PRELIMINARY GUIDELINES ON FLIGHT DECK PROCEDURES FOR VERY CLOSELY SPACED PARALLEL APPROACHES

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Abstract

The paper describes a concept and procedures to allow simultaneous aircraft operations during instrument meteorological conditions on parallel runways that are 750 ft apart, which will be enabled with advanced navigation, guidance, surveillance and new cockpit technologies. A real-time, human-in-the-loop simulation study investigated the information requirements from a human factors perspective and assessed pilot procedures. The participants included three retired pilots from commercial airlines, who provided feedback on information requirements, procedures for the operations, and feedback on the display features. The pilots found all the features provided by the displays moderately to highly useful and generally reported situation awareness as high for all conditions.

1 Introduction

Demand in the future air transportation system concept is expected to double or triple by 2025 [1]. Increasing airport arrival rates will help meet the growing demand that could be met with additional runways. But the expansion of the airport is often met with environmental challenges for the surrounding communities when using current standards and procedures.

Independent simultaneous operations are allowed today with 4300 ft spacing or down to 3000 ft if special radar is used [2]. Simultaneous Offset Instrument Approaches (SOIA) are allowed for closer runway spacing (down to 750 ft) by offsetting the aircraft longitudinally and requiring visual separation, which reduces arrival rate during poor weather [3]. Independent simultaneous approaches down to 2500 ft spacing were examined by Airborne Information for Lateral Spacing (AILS) through autopilot-flown approaches with on-board warnings provided to the pilot when a breakout needed to be performed due to an aircraft blunder [3].

To achieve capacity gains, runways closer than 2500 ft need to be explored. 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). The concept 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.

1.1 Background

The FAA has successfully conducted independent approaches to parallel runways for over forty years using the Instrument Landing System (ILS) navigation and terminal radar monitoring [2]. The simultaneous approaches that utilize standard radar are conducted on parallel runways that are separated by at least 4300 ft apart. 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 s. The separation standards between the aircraft on these parallel approaches are 1000 ft vertical separation. Additionally, there is a 2000 ft wide "no-transgression zone" (NTZ) that was placed equidistant from the centerlines of the approach paths on the two parallel runways. Some airports like San Francisco International Airport can support approximately 60 landings per hour on its two parallel runways that are 750 ft apart by using SOIA [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 4nm 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 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 [6] [7] [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 [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. The study to investigate pilot response towards the VCSPR operations for the AILS concept is one such example [4]. NASA developed the AILS concept to further examine independent parallel runway operations to runways as a 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 break-out maneuver.

The AILS experiment was designed to study three variables- intruder geometry, runway separation (3400 ft or 2500 ft), and flight control mode (auto-pilot 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 break out maneuvers was not affected by runway separation. Across all conditions the average pilot reaction time was 1.11 s, with a standard deviation of 0.45 s. The experiment found a statistically significant effect for the flight control mode, with auto pilot use prior to the emergency escape maneuver leading to longer reaction times.

TACEC aims to fly paired approaches on runways that are 750 ft apart in instrument meteorological conditions [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 4D trajectories to the aircraft in the pair. It is assumed that all aircraft will use differential GPS-enabled, and high precision 4-Dimensional (4-D) flight management system 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. The current study is different from the AILS experiment because it considers wake, and dynamically generates break-out maneuver.

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

2 Experimental Approach

2.1 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 Dallas/Fort Worth International Airport (DFW) layout and operations. The airport used for the simulation was referred to as "KSRT." Because the simulation was 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 only utilized runways 18R, 18L, 17R, and 17C (re-named to 17L). All four runways were assumed to be equipped to a CAT-IIIB level. Both 18R and 17L were moved to within 750 ft of their inboard runways, 18L and 17R respectively. This required an adjustment of 464 feet from their current DFW positions.

2.2 TACEC procedures

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

2.3 Arrival Traffic Flow

South flow of traffic was simulated for the generic airport KSRT. All 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.

Paired aircraft must fly their assigned 4D 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 4D 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 4D 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 Figure 1). At the coupling point, the aircraft were laterally separated by slightly more than 1 nmi. Each of the final segments were aligned with the runway centerlines and extended 2 nmi from the runway threshold and were about 600 ft Above Ground Level (AGL) in order to provide a straight-in flight path to touch down.

Once the aircraft reached the coupling point, the following aircraft precisely maintained spacing behind the lead aircraft in order to avoid the lead's wake. This 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 ADS-B by the lead aircraft. Figure 1 shows the geometry of the final approach portion of the arrivals (i.e. the final 12nmi before landing).

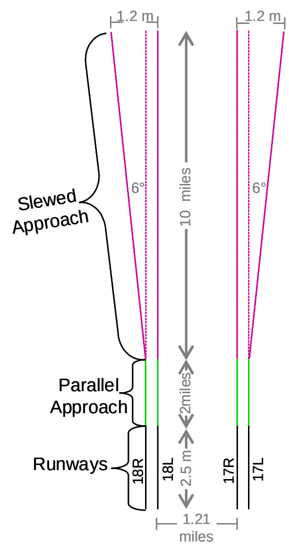

Figure 1 Final approach geometry for TACEC

2.4 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 2 shows the PFD on the straight-in parallel final at 532 ft radar altitude while Figure 3 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 (2004) [8].

2.4.1 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 same perspective triangular lead aircraft position 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 feet.

2.4.2 Hazardous wake area depiction

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

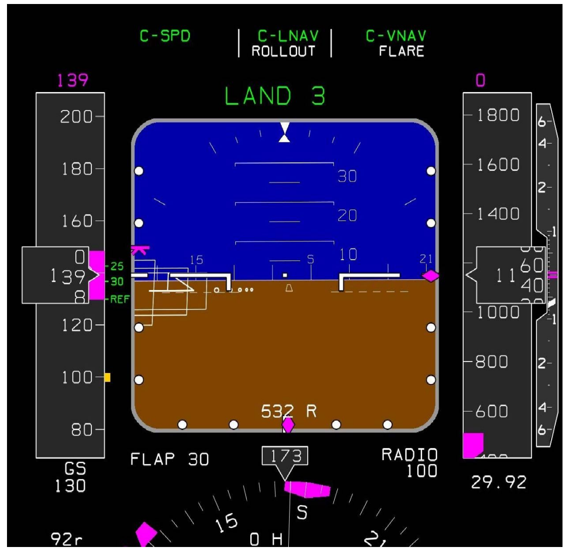

Figure 2 Primary flight display on straight-in parallel final

2.4.3 Predictor dots

Five two-second predictor dots, for a total of ten seconds were added to the ND for both aircraft (see slightly to the right of the nominal path for the simulator in Figure 3) and also were presented on the PFD (aligned with the lead aircraft's position icon). These show fight path trend information to help the pilot determine the future location of the aircraft.

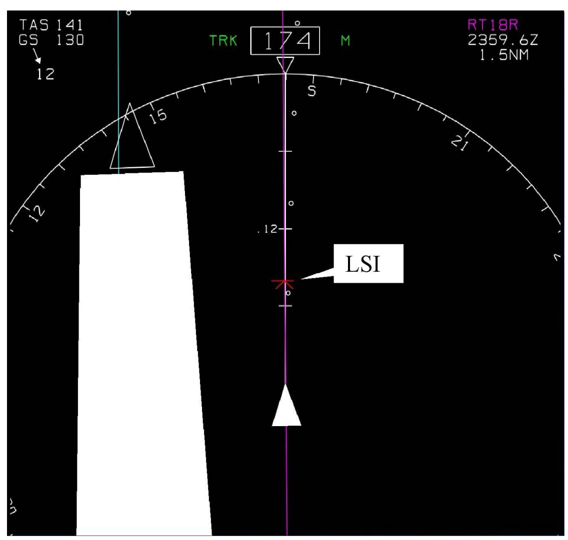

Figure 3 Navigation Display on straight-in parallel final

2.4.4 Longitudinal Situation Indicator

To maintain the aircraft's position in the "Safe" zone, as shown in Figure 3, a Longitudinal Situation Indicator (LSI) was added. The LSI is flagged on the ND and shows the nominal location (in this case five seconds behind the lead aircraft) that the auto-throttle is attempting to keep. For this example, the simulator is approximately 400 feet behind its nominal location. The same LSI information is shown on the deviation scale added on the left side of the PFD (Figure 2).

2.4.5 Display scaling

A conventional PFD has a field of view of about 40 degrees. To be able to see the lead aircraft position and wake information this was increased to 80 degrees. This 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 ten-mile 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.

3 Methodology

The objective of the study was to explore new procedures called paired approaches that are intended for very closely spaced parallel runways (750 ft apart in this study). Retired commercial airline pilots participated and flew a series of scenarios using a flight simulator of a glass cockpit aircraft that included new tools and procedures.

3.1 Advanced Concept Flight Simulator (ACFS)

The human-in-the-loop study conducted to assess the paired TACEC approaches used the Advanced Cockpit Flight Simulator (ACFS) located at NASA Ames. The ACFS is a motion-based simulator that represents a generic commercial transport aircraft, enabling it to be reconfigured to represent future aircraft. It has the performance characteristics of Boeing 757 aircraft, but its displays have been modified to study different advanced concepts. In this study, the cockpit display described in Section 2 was integrated with the flight display systems in the cockpit. The visual systems offer a 180-degree horizontal and a 40-degree vertical field of view.

3.2 Experimental matrix

The three variables that were 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 (simulator), thus, the direction of winds was coupled with the follower (simulator) landing on the left or right runway (18L or 18R runways in this study). The approach to 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 10s or 5s.

3.3 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 total years of experience as a pilot was about 40 years. They had on an average about 16,500 hours of flying. Their average number of years since retirement was 6.5 years. 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 he received a demonstration of the simulator, and more hands-on training on the CDTI and related procedures.

3.4 Procedure

The procedures for VCSPR were being explored in this study, so each pilot flew the ACFS as a captain along with a confederate who acted as the first officer. The role of the pilot, in general, was to fly in auto pilot 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 flight mode annunciation also changed to show that the two aircraft were coupled for speed (C-SPD), coupled for Lateral navigation (C-LNAV) and coupled for Vertical navigation(C-VNAV). Since the autopilot flew the approach, the pilot primarily monitored the aircraft performance and the displays for the remainder of the flight.

3.5 Traffic Scenario

The traffic scenario had two aircraft: the following aircraft in the pair, as represented by the ACFS, and another aircraft, which was recorded or scripted for this study. The simulator 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 simulated Boeing 747-400. Based on the wind condition, the simulator was either on the slewed approach landing on runway 18R or on the straight in approach landing on runway 18L.

3.6 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 Situation Awareness Rating Tool (SART) [10]. The SART gathers a participant’s rating of his/her situation awareness (SA) for the preceding period of time on ten 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 ten SART ratings were gathered from every participant at the end of each run – a total of 8 ratings per participant were collected.

4 Results and Discussion

This section reports results that focus on the data captured by the tools mentioned in section 3.6. Results of the post interaction survey, feature comparison, situation awareness, and observer notes are described in the following section.

4.1 Post Interaction Survey

The post interaction survey was administered to each pilot at the end of the eight trial runs. Since the questions administered after the simulation was complete, there were no distinctions among the different experimental conditions, but instead queried the participants about the general experiences of using VCSPR procedures and tools. Also, due to 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). In general, on average the pilots found that the displays provided enough information, and that it was relatively easy to extract the information 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 they were able to effectively monitor separation of the aircraft from the wake.

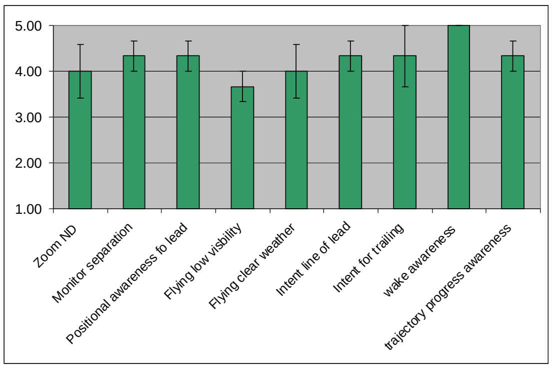

Figure 4 Ratings for ease of deriving information from the displays

All the pilots reported that they were able to effectively monitor the lead aircraft. Also, none of the pilots were confused by the interface. On the ability to zoom on the navigation display, the pilots reported that having a separate zoom capability for the pilot flying and pilot non-flying will enable them to maintain both a strategic and tactical view at the same time. The navigation display zoom capability was handled by a toggle switch on the center console and was available as a function 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 also said that the system and the new displays 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 IMC. They were all concerned about procedures for breakout 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 it.

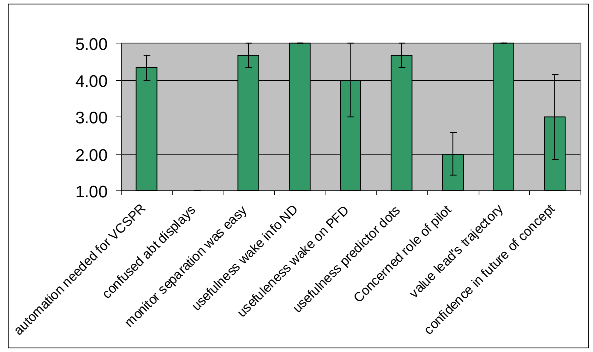

Figure 5 Pilots' subjective ratings on statements regarding the concept and displays

The pilots were also asked to rate some statements regarding the concept and displays (Figure 5). 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 navigation display and the predictor dots very useful, and they valued being able to visualize the lead aircraft's trajectory. 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.

4.2 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 several participants complained about not being able to visually track the LSI because it was hidden under the aircraft's solid white icon. The LSI on the PFD provided the information about the simulator's actual position versus expected position in terms of distance, whereas the LSI on the ND provided temporal information as referenced by the 2s predictor dots. Despite its poor visibility at certain times, the LSI on the ND was preferred by most pilots. The lead aircraft's predictor dots were considered to have 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 in color, 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 FMS annunciation to "coupled" and did not give the pilots a chance to "arm." This created some confusion and led to the comments made by the pilots.

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 pilot to adjust the throttles or speed without disengaging the autopilot.

4.3 Situational Awareness

The situation 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 has been analyzed for the all the conditions for each of the three pilots. Due to low statistical power for testing, significance tests were not calculated. The situation awareness ratings have been depicted on a line graph to enable better trend comparisons for the conditions. Figure 6 shows that the SA trends for the different sub-elements are the same for the aircraft starting with 10s or 5s 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 that increased the chances of the aircraft getting into the wake zone and out of the safe zone.

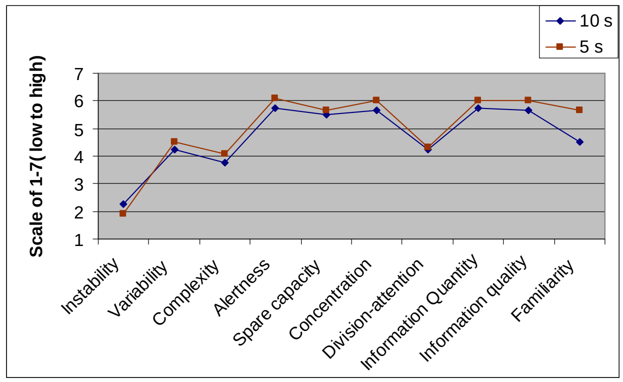

Figure 6 Situation awareness responses 10s v/s 5s distance between the two aircrafts

Pilot's responses on situation awareness for the simulator flying on the straight-in path (landing on 18L) or on the slewed path (landing on 18R) (Figure 7) show similar trends. The slewed path was considered slightly more unstable, variable, and complex by the pilots, but they also felt that higher level of concentration and familiarity was required with the situation.

The situation awareness responses for the visibility condition (Figure 8) 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

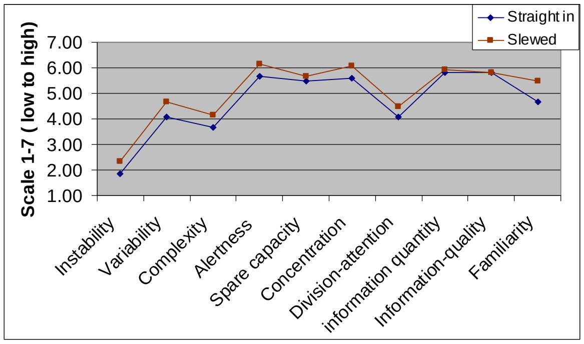

Figure 7 SA responses for aircraft on straight in v/s slewed approach

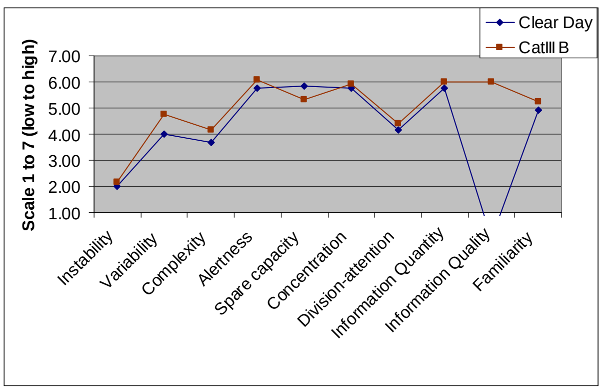

Figure 8 SA responses clear day v/c category III B visibility

4.4 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 non-normal events. In addition, many comments were provided that 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 stated that they felt that 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 feet of Runway Visibility 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 maneuver. 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 had 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 they 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.

5 Summary

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 simulator with the emulation of a 4-D 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 VCSPR approaches and automation in VMC rather than CAT-IIIB visibility conditions, even though their situational awareness ratings showed similar responses for both conditions. In addition, they indicated that they preferred 10 s versus 5 s spacing between the lead and follower aircraft. The participants stated that they felt it was important for them to be able to deploy gear and flaps manually, and influence speed and throttles without disengaging autopilot. All the pilots were concerned about potential breakout procedures, and 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.

6 Future Work

The study provides future research ideas, and guidelines for developing procedures for VCSPR. Current research efforts by NASA and Raytheon are examining the safety and viability of the procedures and technologies associated with escape maneuvers. 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 autopilot could also be explored.

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