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Closely Spaced Parallel Operations (CSPO) Site Specific Evaluation for Chicago O'Hare

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****CORRECTION as of November 2014:**
Correction to ORD RWY number in Section 7.0 Recommendations: Page 23 number 2a:
Changing 10C/28C to 10L/28R

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Flight Systems Laboratory
Flight Technologies and Procedures Division
Flight Standards Service

Closely Spaced Parallel Operations (CSPO) Site Specific Evaluation for Chicago O'Hare

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12. Abstract

The Flight Systems Lab was requested by ATO Terminal to conduct a study to evaluate the combinations of simultaneous independent approach operations that could be authorized by ATC at Chicago O'Hare International Airport (ORD) with the runways resulting from the modernization plan.

Dual, triple, and quadruple approaches were evaluated, using a Standard Terminal Automation Replacement System (STARS) with Final Monitor Aid (FMA) display with visual and aural alerts, and a 4.8 second surveillance update rate.

Dual approaches using the new ORD runway pairs 10R/28L and 10C/28C, separated by only 3,100 feet, require either a 1.0 second update rate surveillance, or a 2.5° offset to 10R/28L to meet the acceptable level of risk. Duals to other runway pairs can be made within current requirements. Using either a 1.0 second update rate surveillance, or a 2.5° offset to 10R/28L, triples to 9L/27R, 9C/27C and 10C/28C or to 9C/27C, 10C/28C and 10R/28L and quadruples to 9L/27R, 9C/27C, 10L/28R and 10R/28L; or to 9L/27R, 9C/27C, 10C/28C & 10R/28L will meet the acceptable level of risk.

13. Key Words	14. Distribution Statement
Blunder Data Collection Effort (DCE) High Update Rate (HUR) Surveillance Human in the Loop (HITL) No Transgression Zone (NTZ) Normal Operating Zone (NOZ) probability density function (pdf) Precision Runway Monitor (PRM) Simultaneous Independent Parallel Instrument Approach (SIPIA) Simultaneous Offset Independent Dual Instrument Approach (SOIDIA) Test Criteria Violation (TCV)	Controlled by AFS-450
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EXECUTIVE SUMMARY

The purpose of this study is to evaluate the combinations of simultaneous independent instrument approaches that could be authorized by ATC at Chicago O'Hare International Airport (ORD) with the final runway configuration resulting from the ORD Modernization Plan (OMP). This report presents the results of the evaluations of dual, triple, and quadruple simultaneous independent instrument approaches to the OMP final runway configuration. This study was requested by Air Traffic Organization (ATO) Terminal Safety and Operations Support Office, AJT-2.

The data sets used for these evaluations were collected through two Human in the Loop (HITL) Data Collection Efforts (DCEs) using the ORD final runway configuration. The first DCE was conducted in November 2011 at the Chicago Terminal Radar Approach Control Facility (TRACON), referred to as C90. The second DCE was conducted in May 2012 at the Air Traffic Control Simulation Facility located within the Flight Operations Simulation Laboratory, AFS-440, in Oklahoma City (OKC).

The FAA Safety Management System acceptable level of risk of 1×10^{-9} per operation for a catastrophic event was used as the success criteria. The evaluations were based on a Standard Terminal Automation Replacement System (STARS) Final Monitor Aid (FMA) with a color digital display, visual and aural alerts, 4:1 aspect ratio, and a 4.8 second surveillance update rate. Navigation systems included the Instrument Landing System (ILS), Localizer Performance with Vertical guidance (LPV), Ground Based Augmentation System (GBAS) Landing System (GLS), and Global Positioning System (GPS) required Area Navigation (RNAV)/Required Navigation Performance (RNP).

The new ORD runways 10C/28C and 10R/28L are separated by 3,100 feet. The threshold of 28L has a stagger of 2,306 feet west of the 28C threshold, while the threshold of 10R has a stagger of 994 feet east of the 10C threshold. The parallel approach evaluation analyzed a 1,600 feet No Transgression Zone (NTZ) and High Update Rate (HUR) surveillance with a 1.0 second update rate. This study also evaluated a 2.5° and 3.0° offset approach to runway 10R/28L using an Airport Surveillance Radar-9 (ASR-9) with a 4.8 second update rate and a 2,000 feet NTZ. Both evaluations met the acceptable level of risk.

The evaluation concluded that triple simultaneous independent instrument approaches using 9C/27C, 10C/28C and 10R/28L may be conducted with either HUR surveillance with no course offset or an ASR-9 and a 2.5° to 3.0° offset to 10R/28L.

Additionally, quadruple approaches to 9L/27R, 9C/27C, 10L/28R, and 10R/28L; or to 9L/27R, 9C/27C, 10C/28C, and 10R/28L (with HUR surveillance with no course offset or an ASR-9 and a 2.5° to 3.0° offset to 10R/28L) meet the acceptable level of risk.

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1.0 INTRODUCTION

The Federal Aviation Administration (FAA) Next Generation Air Transportation System (NextGen) Implementation Plan (NGIP) and the National Airspace System (NAS) Enterprise Architecture (EA) identify improvements to Closely Spaced Parallel Operations (CSPO) as a key future capacity enabler, with three high level goals:

- Increasing Capacity: Reduce the impact of lower visibility conditions by closing the gap in capacity between Visual Meteorological Conditions (VMC) and Instrument Meteorological Conditions (IMC).
- Reducing Delay: Reduce system wide NAS delay.
- Maintaining Safety: Ensure an acceptable level of safety exists in reduced visibility conditions with an increased number of approach operations to near that of VMC.

To meet these goals, the FAA is investigating methods to conduct closely spaced simultaneous independent parallel instrument approaches to closely spaced parallel runways.

The distance between parallel runways is one of the main parameters that affect airport capacity and that determine whether independent (higher throughput), dependent (lower throughput), or single runway arrival operations can be conducted. Other factors include an airport's radar surveillance capabilities, the air traffic automation system, and supported approach types and runway threshold stagger. A principal safety concern is the risk of collision due to a blunder, where one aircraft unexpectedly turns toward the aircraft on the parallel final approach course, putting both aircraft at risk. At risk means that if no action is taken, the aircraft will collide.

1.1 Background

The Chicago O'Hare International Airport (ORD) Modernization Plan (OMP) increases the number of runways and changes their geometric relationship. The OMP and the Environmental Impact Statement (EIS) outlines numerous alternatives for conducting approaches using the final runway configuration (See Figure 1). [1,2]

Operations allowed to the new south runways, 28L and 28C, are restricted due to the limitations imposed by the Runway Centerline Spacing (RCLS) of the runways. Because of these limitations, capacity is limited to 28L and 28C during IMC conditions. The Air Traffic Organization (ATO) Terminal Safety and Operations Support Office, AJT-2, requested the Flight Technologies and Procedures Division, AFS-400, to evaluate alternative operations that might be allowed while using these runways to increase capacity in less than visual conditions. Any modifications to the OMP and EIS approved operations to include the alternative operations would be addressed at a later date.

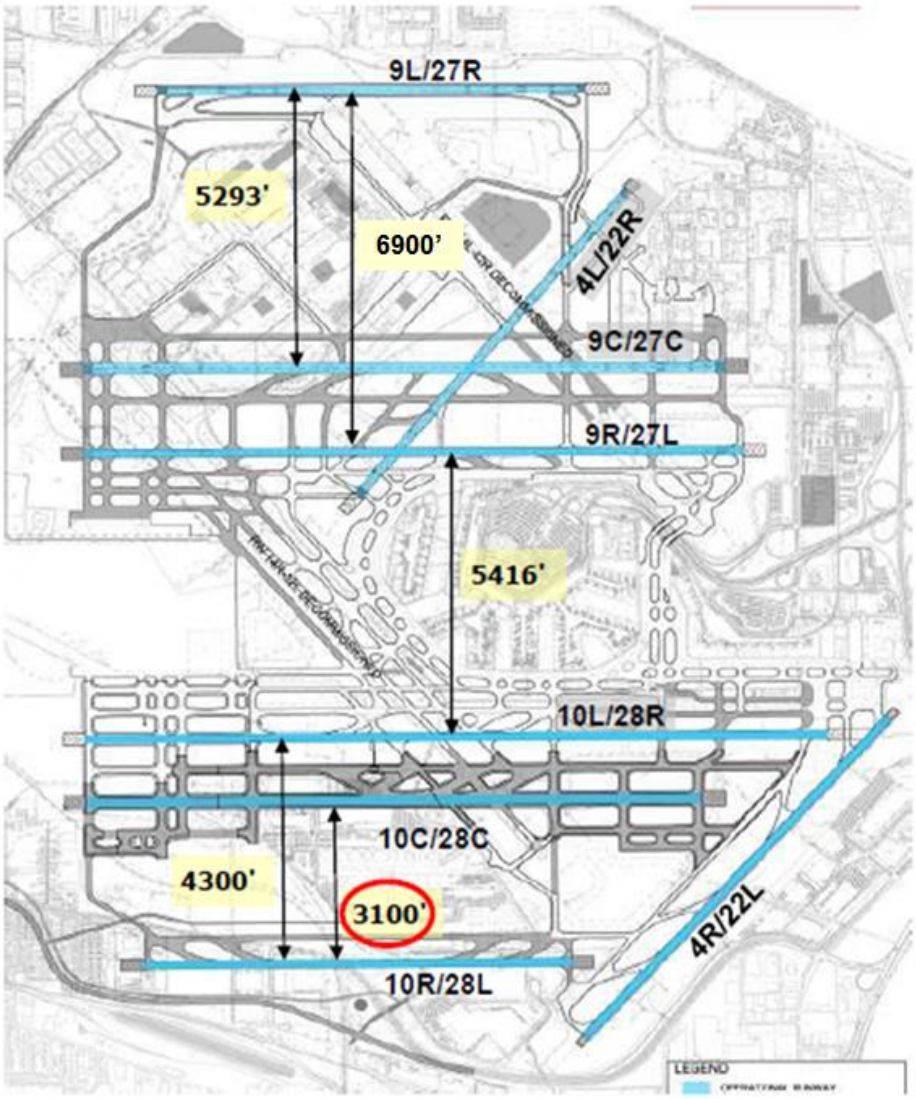

Figure 1: ORD Final Runway Configuration

2.0 DISCUSSION

FAA Technical Report, DOT-FAA-AFS-450-69 "Simultaneous Independent Close Parallel Approaches High Update Radar Not Required, September 2011," provides the basis for allowing Simultaneous Independent Parallel Instrument Approach (SIPIA) operations to parallel runways spaced as closely as 3,600 feet between centerlines using an Airport Surveillance Radar-9 (ASR-9) radar with a 4.8 second update rate in lieu of HUR surveillance, an Instrument Landing System (ILS), Standard Terminal Automation Replacement System (STARS) plus Final Monitor Aid (FMA) display with audio and visual alerts, a No Transgression Zone (NTZ) width of 2,000 feet and Normal Operating Zone (NOZ) widths of at least 800 feet on either side of the NTZ. [3]

However, ORD runways 28L and 28C have centerlines spaced 3,100 feet apart (See Figure 2). This reduced separation was the primary consideration for evaluating dual SIPIA operations to these runways.

A second report, DOT-FAA-AFS-450-84, "Separation Requirements for Simultaneous Offset Independent Dual Instrument Approaches-High Update Rate Surveillance Not Required," evaluated the risk of conducting Simultaneous Offset Independent Dual Instrument Approaches (SOIDIA) using an approach with an offset of 2.5° to 3.0° to one runway without high update rate surveillance. [4] The dual parallel runways evaluated in DOT-FAA-AFS-450-84 had a centerline spacing of 3,000 feet and no stagger between runway thresholds. The NTZ was 2,000 feet wide, resulting in a Normal Operating Zone (NOZ) of 500 feet at the runway thresholds. This report provides the basis for allowing SOIDIA operations to parallel runways with centerline spacing as close as 3,000 feet without HUR surveillance.

Two Human in the Loop (HITL) Data Collection Efforts (DCEs) were conducted for the ORD final runway configuration. The first DCE was conducted in November 2011 at C90 and the second DCE was conducted in May 2012 at the Air Traffic Control Simulation Facility located within the Flight Operations Simulation Laboratory, AFS-440, in Oklahoma City (OKC). The purpose of the first DCE was to collect controller response times (CRTs) for a dual SIPIA operation to runways 28L and 28C utilizing a 1,600 feet NTZ, 750 feet NOZs, with ASR-9 surveillance (See Figure 2 and Figure 3).

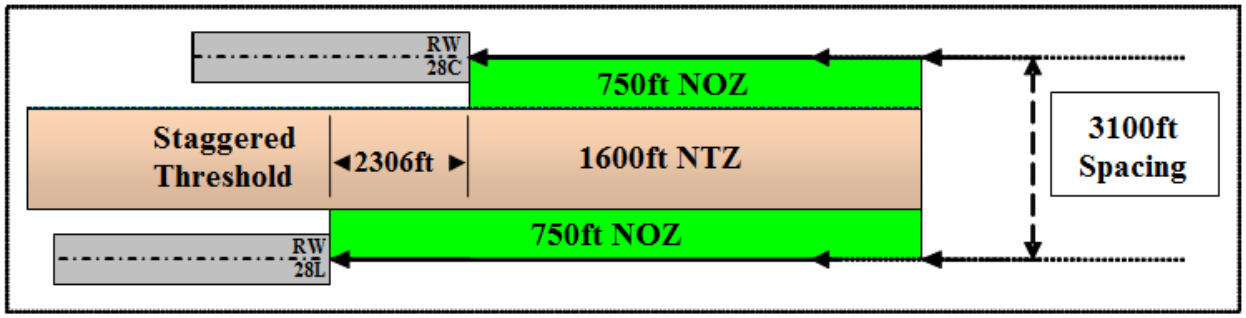

Figure 2: Runway Spacing and NTZ/NOZ Depictions for 28C and 28L at ORD

The evaluations were based on a Standard Terminal Automation Replacement System (STARS) Final Monitor Aid (FMA) with a color digital display, 4:1 aspect ratio, visual and aural alerts. The navigation system used was an ILS to both runways. Controllers performed final monitor duties for parallel approaches as they would in actual National Airspace System (NAS) operations.

An additional area of interest to be evaluated was the impact of FMA display Aspect Ratio (AR) on CRTs. All prior controller performance testing had been accomplished using an AR of 4:1. Controllers from recently conducted HITL DCEs had commented on the sensitivity of the 4:1 AR as compared to the 1:1 AR (See Human Factors Analysis, Chapter 5.0). Therefore, all AR scenarios were repeated for each subject pair of controllers and included:

1. FMA display set to a 1:1 AR

2. FMA display set to a 4:1 AR

The simulated dual SIPIA operation at C90 utilized the ORD operations plan as depicted in the EIS and the Chicago TRACON Operating Procedures Order, C90 7110.65D. [5]

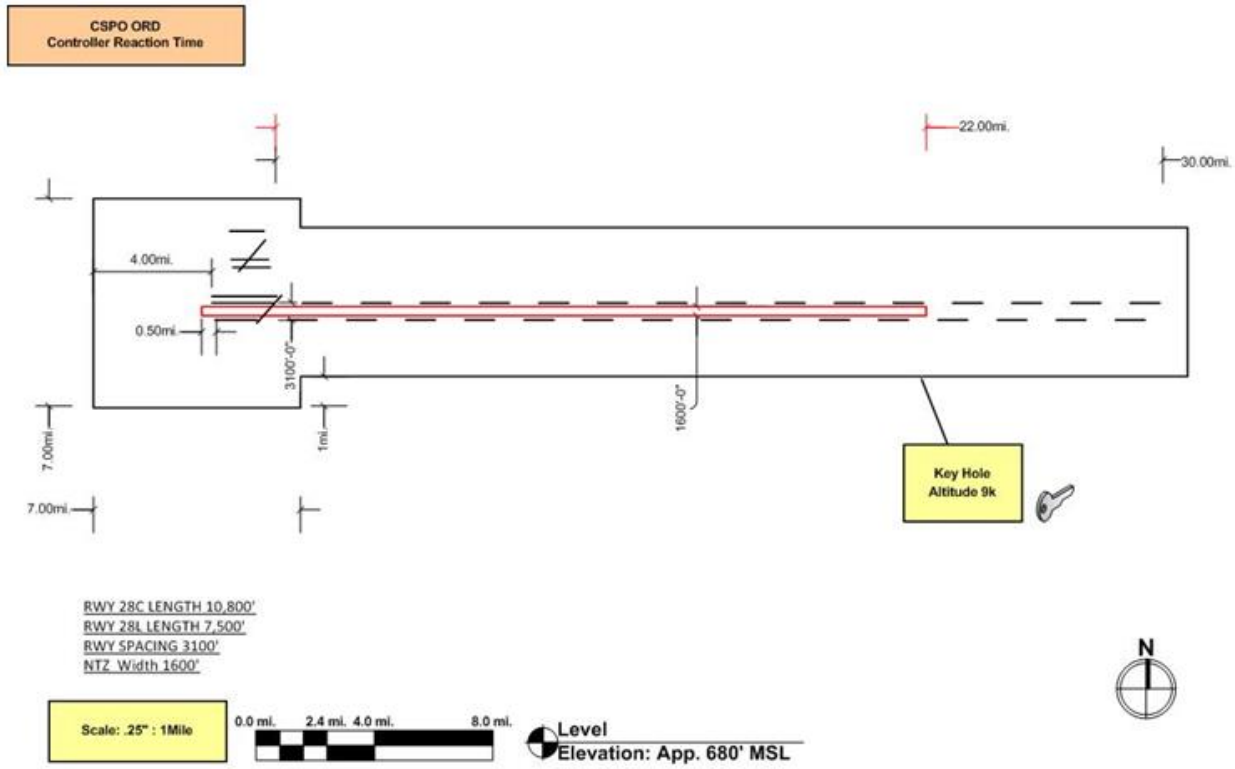

Figure 3: C90 ORD Duals Depiction

The purpose of the second DCE (May 2012 at the Mike Monroney Aeronautical Center (MMAC) in Oklahoma City) was to collect CRTs for quadruple operations and dual SIPIA operations to 28L and 28C. The quadruple SIPIA testing consisted of the following scenario:

1. ORD quadruple approaches to runways 28L, 28C, 27R, and 27C (see Figure 5).

The dual SIPIA testing consisted of the following two scenarios:

1. ORD runways 28C and 28L with 3,100 feet RCLS, a 2,306 feet 28L threshold stagger to the west of 28C, a 2,000 feet wide NTZ, and a 2.5°offset approach to 28L with ASR-9 surveillance (see Figure 4).
2. JFK runways 22L and 22R with a 3,000 feet RCLS, no threshold stagger, a 1,600 feet wide NTZ, and HUR surveillance.

The simulated JFK configuration is more conservative than ORD. The runways are 100 feet closer together and the existing threshold stagger at JFK was removed for the simulations.

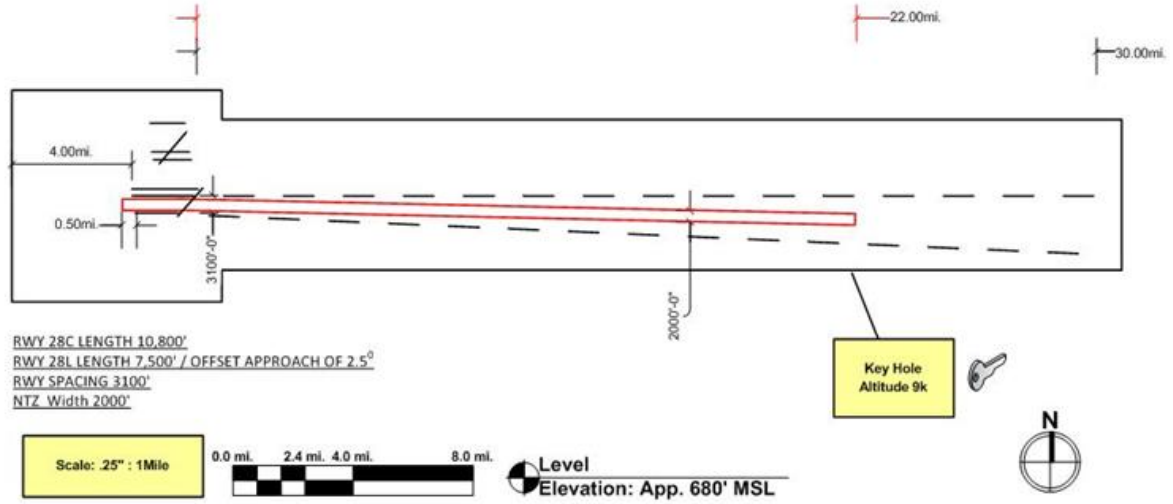

Figure 4: ORD Duals with Offset Depiction

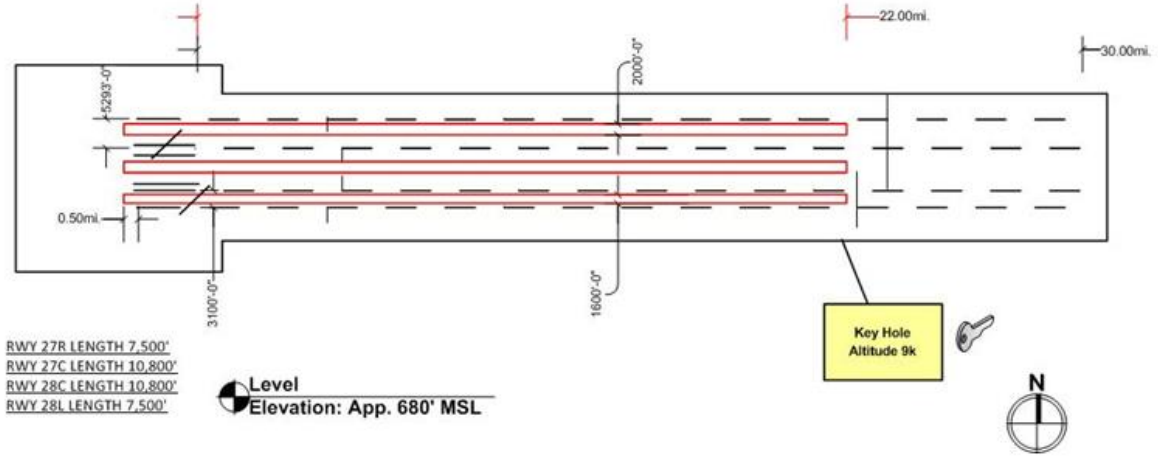

Figure 5: ORD Quads Depiction

Several blunder scenarios were considered. When considering quadruple approach operations, this study considered worst-case situations with all aircraft flying the approach procedure in an at-risk state.

During both HITLs, the subject controllers were given a briefing at the beginning of their simulation session. The briefing included a review of FAA Order JO 7110.65U, Air Traffic Control, paragraph 5-9-7, "Simultaneous Independent ILS/MLS Approaches - Dual & Triple" that governs this particular operation and a depiction of the STARS/FMA depiction. Subject air traffic controllers used for this data collection were Certified Professional Controllers and certified for the Final Monitor position.

Both HITLs utilized pseudo pilots who were responsible for controlling computer generated aircraft, controllers who performed as they would in actual NAS operations, and ORD traffic data to generate the simulated parallel approach traffic. Monitor controllers used STARS with FMA displays, a color digital display with aural and visual alerts, and an aspect ratio of 4:1. At C90, an

AR of 1:1 was also evaluated. The navigation system was the Instrument Landing System. Surveillance was provided by an ASR-9 with a 4.8 second update rate. At MMAC, HUR surveillance was also evaluated for the dual operation with no offset.

Human Factors (HF) data were collected during the HITL testing. The HF analysis included elements based on controller performance such as perceived workload changes, primary and secondary task performance, visual scanning and acquisition strategies, and controller coordination. The HF study analyzed how well controllers developed strategies and how potential limitations, such as human, environmental, automation/display, etc., affect their performance. The analysis included both subjective and objective measures. The resultant human factors analysis can be reviewed in Section 5 of this document with supporting analysis contained in Appendix I.

2.1 Objectives

The objectives of this study were to:

1. Determine the level of risk of dual SIPIA operations to runways 28L and 28C.
2. Evaluate alternative SIPIA operations including triple and quadruple operations while utilizing runway 28L and 28C.
3. Determine controller preference for display AR (4:1 vs. 1:1)
4. Evaluate Required Navigation Performance (RNP) overlay of proposed Charted Visual Approach (CVA) to 28L (see Figure 6).
5. Provide the results and recommendations of this evaluation to Air Traffic Organization (ATO) Terminal Safety and Operations Support Office, AJT-2.

3.0 SYSTEM DESCRIPTION

3.1 Air Traffic Control (ATC) Laboratory (OKC)

The Simulation Model for Air Traffic Research and Testing (SMART) system, located within the AFS-440 ATC Simulation Facility, drives the simulated TRACON and ATC functions and positions, as well as the Test Director and pseudo pilot positions. The pseudo pilots control the computer generated aircraft as directed by the subject air traffic controllers. SMART provides a realistic radio communications link to all participants.

The SMART system software uses accurate computer models for different components of the NAS including aircraft, surveillance systems, terminal automation systems, navigation aids, and airport components. The terminal automation system simulated during these studies was the STARS. Controllers participated in the simulation through two STARS workstations with FMA displays set at either a 4:1 AR (C90 and OKC) or a 1:1 AR (C90 only), and including visual and aural alerts. The NTZ is normally depicted as a white rectangle on the display. If the STARS/FMA system predicts a penetration of the NTZ within 10 seconds, the NTZ rectangle turns yellow. This indicates a visual CAUTION alert and is accompanied by an aural "CAUTION" alert. If the aircraft penetrates the NTZ, the NTZ rectangle turns red. This indicates a visual WARNING alert and is accompanied by an aural "WARNING" alert. Both are

accompanied by the blundering aircraft's call sign. CRT is defined as the amount of time between the onset of the CAUTION alert and the instant the controller presses the push-to-talk switch. The system collected data as defined by the specific test plan requirements for this study. Data from aircraft and the controller work stations were analyzed and provided as input parameters to the ASAT^{ng} for risk analysis**.**

The variables recorded by the SMART system for this DCE included the following:

1. The blundering aircraft call sign
2. The evading aircraft call sign
3. Blunder start time
4. NTZ caution time (yellow alert)
5. NTZ warning alert time (red alert)
6. Monitor controller communication start time
7. Monitor controller communication stop time
8. Distance to NTZ at yellow alert
9. Distance to NTZ at red alert
10. Distance to NTZ at monitor controller communication start.
11. Closest point of approach, 2-dimension
12. Closest point of approach, 3-dimension
13. Blunder angle

Other variables that were derived from the recorded variables included:

1. Monitor controller message duration
2. Yellow alert to monitor controller message start time (CRT)
3. Red alert to monitor controller message start time
4. Monitor controller message start to pilot roll time
5. Monitor controller message start to pilot pitch time
6. Monitor controller message start to pilot throttle time

Other variables that were derived from pilot and controller questionnaires:

1. Qualification of left monitor controller
2. Qualification of right monitor controller

3.2 SMART System ATC Simulation at C90

The SMART System from the ATC Laboratory in OKC (as described above) was transported to C90 and used to collect CRT data as defined by the CSPO ORD Data Collection Plan requirements.

3.3 SMART Post-Processing and Analysis (SPA) Tool

The SPA program allows the end user to visually and audibly examine the events that were recorded by the SMART system. This multifaceted approach allows for close examination of the

quality of the data recorded, testing parameters, conditions, and effects of the selected simulation elements. The collected data set is portable and can be verified and transported to other software tools for further analysis and simulations such as the Airspace System Analysis Tool - new generation ($ASAT^{ng}$).

3.4 Airspace System Analysis Tool – new generation ($ASAT^{ng}$)

The primary analysis tool for this safety study was the Flight Systems Laboratory, AFS-450, $ASAT^{ng}$. $ASAT^{ng}$ is a multifaceted fast-time simulation tool for aviation related safety assessments. The analysis tool uses high fidelity models of all components of an aviation scenario to evaluate the overall risk of the operation. A wide range of parameters covering operational aspects, such as aircraft performance, atmospheric conditions, navigation system performance, ATC monitoring and surveillance equipment, and pilot and controller response times enable very efficient and realistic modeling of complex operational scenarios. $ASAT^{ng}$ uses official FAA databases of navigation and surveillance facilities, runways, fixes, etc. The $ASAT^{ng}$ flight dynamic models account for atmospheric conditions. Additionally, aircraft fleet mix for the area of interest is incorporated into the simulations. The probability density functions (pdfs) described within this report were incorporated into $ASAT^{ng}$ to perform fast-time, Monte Carlo simulations to assess the risk level of conducting close parallel operations at ORD.

4.0 DATA ANALYSIS

One important purpose of the simulation was to collect data that can be used to develop pdfs. The pdfs are used in the $ASAT^{ng}$ simulation to determine the probability of a collision during closely spaced parallel approach operations due to a blunder. The probability of a collision can be compared to a standard probability or risk, i.e., a target level of safety, to determine the acceptability of the operation. A mathematical algorithm is used to determine a pdf of best fit to the data in question such as controller response time. Confidence in the suitability of the derived pdf increases with increased numbers of observations in the data set.

Statistical tests have been devised to enable the analyst to decide whether two or more independent samples should be regarded as having come from the same population. Values from different independent samples almost always differ somewhat in means, variance, and other measures that describe properties of the data. The problem is to determine whether the observed sample differences signify differences among populations or whether they are merely the chance variations that are to be expected among random samples from the same population. Refer to Appendix A for a detailed discussion of the statistical tools used in the analysis.

4.1 Analysis of Means and Variances of November 2011 C90 Data.

Two parameters were tested during the November 2011 C90 HITL, blunder angle and aspect ratio. Two-way analysis of variance (ANOVA) was used to examine the effect of blunder angle and aspect ratio on Cautiontocommstart data. No significant differences of Cautiontocommstart due to blunder angle, aspect ratio, or interaction were found. Therefore, all the Cautiontocommstart data were combined into one set without regard to blunder angle or aspect ratio for pdf fitting. Refer to Appendix B for the complete analysis.

4.2 Analysis of May 2012 DCE data.

This section addresses the analysis of and results from the May 2012 DCE data.

4.2.1 Analysis of Means and Variances by Controller Qualification.

Cautiontocommstart data were grouped according to whether the controller was qualified or not qualified. The HUR analysis did not reveal any significant differences in either means or dispersion of Cautiontocommstart data caused by controller qualification. This is true regardless of blunder angle, controller seat, or runway. The Offset data analysis did not reveal any significant differences in either means or dispersion of Cautiontocommstart data caused by controller qualification. This is true regardless of blunder angle, controller seat, or runway. The Quads data analysis did not reveal any significant differences in either means or dispersion of Cautiontocommstart data caused by controller qualification. This is true regardless of blunder angle, controller seat, or runway. Therefore, the HUR Cautiontocommstart data were combined into one HUR data set without regard to controller qualification. The Offset Cautiontocommstart data were combined into one Offset data set without regard to controller qualification. The Quads Cautiontocommstart data were combined into one Quads data set without regard to controller qualification. Refer to Appendix C for the complete analysis.

4.2.2 Analysis of Means and Variances of 2.5° Offset Data.

After the Cautiontocommstart data were combined without regard to controller qualification, the Cautiontocommstart 20° blunder data of the two runways were compared, and no significant differences in means or variances were found. Therefore, the 20° data from the two runways were combined into a single data set. The Cautiontocommstart 30° data from the two runways were compared, and no significant differences in means or variances were found. Therefore, the 30° data from the two runways were combined into a single data set.

The 2.5° offset of the ILS localizer results in increasing approach path separation with increasing distance from the runway threshold. Regression analysis was used to test whether there is linear correlation between distance from threshold and approach path separation of the Cautiontocommstart data. No linear correlation of the Cautiontocommstart data was indicated. Refer to Appendix C for the complete analysis.

4.2.3 Analysis of Means and Variances of HUR Data

After the Cautiontocommstart data were combined without regard to controller qualification, the Cautiontocommstart 20° blunder data of the two runways were compared, and no significant differences in means or variances were found. Therefore, the 20° data from the two runways were combined into a single data set. The Cautiontocommstart 30° data from the two runways were compared, and no significant differences in means or variances were found. Therefore, the 30° data from the two runways were combined into a single data set. Refer to Appendix D for the complete analysis.

4.2.4 Analysis of Means and Variances of Quads Data.

The number of quad approaches is small with only 48 runs. Runways 27R, 27C, 28C and 28L were analyzed for the Quads study (see Figure 1). No blunders originated from 27C. All

blunders from 27R were to the left; all blunders from 28L were to the right; and all blunders from 28C were to the left.

After the Cautiontocommstart data were combined without regard to controller qualification, the Cautiontocommstart 20° blunder data of the two runways were compared, and no significant differences in means or variances were found. Therefore, the 20° data from the two runways were combined into a single data set. The Cautiontocommstart 30° data from the two runways were compared, and no significant differences in means or variances were found. Therefore, the 30° data from the two runways were combined into a single data set. Refer to Appendix E for the complete analysis.

4.3 Comparison of Means and Variances by Approach Type by Blunder Angle

In this study, the means and dispersion of Cautiontocommstart data of the four data sets, C90, HUR, Offset, and Quads by blunder angle were compared. All data from qualified and unqualified controllers were included. A two-way ANOVA was used to determine whether Cautiontocommstart data exhibited differences in means or variances caused by the effects of different approach type or different blunder angles. The ANOVA indicated that there was a significant difference in means by approach type. Grouping the tests indicated that the mean of the C90 data was significantly larger than the means of the other three data sets. A second two-way ANOVA was used to verify that there was no significant difference in the means or variances of the HUR, Offset or Quads. Therefore, all the Cautiontocommstart data from the HUR, Offset, and Quads data could be combined into one set without regard to blunder angle. Refer to Appendix F for the complete analysis.

4.4 Controller Response Time Probability Density Functions.

Based upon the results of the analysis of the effects of qualifications and blunder angles on controller response times as described in this section, Johnson curves were fitted to the combined HUR, Offset, and Quads controller response data, and pdfs were generated. Refer to Appendices G and H for the complete analysis.

5.0 HUMAN FACTORS ANALYSIS

The C90 subject controllers used in the DCE at ORD were all qualified controllers proficient with current procedures at the test location and certified to control dual simultaneous independent ILS approaches. The NAS-wide subject controllers used in the HUR, Offset and Quad DCE at OKC, were qualified controllers proficient with current procedures at their assigned facilities and certified to control dual simultaneous independent ILS approaches.

Only two of the 50 C90 subject controllers versus seven of the 36 NAS-wide subject controllers had experience operating the STARS/FMA display or Precision Radar Monitor (PRM) display. All controllers received a briefing on the visual and aural aspects of the display as well as a description of system functions.

Similarly, only two of the 50 C90 subject controllers versus six of the 36 NAS-wide subject controllers were familiar or had experience using the 4:1 AR display. The 4:1 AR expands the display area 400% in the direction perpendicular to the final approach course providing an exaggerated indication of deviations from the final approach course. Most controllers indicated that the 4:1 AR display offered better situational awareness over the 1:1 AR display, when used during closely spaced SIPIA operations. Consistent comments were that the 1:1 AR display resulted in the controllers having less time to react to alleviate problems. Of the 48 subject controllers with no previous STARS/FMA display or Precision Radar Monitor (PRM) display experience who participated in the C90 DCE, only two preferred the 1:1 AR over the 4:1 AR.

During the debrief, several controllers stated that they waited for the red alert Warning indication before directing a breakout. There seemed to be a heavy reliance on the yellow and red alerts as critical cues for making breakout/course deviation decisions. Some controllers commented that since they could not clearly discern trends, they could not differentiate normal course deviations from blunders. Most controllers felt that the course deviations simulated in this DCE had higher angles than seen in normal operations. Therefore, with the high-degree turn and rate of speed of the 20° and 30° blunders simulated, the controllers felt they had little or no time to react and subsequently had to adopt a heavy reliance on the yellow and red alerts (both visual and aural).

Overall, controller comments and observer notes indicate that controller performance improved in proportion to the number of scenarios experienced during the two DCEs. As the simulation progressed, controllers' strategies became more efficient through learned behavior (i.e., controllers were more reluctant to allow traffic to deviate dramatically from the required path and were more likely to intervene earlier).

However, comments also indicated that a higher level of controller vigilance was required during both DCEs as compared to normal final monitor duties at the controllers' facilities.

An Attention All Users Page (AAUP) is published for all Simultaneous Close Parallel approaches. The AAUP informs the pilots to expect the phraseology contained in the FAA Order JO 7110.65. Final Monitor Controller training, experience, and daily operations do not provide a high level of exposure to blunders and the required corrective action or phraseology. Controllers are highly trained, but they function optimally in those conditions for which they are habitually exposed. Those habit patterns may have influenced the use of phraseology and instruction sequences during the DCEs.

Few controllers were proficient in the use of the STARS/FMA display. Very few controllers had experience using the 4:1 AR. This lack of experience and proficiency may have impacted workload and comfort levels during the DCEs.

Controllers were queried during debriefing regarding the benefit of training on performance of final monitor duties. Controllers stated that training would have a positive impact on performance. However, the content of controller training is beyond the scope of this analysis.

See Appendix I for details of the Human Factors Analysis.

6.0 SUMMARY OF FINDINGS

This section summarizes the results of the data analysis and recommendations for its use.

6.1 FAA Order JO 7110.65U Requirements

1. Dual and Triple SIPIA – Paragraph 5-9-7, Simultaneous Independent Approaches− Dual & Triple, requires RCLS of 4,300 feet for dual approaches. For Triple approaches, the RCLS must be 5,000 feet and the airport elevation must be less than 1,000 feet MSL. [6]

2. Close Parallel SIPIA – Paragraph 5-9-8, Simultaneous Independent Close Parallel Approaches – High Update Radar, requires an RCLS of at least 3,400 to 4,300 feet to dual runways when precision runway monitors are utilized with a radar update rate of 2.4 seconds or less. With one final approach course offset by 2.5°, using a precision runway monitor system with a 4:1 AR and a 1.0 second radar update system, simultaneous independent approaches may be made to dual runways with an RCLS of at least 3,000 feet.

3. Quadruple SIPIA – There are no criteria for quadruple SIPIA included in this version.

6.2 Dual SIPIA Operations

Analysis indicates that:

1. The subject controllers at C90 preferred the 4:1 AR over the 1:1 AR for the FMA display.

2. HUR surveillance is required to achieve an acceptable level of risk (5.06E-10) for dual SIPIA operations to runway 28C and 28L with no course offset.

3. Although ATO Terminal Safety and AJT-2 requested analysis only for west traffic flow (28L and 28C), AFS-450 also analyzed east flow traffic for runways (10R and 10C).

4. Analysis indicates that SIPIA operations to these runways, using HUR surveillance, also achieved an acceptable level of risk (5.03E-10) with no course offset.

5. Utilizing a straight in approach to runway 28C and a 2.5° to 3.0° offset approach to runway 28L decreases the risk of collision, nuisance breakouts (NBOs) and Traffic Alert and Collision Avoidance System (TCAS) Resolution Advisories (RAs). The offset operation achieved an acceptable level of risk (less than 1.0E-9). Using ASAT^{ng}, the overall collision risk was determined to be 4.55E-10**.** The John A. Volpe National Transportation Systems Center analyzed this operation and confirmed that it achieved an acceptable level of risk. [7] This alternative offset operation is not specifically addressed in and will require an update to the EIS prior to utilization.

6. Utilizing a straight in approach to runway 10C and a 2.5° to 3.0° offset approach to runway 10R decreases the risk of collision, NBOs and TCAS RAs. As discussed above, and shown in DOT-FAA-AFS-450-84 [4], this operation achieves an acceptable level of

risk (less than 1.0E-9). This alternative offset operation is not specifically addressed in and will require an update to the EIS prior to utilization.

7. The RNP overlay of the Charted Visual Approach (CVA) to 28L proposed by C90 results in the aircraft being established on the approach course approximately 8 NM from the threshold (Figure 6). A turn of approximately 30° is required to align the aircraft with this final segment of the approach. This turn creates a point of conflict for any straight-in traffic to runway 28C. The RNP overlay procedure for the CVA has not been designed. Therefore, this analysis only evaluated the 8 mile final portion. This scenario resulted in a collision risk of 1.26E-9 despite using a tailored localizer course for 28C. Further analysis is required to assess the collision risk associated with the turn onto the final approach course.

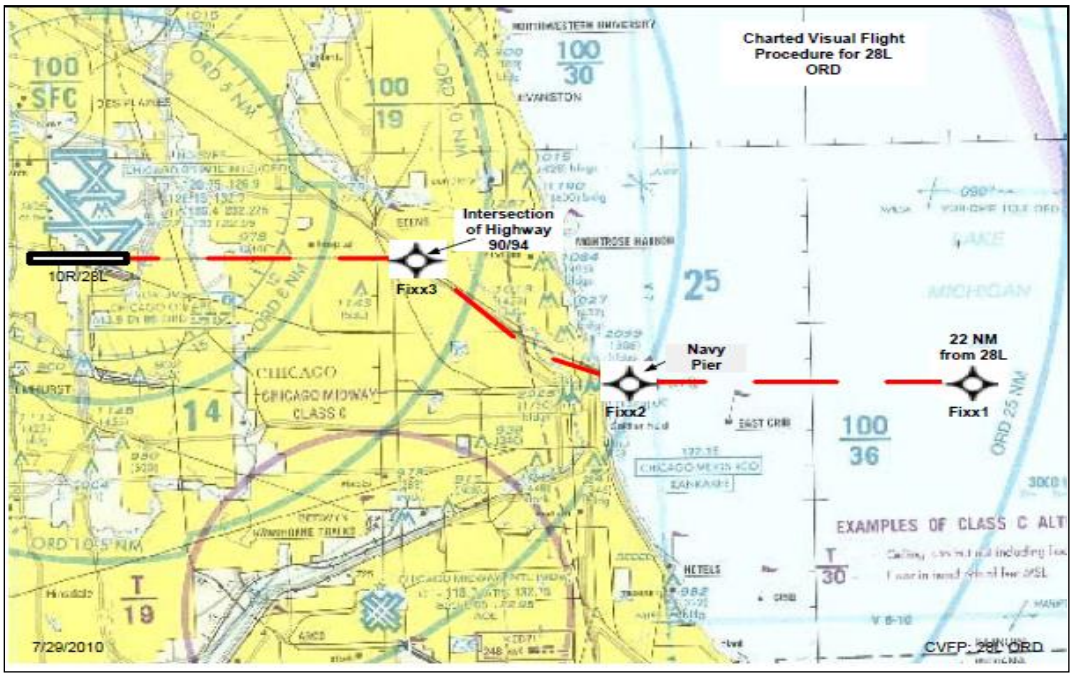

Figure 6. Proposed RNP overlay of the CVA to 28L

6.3 Triple SIPIA

When considering the inboard runways (9R/27L and 10L /28R) as departure runways, triple SIPIA can be operated using current restrictions as outlined in the OMP and EIS and as specified in paragraph 6.1 using the following configurations:

1. 28C, 27C, and 27R
2. 28L, 27C, and 27R
3. 10C, 9C, and 9L
4. 10R, 9C, and 9L

Triple SIPIA using 28L, 28C, and 27C or 10L, 10C, and 9C is not suggested by the OMP. However, triple approaches to these runways may be conducted with either HUR surveillance or a 2.5° to 3.0° offset to 28L/10R.

Breakouts become increasingly difficult to manage during triple SIPIA. Subject controllers at C90 stated that the typical breakout procedure for the middle runway is to continue straight ahead and climb or descend as directed to ensure separation. The close proximity of runways 10R/28L and 10C/28C necessitate a turn as well as vertical de-confliction. Any breakout considerations will require coordination between adjacent monitor controllers.

6.4 Quadruple SIPIA

ORD and C90 requested analysis of quadruple SIPIA, specifically for west flow traffic. East flow traffic corresponding to the options discussed below were also considered and can be operated with similar risk factors. Quadruple SIPIA can be operated using current restrictions as outlined in the OMP and EIS.

6.4.1 Runway 28L, 28R, 27C, and 27R

This configuration will achieve an overall acceptable level of risk of 1.38E-10 for the operation.

The following scenarios were considered while evaluating quadruple approaches to the above runway configuration (refer to Table 1 for a detailed comparison of runway pair scenarios):

1. **28R blunder left into 28L.** Runways 28L and 28R are separated by 4,300 feet. The resulting risk was acceptable for the operation at 1.02E-10.

2. **28R blunder right into 27C.** Runways 27C and 27R are separated by 5,293 feet, while 27C and 28R are separated by 7,023 feet. An aircraft on 28L was considered a non-blundering aircraft. The resulting risk was acceptable for the operation at 1.23E-10.

3. **27C blunder right into 27R.** Runways 27C and 27R are separated by 5,293 feet. The resulting risk was acceptable for the operation at 2.27E-10.

4. **28L blunder right into 28R.** Runways 28L and 28R are separated by 4,300 feet. The resulting risk was acceptable for the operation at 1.02E-10.

5. **27C blunder left into 28R.** Runways 27R and 27C are separated by 5,293 feet, while runways 27C and 28R are separated by 7,023 feet. The resulting risk was acceptable for the operation at 1.23E-11.

6. **27R blunder left into 27C.** Based on the above discussion, this scenario would be viewed as the northern dual pair runway. The resulting risk was acceptable for the operation at 2.27E-11.

6.4.2 Runway 28L, 28C, 27C, and 27R

Quadruple SIPIA using 10R/28L and 10C/28C relies on using either a 2.5° offset approach to 10R/28L or HUR surveillance as discussed in 6.2.

The scenarios discussed in paragraph 6.4.1 apply to this configuration with the exception of the following runway pairs:

1. **28C blunder left into 28L.** As stated above this operation meets the acceptable level of risk for dual simultaneous independent instrument approach operations to RW 28C and 28L.

2. **28C blunder right into 27C.** Runways 27C and 28C are separated by 8,223 feet. The RCL distance between 28C and 27C is 1,200 feet greater than the RCL distance for the 27C and 28R pair discussed paragraph 6.4.1. The increased distance decreases the collision risk associated with potential secondary interaction discussed in 6.4.3 involving the northern runway pair.

3. **27C blunder left into 28C.** Same as in 2 above.

4. **28L blunder right into 28R.** As stated above this operation meets the acceptable level of risk for dual simultaneous independent instrument approach operations to RW 28C and 28L.

The following table describes quadruple approach data for various runway pairs at ORD. Scenarios for level and descending 20° and 30° blunders were analyzed for the following runway pairs.

Table 1. Quadruple Approach Analysis

Scenario #1	Blunder Angle (°)	Level Blunders	Descending Blunders	P(TCV)
27R Blunder Left - 27C Evade	20	227	419	27R – 27C Pair: 2.27E-10
	30	5524	7331	
27C Blunder Right - 27R Evade	20	1626	1027	
	30	17749	8816	
Scenario #2	**Blunder Angle (°)**	**Level Blunders**	**Descending Blunders**	**P(TCV)**
27R Blunder Left - 28R Evade	20	0	5	27R – 28R Pair: 1.32E-12
	30	0	154	
28R Blunder Right - 27R Evade	20	0	16	
	30	0	71	
Scenario #3	**Blunder Angle (°)**	**Level Blunders**	**Descending Blunders**	**P(TCV)**
27C Blunder Left - 28R Evade	20	3	8	27C – 28R Pair: 1.23E-11
	30	757	855	
28R Blunder Right - 27C Evade	20	6	3	
	30	614	255	
Scenario #4	**Blunder Angle (°)**	**Level Blunders**	**Descending Blunders**	**P(TCV)**
27C Blunder Left -	20	0	0	27C – 28L Pair:

28L Evade	30	0	32	2.69E-12
28L Blunder Right - 27C Evade	20	0	1	
	30	92	427	
Scenario #5	**Blunder Angle (°)**	**Level Blunders**	**Descending Blunders**	**P(TCV)**
28R Blunder Left - 28L Evade	20	1819	441	27C – 28L Pair: 1.02E-10
	30	12298	3686	
28L Blunder Right - 28R Evade	20	0	10	
	30	2	39	
Overall Quad Operation	**Blunder Angle (°)**	**Level Blunders**	**Descending Blunders**	**P(TCV) Total**
	20	3681	1930	1.38E-10
	30	37036	21666	

6.4.3 Secondary Interactions

In December, 2005, AFS-400 published DOT-FAA-AFS-440-16, *Safety Study Report on Triple Simultaneous Parallel ILS Approaches and RNAV/RNP Approaches at* KIAH. This report examined all combinations of ILS and RNP/RNAV aircraft (RNP levels 0.1, 0.2 and 0.3 NM) performing simultaneous approach operations at George Bush Intercontinental Airport (KIAH). [8] During triple SIPIA operations, secondary interactions caused by an evading aircraft due to a blunder situation should be closely observed and coordinated by the controller monitoring the operation.

Numerous breakout scenarios were included during the quadruple approach DCE at OKC in order to observe the interactions between the controllers monitoring the northern and southern dual runway pairs. When considering quadruple SIPIA approaches to runways 28L, 28R, 27C, and 27R or to runways 28L, 28C, 27C, and 27R, the C90 controllers' suggested breakout solution for quadruple SIPIA is for the interior approach aircraft either to continue straight ahead and climb or descend, or to initiate a turn away from the blunder and climb, then turn back to a 270° heading. East flow breakouts would normally follow the same guidance as west flow traffic. The key element to any successful breakout scenario is early detection and close coordination between the northern and southern dual runway pair monitor controller teams.

6.4.4 Controller Training Considerations

Training implications exist from a controller standpoint with regard to the use of the STARS/FMA display with a 4:1 AR as well as controller phraseology during breakouts. Thus, the type, duration and repetition of training should be investigated. Increased or modified training may not be sufficient to resolve any problems associated with this procedure since the underlying issue of habitual actions formed during normal day to day operations is still prevalent.

7.0 RECOMMENDATIONS

It is recommended that the following simultaneous independent instrument operations be authorized for the ORD final runway configuration as described below:

1. Dual approaches to:

    a. 10R/28L and 10C/28C using either of the following:
        i. 1.0 second update rate surveillance
        ii. 2.5° offset to 10R/28L

2. Quadruple approaches to:
    a. 09L/27R, 09C/27C, 10C/28C, and 10L/28R
    b. 09L/27R, 09C/27C, 10C/28C, and 10R/28L using either of the following:
        i. 1.0 second update rate surveillance
        ii. 2.5° offset to 10R/28L

3. All breakout considerations and subsequent policy guidance require close coordination between ORD and C90.

Note: If it is desired that a collision risk analysis be conducted of the RNP overlay of the CVA as described in 6.2.4, the RNP overlay procedure for the CVA must be designed and approved.

REFERENCES

[1] "O'Hare Modernization Plan (OMP) Concept Development/Refinement," Ricondo & Associates, Inc., February 2003

[2] "O'Hare Modernization Environmental Impact Statement (EIS)" Appendix D, City of Chicago's Consultant Team (CCT) and FAA, July 2005

[3] DOT-FAA-AFS-450-69, Technical Report, Simultaneous Independent Close Parallel Approaches – High Update Radar Not Required, September 2011

[4] DOT-FAA-AFS-450-84, Technical Report, Separation Requirements for Simultaneous Offset Independent Dual Instrument Approaches - High Update Rate Surveillance Not Required, July 2013

[5] "Chicago TRACON Operating Procedures Order C90 7110.65D" DOT/FAA, November 20, 2008

[6] U.S. Department of Transportation/Federal Aviation Agency/Air Traffic Organization Policy FAAO JO 7110.65U CHG 1, Air Traffic Control, Feb. 2012

[7] Fuchs, Alan E., *Chicago O'Hare International Airport Simulation Safety Study of Proposed Runways 28L (2.5° Offset Approach) and 28C*, DOT-RITA-RVT-72-12-08-1.0, John A. Volpe National Transportation Systems Center, Cambridge, MA, September 2012

APPENDIX A: STATISTICAL ANALYSIS TOOLS

One important purpose of the simulation was to collect Controller Response Time (CRT) data that can be used to develop CRT probability density functions (pdfs). The pdfs can be used in a fast-time, Monte Carlo simulation to determine the probability of a collision due to a blunder during closely spaced parallel approach operations. The probability of a collision can be compared to a standard probability or risk, i.e., a target level of safety, to determine the acceptability of the operation. A mathematical algorithm is used to determine a pdf of best fit to the data in question such as CRT. Confidence in the suitability of the derived pdf increases with increased numbers of observations in the data set. In this simulation, data such as CRTs were collected using controllers with varied experience. For data analysis purposes only, controllers who had never worked as a monitor controller during SIPIA operations are depicted as *unqualified* controllers in the tables contained in Appendices B through E. To build an adequate data set, the analyst must determine whether the response times, based on controller qualifications, can be pooled into one data set.

Statistical tests have been devised to enable the analyst to decide whether two or more independent samples should be regarded as having come from the same population. Values from different independent samples almost always differ somewhat in means, variance, and other measures that describe properties of the data. The objective is to determine whether the observed sample differences signify differences among populations or whether they are merely the chance variations that are to be expected among random samples from the same population.

One of the most powerful and flexible statistical tests of differences in means of independent sample sets is analysis of variance (ANOVA). ANOVA is a parametric test since it is based on certain assumptions about the data. ANOVA assumes that the data were generated from normal distributions, but having the same variance. These conditions are not often completely met in practical applications and it will be shown that the curves that best fit the data sets are bounded and obviously not from a normal distribution. Statisticians have conducted many studies to ascertain the effects of violations of the assumptions. In most cases, violations of the assumptions, even fairly extreme ones, do not severely affect the outcome of the analysis of variance. ANOVA is easily performed using any statistical software package such as Statistical Package for the Social Studies (SPSS). Data sets can have similar means, but obviously have different spreads or dispersions. Levene's test (Snedecor, George W; Cochran, William G; 1989; *Statistical Methods*, Blackwell Publishing; Ames, Iowa.), a test of homogeneity of variance, is conducted concurrently with ANOVA. Levene's test is useful since it provides another measure of whether the data sets are similar enough to be pooled into one set.

Statistical tests are used to decide whether a hypothesis concerning the data should be rejected. ANOVA tests whether the hypothesis that the means of the various data sets are equal should be rejected. Levene's test is used to decide whether the hypothesis that the variances or standard deviations of the various data sets are equal should be rejected. Each test produces a test statistic and the probability that a test statistic of that size will occur, given the hypothesis the means are equal or the variances are equal.

If we reject a hypothesis when it should be accepted, we say that a Type I error has been made. If we accept a hypothesis when it should be rejected, we say that a Type II error has been made. The only way to reduce both types of error is to increase the sample size.

In testing a given hypothesis, the maximum probability with which we would be willing to risk a Type I error is called the level of significance of the test. This probability is generally specified before any samples are drawn, so that the results obtained will not influence our decision whether to reject the hypothesis.

In practice, a level of significance of .05 or .01 is customary. The level of significance in this analysis was chosen to be .05. This means that there are about five chances in 100 that we would reject the hypothesis (Type I error) when it should be accepted, i.e., we are about 95% confident that we have made the correct decision. In such case we say that the hypothesis has been rejected at a .05 level of significance, which means that we could be wrong with probability .05. The Type II error is more difficult to determine.

APPENDIX B: ANALYSIS OF NOVEMBER 2011 C90 DATA

We examined the caution to communication start (Cautiontocommstart) data for outliers. Since we assumed that negative values of Cautiontocommstart are unlikely during actual operations, we deleted negative values from the Cautiontocommstart data.

Two factors were tested during the November 2011 C90 HITL, blunder angle and aspect ratio. Two-way ANOVA was used to examine the effect of blunder angle and aspect ratio on Cautiontocommstart data.

Tables B1 and B2 contain the results of the ANOVA applied to the Cautiontocommstart data. The significance value in Table B1, labeled "sig." is larger than 0.05, which indicates that there is no significant difference between the variances. The significance value in the row labeled "aspect ratio" of Table B2 is larger than 0.05, which indicates that no significant difference is detected due to aspect ratio. The significance value in the row labeled "Angle" is larger than 0.05, which indicates that no significant difference is detected due to blunder angle. The significance value in the row labeled "aspectratio * Angle" is larger than 0.05, which indicates that there is no significant interaction between the factors aspectratio and Angle. Therefore, the Cautiontocommstart data were combined into one set.

Table B1: Levene's Test of Equality of Error Variances of Caution to Comm Start by Aspect Ratio and Blunder Angle

Levene's Test of Equality of Error Variances[a]

Dependent Variable:Cautiontocommstart

F	df1	df2	Sig.
1.736	7	161	.104

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + aspectratio + Angle + aspectratio * Angle

Table B2: Two-Way ANOVA of Caution to Comm Start by Aspect Ratio and Blunder Angle.

Two-Way ANOVA of Caution to Comm Start by Aspect Ratio and Blunder Angle

Dependent Variable:Cautiontocommstart

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	73.369[a]	7	10.481	.823	.570
Intercept	7703.073	1	7703.073	604.688	.000
aspectratio	33.673	1	33.673	2.643	.106
Angle	34.641	3	11.547	.906	.439
aspectratio * Angle	3.401	3	1.134	.089	.966
Error	2050.967	161	12.739		
Total	9949.780	169			
Corrected Total	2124.336	168			

a. R Squared = .035 (Adjusted R Squared = -.007)

APPENDIX C: ANALYSIS OF MAY 2012 ORD 2.5° OFFSET DATA

In the offset analysis, we do not see any significant differences in either means or dispersion. This is true regardless of blunder angle, controller seat, or runway. The following tables indicate that there are no significant differences in means or variance by runway, blunder angle, controller qualifications.

Table C1: Descriptive Statistics of Cautiontocommstart Offset Rt. 20° Blunder.

Descriptives: Offset Rt Controller, Left Bldr Rwy, 20°, 1 = Qualified, 2 = Unqualified

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Caution to Comm Start	1	16	5.250	3.2995	.8249	3.492	7.008	-1.0	12.7
	2	8	6.875	2.9237	1.0337	4.431	9.319	2.4	10.9
	Total	24	5.792	3.2115	.6555	4.436	7.148	-1.0	12.7

Table C2: Test of Homogeneity of Variances: Offset Rt. 20° Blunder by Qualification.

Test of Homogeneity of Variances: Offset Rt Controller, Left Bldr Rwy, 20°

	Levene Statistic	df1	df2	Sig.
Caution to Comm Start	.052	1	22	.821

Table C3: ANOVA: Offset, Rt. 20° Blunder by Qualification.

ANOVA: Offset Rt Controller, Left Bldr Rwy, 20°

		Sum of Squares	df	Mean Square	F	Sig.
Caution to Comm Start	Between Groups	14.083	1	14.083	1.389	.251
	Within Groups	223.135	22	10.143		
	Total	237.218	23			

Table C4: Descriptive Statistics of Cautiontocommstart Offset Rt. 30° Blunder.

Descriptives: Rt Controller, Left Bldr Rwy, 30°, 1 = Qualified, 2 = Unqualified

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Caution to Comm Start	1	15	5.573	2.8065	.7246	4.019	7.128	.7	9.9
	2	9	6.811	3.3517	1.1172	4.235	9.387	2.4	13.8
	Total	24	6.038	3.0127	.6150	4.765	7.310	.7	13.8

Table C5: Test of Homogeneity of Variances: Offset Rt. 30° Blunder by Qualification.

Test of Homogeneity of Variances: Offset Rt Controller, Left Bldr Rwy, 30°

	Levene Statistic	df1	df2	Sig.
Caution to Comm Start	.060	1	22	.808

Table C6: ANOVA: Offset, Rt. 30° Blunder by Qualification.

ANOVA: Offset Rt Controller, Left Bldr Rwy, 30°

		Sum of Squares	df	Mean Square	F	Sig.
Caution to Comm Start	Between Groups	8.618	1	8.618	.947	.341
	Within Groups	200.138	22	9.097		
	Total	208.756	23			

Table C7: Descriptive Statistics of Cautiontocommstart Offset Left 20° Blunder.

Descriptives: Offset Left Controller, Rt Bldr Rwy, 20°, 1 = Qualified, 2 = Unqualified

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Caution to Comm Start	1	14	5.457	5.4740	1.4630	2.297	8.618	-3.4	13.6
	2	11	4.036	4.5566	1.3739	.975	7.098	-5.6	11.6
	Total	25	4.832	5.0398	1.0080	2.752	6.912	-5.6	13.6

Table C8: Test of Homogeneity of Variances: Offset Left. 20° Blunder by Qualification.

Test of Homogeneity of Variances: Offset Left Controller, Rt Bldr Rwy, 20°

	Levene Statistic	df1	df2	Sig.
Caution to Comm Start	.911	1	23	.350

Table C9: ANOVA: Offset, Left 20° Blunder by Qualification.

ANOVA: Offset Left Controller, Rt Bldr Rwy, 20°

		Sum of Squares	df	Mean Square	F	Sig.
Caution to Comm Start	Between Groups	12.435	1	12.435	.479	.496
	Within Groups	597.160	23	25.963		
	Total	609.594	24			

Table C10: Descriptive Statistics of Cautiontocommstart Offset Left 30° Blunder.

Descriptives: Offset Left Controller, Rt Bldr Rwy, 30°, 1 = Qualified, 2 = Unqualified

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Caution to Comm Start	1	11	3.373	4.5449	1.3703	.319	6.426	-4.1	13.6
	2	13	6.323	6.7272	1.8658	2.258	10.388	-3.1	20.4
	Total	24	4.971	5.9032	1.2050	2.478	7.464	-4.1	20.4

Table C11: Test of Homogeneity of Variances: Offset Left 30° Blunder by Qualification.

Test of Homogeneity of Variances: Offset Left Controller, Rt Bldr Rwy, 30°

	Levene Statistic	df1	df2	Sig.
Caution to Comm Start	1.407	1	22	.248

Table C12: ANOVA: Offset, Left 30° Blunder by Qualification.

ANOVA: Offset Left Controller, Rt Bldr Rwy, 30°

		Sum of Squares	df	Mean Square	F	Sig.
Caution to Comm Start	Between Groups	51.865	1	51.865	1.522	.230
	Within Groups	749.625	22	34.074		
	Total	801.490	23			

The offset ILS localizer results in increasing separation distance of the two approaches with increasing distance from the runway threshold. It was thought that the increasing distance could have an effect on the controller response times. However, tests showed that there is practically no correlation of controller time to the increasing distance. The following table gives an indication of the linearity of the data for Caution to Comm Start versus Caution to Comm Start Distance. The table entry labeled R square is a measure of how well the data fits a straight line. A value near 1.0 indicates a very good fit. A value near 0.0 indicates a poor or no fit. In this case there is no fit. This result simplifies the development of a pdf for the Offset Data.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.089[a]	.008	-.002	4.4153

APPENDIX D: ANALYSIS OF MAY 2012 ORD HUR DATA

The following three tables describe data for a 20° blunder from the left runway with a right controller for the evading aircraft. There is no significant difference in either mean times or dispersion.

Table D1: Descriptive Statistics of Cautiontocommstart HUR Left 20° Blunder.

Descriptives: HUR Left Bldr, Rt Controller, 20° Bldr, 1 = Qualified, 2 = Unqualified

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Caution to Comm Start	1	9	3.922	1.9835	.6612	2.398	5.447	.8	6.9
	2	9	5.011	3.9804	1.3268	1.952	8.071	2.0	15.2
	Total	18	4.467	3.1018	.7311	2.924	6.009	.8	15.2

Table D2: Test of Homogeneity of Variances: HUR Left 20° Blunder by Qualification.

Homogeneity of Variance: HUR Rt Controller, Left Bldr Rwy, 20°

	Levene Statistic	df1	df2	Sig.
Caution to Comm Start	.764	1	16	.395

Table D3: ANOVA: HUR, Left 20° Blunder by Qualification.

ANOVA: HUR Rt Controller, Left Bldr Rwy, 20°

		Sum of Squares	df	Mean Square	F	Sig.
Caution to Comm Start	Between Groups	5.336	1	5.336	.540	.473
	Within Groups	158.224	16	9.889		
	Total	163.560	17			

The following three tables describe data for a 30° blunder from the left runway with a right controller for the evading aircraft. There is no significant difference in either mean times or dispersion.

Table D4: Descriptive Statistics of Cautiontocommstart HUR Left 30° Blunder.

Descriptives: HUR Rt Controller, Left Bldr Rwy, 30° Bldr, 1 = Qualified, 2 = Unqualified

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Caution to Comm Start	1	13	5.946	3.3135	.9190	3.944	7.948	1.3	14.1
	2	15	3.973	1.8851	.4867	2.929	5.017	1.3	7.9
	Total	28	4.889	2.7796	.5253	3.811	5.967	1.3	14.1

Table D5: Test of Homogeneity of Variances: HUR Left 30° Blunder by Qualification.

Test of Homogeneity of Variances: HUR Rt Controller, Left Bldr Rwy, 30°

	Levene Statistic	df1	df2	Sig.
Caution to Comm Start	1.479	1	26	.235

Table D6: ANOVA: HUR, Left 30° Blunder by Qualification.

ANOVA: HUR Rt Controller, Left Bldr Rwy, 30°

		Sum of Squares	df	Mean Square	F	Sig.
Caution to Comm Start	Between Groups	27.105	1	27.105	3.883	.060
	Within Groups	181.502	26	6.981		
	Total	208.607	27			

The following three tables describe data for a 20° blunder from the right runway with a left controller for the evading aircraft. There is no significant difference in means or dispersion.

Table D7: Descriptive Statistics of Cautiontocommstart HUR Right 20° Blunder.

Descriptives: HUR Left Controller, Rt Bldr Rwy, 20°, 1 = Qualified, 2 = Unqualified

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Caution to Comm Start	1	19	5.189	3.4771	.7977	3.514	6.865	-1.8	12.8
	2	12	6.367	4.2167	1.2173	3.687	9.046	2.2	15.6
	Total	31	5.645	3.7568	.6747	4.267	7.023	-1.8	15.6

Table D8: Test of Homogeneity of Variances: HUR Right 20° Blunder by Qualification.

Test of Homogeneity of Variances: HUR Left Controller, Rt Bldr Rwy, 20°

	Levene Statistic	df1	df2	Sig.
Caution to Comm Start	.315	1	29	.579

Table D9: ANOVA: HUR, Right 20° Blunder by Qualification.

ANOVA: HUR Left Controller, Rt Bldr Rwy, 20°

		Sum of Squares	df	Mean Square	F	Sig.
Caution to Comm Start	Between Groups	10.192	1	10.192	.715	.405
	Within Groups	413.205	29	14.248		
	Total	423.397	30			

The following three tables describe data for a 30° blunder from the right runway with a left controller for the evading aircraft. There is no significant difference in means or dispersion.

Table D10: Descriptive Statistics of Cautiontocommstart HUR Right 30° Blunder.

Descriptives: HUR Left Controller, Rt Bldr Rwy, 30°, 1 = Qualified, 2 = Unqualified

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Caution to Comm Start	1	8	3.863	1.6928	.5985	2.447	5.278	1.8	5.9
	2	13	5.677	5.3014	1.4704	2.473	8.881	.6	21.7
	Total	21	4.986	4.3222	.9432	3.018	6.953	.6	21.7

Table D11: Test of Homogeneity of Variances: HUR Right 30° Blunder by Qualification.

Test of Homogeneity of Variances: HUR Left Controller, Rt Bldr Rwy, 30°

	Levene Statistic	df1	df2	Sig.
Caution to Comm Start	1.653	1	19	.214

Table D12: ANOVA: HUR, Right 30° Blunder by Qualification.

ANOVA: HUR Left Controller, Rt Bldr Rwy, 30°

		Sum of Squares	df	Mean Square	F	Sig.
Caution to Comm Start	Between Groups	16.304	1	16.304	.867	.363
	Within Groups	357.322	19	18.806		
	Total	373.626	20			

APPENDIX E: ANALYSIS OF MAY 2012 ORD QUADS DATA

The number of Quad approaches was small with only 48 runs to runways 27R, 27C, 28C and 28L. There were no blunders from 27C. All blunders from 27R were to the left; all blunders from 28L were to the right; and all blunders from 28C were to the left.

All controllers working the left seat, 28L, were qualified. Therefore there were no comparisons of controller times for blunders starting from 28C because they were previously analyzed in the dual runway analysis (Appendix D).

The following tables describe the results of blunders from runway 28L toward 28C. There were only 12 runs with 3 worked by unqualified controllers.

Table E1: Descriptive Statistics of Cautiontocommstart Quads, Left RWY, 20° Right Blunder.

Descriptives: Quads, Left Bldr Rwy, Left Center Controller, 20°

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Caution to Comm Start	1	9	8.711	6.0410	2.0137	4.068	13.355	3.7	23.2
	2	2	8.900	2.5456	1.8000	-13.971	31.771	7.1	10.7
	Total	11	8.745	5.4634	1.6473	5.075	12.416	3.7	23.2

Table E2: Test of Homogeneity of Variances: Quads, Left RWY, 20° Right Blunder by Qualification.

Test of Homogeneity of Variances: Quads, Left Blunder Rwy, Left Center Controller, 20°

	Levene Statistic	df1	df2	Sig.
Caution to Comm Start	.692	1	9	.427

Table E3: ANOVA: Left RWY, 20° Right Blunder by Qualification.

ANOVA: Quads, Left Bldr Rwy, Left Center Controller, 20°

		Sum of Squares	df	Mean Square	F	Sig.
Caution to Comm Start	Between Groups	.058	1	.058	.002	.967
	Within Groups	298.429	9	33.159		
	Total	298.487	10			

The results for Left Blunder Runway, Left Center Controller, 30° are similar. There were only seven blunders worked by qualified controllers and three blunders worked by unqualified controllers.

The results for right blunder runway, left center controller, 20 and 30° are similar. There were only three blunders worked by qualified controllers and five blunders worked by unqualified controllers.

APPENDIX F: COMPARISON OF APPROACH TYPES BY BLUNDER ANGLE

In this study, we compared the Cautiontocommstart data of the four data sets, C90, HUR, Offset, and Quads by blunder angle. It has been established that controller qualification and aspect ratio did not produce significant differences. The next three tables are the results of a two-way ANOVA. Numerals are used to denote the four data sets: 1=HUR, 2= Offset, 3=Quads, and 4=C90. The first table contains descriptive statistics of the four data sets. The second table indicates that there is no significant difference in the variances of the four data sets. The third table indicates that there is not a significant difference due to blunder angle, but it indicates that there is a significant difference in means. Therefore, the four data sets cannot be combined into one set.

Table F1: Descriptive Statistics of Cautiontocommstart of Four Approach Types by Blunder Angle

Descriptive Statistics

Dependent Variable:Caution to Comm Start

approach type	absolute Bl Ang	Mean	Std. Deviation	N
1	20	5.358333	3.4288410	48
	-- 30	4.930612	3.4831262	49
	Total	5.142268	3.4450398	97
2	20	5.770833	3.5641810	48
	-- 30	5.902041	4.2203618	49
	Total	5.837113	3.8896583	97
3	20	6.123810	5.0770961	21
	-- 30	4.877778	1.8093078	18
	Total	5.548718	3.9277603	39
4	20	6.510112	3.4518455	89
	-- 30	7.132500	3.6621145	80
	Total	6.804734	3.5559610	169
Total	20	6.030097	3.6687829	206
	-- 30	6.067347	3.7439257	196
	Total	6.048259	3.7010290	402

Table F2: Test of Homogeneity of Variances of Four Approach Types by Blunder Angle

Levene's Test of Equality of Error Variances[a]

Dependent Variable:Caution to Comm Start

F	df1	df2	Sig.
1.259	7	394	.270

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + numname + absBlAng + numname * absBlAng

Table F3: Two-Way ANOVA of Four Approach Types by Blunder Angle

Tests of Between-Subjects Effects

Dependent Variable:Caution to Comm Start

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	226.608[a]	7	32.373	2.422	.019
Intercept	10373.390	1	10373.390	776.113	.000
numname	195.902	3	65.301	4.886	.002
absBlAng	4.044	1	4.044	.303	.583
numname * absBlAng	35.739	3	11.913	.891	.446
Error	5266.135	394	13.366		
Total	20198.480	402			
Corrected Total	5492.744	401			

a. R Squared = .041 (Adjusted R Squared = .024)

We examined the descriptive statistics, Table F1, and noted that the mean of the C90 data appeared to be the largest. In the following three tables, the C90 data set was omitted from the two-way ANOVA. This resulted in no significant difference in variances or means. Therefore, these data sets can be combined into one set. We can compute a pdf for the combined data set for use in a high-speed simulation.

Table F4: Descriptive Statistics of Cautiontocommstart of Three Approach Types by Blunder Angle

Descriptive Statistics

Dependent Variable:Caution to Comm Start

approach type	Bl Ang.	Mean	Std. Deviation	N
1	20	5.358333	3.4288410	48
	−30	4.930612	3.4831262	49
	Total	5.142268	3.4450398	97
2	20	5.770833	3.5641810	48
	−30	5.902041	4.2203618	49
	Total	5.837113	3.8896583	97
3	20	6.123810	5.0770961	21
	−30	4.877778	1.8093078	18
	Total	5.548718	3.9277603	39
Total	20	5.664957	3.7995534	117
	−30	5.332759	3.6361417	116
	Total	5.499571	3.7148061	233

Table F5: Test of Homogeneity of Variances of Three Approach Types by Blunder Angle

Levene's Test of Equality of Error Variances[a]

Dependent Variable:Caution to Comm Start

F	df1	df2	Sig.
1.655	5	227	.146

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + numname + BlAng + numname * BlAng

Table F6: Two-Way ANOVA of Three Approach Types by Blunder Angle

Tests of Between-Subjects Effects

Dependent Variable:Caution to Comm Start

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	43.431[a]	5	8.686	.624	.681
Intercept	5852.635	1	5852.635	420.677	.000
numname	23.223	2	11.612	.835	.435
BlAng	12.816	1	12.816	.921	.338
numname * BlAng	13.522	2	6.761	.486	.616
Error	3158.119	227	13.912		
Total	10248.700	233			
Corrected Total	3201.550	232			

a. R Squared = .014 (Adjusted R Squared = -.008)

APPENDIX G: FITTING JOHNSON PROBABILITY DENSITY FUNCTIONS

After the data have been tested and appropriately combined, the next step was to fit probability curves to the data sets. We have more confidence in the accuracy of the curve fit to the data with increased data set sizes. That is why we combined similar data sets to form larger sets.

The Johnson family of probability curves was chosen for this purpose since there are Johnson curves that are unbounded, bounded, or bounded on one side. The Johnson family of empirical distributions is based on transformations of a standard normal variate. An advantage of such a transformation is that estimates of the percentiles of the fitted distribution can be obtained either from a table of areas under a standard normal distribution or from a computer program that computes areas under a standard normal distribution. Another advantage is that during a Monte Carlo simulation, variates from the distribution are readily computed from the standard normal distribution. The Johnson distributions are divided into three families as follows:

The S_L family is characterized by the transformation:

$$z = \gamma + \delta \ln\left(\frac{x-\varepsilon}{\lambda}\right),\ x > \varepsilon,$$

where x is the variable to be fitted by the Johnson distribution and z is a standard normal variate. Each curve in this family is bounded on the left by ε and is unbounded on the right.

The S_B family is characterized by the transformation:

$$z = \gamma + \delta \ln\left(\frac{x-\varepsilon}{\lambda+\varepsilon-x}\right),\ \varepsilon < x < \varepsilon + \lambda.$$

where x is the variable to be fitted by the Johnson distribution and z is a standard normal variate. Each curve in this family is bounded on the left by ε and on the right by ε + λ.

The S_U family is characterized by the transformation:

$$z = \gamma + \delta \sinh^{-1}\left(\frac{x-\varepsilon}{\lambda}\right),\ -\infty < x < \infty.$$

where x is the variable to be fitted by the Johnson distribution and z is a standard normal variate. Each curve in this family is unbounded and unimodal.

APPENDIX H: JOHNSON PROBABILITY DENSITY FUNCTION PARAMETERS

Johnson Type	S - U
Gamma	-0.4859474933E+00
Delta	0.1296215967E+01
Lambda	0.3531547350E+01
Xi	0.3236638238E+01

APPENDIX I: HUMAN FACTORS ANALYSIS

C90 Controller HITL (November 2011) and NAS-Wide Controller HITL (May 2012)

Test Methodology

Two Human in the Loop (HITL) Data Collection Efforts (DCEs) were conducted with the primary purpose of measuring Controller Response Times (CRT) in response to blunders on the 28C and 28L runway pair at ORD. The first DCE was conducted in November 2011 at the Chicago TRACON (C90) and a second was conducted in May 2012 at the Air Traffic Control Simulation Facility located within the Flight Operations Simulation Laboratory, AFS-440, in Oklahoma City (OKC). Subject controllers, who were required to be qualified and certified to control dual simultaneous independent ILS approaches, were used as Final Monitor Controllers. Subject controllers were required to monitor, correct minor course deviations and breakout the aircraft for major course deviations. They had the capability to override the Tower/Local controller and had an additional frequency that pilots were required to monitor to ensure those commands were received.

General

Several relevant issues surfaced during the course of this DCE. Among those were controller phraseology in the breakout instruction and the aspect ratio of the STARS/FMA. Each will be discussed further.

Controllers were instructed to, "Control as you do every day at your facility." After lengthy discussions during the post-simulation de-briefing, it seems the concept of blunders and directing an evasive maneuver is not consistent with day-to-day controller experience with planning and positioning aircraft. This appeared to influence the use of phraseology during instruction sequences. Most of the phraseology used was consistent with typical day-to-day traffic management rather than the specific breakout phraseology required by Air Traffic Orders for closely spaced operations. This put the subject controllers at a disadvantage due to their extremely limited exposure to these operations.

Only two of 50 controllers at C90 had experience with the STARS/FMA equipment or PRM controller displays (Figure 1), while seven of 36 controllers at OKC had experience with the STARS/FMA equipment or PRM controller displays (figure 2). All controllers received a short 5-10 minute presentation/briefing on the visual aspects of the system, what they could expect and the functions of the system that were available for them to modify in accordance with their own desires.

Controller reaction time might not be fully representative as they were not sufficiently versed in this visual representation. Vigilance requirements were appropriately higher as controllers had to modify their own culturally established levels of automaticity in detecting, strategizing and reacting to a blunder.

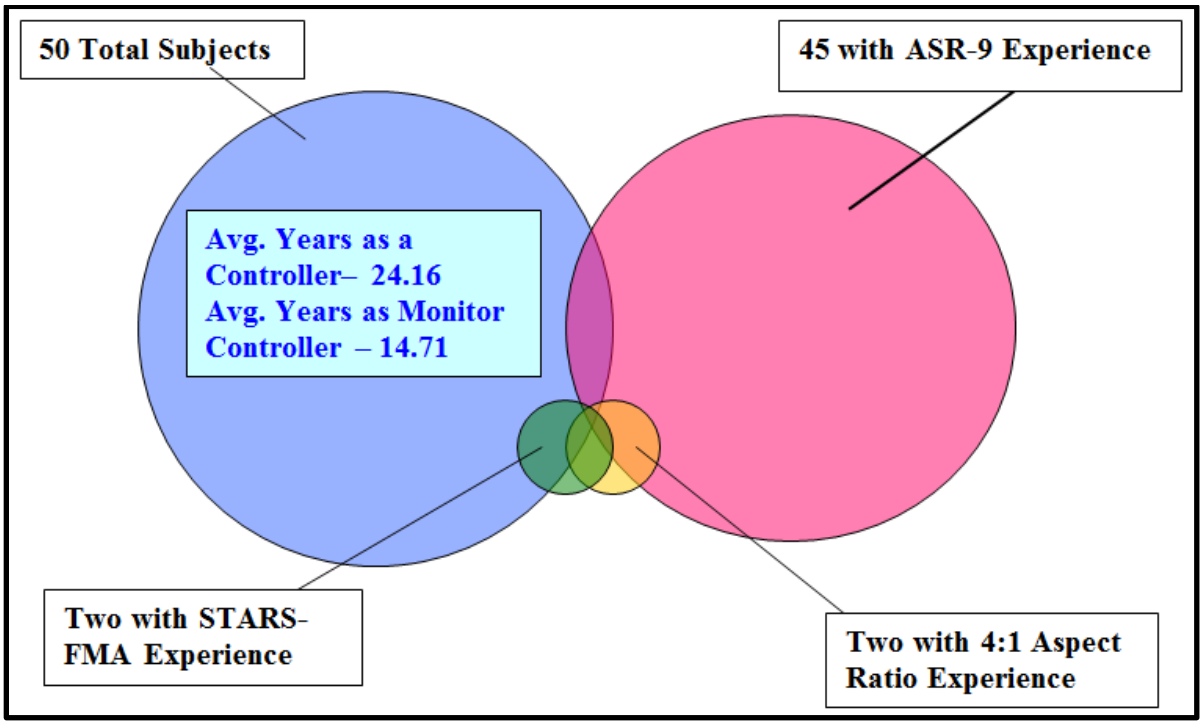

Figure 1. Chicago TRACON (C90) Controller HITL Demographics

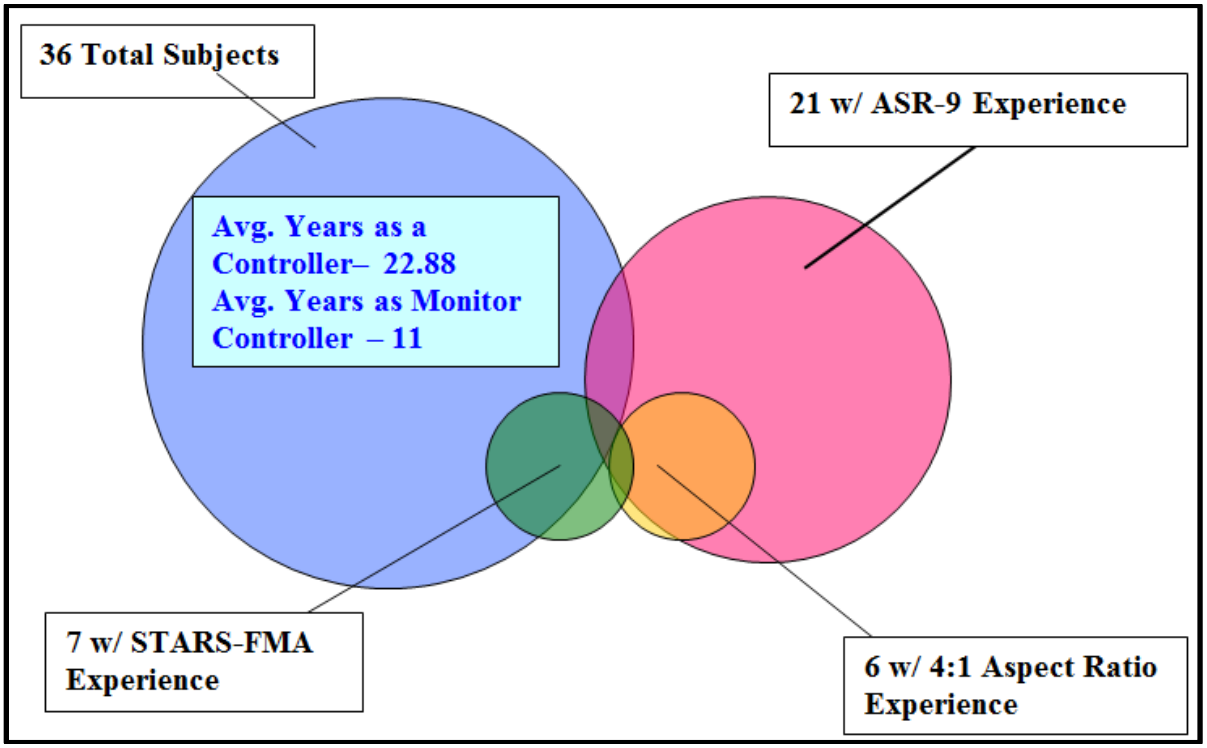

Figure 2. NAS-Wide Controller HITL Demographics (OKC) Subjective Controller Response Data

Subjective response data from each controller was elicited immediately following each final monitor session. Controller feedback was given for each of seven questions, designed to get controller response in the areas of perceived workload, comfort and difficulty, all as they compare to their normal controller duties (See Figure 3 (ASR-9), Figure 4 (HUR), Figure 5 (Offset), and Figure 6 (Quads). When queried following each HUR scenario, controllers felt slightly more comfortable, but indicated a slightly higher perception of collective workload. Responses for the Quad Approach Scenarios have been parsed out and are graphed separately from those of *all* the scenarios for this DCE. Both are represented in Figure 6. As the graphs indicate, with the exception of comfort with aircraft on the nominal path and comfort with a blunder, controller subjective feedback hovered close to the median value of 5. Controller responses in the Quad scenarios exceed the mean for all runs in all but one category; "Perceived Timeliness of the Breakout Instruction." Controllers are clearly less comfortable in Quad Approach Scenarios and their perception of both individual and collective workload is higher. Note that both of these indices represent testing conditions on both ends of the induced difficulty spectrum. Inherent with the closer proximities of aircraft is a decrease in comfort levels. In a later discussion, controllers pointed out that this is a result of having less reaction time to react to abnormal situations (e.g., blunder). Post evaluation de-briefing discussion also indicates that controllers felt that situational awareness and vigilance requirements increased commensurately with traffic on four-versus-two parallel runways.

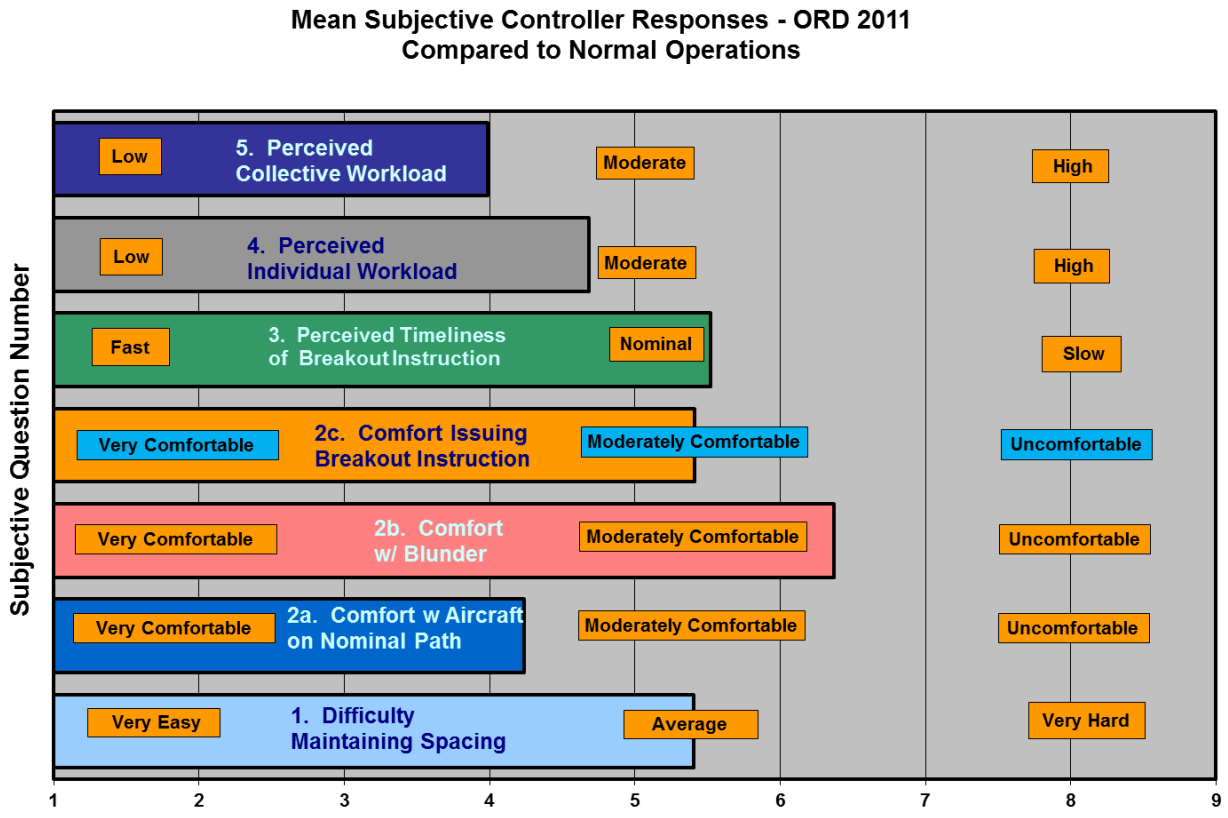

Figure 3. ASR-9 at C90

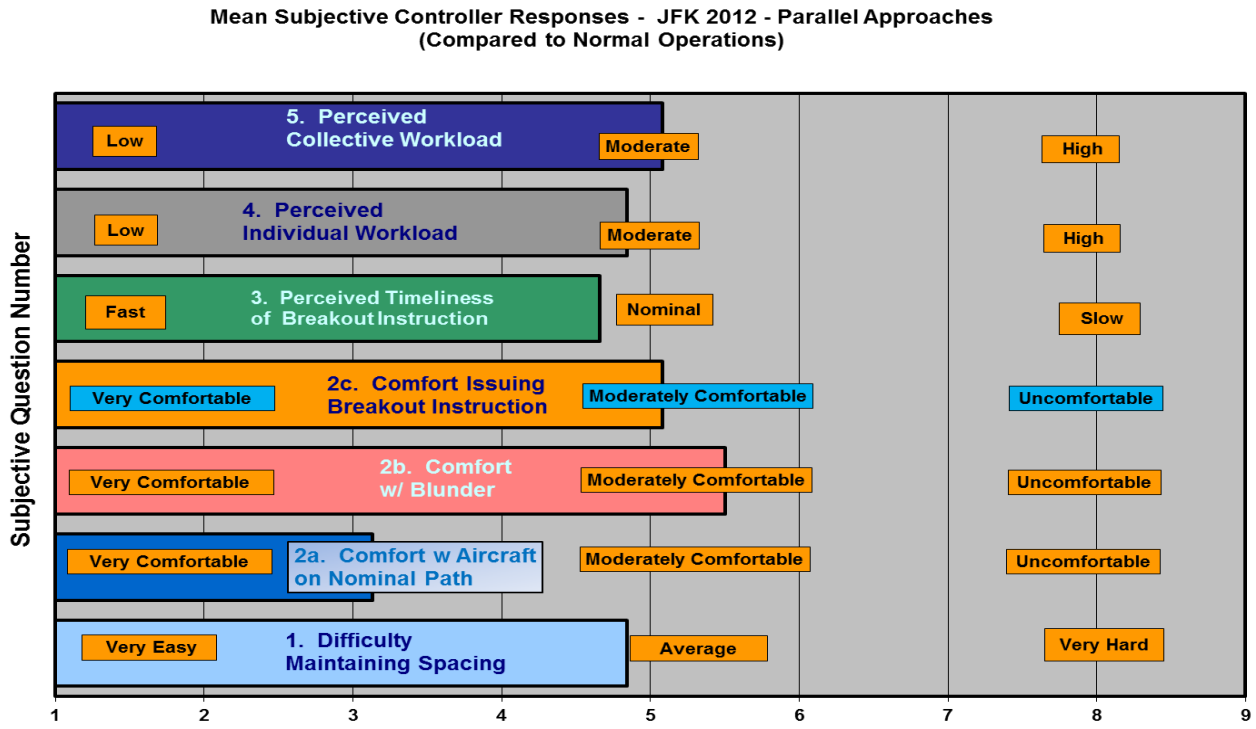

Figure 4. HUR Surveillance

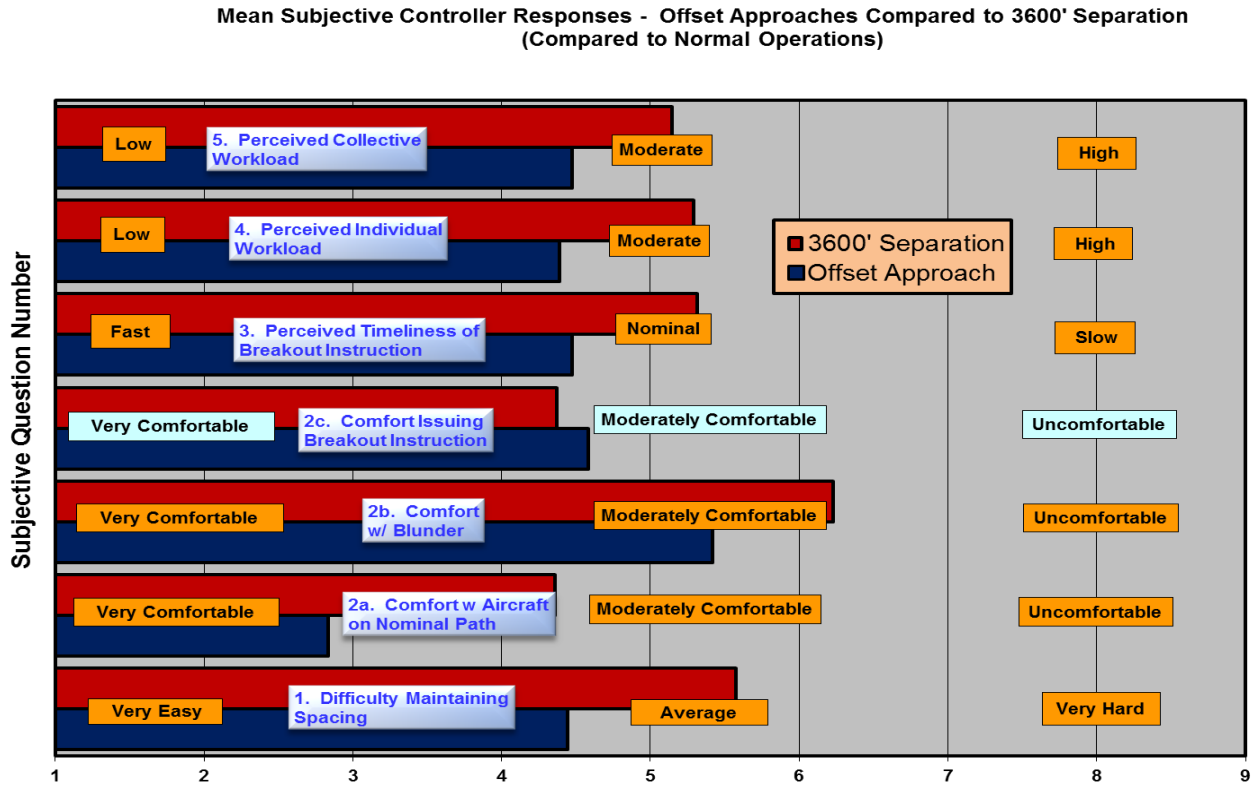

Figure 5. Offset Approaches

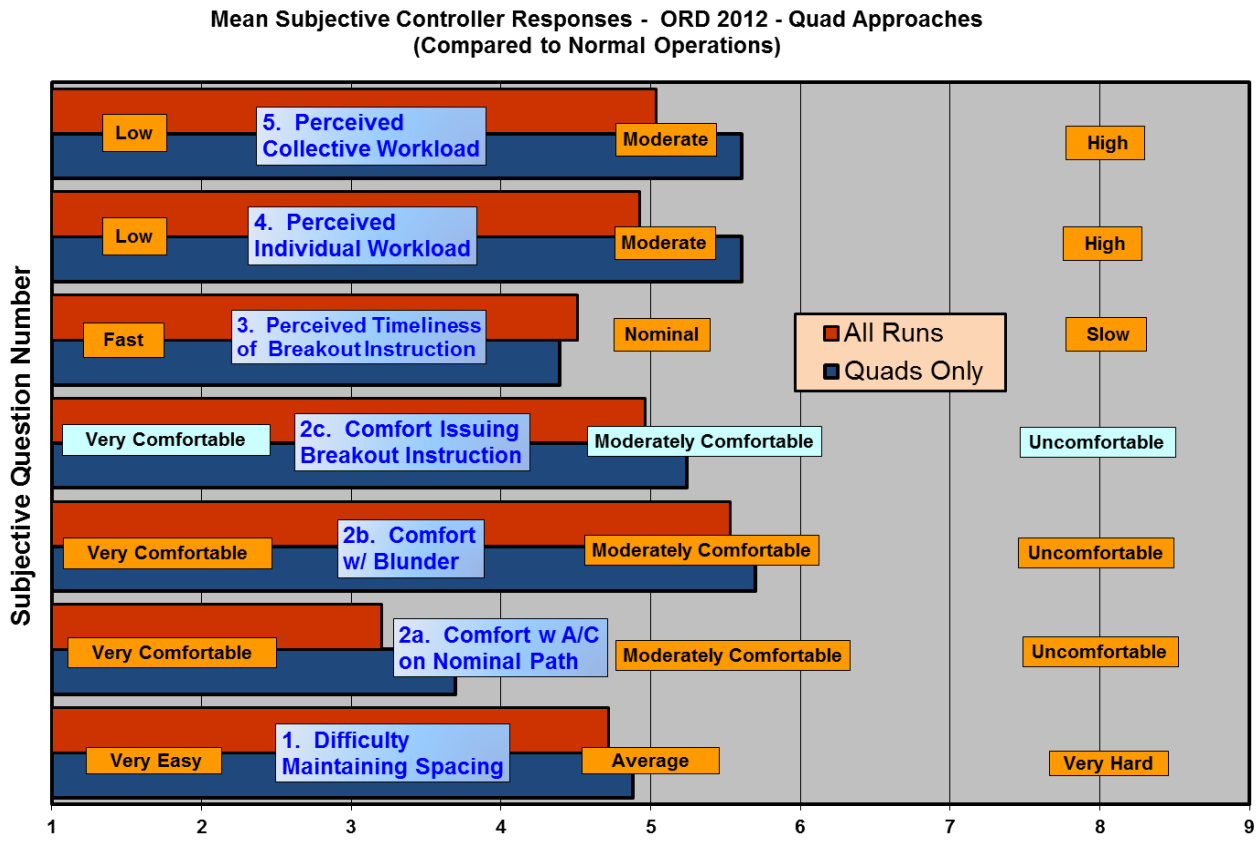

Figure 6. Quad Approaches

Phraseology

Throughout the evaluation, during breakout events, none of the final monitor controllers used the required JO 7110.65U phraseology. Several controllers used the proper sequence of phraseology but omitted "Traffic Alert." There is a common perspective amongst controllers concerning what information is essential to having an aircraft break off an approach. Despite the feedback from all subject controllers that the essential information should be the call-sign followed by a directive, actual transmissions do not validate this. For instance, several controllers used: "Cancel approach clearance" before issuing control instructions. Others simply directed the aircraft on a heading correction. Also, despite having been briefed on the proper phraseology prior to the test, very few controllers actually used the term "Traffic Alert." Those that did used it in an improper sequence. Several controllers issued the term to the blundering aircraft. While they were briefed of its inclusion in the FAA Order, in all de-briefings, controllers conveyed that it was superfluous information that detracted from the absolute primary task of making an aircraft deviate from its path. Usually, the aircraft call sign was stated first in the sequence but this is counter to the requirement(s) outlined in FAA Order JO 7110.65U.

C90 ASR-9 (4.8 second update rate), STARS/FMA, 4:1 AR

With an ASR-9 Radar update rate of 4.8 seconds, some of the surveyed controllers at C90 felt they could recognize a blunder, but a timely and effective response might be problematic. Others were somewhat more optimistic, indicating that they were confident in keeping aircraft from colliding but most probably could not maintain required separation, at least not with any degree of comfort.

HUR Surveillance (PRM – 1.0 Second Update Rate)

Controller feedback during debriefing sessions was equally mixed between those that preferred to use HUR surveillance, those that felt inhibited by it and those that were ambivalent. Controllers who preferred to use HUR surveillance felt that having an updated display of traffic movement increased their awareness and improved their vigilance level and ability to control assigned traffic. These controllers made a quick cognitive transition from what they were habitually accustomed to, to the new paradigm. They simply were able to process the information presented by the HUR surveillance system displays and use it to control traffic.

Those controllers that preferred the slower-updated systems to HUR surveillance indicated that they felt the information presented did not effective enhance their performance. It appeared that they were not able to overcome a change in habit.

Aspect Ratio

During the C90 DCE, 48 of the 50 subject controllers were unfamiliar with the 4:1 aspect ratio or, at least, had no experience with using it. The 4:1 AR expands the display four times, perpendicular to the final course. This exaggerates movement of the aircraft in the lateral direction. The 4:1 aspect ratio provides a more definitive indication of any deviation from the final approach course. Controllers often issued traffic headings as if the 4:1 presentation was a ratio of 1:1. This exaggerated presentation and the repeated blunder scenarios that were presented may have primed the controllers to breakout parallel traffic at an earlier indication of a course deviation than what they normally would. Regardless, most controllers felt that the 4:1 AR was much better than the 1:1. Consistent comments at C90 were that the 1:1 ratio puts the controllers in an untenable position with very little time to react to fix a problem.

Alert (Cautions/Warnings)

Some of the controllers stated that they waited for the Red Alert indication before directing a breakout. There seemed to be a heavy reliance on the yellow and red alerts as critical cues for making breakout/course deviation decisions. Controllers that pointed this out stated that since they cannot clearly discern trends, they cannot anticipate course deviation. Therefore, with a high-degree turn and rate of speed, they have little or no time to react, causing a heavy reliance on the yellow and red alerts (both visual and auditory).

Note: Some facilities do not broadcast alerts/warnings over an intercom to the entire facility; only to each individual screen. In this particular simulation, alerts/warnings were broadcast to the entire room. One controller did not attend to the speakers as he was accustomed to having alarms on his individual monitor.

Controller Strategy Elements

- HUR Surveillance Strategy: Controllers most often relied on habitual, almost automatic, learned/rehearsed responses to initial blunders (i.e. little or no cognitive liability). Initial responses were commensurate with their training, experience and standard operating procedures. After the initial few blunders in a scenario string, the controllers tended to formulate deliberate strategies before the next blunder. This reaction is less "automatic" and more deliberate. We found this to be the case in the study.

- Conscious spacing (staggering) of aircraft as far out as feasible to avoid issues later

- Reaction to yellow and red alerts primarily; very few able to anticipate blunder and react before alerts

- Preference and a heavy reliance on a consistent and accurate altitude readout in the data-block (versus the alternating altitude/heading information) as this directly impacts controller strategy and reaction to blunders

- An even mix of altitude changes and direction changes to keep aircraft apart. Very controller-specific. However, when direct coordination is effected between controllers, it is almost exclusively done in the altitude dimension

- Some controllers were very situationally aware of the altitude differences between paired aircraft and made conscious decisions to separate blundering aircraft by altitude versus heading differential

- Quad Approach Controller Strategy

    - There is a general sense that workload would be higher and greater vigilance would be required since controllers have to monitor more lanes of traffic. Part of that vigilance is continually formulating strategies for blunder or deviation scenarios

    - Virtually all the controllers felt that altitude corrections would affect changes faster and would be safer than heading changes. They felt this would be the best strategy, especially when having to divert the "in-board" aircraft.

Post-Simulation Debriefing Discussion

- All controllers voiced that the current breakout phraseology requirement IAW Order JO 7110.65U is unrealistic. The essential elements of "call-sign," followed by a "direction/altitude change" are most important.

- There are definitely increased training implications should this system be implemented at this facility. Evaluators did not specifically solicit the type and amount of training that should be mandated.

- At OKC, most subject controllers were confident that they could detect a blunder but were not comfortable in their ability to react timely enough. This was based upon either the update rate of the radar, the aspect ratio or a combination of both. Those same controllers felt they could keep the situation safe, but would lose aircraft separation.

- There are definitely increased training implications should this system be implemented at this facility. Evaluators did not specifically query controllers concerning the type and amount of training that should be mandated.

- All C90 controllers felt that the depiction of both speed and degree of blunder is unrealistic (respective to what they're most accustomed to or expect). The 1:1 aspect ratio is worse. When asked, controllers felt that their vigilance levels were higher, resulting in a higher level of workload, both individually and collectively. This is not consistent with the subjective scores in Figure 3.

- More than half of the subject controllers at C90 pointed out that the alternating altitude/heading information in each aircraft's data-block was not consistent with their training and experience. They felt that this directly impacted controller strategy and reaction to blunders.

- When asked to choose, of the 48 subject controllers who participated in the C90 DCE, only two preferred the 1:1 AR over the 4:1 AR.

- Quad scenario: Controllers generally agreed that there is no system tolerance for even the slightest aircraft deviation off the centerline

- As stated earlier, some subjects immediately grasped the benefits of HUR surveillance and embraced its use. Specifically, one controller felt that HUR surveillance was more responsive, while the 4.8 second update rate forced him to be more pre-emptive with deviating traffic. Another controller commented that: "the 1-sec update is making me dizzy," and "the 1-sec update takes some getting used to." Still others did not even notice the difference between the HUR and a 4.8 second update rate.

Human Performance Observations And Potential Implications

- Voice and auditory alerts. Redundant alert coding (i.e., more than one modality) may be a factor in controller reaction time, strategy and compliance. Some controllers feel that they pay more attention to and react better to visual representations of blunders; others feel that they react better to auditory stimuli; still others prefer both.

- Quad scenario: Altitude separation strategies seemed to predominate since controllers felt that heading deviations would have a deleterious cascading effect on parallel traffic

- Quad scenario: In order for controllers to recognize and effectively deal with blunders requires great situational awareness and vigilance during quadruple operations; perhaps more than what they are accustomed to. Additionally, direct controller-to-controller verbal interaction is critical.

- The subject controllers at C90 were very familiar with the operation being tested. Having controllers work with simulated traffic in their own operational area eliminated a potential required learning effect. The radar displays should also be consistent with what the controllers are using at their respective facility.

- Quad Scenario: Direct interaction between paired controllers is not necessarily a given. Some pairs rely heavily upon interaction, others do not. It appeared that those controllers that engaged in frequent and effective interaction were very familiar with each other's techniques and procedures.

- As the simulation progressed, controllers' strategies became more efficient through learned behavior (i.e., controllers were more reluctant to let traffic deviate drastically from the required path and were more likely to intervene earlier). *Note*: This may have artificially affected the consistency of reaction times between the early versus later scenarios.

- Performance could be affected when mixing controller pairs from different facilities (i.e., different habit patterns, local requirements and cultural expectations). Anecdotally, controller pairs from the same facility tended to have greater interaction between each other.

- The use of controller display tools and alerts vary between facilities and not all facilities have STARS with FMA displays. These differences between the controllers' "home" facility and the AFS-400 lab could introduce negative habit transfer issues which may affect performance.

- Observers recorded, both during the simulation and during the de-briefing, controllers verbalizing that TCAS would always intervene and keep aircraft from colliding, most often well before controllers would have to take action. This might be a dangerous assumption.

- C90: Given the sensitivity of aircraft movement and close proximity to the NTZ (especially in the 1:1 AR configuration), any decrement on performance or distraction from

their primary task (e.g. watching aircraft on two-mile final, conversing with other controller, etc.) increases critical reaction time in a blunder scenario, sometimes to the point where they cannot sufficiently react. De-briefing comments point out that a higher level of vigilance was required during this simulation over what they do as part of their normal final monitor duties.

- Aural and visual NTZ alerts inject an increased redundancy that enhances vigilance and reduces controller perceptual/cognitive requirements, leading to reduced reaction time.

- Controller success appeared to be more of an issue of vigilance rather than fatigue. These procedures and situations required that controller vigilance be at heightened levels to ensure rapid identification and processing of a blunder. The margin for misdiagnosis and/or latency of reaction is very slim.

Post-Simulation After-Action-Review – All Test/Support Personnel

- Ghost pilots phraseology evolved to a more realistic level versus the academy-specific script that they were accustomed to.

- Perhaps too many personnel were brought on this evaluation.

- Care should be taken during the in-brief and orientation not to give away too much information regarding the specifics of the evaluation.

- Ghost pilots get more comfortable and proficient from Day one to Day nine.

- All support folks (i.e., Ghost pilots, local controllers, etc.) function optimally when located in one room