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Preliminary Human-in-the-Loop Assessment of Procedures for Very-Closely-Spaced Parallel Runways

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April 2010

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NOMENCLATURE

4-D	four-dimensional
ACFS	Advanced Cockpit Flight Simulator
ADS-B	Automatic Dependent Surveillance–Broadcast
AGL	above ground level
AILS	Airborne Information for Lateral Separation
ATL	Hartsfield-Atlanta International Airport
BOS	Boston/General Edward Lawrence Logan International Airport
cg	center of gravity
CDTI	cockpit displays of traffic information
C-LNAV	Coupled Lateral Navigation
C-SPD	Coupled Speed
C-VNAV	Coupled Vertical Navigation
CVSRF	Crew Vehicle Systems Research Facility
DEN	Denver International Airport
DFW	Dallas Fort Worth International Airport
EICAS	Engine Indicating and Crew Alerting System
FAA	Federal Aviation Administration
FMS	flight management system
GPS	Global Positioning System
ILS	instrument landing system
JAL	Japan Airlines
JFK	John F. Kennedy International Airport
KSRT	fictitious airport used for the simulation; based on current DFW layout and operations
LAX	Los Angeles International Airport
LSI	longitudinal situation indicator
ND	navigation display
nmi	nautical miles
NTZ	no-transgression zone
ORD	O'Hare International Airport
PFD	primary flight display

NOMENCLATURE (cont.)

PRM	Precision Runway Monitor
RVR	runway range visual
SA	situation awareness
SART	Situational Awareness Rating Technique
SEA	Sea-Tac Airport
SFO	San Francisco International Airport
SIDs	standard instrument departures
SOIA	Simultaneous Offset Instrument Approaches
SRT	airport used for the experiment
STARs	Standard Terminal Arrival
TACEC	Terminal Area Capacity Enhancing Concept
VAST	Virtual Airspace Simulation Technologies
VCSPR	very-closely-spaced parallel runway
VFR	visual flight rules
VMC	visual meteorological conditions

PRELIMINARY HUMAN-IN-THE-LOOP ASSESSMENT OF PROCEDURES FOR VERY-CLOSELY-SPACED PARALLEL RUNWAYS

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INTRODUCTION

Demand in the future air-transportation-system concept is expected to double or triple by 2025 (ref. 1). Increasing airport arrival rates will help meet the growing demand that could be met with additional runways, but the expansion airports are met with environmental challenges for the surrounding communities when using current standards and procedures. Therefore, changes to airport operations can improve airport capacity without adding runways.

Building additional runways between current ones, or moving them closer, is a potential solution to meeting the increasing demand, as addressed by the Terminal Area Capacity Enhancing Concept (TACEC). TACEC requires robust technologies and procedures that need to be tested such that operations are not compromised under instrument meteorological conditions. The reduction of runway spacing for independent simultaneous operations dramatically exacerbates the criticality of wake vortex incursion and the calculation of a safe and proper breakout maneuver.

The study presented here developed guidelines for such operations by performing a real-time, human-in-the-loop simulation using precision navigation, autopilot-flown approaches, with the pilot monitoring aircraft spacing and the wake vortex safe zone during the approach.

BACKGROUND

The Federal Aviation Administration (FAA) has successfully conducted independent approaches to parallel runways for over 40 years using the instrument-landing-system (ILS) navigation and terminal radar monitoring (ref. 2). The simultaneous approaches that utilize standard radar are conducted on parallel runways that are separated by at least 4300 ft. It is possible to conduct independent approaches on runways separated by as little as 3000 ft, but it requires a Precision Runway Monitor (PRM) with an update rate of 1 sec. The separation standards between the aircraft on

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these parallel approaches are 1000-ft vertical separation. Additionally, a 2000-ft-wide "no-transgression zone" (NTZ) was placed equidistant from the centerlines of the approach paths on the two parallel runways. Some airports, like San Francisco International Airport (SFO), can support approximately 60 landings per hour on its two parallel runways that are 750 ft apart by using simultaneous offset instrument approaches (SOIA) (ref. 3). SOIA approaches require the trailing aircraft in the paired approach to obtain a visual sighting of the lead aircraft with at least a 1200-ft ceiling with 4-nmi visibility. As weather degrades, the current navigation and surveillance system, as well as the existing procedures, lack the accuracy to support SOIA approaches, reducing the landing rate to half the visual-flight-rules (VFR) capacity.

Several researchers have investigated alternative procedures for very-closely-spaced parallel runway (VSCPR) operations. Studies have focused on the technologies required to enable the VCSPR operations. Several different requirements have been identified from these studies, such as cockpit displays, collision-prevention systems, and precision navigation, communication, and surveillance systems (refs. 6, 7, and 8). Another critical component that is necessary for the safe execution of VSCPR procedures is the ability to predict the wake vortices for the aircraft nearby and provide wake information to the affected aircraft.

Previous research has also evaluated procedures for VCSPR approaches, but most of them have used fast-time simulation to investigate the performance of the procedures. Pritchett & Landry (ref. 6) identified the various parameters related to VCSPR operations, such as separation responsibility and different separation and spacing objectives between the paired aircraft.

Few human-in-the-loop studies have been conducted for VCSPR operations. A study to investigate pilot response to VCSPR operations for the Airborne Information for Lateral Separation (AILS) concept is one such example. NASA developed the AILS concept to further examine independent parallel runway operations for runways as close as 2500 ft. The concept requires technologies that enable the use of precise navigation and surveillance data. Automation is presumed to detect blunders or situations that may require the aircraft to perform a breakout maneuver (ref. 4).

The AILS experiment was designed to study three variables: 1) intruder geometry, 2) runway separation (3400 or 2500 ft), and 3) flight control mode (autopilot versus manual prior to the warning for breakout). The dependent variables were pilot reaction time and miss-distance in off-nominal situations that required the pilot to perform an escape maneuver. The study found that pilot reaction time to detect and perform breakout maneuvers was not affected by runway separation. Across all conditions the average pilot reaction time was 1.11 sec, with a standard deviation of 0.45 sec. The experiment found a statistically significant effect for the flight control mode, with autopilot use prior to the emergency escape maneuver leading to longer reaction times. The current study is different from the AILS experiment because it considers wake, and dynamically generates breakout maneuver.

TACEC aims to fly paired approaches on runways that are 750 ft apart in instrument meteorological conditions (ref. 5). A ground-based processor will identify aircraft that could be paired approximately 30 minutes from the terminal boundary. The aircraft are selected for pairing based on several parameters, such as aircraft performance, arrival direction, relative timing criteria, and aircraft size-of-wake considerations. The ground-based processor then assigns four-dimensional

(4-D) trajectories to the aircraft in the pair. It is assumed that all aircraft will use differential Global Positioning System (GPS)-enabled and high-precision 4-D flight-management-system (FMS) capabilities for the execution of these trajectories. Enhanced cockpit displays that depict both traffic and wake information will also be a requirement for these operations. These operations guarantee a wake-free region by positioning a following aircraft sufficiently close to the lead aircraft on the parallel approach so that the vortex does not have time to spread into the path of the following aircraft (fig. 1). When the paired aircraft reach 12 nmi from the airport, their autopilot systems become “coupled” via a longitudinal spacing control mode. In this mode, a speed-control algorithm on the following aircraft uses state data broadcast by the lead aircraft to precisely maintain the separation between the two aircraft until touchdown.

The TACEC concept envisions nearly completely automated approaches and landings. Advanced 4-D-capable FMSs execute the assigned 4-D trajectories, and an integrated coupling system maintains safe spacing between the paired aircraft during the final 12 nmi of flight. The pilot is responsible for approving the engagement of coupling and monitoring safe progress using cockpit displays of traffic information (CDTIs) that include display of predicted wake location, alerts for wake hazards, display of ownership and traffic assigned trajectories, and indication of navigation performance relative to assigned trajectories.

Little data exist regarding the use of VCSPR technologies and procedures. The objective of the current study was to develop guidelines for the procedures defined by the TACEC using a human-in-the-loop simulation study. Thus the objective of this simulation also included exploring the usefulness and usability of the cockpit displays and procedures associated with this new concept.

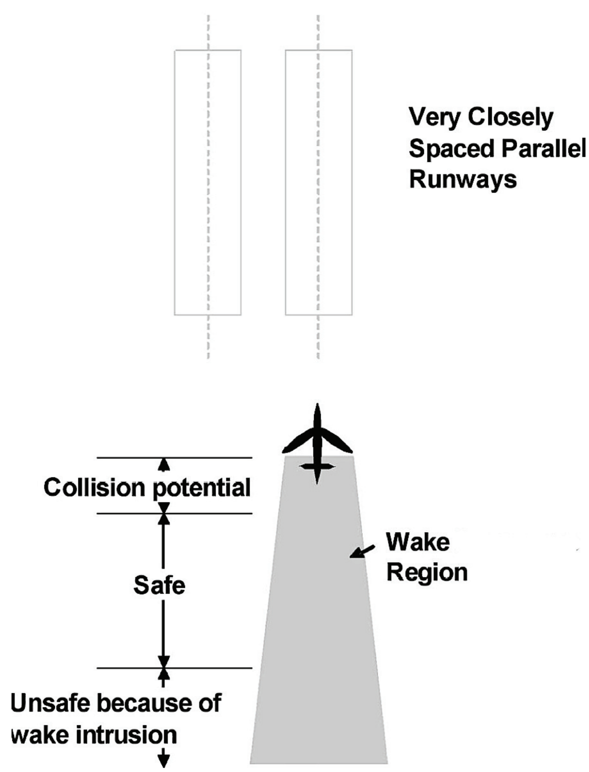

Figure 1. Wake-safe zone for following aircraft.

HUMAN-IN-THE-LOOP EXPERIMENT

Objectives and Hypotheses

The objective of the study was to assess and develop preliminary guidelines for the procedures for the Terminal Area Capacity Enhancing Concept (TACEC) by performing a real-time, human-in-the-loop simulation to conduct human-factors studies of prototype displays and to investigate procedures. This process accelerates development of a far-future (2025) concept through early implementation. The effort required development of a simulated airport with parallel runways 750 ft apart, and designing the airspace around this generic airport to facilitate very-closely-spaced parallel runway (VCSPR) approaches. The concept was implemented in the Advanced Cockpit Flight Simulator (ACFS) by integrating displays that depict wake and traffic information. The participants of the study flew the simulator under various conditions and provided feedback on changes in roles and responsibilities, new procedures, and their opinions about the concept. The report describes all aspects of the study, starting with the approach.

Appendices A through D give pilot schedule, demographic, and survey information, appendix E gives observer feedback, appendix F lists questions for group discussion, and appendix G discusses the layout of the airport used in the study.

Approach

Test Facility

The human-in-the-loop study conducted to assess the paired TACEC approaches used the ACFS, a full-mission simulator that resides in the Crew Vehicle Systems Research Facility (CVSRF). The ACFS simulates a generic commercial transport aircraft, and it can be reconfigured to represent future aircraft. Currently, the ACFS can simulate two aerodynamic aircraft models, narrow-body transport aircraft (similar to a Boeing 757) and a C-17 transport. The simulator, as it stands, includes fly-by-wire flight controls, touch controls, touch-sensitive electronic checklists, schematics of aircraft systems, a customizable FMS, and graphical flight displays. The cab is mounted on a six-degree-of-freedom synergistic motion system and uses side stick controllers for aircraft control in the pitch and roll axes. The simulator is run from Silicon Graphics, Inc, (SGI) computers, which provide the simulator flight systems and programmable flight displays. In this study, the CDTI described in the “Background” section was integrated with the flight-display systems in the cockpit. The ACFS motion capabilities were also used for the study.

The visual systems in the ACFS offer a 180-degree horizontal and a 40-degree vertical field of view. The ACFS visual databases can depict as many as nine airports (SFO, Los Angeles International Airport (LAX), John F. Kennedy International Airport (JFK), Denver International Airport (DEN), Dallas Fort Worth International Airport (DFW), Sea-Tac Airport (SEA), Hartsfield-Atlanta International Airport (ATL), O’Hare International Airport (ORD), and Boston/General Edward Lawrence Logan International Airport (BOS). For the VCSPR study, the SRT airport visual database was created, which is a modification of the DFW airport, as described in appendix G on the DFW layout.

Airport and Airspace Design

The airport and airspace used to investigate procedures for the TACEC concept used a fictitious airport that was based on the current DFW's layout and operations. The airport used for the simulation was referred to as "KSRT." The simulation focused on studying TACEC approaches to very closely spaced parallel runways. Since a south air traffic flow was used for the simulation scenarios, the SRT airport utilized only runways 18R, 18L, 17R, and 17C (renamed to 17L). All four runways were assumed to be equipped to a Category IIIB (CAT-IIIB) level. Both 18R and 17L (see figure 2) were moved to within 750 ft of their inboard runways, 18L and 17R, respectively, requiring an adjustment of 464 ft from their current DFW positions. The layout of the DFW is described in detail in appendix G.

TACEC Procedures

The TACEC concept calls for TACEC-assigned 4-D arrival trajectories for both of the aircraft to be paired at meter fixes located near the edge of the terminal airspace, normally 40–60 nmi from the airport (ref. 5). Flights in the simulation began 25 nmi from the airport, assuming they were already paired. Routes to the KSRT airport included approach and departure routes and procedures similar to those for DFW airport. This study focused upon arrivals; no departures were included.

Arrival Traffic Flow

South flow of traffic was simulated for the generic airport KSRT. All of the four runways (18R, 18L, 17R, 17L) were used for arrival operations. The concept allows for any aircraft arriving from any of the four arrival meter fixes (NE, NW, SE, and SW) to be paired for a simultaneous parallel landing, based on aircraft characteristics and relative timing criteria.

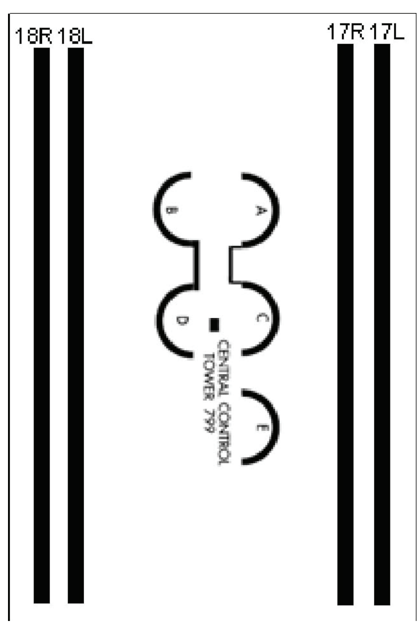

Figure 2. SRT airport diagram.

Paired aircraft must fly their assigned 4-D trajectories with a high level of accuracy in order to meet timing constraints at the coupling point and ensure wake safety throughout the approach. The 4-D trajectories were carefully designed to provide safe wake-avoiding routes from the arrival meter fixes to the runways. Each route consisted of three segments, and each one of the first segments provided vortex-free 4-D routes extending from the meter fix to the coupling point at 12 nmi from the runway. The second segment began at the coupling point and ended 2 nmi from the runway. During the second segment, one route was straight in, aligned with the runway centerline, while the other was at a 6-degree slew angle from the straight-in route (see fig. 3). At the coupling point, the aircraft were laterally separated by slightly more than 1 nmi. Each of the final segments was aligned with the runway centerlines, extended 2 nmi from the runway threshold, and was about 600 ft above ground level (AGL) in order to provide a straight-in flight path to touchdown.

Once the aircraft reached the coupling point, the following aircraft precisely maintained spacing behind the lead aircraft in order to avoid the wake of the lead aircraft. This operation was accomplished by an automated speed-control algorithm on board the following aircraft that maintained the assigned time-based spacing relative to the lead based on state information broadcasted via Automatic Dependent Surveillance – Broadcast (ADS-B) by the lead aircraft. Figure 3 shows the geometry of the final approach portion of the arrivals (i.e., the final 12 nmi before landing.

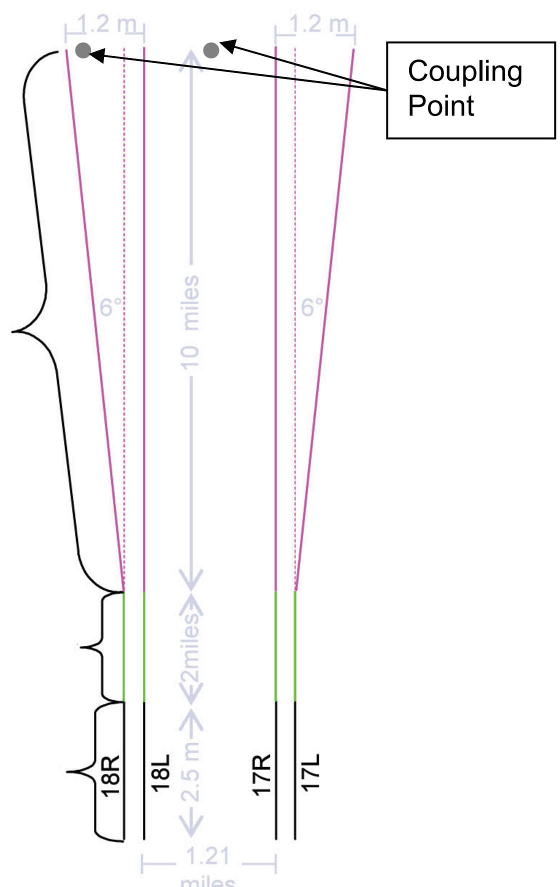

Figure 3. Final approach geometry for TACEC.

Traffic Scenario

The traffic scenario had two aircraft in the simulation: the following aircraft in the pair, as represented by the ACFS, and the lead aircraft, which was recorded or scripted for this study. The ownship was always the following aircraft, and the recorded one was always the leader aircraft in the closely spaced parallel runway approach. The leader aircraft was a Boeing 747 heavy aircraft representing Japan Airlines (JAL). Based on the wind condition, the ownship was either on the slewed approach landing on runway 18R or on the straight-in approach landing on runway 18L.

Cockpit Display of Traffic and Wake Information

The primary purpose of the displays used for the TACEC evaluation was to provide the flight crews with information to ensure that adequate separation was being maintained with the lead aircraft and its hazardous wake area. While not evaluated in the present simulation, the displays also provide "breakout" annunciation and guidance if adequate separation is not maintained with the lead aircraft or its wake. The primary flight display (PFD) and the navigation display (ND) are modifications of standard current-generation transport flight displays with added lead-aircraft position and wake information. Figure 4 shows the PFD on the straight-in parallel final at 532-ft radar altitude, while figure 5 shows the ND for the same location. Lateral spacing of the flight paths at this part of the approach was 750 ft. The displays are adaptations of those previously developed by Hardy and Lewis (ref. 8).

Lead-Aircraft Position

The position of the simulator was shown on the ND with the conventional triangular icon (solid) at the lower center of the ND. The lead-aircraft position was shown with the open icon at the upper left of the ND. The triangular lead aircraft with the same perspective was shown on the PFD at the left of the display. With augmented GPS navigation, it was assumed that position information was known, with ADS-B to be within a few ft.

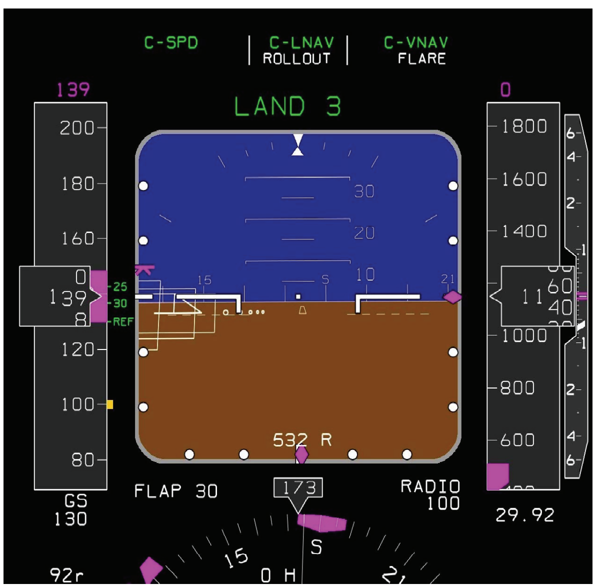

Figure 4. Primary flight display on straight-in parallel final.

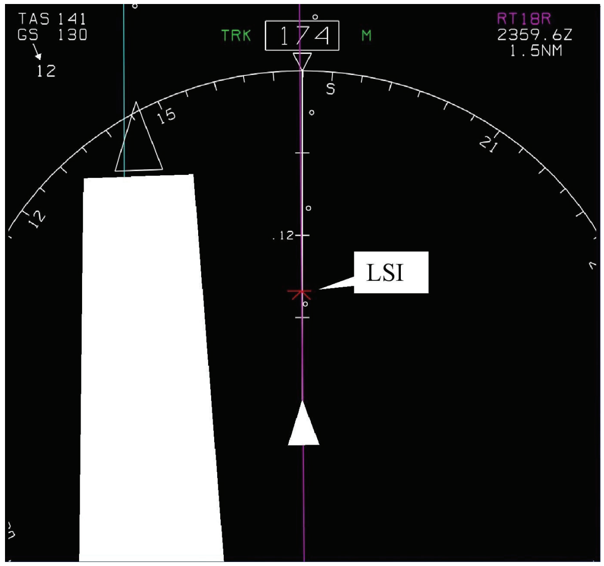

Figure 5. Navigation display on straight-in parallel final.

Hazardous-Wake-Area Depiction

The shaded white area on the ND and the wake frames on the PFD depict the hazardous wake area. This area was defined as that volume of airspace such that if the apex or center of gravity (cg) of the following aircraft (simulator) remains outside the wake area, no noticeable wake activity would be detected. This area was predicted in real time from aircraft characteristics and onboard sensors of crosswind and atmospheric turbulence. The prediction algorithms were conservative to account for model and sensor errors (ref. 9). The shaded area on the ND and the wake frames on the PFD turn amber if the cg of the following aircraft moves to within one wingspan of the hazardous area, and they turn red if its cg penetrates it.

Predictor Dots

Five 2-second predictor dots, for a total of 10 seconds, were added to the ND for both aircraft (see slightly to the right of the nominal path for the simulator in fig. 5) and also were presented on the PFD (aligned with the position icon of the lead aircraft). These dots show flight path trend information to help the pilot determine the future location of the aircraft.

Longitudinal Situation Indicator

To maintain the position of the aircraft in the "safe" zone, as shown in figure 4, a longitudinal situation indicator (LSI) was added. The LSI is flagged on the ND and shows the nominal location (in this case 5 seconds behind the lead aircraft) that the auto-throttle is attempting to keep. For this example, the simulator is approximately 400 ft behind its nominal location. The same LSI information is shown on the deviation scale added on the left side of the PFD (fig. 4).

Display Scaling

A conventional PFD has a field of view of about 40 deg. To be able to see the lead aircraft position and wake information, this field was increased to 80 deg. This increase decreases the resolution of the display, but with future larger display hardware it may not be objectionable. A conventional

ND has a maximum zoom-in capability of a 10-mi. range scale. To have adequate resolution for this task, the maximum zoom-in range scale is 0.25 nmi. The display zoomed in increments of 10-, 5-, 2-, 1-, and 0.5-nmi scales.

Experimental Matrix and Independent Variables

The three variables examined in the study were visibility conditions, direction of the wind, and the distance between the lead and follower aircraft. The visibility conditions were a clear day, or Category IIIB. The study aimed at exploring an adverse cross wind on the follower (ownship), thus the direction of winds was coupled with the follower (ownship) landing on the left or right runway (18L or 18R runways in this study), as shown in figure 5. The approach to runway 18R is referred to as the slewed approach, and the one to 18L is the straight-in approach. The third variable examined in the study was the distance between the lead and follower aircraft at initialization points, which was either 10 or 5 sec. The matrix for the study is shown in table 1, where the gap between the lead and trailing aircraft was 10 sec, and table 2, where the gap between the lead and trailing aircraft was 5 sec. In addition, an additional run led to the consideration of a potential escape maneuver due to the location of the wake and traffic. This situation was observed by the pilots for purposes of preliminary discussion, and the identification of procedures for off-nominal situations.

Dependent Variables

The dependent variables collected during the study included subjective data on situation awareness, comparison of features provided by the displays, and other subjective questions asked about the usefulness and usability of the displays in a post-interaction survey.

TABLE 1. MATRIX WHERE THE DISTANCE BETWEEN THE LEAD AND TRAILING AIRCRAFT IS 10 SEC

	Straight Approach (18L)	**Slewed Approach (18R)**
Clear day	Run 1	Run 4
Low visibility (Category-III b)	Run 2	Run 3

TABLE 2. DISTANCE BETWEEN THE LEAD AND TRAILING AIRCRAFT IS 5 SEC

	Straight Approach (18L)	**Slewed Approach (18R)**
Clear day	Run 5	Run 6
Low visibility (Category-III b)	Run 8	Run 7

Participants

The participants of the study were three retired pilots from commercial airlines; all of them had experience with glass cockpits and some experience flying SOIA approaches in San Francisco. Their mean age was 65 years, and their mean total years of experience as a pilot was about 40 years. They had an average about 16,500 hours of flying. Their average number of years since retirement was 6.5 years.

Test Scenarios

The study was run for three days, with one pilot participating each day. At the beginning of the day, the pilot was familiarized with the project, the concept, and the new displays in the cockpit. Next, the pilot was taken to the ACFS, where the pilot received a demonstration of the simulator, and more hands-on training on the CDTI and related procedures. The schedule for the study is included in appendix A. The schedule included the eight runs specified earlier (see tables 1 and 2 and appendix A) and an off-nominal escape maneuver run mentioned in the "Observer Notes and discussion" section.

Protocol

The procedures for VCSPR were being explored in this study, so each pilot flew the ACFS as a captain. The role of the pilot, in general, was to fly in autopilot mode, and monitor the displays to check separation with the lead aircraft and wake. At the coupling point the pilots heard a chime, saw the acknowledgement button light up, and a message on the lower Engine Indicating and Crew Alerting System (EICAS) appeared that read "TACEC Coupling." At this point the pilots pressed the acknowledgement button, and continued to monitor the separation between the two aircraft. The traffic scenario in the next section describes the tow aircraft that were simulated for the study.

Tools Used for Data Collection

Several tools were used for collecting subjective data from the pilots. All participants completed a demographic survey before the simulation runs were conducted. It collected information about the pilots such as their age, experience as a pilot, and number of hours flying different aircraft types, any experience with SOIA, and experience using personal computers.

Each pilot was asked to complete a Post Interaction Survey at the end of all the runs. It collected information on the pilot-rated usefulness and usability of the displays. Similarly, a feature comparison survey was administered at the end of all of the runs. The pilots had the opportunity to rate the importance of different features in the displays on a scale of 1 to 5, where 1 was equivalent to "very unimportant" and 5 was equivalent to "very important."

Pilots also completed the Situational Awareness Rating Technique (SART) (ref. 10). The SART gathers a participant's rating of his/her situational awareness (SA) for the preceding period of time on 10 different scales. Each scale has 7 points, with the end points representing the opposite ends of the construct. Participants circled the point on the scale that most closely represented their experienced level of SA. The 10 SART ratings were gathered from every participant at the end of each run—a total of 8 ratings per participant were collected.

RESULTS

This section reports results that focus on the data captured by the tools mentioned in the above paragraph . Results of the post-interaction survey, feature comparison, situation awareness, and observer notes are described in the following section.

Post-Interaction Survey

The post-interaction survey was administered to each pilot at the end of the eight trial runs. Since the questions were administered after the completion of the simulation, there were no distinctions among the different experimental conditions. The questions instead queried the participants about the general experiences of using VCSPR procedures and tools. Also, because of low statistical power for testing, tests for significance were not conducted.

The pilots responded to the question on the overall utility of the displays for VCSPR approaches as highly useful (average of 3, on a scale of 1 to 5). The questions focused on the ease of using the displays to derive information for some of the functions handled by the pilots using the displays. The pilots found that the overall level of ease for extracting information from the displays was very high (M = 5 on a scale of 1 to 5, where 1 was very hard and 5 was very easy). A detailed analyses of ease of deriving information is shown in figure 6. In general, on average the pilots found that the displays provided enough information, and that it was relatively easy to extract for most of the functions. The mean value was greater than or equal to 4 for all functions except flying in low visibility. During the group discussions, the pilots mentioned that they would like to see the tool deployed in clear weather conditions for a period of time to allow the pilots to develop enough trust in the automation before it is used for flying under Category IIIB visibility conditions. They felt that this trust could be improved with more familiarity and use of this type of automation. Also, the pilots mentioned that deriving information about wake characteristics was very easy in this simulation (M = 5). One can infer that the pilots were able to effectively monitor separation of the aircraft from the wake.

All the pilots reported that they were able to effectively monitor the lead aircraft, mostly by using the ND. Also, none of the pilots were confused by the interface. On the ability to zoom on the ND, the pilots reported that having a separate zoom capability for the pilot flying and pilot not flying will enable them to maintain both a strategic and tactical view at the same time. The ND zoom capability was handled by a toggle switch on the center console and was available as a function

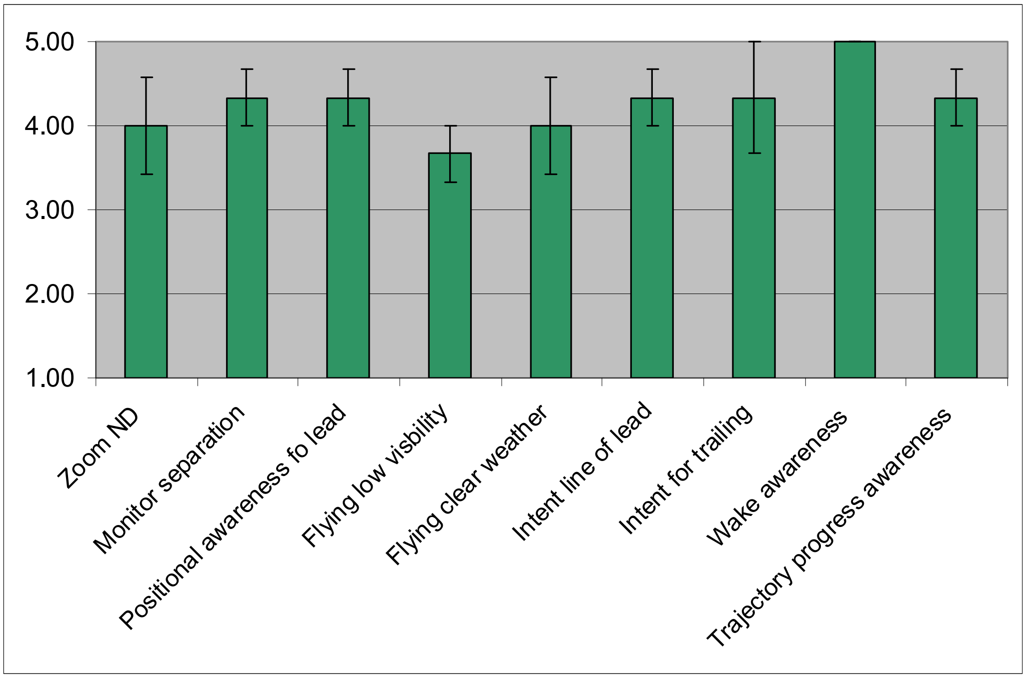

Figure 6. Ratings (mean and Standard Error (SE)) for ease of deriving information from the displays.

only to the pilot flying. The pilots were asked which aspects of the concept they liked the best, and which aspects they liked the least. The pilots liked the system and the new displays because they will greatly enhance safety in today's air traffic environment. They also agreed that the system will enhance capacity at the airports. In contrast, the pilots repeated that this automation needs to be implemented in good visibility conditions before the pilots will trust the automation for use during instrument meteorological conditions (IMC). They were all concerned about procedures for break-out maneuvers, and definition of standards for proximity. They also wanted more flexibility with maneuvering throttles without disengaging the auto throttles. One pilot also mentioned that all procedures, including airspeed requirements between the coupled aircraft, must be agreed upon by the pilots and controllers involved in the procedures prior to flying.

The pilots were also asked to rate some statements regarding the concept and displays (fig. 7). They all agreed that automation is required for VCSPR approaches, and that there was little confusion about the displays. They responded with above-average ratings for ease of monitoring separation from the lead aircraft. The participants also found the wake information on the ND and the predictor dots very useful, and they valued being able to visualize the trajectory of the lead aircraft. They rated their level of confidence in the concept as average, and they did not indicate concern in their responses about the role of the pilot in this concept.

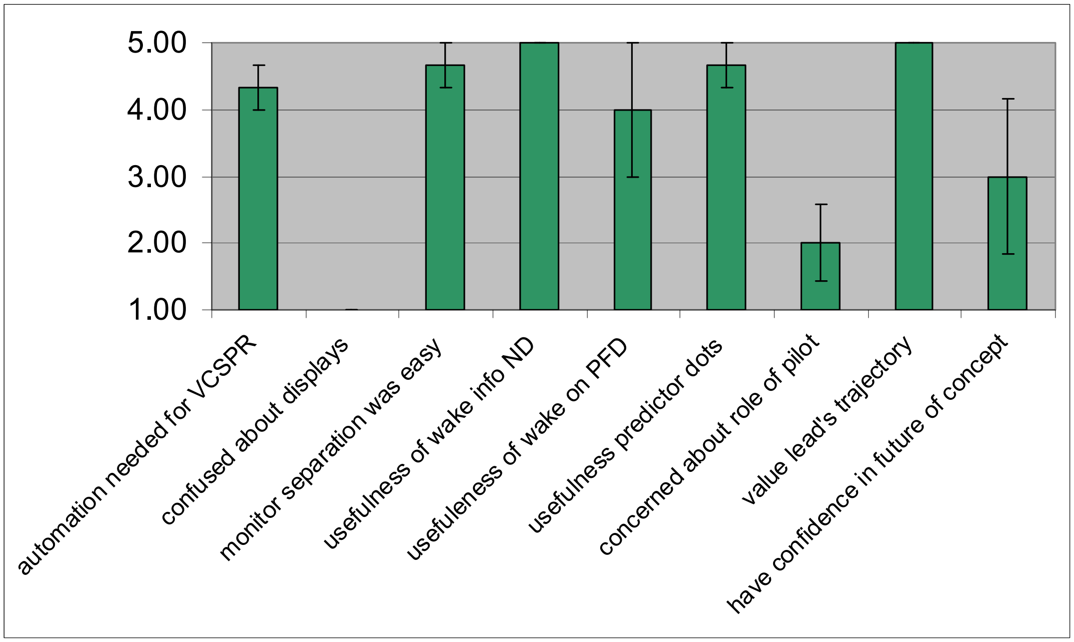

Figure 7. Pilots' subjective ratings (mean and SE) on statements regarding the concept and displays.

Feature Comparison

The participants were asked to rate the various features on the displays provided to them in the simulator. They rated most features as having above-average importance (ranging from 4 to 4.5 on a scale of 1 to 5) except the lead aircraft and the LSI on the PFD. Those were rated at an average of 3.5 on a scale of 1 to 5, where the higher number indicates higher level of importance. The LSI on the ND was not always visible, and all participants complained about not being able to visually track the LSI because it was hidden under the solid white icon of the aircraft. The LSI on the PFD provided the information about the actual position versus expected position of the simulator in terms of distance, whereas the LSI on the ND provided temporal information as referenced by the 2-sec predictor dots. Despite its poor visibility at certain times, most pilots preferred the LSI on the ND. The predictor dots on the lead aircraft were considered to have an average level of importance, because the pilots always flew the follower aircraft in the approach, and they were concerned with their own trajectory predictions to monitor separation from the lead aircraft and its wake. Similarly, the feature “out-of-the-window visibility” received a 3.5 rating, and the acknowledgement button used for accepting the coupling between the paired aircraft received a 2.6 average rating. During the group discussion, the pilots suggested that pressing the acknowledgment button should arm the coupling of the two aircraft, before they are actually at the coupling point, to keep it consistent with other standard displays. The pilots also mentioned that the flight-mode annunciation should have a visual indicator that is white, depicting that the system is armed before coupling. Eventually it should turn green when actual coupling occurs, at the coupling point. In the present experimental setup, the acknowledgement button changed the flight-management-system (FMS) annunciation to “coupled” and did not give the pilots a chance to “arm.” This situation created some confusion and led to the comments the pilots made.

Among other concerns and suggestions for improving the design of the system, some pilots had difficulty with interpreting the wake depiction and monitoring the lead aircraft on the PFD. Other pilots felt that when the aircraft starts deviating from its longitudinal position, the procedure should allow for the pilot to adjust the throttles or speed without disengaging the autopilot.

Situational Awareness

The situational awareness questionnaire, SART was administered to the pilots after every simulation run. They rated 10 SART elements on a scale of 1 to 7, where 1 is “low” and 7 is “high.” Thus the data have been analyzed for all the conditions for each of the three pilots. Because of low statistical power for testing, significance tests were not calculated. The SA ratings have been depicted on a line graph to enable better trend comparisons for the conditions. Figure 8 shows that the SA trends for the different sub-elements are the same for the aircraft starting with 10- or 5-sec temporal separation between them. The pilots did not feel that any of these situations were unstable, and level of variability and complexity was similar in the two conditions. In the group discussions, the pilots mentioned that they preferred their aircraft to be ahead rather than behind on the LSI because being behind increased the chances of the aircraft getting into the wake zone and out of the safe zone.

Pilots’ responses on SA for the simulator flying on the straight-in path (landing on 18L) or on the slewed path (landing on 18R) (fig. 9) show similar trends. The pilots considered the slewed path slightly more unstable, variable, and complex, but they also felt that a higher level of concentration and familiarity was required with the situation.

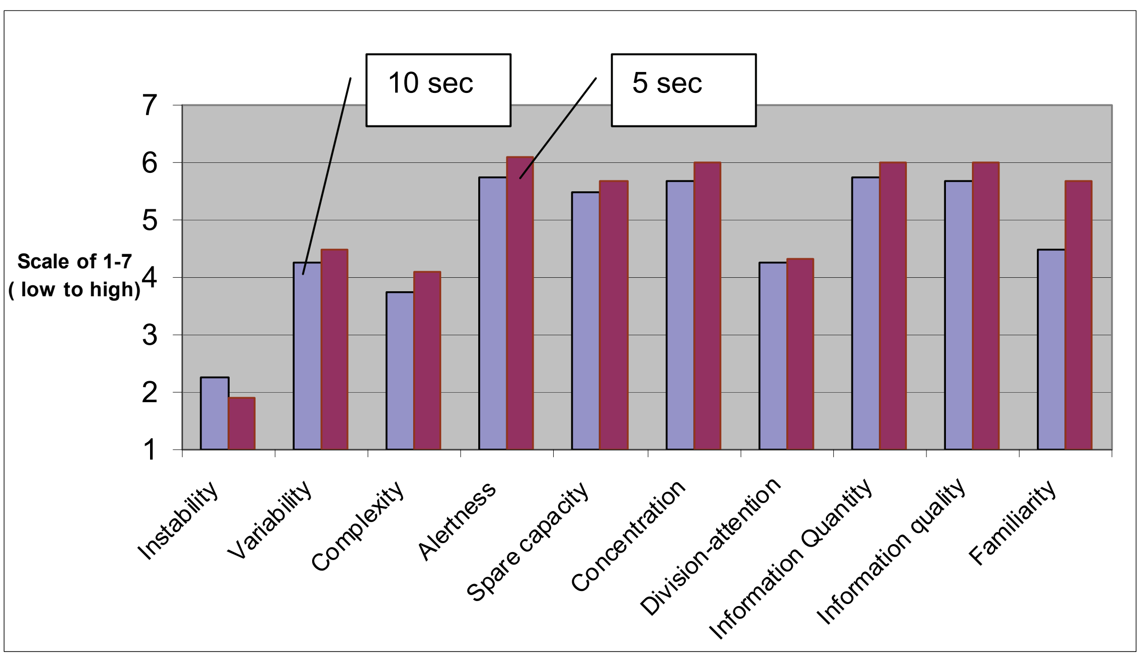

Figure 8. SA responses for 10- vs. 5-sec distance between the two aircraft.

The SA responses for the visibility condition (fig. 10) showed that the pilots experienced similar levels of awareness in the clear versus poor visibility condition. In general, they felt that the poor visibility condition was slightly more variable, unstable, and complex. The pilots required slightly more alertness, and they had slightly less spare mental capacity in the poor visibility condition as compared to clear visibility condition. The information quality, information quantity, and familiarity with the situation were about the same for both of the visibility conditions.

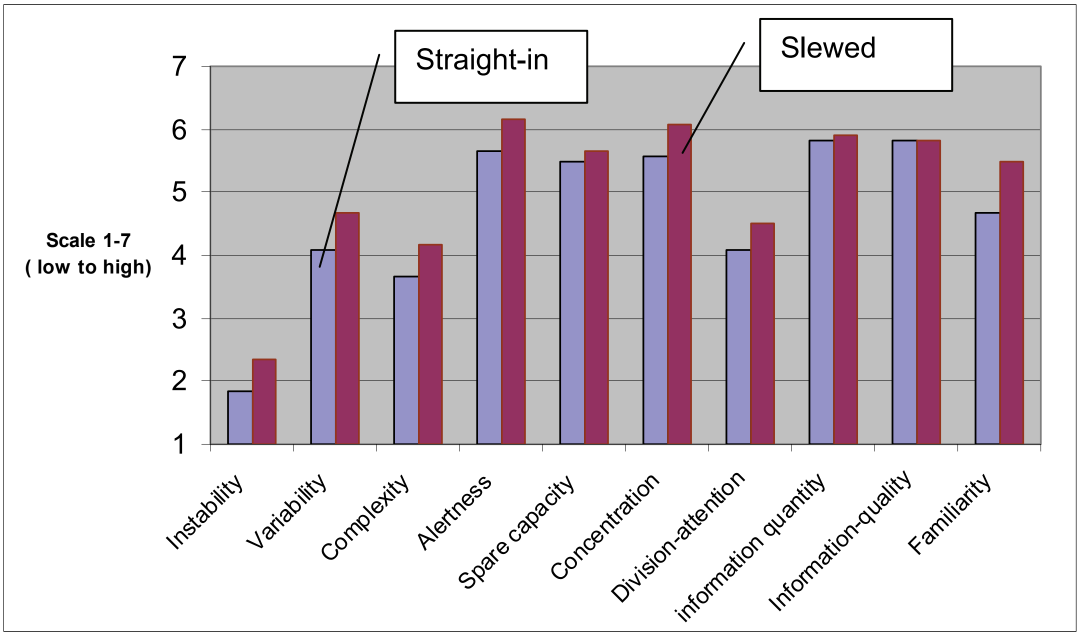

Figure 9. SA responses for aircraft on straight-in vs. slewed approach.

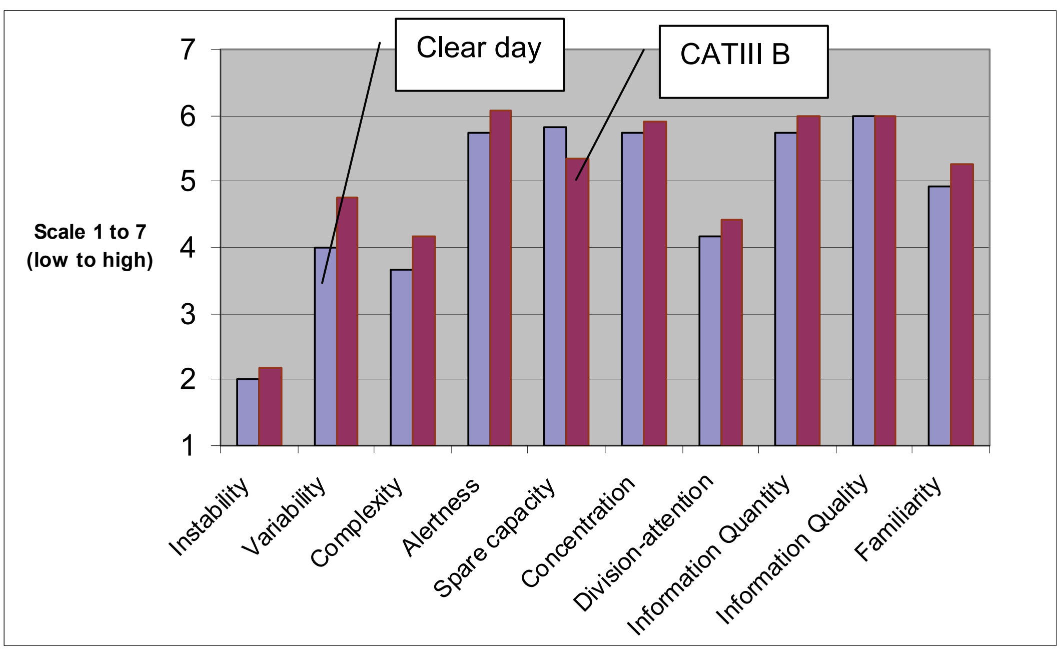

Figure 10. SA responses on clear day vs. Category IIIB visibility.

Observer Notes and Group Discussions

The observer data yielded some interesting findings. Comments during and after the simulation runs from the three participants pertained to issues related to the tools and procedures for closely spaced parallel approaches, wake avoidance, and nonnormal events. In addition, many comments were associated with the interface of the concept elements, in particular the alerting and display features.

The three pilot participants had several comments about what they perceived were the critical aspects of the closely spaced parallel approach concept as it was represented in this study. Pilots felt the high degree of automation required for the closely spaced tasks was necessary for the precision of the procedure; however, they all expressed the need for some opportunity to intervene or "fine tune" the automation. For example, the ability to manually adjust the speed was recommended by two of the participants. In four of the eight scenarios, pilot participants flew these procedures with visibility at the KSRT airport down to about 600 ft of runway visual range (RVR).

Another opinion that had general consensus was that flying these types of closely spaced procedures had a higher risk in these low-visibility surface environments. The comments indicated that although the pilots understood that automation tools would be necessary for navigation guidance and the avoidance of wake vortices, they preferred attaining a visual of the other aircraft to detect any cues that may indicate wake-vortex threat or the threat of a possible unexpected escape maneuver. Pilots also helped identify factors necessary to create and fly an escape maneuver such as traffic, terrain and rest of the airspace. The other four scenarios were in clear weather, and were generally found to be more acceptable conditions for the approaches.

The pilot participants had many comments about the display of the wake information. In general, they found the wake depiction and the display locations acceptable. They preferred wake depiction on the ND versus the PFD. One pilot stated that it took him some time to understand wake on the PFD, raising the issue of the limited training the pilots received for this simulation. As the previous comments indicated, there were some concerns about the ability to predict wake responses during low-visibility conditions. In addition, all three pilots stated that they did not fully understand the nature of wake characteristics, and how these characteristics may impact their own aircraft in closely spaced parallel approaches like those flown in our scenarios. They welcomed aircraft automation that provided information on wake behaviors and their impact on these procedures.

CONCLUSIONS

This study investigated a concept that incorporates wake information and new technologies to allow for the use of very-closely-spaced parallel runways in all-weather conditions. The airport and 25 nmi of surrounding airspace were created and simulated as a part of this effort. A high-fidelity full-motion simulator with the emulation of a four-dimensional (4-D) flight management system (FMS) was used to implement the concept, and several displays were enhanced to enable simultaneous approaches.

The pilots provided feedback through their responses to the questionnaires and debriefings. The three pilots had similar results, and their suggestions were consistent. In general, they were marginally more comfortable with very-closely-spaced parallel runway (VCSPR) approaches and automation in visual meteorological conditions (VMC) rather than Category IIIB visibility conditions, even though their situational awareness (SA) ratings showed similar responses for both conditions. In addition, they indicated that they preferred 10- versus 5-sec spacing between the lead and follower aircraft. The participants felt it was important for them to be able to deploy gear and flaps manually, and influence speed and throttles without disengaging the autopilot. All the pilots were concerned about potential breakout procedures, and they all think automation will play a large role in the determination of the procedures, with direct involvement of the air traffic controller necessary for safe procedures.

FUTURE WORK

The study provides future research ideas and guidelines for developing procedures for VCSPR. Future research efforts by NASA and Raytheon could examine the safety and viability of the procedures and technologies associated with breakout or escape maneuvers under conditions where a simultaneous approach needs to be abandoned. In addition, the representation of more airport traffic and structures are included so that the implications of surrounding constraints could be explored. The possibility of providing more flexibility in the system where pilots could, for example, deploy gears or use throttles for speed control without disengaging the autopilot could also be explored.

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APPENDICES

Appendix A – Schedule and Test Matrix for March 27–29, 2007

8:30–9:00	Introduction to project
9:00–9:30	Introduction to concept
9:30–10:00	Classroom training
10:00–10:15	Break
10:15–10:25	Motion briefing
10:30–10:45	Demo run
10:45–10:55	Run 1
11:00–11:10	Run 2
11:15–11:25	Run 3
11:30–11:40	Run 4
11:45–12:45	Lunch break
12:45–12:55	Run 5
1:00–1:10	Run 6
1:15–1:25	Run 7
1:30–1:40	Run 8
1:40–2:00	Break
2:00–2:30	Breakout
2:30–4:00	Debrief

Appendix B – Demographic Survey

Personal Information	
1. Name	
2. Age	

Pilot Experience	
3. Total years of experience as a pilot	
4. Airlines you have worked with	
a.	
b.	
c.	

5. Types of aircraft flown/hours flown

Type of aircraft	No. of hours flown

6. Do you have any experience flying closely spaced parallel approaches such as SOIA? If yes, please describe.

7. If retired as a pilot, state number of years since retirement:		Years

8. Please list all computer systems, displays, and other technology aids you used or had access to as a pilot.

9. Please indicate your years of personal computer experience.		
1 ☐	2 ☐	3 ☐
Less than 2 years	2–4 years	5+ years

Appendix C – Post-Interaction Survey

Participant #	

VCSPR Post-Interaction Survey

1. Overall how would you rate the utility of the displays for very-closely-spaced parallel approaches:

Not useful at all	Somewhat not useful	Neutral	Somewhat useful	Very useful
1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

1. What aspects of the concept are you most excited about or think are most worthy of future implementations?

____

____

____

2. What aspects of the concept are you the least excited about or think are unworthy of future implementations?

____

____

____

3. Is there some information that should be included here but isn't? Please list.

____

____

____

4. Were you able to effectively monitor the lead aircraft?

Yes ☐ No ☐ If No, please explain:

____

____

5. Did any aspect of the interface ***confuse*** you at any time?

Yes ☐ No ☐ If Yes, please explain:

____

____

6. Overall how would you rate the apparent ***ease to derive information*** from the displays?

Very difficult	Somewhat difficult	Neutral	Somewhat easy	Very easy
1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

7. Looking at the interfaces in the displays in the cockpit, please rate the ease of deriving information from the displays for the following tasks:					
	Very difficult	Somewhat difficult	Neutral	Somewhat easy	Very easy
Zooming the navigation display	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Monitoring separation from lead aircraft	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Maintaining positional awareness of lead aircraft	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Flying in low visibility after coupling point	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Flying in clear weather day after coupling point	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Viewing the trajectory/intent line of the lead aircraft	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Viewing trajectory/intent line of the trailing aircraft	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Wake-vortex hazard awareness	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Trajectory progress awareness	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

8. Please state your agreement/disagreement with each of the following statements (check one number in each row)					
	Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree
This automation concept is needed for the pilots.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
I did not understand what I was looking at most of the time.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Monitoring separation with the lead aircraft was easy.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Seeing wake information on ND was useful for me.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Seeing wake information on PFD was useful for me.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Seeing the predictor paths was useful for me.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
I am concerned about the role of the pilot in the use of this automation.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
I value being able to see the route of the lead aircraft.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
I am confident that this concept can be integrated into flight operations in the future.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

9. Please list any concerns you may have about very-closely-spaced parallel approaches.

Appendix D – Feature Comparison Survey

Participant #:______________

The following survey is intended to capture your value ratings for various features and design elements of the new very-closely-spaced parallel approach runways. Please rate how much you value each of the following features.

	Very unimportant	Somewhat unimportant	Neutral	Somewhat important	Very important
Ownship on navigation display (ND)	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Lead aircraft on ND	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Lead aircraft on primary flight display (PFD)	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Waypoints on ND	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Intent line or route of ownship	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Intent line/route of Lead aircraft	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Zooming capability on ND	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Longitudinal situation indicator (LSI) on ND	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
LSI on PFD	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Predictors of path information for lead aircraft on ND (dots)	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Predictors of path information for trailing aircraft on ND (dots)	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Predictors of path information for lead aircraft on PFD (dots)	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Out-the-window visibility of lead aircraft in a clear day	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Wake hazard zone of lead aircraft on ND	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Wake hazard zone of lead aircraft on PFD	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Changes in FMS/PFD annunciation after coupling	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Acknowledgement button for coupling	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
Datalink message showing “TACEC Coupling “ on EICAS	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

1. Do you have suggestions for improving the design, presentation, or behavior of any of the elements listed in these questions? If so, please describe below.

Appendix E – Observer Form

TACEC March Study

Date:		Run #		Condition:	
Scenario:		Observer:		Time:	
Describe the incident:					

Time		Describe the incident

Time		Describe the incident

Time		Describe the incident

Time		Describe the incident

TACEC March Study (continued)

Date:		Run #		Condition:	
Scenario:		Observer:			

Did the pilot appear to **notice the TACEC coupling immediately (e.g., hit “accept”)?**

Did you see any events or hear any comments from the pilot regarding the **TACEC alerting?**

Did you see any events or hear any comments from the pilot regarding **situational awareness?**

Did you see any events or hear any comments from the pilot regarding the **display?**

Did you see any events or hear any comments from the pilot regarding **workload?**

Were there any **events** that you thought were **significant**? (Please include description of any malfunctions, display distortions, motion problems, etc.)?

Appendix F – List of Questions for Group Discussion

1. What information would you require from the lead to perform a breakout maneuver?
2. Would you like to see zoom feature change the size of the aircraft icon?
3. Would you like to see a forward boundary of safe flying zone on display?
4. Would you like to see the number of seconds in trail added to the display somewhere?
5. Are we scaling the wake display to the icon size in the way you would like?
6. Do we want predictors (dots) past 10 seconds?
7. Was the datalink message showing the flight trajectory at the start of the simulation to be flown useful? Would you like to see it differently?
8. Was the acknowledgement button before coupling useful?
9. What do you like about the concept?
10. Discuss breakout maneuvers based on a scenario as shown
11. Discuss low-visibility problems. Are the displays sufficient?
12. Discuss questions from the post-interactive survey.
13. What do you think about the jurisdiction of the tower controller? Where should it start and end? What will be the responsibilities of the controller before and after the coupling point?
14. What did you think about the display changes that occur after coupling of aircraft? FMS annunciation? Dashed magenta line for lead aircraft?
15. What do you think about having no manual control over the system?
16. If you are in manual control, could you be at the coupling as accurately as with automation? What kind of cues will you need?

Appendix G – Layout and Design of SRT Airport

As stated previously, the SRT airport is based on the current Dallas/Fort Worth International Airport (DFW) layout. Figure G-1 illustrates the current DFW airport configuration, and figure G-2 illustrates the modifications made for the Virtual Aerospace Simulation Technologies (VAST) Terminal Area Capacity Enhancing Concept (TACEC) simulation.

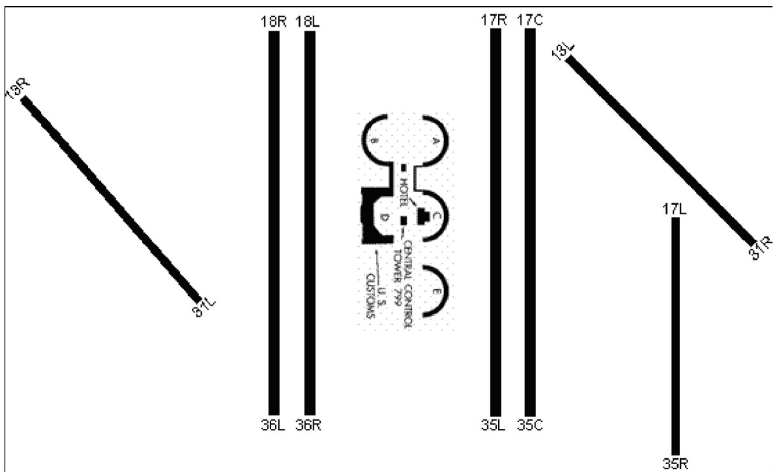

Figure G-1. Current DFW Airport layout.

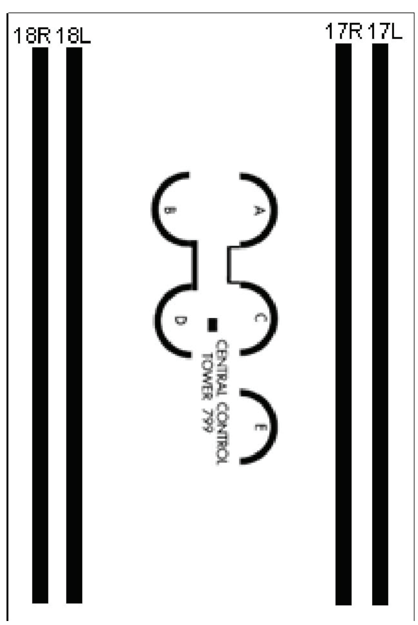

Figure G-2. SRT Airport layout.

Because the simulation focused on studying TACEC approaches to very-closely-spaced parallel runways, and because of the decision to have a south air traffic flow for the simulation scenarios, the SRT airport utilized only runways 18R, 18L, 17R, and 17C (renamed to 17L). All four runways could be used for arrivals and departures, and all were assumed to be equipped to a Category IIIB level. Both runways 18R and 17L were moved to within 750 ft of their inboard runways, 18L and 17R, respectively, requiring an adjustment of 464 ft from their current DFW position. See table G-1 for the DFW runway position changes made for the simulation.

In order to support a variety of scenarios, five runway configurations and associated airspace routes were developed. These configurations are summarized in tables G-2 and G-3. Configuration #2 is the only configuration that the DFW airport currently supports. For this configuration, the airspace design matches the current DFW design. The other four configurations were based on current DFW operations (Standard Terminal Arrivals (STARs), Standard Instrument Departures (SIDs), and Approach Plates), but had to be modified to accommodate both the desired runway configurations and the TACEC concept.

TABLE G-1. SRT RUNWAY POSITIONS

Runway	Old Latitude/Longitude	New Latitude/Longitude
18R	32-54-56N / 097-03-17W	32-54-56N / 097-03-12W
18L	32-54-56N / 097-03-03W	same
17R	32-54-56N / 097-01-47W	same
17L	32-54-56N / 097-01-34W	32-54-56N / 097-01-39W

TABLE G-2. RUNWAY CONFIGURATIONS BY PROCEDURE

Name	Paired Arrivals	Single Arrivals	Paired Departures	Single Departures
Configuration #1	18R and 18L	17L	–	17R
Configuration #2	–	18R and 17L	–	18L and 17R
Configuration #3	–	17L	18R and 18L	17R
Configuration #4	17R and 17L	18R	–	18L
Configuration #5	–	18R	17R and 17L	18L

TABLE G-3. RUNWAY CONFIGURATIONS BY OPERATION
(A = ARRIVAL, D = DEPARTURE)

Name	18R	18L	17R	17L
Configuration #1	A	A	D	A
Configuration #2	A	D	D	A
Configuration #3	D	D	D	A
Configuration #4	A	D	A	A
Configuration #5	A	D	D	D

The TACEC concept calls for TACEC-assigned four-dimensional (4-D) arrival trajectories to begin at meter fixes located near the edge of the terminal airspace, normally 40–60 nmi from the airport. Flights in the VAST TACEC simulation began 25 nmi from the airport. Routes in the SRT airspace were designed to work both with and without TACEC tools and procedures. In order to facilitate a comprehensive design, an effort was made to reuse as much of the existing DFW traffic-flow operations as possible, including: STARs, SIDs, Approach Plates, Arrival Meter Fixes, Departure Meter Fixes, and Standard Operating Practices.