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Simultaneous Independent Close Parallel Approaches - High Update Radar Not Required

Flight Systems Laboratory
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12. Abstract

In an effort to increase National Airspace System (NAS) capacity, the AFS-400 Closely Spaced Parallel Operations (CSPO) Team has worked to reduce the current 4300 feet runway separation standard for dual Simultaneous Independent Parallel Instrument Approaches (SIPIA). This effort utilized revised blunder assumptions, updated data collection and analysis techniques, modified Test Criteria Violation (TCV) volume, fast-time simulations, and human factors analysis. The Traffic Alert and Collision Avoidance System (TCAS) was evaluated for potential influence on SIPIA operations as well.

Final results indicate parallel runway separation of 3600 feet and greater will meet current safety standards without the use of a high update rate (HUR) surveillance.

This spacing reduction study utilized the following: Airport Surveillance Radar (ASR-9), Standard Terminal Automation Replacement System (STARS) plus Final Monitor Aid (FMA) with visual and audible alerts, a display Aspect Ratio (AR) of 4:1 and ILS/GLS/LPV navigation systems only (vertical guidance required). However, this does not apply to LNAV/VNAV, LOC ONLY, RNAV or RNP.

The operation must comply with the procedures in paragraph 5-9-8 of FAA Order JO 7110.65, the Aviation Safety Operational Safety Assessment (OSA), and with the system description and limitations identified within this report.

13. Key Words HITL, DCE CSPO PRT, CRT, NTZ ILS, GPS, RNAV, RNP (GPS), LPV, IMC, VMC SOIA and SIPIA PRM, HUR, STARS, FMA, AR, ASR, MSSR TCAS, NAS Infrastructure	**14. Distribution Statement** Controlled by AFS-450
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Executive Summary

The Federal Aviation Administration (FAA) is identifying improvements to Closely Spaced Parallel Operations (CSPO) as a key enabler to increase National Airspace System capacity and efficiency in less than Visual Meteorological Conditions (VMC). This report proposes Simultaneous Independent Parallel Instrument Approach (SIPIA) operations to dual parallel runways spaced at 3600 feet or greater while maintaining safety standards.

The recommended dual operation is based upon runway spacing of 3,600 feet or greater with a No Transgression Zone (NTZ) of 2,000 feet. The operation utilizes an Airport Surveillance Radar (ASR-9) with 4.8 second update rate, Standard Terminal Automation Replacement System (STARS) Final Monitor Aid (FMA) with a color digital display, 4:1 Aspect Ratio (AR), visual and aural alerts. With the exception of high update rate (HUR) surveillance, this operation has all the requirements of FAA Order JO 7110.65, Air Traffic Control, paragraph 5-9-8; "*SIMULTANEOUS INDEPENDENT DUAL ILS/MLS APPROACHES - HIGH UPDATE RADAR*".[1]

The Multiple Parallel Approach Program (MPAP)[2] models and assumptions were refined for this study using actual approach data. 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).[3] If the blundering aircraft Center of Gravity (CG) penetrated the cylinder centered at the evading aircraft's CG, a TCV occurred. Controller Response Times (CRT) and Pilot Response Times (PRT) were refined during several Human in the Loop (HITL) Date Collection Efforts (DCE) conducted since July 2009.[4] [5] [6] These refinements were used in the fast-time simulations to study various runway spacing.

The fast-time simulations and resultant risk analysis focused primarily on Instrument Landing System (ILS). Since Wide Area Augmentation System (WAAS) Localizer Performance with Vertical guidance (LPV) and Ground Based Augmentation System (GBAS) Landing System (GLS) provide lateral performance comparable to ILS, they are included as acceptable navigation systems. Only ILS, GLS and LPV with vertical guidance may be used. This operation does not allow the use of LNAV/VNAV, LOC ONLY, RNAV or RNP.

Constraints considered in this report are the resultant nuisance breakout (NBO) rate, autopilot (AP) and flight director (FD) usage, and the effect of Traffic Alert and Collision Avoidance System (TCAS) Resolution Advisories (RA). A Human Factors (HF) analysis and an Operational Safety Assessment (OSA) were performed and identified hazards and mitigations.[7]

Using these refinements, the studies referenced in this report combine to demonstrate that the current acceptable level of risk of 1×10^{-9} per operation is met for parallel runways separated by 3600 feet or greater during dual SIPIA operations.

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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 delays.
- 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.

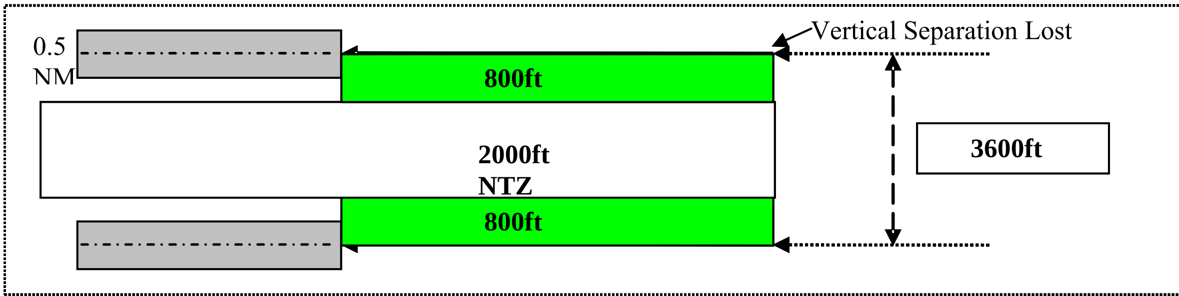
To meet these goals, the FAA is investigating methods to conduct closely spaced parallel independent approaches at runway spacing closer than currently authorized (4,300 feet) using existing NAS infrastructure.

For the purposes of this report, NAS infrastructure incorporates and is limited to Airport Surveillance Radar (ASR-9) with a 4.8 second update rate, Standard Terminal Automation Replacement System (STARS) Final Monitor Aid (FMA) with a color digital display, 4:1 Aspect Ratio (AR), visual and aural alerts; Instrument Landing System (ILS), Wide Area Augmentation System (WAAS) Localizer Performance with Vertical guidance (LPV) and Ground Based Augmentation System (GBAS) Landing System (GLS) navigation systems with vertical guidance. The results of these studies do not apply to LNAV/VNAV, LOC ONLY, RNAV or RNP.

The distance between parallel runways is one of the main parameters which affect airport capacity by determining whether independent (higher throughput) or dependent (lower throughput) parallel operations can be conducted, or single runway arrival operations must be conducted. Runway stagger was not evaluated because it is not a factor that adversely impacts the overall risk. A principal safety concern is the risk of collision due to a blunder, where one aircraft unexpectedly turns toward the aircraft on the adjacent parallel final approach course, putting both aircraft at risk.

The dual Simultaneous Independent Parallel Instrument Approach (SIPIA) operation studied for this report includes runway spacing of 3,600 feet, or greater, with a 2,000 feet No Transgression Zone (NTZ). With the exception of High Update Rate (HUR) surveillance, this operation has all the other requirements of FAA Order JO 7110.65, Air Traffic Control, paragraph 5-9-8; "*SIMULTANEOUS INDEPENDENT DUAL ILS/MLS APPROACHES - HIGH UPDATE RADAR*".[1]

The NTZ is 2,000 feet wide equidistant between the approach courses for the runway pair. It begins at the farthest point in the adjacent runway pair where any aircraft established on the approach is permitted to lose vertical/lateral separation. It ends 0.5 nautical miles (NM) past the farthest departure end of runway (DER) in the pair or where the missed approach tracks diverge, whichever occurs last. Note: The NTZ dimensions are not affected by the point where Air Traffic Control (ATC) is permitted to discontinue radar monitoring.



Runway Spacing and NTZ/NOZ Depictions

The Multiple Parallel Approach Program (MPAP)[2] models and assumptions were refined for this study using actual approach data and replaced the assumption of a single blunder rate and angle. 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).[3] Controller Response Times (CRT) and Pilot Response Times (PRT) were refined from several Human in the Loop (HITL) Data Collection Efforts (DCE) conducted since July 2009.[4] [5] [6] All of these studies were conducted with the aircraft flown on flight director (FD) or autopilot (AP).

Human Factors (HF) data were collected during the HITL testing. The HF analysis included elements based on pilot and controller performance, such as, perceived workload changes, primary and secondary task performance, visual scanning and acquisition strategies, and controller or pilot/crew coordination. The HF study analyzed how well controllers or aircrews developed strategies and how potential limitations, such as, human, environmental, automation/display and aircraft design, etc., affect their performance. The analysis included both subjective and objective measures. The resultant human factors analysis, which can be reviewed in Appendix A, provided areas of concern that will need mitigation.

SIPIA operations to dual parallel runways spaced at 3600 feet or greater, using the Aviation Safety Operational Safety Assessment (OSA) requirements, along with the system description(s) identified within this report, will meet the current Target Level of Safety (TLS).[7]

2.0 OBJECTIVES

The objective of these studies was to determine if a reduction in the lateral runway separation criteria for a dual SIPIA operation could be made using current NAS infrastructure and no HUR surveillance. RTCA Task Force 5 made several recommendations to the FAA for accelerating NextGen.[8] The following are recommendations applicable to these investigations:

- Operational Capability 13: Implement CSPO in a phased manner: Revise and update blunder assumptions through actual data collection. Re-evaluate the assumed blunder frequency (blunder rate) and severity (blunder angle).

- Operational Capability 37a: Implement CSPO in a phased manner: Instrument landing System (ILS) or Satellite Navigation. Allow the use of satellite navigation-based procedures as an alternative to ILS during simultaneous parallel approaches.

3.0 SYSTEM DESCRIPTION

3.1 ASAT^{ng} Fast Time Simulation Tool

The primary analysis tool for this safety 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. ASAT^{ng} 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, Air Traffic Control (ATC) monitoring and surveillance equipment and pilot and controller response times enable very efficient and realistic modeling of complex operational scenarios. ASAT^{ng} also uses official FAA databases of navigation and surveillance facilities, runways, fixes, etc. The ASAT^{ng} flight dynamic models also account for atmospheric conditions. Additionally, aircraft fleet mix for the area of interest is incorporated into the simulations.

3.2 Flight Simulators

Flight simulation was conducted using the Flight Operations Simulations Branch (AFS-440) Boeing 737-800 (B737) and Airbus 330-200 (A330) Level D qualified flight simulators. These simulators were linked to a high fidelity simulated Terminal Radar Approach Control (TRACON) with two STARS with FMA radar controller workstations to replicate real world flight conditions for DCE. Both of these aircraft flight simulators are state of the art and used for research, development and evaluation of proposed NAS operations.

3.3 Air Traffic Controller (ATC) Laboratory

In the AFS-440 ATC Lab, the Simulation Model for Air Traffic Research and Testing (SMART) system drives the simulated TRACON and other ATC functions and positions as well as the Test Director and pseudo pilot positions. The pseudo pilot controls the computer generated aircraft during the simulations, as directed by the test plan and/or by subject air traffic controllers. Radio Communications, a component of SMART, links all participants with realistic radio communications using Voice Over-IP technology (VOIP).

The SMART software used accurate computer models for the different components of the NAS, including aircraft, surveillance systems, terminal automation systems, navigation aids and airport components. The automation system supported during these studies was the STARS and the controllers participated in the simulation through the two STARS workstations with FMA display set at a 4:1 AR, including visual and audible alerts. The visual alerts were colored yellow for a potential penetration of the NTZ within 10 seconds, and the visual alert turned red when the NTZ was penetrated. The yellow audible alert was “CAUTION”, while the red audible alert was “WARNING”. Both were accompanied by the blundering aircraft's call sign.

The system collected data as defined by the specific Test Plan requirements. Data from aircraft and the controller work stations were analyzed and provided as input parameters to the ASAT^{ng} for risk analysis.

3.4 SMART System with 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 ASAT^{ng}.

3.5 Pilot and Controller Participants

Subject pilots used in the simulations that supported these studies were selected using the following criteria:

- Current Part 121 air carrier pilot
- Precision Runway Monitor (PRM) trained
- Qualified in the B737 or A330 series aircraft as required

Prior to the PRT data collections, it was discovered that insufficient A330 pilot candidates were available. However, A320 pilot candidates were readily available. The aircraft systems, cockpit controls and displays of these two aircraft are remarkably similar even though the A330 is a larger aircraft with more inertia and slower reaction times. It was the consensus of AFS-400 that substitution of A320 pilots would result in conservative (i.e. slightly increased) pilot plus aircraft response times, and the determination was made to use A320 pilots as suitable replacements in order to fulfill the test plan requirements.

Subject controllers were selected using the following criteria:

- Fully certified
- Operationally current
- Experienced using FMA

Subjects used in these DCEs represented a wide range of experience and thus provided a reasonable sample of the population of pilots and controllers operating in the NAS.[3] [4] [8]

3.6 Traffic Alert and Collision Avoidance System (TCAS)

TCAS is an airborne system that operates independently from the ground-based ATC system. It was designed to increase cockpit awareness of proximate aircraft and to serve as a "last line of defense" for the prevention of mid-air collisions. TCAS provides pilots with Traffic Advisories (TA), indications to the flight crew that a particular intruder is a potential threat, and traffic Resolution Advisories (RA), indication that commands a maneuver to provide separation from the threat.

The July 2009 DCE [6] evaluated parallel runways separated by 3,000 feet utilizing an NTZ of 1200 feet. Due to the close proximities of the simulated aircraft during the DCE, TCAS RAs were issued just before controller instructions for a breakout maneuver. Unfortunately, pilot responses to these nuisance RAs partially corrupted the data for determining both pilot and controller response times. The data that was not corrupted was analyzed and used in the fast-time simulations.

A follow-on PRT DCE was conducted with the RA function inhibited to acquire uncorrupted PRT data. Additionally, follow-on CRT DCEs were conducted with only controller participants to acquire CRT data without the influence of nuisance TCAS RAs.

3.7 Radar

To maximize availability and utilization possibilities throughout the NAS, ASR-9 with associated Monopulse Secondary Surveillance Radar (MSSR) and update rate of 4.8 seconds, with an accuracy of 2 milliradians, was selected for radar monitoring. Radar coverage should be provided down to 50 feet over the runway and through out the entire length of the NTZ.

3.8 Nuisance Break Outs

Nuisance Break Outs (NBO) occur when an aircraft wanders too close to the NTZ and the final monitor controller breaks out the presumed blunderer. The aircraft can be on the ILS/LPV/GLS final course, yet close to the NTZ due to Total System Error (TSE). The probability density functions (pdf) used in fast-time simulations can be used to estimate the rate of NBOs. The NBO rate is directly proportional to the length of final. Since aircraft on longer finals cause a higher rate of NBOs, the length of final is a limiting factor when considering the resultant capacity gained by operating SIPIA to closely spaced parallel runways. Operational experience at Minneapolis revealed an NBO rate between 3% and 4% reduced capacity and SIPIA operations were terminated.

The ATSI NTZ Incursion Analysis Tool (NIAT) utilized the listed parameters to estimate the rate of NBOs.

- runway spacing
- NTZ width
- approach offset (zero for the parallel case)
- navigation system
- distance between the localizer (LOC) antenna and the threshold (THR), or angular course width of GLS & LPV
- length of final
- Flight Technical Error (FTE) model
    - CAT I ILS hand flown using raw data
    - CAT II ILS hand flown using a Flight Director (FD)
    - CAT II ILS using an autopilot

For example, a 20 NM final and 10,000 feet LOC to THR distance resulted in a probability of an incursion between 6.8% and 18.6%, depending on the approach type. The approach design must take into account the resultant NBO rate when determining the length of final.

3.9 Operational Safety Assessment

The Aviation Safety (AVS) Operational Safety Assessment (OSA) supports AVS Safety Management System (SMS) efforts and risk-based data-driven decisions.[7] The OSA identifies, eliminates, and/or mitigates aviation risks. It uses classical system safety principles and practices that identify risks via hazard analyses, and provides qualitative risk assessment. Risks not eliminated are mitigated to an acceptable level.

A key risk mitigation in the OSA highly recommends autopilot coupled approaches to approach minimums. It is expected that most aircraft will fly coupled approaches; however, service should not be denied to the occasional aircraft flying an uncoupled approach. The following note should be included in the Attention All Users Page (AAUP): "Coupling is highly recommended."

4.0 BLUNDER ANALYSIS

In 1988, the FAA formed the Precision Runway Monitor Program (PRMP). At that time, there were no data available to determine the magnitude or rate of blunders so a method was developed to verify that the target level of safety was met without knowledge of the blunder rate. The *Precision Runway Monitor Demonstration Report (1991)*[9] stated a maximum blunder rate of one 30° blunder in 2,000 approaches, or one in 1,000 dual approaches, and no more than one non-responding blunder per one hundred blunders would satisfy the TLS of 4×10^{-8} per approach. This TLS was derived for this operation during the MPAP.

This report noted that if blunders were occurring at that rate, Chicago would have about ten blunders per year during IMC and Atlanta would have about fourteen. Since anecdotal evidence suggested that the actual rate at Chicago was no more than one per year, it was assumed that the target level of safety was met. The risk analysis adopted during the PRM study was very conservative and it was felt that the actual risk of the operation was far less than the TLS.

With the advent of databases such as the National Offload Program (NOP) and the Aviation System Performance Metrics (ASPM), large amounts of data became available to examine both the rate of blunders and the magnitude of deviation from the approach course. MITRE was tasked by the FAA to examine approach data at 12 major airports where SIPIA are conducted during less than visual weather conditions. Based on the particular aspects of each airport, such as geography, traffic density, etc., this data will vary from airport to airport.

In FY2009, MITRE provided analysis of data from 785,203 approaches conducted during actual dual SIPIA.[10] The Flight Systems Laboratory further analyzed this data set. The results are documented in the "*Angles of Deviation from Localizer Course during Simultaneous Independent Approaches to Parallel Runways*" report.[11] Even though the number of approaches that were examined is a large number, it is still only a sample of the total population of simultaneous IFR approaches. To indicate the uncertainty associated with the rates, confidence intervals were computed. Since the consequences of a collision are so severe, the prudent use of a confidence interval is to use the largest value of the confidence interval as the estimate of the blunder rate. This was done in the fast time simulations.

Through June 30, 2011, MITRE has collected data for over 1.4 million simultaneous approaches, recording only 60 events which met criteria for a blunder.[12] Data collection and analysis will continue to further refine the blunder assumptions.

The blunder data collected and analyzed to date indicate the actual blunder rate is significantly lower than the MPAP assumptions. Blunder angles are varied and typically less than the original 30° assumption; although, it should be noted that uncorroborated MITRE data contains a blunder of 42°.[12]

5.0 PILOT RESPONSE TIME (PRT) ANALYSIS

PRT DCEs were accomplished in July 2009 and March 2010 to determine pilot response times to controller breakout instructions during dual SIPIA operations. As recommended by the CSPO Safety Risk Management Panel (SRMP), the July 2009 DCE evaluated simultaneous independent dual straight-in ILS approaches with runway centerline spacing of 3,000 feet, an NTZ width of 1,200 feet, and a 4.8 second surveillance update rate. The testing collected data for both pilot and controller response times during "at risk" blunder scenarios, i.e., an absence of corrective action would result in a collision.

The July 2009 PRT data was partially corrupted due to excessive TCAS RA interference which caused the pilots to react prior to any ATC guidance. Despite this interference, data from the pilots pitch and roll times to TCAS RA guidance and ATC breakout instructions as well as the aircraft dynamics for maximum roll angle and roll rates were collected. The data sets were similar enough to pool into one database. New PRT probability density functions (pdf) were developed and provided as input to the ASAT^{ng} simulations.

The follow-on, March 2010, PRT DCE evaluated the same parameters, but inhibited the TCAS RA function. A full description of the PRT DCEs can be found in the respective PRT technical reports.[4] [6]

6.0 CONTROLLER RESPONSE TIME (CRT) ANALYSIS

In August and December 2010, two CRT HITL/DCEs to dual parallel runways spaced 3,600 feet apart with a 2,000 feet NTZ, were conducted with qualified FAA controllers to gather CRT data as a result of the TCAS RA interference in the initial July 2009 PRT/CRT data collection effort.[6] At the time of these DCEs, the maximum blunder angle detected was approximately 30°. Based on the blunder analysis described above, a second blunder angle of 20° was added to the DCEs. To limit the number of scenarios, an equal sampling of 20° and 30° blunders was collected.

Statistical analysis of the CRTs to the 20° and 30° blunders indicated that the mean CRTs to the two angles were significantly different, with the mean CRT to the 20° blunder being 4.07 seconds and to the 30° blunder being 4.9 seconds. New CRT pdfs were developed and provided as input to the ASAT simulations. A full description of the CRT DCE data can be found in reference.[5]

7.0 AIRCRAFT SEPARATION RISK ANALYSIS

The Flight Systems Laboratory performed fast-time simulations of blunder scenarios to study the effects of various CSPO parameters including TCV volumes, pilot and controller response times, airport elevations, aircraft dynamics and navigation system errors.

Using a runway separation of 3,600 feet, a 2,000 feet NTZ, an airport elevation of 1,000 feet MSL, a TCV cylindrical volume, the updated blunder rates and the pilot and controller response times mentioned previously, the TCV risk per operation was determined to be 7.28×10^{-10}. This met the acceptable level of risk under current FAA Safety Management System (SMS) guidelines of 1×10^{-9} per operation. Airports where the airport field elevation is more than 1,000 feet Mean Sea Level (MSL) require an approved FAA aeronautical study.

This TCV risk per operation was mostly attributable to the updated blunder rates. As important, however, was changing the TCV volume from a sphere to a cylinder. This change resulted in meeting the new SMS acceptable level of risk, at a reduced of runway spacing of 3600 feet. Previous CSPO studies used a TLS of 4×10^{-8} with the spherical TCV volume. Any TCV volume utilized during analysis must result in meeting the current acceptable level of risk of 1×10^{-9} per operation. The previously used spherical TCV volume would not have allowed the runways to be separated by 3600 feet, even with the updated blunder rates.

Fast-time simulations were performed using ASAT^{ng}. The purpose of the simulations was to develop a collision rate that can be compared to the TLS. The probability distributions for CRT and PRT developed from the DCEs were used in the ASAT^{ng} simulations. Probability density functions for aircraft performance parameters for the A330 and B737 were also developed from the PRT study. Aircraft performance parameters for the Boeing 747-400 and the Embraer Regional Jet are resident in ASAT^{ng}. The simulations utilized heavy, large and small aircraft categories, having different approach speeds and dynamics in response to pilot inputs, to develop the traffic mix which is representative of the traffic at the airports where operations are simulated. The B747-400 and A330 are both representative and subsets of the heavy category, while the B737 and ERJ are representative of the large and small categories, respectively.

Four scenarios of interest were developed for the Monte Carlo study. In the first scenario, an aircraft turned toward the second aircraft at an angle of 30° from the localizer course and continued in level flight. In the second scenario an aircraft turned toward the second aircraft at an angle of 30° from the localizer but continued descending at the same vertical speed it had at the initiation of the blunder. The remaining two scenarios were the same with the exception that the blunder angle was 20°. The level and descending flight conditions were chosen since both conditions exist in the operation and from previous studies the risks are different. No determination has been made of the prevalence of a descending or level blunder. The choice was made to cover the two equally.

In each simulation, the evading aircraft was randomly placed between the final approach fix and

0.5 NM from threshold. Since the standard in-trail separation distance was three miles, the blundering aircraft was randomly placed between ±1.5 NM relative to the evading aircraft. Each aircraft was randomly provided with a navigation error relative to the localizer and glide slope using probability distributions from the ICAO Collision Risk Model (CRM). Each aircraft was assigned an airspeed from a uniform distribution of speeds appropriate for the aircraft type.

In each ASAT^{ng} simulation run, the smallest separation distance of the two aircraft as they flew simulated flight tracks, called the closest point of approach (CPA), was recorded along with the position of the blundering aircraft relative to the evading aircraft. If the blundering aircraft's Center of Gravity (CG) penetrated a cylinder with a radius of 265 feet and a height of 160 feet (±80 feet) centered at the evading aircraft's CG, then a TCV occurred. Although, it was possible for the blundering aircraft CG to penetrate the cylinder without a resultant collision, for simplicity, every TCV was considered to result in a collision.

7.1 Probability of a TCV by Blunder Angle

After a large number of simulation runs have been performed, the number of TCVs are used to estimate the rate or probability of a TCV resulting from a blunder. The risk of a collision due to a blunder for a given blunder angle can then be computed from a risk or probability equation. In order for a TCV to occur a sequence of events must occur. A blunder, denoted BL in the equation, must occur. The blundering aircraft must be aligned so that a TCV will occur without timely action from both the air traffic controller and the pilot of the evading aircraft. An aligned blunder is called an "at-risk blunder" and is denoted by ARB in the equation. In addition the blundering aircraft must not respond to ATC directions to return to the localizer course. This is called a non-responding blunder, or NRB. The equation can be written as follows:

$$P(\text{Collision}) = P(\text{TCV}|\text{NRB} \cap \text{ARB} \cap \text{BL}) \times P(\text{NRB}|\text{ARB} \cap \text{BL}) \times P(\text{ARB}|\text{BL}) \times P(\text{BL}) \qquad (1)$$

The symbol "∩" stands for "and". The symbol " | " stands for "given".

The first factor in the equation:

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

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

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

is the probability that the blundering aircraft does not respond to ATC instruction to return to course given that an at-risk blunder has occurred. The accepted value of this factor is 1/100.

The third factor:

$$P(\text{ARB}|\text{BL})$$

is the probability that the blunder is an at-risk blunder given that a blunder has occurred. The value of this factor was estimated from the simulation data. It was found to be 3.17×10^{-2}.

The fourth and final factor:

$$P(BL)$$

is the probability of a blunder of a specified angle such as 20 degrees.

7.2 Total Probability of a TCV

Equation 1 is used to find the probability of a TCV for a particular type of aircraft (heavy, large, etc.) and a particular blunder angle (20 degrees, 30 degrees). To find an estimate of the probability of a TCV for a fleet of aircraft of varying types and for a range of blunder angles, other equations must be developed that build upon equation 1.

7.2.1 Probability of a TCV for a Fleet of Aircraft by Blunder Angle

A fleet of aircraft that participate in CSPO at a particular airport will consist of a number of different brands such as Airbus, Boeing, and Embraer with different performance capabilities and different weight categories. Records of aircraft arrivals must be examined to determine the percentage of different types or categories of aircraft that typically arrive at the airport of interest. This examination can be very comprehensive and list the percentages by brand and type (e.g. Boeing 747-400, Boeing 737-800, Airbus 330-200, and Embraer RJ-145) or it can be much more coarse and group the aircraft by weight category (large, heavy, small). The type or category of the evading aircraft is of particular importance since its ability to turn and climb corresponds to its ability to avoid collision with the blundering aircraft.

For simplification, assume that the aircraft are sorted by weight category. Then the probability that an arriving aircraft is in the large category will be denoted as P(Large). The probability that an arriving aircraft is in the heavy category will be denoted as P(Heavy) and the probability that the aircraft is in the small category will be denoted as P(Small). Then for a given blunder angle such as 20 degrees, equation 1 is applied to each aircraft category. From equation 1, the probability of a TCV given the evading aircraft is heavy is denoted by P(TCV|Heavy). The probability of a TCV given the evading aircraft is large is denoted by P(TCV|Large) and the probability of a TCV given the evading aircraft is small is denoted by P(TCV|Small). The probability of a TCV for a particular angle is computed using the following equation.

$$P(TCV) = P(TCV|Small) \times P(Small) + P(TCV|Large) \times P(Large) + P(TCV|Heavy) \times P(Heavy) \quad (2)$$

If the aircraft are sorted by aircraft brand and type, the computation of P(TCV) would be done in a similar manner, but instead of only 3 terms as in equation 2, there would be as many terms as brands and types of aircraft.

7.2.2 Probability of a TCV for a Fleet of Aircraft

The computations of equation 1 and equation 2 are done assuming a certain blunder angle such as 20° or 30°. To find the probability of a TCV over the range of all blunder angles requires a pdf of blunder angles. An insufficient number of blunder angles are now available to develop a pdf since at least 100 blunder angles are required. Therefore histograms of blunder data have been prepared and the probability of the occurrence of a blunder ranging from 15° to 25° and ranging from 25° to 35° has been estimated using binomial probability density function methods.[11] The probability of a blunder between 15° and 25° will be referred to as the probability of a 20° blunder and the probability of a blunder between 25° and 35° will be referred to as the probability of a 30° blunder. The probability of a 20° blunder was found to be 2.55×10^{-5}. The probability of a 30° blunder was found to be 1.18×10^{-5}.

The total probability of a TCV is found by first computing the fleet mix probability from equation 2 for each blunder angle and then finding the sum of those probabilities. The result is the following equation.

$$P(TCV) = P(TCV|20° \text{ blunder})\times P(20° \text{ blunder}) + P(TCV|30° \text{ blunder})\times P(30° \text{ blunder}) \quad (3)$$

7.3 Sensitivity Analysis

A test environment can sometimes lead to erroneous sample results. For example, in the real-time simulations used to collect pilot and controller reaction times, blunders are simulated at an unrealistic rate. Since each pilot or controller participates in numerous blunder scenarios there is the possibility that reaction times are shortened due to the learning effect. The investigator can gain insight into the significance of the learning effect by a process called sensitivity analysis. In this case, the mean of the controller or the pilot response time can be shifted or increased by known increments to determine the effect of longer response times than those observed during the real-time simulation.

The mean of a distribution used in a Monte Carlo simulation can be easily increased during the simulation by adding the desired amount of the shift to each random value generated by the probability density function.

7.4 Total Probability of an Accident

The process and equations described in section 7.2 are used to find the probability of a TCV. The probability of a TCV is actually a rate. The units of the rate are TCV per run or TCV per approach pair since a run consists of two aircraft flying instrument approaches. For risk analysis purposes, the TCV rate must be converted to accidents per approach.

Since the target level of safety is an accident rate, the probability of a TCV must be converted to the probability of an accident. A TCV is assumed to result in a collision and a collision is assumed to result in the loss of both aircraft and their passengers. Therefore, a TCV results in two accidents or there are two accidents per TCV. There are two approaches in an approach pair so there is one approach pair per two approaches. To convert a value from TCV per approach pair to accidents per approach do the following: multiply the value by 2 accidents per TCV and multiply again by 1 approach pair per 2 approaches. This is summarized as follows:

(TCV / 1 appr pair) × (2 acc / TCV) × (1 appr pair / 2 appr) = (accidents / approach)

Therefore, the results of the process and equations of section 7.2 are the probability of an accident per approach.

Table 2 contains the values of the factors and terms used in equations 1, 2 and 3. The traffic mix rates represent 20% Heavy traffic and 80% Large traffic. The At-Risk rate was found by running ASAT^{ng} with no evasion maneuvers and counting the number of TCVs. The blunder rates were taken from reference 11. The non-responding rate is based on expert opinion.

	A330	B738	B744	ERJ
Traffic Mix	0.1	0.4	0.1	0.4
At-Risk Rate	0.0317	0.0317	0.0317	0.0317
Non-Responding Rate	0.01	0.01	0.01	0.01
20° Blunder Rate	0.0000255	0.0000255	0.0000255	0.0000255
30° Blunder Rate	0.0000118	0.0000118	0.0000118	0.0000118

Table 1: Factors Used in Risk Analysis

Table 3 contains the results of ASAT^{ng} simulation runs. Runs were performed by aircraft type, blunder angle, and blunder type. Two types of blunders were simulated, level blunders (LB), i.e., the blundering aircraft maintained the altitude it had when the blunder was initiated, and descending blunders, i.e., the blundering aircraft continued to descend along the glide path. Each TCV entry indicates the number of TCVs occurring in 100,000 runs. Sensitivity analysis was performed on the combined controller and pilot reaction time by adding seconds to the combined time. This had the effect of shifting the mean of the total reaction time to the right. For example, under the column headings, Delta Time Seconds, 1, the mean total reaction time was increased one second. The row labeled “TCV per Approach Pair” contains the TCV rates by delta time. The row labeled “Accidents per Approach” gives the probability of an accident during a CSPO approach.

			Delta Time Seconds			
Aircraft Type	Blunder Angle	Blunder Type	0	1	2	3
			Number of TCVs per 100K runs			
A330	20	LB	2669	3368	4194	4882

		DB	1671.5	2376	3324	4395
	30	LB	19363	19601	19375	18566
		DB	18545	22027	25280	29162
B738	20	LB	1927	2571	3330	4080
		DB	1231	1826	2500	3513
	30	LB	17334	17900	18305	17742
		DB	16647	20017	23718	27485
B744	20	LB	640	919	1371	1973
		DB	1428.5	2005	2897	3910
	30	LB	20363	21136	20897	20360
		DB	16432	19969	23114	26614
ERJ	20	LB	219	351	498	740
		DB	1270	1788	2663	3657
	30	LB	14074.5	14786	14795	14574
		DB	17124	20653	24569	28290
TCV per Approach Pair			7.28E-10	8.44E-10	9.68E-10	1.09E-09
Accident per Approach			7.28E-10	8.44E-10	9.68E-10	1.09E-09

Table 2: TCV Rates and Expected Accident Rates

Since the Target Level of Safety is 1×10^{-9} accidents per approach, the operation meets the TLS. The sensitivity analysis indicates that the mean total response time could be increased by 2 seconds and the TLS would still be met. If the mean total response time were increased by 3 seconds, the probability would exceed the TLS by only 9×10^{-11}.

This study did not take into account the risk of collision with obstacles during a breakout. Evaluation of the procedure should include consideration of the obstacle environment which might affect aircraft involved in any breakout.

8.0 HUMAN FACTORS ANALYSIS

Based on Pilot Observer notes, pilot performance improved after completing a number of blunder scenarios during the DCE. Crew reaction times were likely decreased due to a learning effect that allowed them to have a strategy/plan in place prior to hearing the entire breakout communication. Crews evolved from a step by step methodical process to a predicted reaction process based upon their learned behaviors.

While TCAS can enhance pilot situational awareness, confusion occurred when TCAS RAs were followed in quick succession by a breakout instruction. Pilot performance seemed to improve with TCAS TAs, probably due to the increased situational awareness. However, TAs may have encouraged some pilots to fixate on the TCAS display as they anticipated an RA/breakout maneuver. Pilots typically complied with the TCAS RA over a breakout instruction, but comfort levels were reduced and confusion interfered with their performance. When RAs and breakout instructions conflicted, confusion and workload increased.

An Attention All Users Page (AAUP) was used in these studies. The AAUP informs the pilots to expect the phraseology contained in the FAA Order JO 7110.65. The AVS OSA for SIPIA operations requires controllers to use the phraseology specified in Order JO 7110.65 when giving breakout instructions. Despite these requirements, the importance of the use of "Traffic Alert" did not appear to be understood by the controllers. This was apparent by the low percentage of correctly phrased breakout instructions during the DCEs.

Controller CSPO training, experience and daily operations in their current positions do not provide a high level of exposure to blunders and the required corrective action. 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.

Controller phraseology must be effective enough to minimize total response time. Breakout phraseology should include the minimal basic information that is required to convey the meaning and intent of the controller's message (e.g. aircraft call-sign, direction to turn, etc.). The sequence of those words may not be as critical as the essential elements of information to prevent a collision. It is recommended that Order JO 7110.65 phraseology, as specified in the AVS OSA, be used wherever SIPIA are performed.

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

Special pilot training is required to fly an ILS PRM approach. An AAUP is published for all ILS PRM approaches. These conditions must be utilized in the recommended operation.

See Appendix A for details of the Human Factors Analysis.

9.0 TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEM (TCAS) STUDY

TCAS is a significant factor during parallel approach operations, which was evident in the July 09 DCE. Nuisance RAs have a detrimental effect upon pilot and controller workload during an already exacting operation. This is a result of the close proximity of aircraft executing the approaches and the necessity for operational integrity. Furthermore, the effect of a TCAS RA upon the procedure itself can significantly reduce the capacity gains being sought after; even with occurrence rates ≤ 3%.

Independent and separate TCAS evaluations by Air Traffic Simulation, Inc. (ATSI) and Massachusetts Institute of Technology-Lincoln Laboratory (MIT-LL), at the reduced runway separation of 3,600 feet with zero offset ILS navigation, yielded a probability of RA occurrence at ≤ 3% when overtake speeds are less than 50 knots when both aircraft use the AP and 30 knots if both aircraft are hand flown using the FD.[13]

The *"Traffic Alert and Collision Avoidance System Resolution Advisory Impact on Approaches* *to Closely Spaced Parallel Runways"* concludes that TCAS system interference should not be excessive during CSPO at 3600 feet. The report contains a summary of the effects each parameter was found to have on the likelihood of a TCAS RA with respect to any particular parameter within the approach design to parallel runways.[13] This TCAS study was conducted using a localizer antenna to threshold distance of 12,467.2 feet with a course width of 700 feet at the threshold and a final length of 10 NM. Shorter runways and longer finals result in wider localizer course widths. Therefore, this study may be too limited to fully address the effects of approach design parameters used for SIPIA operations at reduced lateral runway spacings.

10.0 CONCLUSIONS AND RECOMMENDATIONS

The recommended dual operation is based upon runway spacing of 3,600 feet or greater with a No Transgression Zone (NTZ) of 2,000 feet. Runway stagger was not evaluated because it is not a factor that adversely impacts the overall risk. The operation utilizes an Airport Surveillance Radar (ASR-9) with 4.8 second update rate, Standard Terminal Automation Replacement System (STARS) Final Monitor Aid (FMA) with a color digital display, 4:1 Aspect Ratio (AR), visual and aural alerts. With the exception of high update rate (HUR) surveillance, this operation has all the requirements of FAA Order JO 7110.65, Air Traffic Control, paragraph 5-9-8; "*SIMULTANEOUS INDEPENDENT DUAL ILS/MLS APPROACHES - HIGH UPDATE RADAR*".[1]

Since Wide Area Augmentation System (WAAS) Localizer Performance with Vertical guidance (LPV) and Ground Based Augmentation System (GBAS) Landing System (GLS) provide lateral performance comparable to ILS, they are included as acceptable navigation systems. Only ILS, GLS and LPV with vertical guidance may be used. This operation does not allow the use of LNAV/VNAV, LOC ONLY, RNAV or RNP.

This operation requires the aircraft to be flown using the FD or AP. It is recommended that autopilot coupled approaches be used to the maximum extent possible.

There are training implications from both a pilot and controller standpoint. 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. Special pilot training is required to fly an ILS PRM approach. An AAUP, which informs the pilots to expect the phraseology contained in the FAA Order JO 7110.65, is published for all ILS PRM approaches. The conditions above, and those contained in the AVS OSA, must be utilized in the recommended operation.

Future pilot and controller response time DCEs may be required if any NAS parameter(s) or FAA Order(s) change which could influence response times.

It is recommended that:

- further testing and analysis be conducted in the following areas:

    - RNAV/RNP (GPS) approach capabilities
    - Triple and quadruple approach capabilities
    - Use of Automatic Dependent Surveillance - Broadcast (ADS-B)
    - HUR operations

- airports implementing these procedures coordinate with AFS to evaluate the operation. The following areas should be addressed:
    - the predicted NBO rate for the runway length and length of final
    - the impact of TCAS RAs due to runway length and length of final
    - the obstacle environment which might affect aircraft involved in any breakout

These recommendations are limited to Airport Surveillance Radar (ASR-9) with a 4.8 second update rate, Standard Terminal Automation Replacement System (STARS) Final Monitor Aid (FMA) with a color digital display, 4:1 Aspect Ratio (AR), visual and aural alerts; Instrument Landing System (ILS), Wide Area Augmentation System (WAAS) Localizer Performance with Vertical guidance (LPV) and Ground Based Augmentation System (GBAS) Landing System (GLS) navigation systems with vertical guidance. The results of these studies do not apply to LNAV/VNAV, LOC ONLY, RNAV or RNP.

REFERENCES

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APPENDIX A HUMAN FACTORS ANALYSIS

PART I PILOT HUMAN PERFORMANCE EVALUATION

Test Methodology

The July 2009 PRT data collection effort (DCE) was conducted over a two week period with 10 crews in the Airbus 330-200 (A330) and 10 crews Boeing 737-800 (B737) Level D qualified flight simulators. The crews are annotated as crews 1-5 in the 330 and crews 6-10 in the B737. The March 2010 PRT was conducted over a two week period with 5 crews in the A330 and 5 crews in B737 simulators, without the TCAS RA function. This was inhibited due to excessive RAs interfering in the July 2009 DCE.[8] In both data collection efforts, subject pilots were to be qualified and current in the aircraft type, and active Part 121 air carrier pilots. In the case of limited access to current and qualified A330 pilots, pilots that met FAR Part 121 currency and qualification requirements in the A320 were used in lieu of current A330 pilots. Crews consisted of Captains (CA) and First Officers (FO) from the same company in each aircraft simulator each day. In case of an unplanned pilot absence, the test director substituted a trained FAA pilot for the sole purpose of pilot monitoring (PM) duties.

During the data collection in the B737, a total of 30 pilots (15 CA and 15 FO) flew as subjects. Out of 30 pilots, four pilots were not qualified in accordance with the test plan and their data were not analyzed. Some factors that may have influenced pilot performance included: flight display differences between the AFS-400 flight simulator(s) Primary Flight Display (PFD) and Navigation Display (ND) compared to the air carrier aircraft, and three of the 15 crews consisted of pilots who were not from the same airline.

In the A330, out of 30 pilots, four pilots were not qualified in accordance with the test plan and their data were not analyzed. Only one of the 30 pilots was current and qualified on the A330. The remaining pilots were current and qualified in the A320 in accordance with the test plan. During the March 2010 DCE, 9 out of 10 pilots were from the same airline. The tenth pilot was a Check Airman from another airline and sat in the FO seat for the DCE. As a result of this pilot's increased training and testing exposure, the pilot's performance may not represent an accurate sampling of the Airbus pilot population.

A pre-brief was conducted with the subject pilots and the observers using the briefing guides contained in test plan. Approach charts were also provided to the participants. The approaches and the Attention All User’s Page (AAUP) were briefed as part of the aircrew coordination brief at the start of each day.

A Human Factors (HF) observer, a flight simulator operator, and a pilot observer were located inside each of the simulators. The simulator operator and pilot observer may have been the same person if a suitable pilot observer acceptable to the test director was not available. After each run, the HF observer gave the subject pilots a post-run questionnaire to complete while the simulator operator re-configured the simulator for the next scenario. After the test completion, pilots completed a post-simulation questionnaire.

Human Performance

The Human in the Loop (HITL) elements of this analysis were based on pilot/crew performance, primarily as it related to controller breakout instructions. The HF analysis includes, but is not limited to: perceived pilot workload changes, primary and secondary task performance, visual scanning and acquisition strategies during all phases of the approach, and crew coordination. The HF studies analyzed how well aircrews develop piloting strategies and how potential limitations (human, environmental and aircraft design) might affect the development of those strategies. The analysis includes both subjective and objective measures. Subjective performance measures included post-run and post-simulation questionnaires, designed specifically to solicit comments and opinions from the test subjects.

The primary task measures included all those tasks and maneuvers directly associated with and specific to performing closely-spaced parallel operations, e.g., maintaining the speeds and altitudes assigned by Air Traffic, precisely flying the ILS course, and promptly executing the breakout instructions issued by the controllers. Secondary task measures included all those other tasks considered part of normal flight duties, e.g., cockpit/ATC communication procedures, timely and accurate accomplishment of checklists, etc.

A multi-dimensional rating procedure was used with the questionnaires, intended to capture subjective measures of crew's sense of realism, perceived comfort level and perceived level of both individual and crew workload. A single-page, six-question form was used for the post-run questionnaire. That questionnaire was presented to the subjects via an Electronic Flight Bag (EFB), located immediately to the left or right of each crew member. It took the crew no more than 3 minutes to complete the post-run questionnaire. Additional crew performance measures were taken through observation of pilot/crew performance. Cockpit observers were unobtrusively located in the flight simulators rear observer seat to record actions, behaviors and data relative to the operation. The degree of difficulty of each scenario was slightly manipulated to elicit certain levels of both crew and individual pilot workload. During periods of potentially heightened activity or workload, reaction times, latency of task completion or task shedding may have taken place. These events were recorded by the observers for later analysis.

Dependent Variables

Dependent variables were elicited results of independent variable manipulation. The variables evaluated as part of the HF analysis included:

1. Subjective workload and comfort level response and observation of performance.
2. Stabilized Flight Characteristics, e.g. bank angle, pitch angle, yaw angle, altitude variation, and airspeed as they relate to subjective and observational input.
3. Pilot response to breakout instructions.

General

Crews commented that they did not have any problems flying in close proximity to parallel traffic, but their performance contradicted this during the crew's first few runs. After the initial run(s), most perceived an increased comfort level with experience, possibly due to a learning effect. They also noted that any comfort gained from the learning effect may have been offset by fatigue toward the end of the session(s).

The differences between Airbus and Boeing technology were observed during the DCEs. For example, when coupled to the autopilot, A330 pilots have to take multiple steps to uncouple the autopilot. Pilot comments reveal that workload increased during this procedure. Pilot comments also reveal that Airbus training and operational procedures have pilots flying almost exclusively with autopilot and auto-throttles engaged during all operations. The AAUP specifies that all breakouts must be hand flown. In addition, subject pilots were briefed to disengage the autopilot and manually fly any deviations from nominal flight profiles. Subject pilots commented that their comfort levels were degraded as a result. This was not corroborated by post run subjective response data.

B737 crews had less workload with blunder scenarios than A330 crews, due to less automation control and fewer steps to uncouple. Also, a majority of the B737 crews indicated that closely-spaced parallel operations would not be problematic, with the exception of those aspects that displayed commonality between the aircraft types.

During the July 2009 DCE, the first set of 10 crews in both the Airbus and Boeing experienced a very high rate of RAs. During the March 2010 DCE, the second set of crews (5 each in the Boeing and Airbus) flew with the TCAS RA function disabled.

Subjective Pilot Response Data (see figures 1-4)

Subjective responses to workload did not vary appreciably across all crews. Pilots' stated in the post-run questionnaire(s) that their workloads were not significantly different with or without an RA. However, this is contradicted by the pilot observer notes and debriefing comments. The pilots stated, during the debrief(s), that the scenarios with RAs increased both cognitive and physical workload.

Common References Across Both A330 and B737 Crews Included:

1. Proper ATC Breakout phraseology was expected; if other than proper phraseology was used, the action expressed by the wording became important. Voice inflection also made a difference in the crews reaction, such as "IMMEDIATELY".

2. Several crews mentioned that comfort levels would be increased if they had visual acquisition of parallel traffic. (Not possible in IMC conditions).

3. There is a potential for becoming desensitized to the aural TCAS TAs because of the increased frequency during the test. RA reaction time may have been increased.

4. All crews commented that there would be training implications, without specifying what those specific training requirements would be.

5. All crews generally felt that changing call-signs for each run was taxing and added to the workload. Secondary task shedding may have resulted (e.g. latency in responding to air traffic instructions or radio calls).

6. Learning effect acquired from multiple approaches may have offset the effects of fatigue induced crew performance degradation.

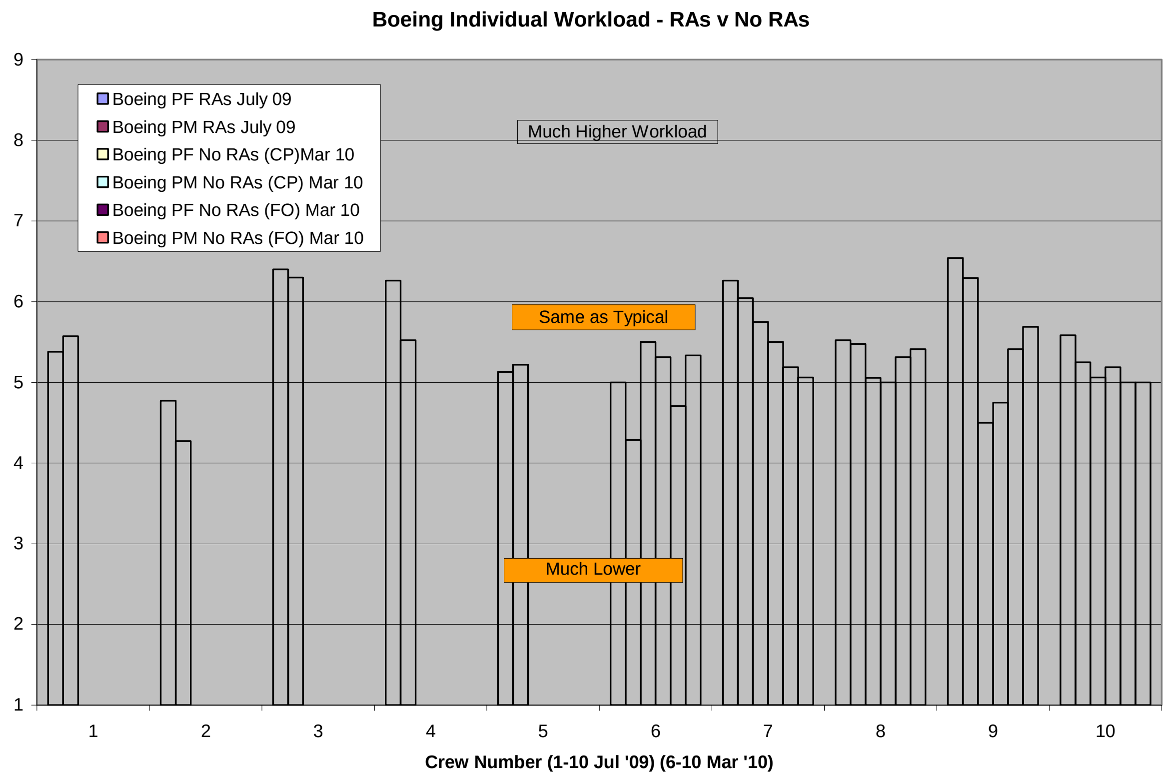

FIGURE 1

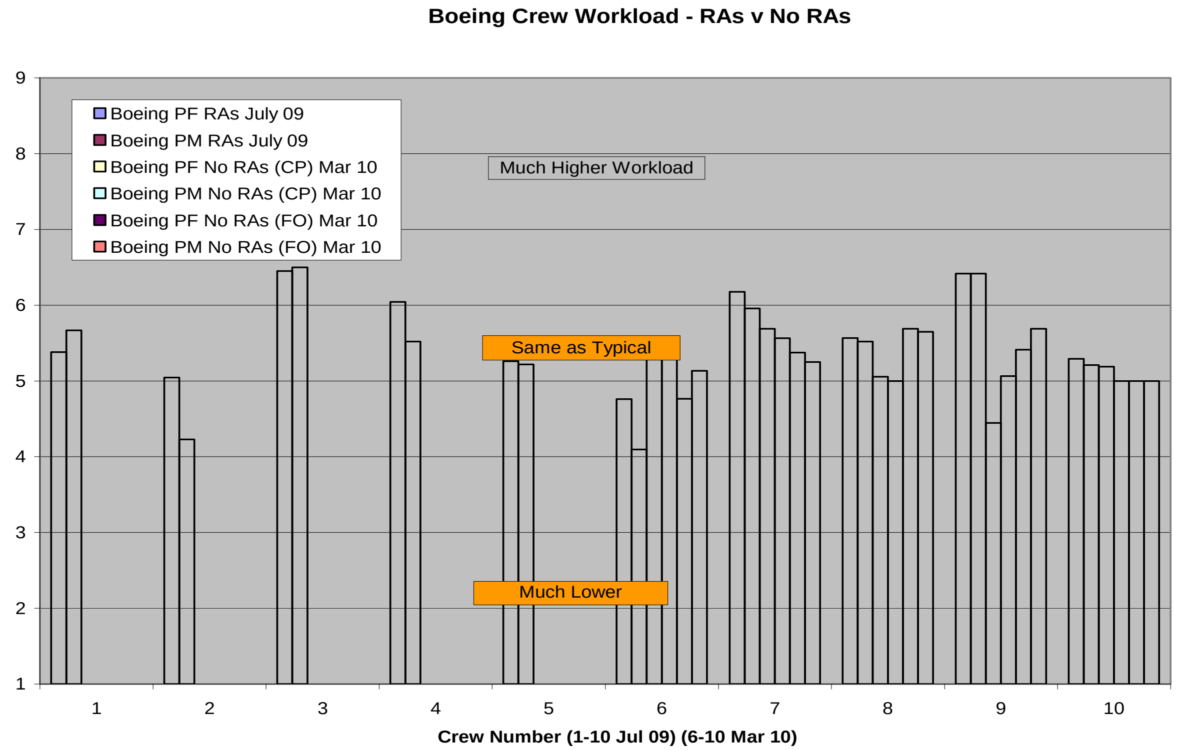

FIGURE 2

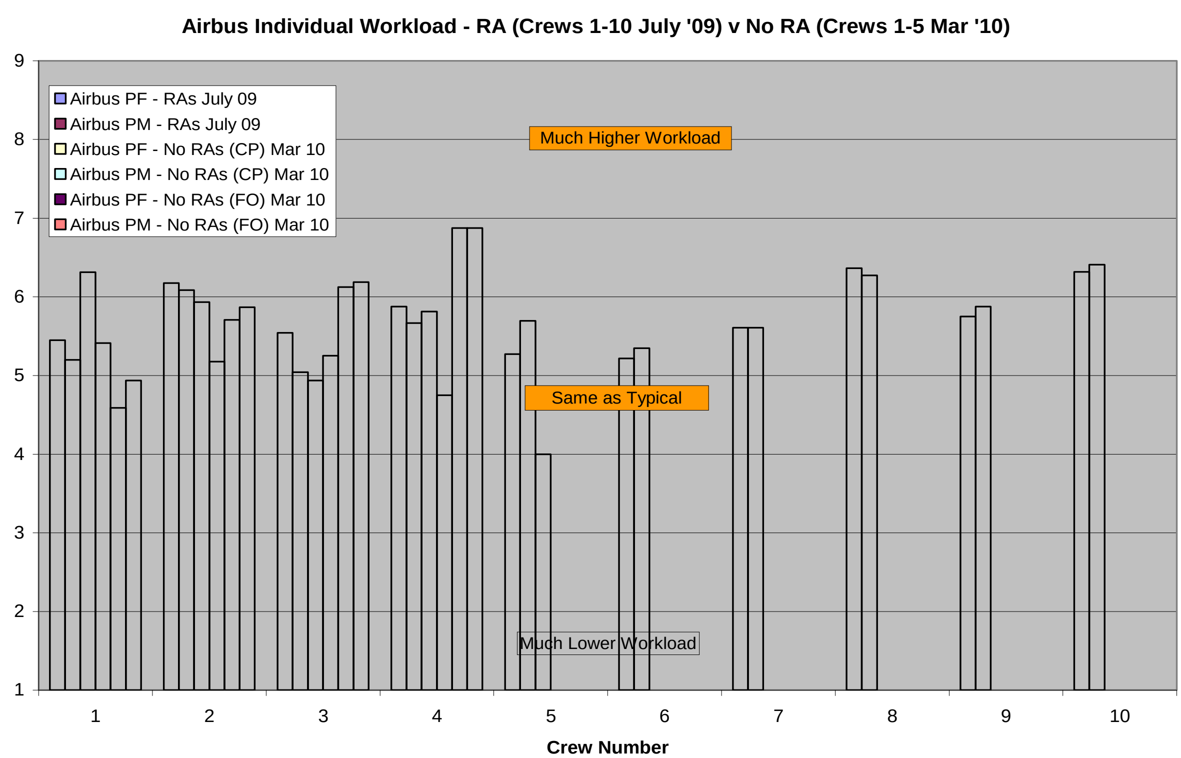

FIGURE 3

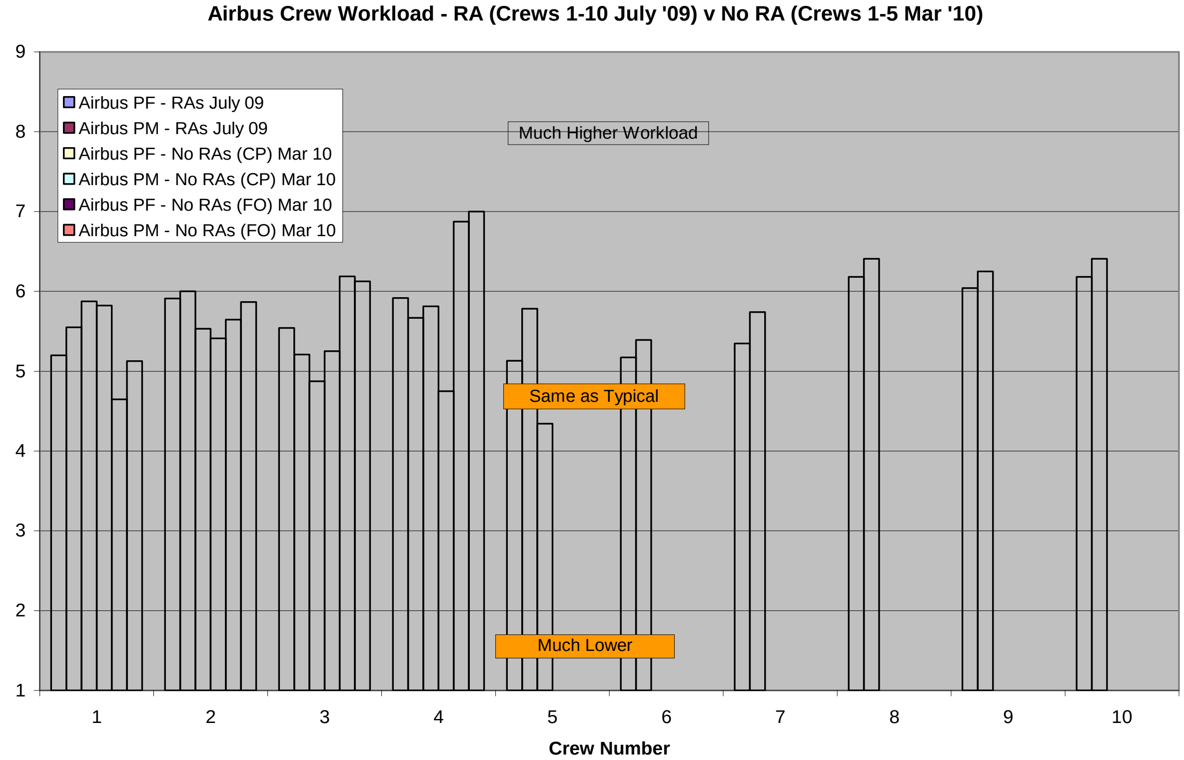

FIGURE 4

Most crews felt it would be better if some "stagger" between aircraft were introduced, as opposed to paired, side by side operations. Several wanted to adjust speed to purposely introduce a stagger to increase their perceived comfort level during the scenarios.

The key to expeditious breakouts within acceptable parameters appeared to be related to the crew's familiarity with their company's defined breakout maneuver. For example, the Day 7 Captain cycled the flight directors (F/Ds) OFF, then ON, and then re-established HDG SEL. He stated this was Company SOP. Following that, he emphasized this was not a go around, so he did not want the FO, the pilot flying in this case, to utilize Take-Off Go Around (TOGA) (this was technique, not SOP). It was a controlled procedure and was more effective when the crew first established the turn and the climb/descent, then began the clean-up/reconfiguration. The Day 10 Captain knew the Company breakout SOP and emphasized in the pre-approach briefing that if they received a breakout instruction, it would not be a go around procedure (technique), but a controlled breakout maneuver. The only difference between the two SOPs was that the Day 10 Captain waited to re-engage the F/Ds until after level off, while the Day 7 captain was quicker to re-engage the F/Ds. This resulted in the Day 10 crew flying the entire breakout procedure using raw data, while the Day 7 crew had access to F/D data, rather quickly after breakout initiation. The most effective control method appeared to be when the TOGA mode was not activated. When TOGA was engaged, control of the aircraft was more problematic.

Some crews appeared to be unfamiliar with their company's breakout procedure. All of the carriers represented have breakout procedures in their manuals, yet one crew stated they were not aware of that. The crews that were unfamiliar with their company's procedure had observed aircraft control performance deviations. When referencing the aircraft manufacturer guidance, both call for the F/Ds to be OFF.

During the March 2010 data collection effort, TCAS RAs were disabled, which allowed collecting PRTs based solely on ATC breakout instructions. Overall, pilots found complying with breakout procedures challenging but acceptable. Two Captains were familiar with their company breakout procedures and were very effective in their coordination and aircraft control. The remaining pilots were less familiar, which was evident in their first few runs. Many pilots commented that their company either didn't have specific breakout procedures or it had been so long since they had received breakout procedure training that the pilots couldn't remember them.

Most A330 pilots commented that they rarely hand flew and their hand flying skills had markedly decreased. Many A330 pilots desired to fly breakout maneuvers using the autopilot in order to maintain a higher level of Situational Awareness (SA). An apparent decrease in SA was observed during hand-flown breakouts in the A330.

In the A330, the selection of Take-Off Go-Around (TOGA) switches the aircraft navigation system to Go-Around Track (GA TRK) and the F/Ds re-engage, even if they had been selected off by the PM. This means that if the PF wants to select TOGA mode, he must do so prior to the PM turning off the F/Ds. These system interface issues resulted in an observed loss of SA and crew confusion during RAs and breakouts. Similar problems were observed in the B737 due to the loud volume of the autopilot disconnect warning that tended to interfere with communications.

Workload

Pilots commented their workload was extremely high during breakouts. Many felt the workload was unacceptably high, especially if ATC was issuing breakout instructions while TCAS maneuvering was under way. However, pilot post-run questionnaire responses did not validate this perception. Some pilots indicated the workload was acceptable. Others referred to a breakout with an RA as an "emergency procedure", while one A330 pilot called the situation "out of control". As the crews progressed through the scenarios, both comfort and workload moved from moderate to relatively benign levels.

Negative Habit Transfer

Pilots indicated they tended to revert to standard go-around procedures, especially during the first couple of runs, since they rarely practice breakout procedures. Breakout procedures are markedly different from standard go-around procedures and can lead to flight director guidance that is contrary to ATC breakout instructions. Most pilots felt that training would not solve this problem since breakout procedures are seldom, if ever, flown. For example, one crew stated that their carrier requires breakout training as part of annual recurrent training, yet their performance was not better.

TCAS versus Controller Instructions

During the July 2009 evaluation, the use of TCAS corrupted the PRT data, since most of the scenarios resulted in TCAS RAs just prior to the issuance of ATC instructions. Pilots found the combination of TCAS RA compliance and simultaneously following an ATC breakout instruction to be extremely challenging.

Often, controllers did not recognize that pilots were responding to RAs and continued to issue instructions, some of which were contrary to the direction of the RA. This caused some crews to maneuver contrary to RA guidance. Pilot failure, or inability, to immediately notify ATC of the RA guidance compounded this problem. There were many instances where the crew did not hear or process controller breakout instructions while they were responding to and reporting an RA. Neither the pilots nor the controller(s) realized their attempt at communication had failed.

The pilot observer in the A330 simulator recorded scenarios with descending RAs that would not be acceptable in line operations from a safety standpoint. It was not unusual to see excessive descent rates and bank angles during descending RAs or descending breakouts. In one case, descent rates were in excess of 4,000 Feet Per Minute (FPM), and in another case bank angle approached 45 degrees.

Pilot debriefing comments indicated confusion and reduced comfort levels when the RAs were initiated in close temporal proximity to the breakout instructions. One crew mentioned that audio volume of RAs in the actual aircraft is much louder, to the point of masking some or all controller commands. Pilots felt their comfort levels increased as they progressed through a number of scenarios, however, all crews were uncomfortable with descending RAs. All crews stated that they would honor TCAS RAs over ATC instruction. This was contradicted by their actions.

TCAS does not incorporate information about Minimum Vectoring Altitudes (MVA). It does, however, inhibit descending RA instructions when the aircraft is less than 1000 feet (±100 feet) Above Ground Level (AGL). It must be noted that if above 1000 feet AGL, and within acceptable tolerances, a descending RA will be given if warranted and the aircraft may continue to altitudes less than 1000 feet AGL. During several scenarios, the Enhanced Ground Proximity Warning System (EGPWS) was activated in both the A330 and B737, issuing “Terrain, Terrain” warnings.

The close proximity of the parallel traffic displayed on TCAS was initially a distraction for the pilots. Some pilots devised and discussed escape strategies based on the displayed TCAS Traffic Alert (TA) target and altitude differential (above or below). This process may have reduced their reaction time to the actual RA or breakout.

Phraseology

The AAUP and DCE pilot in-briefings discussed the proper breakout phraseology. However, during the debriefing, only a couple of crews remained expectant to receive proper ATC breakout phraseology after experiencing numerous breakouts involving improper phraseology during the test. Despite this expectation, the use of the term "TRAFFIC ALERT", as the first part of the ATC breakout instruction, did not appear to have much, if any, effect on the crew's performance. Most of the crews did say afterwards that they believe the use of "TRAFFIC ALERT" is important regardless of the sequence. It should be noted anytime the word "immediate" was used the flight crews displayed an appropriate sense of urgency. If proper phraseology was not used, pilots reacted with immediacy to voice inflection and essential elements (e.g. call sign and direction).

Noise Factors

Cockpit noise from the A/P disconnect aural warning, combined with pilot workload, often interfered with or prevented the crew from hearing and processing the complete ATC breakout instruction.

PART II CONTROLLER HUMAN PERFORMANCE EVALUATION

Test Methodology

In the July 2009 DCE, there were many instances where the crew did not hear or process controller breakout instructions while they were responding to an RA. As a result, two HITL data collection efforts were conducted in August and December 2010 with the primary purpose of measuring Controller Response Times (CRT) during a blunder. Subject controllers were required to be full-performance-level controllers, qualified to control dual simultaneous independent ILS approaches, and were used as Final Monitor Controllers. 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 both DCEs, centered on controller phraseology in the breakout instruction and the aspect ratio of the STARS FMA.

Controllers were instructed to: "control as you do every day at your facility." After lengthy discussions during the post-simulation de-briefing, it became apparent that the concept of blunders and breakout instruction issuance is not consistent with day to day controller experiences. This influenced the use of phraseology during breakout instructions. 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 blunder events during SIPIA operations.

Controller Subjective Response Data

Subjective response data from each controller were elicited immediately following each final monitor session. Controller questionnaires were designed to obtain controller response in the areas of perceived workload, comfort and difficulty when compared to normal controller duties (See Figure 5 below). As the graph indicates, controller subjective feedback hovered at or slightly above the median value of 5. Controllers indicated they were somewhat uncomfortable during blunder events.

Phraseology

FAA Order JO 7110.65, 5-9-8, requires the following phraseology to be used during a breakout instruction: "TRAFFIC ALERT, (call sign), TURN (right/left) IMMEDIATELY HEADING (degrees), CLIMB AND MAINTAIN (altitude)."

During the 2010 CRT evaluations, only 7% of the final monitor controllers' instructions used the required phraseology. Four percent used the proper sequence of phraseology but omitted "Traffic Alert". This omission could be attributed to their day to day traffic management duties that typically do not involve breakouts, and from their respective TRACON SOP(s). For instance, several controllers used "Cancel approach clearance" before issuing the appropriate breakout instructions. Others simply directed the aircraft on a heading correction. Also, despite having been briefed on the proper phraseology prior to the test, "Traffic Alert", which is meant to convey urgency and prevent the clipping of aircraft call signs, did not appear to be understood.[1] During the DCEs, the aircraft call sign was typically stated first in the sequence.

Total response time is the sum of CRT and PRT. Controller response time was measured from the time of alert to the activation of the controllers push to talk (PTT) switch. The pilot response time is measured from the beginning of the controllers PTT to activation of aircraft controls. Therefore, the PRT is lengthened by any delay or error in controller instruction. Thus, the combination of efficient delivery of break instruction and the proper phraseology should yield the shortest total time.

Aspect Ratio

All but one controller were unfamiliar with the 4:1 AR of the FMA display. The 4:1 AR expands the display four times perpendicular to the final course. This exaggerates movement of the aircraft in the lateral direction and can provide a more definitive indication of any deviation from the final approach course. This exaggerated presentation coupled to multiple blunder scenarios primed the controllers to breakout parallel traffic at an earlier indication of a course deviation. This resulted in occasional Nuisance Breakouts (NBO). Some controllers stated that they waited for the red alert warning before directing a breakout.

Human Performance Observations and Potential Implications

- Visual and auditory alerts: Redundant alert coding (i.e. more than one modality) may have been a factor in controller reaction time, strategy and compliance. Some controllers paid more attention to, and reacted to visual representations of blunders; some reacted better to auditory stimuli; and some preferred both.

- Direct interaction between paired controllers was not necessarily a given. Some pairs relied heavily upon interaction, others did not.

- Whether controller pairs were using one monitor (shared between two controllers) or two, it was imperative that there were no physical barriers between them.

- The orientation of the test display was fixed (North up) and may not have been compatible with the orientation of the display at their facility. Several controllers stated that the difference in orientation caused an increase in mental workload.

- 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 final course.

- Performance could have been affected when mixing controller pairs from different facilities (i.e. different habit patterns, local requirements, cultural expectations, and display orientation). Controller pairs from the same facility tended to have more interaction with each other.

- The use of controller display tools and alerts vary between facilities, and not all facilities have STARS with FMA. Some controllers commented that they had other tools added to their displays that were not available during the DCEs. Some facilities only have a Common Automated Radar Terminal System (CARTS).

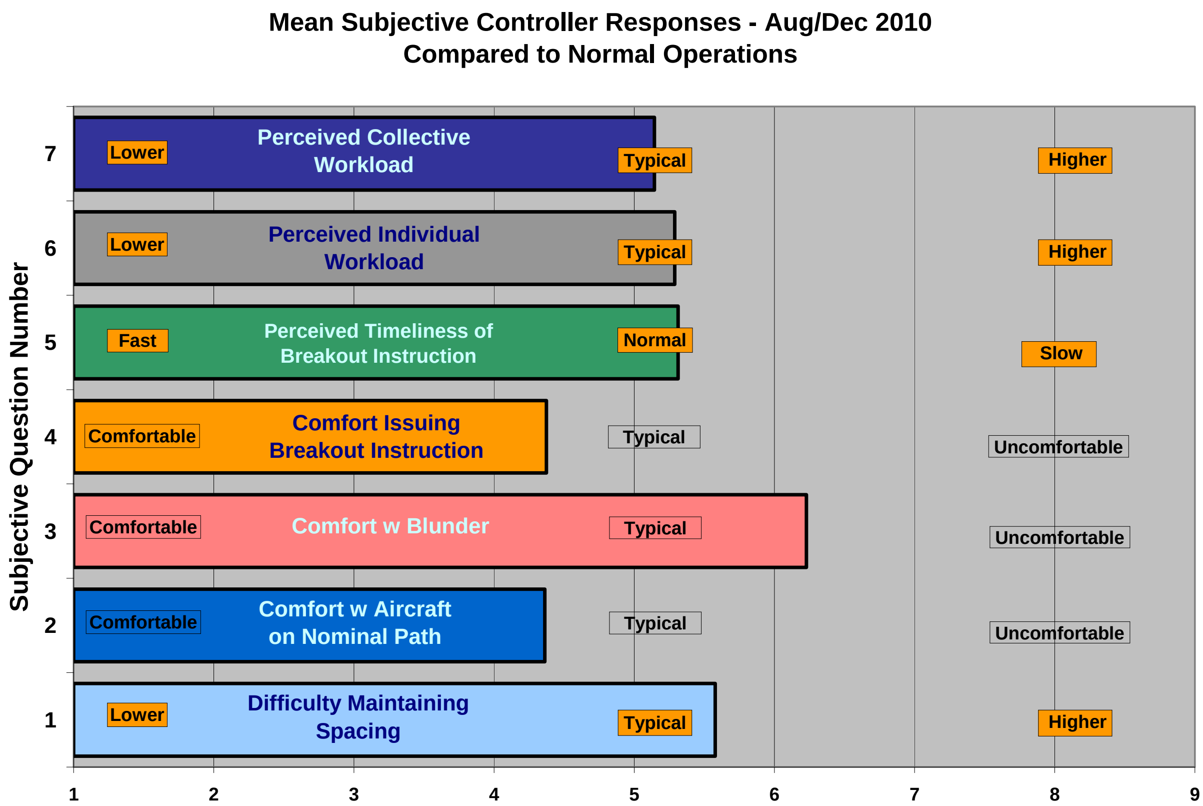
Mean Subjective Controller Responses - Aug/Dec 2010
Compared to Normal Operations
Subjective Question Number
7
Lower
Perceived Collective Workload
Typical
Higher
6
Lower
Perceived Individual Workload
Typical
Higher
5
Fast
Perceived Timeliness of Breakout Instruction
Normal
Slow
4
Comfortable
Comfort Issuing Breakout Instruction
Typical
Uncomfortable
3
Comfortable
Comfort w Blunder
Typical
Uncomfortable
2
Comfortable
Comfort w Aircraft on Nominal Path
Typical
Uncomfortable
1
Lower
Difficulty Maintaining Spacing
Typical
Higher
1 2 3 4 5 6 7 8 9

Figure 5