Safety Study Report
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Safety Study Report on Triple Simultaneous Parallel Instrument Landing System (ILS) Approaches using the Standard Terminal Automation Replacement System (STARS) at Covington/Cincinnati/Northern Kentucky International Airport (KCVG)

Gerry McCartor, AFS-440
Shahar Ladecky, Air Traffic Simulation, Inc.

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Flight Operations Simulation
and Analysis Branch, AFS-440
6425 S. Denning, Room 104
Oklahoma City, Oklahoma 73169
Phone: (405) 954-8191

Flight Systems Laboratory

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Flight Operations Simulation and Analysis Branch
Flight Technologies and Procedures Division
Flight Standards Service

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Reviewed by:

12/16/2005

Stephen W. Barnes **Date**
Manager, Flight Operations Simulation and Analysis Branch, AFS-440

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John W. McGraw **Date**
Manager, Flight Technologies and Procedures Division, AFS-400

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12. Abstract

FAA Order 7110.65P *Air Traffic Control*, section 5-9-7 (SIMULTANEOUS INDEPENDENT ILS/MLS APPROACHES- DUAL & TRIPLE) contains the current provisions governing air traffic control separation for independent ILS/MLS precision approach operations at airports with dual and triple runway configurations. The baseline system for these provisions was the Automated Radar Terminal System (ARTS), version IIIA, driven by an ASR-9 radar with the Data Entry Display Subsystem (DEDS) console or the Full Digital ARTS Display System (FDADS). The Standard Terminal Automation Replacement System (STARS), now being installed at airports across the National Airspace System (NAS), has superior resolution and many capabilities not available on older systems. AFS-440 was requested by the STARS Program Office to conduct a study (or studies) to verify that the new system is capable of achieving the same safety levels for simultaneous independent ILS approaches as the older system. A simulation using the AFS-440 Airspace Simulation and Analysis Tool (ASAT) was designed to look at aircraft performing simultaneous approach operations at the airport under STARS surveillance at Covington/Cincinnati/Northern Kentucky International Airport (KCVG)

Analysis of the results of the simulations indicated that triple ILS approaches for the current fleet mix tracked by the ASR-9/STARS and any reasonable variation would produce TCV rates that met the target level of safety for the KCVG runway configuration.

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Executive Summary

FAA Order 7110.65P *Air Traffic Control*, section 5-9-7 (SIMULTANEOUS INDEPENDENT ILS/MLS APPROACHES- DUAL & TRIPLE) is the current provision governing air traffic control separation, including No Transgression Zone (NTZ) monitoring, for independent precision approach operations at airports with dual and triple parallel runway configurations when runway centerlines are at least 4300 feet apart. These standards were developed from simulations performed by the Federal Aviation Administration (FAA) based on Instrument Landing System (ILS) precision approach operations to determine the parameters necessary to meet the target level of safety for the blunder scenario. This scenario involves two or more aircraft established on approach to parallel runways, where one of the aircraft (the blunderer) deviates from the approach path towards the adjacent traffic (the evader). When such a scenario occurs, the system must enable Air Traffic Control (ATC) to maintain safe separation between the blundering and evading aircraft. The baseline system for the simulations was the Automated Radar Terminal System (ARTS), version IIIA, driven by an ASR-9 radar with the Data Entry Display Subsystem (DEDS) console or the Full Digital ARTS Display System (FDADS).

The Standard Terminal Automation Replacement System (STARS) is being installed at airports across the National Airspace System (NAS). The STARS console has superior resolution and many capabilities not available on older systems. These additional capabilities come with considerable processing overhead; however, the available computing power has also increased substantially.

The Flight Operations Simulation and Analysis Branch, AFS-440, was requested by the STARS Program Office to conduct a study (or studies) to verify that the new system is capable of achieving the same safety levels for simultaneous independent ILS approaches as the older systems. The branch's Airspace Simulation and Analysis Tool (ASAT) has been used for a number of similar problems related to simultaneous approach operations. The tool models all components of the scenario (aircraft, avionics, pilot and controller, surveillance system, etc.) and performs a Monte Carlo simulation where all significant parameters are varied according to appropriate probability distributions. The purpose of the study is to determine the acceptability of STARS as a final monitor control system for ILS approach operations to parallel runways (duals, triples), without the necessity of waivers. Study results will also address acceptable mitigations against which any waiver requests would be considered.

It was requested that the first case to be examined would be Covington/Cincinnati/ Northern Kentucky International Airport (KCVG). The airport has installed STARS and is opening a new runway in December of 2005 that will allow triple simultaneous approaches. Runway spacing is approximately 4300 feet between 18R/36L and 18C/36C with 2240 and 5250 feet staggers between landing thresholds respectively. The spacing is approximately 6220 feet between 18C/36C and 18L/36R with 3240 and 2240 feet staggers between landing thresholds. See Figure 1 for the airport layout.

Since one of the runway separations was less than 5000 feet, a waiver was previously issued to approve the operation based on the use of the high-resolution color monitors with alert algorithms (see Appendix I). Those monitors were the STARS consoles and it was originally believed that they were equivalent to the Final Monitor Aid (FMA) system installed at Denver International Airport (KDEN) that had been previously studied (Reference 10). When the issue of the STARS processing requirements was raised, this study was initiated. A simulation was designed to look at ILS aircraft performing simultaneous approach operations at KCVG. Scenarios were run with both north and south traffic flows. Fourteen test scenarios were examined with 50,000 runs performed for each scenario.

The simulation factored in the fleet mix for KCVG based on data provided by the local Air Traffic Control. Aircraft performance was based on data collected from prior flight simulator tests and data provided by aircraft manufacturers. Each type of aircraft in the KCVG fleet mix was matched to the closest model in the ASAT repertoire. Because the current fleet mix is dominated by small regional jets, additional scenarios were designed to consider possible increases in the proportion of heavier jets. ILS tracking performance was based on International Civil Aviation Organization Collision Risk Model data for both the lateral and vertical displacements. Pilot and controller response times were based on data collected during the Multiple Parallel Approach Program testing. Pilot response times were based on distributions collected from line pilots. ATC response times were based on testing done on simulated 4300-foot triple simultaneous approaches with a FMA display and an ASR-9 radar. Surveillance system errors and delays were based upon information obtained from MIT Lincoln Labs reports for ASR-9 data and the STARS Program Office for STARS data. Additional scenarios were also run to examine the case where the STARS performance may be degraded.

The target level of safety (TLS) for the triple approach configurations was determined to be 4×10^{-8} (see Appendix D). From the TLS, a maximum acceptable Test Criteria Violation (TCV) rate can be derived (also Appendix D). The TCV rate for at-risk blunders must be less than 5.1% overall and less than 6.8% for each of the embedded dual operations. Analysis of the results of the simulations indicated that triple ILS approaches for the current fleet mix tracked by the ASR-9/STARS and any reasonable variations would produce TCV rates that met the target level of safety for the KCVG runway configuration.

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1.0 Introduction

1.1 Purpose and Structure of This Document

The purpose of this study was to provide a risk assessment for simultaneous independent parallel approach operations to Covington/Cincinnati/Northern Kentucky International Airport (KCVG) with a Standard Terminal Automation Replacement System (STARS) operating in Final Monitor Aid (FMA) mode using an ASR-9 radar system. The study used a Monte Carlo simulation of the operation to evaluate the risk associated with a blunder where one aircraft (the blunderer) deviates 30-degrees from the approach course toward other aircraft (the evader(s)). The simulation examined a series of scenarios involving different fleet mix combinations and system performance degradations.

This document defines the problem (Section 1.2), explains the technical approach that was used (Section 2.0), the structure of the Monte Carlo simulation involved (Section 2.1), details the inputs to the simulation (Section 2.2). The analysis of the results of the simulation (Section 3) was based on substantial work previously performed and summarized in Reference 6. Relevant excerpts from that report are included (Appendix D). Conclusions and recommendations are given in Section 4. Appendices address the fleet mix, pilot and air traffic controller reaction time, risk analysis, and other topics.

1.2 Statement of the Problem

FAA Order 7110.65P *Air Traffic Control*, section 5-9-7 (SIMULTANEOUS INDEPENDENT ILS/MLS APPROACHES- DUAL & TRIPLE) is the current provision governing air traffic control separation, including No Transgression Zone (NTZ) monitoring, for independent precision approach operations at airports with dual and triple parallel runway configurations having runway centerline separation of at least 4300 feet. These standards were developed from simulations performed by the Federal Aviation Administration (FAA) based on Instrument Landing System (ILS) precision approach operations, primarily during the Multiple Parallel Approach Program (MPAP) in the late 1980's through the mid-1990's. The operation of interest is an independent simultaneous parallel approach procedure with an "at-risk" blunder. See Figure 2 for an illustration. This involves two or more aircraft established on approach (with vertical guidance) to parallel runways, where one of the aircraft deviates from the approach path by 30-degrees towards the adjacent traffic. The ultimate requirement on the system is that Air Traffic Control (ATC) must be able to maintain at least a 500-foot slant range separation between the blundering and evading aircraft. For simultaneous independent approach operations, the Orders require a "final monitor controller" position for each runway. These controllers maintain longitudinal spacing between landings and are responsible for attempting to return a blundering aircraft to the correct course and, if that fails, direct threatened traffic to evade, usually by giving them an immediate turn command.

The baseline system for the MPAP simulations was the Automated Radar Terminal System (ARTS), version IIIA, driven by an ASR-9 radar with the Data Entry Display Subsystem (DEDS) console or the Full Digital ARTS Display System (FDADS). Other systems evaluated during the program included high update radars such as the Precision Runway Monitor (PRM) system and high resolution color monitors with alerting logic such as the PRM display and the FMA system installed at Denver International Airport (KDEN). STARS is to be installed at airports across the National Airspace System (NAS). The STARS display has the same resolution, color, and alerting capabilities as the PRM and FMA displays and many capabilities not available on older systems. These additional capabilities come with considerable processing overhead; however, throughput tests have shown that the computing power available to the system is sufficient to compensate for the additional load.

As requested, the first case examined was proposed triple ILS approach operations to Covington/Cincinnati/Northern Kentucky International Airport. As shown in Figure 1, the new runway 18R/36L provides the airport with three parallel runways, potentially supporting triple simultaneous ILS operations from either north or south flows. Runway spacing is approximately 4300 feet between 18R/36L and 18C/36C with 2240 and 5250 feet staggers between landing thresholds respectively. The spacing is approximately 6220 feet between 18C/36C and 18L/36R with 3240 and 2240 feet staggers between landing thresholds.

The Airspace Simulation and Analysis Tool (ASAT) has been used for a number of similar studies related to simultaneous approach operations. The tool models all components of the scenario (aircraft, avionics, pilot, controller, etc.) and performs a Monte Carlo simulation where all significant parameters are varied according to appropriate probability distributions. The results of this study, and subsequent ones, are expected to provide guidance for determining the allowable runway configurations (separation and stagger) that can be safely supported by a STARS/ASR-9 surveillance system. The study results will also address acceptable mitigations against which any waiver requests would be considered.

The “at-risk” term used above implies that, if no corrective action is taken, the aircraft will come within 500 feet of each other and potentially collide. Violation of the 500-foot separation is referred to as a Test Criteria Violation (TCV). A 2000-foot wide No Transgression Zone (NTZ) is located midway between adjacent pairs of approach paths to aid controllers in determining that an aircraft is blundering. If an aircraft deviates from course far enough to penetrate the NTZ, the controller must assume that it is blundering and the adjacent aircraft must be directed to take evasive action. Controllers may determine that a blunder is occurring before NTZ penetration and act accordingly. However, due to the time and fuel costs associated with a “nuisance” breakout, the controllers should be reasonably certain that the blundering aircraft cannot be returned to its intended course before breaking the threatened aircraft out.

The target level of safety (TLS) for approaches has been determined to be 4×10^{-8} fatal accidents per approach (see Appendix D). From the TLS, a maximum acceptable TCV rate can be derived for simultaneous operations (also Appendix D). The TCV rate for at-risk blunders in a triple approach must be less than 5.1% overall and no more than 6.8% for each of the embedded dual operations. This generates an unambiguous pass-fail criterion for each test scenario.

This study determined whether monitoring simultaneous approach operations to Covington/Cincinnati/Northern Kentucky International Airport with a STARS/ASR-9 surveillance system presents any unacceptable risks.

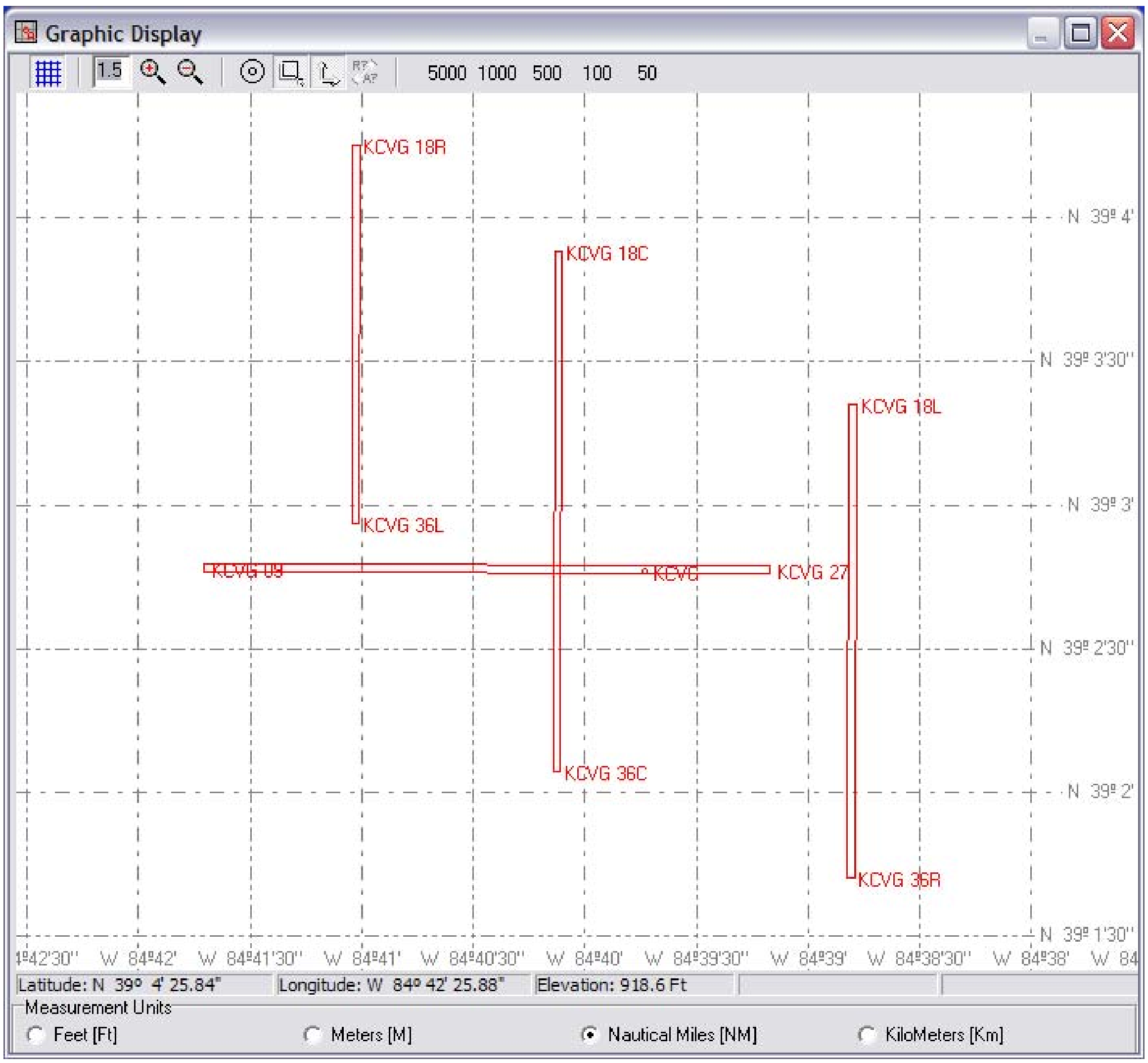


Figure 1. Covington/Cincinnati/Northern Kentucky International Airport Runway Diagram

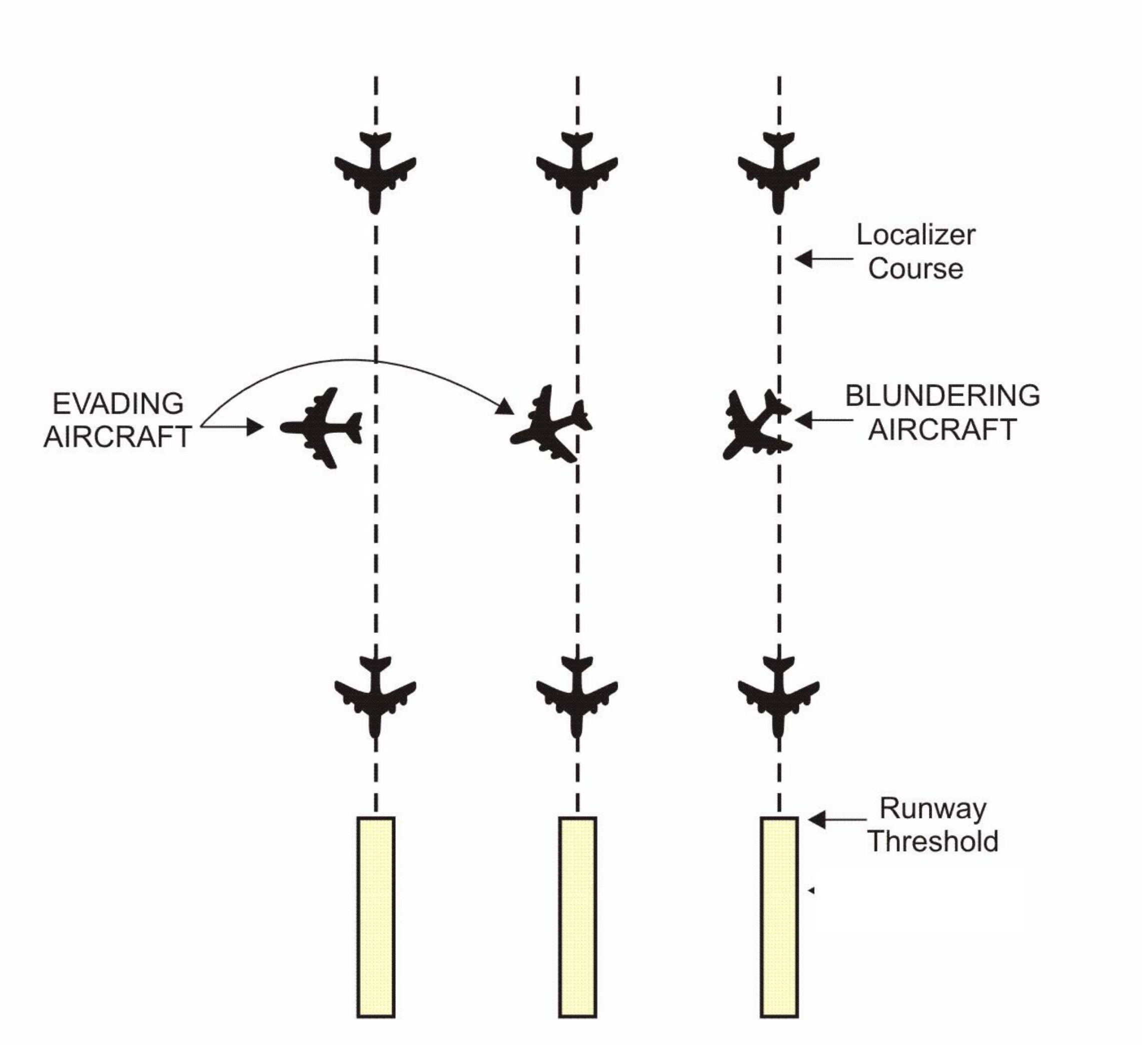


Figure 2. Triple Simultaneous Approach with Blunder

1.3 STARS Considerations/Background

From the STARS home page at http://www.faa.gov/aua/ipt_prod/terminal/ex-stars.htm:

STARS Description

The Standard Terminal Automation Replacement System (STARS) is a joint Federal Aviation Administration (FAA) and Department of Defense (DoD) program to replace Automated Radar Terminal Systems (ARTS) and other capacity-constrained, older technology systems at 172 FAA and up to 199 DoD terminal radar approach control facilities and associated towers.

STARS will be used by controllers to provide air traffic control (ATC) services to aircraft in terminal areas. Typical terminal area ATC services include: the separation and sequencing of air traffic, the provision of traffic alerts and weather advisories, and radar vectoring for departing and arriving traffic. The system will accommodate air traffic growth and the introduction of new automation functions which improve the safety and efficiency of the National Airspace System (NAS).

Controllers' Giant Leap. The most prominent feature of STARS will be the 20-by-20 inch full color display, which presents aircraft positions and flight information to the controller. This display has been specially developed for air traffic control, and is exceptionally readable when viewed at close range by the controller. When combined with modern computer windows and graphics, this display will bring the controllers from the 1970s to the next century in one giant leap. STARS takes advantage of computer designs proven in hundreds of offices and laboratories.

- Features large screen color displays for air traffic controllers at every terminal facility in the country
- Uses powerful commercial workstation computers interconnected by modern local area networks (LANs)
- Gives technicians modern computer maintenance technology, providing increased reliability at reduced cost
- Provides equal or better levels of service and safety while lowering operating and maintenance costs

[End excerpt]

Inside the ASAT model, the only relevant parameters related to STARS are the processing delays and the accuracy of the target presentation to the controller. AFS-440 personnel met with experts from the STARS Program Office, FAA William J. Hughes Technical Center, and Raytheon, the system manufacturer, to discuss the modeling and determine the appropriate parameter values for the simulation. It was verified there were no STARS artifacts that would affect the presentation of the targets.

One of the most significant attributes of STARS is its versatility. It can operate in a large number of modes using various sensors. It has also gone through considerable evolution. Many of the negative perceptions of the system are based on experiences with earlier versions. Most identified shortcomings from those versions have been addressed in current releases.

When serving as an FMA, the STARS will be receiving slant range data essentially direct from the radar, just as the previous tests at KDEN had assumed. While it is not totally clear whether the slant range data is extracted from system plane data (calculated from slant range data…), any conversions to and from the radar's system plane will involve a negligible amount of processing overhead and will not induce any significant errors. The data are filtered to the extent that radar alignment errors, clutter, and similar items are removed from the data stream. These tasks are performed by the radar processor and are not considered part of the normal surveillance system processing.

The actual target, without any tracking logic alterations, is used to drive the system alerts. STARS alerts are a superset of the PRM system alerts, i.e. they include all the PRM alerts and have some additional ones. The PRM yellow and red alerts are intact. The yellow alert is currently based on a slightly different tracking algorithm than the PRM system but the simulation is not based on the yellow alert time. The red alert is issued when the target is reported in the NTZ, not any tracking prediction artifact, and the red alert triggers events in the simulation.

The latency of the target display with respect to the data leaving the radar processor is actually less than the system specification the ASAT model has used in all previous tests. STARS personnel explained the testing process used to determine this latency and provided data to support the lower value. In essence, the only change to the ASAT model for this analysis is the substitution of the 1.2 second surveillance system display latency/processing delay with a 1.0 second value.

2.0 Study Methodology

The study used a Monte Carlo simulation of the operation to evaluate the risk. The simulation examined a series of scenarios involving aircraft conducting ILS approaches. The scenarios modeled approaches to both north and south runways, examined changes to the KCVG fleet mix, and degradations to the surveillance system performance. The primary result of the simulation was the percentage of TCVs occurring during each scenario. Those percentages, scaled as needed, were compared to the pass-fail requirements mentioned above and the scenarios were identified as acceptable or not.

2.1 Model Description

The ASAT consists of a family of software components running on a collection of high-speed computers. The system performs Monte Carlo studies involving 10^4 to 10^6 runs to represent the full ranges of parameter values. The ASAT uses high fidelity models of all components of an aviation scenario to achieve the most realistic simulation possible with the information provided. Wherever available, manufacturer provided data were used as a basis for some of the components of the simulation. When empirical data were available from relevant tests, they were used to the extent possible as a basis for some of the components of the simulation. The various data components are discussed in detail in the next section.

The particular ASAT component used for this task was called ASAT4ILSRNP. It includes capabilities to model Required Navigation Performance (RNP) approaches that were not used for this study. Figure 3 shows the ASAT screen for a typical run. The aircraft approaching runway 18C (the middle runway on the screen), a Fokker 100, has blundered and the 18L traffic, an Embraer RJ, has successfully evaded. Another Embraer RJ approaching runway 18R and was not affected. The closest point of approach (CPA) was 1556 feet slant range or 1546 feet, ignoring vertical separation. The STARS delay has been set to 1.0 seconds.

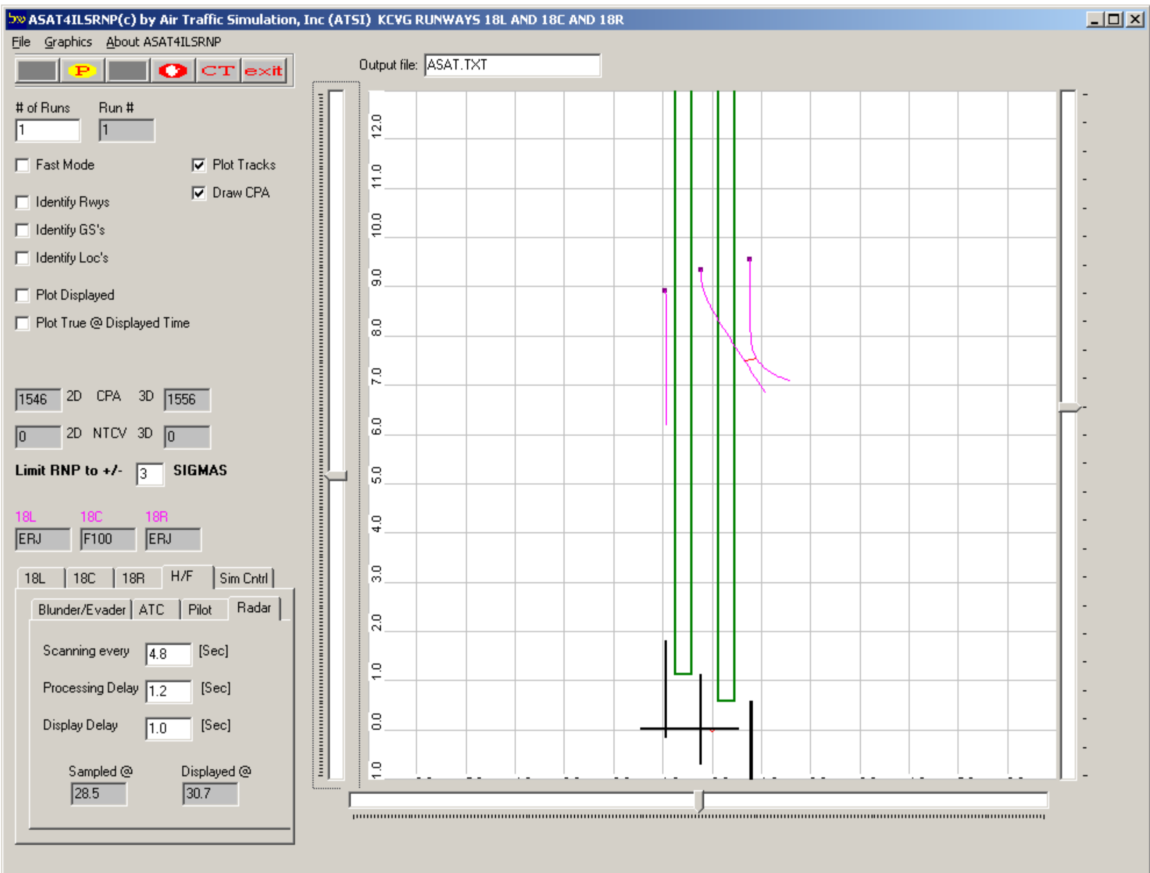


Figure 3. Typical ASAT Run

The simulation was set to initiate blunders between 2 and 14 Nautical Miles (NM) from threshold. Outside 14 NM, there was at least 1000-foot vertical separation per requirements for simultaneous operations. Inside 2 NM, the evader will have landed before the blunderer can cross its approach path.

The display can show both the actual and reported position of the blundering aircraft. When running in high-speed mode, all display features are not updated, to minimize run times.

An ASAT run consists of three phases.

Phase 1: Initialization. The aircraft types were selected randomly according to the fleet mix. Their performance data were loaded and approach airspeeds determined. They were assigned to a runway and the blunderer selected. The blundering aircraft was positioned at a random distance from the airport (uniformly distributed within the user selected range limits) with appropriate lateral and vertical errors. The adjacent evader aircraft was positioned laterally and vertically and then placed longitudinally to maximize the chance of a collision if corrective action was not taken in a timely manner. The time to the next surveillance system update was selected from a uniform distribution ranging from 0 to 4.8 seconds for ASR-9. All parameters that were based on probability distribution functions, such as evader rate of climb, roll rate, pilot and ATC response times, etc., were selected.

Phase 2: Performance. The aircraft were "released" and the simulation advanced in simulated 50 millisecond steps with continuous updates of the aircraft state vectors based on their flight dynamics and performance data. Course deviations and corrections were based on the "Flight Technical Error" (FTE) filter and the navigation system models. Immediately after release, the blunderer started a 30-degree heading change and began converging on the evader aircraft. Surveillance system reports were generated at appropriate times with appropriate errors in range and azimuth. These errors affect where the targets were depicted on the controller's screen and, hence, when it was perceived by the controller as being in the NTZ, or, at least, definitely headed toward the NTZ. A certain percentage of target reports were randomly dropped per the surveillance system specifications. When the blunderer was identified as being within the NTZ or the ATC response time was reached, whichever was later, the evader was ordered to perform a 90-degree course change. After another delay for the pilot response time, the evader began to climb and roll into the course change (per the selected performance parameters). Slant range and system plane separation were continuously monitored and the simulation continued for approximately 20 seconds (simulation time) past the point where the slant range stopped decreasing and started increasing, i.e. the minimum separation point. The simulation did not detect collisions so that even if the slant range separation reached 0.0, the model kept running.

Phase 3: Reporting the run. For each run, critical parameters were recorded and saved to output files. These included the aircraft types and runways involved, the pilot and ATC response times, the range of the blunderer from the threshold when the blunder began, the minimum 2-dimensional and 3-dimensional separation, and a flag indicating that a TCV had occurred. A sample output file is included as Appendix F.

The variables between scenarios were the runway ends, the fleet mix and the surveillance degradation. Each scenario was performed 50,000 times so that all reasonable combinations of aircraft types, performance parameters, radar update times, and pilot and controller response times would be considered.

2.2 Summary of Data Used

The primary data components of the ASAT system are listed below.

a.) Geography: ASAT uses the latest FAA databases to establish runway coordinates (including elevation), localizer and glideslope antenna positions, and relevant obstacle and terrain feature locations.

b.) Aircraft: Aircraft fleet mix information was received from KCVG ATC (see Appendix A) and incorporated into the simulation. Aircraft types from the report were mapped into performance models in the ASAT. Typical performance data (roll rate, climb rate, achieved bank, indicated airspeed) for those types were collected in previous tests and from manufacturers and distributions were developed for use in the Monte Carlo process.

c.) Environmental conditions: The ASAT aerodynamics models automatically compensated for altitude effects based on the airport elevation and for any wind or turbulence conditions included in the model. Because the approach paths are relatively close and parallel, wind effects were considered to be negligible since all aircraft were equally affected. Earlier MPAP studies have supported this assumption.

d.) Pilot response times: This time was the period from the start of the ATC evasion command until the aircraft achieved 3-degrees of bank. These distributions were based on data collected during the MPAP testing and are discussed in more detail in Appendix B.

e.) Air traffic controller response times: This time was the delay from the initiation of the blunder to the activation of the microphone by the evading aircraft's monitor controller to begin the evasion command. The MPAP testing looked at a range of surveillance systems, displays, and runway spacings and collected response times for each. Appendix C includes a list of the configurations tested. One of the test configurations that the MPAP examined was 4300-foot triples with an ASR-9 radar and an FMA displays. This was the closest to the KCVG configuration, so it was selected for this simulation. Differences in the controller response times on the wider side were assumed to be negligible. The proportion of TCVs that occurred between traffic on the wider spaced pair was so small that this assumption is almost moot. The controller response times in the simulation were further restricted to occur no earlier than when the blundering aircraft was 500 feet from the NTZ. This was a conservative assumption to address the requirement in Order 7110.65P, para. 5-9-7.c.2 that the evasion command should only be given "when an aircraft is observed penetrating or in the controller's judgment will penetrate the NTZ."

f.) Navigation: Previous testing for evaluating ILS operations used the International Civil Aviation Organization (ICAO) Collision Risk Model (CRM) to determine initial

positions (lateral and vertical). The simulation proceeded along the localizer and glideslope using control filters to simulate FTE.

g.) Surveillance system: An ASR-9 model, with appropriate errors and latencies was part of the simulation. The model was based on data provided by MIT Lincoln Labs and the William J. Hughes Technical Center. Latencies and delays in the STARS display were based on discussions with technical experts from the STARS Program Office, Raytheon (the system manufacturer), and FAA contractor support.

2.3 Simulation Performance

The test scenarios are depicted in Table 1 below. Fifty thousand runs were performed for each scenario for each end of the airport. For every scenario, the blunders were evenly distributed across the three runways. From the outer runways, the blunder was always toward the other runways; from the center, it randomly went right or left. A typical set of runs involved 25,000 interactions between the right and center runways and 25,000 between the left and center.

The total distance between the two outboards was so great at KCVG (10,520 feet), that there was essentially no interaction between the two. When the blundering aircraft reached the NTZ, it was generally on its 30-degree offset course and was closing the lateral distance between it and the other aircraft at between 100 and 120 feet per second (assuming typical approach speeds between 120 and 140 knots). For the worst-case configuration, the controller on the opposite outboard runway had more than a minute to get his/her evading aircraft out of the danger area.

Test Scenarios			
Scenario #	Scenario	Scenario #	Scenario
1N	Baseline	1S	Baseline
2N	10% heavies	2S	10% heavies
3N	20% heavies	3S	20% heavies
4N	30% heavies	4S	30% heavies
5N	25% degrad.+Baseline	5S	25% degrad.+Baseline
6N	50% degrad.+Baseline	6S	50% degrad.+Baseline
7N	25% degrad.+10% heavies	7S	25% degrad.+10% heavies

Table 1. Test Scenarios

3.0 Summary of Data Analysis and Risk Evaluation

This section examines the results of the simulation and defines the acceptability of the results for operational implementation.

3.1 Summary of the TCV Probability Analysis

Table 2 lists the resultant TCV counts, number of runs for each scenario, and the associated TCV rate. The simulation included algorithms to longitudinally place evader aircraft relative to the blundering aircraft so that they were at-risk. However, the significant runway staggers at KCVG reduced the efficiency of this algorithm and test cases ran without an evasion maneuver showed that only about 90% of the evader aircraft were at-risk. Therefore, the numerical result of the TCV count divided by the number of runs was scaled by 1.1111. This assumes that an aircraft that was not at risk could not generate a TCV, a reasonable, but not absolute, expectation.

The wider spacing between the east and center runways was so great that less than 2% of the TCVs occurred on blunders between those two.

	Right-Center			Left-Center			Total
Scenario #	3-D TCVs	# of Blunders	%*	3-D TCVs	# of Blunders	%*	%*
1N	3	25069	0.01	180	24931	0.80	0.41
2N	4	24819	0.02	211	25181	0.93	0.48
3N	4	24989	0.02	218	25011	0.97	0.49
4N	1	24989	0.00	234	25011	1.04	0.52
5N	3	25069	0.01	207	24931	0.92	0.62
6N	3	24860	0.01	225	25160	0.99	0.66
7N	3	25212	0.01	210	24788	0.94	0.87
1S	235	25214	1.03	2	24786	0.01	0.46
2S	231	25000	1.02	2	25000	0.01	0.56
3S	252	25003	1.11	4	24997	0.02	0.62
4S	276	24964	1.23	2	25036	0.01	0.72
5S	227	25027	1.01	2	24973	0.01	0.50
6S	305	24994	1.35	4	25006	0.02	0.59
7S	228	24864	1.02	4	25136	0.02	0.60

Table 2. Simulation Results by Scenario
(* Percentage is scaled by 1.11 to compensate for non-at-risk traffic.)

3.2 Summary of Acceptable Level of Risk

In 1988, the MPAP was initiated to investigate capacity enhancing procedures for simultaneous ILS approaches to parallel runways. The program established the MPAP Technical Work Group (TWG) to unite various areas of expertise for the evaluation of multiple parallel approaches in an effort to increase airport capacity in a safe and acceptable manner. FAA representatives from the Secondary Surveillance Product Team, Office of System Capacity, Flight Standards Service, Air Traffic Operations, Air Traffic Plans and Requirements, and various regional offices composed the MPAP TWG.

MPAP researchers extracted the total number of air carrier accidents as well as the number of fatal accidents on final approach from National Transportation Safety Board

(NTSB) data for the time period, 1983-1989. This number, together with the total number of ILS approaches flown during this time period, lead to an estimated fatal accident rate during ILS operations performed during IMC of 4×10^{-7} fatal accidents per approach. There are a number of causes of accidents during final approach, such as structural failure, engine failure, or midair collision. An initial estimate was that there are nine possible causes of accidents on final approach. The implementation of simultaneous parallel approaches created a tenth possible accident cause, a collision with an aircraft on an adjacent approach. The researchers assumed that the risks of the ten potential accident causes were equal. Thus, the contribution of any one of the accident causes would be one-tenth of the total accident rate. Based on this, the target safety level for midair collisions on simultaneous parallel approaches is 4×10^{-8}, or:

$$\frac{1 \text{ accident}}{25 \text{ million approaches}}$$

The MPAP test team adopted a method for determining a simulation's maximum acceptable TCV rate from work done on the PRM Demonstration Program. In the PRM Demonstration Report (Reference 1), researchers computed a TCV rate from the population of all worst-case blunders (WCBs). They found that a TCV rate not greater than 0.004 TCV per WCB would meet the target level of safety, if the overall 30-degree blunder rate did not exceed one 30-degree blunder per 2,000 approaches. The Monte Carlo simulation, however, measured a TCV rate based on at-risk WCBs, not the population of all WCBs. Therefore, for comparison purposes, the population TCV rate was converted to an at-risk TCV rate. Based on a simulation of aircraft speeds and types, a conservative ratio of 1/17 at-risk WCB per WCB was applied, resulting in an at-risk TCV rate criterion of 5.1% for triple approaches. The MPAP test team also determined that the criterion for dual approaches is 6.8%. For the triple approach operation, the MPAP TWG determined that 1) the triple approach must meet the criterion for triple approaches, and 2) each proximate pair must meet the criterion for dual approaches. This methodology was employed because it is possible that the criterion for the triple approach could be met, while one of the proximate pairs of runways did not meet the criterion for dual approaches.

To achieve a fatal accident rate that meets the target level of safety, a Monte Carlo simulation with the evader at-risk must result in a TCV rate (plus twice the standard error) that does not exceed 5.1% for the triple approach and 6.8% for each proximate pair of dual approaches. A Monte Carlo confidence interval that extends above 5.1% for the triple approach or 6.8% for the dual approach would indicate that the operation might not meet the target level of safety. For these simulations, the confidence intervals on the results are quite small (standard errors<0.1%) due to the large number of runs.

The risk analysis is covered in more detail in Appendix D, which is excerpted from Reference 6, Appendix C.

4.0 Results and Conclusions

This section summarizes the key results, the scenario risk evaluation, and the conclusions of the study.

4.1 Summary of Results

Table 3 summarizes the results by fleet mix and runway spacing. Due to the significant runway threshold staggers, these results should not be considered as general guidelines for runway spacing requirements.

Fleet mix	Runway Spacing	Acceptable
Baseline	4300	Y
+10% Heavies	4300	Y
+20% Heavies	4300	Y
+30% Heavies	4300	Y
Baseline	6220	Y
+10% Heavies	6220	Y
+20% Heavies	6220	Y
+30% Heavies	6220	Y

Table 3. Summary of Results by Fleet Mix and Runway Separation

4.2 Scenario Risk Evaluation

The study indicates that the TCV rates for all scenarios were much less than the 5.1% TCV rate allowed for the triples operation, and the 6.8% requirement for the embedded duals. Given that 4300 feet is the minimum runway separation allowed in the Orders for duals using 4.8 second update radar systems and the DEDS/FDADS consoles, a TCV rate closer to the 6.8% failure level might have been expected for the closer runways at KCVG (which are at 4300 feet). However, high-resolution color monitors with alerts, as used in the FMA position, have been shown to provide a substantial improvement in controller response time as compared to the DEDS/FDADS (see Reference 7). The runway stagger also contributes to the slant range separation with vertical separations between the glideslopes ranging from 110 to 260 feet. The minute decrease in surveillance system processing time over the previously used value is not significant and can only improve the TCV rate. The fleet mix at KCVG is also heavily weighted toward the smaller, faster responding regional jets, which contributes to the reduction.

In Appendix H, three additional scenarios were run based on adding 2, 4, and 6 seconds to the total response time. While 2 seconds doesn't appear to be a large value, it would represent a substantial degradation in the overall system performance or a significant increase in the mean controller response time. The system still achieves an acceptable TCV rate even with a 4 second delay.

4.3 STARS Issues

Previous ASAT blunder scenario simulations have used a 1.2 second processing/display delay, as provided in the system specifications (ARTS IIIE System Functional Specification, FAA-E-2759, 13 August 1993). The STARS test data provided by the FAA Tech Center and Raytheon showed that, even under heavier traffic loads than would normally be seen in an FMA position, the equivalent value for a STARS implementation is less than 1.0 second. The STARS display uses the same monitor as the PRM and FMA displays and there is no data to suggest that the resultant target display is less accurate or distorted in any way. It is therefore difficult to imagine a scenario in which safety would be reduced by replacement of a conventional surveillance system with the STARS. The ASAT model, which represents the STARS as a limited number of time delay and display error values, will only show results driven by combinations of those values.

4.4 Conclusions

In this study a risk analysis methodology was employed that was developed by the MPAP for simultaneous independent ILS approaches to parallel runways to determine if the STARS surveillance system increased the risk in the triple approach operation at Covington/Cincinnati/Northern Kentucky International Airport. The study used a high fidelity simulation of the operation to perform a Monte Carlo analysis. The study examined 14 test scenarios that looked at the current fleet mix and other mixes with higher percentages of heavies and examined certain degraded performance parameters. The study concludes that the system at KCVG meets the target level of safety with regard to the blunder scenario and will still meet the target level of safety even with substantial fleet mix changes or system degradations.

Appendix A

Aircraft Mix and Performance Modeling

The following information was provided by KCVG ATC.

Typical Daily Fleet Mix

KIAH Traffic	Count	ASAT Model
A320	2	A320
A340-300	1	B757
Astra	2	Fokker 100
Beech 1900	4	ATR-42
B300 Super KingAir 350	2	ATR-42
727 Stage3	3	B727
737-200	32	B737-200
737-300	1	B737-200
737-500	1	B737-200
737-700	1	B737-800
737-800	23	B737-800
757-200	23	B757
767-300	12	B777
767-400	1	B777
777-200	1	B777
BeechJet 400	3	Fokker 100
Beech Super KingAir	1	ATR-42
Beech KingAir	6	ATR-42
Beech Baron	8	ATR-42
Beech, Cessna, Piper L1Ps	27	ATR-42
Cessna Caravan	1	ATR-42
Cessna-Piper L2Ps	36	ATR-42
Cessna 525 CitationJet	4	F100
Cessna 550 Citation	4	F100
Cessna 560XL Citation Excel	12	F100
Cessna 650 Citation 3/6/7	1	F100
Cessna 750 Citation 10	2	F100
Canadair CRJ-100	229	ERJ
Canadair CRJ-200	152	ERJ
Canadair CRJ-700	72	ERJ
DC-9-30	1	MD88
Embraer 135 RJ	12	ERJ
Embraer 145 RJ	17	ERJ
Embraer 170 RJ	1	ERJ
Embraer 145XR RJ	2	ERJ
Falcon 2000	1	F100
Falcon 50	1	F100
Gulfstream 4	1	F100
Gulfstream 5	2	F100
BAE 125-700	6	F100
LearJets	27	F100
Bae 3100 JetStream	2	SAAB
MD-80	19	MD88
MD-90	8	MD88
Fairchild Metro	4	ATR42
Bae RJ85	3	ERJ
Westwind 1124	1	F100

Table A-1. Fleet Mix and Model Assignments

One of the ASAT initiation files contains a section where the number of each type of aircraft is given. It automatically sets the frequency of occurrence for each aircraft type during the simulation. Based on the type, several aircraft performance distributions are loaded: approach speed, go around speed, deceleration, acceleration, rate-of-climb, and rate-of-change of rate-of-climb. Roll-rate distributions are also based on simulator testing. The achieved bank angle for this test was set to provide 10% more than a standard rate turn. Given that the evader pilot is responding to an ATC breakout instruction to avoid a mid-air collision, this is a conservative value.

Appendix B

Pilot Reaction Time Distribution Analysis

The MPAP testing included line pilots operating high-fidelity full motion simulators. The simulators were connected to the test facility at the William J. Hughes Technical Center by phone (so that the pilots were in direct contact with the controllers) and high-speed data lines. One of the parameters that was recorded during the testing was the time from the controller's initial evasion command until the aircraft achieved a 3 degree angle of bank in a roll that was determined to be part of the evasion maneuver. Every attempt was made to eliminate normal control motions from being considered as the start of the maneuver.

Test results that involved the use of the Precision Runway Monitor system to monitor closely spaced parallel runways led to the development of a training requirement to insure that the pilots did not delay their response to a "traffic alert" message. This training was not considered necessary for operations using conventional radar systems with runways spaced 4300 feet or more. Though not required, a significant part of the present pilot population has completed the training (which consists of a short video presentation).

A problem identified by the pilots during the testing in the late 1980s was controller's use of the word "immediate." The pilots, at that time, claimed that controllers frequently used the term when there was no need for an immediate response and this tended to lower pilot sensitivity to phrases that included the word. As a result, Air Traffic directives were modified to limit the use of the term except for real emergencies that did require "immediate" action. The current directive, FAAO 7110.65P, provides only three phraseologies that include "immediate," two of those are associated with simultaneous approaches; the third is when collision with terrain appears imminent. Contemporary pilots are aware of the urgency of action required when the word "immediate" is used.

The pilot response time distribution selected for this test was based on data collected during two test programs performed in 1995 and 1996. It is averaged across the fleet so there was no attempt to correlate response time with aircraft type. A Johnson S-L distribution was fitted to the data resulting in the following parameters: (Johnson distributions are discussed in Appendix E.)

Parameter	Value
Type	S-L
Delta	2.04
Gamma	1.98
Lambda	12.7
Xi	0.5
Truncation-Low	1.0
Truncation-High	17.0
Offset	-1.0

The truncation points were chosen to reflect the empirical data. No data points were collected greater than 15.5 seconds so the maximum value considered was set to 17.0. The offset value is to compensate for the time to roll the aircraft to 3 degrees of bank. In the model, the pilot response time is to the start of the maneuver, so 1.0 second is subtracted from the distribution value to compensate.

Figure B-1 shows the resultant distribution overlaying the histogram of the pilot response times. The dashed blue lines represent the approximate quartile (25%, 50%, and 75%) points of the histogram data and the 97.5% point (cumulative to +2 standard deviations). The solid red lines are the equivalent points for the Johnson S-L function fitted to the data.

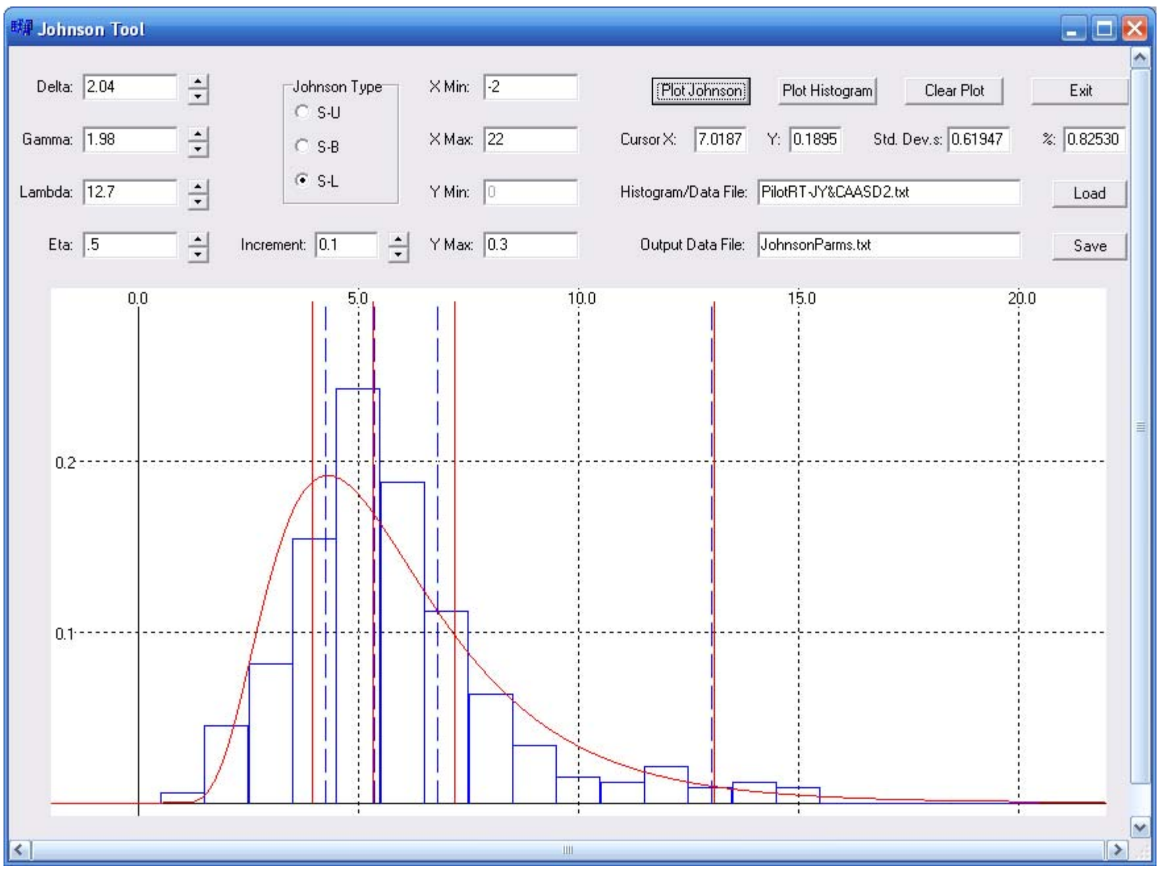


Figure B-1. Pilot Response Times Distribution

A Chi-square goodness of fit test was run on the distribution and did not show a very good fit, however the quartile and 2-sigma lines indicate the distribution errors should be primarily on the conservative side, especially for the longer times.

Appendix C

Air Traffic Controller Reaction Time Distribution Analysis

The MPAP testing used full performance level controllers from a number of facilities working in a test facility that was designed to be as close as practical to their actual working environment. Table C-1 shows the configurations of systems used during the various MPAP tests.

The test program, identified as VA in Table C-1, examined triple approaches to runways spaced 4300 feet apart using standard ASR-9 radar and Final Monitor Aid (FMA) displays. A histogram of the controller response times from that test was found in Reference 7. The data were fitted with a Johnson S-L distribution resulting in the following. (Johnson distributions are discussed in Appendix E.)

Parameter	Value
Type	S-L
Delta	5.49
Gamma	-9.4
Lambda	3.57
Xi	-9.94
Truncation-Low	3.0
Truncation-High	22.0
Offset	0.0

Figure C-1 shows the resultant distribution overlaying the histogram of the pilot response times. The dashed blue lines represent the approximate quartile (25%, 50%, and 75%) points of the histogram data and the 97.5% point (cumulative to +2 standard deviations). The solid red lines are the equivalent points for the Johnson S-L function fitted to the data. The distribution was truncated at 3 seconds on the low end. No test data was collected beyond 21 seconds so the distribution of controller response times was truncated at 22 seconds.

A Chi-square goodness of fit test was run on the distribution and did not show a very good fit, however the quartile and 2-sigma lines indicate the distribution errors should be primarily on the conservative side, especially for the longer times.

Multiple Parallel Approach Program: 1988 – 1999

Approach	Sim Order	Dates	Purpose	Runway Spacing	Display	Simulated Radar	Other	TWG Recommendation	Documentation
Dual	NA	6/ 1990	National Standards	3400 ft	FMA	Mode S 4.8s / E-Scan 1.0s		Approved	Published Report Precision Runway Monitor Demonstration Report (DOT/FAA/RD-91/5)
Dual	9	9/16-9/23 1991	National Standards	3000 ft	FMA	E-Scan 1.0s	1-Degree Localizer Offset	No Decision Rendered See June '94	NO DOCUMENTATION
Dual	15	6/6-6/17 1994	National Standards	3000 ft	FMA	E-Scan 1.0s	1-Degree Localizer Offset	Not Approved	
Dual	16	7/11-7/22 1994	National Standards	3000 ft	FMA	E-Scan 1.0s	2.5-Degree Localizer Offset	Not Approved	Published Report (DOT/FAA/CT-96/2)
Dual	18	10/16-10/27 1995	National Standards	3000 ft	FMA	E-Scan 1.0s	2.5-Degree Localizer Offset	Approved	
Dual and Triple	4	4/24-5/3 1990	National Standards	4300 ft	ARTS III	ASR-9 4.8s		Not Approved	NO DOCUMENTATION
Dual and Triple (VA)	8	5/15-5/24 1991	National Standards	4300 ft	FMA	ASR-9 4.8s		Approved	Published Report (DOT/FAA/CT-92-16-I)
Dual and Triple	6	3/18-4/5 1991	National Standards	3000 ft	FMA	E-Scan 1.0s		Not Approved	Memorandum
Dual and Triple	12	7/27-8/14 1992	National Standards	4000 ft	FMA	ASR-9 4.8s		Inconclusive	Memorandum
Triple	10	9/24-10/4 1991	National Standards	4000 ft	FMA	ASR-9 4.8s		Inconclusive	
Triple	2	9/25-10/5 1989	DFW	5000 & 8800 ft	DEDS	ASR-9 4.8s		Approved	Published Report (DOT/FAA/CT-90-2)

Triple (IVB)	5	9/17-9/28 1990	National Standards	5000 ft	ARTS III	ASR-9 4.8s		Approved	Published Report (DOT/FAA/CT-91-31)
Triple	7	5/6/-5/14 1991	National Standards	3400 ft	FMA	Mode S 2.4s		Inconclusive	Memorandum
Triple	11	3/2-3/13 1992	Human Factors Study	3400 ft	FMA	E-Scan 1.0s	1 Mr Radar Accuracy	No Recommendation Made	
Triple	14	11/16-11/20 11/30-12/17 1992	DIA (DEN)	7600 ft 5280 ft	FDADS FMA	ASR-9 4.8s	Field Elevation 5431 ft	Not Approved Approved	Published Report (DOT/FAA/CT-94-36)
Triple	17	8/14-8/25 1995	National Standards	4000 ft 5300 ft	FMA	E-Scan 1.0s		Not Approved	Published Report (DOT/FAA/CT-TN02/16) Appendix
Triple	19	4/15-4/26 1996	National Standards	4000 ft 5300 ft	FMA	E-Scan 1.0s		Approved	
Quadruple	1	5/16-6/10 1988	DFW	5000 ft 5800 ft 8800 ft	DEDS	ASR-9 4.8s		Approved	Published Report (DOT/FAA/CT-90-15)
Dual and Quadruple	3	11/29/89-2/9 1990	DFW	5000 & 5800 ft 8800 ft	DEDS	ASR-9 4.8s		Approved	Published Report (DOT/FAA/CT-TN89/28-1)
Triple and Quadruple	13	9/8-9/25 1992	High-Altitude Study	7600 ft 5280 ft 5348 ft	ARTS III	ASR-9 4.8s	Field Elevation 5431 ft	No Recommendation Made	Memorandum
MPAP Summary Report	20	12/ 1999	National Standard and Site-Specific Results	Published Report (DOT/FAA/CT-TN99/24)					

Table C-1

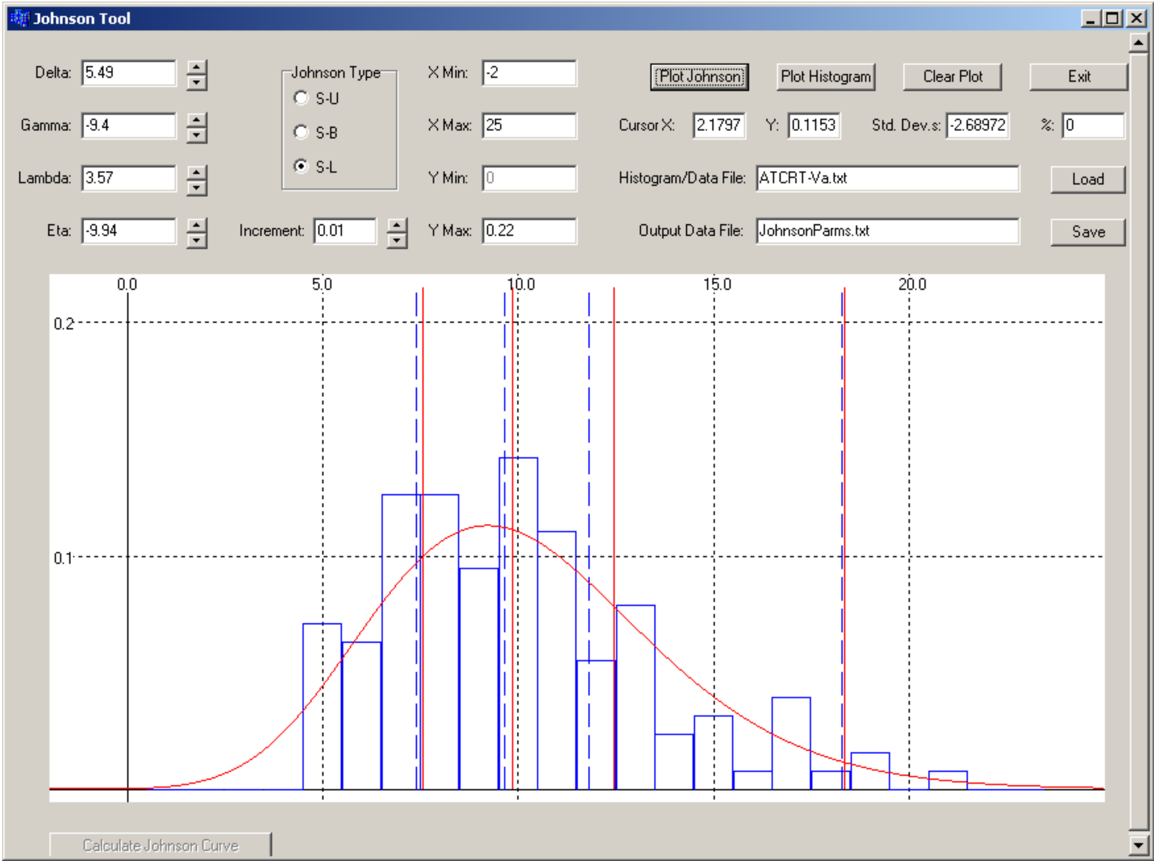


Figure C-1. ATC Response Time Distribution

Appendix D

Risk Analysis

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. Previous testing has shown that blunders other than worst-case blunders (WCBs) are of negligible risk, so the blunder must be a WCB. Also, the blundering aircraft must have a critical alignment with an aircraft on an adjacent course (i.e., it must be at risk). If all of the above events develop, a TCV will occur if the controller and pilots cannot react in sufficient time to separate the blundering and the evading aircraft. In addition, one collision will involve two aircraft and will probably produce two accidents, as defined by the NTSB.

Assuming that a TCV will result in a collision, the probability of a collision accident can be expressed in mathematical terms by:

(1) P(Accident) = P(TCV and At-risk and WCB and Blunder) x 2

or

(2) P(Accident) = P(TCV|At-risk and WCB and Blunder) x
P(At-risk|WCB and Blunder) x
P(WCB|Blunder) x
P(Blunder) x 2

Where:

- P(TCV and At-risk and WCB and Blunder) is the probability of all relevant events occurring simultaneously (i.e., an at-risk WCB that results in a TCV).
- P(TCV|At-risk and WCB and Blunder) is the probability that a TCV occurs given that an at-risk WCB has occurred. This quantity is estimated by the simulation of at-risk WCBs in the real-time and Monte Carlo simulations (i.e., the TCV rate in the simulation).
- P(At-risk|WCB and Blunder) is the probability that a WCB has critical alignment with an aircraft on an adjacent approach. Analysis conducted in preparation for this simulation indicates that a value of 1/17 is a good approximation of this quantity, given 3 nm in-trail spacing.
- P(WCB|Blunder) is the probability that a blunder is a WCB. This probability is unknown, but is estimated to be approximately 1/100 (PRM Demonstration Report, 1991).
- P(Blunder) is the probability that a blunder occurs during a simultaneous instrument approach. This rate is also unknown, but is estimated to be no more

than 1/2000 approaches (or 1 for 1000 dual approaches). This is a conservative

value derived from the risk analysis conducted during the PRM demonstration program. Until a blunder rate estimate can be derived from field data of actual blunder occurrences or other evidence suggests using a different value, the TWG has agreed to use 1/1000 30-degree blunders per dual approach pair. Researchers can show the rate for triple approaches to be 1/1500 30-degree blunders per triple approach trio.

- The factor of 2 represents two accidents per collision.

Target Level of Safety

The total number of air carrier accidents, as well as the number of fatal accidents on final approach, has been extracted from NTSB data for the time period, 1983-1989. This number, together with the total number of ILS approaches flown during this time period, leads to an estimated fatal accident rate during ILS operations performed during IMC of 4×10^{-7} fatal accidents per approach. There are a number of causes of accidents during final approach, such as structural failure, engine failure, or midair collision. An initial estimate is that there are nine possible causes of accidents on final approach. A tenth possible accident cause, a collision with an aircraft on an adjacent approach, is created with the implementation of simultaneous parallel approaches.
For simplicity of model development, it is assumed that the risks of the ten potential accident causes are equal. Thus, the contribution of any one of the accident causes would be one-tenth of the total accident rate. Based on this, the target safety level for midair collisions on simultaneous parallel approaches is 4×10^{-8}, or:

1 accident / 25 million approaches

Maximum Allowable Test Criterion Violation Rate

Since the only undefined variable in equation (2), used to compute the maximum acceptable accident rate, is the TCV rate, it is possible to determine the maximum allowable TCV rate which would meet the target level of safety. Knowledge of this number would allow the TWG to quickly decide if the simulated operation would meet the target level of safety. The maximum allowable TCV rate may be found from following analysis.

Given the target level of safety, P(Accident) = 4×10^{-8}, then the equation (2) becomes:

$$P(TCV|\text{At-risk and WCB and Blunder}) \times P(\text{At-risk}|\text{WCB and Blunder}) \times P(WCB|\text{Blunder}) \times P(\text{Blunder}) \times 2 = 4 \times 10^{-8}$$

or,

(3) P(TCV|At-risk and WCB and Blunder) =

$$\frac{4 \times 10^{-8}}{1} \times \frac{1}{P(\text{At-risk}|\text{WCB and Blunder})} \times \frac{1}{P(\text{WCB}|\text{Blunder})} \times \frac{1}{P(\text{Blunder})} \times \frac{1}{2}$$

Substituting values from (2) into (3):

(4) P(TCV|At-risk and WCB and Blunder) =

$$\frac{4 \times 10^{-8}}{1} \times \frac{17}{1} \times \frac{100}{1} \times \frac{1500}{1} \times \frac{1}{2} = 5.1\%$$

Thus, if the simulation results support the assertion that the probability of a TCV, given that an at-risk WCB occurs (P(TCV|At-risk and WCB and Blunder)), is less than 5.1 percent, then the simultaneous approach procedure simulated should have an acceptable accident rate. For the embedded duals, the factor 1500 was replaced by 2000 and the allowable percentage became 6.8 percent.

Appendix E

Johnson Distributions

The Johnson family of empirical distributions is based on transformations of a standard normal variate. An advantage of such a transformation is that estimates of the percentiles of the fitted distribution can be obtained either from a table of areas under a standard normal distribution or from a computer program which computes areas under a standard normal distribution. Another advantage is that during a Monte Carlo simulation, variants from the distribution are readily computed from the standard normal distribution. The Johnson distributions also can be fitted to the data with relative ease compared to the Pearson distributions. The Johnson distributions are divided into three families as follows:

1. The S_L family is characterized by the transformation:

$$z = \gamma + \delta \ln\left(\frac{x-\varepsilon}{\lambda}\right), \ x > \varepsilon, \qquad (1)$$

where x is the variable to be fitted by the Johnson distribution and z is a standard normal variate. Each curve in this family is bounded on the left by ε and is unbounded on the right. By performing, a certain transformation of the parameters δ and γ the curves can be converted to the log-normal distribution.

2. The S_B family is characterized by the transformation:

$$z = \gamma + \delta \ln\left(\frac{x-\varepsilon}{\lambda+\varepsilon-x}\right), \ \varepsilon < x < \varepsilon+\lambda. \qquad (2)$$

where x is the variable to be fitted by the Johnson distribution and z is a standard normal variate. Each curve in this family is bounded on the left by ε and on the right by ε + λ. These curves resemble the Weibul or extreme-value families. The parameters γ and δ are shape parameters, ε is a location parameter, and λ is a scale parameter.

3. The S_U family is characterized by the transformation:

$$z = \gamma + \delta \sinh^{-1}\left(\frac{x-\varepsilon}{\lambda}\right), \ -\infty < x < \infty. \qquad (3)$$

where *x* is the variable to be fitted by the Johnson distribution and *z* is a standard normal variation. Each curve in this family is unbounded and unimodal. The parameters γ and δ are shape parameters, ε is a location parameter, and λ is a scale parameter.

In order to use the Johnson family of curves it is necessary to invert equations 1, 2, and 3, i.e., each of the equations must be solved for *x*.

1. The S_L transformation after inversion is:

$$x = \varepsilon + \lambda \exp\left(\frac{z-\gamma}{\delta}\right), \; -\infty < z < \infty. \qquad (4)$$

2. The S_B transformation after inversion is:

$$x = \varepsilon - \frac{\lambda}{1-\exp\left(\frac{\gamma - z}{\delta}\right)}, \; -\infty < z < \infty. \qquad (5)$$

3. The S_U transformation after inversion is:

$$x = \varepsilon + \lambda \sinh\left(\frac{z-\gamma}{\delta}\right), \; -\infty < x < \infty. \qquad (6)$$

Since the variable z in each transformation is a standard normal variate, the probability distribution of each Johnson family of curves may be determined from a normal table.

1. The probability density function of a member of the Johnson S_L family has the following form:

$$f_1(x) = \frac{\delta}{(x-\varepsilon)\sqrt{2\pi}} \exp\left\{-\frac{1}{2}\left[\gamma + \delta \ln\left(\frac{x-\varepsilon}{\lambda}\right)\right]^2\right\}, \; x \geq \varepsilon,$$
$$\delta > 0, -\infty < \gamma < \infty, \lambda > 0, -\infty < \varepsilon < \infty.$$

2. The probability density function of a member of the Johnson S_B family has the following form:

$$f_2(x) = \frac{\delta\lambda}{(x-\varepsilon)(\lambda - x + \varepsilon)\sqrt{2\pi}} \exp\left\{-\frac{1}{2}\left[\gamma + \delta \ln\left(\frac{x-\varepsilon}{\lambda - x + \varepsilon}\right)\right]^2\right\},$$

$$\varepsilon < x < \varepsilon + \lambda, \delta > 0, -\infty < \gamma < \infty, -\infty < \varepsilon < \infty.$$

3. The probability density function of a member of the Johnson S_U family has the following form:

$$f_3(x) = \frac{\delta}{\sqrt{2\pi\left[(x-\varepsilon)^2 + \lambda^2\right]}} \exp\left[-\frac{1}{2}\left(\gamma + \delta \ln\left\{\left(\frac{x-\varepsilon}{\lambda}\right) + \left[\left(\frac{x-\varepsilon}{\lambda}\right)^2 + 1\right]^{1/2}\right\}\right)^2\right],$$

$$-\infty < x < \infty, \delta > 0, -\infty < \gamma < \infty, \lambda > 0, -\infty < \varepsilon < \infty.$$

Sampling From a Johnson Curve.

After the appropriate Johnson curve has been selected and the parameters γ, δ, ε, and λ have been determined, then it is a simple matter to select random variates from the Johnson distribution. The method involves the following steps:

1. Select two random numbers r_1 and r_2 from the uniform interval (0, 1).

2. Use one of the *Box-Muller* equations to compute a random variate z from the standard normal distribution, N(0, 1).

3. Substitute z into the appropriate Johnson transformation. If the Johnson curve is of type S_L then substitute z into equation (4) to obtain the random variate x. If the Johnson curve is of type S_B then substitute z into equation (5) to obtain the random variate x. If the Johnson curve is of type S_L then substitute z into equation (6) to obtain the random variate x.

Appendix F

ASAT Input Files

1. APF file: Fleet mix, Aircraft actions, Links to airport and CRM data, and Air Traffic and Pilot response time parameters

---

```
Description: KCVG Runways 18L and 18C and 18R
;
;     Aircraft types and % of overall traffic
;     - - - - - - - - - - - - - - - - - - - -
Aircraft:   DATA\\A320.TXT
PercentageMix:    2                   ;     [-] out of 1000

Aircraft:   DATA\\ATR42.TXT
PercentageMix:    100                 ;     [-] out of 1000

Aircraft:   DATA\\B732.TXT
PercentageMix:    34                  ;     [-] out of 1000

Aircraft:   DATA\\B738.TXT
PercentageMix:    24                  ;     [-] out of 1000

Aircraft:   DATA\\B752.TXT
PercentageMix:    24                  ;     [-] out of 1000

Aircraft:   DATA\\B777.TXT
PercentageMix:    14                  ;     [-] out of 1000

Aircraft:   DATA\\ERJ.TXT     ;      INSTEAD OF B727s !!!!!!!
PercentageMix:    488                 ;     [-] out of 1000

Aircraft:   DATA\\F100.TXT
PercentageMix:    57                  ;     [-] out of 1000

Aircraft:   DATA\\MD88.TXT
PercentageMix:    28                  ;     [-] out of 1000

Aircraft:   DATA\\SAAB.TXT
PercentageMix:    2                   ;     [-] out of 1000

AirportFile: Airports & ASAT Projects\\KCVG.out

ScenarioNumber:   1
;     Active runways (from LEFT to RIGHT)
;     - - - - - - - - - - - - - - - - - -
;     Make sure the BLUNDER is [0] and the EVADER is [1] !!!
Runway:           18L
FlightMode:     REJECT
Runway:           18C
FlightMode:     REJECT
```

```
Runway:          18R
FlightMode:     REJECT

;     Air Traffic Control Response Time Definition
;     - - - - - - - - - - - - - - - - - - - - - - - -
AtcJohnsonType:     2
AtcDelta:           5.49
AtcLambda:          3.57
AtcXi:             -9.94
AtcGamma:          -9.4
AtcMin:             3.0
AtcMax:            22.0
AtcDeltaTime:       0.0

;     Pilot response type
;     - - - - - - - - - -
; GRM18
PilotJohnsonType:   2                      ;1:SB   2:SL    3:SU  pdf by
grm 12/01/05
PilotXi:            0.5
PilotLambda:       12.7
PilotDelta:         2.04
PilotGamma:         1.98
PilotMin:           1.0
PilotMax:          17.0
PilotDeltaTime:    -1.0       ;roll time to 3 degrees which is what
;times are based on
; GRM18

CrmData:    DATA\\CAT1030.TXT            ;     CRM distributions
```

---

2. Airport description: Airport and runway coordinates

```
AirportName         : CINCINNATI/NORTHERN KY INT'L AIRPORT
AirportIdentifier   : KCVG
AirportLocation     : COVINGTON
AirportState        : KY
AirportLatLon       :  39 02 46.16,  084 39 50.23
AirportElevation    : 896
AirportMagVarYr     : 1995
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

RunwayName          : 09
RunwayTrueBearing   : 090
RunwayLength        : 12000
RunwayThLatLon      :  39 02 46.91,  084 41 42.36
RunwayThElevation   : 884

RunwayName          : 27
RunwayTrueBearing   : 270
RunwayLength        : 12000
RunwayThLatLon      :  39 02 46.54,  084 39 10.26
```

```
RunwayThElevation  : 875

RunwayName         : 18C
RunwayTrueBearing  : 180
RunwayLength       : 11000
RunwayThLatLon     :  39 03 53.07,  084 40 07.02
RunwayThElevation  : 875

RunwayName         : 36C
RunwayTrueBearing  : 000
RunwayLength       : 11000
RunwayThLatLon     :  39 02 04.35,  084 40 07.47
RunwayThElevation  : 841

RunwayName         : 18L
RunwayTrueBearing  : 180
RunwayLength       : 10000
RunwayThLatLon     :  39 03 21.08,  084 38 48.00
RunwayThElevation  : 886

RunwayName         : 36R
RunwayTrueBearing  : 000
RunwayLength       : 10000
RunwayThLatLon     :  39 01 42.24,  084 38 48.46
RunwayThElevation  : 896

RunwayName         : 18R
RunwayTrueBearing  : 180
RunwayLength       : 10000
RunwayThLatLon     :  39 04 15.18,  084 41 01.45
RunwayThElevation  : 875

RunwayName         : 36L
RunwayTrueBearing  : 000
RunwayLength       : 10000
RunwayThLatLon     :  39 02 56.11,  084 41 01.76
RunwayThElevation  : 841
------------------------------------------------------------------------------------------
```

Appendix G

ASAT Output File

```
ASAT Output file for C:\Documents and Settings\Administrator\Desktop\ASAT4ILSRNP3-

12RunNumber     AcType2     AcType1       CPA2D       CPA3D      BATCRT        BPRT

       1         ERJ         ERJ       2563.8      2565.2        10.7          7.8
       2       ATR42         ERJ       2338.8      2345.1         5.1          2.5
       3         ERJ       ATR42       2226.4      2232.2        13.1          7.0
       4       ATR42       ATR42       2616.1      2625.3         3.3          4.3
       5        B738        B738       1446.7      1446.7         7.1          2.0
       6        F100       ATR42       2660.3      2666.1         8.7          2.5
       7        B752       ATR42       3695.2      3709.9         4.3          1.9
       8         ERJ         ERJ       1767.1      1767.8         7.3         11.8
       9         ERJ         ERJ       2092.5      2093.9         9.4          2.3
      10         ERJ         ERJ       2545.7      2560.9         8.6          3.2

Total Number of Runs     : 10

TCV Range: 500[Ft]
NTCV2D(LCR): 0 / 10
NTCV3D(LCR): 0 / 10

NTCV2D(LC) : 0 / 5
NTCV3D(LC) : 0 / 5

NTCV2D(RC) : 0 / 5
NTCV3D(RC) : 0 / 5
```

Printout ==> continued on next page ==>

Notes:
RunNumber: Run Number
AcType2: Aircraft Type of Evader aircraft
AcType1: Aircraft Type of Blundering aircraft
CPA2d: Closest Point of Approach in system plane (2-dimensional)
CPA3d: Closest Point of Approach – slant range (3-dimensional)
BATCRT: Blunderer ATC Response Time
BPRT: Blunderer Pilot Response Time
EATCRT: Evader ATC Response Time
EPRT: Evader Pilot Response Time
TCV2D: Flag
TCV3D: Flag
BlunderStatus: Which aircraft blunders which way
TCV: Same as TCV3D

a\Airports & ASAT Projects\KCVG 18L 18C 18R.apf ASAT project input file

EATCRT	EPRT	TCV2D	TCV3D	BlunderStatus	TCV
10.6	5.5	0	0	C_Blunders_to_Left	0
13.2	4.1	0	0	L_Blunders_to_Center	0
11.3	3.7	0	0	R_Blunders_to_Center	0
10.1	4.7	0	0	L_Blunders_to_Center	0
8.1	4.0	0	0	R_Blunders_to_Center	0
11.2	3.6	0	0	R_Blunders_to_Center	0
11.7	2.5	0	0	L_Blunders_to_Center	0
11.4	3.5	0	0	R_Blunders_to_Center	0
13.3	1.3	0	0	R_Blunders_to_Center	0
7.0	2.2	0	0	L_Blunders_to_Center	0

Appendix H

Effects of Delays on TCV Rate

Because of the extremely low values for TCV rates obtained in the scenarios, three additional scenarios were run that injected additional delays into the timing sequence. The additional delay times were added onto the pilot response times outside the limiting filters. The three scenarios were for 2 second, 4 second, and 6 second delays from the baseline scenario for southbound traffic. The results are summarized in the following table.

	Right-Center			Left-Center			Total
Scenario	3-D TCVs	# of Blunders	%*	3-D TCVs	# of Blunders	%*	%*
2 sec. Delay	572	24919	2.55	15	25081	0.07	1.30
4 sec. Delay	1329	24923	5.92	47	25077	0.21	3.06
6 sec. Delay	2827	25081	12.52	148	24919	0.66	6.61

Table H-1. Simulation Results by Scenario
(* Percentage is scaled by 1.11 to compensate for non-at-risk traffic.)

The table shows that even with a 4 second delay, the system still has an acceptable TCV rate (less than 5.1% overall and less than 6.8% for the embedded duals). Comparisons between controller response times using DEDS and FMA displays showed just under a 3 second difference in the mean times with a 0.8 second decrease in standard deviation with the FMA. Given the additional factors of runway stagger, reduced processing time and fleet mix, the TCV rates generated by this simulation appear reasonable.

Appendix I

KCVG Waiver

U.S. Department of Transportation

Federal Aviation Administration

Memorandum

Subject: **ACTION**: Waiver Request; AVN-160 Memorandum Dated 08/13/2004

Date: SEP 27 2004

From: Manager, Flight Technologies and Procedures Division, AFS-400

Reply to Attn. of:

To: Manager, National Flight Procedures Office, AVN-100

The waiver to the procedure for Covington/Northern Kentucky International, Covington/Cincinnati, KY "Simultaneous Triple Approaches Runways 17-35" is approved and forwarded for your action.

We are distributing copies of the FAA Form 8260-1 to the office indicated below.

for John W. McGraw

Attachment

cc:
ASO-290
AFS-400/410/420/

U.S. Department
of Transporation

Federal Aviation
Administration

Memorandum

MIKE MONRONEY AERONAUTICAL CENTER
QUALITY AND OPERATIONS ASSURANCE BRANCH, AVN-160
P.O. BOX 25082
OKLAHOMA CITY, OK 73125

Subject: **ACTION**: Waiver Request

Date: AUG 13 2004

From: Manager, Quality and Operations Assurance Branch, AVN-160

Reply to Attn. of: AVN-160B
(405)954-8976
Fax: (405)954-1301

To: Manager, Flight Technologies and Procedures Division, AFS-400
THRU: Manager, Flight Procedure Standards Branch, AFS-420

The attached Waiver(s) for Covington/Northern Kentucky International, Covington/Cincinnati, KY is forwarded for your review and approval.

Please return a signed copy for our files.

8260-1 Simultaneous triple approaches runways 17-35

Glenn D Weeks

Attachments

US Department of Transportation
Federal Aviation Administration

FLIGHT PROCEDURES STANDARDS WAIVER

FLIGHT STANDARDS USE ONLY

CONTROL NO:

1. Flight Procedure Identification:
COVINGTON/CINCINNATI, OH, KY,
CINCINNATI/NORTHERN KENTUCKY INTERNATIONAL
Simultaneous triple approaches runways 17 - 35 (to be renamed 18R - 36L upon commissioning), 18R - 36L (to be renamed 18C - 36C upon commissioning of runway 17 - 35) and 18L - 36R / (Category I and II landing South, Category I, II and III landing North).

2. Waiver Required and Applicable Standard:

"TRIPLE APPROACHES."
"THE MINIMUM distance between parallel FAC's is 5,000 feet." FAA Order 8260.3B, Volume 3, Appendix 2, paragraph 7.2.

3. Reason for Waiver *(Justification for nonstandard treatment)*:

Simultaneous triple approaches are required to increase the airport capacity and to fully utilize the 3rd parallel runway. The minimum separation between runways is:

17 - 35 (future designation 18R - 36L) and 18R - 36L (future designation 18C - 36C) 4313.19 feet
18R - 36L (future designation 18C - 36C) and 18L - 36R 6242.61 feet
17 - 35 (future designation 18R - 36L) and 18L - 36R 10557.83 feet

Airport Elevation is 896.2 feet MSL

4. Equivalent Level of Safety Provided:

Development of FMA capability specific to this airport by ATB-103 to meet requirements of Order 7110.65N, paragraph 5-9-7a.4. "A high-resolution color monitor with alert algorithms, such as the final monitor aid...shall be used to monitor approaches where: (a) Triple parallel runway centerlines are at least 4,300 but less than 5,000 feet apart and the airport field elevation is less than 1,000 feet MSL".

The FMA capability would also meet the requirements of AC 150/5300-13 CHG 5, paragraph 208.a.(2). "Triple simultaneous precision instrument approaches for airports below 1000 feet elevation...the FAA, on a case-by-case basis, will consider proposals utilizing separations down to a minimum of 4300 feet (1310 m) where a 5,000 foot (1525 m) separation is impractical or the airport elevation is at or above 1000 feet (305 m). Reduction of separation may require special radar, monitoring equipment, etc..."

5. How Relocation or Additional Facilities Will Affect Waiver Requirement:

Relocating the runway is economically unfeasible and increased lateral runway separation would expand existing boundaries of noise-sensitive land use areas not currently in the arrival flight path.

6. Coordination With User Organizations *(Specify)*:
AVN-110 ______ **AVN-160** ______
AVN-101 ______

7. SUBMITTED BY

DATE:	Office Identification:	Title:	Signature:
AUG 1 3 2004	AVN-100	MANAGER	Chas. Frederic Anderson

FAA FORM 8260 - 1 / July 2003 (computer generated)

8. CONTINUATION
Comments:

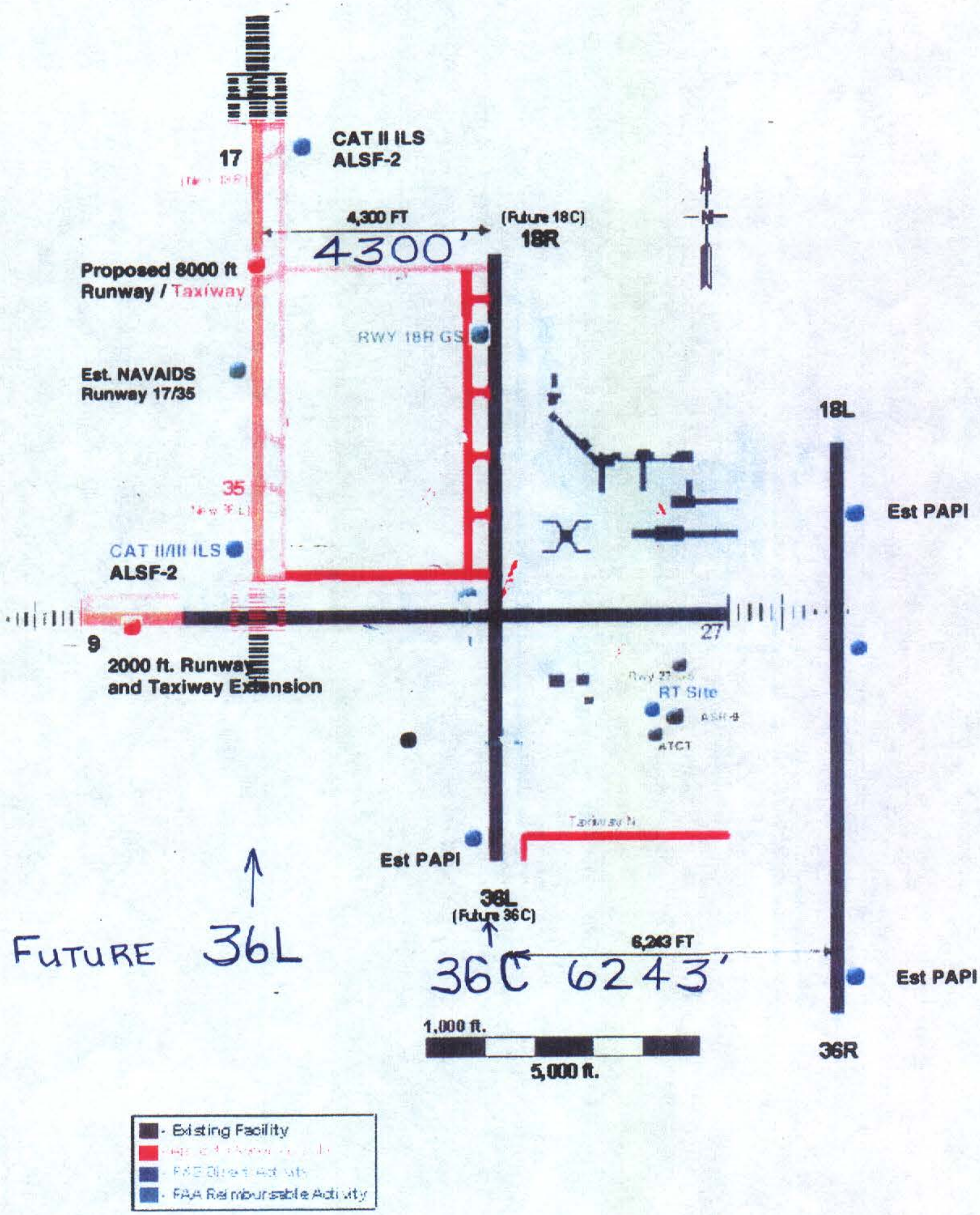
9. AFS ACTION		
	XX	Approved
		Disapproved
		Not Required

Comments:

Approved Based on the Equivalent Level of Safety Provided in Block 4.

Date:	Routing Symbol:	Signature:
9/24/04	AFS-400	for John W. McGraw [signature] Manager, Flight Technologies & Procedures

CINCINNATI/NORTHERN KENTUCKY INTERNATIONAL AIRPORT (CVG)



U.S. Department
of Transportation
Federal Aviation Administration

Route Slip

To: Gene Doser, Lead, AVN-110B **Date:** March 24, 2004

Subject: Waiver Request Cincinnati/Northern Ky Intl (CVG), Covington/Cincinnati, KY

Action:

___ Per Your Request	___ Discuss with Me	_X_ Take Appropriate Action
___ For Your Information	___ For Your Approval	___ Please Answer
___ Per Our Conversation	___ For your Signature	___ Prepare Reply for:
___ Note and Return	___ Comment	

Remarks:

Gene,

Included is a waiver request for triple simultaneous precision instrument approaches (ILS) landing to the north and south ends of Cincinnati/Northern Ky Intl (CVG), Covington/Cincinnati, Ky. The scheduled commissioning/publication is December 2005 when RWY 17-35 (to be renamed 18R-36L upon commissioning) is opened. Obviously development/publication of the SIAPs will be dependent upon approval of the waiver. "Full Operational Capability" to achieve a successful commissioning is dependent upon approval of this waiver.

Dan A. Arnett

Dan A. Arnett
ATL FPO

Phone: 404 305-7402 FAX: 404 305-7380

File:
WP: cvgwvrmemo.doc
ATL FPO,DArnett,DAA,404 305-7402,03/19/2004

Terminal Air Traffic Control Radar and Display System Recommendations for Monitoring Simultaneous Instrument Approaches

technical note

Sherri Morrow-Magyarits, ACT-540
Richard Ozmore, ACT-540

December 1999

DOT/FAA/CT-TN99/24

U.S. Department of Transportation
Federal Aviation Administration

Report is retained in File for Archival Reference.

References

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4. Federal Aviation Administration (2005). *Air Traffic Control* (DOT/FAA/Order 7110.65P). Washington, DC: Federal Aviation Administration.

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6. Ozmore, R., Morrow-Magyarits, S. (1999) *Terminal Air Traffic Control Radar and Display System Recommendations for Monitoring Simultaneous Instrument Approaches* (DOT/FAA/CT-TN99/24). Atlantic City International Airport, NJ: William J. Hughes Technical Center.

7. System Resources Corporation (1992-Draft, 1995-Final) *Comparison of the Final Monitor Aid and the ARTS/DEDS Display Systems* (Contract #DTFA03-94-C-00042) Mays Landing, NJ

8. Haines, A.L. & Swedish, W.J. (1981) *Requirements for Independent and Dependent Parallel Instrument Approaches at Reduced Runway Spacing* (FAA-EM-81-8) Mitre Corporation, McLean, VA

9. Dorfman, G.A. & Higgins, M.K. (1996) *Analysis of Aircrew Responses Affecting Simultaneous ILS Approaches, Volume 2: Main Report* (MTR 96W0000048) Mitre CAASD, McLean, VA

10. Ozmore, Richard E. (1993) *Evaluation of Triple Simultaneous Parallel ILS Approaches Spaced 4300 Feet Apart, Final Monitor Aid with Simulated Radar 4.8 Second Update Rate, Volume 1* (DOT/FAA/CT-92/16). Atlantic City International Airport, NJ: FAA Technical Center.