

CHAPTER

# Preliminary Guidelines on Controller's Procedures for Pairing Aircraft for Simultaneous Approaches under Different Levels of Automation

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## ABSTRACT

The capacity of an airport can be halved during poor visibility conditions if the airport allows simultaneous approaches only during visual conditions. Several concepts are defining new standards, procedures and operations to allow simultaneous operations during poor weather conditions. However, all the concepts assume that the controllers pair the aircraft and align them for simultaneous approaches, but there are no decision support tools that aid them in this process. This study investigates different levels of automation for pairing and aligning aircraft and evaluates the role of the air traffic controller while interfacing with the tool. In all the conditions the goal was to deliver a pair of aircraft with a temporal separation of 15 s (+/- 10s error) at a "coupling" point that is about 12 nmi from the runway threshold. The logical pairing of aircraft is completed much earlier than the physical pairing of the aircraft that occurs at the coupling point. Four levels of automation were selected that ranged from no automation, to full automation suggesting optimal pair assignments. The metrics in this paper describe the highlights of what has been analyzed and include number of pairs made under different conditions, number of pairs broken and controlled as a single aircraft to prevent potential loss of separation, and excessive workload. It was found that the

controllers pair aircraft differently from the pairing algorithm. Also the area coordinator responsible for creating aircraft pairings experienced higher workload than the sector controllers, suggesting that the roles of the controllers, when using this automation need further refinement.

## **INTRODUCTION**

Operations on closely spaced parallel runways have been prevalent in the National Airspace (NAS) for about 40 years. There are several concepts in development and in operational use that define procedures for operations on parallel runways. One concept under development has been Airborne Information for Lateral Spacing (AILS) [Abbott et al., 2001]. Simultaneous Offset Instrument Approach (SOIA) [Magyratis et al., 2001] is currently used at airports like San Francisco International airport. Both concepts support arrivals on runways that are only 750 ft apart and assume that air traffic control will pair the appropriate aircraft for simultaneous landings. However, no tool or formal process exists to facilitate the pairing of aircraft. This paper will evaluate the role of the controller for pairing aircraft under different levels of automation using another pairing concept. The levels of automation define how much functionality the tool and interface provide to facilitate pairing aircraft for simultaneous approaches on parallel runways 750 ft apart.

## **BACKGROUND**

The FAA recognizes that significant capacity is lost when simultaneous operations performed under visual conditions are not operational under poor weather conditions. The FAA, as a part of its NextGen plan [FAA, 2008], aims to reduce the allowable spacing between runways used for simultaneous operations in poor visibility, currently 4300 ft., by revising standards and improving technologies. Several concepts that address the revision of separation standards and new technologies include SOIA, AILS and Terminal Area Capacity Enhancing Concept.

The role of the air traffic controller during simultaneous approaches is different for each of the above mentioned concepts. Under SOIA, the controller has positive control over the aircraft until they break through the clouds and the follower aircraft has visual contact with the leading aircraft, at which time separation authority is delegated to the flight deck. Under the AILS concept, the final approach controller has positive control over the aircraft pair until the flight deck of the trailing aircraft is given a clearance for AILS approach. This clearance is given by the final approach controller just prior to transfer of communications to the tower. Once the AILS clearance is given the trailing aircraft crew is responsible for maintaining separation from traffic on the adjacent parallel approach, while ATC remains responsible for longitudinal separation of in-trail traffic operating in the same stream [Waller, et al., 2000].

The concept investigated in the current study, called Terminal Area Capacity Enhancing Concept (TACEC) [Miller, et. al., 2005], 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. TACEC operations could double the landing capacity of airports with closely-spaced parallel runways (closer than 2500 ft) during low visibility conditions, approaching arrival rates comparable to visual approach operations. The concept defines a safe zone behind the leader (range 5s to 25s) where the trailing aircraft is protected from the wake of the leader. The trailing aircraft flies an approach with a 6 degree slew, and at a coupling point, which is about 12 nmi from the runway threshold, the two aircraft are linked, with the trailing plane using flight deck automation to control speed and maintain precise spacing of 15 sec in trail behind the leader (Figure X.1). The concept assumes Differential Global Positioning System (DGPS), augmented ADS-B, 4 dimensional flight management system, wind detection sensors onboard the aircraft, and cockpit automation that are not extant in today's NAS.

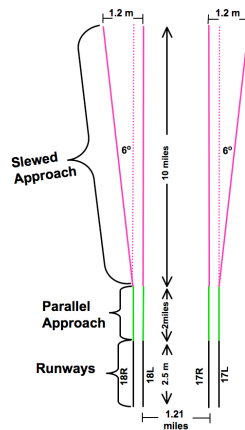


FIGURE X.1 Example of aircraft geometries for the concept under investigation.

All the concepts discussed assume that the air traffic controller will assign aircraft to pairs with the knowledge that they are properly equipped. Given this, the TACEC research explores the role of the air traffic controller in assigning aircraft to pairs so they can perform simultaneous approaches. The pairing of aircraft was done under different levels of automation in order to investigate the appropriate human/automation mix for the given task.

Previous research that explored the role of the controller under different levels of automation included a simulation study by Slattery et al., [1995] who examined the effects of the Final Approach Spacing Tool (FAST) with aircraft landing simultaneously on parallel runways. The simulation contained various combinations of aircraft, equipped and unequipped with advanced navigation systems. Similarly, another study [McAnnulty and Zingale, 2005] investigated the effect of using a

Cockpit Display Traffic Information (CDTI), for enhanced visual operations, on controller workload and situation awareness. They found that advanced concepts involving the use of more sophisticated CDTI functions require modifications to current procedures and additional controller workstation tools. Verma et.al. (2009) also investigated the pilot procedures for breakout maneuvers for simultaneous arrivals that were flown under the manual and auto pilot flight control, but did not explore procedures for controllers.

The work described in this paper involves a simulation experiment to examine the role of controllers using a pairing tool, under four different levels of automation, to assign pairs for simultaneous approaches to runways 750 ft apart. A new ATC position, the area coordinator, was added and given responsibility for pairing the aircraft. The simulation also included flight deck automation on the following aircraft that enabled pilots to achieve precise 15 s in trail spacing between the leader and the follower at the coupling point (Figure 1). Results from the different levels of the human/automation mix are presented with the dependent variables of (1) the number of aircraft pairs made by the controllers, (2) the number of aircraft pairs that had to be broken and brought in as single aircraft to prevent potential loss of separation, and (3) controller workload. The experimental approach section defines the airspace used, the scenarios, and the experimental setup. The results and discussion section focuses on the description of the metrics collected and analyzed.

## **EXPERIMENTAL APPROACH**

### **AIRSPACE ORGANIZATION**

San Francisco International (SFO) airport was used as the test bed. SFO has parallel runways, 28L and 28R that are used for all arrival streams. The traffic scenarios consisted of four arrivals streams – Yosemite and Modesto from the east, Point Reyes from the north, and Big Sur from the south. The airspace was modified to split the route to the two coupling points (CP28L and CP28R) on each of the four streams. This would allow for runway changes and for aircraft from the same stream to be paired. The routes were modified so they were de-conflicted and were set up with a Required Navigation Performance (RNP) of 1.14 nmi meaning that standard separation was not applied. Instead, the closest distance between the routes before the coupling point was 1.14. The RNP level after the coupling point was 0.01.

For this study, the two approach sectors, Niles and Boulder, were configured such that the controller was responsible for the airspace from the TRACON boundary up to the coupling point which is at 4000 ft. AGL. The Niles Sector managed traffic from the two east-side routes- Yosemite and Modesto. The Boulder sector managed the routes from the north and south - Point Reyes, and Big Sur respectively.

## **Traffic Scenarios**

Two different traffic scenarios were used for the simulation. Both the scenarios were equivalent in the rate of arrivals, (approximately 60 arrivals per hour), to the rate of arrivals under visual flight rules (VFR) conditions at SFO. The scenarios also approximated the current distribution of traffic across the four arrival routes simulated for the study.

## **TEST CONDITIONS**

The study included a pairing interface on the Standard Terminal Automation Replacement System (STARS) display, and an algorithm that created pairs. To manipulate the level of automation used for the study, the capabilities of the pairing algorithm and the pairing interface were varied. The role of creating aircraft pairs for simultaneous approaches was assigned to the area coordinator who looked beyond the TRACON boundary, with the sector controllers managing the pair inside the TRACON boundary such that the follower arrived 15 sec behind the lead aircraft at the coupling point. The controllers were also responsible for standard separation between the pairs. They were allowed to use speed only to manage the flow and create adequate separation; vectoring of aircraft was not allowed in any of the conditions.

In the no-automation condition, the area coordinator used current day technologies and flight strips to make pairs and communicate them to the two sector controllers. There was no pairing algorithm or controller interface to assist the area coordinator with creating pairs for simultaneous approaches. The goal for the sector controllers (Niles and Boulder) was to bring the trailing aircraft slightly behind the lead aircraft at the coupling point sans automation.

In the next level of automation (Mixed-1) the area coordinator was responsible for creating pairs, using an interface provided on the STARS display. The area coordinator was able to mouse over the data tag and click on a lead aircraft and a following aircraft to create pairs in the "pairs table" - a new feature added to the STARS display. The area coordinator sent a data link message with pairing information to the two flight decks and waited for an acknowledgement from the pilots. After both acknowledgements were received, a finalized pair was displayed on the area coordinator's and both sector controllers' displays. Under all automated conditions, merging and spacing flight deck automation was used on the simulated flights to achieve 15s temporal distance between leader and follower at the coupling point without the intervention of the controller.

The Mixed-2 condition increased automation. In this condition, the area coordinator selected a leader and a pairing algorithm provided up to three options for trailing aircraft in the "pairs table." The area coordinator evaluated each option offered by the automation against the timeline and finalized the best option by sending datalink messages to the aircraft as in Mixed 1.

The Full Automation condition further increased the role of automation and

reduced the role of the human for the pairing task. The pairing algorithm offered one best option for aircraft pairs to the area coordinator, who finalized the pairs by sending the datalink message after evaluating the pair against the timeline.

## **Methodology**

The experiment was a 3x2 within subjects design, with three controller positions and two scenarios. The three controller positions consisted of one area coordinator, and Niles and Boulder sector controllers. The three participant controllers on each team rotated between the three positions. A total of 24 runs (4 conditions x 6 runs each) were conducted per week for two weeks, with a different team of recently retired controllers each week. The four experimental conditions were not randomly distributed. All six runs for every condition were conducted before the participants were trained on the procedures for the next condition and training always preceded actual data collection runs. This was done to avoid confusion between the different procedures and displays used in the four conditions.

## **EQUIPMENT/ DISPLAYS**

The simulation used the Multi Aircraft Control Systems (MACS) simulation environment including a STARS display that could be used in the Terminal Radar Approach Control (TRACON). MACS is an aircraft target generator system [Prevot et. al, 2004] that provides current controller displays and can be used for rapid prototyping of new displays.

The Airborne Spacing for Terminal Area Routes (ASTAR) modeled flight deck merging and spacing to achieve the 15 sec in trail interval between the lead and following aircraft at the coupling point. ASTAR builds 4D trajectories for both the ownship and the lead aircraft approaching the adjacent runway [Barmore et al., 2008], then provides target speed inputs to the follower's FMS, to achieve the assigned temporal spacing between the leader and follower.

A pairing algorithm was integrated with MACS to identify overlapping Estimated Time of Arrivals (ETAs) between aircraft and chose possible pairs (in Mixed 2) or best pairs (in Full Automation). The window of opportunity for pairing was reduced as the aircraft moved closer to the airport, and the distance that could be made up or lost by speed adjustment shortened. The pairing algorithm assessed and offered pairs that could be made by changing the arrival runway for one aircraft [Kupfer, 2009].

## **TOOLS FOR DATA COLLECTION**

All participants completed a demographic survey that included information such as age, experience at different facilities etc. before the simulation started. Controller workload data was also collected using the Workload Assessment

Keypad (WAK). Metrics such as situation awareness, intra pair spacing and others were analyzed but not presented in this paper.

## RESULTS AND DISCUSSION

The data analysis paradigm used two independent variables, consistent with experiment procedures described earlier. The independent variable of automation condition had four levels: no automation, mixed automation1 (mixed1), mixed automation2 (mixed2), and full automation. The independent variable of controller position had three levels: Boulder, Niles, and area coordinator. The effects of these two independent variables on the three dependent variables are described in this section. The three dependent variables include controller workload, number of aircraft pairs, and number of deleted aircraft pairs.

### CONTROLLER WORKLOAD

Participants recorded their current level of workload by pressing a key on the electronic Workload Assessment Keypad (WAK) [Stein, 1985] at 5 minute intervals throughout the simulation runs. Workload assessments are subjective and could range from 1 (very low workload) to 7 (very high workload).

#### Workload By Controller Position and Automation Level

Analysis of variance results indicated a significant main effect of position on controller workload,  $F(2,4)=11.56, p<0.05$  (Figure X.2).

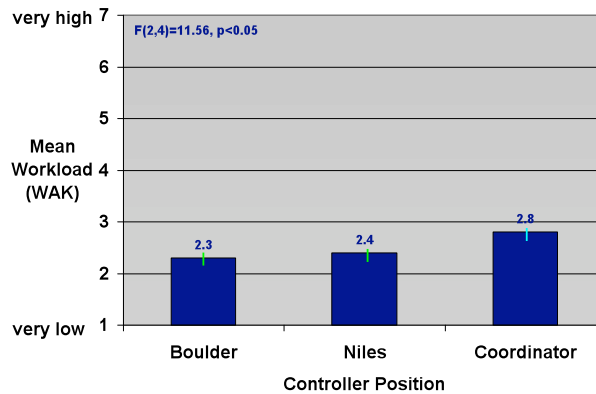


FIGURE X.2 Controller Workload by Position

While overall workload across all positions and conditions was low (mean=2.5, SD=1.0), Figure 2 shows that the area coordinator had a higher level of workload relative to the other two positions. Post-hoc analysis yielded a statistically

significant difference between the area coordinator and Boulder,  $F(1,5)=25.27$ ,  $p<0.01$ , and the area coordinator and Niles,  $F(1,5)=25.55$ ,  $p<0.01$ . This finding is not surprising since the area coordinator is responsible for the area covered by multiple sectors, pairing the aircraft under different positions, and monitoring the aircraft pairs and the flow. In this sense, the area coordinator is required to perform a higher level of multi-tasking relative to the other two positions. Also, the experiment procedures did not allow the sector controllers to form pairs if the area coordinator was too busy. Similarly, the procedures did not allow the area coordinator position to break pairs or directly swap runways for any aircraft - this had to be done through the sector controllers who had ownership of the aircraft. Again, this increased workload suggests the need for additional fine-tuning of the area coordinator's responsibilities.

While statistically significant, the mean difference of less than 1 scale point between positions might also serve to reinforce the main finding, which is that workload was found to be consistently low across all positions. To further illuminate position differences, analysis of the current study factors is currently underway which explores the sub-components that contribute to overall workload.

Workload was also found to be low across the four automation conditions, with the Mixed-2 condition showing the highest workload (mean=2.8, stdev=1.2) and the Full automation condition showing the lowest workload (mean=2.3, stdev=0.7). The higher workload level in Mixed-2 may reflect the excessive task load, which was substantiated with participants' open-ended feedback. However, this result should be viewed as preliminary, since the range was less than 1 scale point. Again, further analysis on workload sub-components might help to illuminate this finding, which may provide an excellent input for the heuristics used by the pairing algorithm.

## **CREATING AIRCRAFT PAIRS**

Analysis of variance results yielded a significant main effect of automation on the number of aircraft pairs made by the study participants,  $F(3,44)=4.69$ ,  $p<0.01$ . A Tukey HSD post-hoc analysis yielded a statistically significant difference between the Mixed-1 and Mixed-2 conditions (mean difference=4.7, std error=1.266,  $p<0.01$ ). Clearly, the controller-participants were more productive in making aircraft pairs under the Mixed-1 condition (mean=18.1, sd=3.3), as compared to the Mixed-2 (mean=13.4, sd=3.9) and the full automation (mean=16.0, sd=2.7) conditions. The controllers used their own judgment in creating pairs under the Mixed-1 and No-automation conditions. However, Mixed-1 provided the option of an alternative interface that eliminated the process of writing pairs on flight strips.

The Mixed-2 condition required the participants to evaluate several pairs before choosing one – a requirement absent from the Mixed-1 condition. Also, the Mixed-1 condition allowed the controller-participants the greatest level of flexibility in aircraft pairing procedures. Controller-participant feedback on the Mixed-1 condition indicated that the display and flight deck automation were very helpful in making aircraft pairs, while being allowed to use their own judgment to create pairs meant they were not constrained by the automation. The Mixed-2 and full



automation conditions sometimes frustrated the controllers if they did not agree with the pairs suggested by the automation, which may have contributed to the relatively low number of aircraft pairs made under those conditions. During discussions, controllers indicated preference for the Mixed-1 condition and expressed a desire for another condition where automation would suggest one good pair while a manual override was allowed. Another heuristic for the algorithm would be to not show pairs that would likely be unacceptable to the controller.

## BREAKING AIRCRAFT PAIRS BY AUTOMATION LEVEL

Some aircraft pairs were broken by the controller-participants because flight deck automation could not achieve 15 s temporal separation at the coupling point and standard separation between the aircraft was not possible (Table X.1).

**Table X.1** Percentage of Aircraft Pairs Deleted by Automation Level

condition	percentage of aircraft pairs broken
No automation	7.6
Mixed-1 automation	15.7
Mixed-2 automation	15.0
Full automation	11.5

It is interesting to note the relatively small percentage aircraft pairs broken under the No automation condition, possibly because the controllers had the goal to bring the aircraft slightly behind each other and they achieved it through speed intervention. In the Mixed-1 condition, the area coordinator created the pairs using the display tools. The higher number of pairs broken under Mixed-1 may have been caused by the flight deck automation’s speed manipulation constraints, making it impossible to drive the following aircraft to meet the temporal separation of 15s at the coupling point for some pairs created by the area coordinator.

## CONCLUSIONS

This simulation study examined the human–automation mix for pairing aircraft for simultaneous approaches to closely spaced parallel runways under different levels of automation. Four levels of automation and three controller positions were examined, and results include analyses of controller-participant workload, the number of pairs made by the controller-participants, and the number of pairs that were broken before the aircraft landed.

Results show that the controller-participants were most productive in forming pairs under the Mixed-1 condition where they used their own judgment to create pairs and used the automation as an interface and for communicating the pairs information to the controllers. Under the Mixed-2 and Full conditions, the study

participants did not perform as well on the number of pairs created because the pairing algorithm suggested pairs that were not acceptable to the controller. The heuristics for the pairing algorithm need further refinement. Allowing the controller to have the final say and override any pairing suggestion made by algorithm will be the key for maintaining flexibility for the controller. Finally, while controller workload remained at a manageable level across all automation levels and controller positions, there was higher workload under the Mixed-2 condition and for the area coordinator position, which may suggest the need for additional fine-tuning of the pairing procedures and the area coordinator's responsibilities.

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