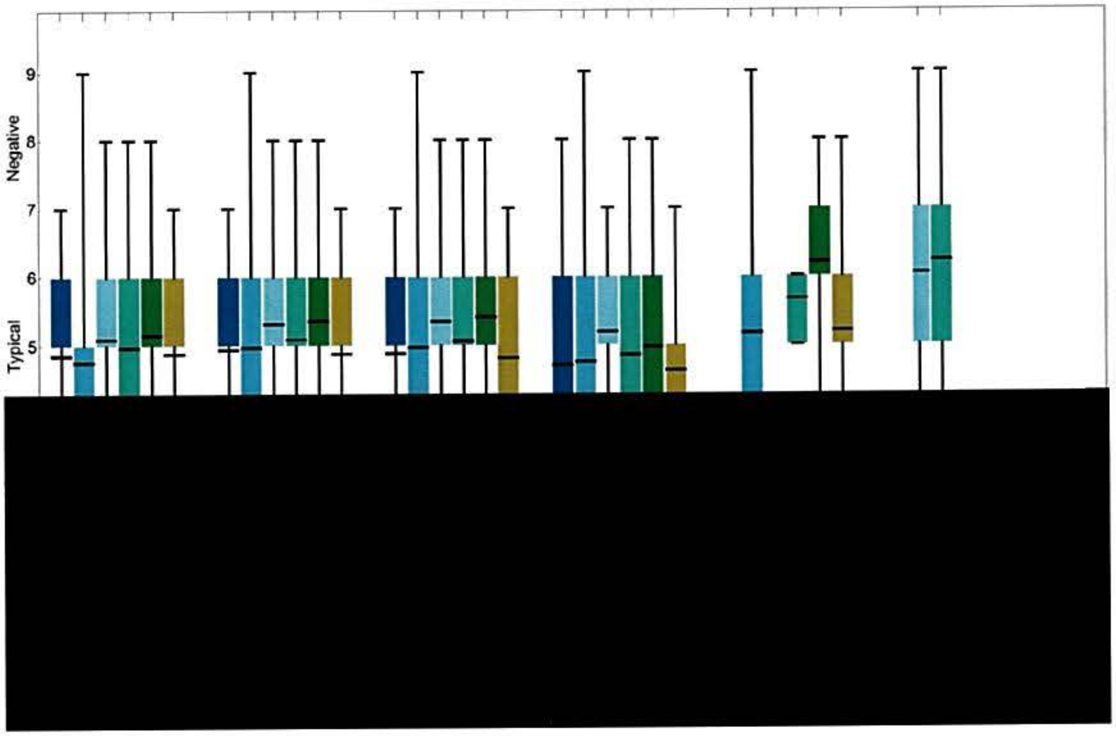


Figure G-5: All Profiles DSG Symbol ON/OFF (Difficulty & Workload Questions) – Box & Whisker Plot of Post-Run Questionnaire Responses



[redacted]

Figure G-6: Nominal, Blunder, MA Profiles (DSG Symbol ON/OFF) – Box & Whisker Plot of Post-Run Questionnaire Responses

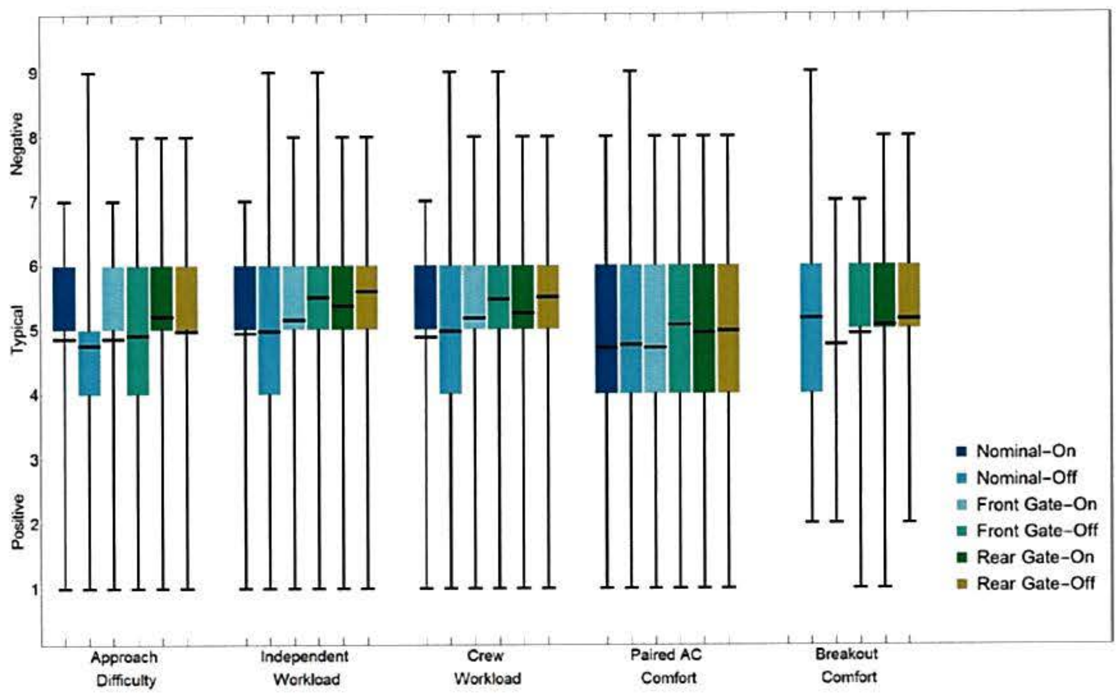


Figure G-7: Nominal, Front, and Rear Gate Profiles (DSG Symbol ON/OFF) – Box & Whisker Plot of Post-Run Questionnaire Responses