Technical Report
DOT-FAA-AFS-400-83

Reduction of Diagonal Separation from 1.5 Nautical Miles to 1.0 Nautical Mile for Parallel Dependent Approaches

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February 2014

*****CORRECTION as of February 2015:***
Correction to Executive Summary and Section 10, Conclusions, to clarify that no changes to existing sectors, no additional equipment, control personnel, positions, or procedures are required.

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NOTICE

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Flight Systems Laboratory
Flight Technologies and Procedures Division
Flight Standards Service

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12. Abstract
The Federal Aviation Administration (FAA) Flight Standards (AFS) Closely Spaced Parallel Operations (CSPO) team evaluated the risk of dual dependent parallel operations associated with reducing the diagonal separation between aircraft from 1.5 Nautical Miles (NM) to 1.0 NM for parallel dependent approaches at runway centerline spacing (RCLS) of 2,500 feet or greater and less than or equal to 4,300 feet. The FAA Safety Management System (SMS) acceptable level of risk of 1×10^{-9} per operation was used as the success criteria. The results show that the risk is acceptable up to an RCLS of 3,600 feet when utilizing the final controller to mitigate final approach course deviations and to accommodate reduction of in-trail spacing at the Final Approach Fix.

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Airspace Simulation and Analysis Tool - New Generation ($ASAT^{ng}$)
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EXECUTIVE SUMMARY

Air Traffic Control (ATC) requested an evaluation of the collision risk of dual dependent approaches to parallel runways spaced 2,500 feet or greater with a diagonal separation between paired aircraft of 1.0 Nautical Mile (NM). ATC currently requires a diagonal separation of 1.5 NM. An aircraft fleet mix representative of the traffic at major airports such as Dallas Fort Worth International, San Francisco International, John F. Kennedy International, etc., was used with a 20% heavy mix (i.e. 300,000 pounds or more).

The FAA Safety Management System (SMS) acceptable level of risk of 1 × 10-9 per operation for a catastrophic event was used as the success criteria for this study. An evaluation of the collision risk associated with a course deviation (blunder) by the lead aircraft in the pair was conducted with and without evasive maneuvers by the trailing aircraft.

As runway centerline spacing increases, the longitudinal spacing between the lead aircraft and the trailing aircraft in the dependent pair must decrease to maintain the diagonal spacing. The results indicate that parallel dependent approaches can be conducted with a minimum of 1.0 NM radar separation diagonally between successive aircraft on adjacent localizer/azimuth courses when runway centerlines are separated by at least 2,500 feet, but no more than 3,200 feet when no evasive maneuvers are made by the trailing aircraft. Given that ATC has the ability to intervene and correct potential loss of separation and aircraft deviations, the study shows this minimum spacing can be increased from 3200 feet to 3600 feet. This assumes no changes to existing sectors, equipment, control personnel, positions or procedures.

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1.0 INTRODUCTION AND BACKGROUND

FAA Order JO 7110.65U paragraph 5-9-6, Parallel Dependent ILS/MLS Approaches, requires controllers to provide a minimum of 1,000 feet vertical or a minimum of 3 NM radar separation between aircraft during turn on and to provide a minimum of 1.5 NM radar separation diagonally between successive aircraft on adjacent localizer/azimuth courses when runway centerlines are spaced at least 2,500 feet, but no more than 4,300 feet apart. Where runway centerlines are more than 4,300 feet, but no more than 9,000 feet apart, 2.0 NM radar separation is required. [1]

There are no requirements for a Non Transgression Zone (NTZ), a Normal Operation Zone (NOZ), Final Monitor Controllers, or discrete communications frequencies for each runway.

The FAA Air Traffic Organization (ATO) requested a collision risk evaluation for reducing the current 1.5 NM diagonal separation (stagger) to 1.0 NM.

2.0 SCOPE

This evaluation considered a reduction in diagonal separation between aircraft from 1.5 NM to 1.0 NM for parallel dependent approaches for runway centerlines spaced 2,500 feet or greater and less than or equal to 4,300 feet.

3.0 OBJECTIVE

To fulfill the ATO request, this analysis and risk assessment was performed to determine if dependent parallel operations could be conducted within the acceptable level of risk of 1×10^{-9} per operation, with the reduction in diagonal separation as described above.

4.0 OPERATION DESCRIPTION

In addition to the vertical and lateral separations to be maintained, the following are required:

- Approach types for this dependent parallel operation are limited to any combination of Instrument Landing System (ILS), Ground Based Augmentation System (GBAS) Landing System (GLS), Wide Area Augmentation System (WAAS) Localizer Performance with Vertical Guidance (LPV), and Global Positioning System (GPS) Required Area Navigation (RNAV) and Required Navigation Performance (RNP) approaches. [2, 3]
- Wake vortex encounters need not be considered for Runway Centerline Spacing (RCLS) greater than 2,500 feet.
- The minimum applicable radar separation between aircraft on the same final approach course must be provided.
- Missed approach procedures must not conflict.

ATC procedures do not explicitly mandate a Final Monitor Controller for these parallel dependent approaches. However, radar separation is required. This Data Collection Effort

(DCE) utilized a Monopulse Secondary Surveillance Radar with an update rate of 4.8 seconds, specifically, an Airport Surveillance Radar-9.

5.0 FAST TIME SIMULATION

The primary analysis tool for this study was the Flight Systems Laboratory (AFS-450) Airspace Simulation and Analysis Tool – New Generation ($ASAT^{ng}$). $ASAT^{ng}$ is a multifaceted fast-time simulation tool for aviation-related safety assessments which uses high fidelity models of all components of an aviation scenario to evaluate the overall risk of the operation. A wide range of parameters were used to realistically model these complex operational scenarios. These parameters include:

- Aircraft fleet mix.
- Pilot response times.
- Controller response times.
- Aircraft performance.
- Atmospheric conditions.
- Navigation system performance.
- ATC monitoring and surveillance equipment.

To determine the minimum diagonal separation without evasive maneuvers by the trailing aircraft, the fast time simulations were conducted using the following conditions:

- Aircraft were established on the final approach course. Aircraft complied with approach control directed speeds up to the point of configuring for the final approach; the aircraft did not slow until within 2 NM prior to the FAF.
- Every run included a blunder by the lead aircraft.
- No evasive maneuvers were made by the trailing aircraft.
- Blunder angles were established within the following ranges: 5° to 15°; 15° to 25°; 25° to 35°.
- A 1.0 NM diagonal separation was set at the start of the blunder.
- Blunders were initiated uniformly along the final approach course.
- Aircraft fleet mix included a 20% Heavy aircraft which is representative of the traffic at major airports such as Dallas Fort Worth International, San Francisco International, John F. Kennedy International, etc.

The fleet mix used in this study and the study in reference 2, was developed to be a representation of the traffic observed in the National Airspace System (NAS). It was developed using data obtained from the Extended Traffic Management System (ETMS) count of aircraft at all major airports in the NAS that operate simultaneous instrument approaches. The ETMS count data suggests that on average, the percentage of Heavy aircraft in the NAS is approximately 5%. During peak intervals, this percentage can increase to a higher level, but it has never been greater than 20%. Not all aircraft types are used, and this particular fleet mix reflects a conservative representation of NAS traffic as it includes a higher percentage of Heavy aircraft. The mix was comprised of 20% of Heavy aircraft (10% Boeing 747-400 and 10% Airbus A330-200), 40% Boeing B737-800 and 40% Embraer Regional Jet ERJ-145.

It was not possible to achieve 4,300 feet separation without evasive maneuvers by the trailing aircraft. Therefore, the evaluation was expanded by use of a Human in the Loop (HITL) DCE using controllers.

For consistency with the recent change to FAA order JO 7110.65U reducing the RCLS requirement for simultaneous independent parallel instrument approaches from 4,300 feet to 3,600 feet, it was desirable to meet the acceptable risk for parallel dependent approaches at an RCLS of 3,600 feet and a diagonal separation distance of 1.0 NM. Therefore, a HITL DCE was conducted to evaluate the effects of utilizing a final controller to mitigate final approach course deviations and to accommodate reduction of in-trail spacing at the FAF (see Section 8.0).

6.0 ATC LABORATORY

The primary data collection tool for this study was the Flight Operations Simulation Branch (AFS-440) ATC Lab. The laboratory simulation system uses accurate computer models of the different NAS components, including aircraft, surveillance systems, terminal automation systems, navigation aids and airport components, and provides work stations for Terminal Radar Approach Control (TRACON) controller, Final Monitor Controller, Tower Controller, Ground Controller, other ATC functions and pseudo pilot positions. The pseudo pilot work stations provide control of high fidelity computer generated aircraft as directed by subject air traffic controllers. The ATC Lab also has interface capabilities with the B737-800NG and Airbus A330/340 fully qualified aircraft simulators, if testing with subject pilots from air carriers is required.

The automation and associated display system used for this HITL DCE was a Standard Terminal Automation Replacement System (STARS) display and keyboard on an Automated Radar Terminal System Color Display console. Radio communication linked all participants with realistic radio communications using a computer-based communications system, with radio and intercom controls at each position. Monitor headsets and a communication link were provided between laboratory personnel and observers.

The system collected and stored blunder initiation and controller response data for post-DCE analysis. The results of the data analysis were combined with controller and observer metrics to arrive at the conclusions for this study.

7.0 CONTROLLER PARTICIPANTS

Subject controllers were requested from FAA facilities that currently and routinely utilize parallel dependent approaches. The facilities were unable to provide Certified Professional Controller (CPC) personnel for the study. As a result, subject controllers were selected using the following criteria: They must be a Certified FAA Terminal Radar Training Facility (RTF), Radar, Advanced Radar, or TRACON Skill Enhancement Workshop (TSEW) instructor. They must have been a CPC in a Facility that utilized simultaneous independent parallel or parallel dependent approaches.

8.0 HUMAN IN THE LOOP DATA COLLECTION EFFORT

The HITL DCE was conducted at the AFS-440 ATC Lab at the Mike Monroney Aeronautical Center, Oklahoma City, OK. The DCE simulated parallel dependent approaches to runways with an RCLS of 3,600 feet using a 1.0 NM diagonal separation and all other requirements of FAA Order JO 7110.65U, paragraph 5-9-6. [1] While not a requirement of 5-9-6, the purpose was to evaluate the effect of utilizing a final controller to recognize final approach course deviations of the lead aircraft into the path of the trailing aircraft and issue mitigating instructions to prevent a collision. Controller Response Time (CRT) was measured from the time of blunder initiation to the time the controller pressed the push-to-talk (PTT) switch to talk to the evading aircraft. CRT probability density functions (pdfs) were determined from the data and were used in the fast time simulation (see Section 9.2).

8.1 DCE Runway Configuration.

The runway layout was based on the Charlotte/Douglass North Carolina International Airport (KCLT), with parallel runways 18C and 18R relocated and configured to be spaced 3,600 feet apart (see Figure 1). The displays were configured without a NTZ between the runways and without any other audio or visual alerts. Blunders were varied between 5° and 35° and initiated within free flowing scenarios that lasted approximately 1 to 1.25 hours. A full description of the HITL DCE is contained in reference. [4]

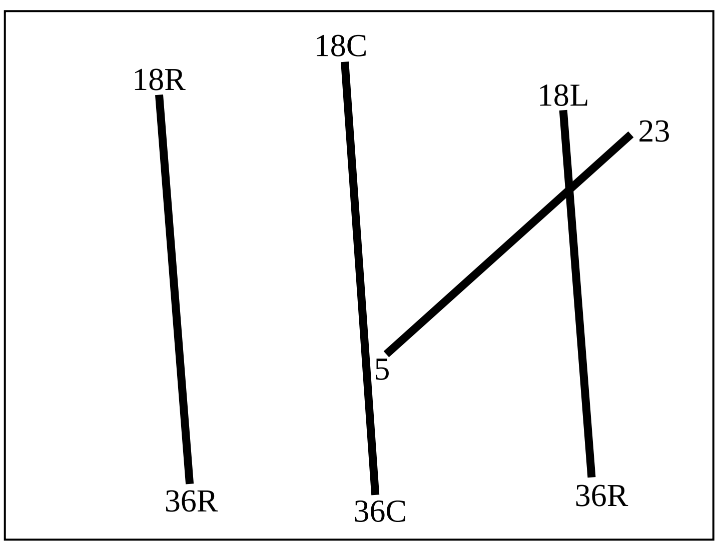

Figure 1. Charlotte/Douglass, NC, Int'l Airport with 18L & 18R at 3,600 feet Spacing

8.2 Human Factors Data Collection.

The Human Factors (HF) data collection consisted of objective and subjective performance metrics. Objective performance measures were recorded using an empirical method of observing controller activities as they managed traffic and reacted to course deviations during their session. The objective performance measures included data obtained through direct observation of controller and/or team performance. Subjective performance measures were recorded through the use of questionnaires that asked subjects to individually rate their perceived level of workload, timeliness, comfort and difficulty experienced during their session compared with their normal separation frame of reference of 1.5 NM (see Figure 2).

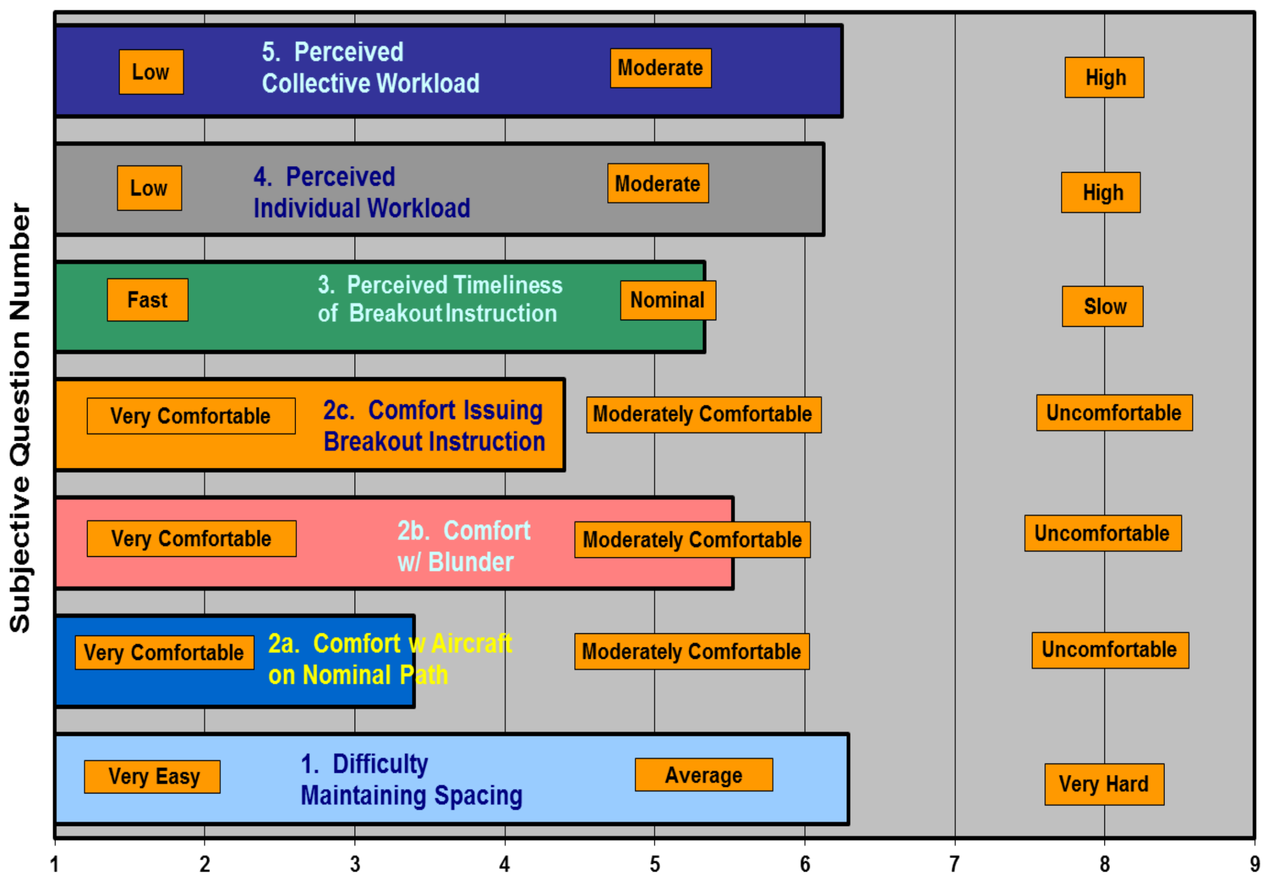

Figure 2. Mean Subjective Controller Responses

The HITL elements of this analysis were based on controller performance, primarily as it relates to controller responses to aircraft blunders during parallel dependent approaches. Following each session, subject controllers completed a post-scenario questionnaire and a controller demographics questionnaire. [4] During the debrief at the end of each day, FAA test evaluators completed a post-simulation questionnaire. [4]

Former FAA CPCs and HF engineers served as observers who monitored controller responses to blunders. The observers were unobtrusively located behind the subject controllers in order to observe and record behaviors and anomalies that were specific to this operation. Each had a communication headset with which to monitor either the 18R or 18C final controller.

The subject controllers were paired into teams of two and given a standard briefing as it related to the task(s) they were to perform, with emphasis on changes to their normal routine. The requirement to achieve a 1.0 NM stagger separation between aircraft was the main change. For the purposes of this test and to collect data all along final, they were requested to compress the aircraft pairs as close as possible to this separation without violating it (i.e. ≥ 1.0 NM) throughout the approach.

During pre-test set-up and scenario validation, the test team controllers were easily able to anticipate, detect and resolve all blunders despite the distractors incorporated into each scenario. Therefore, the test director increased traffic flow up to twice the normal rate for the subject controllers to provide a sufficient level of traffic activity in order to challenge controller vigilance to recognize a blunder and effectively intervene while maintaining a 1.0 NM stagger.

Throughout the evaluation, controller perception of workload was higher with 1.0 NM separation than for 1.5 NM separation. Refer to the Appendix A for a complete description of the HF analysis and associated graphs.

The heavier-than-normal traffic flow caused the controllers to focus a great portion of the available time in establishing the arrival sequence. The CPC and HF observers' notes corroborate this in that the blunders were not perceived and processed in a timely fashion as shown in Tables 3 and 4. One of the ATC observers noted that in all cases, it appeared subject controllers were intently focused on the turn from base-to-final, 18-to-20 miles from the runways. CPC and HF Observers' notes contain many examples of coordination between controller teams. This is a direct result of the physical proximity of controllers and represents a key enabling factor when coordinating traffic flow, spacing and blunder response. One subject controller pair had not worked together on a regular basis, and it appeared that they did not have an adequate familiarity with each other's skill sets. This would not be a factor in a facility where the controllers work together and know their colleagues and facility operations. For more detailed analysis, see Appendix B.

9.0 DATA ANALYSIS AND RISK EVALUATION

This section examines the results of the simulation and analysis. The FAA SMS acceptable level of risk of 1×10^{-9} per operation was used as the success criteria.

A collision between aircraft is the catastrophic event used to determine the acceptable level of risk specified in the FAA SMS. The Test Criterion Violation (TCV) shape used in this study was a cylinder, with a radius of 265 feet and a height of 160 feet (±80) centered on the trailing aircraft's Center of Gravity (CG). [5] If the blundering aircraft CG penetrated this TCV cylinder, a TCV, i.e., a collision, was assumed to have occurred. Several HITL DCEs conducted since July 2009 have been used to refine the CRT, Pilot Response Time (PRT) and aircraft dynamics used in the ASAT^{ng} fast-time simulations to study various runway spacings and proposed operations within the NAS. [2]

In each ASAT^{ng} simulation run, the Closest Point of Approach (CPA) was recorded along with the position of the blundering aircraft relative to the trailing aircraft. Although, it was possible for the blundering aircraft's CG to penetrate the cylinder without resulting in a collision, for simplicity, every TCV was considered to result in a collision.

9.1 Collision Risk for Various Runway Spacings with No Evasion

Fast time simulation runs were performed in accordance with the conditions in section 5.0, by aircraft fleet mix, blunder angle, blunder type, runway separation and diagonal separation of 1.0 NM. These simulation runs included lead aircraft blunders, but did not include any trailing aircraft evasions. Two types of blunders were simulated. The first type of blunder was a level blunder (LB), i.e., the blundering aircraft maintained the altitude it had when the blunder was initiated. The second type of blunder was a descending blunder (DB), i.e., the blundering aircraft continued to descend along the glide path.

From analysis of actual blunder data collected, the rate of a blunder has been determined for 10 degree intervals for all observed blunders (see Table 1). [6] Controllers monitor the approaches, and in the event of an apparent blunder the controller will intervene to instruct the aircraft to return to course. An additional rate of 1 in 100 is used for a non-responding blunder (NRB) (see Appendix A).

Table 1. Blunder Rates

Blunder Angle	Observed Blunder Rate	NRB rate
$5° \leq \Theta < 15°$	4.58E-05	4.58E-07
$15° \leq \Theta < 25°$	2.55E-05	2.55E-07
$25° \leq \Theta < 35°$	1.18E-05	1.18E-07

Table 2 contains the results of the collision risk analysis of the ASAT^{ng} simulation runs for RCLS between 2,500 feet and 4,300 feet. The collision risk analysis is contained in Appendix A. Table 3 contains the results for the time from the start of the blunder to reach the CPA for those cases that resulted in a TCV with a RCLS of 3,600 feet.

Table 2. Collision Risk (No Evasion)

RCLS	Collision Risk at 1.0 NM
2500	3.72E-10
2600	4.35E-10
2700	4.73E-10
2800	5.88E-10
2900	6.87E-10
3000	8.66E-10
3100	9.09E-10
3200	9.52E-10
3300	1.12E-09
3400	1.17E-09
3500	1.34E-09
3600	1.53E-09
3700	1.60E-09
3800	1.88E-09
3900	2.14E-09
4000	2.41E-09
4100	2.71E-09
4200	3.07E-09
4300	3.67E-09

Table 3. Time from Start of Blunder until CPA for 3,600 feet and 1.0 NM (No Evasion)

	Time in Seconds					
Variable	**10 DB**	**10 LB**	**20 DB**	**20 LB**	**30 DB**	**30 LB**
Minimum	63.20	NA	44.40	NA	37.80	39.40
Maximum	169.60	NA	63.60	NA	50.40	39.40
Average	107.21	NA	59.18	NA	44.00	39.40

It is clear from Table 3 that some of the blunders take a long time to result in the CPA. Given these results at 3,600 feet, it was necessary to determine if a controller could detect and resolve some of these blunders prior to a CPA resulting in a TCV. This drove an effort to test the percentage of blunders detected and responded to by the controllers.

9.2 Collision Risk for a Runway Spacing of 3,600 feet with Evasion

The rates controllers did not issue breakout instructions during the DCE are summarized in Table 4.

Table 4. ATC Non-Response Rate to Blunders for 3,600 feet and 1.0 NM

Blunder Angle	ATC Non-Response Rate
$5° \leq \Theta < 15°$	15.9% (14 out of 88)
$15° \leq \Theta < 25°$	22.6% (19 out of 84)
$25° \leq \Theta < 35°$	27.5% (22 out of 80)

The compression caused by the lead aircraft decelerating to the final approach speed at the FAF while the trailing aircraft is still at the speed assigned by ATC is a key contributor to maintaining aircraft separation. This compression was shown to increase the risk of collision in the analysis. To allow the use of a 1.0 NM diagonal separation standard, operational mitigations must be utilized by the controller that will take this compression into account.

Since the controllers did not intervene in all blunder events, often based on their judgment of the probability of a collision, the collision risk is calculated using a combination of the probability of TCV with an evasion and probability of TCV without an evasion based on the percentages in Table 4. Using the CRT pdfs determined from the DCE data, the collision risk was calculated from the results of the ASAT^{ng} simulations and tabulated in Table 5. For a description of the analysis, see Appendix A.

Table 5. Collision Risk for 3,600 feet and 1.0 NM Stagger

Evasion	BL Angle (°)	P(Collision)	ATC Response Rate (%)	P(Collision) * Rate	Subtotal	Total
No	5≤Θ<15	1.31E-9	15.91	2.08E-10	2.58E-10	5.68E-10
	15≤Θ<25	1.89E-10	22.62	4.27E-11		
	25≤Θ<35	2.66E-11	27.50	7.30E-12		
Yes	5≤Θ<15	2.84E-10	84.09	2.39E-10	3.10E-10	
	15≤Θ<25	6.89E-11	77.38	5.33E-11		
	25≤Θ<35	2.48E-11	72.50	1.80E-11		

The only blunder resulting in a probability of a collision exceeding the acceptable level of risk is the 10 degree blunder with no evasion (1.31×10^{-9}). With evasion, the acceptable level of risk for the 10 degree blunder is met (2.08×10^{-10}). When combining all probabilities of collision, both with and without evasion, the total collision risk is less than the acceptable level of risk of 1×10^{-9} by a factor of almost 2.

Additional analysis was performed by MITRE. [7] MITRE's analysis indicates the limit for no evasion at a diagonal separation of 1.0 NM is an RCLS of 3,600 feet (see Table 6). MITRE's analysis used a probability of 4×10^{-5} for all blunder angles. In contrast, this study used the probabilities in Table 1 for blunders in the calculation of collision risk (see Section 9.1). The sensitivity of this analysis to the blunder rate warrants continued monitoring of the actual events that occur in the NAS.

Table 6. Collision Risk at 1.0 NM Stagger – MITRE (No Evasion)

RCLS	Collision Risk
2500	0
3400	0
3500	2.4E-10
3600	4.4E-10
3700	1.8E-09
3800	1.6E-09

10.0 CONCLUSIONS

This analysis and risk assessment was performed to evaluate the collision risk associated with reducing the current 1.5 NM diagonal separation (stagger) to 1.0 NM for parallel dependent approaches.

Subject controllers that participated in the HITL stated that a proximity alerting feature in the display would assist them in detecting blunders. Participants also expressed that it is desirable for a coordinator to assist the final controllers during high traffic rate periods.

Parallel dependent approaches conducted with a 1.0 NM diagonal radar separation between successive aircraft on adjacent localizer/azimuth courses with runway centerlines separated by at least 2,500 feet, but no more than 3,200 feet apart meet the FAA SMS acceptable level of risk. This assumes that no controller intervention is available for correcting potential separation losses or aircraft deviations on final. Given that ATC has the ability to intervene and correct potential loss of separation and aircraft deviations, the study shows this minimum spacing can be increased from 3200 feet to 3600 feet. This assumes no changes to existing sectors, equipment, control personnel, positions or procedures.

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APPENDIX A. RISK ANALYSIS

A.1 Probability of a Collision

Several events must occur simultaneously for a collision to occur during simultaneous instrument approaches. Clearly, a blunder must occur, or there would be no significant deviation from course (see Figure A-1). Diagonal separation and RCLS must be below the thresholds where a collision would not occur should a blunder take place. For a given blunder angle and diagonal separation, there exists a certain RCLS, at which a TCV will not occur unless the lead aircraft airspeed (V_L) is less than the trailing aircraft airspeed (V_T). If all of the above events develop in a manner supporting a collision, a TCV occurs if the controllers and pilots fail to react in sufficient time to separate the blundering and the evading aircraft.

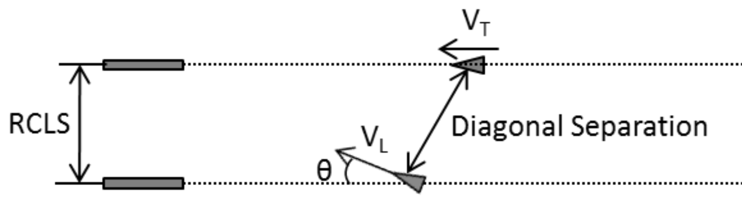

Figure A-1: Blunder Depiction

In addition, the blundering aircraft must not respond to ATC directions to return to the localizer/azimuth course. This is called a Non-Responding Blunder (NRB). The value used for NRB (1/100) has been used in numerous prior studies. [8, 9] This number is further validated by the results of an extensive blunder data collection effort performed by MITRE. [10] MITRE investigated over 1.8 million simultaneous approaches at 12 U.S. airports and observed 82 deviations of aircraft from their final approach courses that entered the NTZ, whether or not there was an aircraft on the parallel approach. These were determined to be blunders. Of these 82 blunders, all deviating aircraft corrected back to course. The majority of these corrections are assumed to have been initiated by ATC, highlighting the importance of ATC monitoring the approach. This data is consistent with an NRB rate of 1/100 NRB as follows.

If the random variable *X* represents the number of successes in *n* trials of a binomial experiment in which the probability of a single independent success is *p*, the probability that *X* = *x* is given by the binomial distribution equation:

$$P(X = x) = \binom{n}{x} p^x (1-p)^{n-x} \quad \text{(A-1)}$$

If there are 82 trials (i.e., *n* = 82) and no successes (i.e., *x* = 0) then:

$$P(X = 0) = \binom{82}{0} p^0 (1-p)^{82} = (1-p)^{82} \quad \text{(A-2)}$$

Therefore, a distribution for the unknown parameter, *p*, the probability of a success given the empirical result of no successes in 82 trials can be based on Equation A-2.

Since p represents a probability, its values must range between 0 and 1 and a probability density function (pdf) for the distribution derived from Equation A-2 must integrate to the value 1 between those bounds. This is enough information to derive a unique pdf for *p*, given the empirical result. Equation A-3 is that pdf. And Figure A-2 is its graph.

$$f(p) = 83(1-p)^{82} \qquad \text{(A-3)}$$

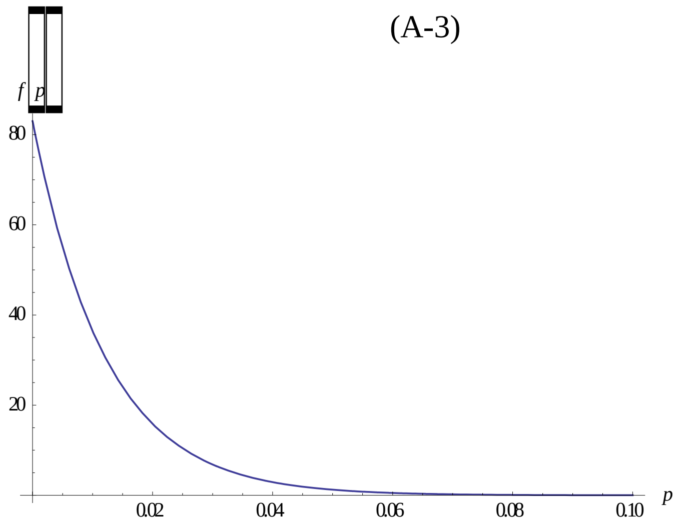

Figure A-2.

So, as *p* varies from 0 to 1, its likelihood (given the empirical result) is given by Equation A-3, its pdf, and depicted by the graph in Figure A-2.

The pdf (Equation A-3) can be used to calculate likely values for *p*. For example, the median value for *p*, is the value p_m for which the integral from 0 to p_m is 0.5. This calculation shows that $p_m = 0.00832$. This value would then be the most realistic estimate, statistically, for *p*, given the empirical result. Thus, the value of 1/100 is a conservative estimate for the NRB factor in calculations below.

A collision involves two aircraft and results in two accidents, as defined by the National Transportation Safety Board (NTSB). Assuming that a TCV will result in a collision, the probability of a collision can be expressed in mathematical terms by:

$$P(\text{Collision}) = P(\text{TCV}|\text{NRB} \cap \text{BL}) \times P(\text{NRB}|\text{BL}) \times P(\text{BL}) \qquad \text{(A-4)}$$

The symbol "∩" stands for "and". The symbol " | " stands for "given"; blunder is represented by BL. The first factor in the equation is expressed as:

$$P(\text{TCV}|\text{NRB} \cap \text{BL})$$

This factor determines the probability that a TCV occurs given that a non-responding blunder has occurred. This is the TCV rate that is determined from the simulation. The second factor in the equation is expressed as:

$$P(NRB|BL)$$

This factor determines the probability that the blundering aircraft does not respond to ATC instruction to return to course given that a blunder has occurred. The industry accepted value of this factor is 1/100. The last factor in the equation is expressed as:

$$P(BL)$$

This factor is the probability of a blunder of a specified angle such as 20°. The probability and frequency of the occurrence of various blunder angles up to 35° has been determined from blunder data captured from actual simultaneous approaches conducted in less than visual conditions.

A.2 Data Analysis

The TCV rate in Table A-1 is the count of TCVs obtained from the fast-time simulations for both LB and DB scenarios divided by the total number of runs. There were 100,000 aircraft pairs generated for each of these blunder types (LB or DB). Thus, the TCV count is divided by 200,000. The resultant probability of collision includes the multiplication of P(NRB|BL) (i.e. 1/100) . Collision risk is then a sum of the P(Collision) for each range of angles for each RCLS. Table A-1 lists the results of these calculations for key RCLS distances for 1.0 NM diagonal separation without an evasion. Table A-2 shows the collision risk for 1.0 NM diagonal separation for 3,600 feet RCLS with an evasion.

Table A-1: Collision Risk for 1.0 NM Diagonal Separation with No Evasion

RCLS	BL Angle	TCV Rate	P(BL)	P(NRB|BL)	P(Collision)	Collision Risk
2500	5≤ϴ<15	8.10E-04	4.58E-05	1/100	3.71E-10	3.72E-10
	15≤ϴ<25	5.00E-06	2.55E-05	1/100	1.28E-12	
	25≤ϴ<35	0.00E+00	1.18E-05	1/100	0	
3200	5≤ϴ<15	1.96E-03	4.58E-05	1/100	8.98E-10	9.52E-10
	15≤ϴ<25	2.05E-04	2.55E-05	1/100	5.23E-11	
	25≤ϴ<35	1.50E-05	1.18E-05	1/100	1.77E-12	
3600	5≤ϴ<15	2.86E-03	4.58E-05	1/100	1.31E-09	1.53E-09
	15≤ϴ<25	7.40E-04	2.55E-05	1/100	1.89E-10	
	25≤ϴ<35	2.25E-04	1.18E-05	1/100	2.66E-11	
4300	5≤ϴ<15	3.99E-03	4.58E-05	1/100	1.83E-09	3.67E-09
	15≤ϴ<25	5.09E-03	2.55E-05	1/100	1.30E-09	
	25≤ϴ<35	4.66E-03	1.18E-05	1/100	5.50E-10	

Table A-2: Collision Risk for 1.0NM Diagonal Separation with Evasion

RCLS	BL Angle	TCV Rate	P(BL)	P(NRB|BL)	P(Collision)	Collision Risk
3600	5≤ϴ<15	6.20E-04	4.58E-05	1/100	2.84E-10	3.78E-10
	15≤ϴ<25	2.70E-04	2.55E-05	1/100	6.89E-11	
	25≤ϴ<35	2.10E-04	1.18E-05	1/100	2.48E-11	

APPENDIX B. HUMAN FACTORS (HF) ANALYSIS

B.1 INTRODUCTION

The HITL DCE scenarios were carefully scripted with a goal of changing required activities within the scope of controller duties to elicit potential individual and collective workload changes. During periods in a given sequence of events when a controller could be required to perform an unexpected or unplanned procedure such as a breakout, both primary and secondary task completion actions were monitored. In those instances, FAA CPC and HF observers recorded items such as reaction times, latency of task completion and task shedding events.

Primary task measures included those tasks associated with sorting, pairing, merging and separating aircraft during CSPO. Secondary task measures included those tasks that controllers perform as part of their normal controlling duties (e.g., communications, flight following, etc.). Task shedding in either the primary or secondary task areas may be indicative of workload changes specific to this operation and may warrant further investigation.

B.2 DEPENDENT VARIABLES

Dependent variables represent elicited results of independent variable manipulation. Dependent variables to be evaluated as part of the HF analysis included, but were not limited to:

- Subjective workload and comfort level response and observation of performance.
- Proper radio procedures.
- Coordination between controllers.
- Controller response to aircraft path deviation or blunders.

B.3 CONTROLLER OBSERVERS

Qualified CPC and HF observers, knowledgeable in air traffic practices and procedures, were seated behind the subject controllers and manually recorded controller comments as well as their reaction to anomalies such as nuisance breakouts. CPC and HF observers monitored controller responses to blunders to include tracking the latency of controller response from the initiation of an aircraft blunder to controller action (press-to-talk button). NOTE: Total time from blunder onset to controller action includes blunder recognition, cognitive processing, decision making and response. Parsing the subcomponents out was beyond the scope of this test.

B.4 SUBJECTIVE RESPONSE DATA

Throughout the evaluation, controller perception of workload was higher with 1.0 NM separation than the normal 1.5 NM separation, especially during the first session of each subject's total participation. Refer to the subjective controller responses in Figure B-1. This was largely attributed to a combination of two factors. The first was a test-induced requirement for monitoring a larger radar area. The second was the rate of air traffic which was twice the rate of the normal traffic rate (approximately 45 to 55 aircraft arrivals per hour) at KCLT. In subsequent sessions, as controllers became more familiar with the scenarios and test parameters, subjective response indices pointed to controller-perceived decreases in workload and a perception that the tasks were easier as illustrated in Figures B-2 and B-3.

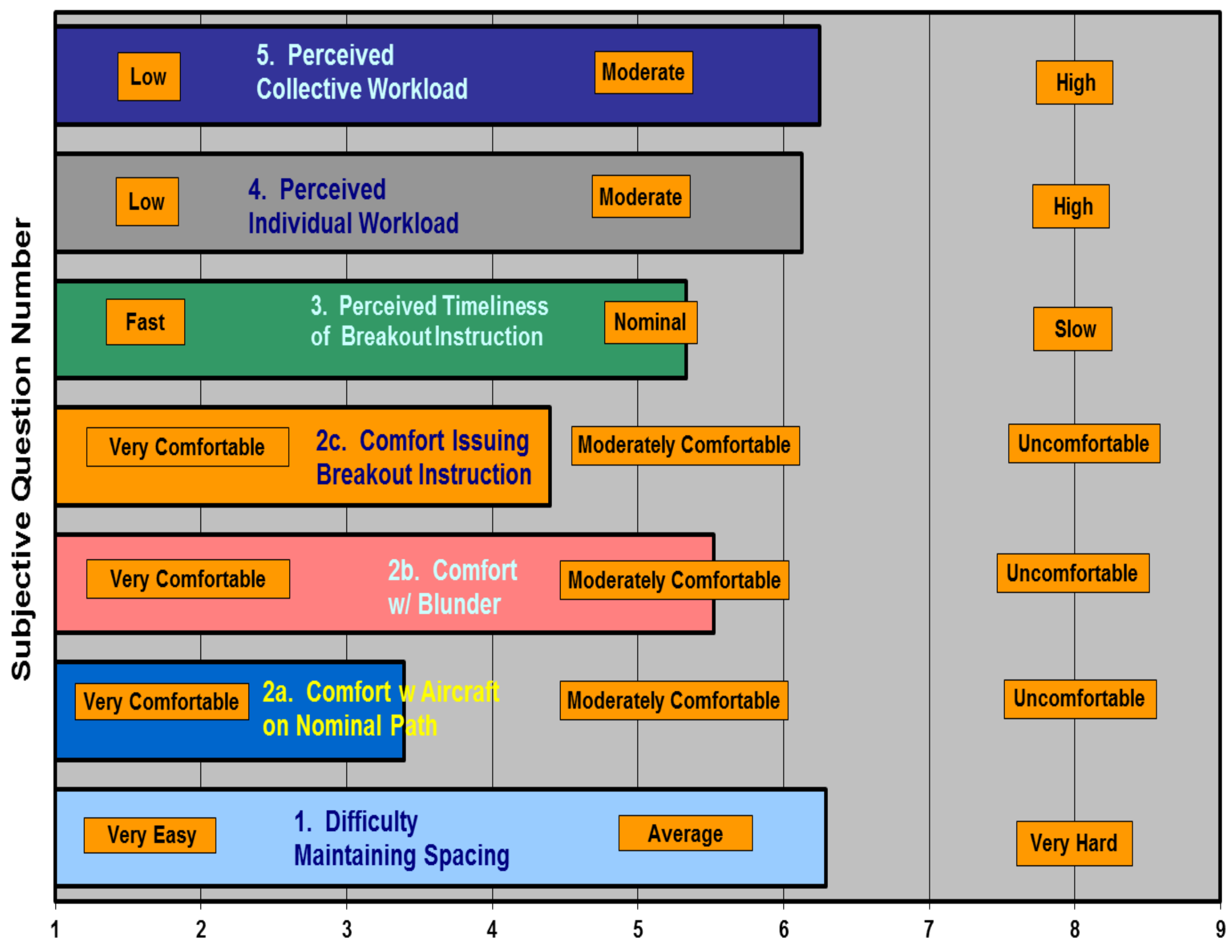

Figure B-1. Mean Subjective Controller Responses

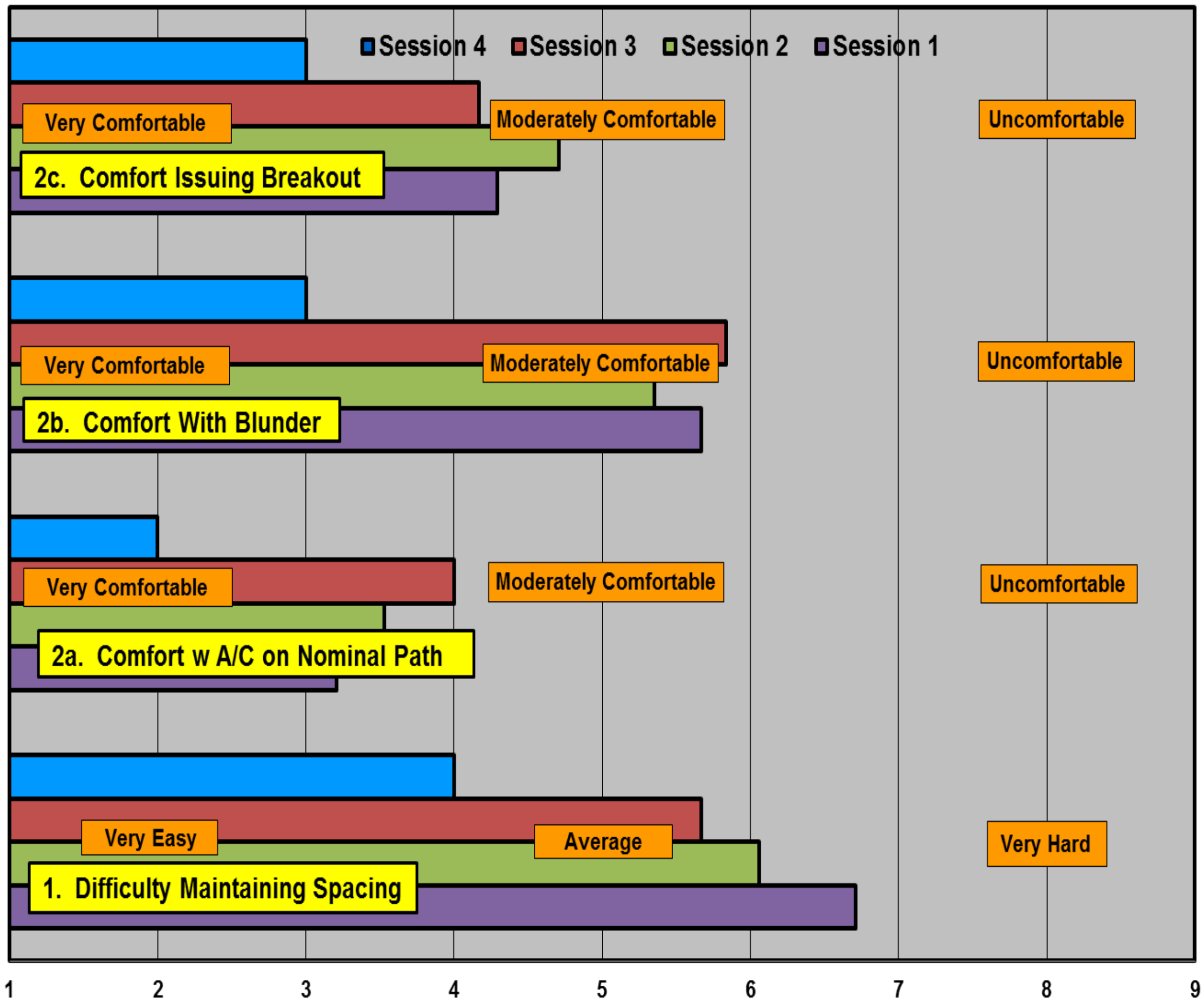

Figure B-2. Mean Subjective Controller Responses by Session

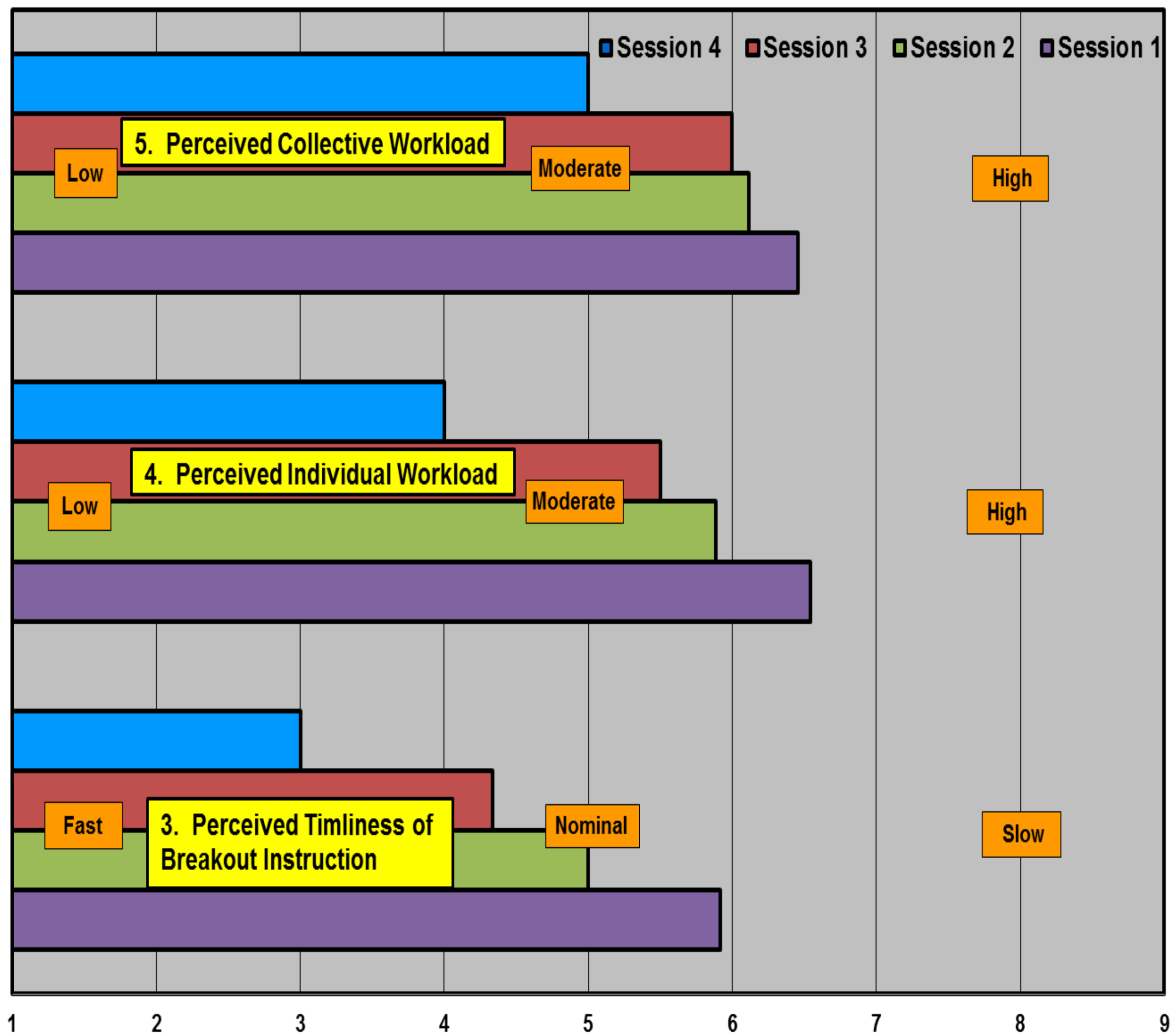

Figure B-3. Mean Subjective Controller Responses by Session

B.4.1 Traffic Rate

At the discretion of test coordinators, subject controllers were subjected to varying levels of traffic rates (90 to 110 aircraft arrivals per hour) that were heavier than normal (up to twice the normal rate). A heavier than normal rate of traffic caused the controllers to focus a great portion of the available time in establishing the arrival sequence. The observer notes corroborate this in that blunders were not perceived and processed in a timely fashion as shown in Tables 3 and 4 in the main body of this report.

B.5 VISUAL SCAN TECHNIQUES

Perhaps the single-most significant impact of the new separation standard combined with the increased traffic rates used in this test was the need for controllers to change their scan patterns over the entire final approach airspace beyond the final approach course. Almost all controllers felt that since they were now responsible for more traffic over a larger area, their dwell time on the most critical quadrant (final approach course) was compromised. Subject controllers stated they could not scan their assigned area and be confident that they could recognize course deviations or blunders with a high degree of certainty or timeliness commensurate with the elevated traffic rates used in this study.

Several controllers voiced that they perceived their scan patterns were more active. It logically follows that when an aircraft is not in an expected position in their assigned airspace, and controllers shift their attention to address the anomaly(s), their scan could be compromised in other areas of their assigned airspace as well. For example, while trying to intervene in a blunder situation in one quadrant, a subsequent problem in another quadrant may go unnoticed within that time period. One controller commented that even if his scan performance were optimal, blunder/fault detection might still be compromised because of the size of the assigned area.

One controller pointed out that if he were to be expected to recognize a blunder, he would need “another set of eyes” to assist in monitoring the final. He further stated that if the traffic flow progressed at a nominal rate, these scenarios would be safe. He felt that if the volume of traffic were increased, he would need additional monitor assistance, perhaps through a coordinator or even a visual tool.

One of the CPC observers noted that in all cases, it appeared controllers were intently focused on the turn from base-to-final, 18 to 20 miles from the runways.

Another controller estimated that 75% of his time was spent on the top of the scope (10-20 miles out) rather than on final (inside the FAF). The message is that the scan is not uniformly distributed across the scope.

Controllers had to make a conscious effort to divert their scan from pairing and merging the aircraft toward the runways to monitor for blunders. In this test, the controllers were required to be more vigilant in scanning the final approach courses. This would represent a negative habit transfer from the duties that the subject controllers are normally accustomed to performing.

Also, when stressed for time as traffic rate increased, controllers' regard of the final was reduced inordinately, which indicates a form of task-shedding.

B.6 CONTROLLER INTERVENTION

Controller intervention normally involves in-trail spacing, stagger or blunders. Some controllers consciously sensed increased reaction time and attributed it to the added scanning burden and increased volume of traffic. Several controllers said they may be able to detect blunders, but may not have enough time to process the information, formulate a strategy and react to it.

As the DCE progressed, controllers quickly learned that blunders were going to occur. Controller debriefings indicate that nearly all controllers adjusted their scan technique to search for blunders. During real-world operations, blunders occur so infrequently that a controller's scan for blunders would not be a conscious effort. Instead, controllers would scan for minimum separation errors and, in the process, identify and rectify blunders serendipitously.

B.7 CONTROLLER TEAMWORK/CRM

Physical orientation of the controllers' work area has an impact on optimal controller teamwork and coordination. Observer notes contained many examples of coordination between controller teams. This is a direct result of the physical proximity of controllers and represents a key enabling factor when coordinating traffic flow/spacing and blunder response.

Controller efficiency and comfort level requires each member of a controller team to possess equivalent levels of training, experience and expertise as well as a working familiarity with fellow crew members. In one case, observers noted that a controller team struggled to manage terminal airspace traffic into a flow. There was constant hesitation from each controller to turn aircraft onto the base leg. It appeared as if the controllers were waiting to see the other final controller commit to a sequence before turning their own traffic. This pair had not worked together on a regular basis, and it appeared that they did not have an adequate familiarity with each other's skill sets.

B.8 TRAFFIC MANAGER

Most subject controllers felt they needed an extra pair of eyes during high traffic times that could be provided by the Traffic Manager (TM). However, one controller was not comfortable with the frequency and content of the TM intervention in this evaluation.

In a positive example, the TM intervened with one team controller to tighten up the sequence and hit the holes generated by the other team controller. The speed control instructions from the TM helped both controllers by facilitating coordination between the two controllers.

B.9 TRAINING/LEARNING EFFECT

Controllers that returned to participate in additional sessions became much more comfortable with traffic sequencing and the detection of blunders. Evaluators felt that much of the discomfort during the first session was based on the establishment of vector and sequencing points. During successive sessions, the controllers had already gained familiarity with the vector and sequencing points, and the comfort/workload responses were commensurately better. It appears that the second/third/fourth time the test is conducted by a controller; the performance is more typical of a CPC at a field facility.

B.10 DISCUSSION

Given that reaction time seems to be compromised due to the nature of this DCE, all controllers felt that a coordinator would be helpful to ensure safe operations and reduce the margin of error during peak volumes of traffic.