

# Integrated Pilot and Controller Procedures: Aircraft Pairing for Simultaneous Approaches to Closely Spaced Parallel Runways

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**Abstract-** Parallel runway operations have been found to increase capacity within the National Airspace but poor visibility conditions reduce the use of these operations [1]. Previous research examined the concepts and procedures related to parallel runways; however, there has been no investigation of the procedures associated with the strategic and tactical pairing of aircraft for these operations. This study developed and examined the pilot and controller procedures and information requirements for creating aircraft pairs for parallel runway operations. The goal was to achieve aircraft pairing with a temporal separation of 15s (+/- 10s error) at a “coupling” point that was about 12 nmi from the runway threshold. Two variables were explored for the pilot participants: two levels of flight deck automation (current-day flight deck automation and auto speed control future automation) as well as two flight deck displays that assisted in pilot conformance monitoring. The controllers were also provided with automation to help create and maintain aircraft pairs. Results show the operations in this study were acceptable and safe. Subjective workload, when using the pairing procedures and tools, was generally low for both controllers and pilots, and situation awareness was typically moderate to high. Pilot workload was influenced by display type and automation condition.

*Keywords-closely-spaced approaches; paired approaches; air-ground integrations*

## I. INTRODUCTION

The biggest challenge airports must address with closely spaced parallel runways is that their capacity is reduced when visual approaches are not possible due to poor visibility [1]. The FAA’s Nextgen and Eurocontrol’s Single European Sky ATM Research (SESAR) [2] have a common goal to maintain visual capacities under all weather conditions at airports with closely spaced parallel runways.

Previous concepts investigated safety issues related to parallel runway operations but did not examine the information and procedures for pairing aircraft. Studies investigated the safety issues associated with parallel approaches that may require aircraft to perform breakout maneuvers due to hazardous conditions [3,4] such as wake of lead aircraft drifting towards the follower or the lead aircraft blundering towards the follower. In addition, the role of controllers in aircraft pairing for simultaneous approaches was explored [5], including the examination of controller responsibilities and communication tasks. A gap exists regarding research examining the integration of the flight deck and ground procedures and tools necessary for pairing aircraft.

This human-in-the-loop study investigates the dynamic role of controllers and pilots for

pairing aircraft to parallel runways for simultaneous approaches. The objective of this investigation was to evaluate the integrated procedures, information requirements, and automation for pilots and controllers when pairing aircraft for closely spaced approaches.

## II. 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 [1]. Some airports, like San Francisco International, can support approximately 60 landings per hour on two parallel runways that are 750 ft apart using visual approaches, and Simultaneous Offset Instrument Approaches (SOIA) under limited cloud ceiling visual meteorological conditions (VMC). As visibility degrades, the current navigation and surveillance system, as well as the existing procedures, cannot support SOIA approaches, dramatically reducing the landing rate.

Several researchers have investigated alternative procedures for Very Closely Spaced Parallel Runway (VSCPR) operations. A number of requirements were identified from these studies, such as cockpit displays, collision prevention systems, precision navigation, communication, surveillance systems and wake information [6] [7]. In addition, Pritchett & Landry [8] explored the parameters and procedures related to VCSPR operations such as separation responsibility and spacing objectives. These studies provided important insight into necessary technologies, information, and procedures for VSCPR implementations.

There have been a number of human-in-the-loop studies that have explored VCSPR operations. The Airborne Information for Lateral Spacing (AILS) concept is an example of an investigation of pilot response to VCSPR operations [9]. The concept requires technologies that enable the use of precise navigation and surveillance data, as well as technology for the detection of blunders. Further simulations have been conducted by NASA to examine pilot procedures for paired approaches on runways that are 750 ft apart in instrument meteorological conditions [3]. Enhanced cockpit displays that depict both traffic and wake information were provided to the flight crew for these operations. The results from these investigations revealed that even in the blunder cases, pilot workload

was manageable, and an adequate level of situation awareness (SA) was maintained.

There are some data regarding the role of the controller in parallel runway operations. Under SOIA, the controller has positive control over the aircraft until the pilot breaks through the clouds and the follower aircraft has visual contact with the leading aircraft. Under AILS, the final approach controller has positive control over the aircraft pair until the trailing aircraft is given a clearance for the AILS approach [10].

The Terminal Area Capacity Enhancing Concept (TACEC) [11] was collaboratively developed by Raytheon and NASA Ames Research Center. TACEC is a technique that can be used for conducting simultaneous instrument approaches to two or even three closely-spaced parallel runways that are 750 ft apart. The concept requires a leader and follower aircraft in a staggered configuration, with a safe zone behind the leader where the trailing aircraft is protected from the wake of the leader. The suggested safe trailing distance for the following aircraft is from 5s to 25s, with 15s representing the optimal temporal distance and +/- 10s representing the tolerance. This recommended distance was derived from analytic assessments and previous human-in-the loop studies, and is intended to allow for a safe wake distance and provide for distance for a potential break-out maneuver [3]. Pilot procedures and information requirements for TACEC were explored in several studies, and controller procedures were examined in a separate investigation [5].

In the pairing concept explored in this research, the controllers determine and suggest an appropriate aircraft pair. The flight crew of the trailing aircraft is responsible for accepting and maneuvering the aircraft into a position, where it is dependent upon the lead aircraft. Prototypic automation tools are provided to both controllers and pilots to assist in the pairing tasks. Although controllers have responsibility for maintaining separation between aircraft pairs, the crew of the trailing aircraft is responsible for maintaining the 5-25 s distance behind the lead aircraft.

The remainder of the paper will discuss the methods and procedures used by both the pilot and controller participants, as well as the results and a summary of the findings from this simulation.

## III. METHODS

The participants were six glass-cockpit qualified flight crews and three controller teams.

Each controller team consisted of three controllers. All participants had at least 10 years of experience in their respective fields. The study was run for two days per flight crew with each ATC team participating for four days. The pairing procedures were developed with the assistance of pilot and air traffic control subject matter experts. The scenarios were based upon airspace around San Francisco Airport. Both teams were briefed and trained on the pairing concept, the new displays, and their automation tools. Nine scenarios with a VFR level of traffic arriving on the approach routes were used. The scenarios were scripted to simulate an upstream scheduler that metered traffic into the terminal area. Each participating flight crew flew a motion-based flight simulator in these nine scenarios. Pseudo-pilots controlled other aircraft targets in the scenarios to add realism. There was always an opportunity to pair with another aircraft, with the simulator always representing the following aircraft. All participants completed questionnaires and took part in a debrief at the end of the study.

#### A. Flight Crew Tools and Procedures

The study used the Advanced Concepts Flight Simulator (ACFS) located at NASA Ames Research Center. The ACFS is a motion-based simulator that represents a generic commercial transport aircraft. The displays were modified to study the pairing concept.

##### 1) Flight Deck Display Conditions

The position of the simulator was shown on the navigation display (ND) in the ACFS with the conventional white triangular icon. The lead aircraft position was shown by an open chevron icon on the ND. With augmented GPS (Global Positioning System) navigation, it was assumed that ADS-B (Automatic Dependent Surveillance-Broadcast) position information was accurate within a few feet. The study varied two sets of displays for the pilot participants to help them monitor their pairing conformance. Each of the two display conditions provided information on both the primary flight display (PFD) and the ND for the captain and first officer. The Display 1 (Position Display) condition provided data about the *distance error* for the aircraft to the coupling point with the use of conformance bars (Figure 1). The coupling point, which is about 12 nmi from the runway threshold, is where the automation systems of the two aircraft would be linked with each other for the rest of the approach. The trailing plane used flight deck

automation to control speed and maintain precise spacing of 15s in trail behind the leader. This distance error was relative to a desired position on the aircraft's profile. Display 2 (Prediction Display) offered an estimated time of arrival (ETA) prediction based upon the aircraft's current ground speed. The features for both display conditions included conformance bars that indicated the spacing window behind the leader on the ND and markers for the spacing on the PFD to help the crews manage conformance. The bars and markers would turn yellow if the aircraft was outside of conformance parameters (5-25s window). Another display feature associated with The Position Display included a Longitudinal Situation Indicator (LSI) for showing the ideal location of the aircraft. The Predictive Display is similar to the green arc currently used by the flight crews in glass cockpits, whereas the position display was a new display and is similar to the one used by the controllers for conformance monitoring.

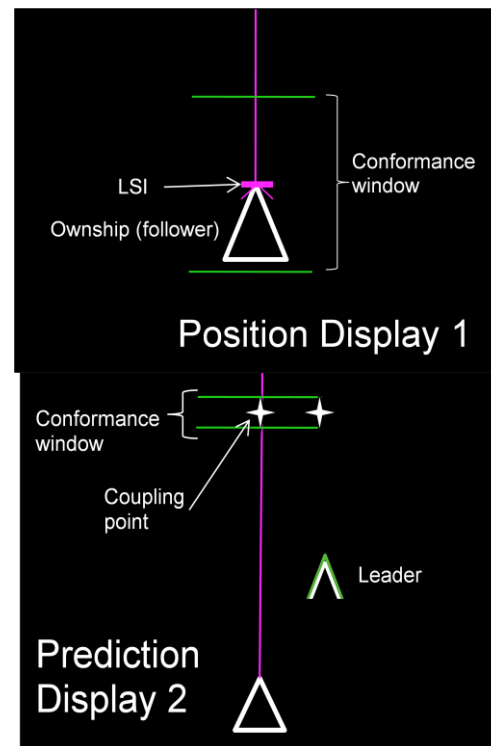


Figure 1: Display conditions 1 and 2 for the navigation display (ND). Triangles represent the following aircraft for both displays.

##### 2) Flight Deck Automation Conditions

In addition to the display variable, the pilot participants were also presented with two automation conditions (see Table 1). An auto speed control flight deck automation tool was

developed to assist the crew in the task of maintaining the required spacing behind the lead aircraft. The Airborne Spacing for Terminal Arrival Routes (ASTAR) was originally developed at NASA Langley Research Center for merging and spacing operations [12]. For this study, ASTAR was modified to manage the speed of the simulator (as the following aircraft) to maintain 5 – 25s behind the lead aircraft on a parallel runway.

	Position Display	Prediction Display
Current Automation	Condition A	Condition B
Auto Speed Control	Condition C	Condition D

Table 1. Flight Crew Experimental Conditions.

In the conditions where the flight crew participants did not have the automation that offered auto speed control, they needed to manage their own aircraft speed using current day flight deck automation (manual automation) (e.g., FMS input or mode control panel [MCP] input).

### 3) *Flight Crew Procedures*

The flight crew pairing procedures involved the use of the display and automation features. When the flight crew received a data link message with the pairing instruction from air traffic control, the Secondary Flight Display (SFD) presented textual information about the relevant pairing parameters. These data included the call sign and aircraft type of the lead aircraft, its current speed, its planned approach speed, the ETA of the lead and following aircraft at the coupling point and the current spacing error and the coupling status. Using the data provided, the crew decided to “accept” or “reject” the clearance. They had the option to use the pairing procedures or to not engage in pairing. The flight crews were also told that if they decided not to engage in pairing, they could cancel the pairing operations; however, they did need to inform the controller. If they did not pair, then they would make the approach as a single aircraft.

On receiving the initial pairing clearance, one of the two display conditions was presented to the crew. In addition, sometimes the auto speed control automation was available and, after the pairing was accepted, the flight crew could select to engage it. In the cases where the auto speed control automation was present and used,

the automation managed the speed to maintain the required separation. The crews did not make speed adjustments manually unless they decided to discontinue use of the automation. The crews were informed that they could turn the automation off whenever they felt it was necessary. In cases where aircraft were early or late, the controller could cancel the pair. Pilots could also cancel the pairing at any time.

### B. *Air Traffic Control Tools and Procedures*

Controllers were able to pair aircraft from any of the five arrival streams; however, two aircraft from the same stream could not be paired. Speed changes were the only adjustments allowed to maintain pairing and spacing. The goal of the pairing procedure was to have the trailing aircraft reach the coupling point between 5 and 25s behind the lead aircraft as this represented the safe zone for the trailing aircraft. The 5s lag allows for the lead aircraft to execute an escape maneuver across the path of the trailing aircraft and the 25s cutoff point protects the trailer from the spreading wake of the leader. The three air traffic controller positions used were an Area Coordinator, Boulder Sector Controller and Niles Sector Controller. The coordinator position was responsible for the creation of pairs and overlays two sectors- Niles and Boulder. The sector controllers were responsible for maintaining the pairs to the coupling point with the desired intra-pair spacing of 15s; and maintaining the current day spacing of 3nmi between consecutive pairs of aircraft. Based on previous research [5], a level of automation was selected for the pairing tool, in which the automation suggested pairs of aircraft, and the controllers could manually override the suggested pairs. The main goal for the coordinator was to evaluate pairs to ensure the two aircraft were capable of landing between 5 and 25s of each other. Each of the three controllers had a pairing table (which listed all pairs in order of their ETA, a continually-updated timeline (configured to show the ETAs of the aircraft to the two parallel runways), and a conformance monitoring tool, which displayed two bars to show the leading and trailing edge of the 5-25s conformance envelope.

Existing/Planned Aircraft Pairs	
Send	Locate
Delete	
<b>LEADER</b>	<b>TRAILER</b>
UAL657	VRD953
EGF3188	SWA410
UAL309	JAL2

Figure 2: Partial view of the finalized pairs in the controller’s pairs table. Leading and trailing aircraft are suggested within the list for each category.

To finalize a pair, the coordinator evaluated the pair suggested by the automation against the timeline. If the pair was acceptable, the coordinator sent a data link message to the two aircraft. When the pilots acknowledged the pairing, the aircraft call signs turned green in the pairing table. Both aircraft in the pair were given an approach clearance electronically by the sector controller who owned the trailing aircraft in the pair. The approach clearance also implicitly delegated separation authority to the aircraft. Aircraft pairs that were out of conformance could not be given approach clearances. If a pair lost conformance, controllers either re-paired aircraft after making speed adjustments (if possible), landed the planes as singles, or vectored them away and returned them back to the flow upstream.

#### IV. RESULTS AND DISCUSSION

The study goal was to explore the feasibility of aircraft pairing on arrival. The key metrics were the spacing of the aircraft relative to each other by the beginning of the coupled approach, and the participant’s subjective ability to complete his/her tasks, including workload and situation awareness. The spacing metric between the aircraft pair helps determine the safety of the operations.

##### A. Number of Aircraft Pairs Created/ Deleted and Number of Single Aircraft

Figure 3 shows the mean number of aircraft pairs created/deleted and the number of aircraft that arrived as singles for all the test conditions. As indicated in this figure, the controller participants, on average, paired most aircraft in each scenario (N=14.7 pairs or 29.4 aircraft/run), canceled very few pairs (N < 1 pair/run) and left a relatively small number of aircraft (N=5.5 aircraft/run) to land as singles. These statistics

seem to provide some evidence of controllers’ ability to use the pairing tool, suggesting a high level of usability.

Although the objective of the controller was to land as many pairs as possible, having a small number of singles helps with efficiency, particularly in cases when an aircraft was vectored or had a go-around and had to be reintegrated into the flow.

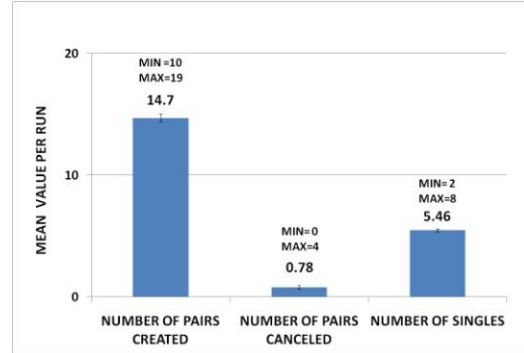


Figure 3. Number of aircraft pairs created/deleted and number of aircraft flown as singles (Note: The error bars on all figures, where indicated, represent 1 standard error above and below the mean).

##### B. In trail Spacing between aircraft

###### 1) Spacing from the flight crew perspective.

The leader-trailer spacing for the aircraft pair including the ACFS was of particular interest. Out of 47 runs, in 32 (61.5%) the ACFS flew over its coupling point close to its ideal position, that is between 10s and 20s behind the leader, and 44 runs (93.6%) were inside the 20s window (5 to 25s in-trail). Figure 4 shows the 47 runs in the order of the simulator’s spacing behind its leader (the ideal 15s behind is the 0 on the y-axis) not in chronological order. Above the top green line the ACFS was more than 25s behind the leader, i.e., late. Below the bottom green line it was less than 5s behind the leader, i.e., early. In 47 runs, only twice was the ACFS spaced outside the 20s window (4.2%) – once it was early (in front of the window, run 1) and once it was late (behind the window, run 47). A third run was on the borderline for being early. Based on crew feedback, both outliers and the borderline run seem to be the result of pilots testing the system to see how long they could wait before they intervened.

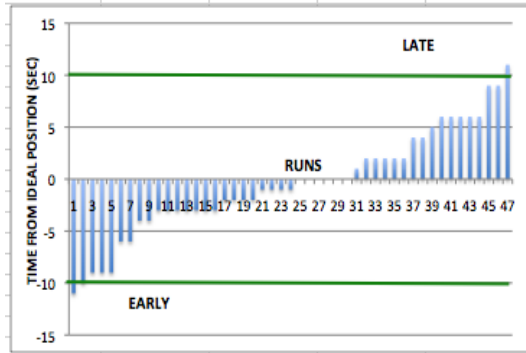


Figure 4: Distance of ACFS-follower behind its leader at the coupling point

At the end of each run, pilots provided feedback about conformance at coupling. For the two outlier runs both crews were aware that they may have not achieved their conformance window. All four pilots commented at some level that they were watching their “current spacing error” indicator vacillate between 10s (which is “on-time”) and 11s (which is late or early).

### 2) In Trail Spacing Between Leader and Follower Aircraft at the Coupling Point (Controller’s Perspective)

This metric was defined as the difference between the time the leading aircraft arrived at the coupling point and the time the trailing aircraft arrived at the coupling point. It was used as a measure of how well the aircraft achieved precise 15s in trail spacing between the leader and the follower within an aircraft pair. Results showing the distribution of this metric across all simulation runs for all aircraft are presented in Figure 5.

While Figure 5 indicates a mean value very close to the optimum separation of 15s and well within the preferred range of in trail spacing values, it is also quite clear that a fairly wide range of values exist within the overall distribution. Still, most of these values fall within the goal of 15s (+/- 10 s) temporal separation, which suggests that most aircraft met the conditions required by the concept under study.

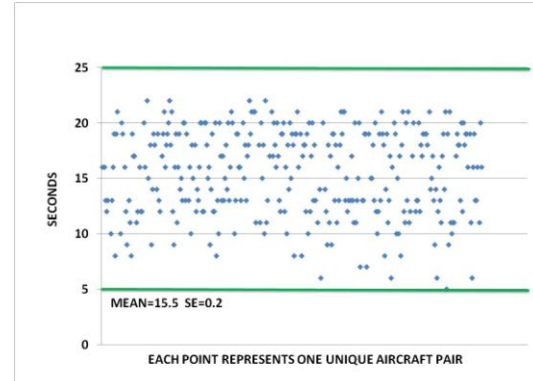


Figure 5. In trail temporal separation between leader and follower aircraft within all aircraft pairs at the Coupling Point.

### 3) Spacing Discussion

Nearly all aircraft pairs in all runs crossed the coupling point within the specified spacing window, suggesting that the concept is feasible. The flight deck crew were aware on the runs when the ACFS did not meet its window, suggesting that procedures need to be more carefully defined (rather than improving the display of in/out of conformance information).

### C. Operator Workload

The ATWIT (Air Traffic Workload Input Technique) [13] was used to collect both pilot and controller opinions of their workload during the scenarios they worked. The seven-point ATWIT scale was built into the controllers’ workstations and was available on a keypad placed in front of the flight crew during each run. Every five minutes, all participants were asked to rate their overall workload level at that moment from 1 = “very low workload” to 7 = “very high workload.”

#### 1) Pilot Workload

With the runs lasting around 20mins, crews rated their workload about 4 times per run. The initial analysis below considers only the mean ratings, which combine these four responses. Across all runs crews reported “a little” workload (M= 2.7), which is encouraging as this was not a full mission simulation. Although most ratings were at the low end of the scale, there were a few individual 6 and 7 ratings, which are important to note because this means some pilots thought at certain points they could not cope with any more load/tasks (interruptions, landing preparation, etc.).

To explore what might affect workload, means were aggregated by the four study conditions. Figure 6 compares these mean

values. Differences between the mean ratings are small – less than 0.5 of a scale-point separates the lowest mean of study condition C from the highest mean of study condition D.

Figure 6 shows the interaction between the two variables over the four conditions – auto speed control automation is linked to both the lowest and the highest mean workload ratings depending upon the type of display crews used. Participants rated the Prediction Display as causing them a higher workload but

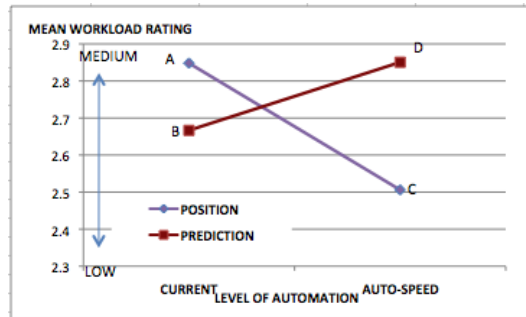


Figure 6: Mean workload by study condition. This figure shows only a portion of the scale.

only in the auto speed control automation condition. A Friedman test was applied on these workload ratings across the four conditions and showed the differences are significant ( $\chi^2(3)=9.423, p=.024$ ). A series of pairwise Wilcoxon tests show the only difference at the  $p<.05$  level was between conditions C and D (Position Display and Prediction Display under auto speed control automation – the two points on the right in Figure 6), where ratings showed participants thought the workload was higher in the D condition ( $p=.024, \text{meanC} = 2.5, \text{meanD} = 2.8$ ). The difference between the Position Display mean workloads under the two automation conditions (A & C) only approached significance ( $p=.054$ ). These results are surprising given that condition A (Position Display) was rated on average to incur a higher workload than condition B (Prediction Display) when participant feedback suggested the Prediction Display was harder to use. The crew experienced lower workload in the Prediction Display used under current automation, possibly because its prediction function is similar to that of the green arc used for altitude prediction in the current glass cockpit. Also, the Position Display was found to be easier to use in the auto-speed (future) condition.

## 2) Controller Workload

Mean workload scores indicated very low workload across all three ATC positions (Table 2) and an Analysis of Variance did not yield a statistically significant effect of controller position on workload.

Position	Mean	SD	Range
Boulder	1.4	0.48	4.00
Coordinator	1.5	0.52	5.00
Niles	1.3	0.44	4.00

Table 2. Controller workload statistics for 47 runs.

The means and standard deviations would seem to suggest that overall workload was low; however, the ranges suggest that it was high at various times. Finally, while the area coordinator had a slightly higher workload compared to the other two positions, the range of the scale means across all positions is less than 0.2, supporting the lack of statistical significance.

## 3) Workload Discussion

Study results suggest that overall workload for both the pilots and controllers was low enough to be manageable. However, workload ratings varied, suggesting that workload was occasionally high enough to require the necessary attention to maintain performance. Crew workload ratings suggest that the style of information presentation in the Position Display coupled with the auto speed control automation’s speed management (condition C) incurred the lowest workload.

## D. Situation Awareness

At the end of each simulation run, study participants completed three subscales of the Situation Awareness Rating Technique (SART) [14]. The three questions were answered on a 7-point scale from “very low” to “very high” and were always answered in the same order. The questions query the respondent’s understanding of, demand from, and supply of attention available to complete their task. Also, an overall SART scale measure was obtained by combining the three subscales in accordance with established practice [14]. The supply subscale rating was subtracted from demand and then this result was subtracted from the understanding rating. Therefore, the SART scale has potentially a 19 point range from -5 (extremely low SA) to 13 (very high SA).

## 1) Pilot Situation Awareness

Overall, crews rated their situation awareness as “good” (mean overall SART=7.8). On the subscales, crews rated their understanding and supply of attention as “high” while the demand was rated as “medium,” suggesting they felt they had enough resources to meet the demand. Pilots’ ratings for the three questions (and the overall SART) were compared by the two display conditions. The mean values for this comparison are shown in Figure 7. The displays’ mean ratings are very close for the SART and its components, with pilots estimating a slightly higher level of understanding of the Position Display with a lower demand but also a lower attention supply for this display set. A Wilcoxon Signed-Rank test shows that pilots found the Prediction Display was significantly more demanding than the Position Display ( $Z=-2.115$ ,  $p=.034$ ,  $\text{meanD1}=4.0$ ,  $\text{meanD2}=4.1$ ). Given the verbal feedback crews gave about the displays, this is a meaningful difference. Neither the SART nor the other two questions were significantly statistically different between display conditions.

The SART ratings were also evaluated by the two levels of automation conditions. Again, there are no clear differences between the SART ratings by the two automation levels (meanCurrent = 7.6, meanAuto speed control=8.0). Comparing the means for the three questions indicates that pilots found the current automation more demanding ( $p=.025$ , meanCurrent =4.2, meanAuto speed control=3.9). Again, although this is a small difference, it is meaningful. While not statistically significant, the other means may suggest that the pilots had less understanding of the situation and slightly more attention capacity when using the current automation.

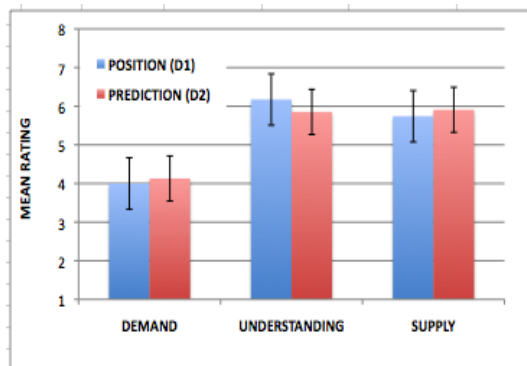


Figure 7: Mean SART ratings under two display conditions

## 2) Controller Situation Awareness

Figure 8 presents the results on these three measures for each controller position.

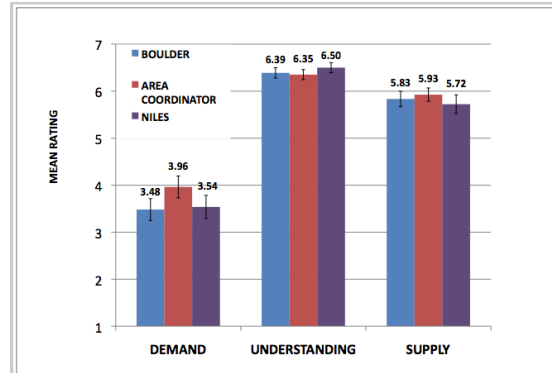


Figure 8. Situation awareness by controller position.

Figure 8 shows that demand on attention was moderate, situation understanding was very high and supply of attention was also high. These results indicate attention demand was low enough to be manageable, but high enough to prevent tedium and vigilance decrement. Results also suggest the controller participants understood the scenarios quite well and that they were not overwhelmed by the task at hand (supply of attention). Collectively, these results would suggest that overall level of controller situation awareness was high.

No statistically significant results were indicated between the three ATC positions on all of the three measures. However, the directionality of means indicates coordinator attention demand was somewhat higher relative to the other two positions, which would reflect the area coordinator’s greater responsibilities overseeing an area encompassing multiple sectors, pairing the aircraft in different sectors, and monitoring the pairs and the flow. Although there is no statistical significance, the trend shows that the area coordinator is required to perform a higher level of multi-tasking relative to the other two positions.

## 3) Situation Awareness Discussion

Results suggest that the overall level of pilot and controller situation awareness was high. Demand on attention was low enough to be manageable, but high enough to prevent tedium. Participants reported good understanding of the situation and a high supply of attention indicating that they were not overwhelmed by the task at hand. Crew situation awareness ratings support a preference for condition C as this condition was reported to be less demanding than the others.



### *E. Participant Opinions*

#### *1) Feedback from the pilots*

Flight deck crews had a number of opportunities to comment generally on the concept and other aspects of the study. They raised concerns over procedures; for example one or two pilots noted that they had to try to fit in with the controller managing the speed of the lead aircraft suggesting that controller-pilot roles need clarification. In addition, they also indicated confusion over the way current speed restriction procedures were related to the pairing procedures.

Situation awareness (SA) was a concern among some pilots. There were SA concerns on approaches where the leader originated in a different sector, which meant crews could not hear ATC communications with the leader. There were also problems with, or omissions on, the displays that crews said made awareness hard to maintain. A number of crews requested more information about the lead aircraft, which some said would be necessary to increase their comfort with reducing current standard separation during pairing. One pilot had a general concern with SA in the concept, stating that it required too much heads-down time, thus losing outside reference and traffic avoidance.

Few comments were collected regarding about workload. Only one crew commented that the mental workload for the pairing task was high. Another pilot noted that workload approaching the coupling point was high. This is potentially problematic because at the coupling point, crews will be busy with tasks to prepare for landing. High workload earlier on the arrival would be more acceptable. There was also some concern that since landing was not required in the study, the full workload of this phase of flight was not represented.

The majority of the general comments were suggestions for display modifications. Overall, pilots preferred the Position Display over the Prediction Display, referencing issues of confusability and apparent instability of the timing parameters related to the pure error calculations. It is interesting to note that the feedback provided on the post-run questionnaire did not indicate any of the confusion about the Prediction Display that was reflected in the debrief or the post-simulation questionnaire. Since the post-run questionnaires were administered after each scenario, the researchers feel that the pilots completed these

questionnaires quickly and perhaps with less care so they could move onto the next simulation scenario or take a break. This may have prompted them to rush through their responses and may therefore account for the inconsistency with the other data. The pilots did suggest that dampening the variability in the error parameters would help for the usability of the timing data. In addition, three common requests were for more information about the lead aircraft, repeating the key conformance data on the PFD and the navigation displays, and modifying the depiction of some of the data.

#### *2) Feedback from the controllers*

Air traffic controllers had several opportunities to provide feedback on the pairing procedures and the distribution of roles and responsibilities between the controllers and pilots. The controllers mentioned that once aircraft are paired, they are not inclined to break the pair unless the flight deck informs them of their inability to stay in the pair. The controllers seem to feel that if there were concerns about the pairs, they preferred to keep the traffic flow stable. The controllers often gave speed commands to the lead aircraft to indirectly manage the following aircraft and keep it inside its conformance bars.

The controllers also expressed frustration at their inability to control the following aircraft directly, since automation on the flight deck was managing its speed to ensure that it landed in the safe window of 5-25s behind the lead aircraft. If the lead and following aircraft were in different sectors, the two sector controllers' collaboration and communication was increased. The controllers were responsible for inter-pair spacing and the automation handled intra-pair spacing and this procedure also impacted communication workload between the two sector controllers.

Different sources of information were used to draw the conformance monitoring graphics for the flight deck and controllers. This sometimes presented different information to the air and ground and became a source of confusion. There is need to have not only clarity in the division of roles and responsibilities but also have clarity on authority and level of hierarchy.

## V. SUMMARY

The objective of this study was to explore the procedures and information requirements for

pairing aircraft for VCSPR. This study focused on three key metrics: the spacing of the aircraft relative to each other by the beginning of the VCSPR and operators' reports of their workload and situation awareness. All three metrics, when taken at a study-wide level, indicated the feasibility of the concept; ATC and the flight deck crews were able to maneuver aircraft into a paired approach and to cross the coupling point in their specified window using the automation options and flight deck display features in all conditions. The average workload for both ATC and crews was manageable and the average situation awareness was adequate.

There were some issues with procedures and information requirements. For example, flight crews were hesitant to cancel their pairing when they were close to coupling if their aircraft was just outside the +/- 10s window. The crews' behavior and feedback indicate that they felt they were "close enough" to the spacing parameters when they were in that range. Procedural parameters need to be specified at a greater level of detail to avoid this in future studies.

While the pilots and controllers were able to complete their respective pairing tasks with the information provided, the presentation format of key information seemed critical to their performance. Scan patterns and heads-down time were concerns expressed by the pilots. They suggested key information should be redundantly presented on their focal displays (PFD, ND) and should be filtered to indicate when they need to act. However, this study has offered an optimistic start by investigating the integrated dynamic role of controllers and pilots and clarifying where controller-pilot-automation interaction confusions exist.

The results of this simulation have identified the need for additional investigation.. Future research is needed to define information requirements for pilots and controllers when conducting pairing operations for parallel runways. Further study is also necessary to determine when the cancellation of pairing may be required, and the impact cancellations may have on arrival procedures.

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