PAIRED APPROACH: A CLOSELY SPACED PARALLEL RUNWAY APPROACH CONCEPT

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ABSTRACT

The paired approach procedure is intended to facilitate IFR approaches to closely spaced parallel runways (closer than 2500 feet) and increase runway throughput where parallel ILS approaches cannot be conducted under instrument meteorological conditions. The paired approach procedure requires that air traffic control pair compatible and eligible aircraft and place them on the final approach courses within a required altitude and longitudinal separation. Within the aircraft pair, the flight crew of the trail aircraft conducts the procedure by achieving and maintaining a defined longitudinal spacing prior to the final approach fix. The flight crew will use a cockpit-based tool set to conduct the spacing task. The initial procedures were examined in a medium fidelity flight simulator to aid in the further definition of the flight deck tasks and to develop the cockpit display requirements. The procedure is in the preliminary stages of development and evaluation, but the spacing concept and tools are being applied and developed further for other approach spacing applications.

INTRODUCTION

Numerous U.S. airports have parallel runways. The spacing between runway centerlines varies by the airport. Approaches to airports with parallel runways have different restrictions depending on the weather conditions. During good visual meteorological conditions (VMC), visual approaches can be conducted. Visual approaches were originally designed to reduce pilot and controller workload and to shorten flight paths to an airport (FAA, 1999). Visual approaches are conducted under an instrument flight rules (IFR) flight plan and allow the pilot to proceed to the airport visually and clear of clouds. The pilot must report either the airport or the preceding aircraft in sight to conduct the visual approach. Upon accepting the visual approach, the pilot is responsible for "maintaining a safe approach interval and adequate wake turbulence separation" (FAA, 1999). Simultaneous visual approaches to parallel runways can be conducted if runway centerlines are at least 700 feet apart.

To conduct visual approaches, reported weather conditions must be at least a 1000-foot ceiling and 3 statute miles visibility (i.e., VMC). Furthermore, the ceiling must be at least 500 feet above the minimum vectoring altitude (MVA) or air traffic control (ATC) cannot provide radar vectors for a visual approach. Therefore, actual visual approach minima differ for each airport. In actual practice, visual approaches are suspended well above even these minima due to the difficulty of spotting aircraft by the flight crew and the incurred controller workload (Olmos & Mundra, 1999). Once visual approaches are suspended, a reduction in capacity generally occurs.

Under Instrument Meteorological Conditions (IMC) and IFR, Instrument Landing System (ILS) approaches to dual parallel runways can be conducted to parallel runways as close as 2500 feet if dependent approaches are conducted.

The paired approach procedure is intended to facilitate IFR approaches to closely spaced parallel runways (closer than 2500 feet) and increase runway throughput where neither simultaneous nor parallel approaches can currently be conducted under instrument conditions.

The procedure is expected to increase capacities at airports during conditions of deteriorated weather conditions. The procedure will allow aircraft to continue use of parallel runways during these conditions.

Such an increase in capacity is expected to allow participating airlines to significantly increase their schedule reliability. This increased capacity and reliability is the primary business justification for the procedure. The paired approach procedure may also result in secondary benefits. For example, it may reduce aircraft holding delays both on the ground and in the air, thereby realizing additional savings in operating costs. An increase in capacity will also facilitate more efficient use of the terminal airspace.

CONCEPT DESCRIPTION

The paired approach procedure is an instrument approach procedure involving two participating aircraft (i.e., a lead and trail) and approved instrument approach procedures serving the runways to be used (See further Bone, et. al., 2000, Stone, 1998, Hammer, 2000, and

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Carrico, 1999. See also Waller, Marvin, Doyle, & McGee, 2000). In the current concept, one of the final approach courses will be offset by 3 degrees from its runway centerline and the other course will be straight in. Since wake vortices do not become an issue until the aircraft are separated by less than 2500 feet laterally, the offset allows for protection from wake vortices for a longer period than if the final approach courses were straight in. Incidentally, the offset also helps overcome ILS localizer overlap at further distances from the threshold on closely spaced parallel approaches.

The paired approach will be conducted when weather conditions prevent the desired arrival rate using current procedures. In addition to ceiling and visibility requirements, the procedure will have established limits on the maximum headwind and crosswind components on final approach, both at altitude and on the surface.

Both aircraft in the pair conducting the procedure must be appropriately equipped and the lead aircraft must maintain a constant speed to the final approach fix (FAF) and execute a predetermined speed profile after the FAF. At a minimum, the trail aircraft must be equipped with Automatic Dependent Surveillance - Broadcast (ADS-B) and Cockpit Display of Traffic Information (CDTI) supported by the Global Positioning System (GPS).

A digital display and some modifications to responsibilities may be required for approach controllers. A method for ATC to determine appropriate equipage will also be required. Nevertheless, the procedure will be designed to function properly in a mixed equipage environment.

To conduct the procedure, ATC must pair compatible and eligible aircraft and place them on the final approach courses with the currently required altitude separation (i.e., 1000 feet) as well as within a paired approach-required longitudinal tolerance. The flight crew of the trail aircraft then conducts the procedure by achieving and maintaining a defined longitudinal spacing to the final approach fix (FAF) within the required bounds. These bounds define the protection zone (See Figure 1). The protection zone is designed such that if the trail aircraft stays within this zone, it is guarded from the wake of the lead (via the aft boundary), and both aircraft are protected from a collision should either aircraft blunder (via the forward boundary) (See further Hammer, 2000 and Pritchett, 1999). To account for ATC / ground equipment and pilot / aircraft reaction time, the protection zone provides a buffer from the actual boundaries that are the absolute limits that prevent wake encounters and collisions. The protection zone and its bounds are depicted on a cockpit display.

The flight crew of the trail aircraft assumes the responsibility to maintain the required spacing within the protection zone, and if unable to do so, will conduct an established breakout maneuver and inform the controller. At this point, the controller would establish another form of separation. The breakout maneuver will be designed such that the trail aircraft never departs the protection zone as it executes the breakout maneuver. In order to provide additional collision protection, Traffic alert and Collision Avoidance System (TCAS) Resolution Advisories (RAs) are expected to remain active during the paired approach procedure.

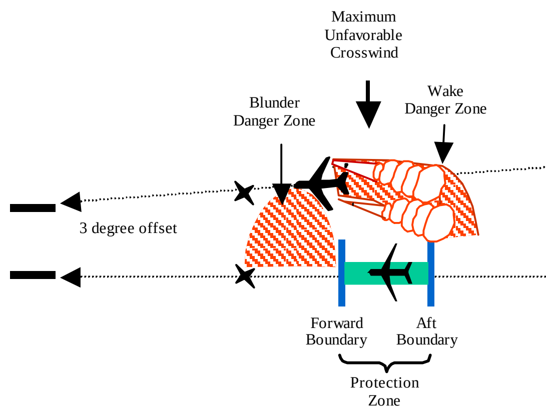

Figure 1. Paired approach concept plan view.

With this concept in mind, a simulation study is reported that investigated the feasibility and acceptability of the paired approach procedure. Also provided, is a description of the cockpit-based tool set developed for a Cockpit Display of Traffic Information (CDTI) to support this concept.

METHOD

Subjects

Twelve line pilots participated in this simulation. The twelve participants were divided into six two-person flight crews. The average subject total flight time was 9480 hours (625 hours in the past year). Subject experience with a Traffic alert and Collision Avoidance System (TCAS) traffic display averaged 3475 hours.

Simulation Environment

The simulation test bed consisted of a generic mid-fidelity transport cockpit with an out-the-window view, a controller station, and simulated traffic representing terminal area operations at the Seattle-Tacoma International Airport (SEA). Pilots controlled the lateral and vertical axes of the aircraft via a combination of autopilot and autothrottle controls. Subject pilots operated as a two-person crew and performed typical duties of pilot-flying and pilot-not-flying (e.g., communications, checklists, call-outs, etc.). A voice communication line was provided to allow communications with an individual acting as a Seattle Approach Controller. Targets appearing on the traffic display were correlated with visible traffic in the out-the-window view. That is, pilots could verify “traffic in sight” using the simulated visual scene and follow that traffic to a landing on a parallel runway.

Procedure

Each flight crew received four hours of training to become familiar with the simulation characteristics, the paired approach procedure, and the CDTI features. Following training, subjects flew eight experimental scenarios, which took between two and three hours.

CDTI Features

A task analysis was conducted to determine the procedural information requirements (for a detailed summary of the task analysis, see Bone, et. al., 2000). Based on the outputs from the task analysis the following functions were developed to support the procedure.

Procedure set-up. An initial flight management system Control and Display Unit (CDU) page (see Figure 2) was developed to support entering necessary information and arming the paired approach function. The information elements within this page included 1) Ownship planned final approach speed and landing runway 2) the paired lead aircraft flight identification, planned final approach speed, and landing runway. Depending on the implementation, this information could be manually entered by the flight crew or it could be automated.

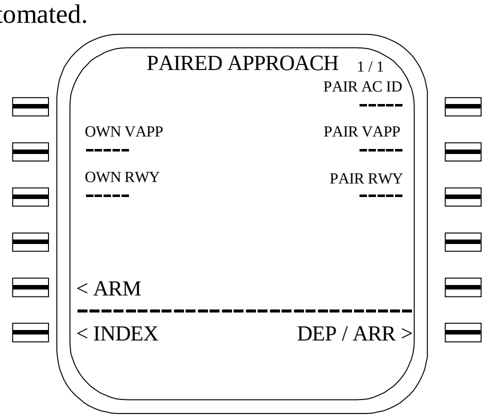

Figure 2. Sample set-up CDU page for paired procedure.

Target selection and highlighting. After entering the required information into the CDU, the flight crew of the trail aircraft must select the lead aircraft on the CDTI. A three-button panel was developed as an illustration of a simple pilot interface for the selection and removal of CDTI features. The panel was located below the navigation display (ND) and was composed of the following: (1) *Forward Selection*- An initial press displays Flight identifications for all aircraft on the CDTI. A subsequent press begins the target selection process in the order of target range with respect to ownship. That is, the closest target to ownship will be selected and highlighted on the CDTI, followed by the next closest target, etc. (2) *Backward Selection*- Enables the pilot to cycle through the targets in reverse order, mainly to recover from ‘selection overshoots’ of the desired target; (3) *Reset*- Removes all non-mandatory CDTI features.

Once an aircraft is selected, additional information appears in the lower left corner of the Primary Flight Display (PFD), which includes target ground speed, range, and flight identification (See Figure 3).

Figure 3. Navigation display- Paired approach engaged. Target position not achieved.

CDTI tools. As described earlier, the paired approach function is armed by the flight crew via the CDU. Once armed, a “PAIRED” annunciation is displayed both on the ND and on the PFD. When specific parameters are met (see further Bone, et. al., 2000) and the paired approach function is enabled, the “PAIRED” annunciations change to green and the following features appear: (1) speed commands, (2) protection zone, and (3) target position arrow (See Figure 3).

As depicted in Figure 3, the protection zone boundaries and target position arrow are yellow since ownship is not yet at the target position. When the target position is achieved and the aircraft remains at the target position, the boundaries open and change to green, as does the target position arrow (See Figure 4). If the aircraft moves from the target position, the boundaries and arrow change back to yellow. If ownship has broken either of the boundaries, the brackets turn red, close to an "x," and the target position arrow disappears. This indicates to the flight crew that a breakout is required.

Figure 4. Navigation display- Paired approach engaged. Target position achieved.

The forward boundary is depicted throughout the approach since protection from collision is always necessary. The aft boundary exists for wake protection and appears at 1 mile prior to the wake turbulence criteria (lateral separation between approach course of approximately 2500 feet).

The speed commands are provided so that the trial aircraft flight crew is able to achieve the target position prior to or at the final approach fix. The speed commands are shown on the ND as well as an airspeed "bug" on the PFD airspeed tape. The speed commands are provided via an algorithm that uses both of the aircraft's final approach speeds and runways to be used and assumes a deceleration profile for both aircraft (See further Hammer, 2000). If the flight crew of the trail aircraft is able to achieve and maintain the target position prior to or at the final approach fix, the spacing task is discontinued, the speed commands and target arrow are removed, and a normal landing is completed.

Experimental Design

The evaluation was carried out using a 3 X 4 within subjects design. The two variables included:

1) Speed Control: As described earlier, outputs from the spacing algorithm were provided to the flight crews in the form of speed guidance. The following methods of complying with this speed guidance were assessed:

- *Mode control panel (MCP) speed input for Auto-throttles*: Flight crews used the MCP to dial in speeds to the auto-throttles to comply with the speed guidance.
- *Coupled Auto-throttles*: Flight crews coupled the speed guidance to the auto-throttles and monitored compliance with spacing algorithm.
- *Combination of MCP input and coupled Auto-throttles*: Flight crews dialed in speeds for the auto-throttles until reaching the correct position (i.e., at the target position arrow) then coupled the speed guidance to the auto-throttles.

2) Weather: Acceptability ratings of the paired approach procedure were collected for the following simulated weather conditions:

- *No cloud layer*: Unlimited ceiling and visibility.
- *Transitional cloud layer*: Cloud layer from 2000' – 700' AGL. Clear above and below the cloud layer with visibility of 4 miles.
- *High cloud layer*: Cloud layer from start of approach to 2100' AGL. Clear below the cloud layer with visibility of 4 miles.
- *Low cloud layer*: Cloud layer from start of approach to 400' AGL. Haze below the cloud layer with visibility of 2 miles.

Scenarios

Each scenario lasted approximately 15 minutes and the SEA facility approach operations were modeled based on actual SEA radar data. Two Southern flow approach operations (runways 16L and 16R) were developed and aircraft were fed to a single final controller. Flight crews flew two scenarios with each weather condition for a total of eight scenarios (the speed control method was counterbalanced across all six crews). Four scenarios simulated approach operations to 16L and four simulated operations to 16R. In addition, four scenarios positioned the flight crew ahead of the desired position, which required a reduction in speed to acquire the correct position, and four positioned the flight crew behind the desired position requiring an increase in speed.

RESULTS

NASA TLX Workload Scale

After completing each scenario with a given condition, flight crews provided subjective ratings on the level of workload experienced using the NASA task load index (TLX) scale. The higher the reported TLX score, the greater is the level of perceived workload, with a maximum score of 120. No significant differences were found for the method of speed control ($p > .05$). There was however a significant effect for weather (See Figure 5), $F(3, 69) = 4.94$, $p < .05$.

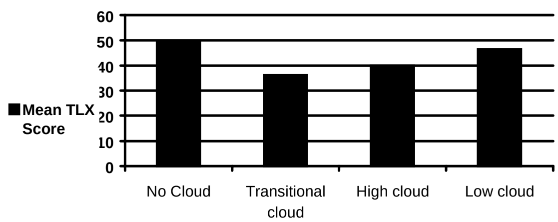

Figure 5. NASA TLX Subjective Workload Ratings for Weather (Maximum score 120).

Separate paired t-tests revealed significantly higher workload ratings with the *no cloud layer* condition with respect to the *transitional cloud layer* ($t(23) = 3.05$, $p < .05$) and the *high cloud layer* ($t(23) = 1.98$, $p < .06$). The *low cloud layer* condition was also rated significantly higher than the *transitional cloud layer* ($t(23) = -4.351$, $p < .05$) and the *high cloud layer* ($t(23) = -1.96$, $p < .07$).

Speed Control and Weather Condition Rank Order

When all scenarios were completed, pilots rank-ordered the methods of speed control that were available during the approach scenarios based on their perceived utility. The ranking data was submitted to a Friedman two-way analysis of variance by ranks, revealing a significant effect for speed control (Chi-Square = 14, $p < .001$). A Bonferroni analysis for all pair-wise comparisons revealed the *coupled autothrottles* and the *combined* method of speed control were ranked significantly higher ($p < .05$) than the *mode control panel (MCP) speed input for autothrottles* condition (see Figure 6).

Pilots also rank-ordered the various weather conditions that were simulated based on their perceived acceptability from 1 (lowest pilot acceptability) to 4 (highest pilot acceptability) (see Figure 7).

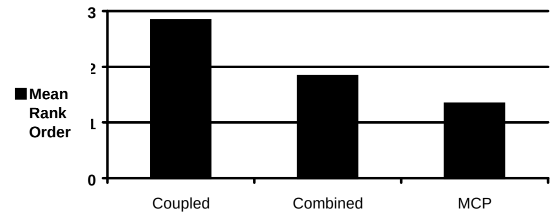

Figure 6. Mean Speed Control Rank Order from 1 (Least Useful) to 3 (Most Useful).

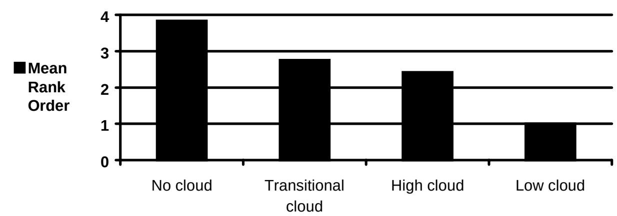

Figure 7. Mean Weather Condition Rank Order from 1 (Lowest Acceptance) to 4 (Highest Acceptance).

The ranking data was submitted to a Friedman two-way analysis of variance by ranks, revealing a significant effect for weather (Chi-Square = 29.5, $p < .0001$). A Bonferroni analysis for all pair-wise comparisons revealed the acceptability of the *no cloud* condition was ranked significantly higher than all other weather conditions ($p < .05$). The *low cloud layer* condition also received significantly lower ratings than the other weather conditions ($p < .05$).

CDTI Feature Examination

Flight crews were asked to rank the effectiveness of the various CDTI features on a 7-point scale (1 = High *negative* effect to 7 = High *positive* effect).

As a whole, there were moderately positive impressions from the flight crews on the CDTI features (e.g., speed guidance, spacing tools, CDU set-up) that were developed for this procedure. The average score was 5.8 (moderately *positive* effect).

Areas for Improvement

After completing all scenarios, subjects were asked to identify problem areas in the procedure from eight potential areas of difficulty (e.g., phraseology, inputting information for the approach algorithm). Of the twelve pilots queried, four identified the target selection process and the task of monitoring speed guidance from the algorithm as areas that need improvement for future development of this procedure. Three pilots felt that inputting information for the approach algorithm and the phraseology developed also needed improvement.

CONCLUSION

These preliminary simulation results indicate that the procedure appears feasible, from a pilot perspective, under the proper weather conditions. The workload data indicates the flight crews preferred the procedure when a relatively high or transitional cloud layer existed so that they were able to visually acquire the lead aircraft in a timely manner (after the spacing task was complete but prior to landing). This implies that the fielding of the procedure would initially need to occur in relatively high cloud ceiling conditions and then move to lower conditions as the procedure gains acceptability through pilot and controller experience.

The flight crews reported generally positive ratings for the proposed CDTI features. Flight crews also indicated a preference for coupling the autothrottles to the spacing algorithm to assist in achieving the required speed commands. Additional areas that need further work were also identified by flight crews, e.g., phraseology and inputting required information.

The paired approach concept is in the preliminary stages of development and evaluation. Considerable additional development is required before flight tests and implementation can be considered. At this point, the future of the paired approach program with respect to further development aimed toward implementation is unclear. However, lessons learned in the development of the procedure have led to other approach spacing applications that are currently being developed by the Federal Aviation Administration in its Safe Flight 21 program. Specifically, an operational evaluation of an initial approach spacing capability was conducted in the Fall of 2000 (see FAA, 2001).

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