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Safety Study Report for Multilateration/STARS FMA Used as a Precision Runway Monitoring System for Triple Simultaneous Independent Approaches to Detroit Metropolitan Wayne County Airport

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Flight Operations Simulation and Analysis Branch
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Flight Standards Service

Safety Study Report for Multilateration/STARS FMA Used as a Precision Runway Monitoring System for Triple Simultaneous Independent Approaches to Detroit Metropolitan Wayne County Airport (KDTW)

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12. Abstract This report presents the results from an Airspace Simulation and Analysis Tool (ASAT) Monte Carlo simulation study on triple simultaneous approaches to Detroit Metropolitan Wayne County Airport (KDTW) with surveillance provided by a Precision Runway Monitor-A (PRM-A) system based on multilateration. The runway configuration includes an offset localizer to one of the outer runways in the triple configuration.		
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Executive Summary

Federal Aviation Administration (FAA) Order 7110.65R, *Air Traffic Control*, paragraphs 5-9-6 through 5-9-8 contain the current provisions governing Air Traffic Control (ATC) separation for dependent and independent precision approach operations at airports with dual or triple parallel runway configurations. These standards were developed in part from simulations performed by the FAA based on Instrument Landing System (ILS) precision approach operations to determine the parameters necessary to meet the Target Level of Safety (TLS) for the blunder scenario. The blunder scenario involves two or more aircraft on final approach to parallel runways, when one aircraft unexpectedly turns toward the other final approach course at a predetermined angle, usually around 30°, endangering the adjacent traffic. Paragraph 5-9-8 specifically addresses approaches to closely spaced parallel runways where the runway separation is less than 4,300 feet that require the use of a Precision Runway Monitor (PRM) system.

A PRM system consists of the following major components:

- High update rate radar - Typical approach radars provide a position report roughly every 5.0 seconds. Because of the reduced runway separation, the high update radar component of the PRM must provide updates at least every 2.4 seconds for parallel approaches to runways separated by 3,400 to 4,299 feet or at least every 1.0 second for approaches to runways separated by at least 3,000 feet with one localizer offset by 2.5°. This requirement is typically met by electronically scanned phased array (e-scan) radar.

- Final Monitor Aid (FMA) - An FMA is a large (not less than 20" x 20"), high resolution color monitor used by final monitor controllers (one for each runway in a dual or triple runway configuration). The FMA must be capable of displaying the 2,000-foot wide No Transgression Zone (NTZ) located equidistant between the runway final approach courses. In addition, the FMA is equipped with visual and/or audible alert algorithms which alert the final monitor controller when an aircraft is projected to enter or has entered the NTZ. The Standard Terminal Automation Replacement System (STARS) includes an FMA-like display that has essentially the same capabilities plus a number of other features.

The FAA developed a multilateration monitoring system to provide the same capability as the e-scan PRM, combining the technology in the STARS and Airport Surface Detection Equipment – Model X (ASDE-X) systems. The multilateration system, referred to as PRM-A, measures the time of arrival of the signal from an aircraft's beacon transponder to small, strategically placed sensors around an airport and uses the different delay times to triangulate the aircraft's position.

Previous simulations determined acceptable combinations of the following critical parameters when the multilateration system is used as a PRM: (1) surveillance system

update rate, (2) data display processing delay, and (3) position measurement accuracy. The previous study also evaluated the impact of using STARS instead of a direct connection from the surveillance system to an FMA display.

This report presents the results of a simulation study of simultaneous triple independent approach operations to Detroit Metropolitan Wayne County Airport (KDTW) using PRM-A with STARS. KDTW intends to conduct these operations to Runways 4L-4R-3R and Runways 21L-22L-22R. The centerlines of runway pairs 4R-3R and 21L-22L are separated by roughly 5,800 feet with about 300-foot and 1,700-foot arrival threshold staggers, respectively. The 4L-4R and 22L-22R pairs are separated by 3,000 feet with 1,700-foot and 3,700-foot arrival threshold staggers, respectively. Because of the 3,000-foot separation, simultaneous operations to the 4L-4R and 22R-22L runway pairs require offset localizers on Runway 4L and Runway 22R. This study was conducted by the FAA Flight Operations Simulation and Analysis Branch (AFS-440) and Air Traffic Simulation, Inc. (ATSI).

A computer-based Monte Carlo simulation was conducted using a modified version of AFS-440's Airspace Simulation and Analysis Tool (ASAT). ASAT was modified to allow modeling of operational blunder scenarios to closely spaced runways, to allow statistical variation of the critical parameters bearing on the operational scenarios, and to model the offset localizers.

The basic operational scenario consisted of three aircraft initialized on their respective final approach courses. While navigating the final approach course, one aircraft unexpectedly blundered toward the other final approach course at a predetermined angle, nominally 30°. The aircraft were aligned so that the blundering aircraft would collide with the adjacent aircraft if ATC and pilot responses are not able to move the threatened aircraft out of the way. When the blundering aircraft was determined by the surveillance system to be 10 seconds from NTZ penetration, a simulated "yellow" alert was issued to the final monitor controller. After a suitable response time to the yellow alert, simulated evasion instructions were issued by the final monitor controller to the pilot(s) of the non-blundering (threatened) aircraft. Controller actions were simulated and sampled from a statistical distribution. The pilot reaction time to the controller instructions was sampled from another statistical distribution.

While the operational scenario was playing out, ASAT constantly monitored the distance between the blundering aircraft and the non-blundering aircraft and recorded the Closest Point of Approach (CPA) for each simulation run. For this study, the PRM safety requirements were satisfied if, for a given scenario (set of conditions), the frequency of blunders that resulted in a CPA of less than 500 feet (referred to as a Test Criteria Violation [TCV]) was less than or equal to 5.1% overall and less than 6.8% for each of the embedded dual operations.

Two surveillance system update rates (1.0 second and 2.0 seconds) were evaluated and three data display processing delays (1.0 second, 2.0 seconds, and 3.0 seconds) were evaluated. The position measurement accuracy values were modeled as normal distributions with means of zero and one standard deviation (σ) value of 100 feet. Actual multilateration system accuracy is a complex matter but 100 feet is assumed to be a worst case. The position measurement accuracy distributions were bound between the ranges of ±4 standard deviations, i.e., no target was reported more than 400 feet from its true position.

The simulation evaluated the scenarios using the current fleet mix at KDTW (less than 5% Heavies during 2005-2006), a mix with 10% Heavies, and a mix with 20% Heavies. Aircraft that are classified as Heavies tend to respond more slowly and to be less maneuverable, thus reducing the probability of a successful evasion. Fleet mix determination is discussed in Appendix D.

This mix of test parameters was examined for both sets of runways and resulted in a matrix of 36 different sets of test conditions and 50,000 Monte Carlo simulation runs were completed for each of the condition sets for a total of 1,800,000 runs.

The results from the simulations indicate that for all system configurations examined, the triple simultaneous approach operations at KDTW are safe as far as the blunder scenario is concerned. This report does not address any other operational issues related to using the offset localizers in a triples configuration. The ability of the multilateration system to meet the performance assumed in this report is also taken for granted and a no-fault operation is assumed.

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1.0 Introduction

This report presents the results of a simulation study of proposed simultaneous triple independent approach operations to Detroit Metropolitan Wayne County Airport (KDTW) under a Precision Runway Monitor-A (PRM-A) system with the Standard Terminal Automation Replacement System (STARS). This study was conducted by the Federal Aviation Administration (FAA) Flight Operations Simulation and Analysis Branch (AFS-440).

1.1 Purpose and Structure of the Report

This report presents the results from an Airspace Simulation and Analysis Tool (ASAT) Monte Carlo simulation study on triple simultaneous approaches to KDTW with surveillance provided by a PRM-A system based on mutlilateration. The simulation study was designed to examine the safety of triple simultaneous approach operations during blunder scenarios. This report does not address any other operational issues related to using offset localizers in a triples configuration.

This report provides information about the runway configuration, PRM-A system, methods used during the Monte Carlo simulation, and the data obtained from the study. This report also presents conclusions and recommendations based on the study that can be extrapolated about the safety of triple simultaneous approach operations during blunder scenarios.

1.2 KDTW Runway Configuration

See Figure 1 for a diagram of the airport runway layout at KDTW. KDTW intends to conduct simultaneous triple independent approach operations to Runways 4L-4R-3R and 21L-22L-22R. The centerlines of runway pairs 4R-3R and 21L-22L are separated by roughly 5,800 feet with about 300-foot and 1,700-foot staggers, respectively. The 4L-4R and 22L-22R pairs are separated by 3,000 feet with 1,700-foot and 3,700-foot staggers, respectively. Since the 4 and 22 runway pairs are separated by less than the 5,000 feet required for conventional terminal surveillance systems, high update radar is required. Because of the 3,000-foot separation, simultaneous operations to the 4L-4R and 22R-22L runway pairs require offset localizers. The original criteria relating to the offset localizers only considered operations to a pair of runways. Implementation of this type of operation in a triples configuration may require additional operational considerations outside the focus of this study.

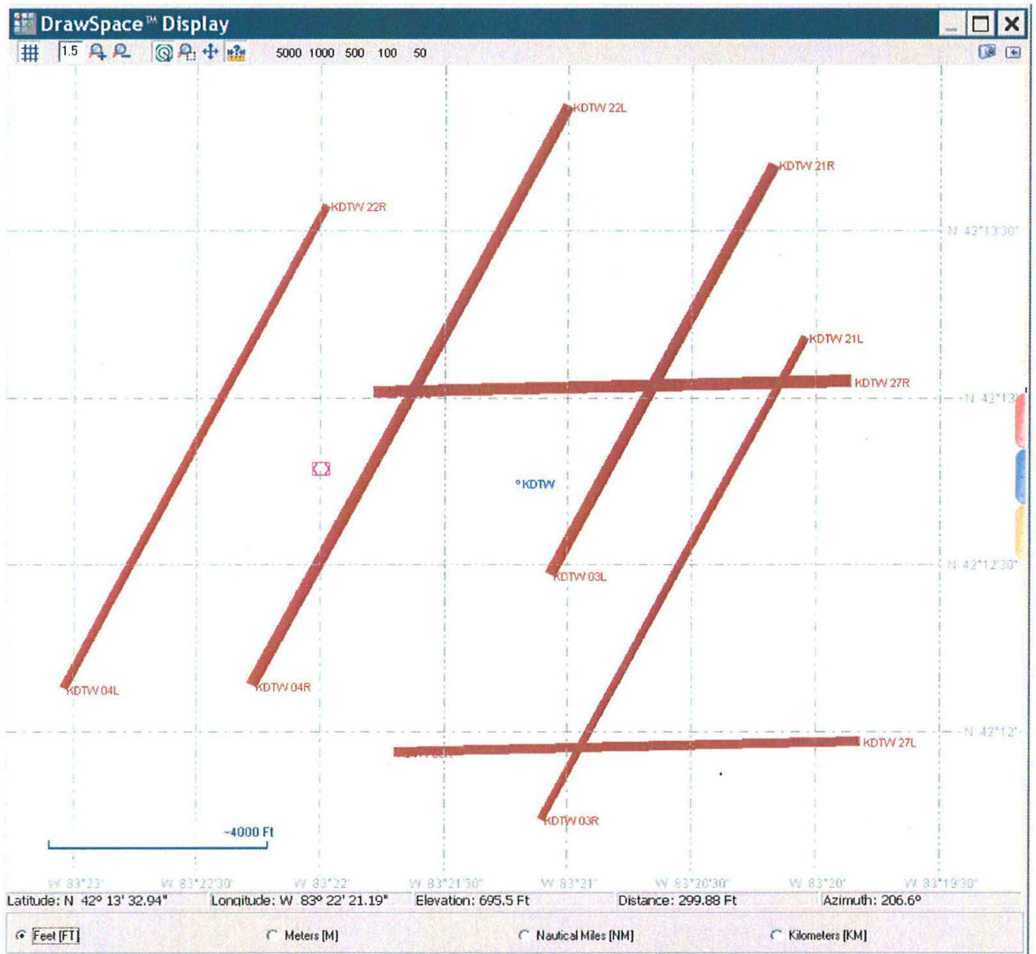

Figure 1: Detroit Metropolitan Wayne County Airport (KDTW) Runway Configuration

1.3 Closely Spaced Parallel Approach Requirements

FAA Order 7110.65R, *Air Traffic Control*, paragraphs 5-9-7 and 5-9-8 contain the current provisions governing Air Traffic Control (ATC) separation for independent precision approach operations at airports with dual or triple parallel runway configurations *Air Traffic Control* [2]. These standards were developed in part from simulations performed by the FAA based on Instrument Landing System (ILS) precision approach operations to determine the parameters necessary to meet the Target Level of Safety (TLS) for the blunder scenario. The blunder scenario involves two or more aircraft on final approach to parallel runways, when one aircraft unexpectedly turns toward the other final approach course at a predetermined angle, usually around 30°, endangering the adjacent traffic. Paragraph 5-9-8 specifically addresses approaches to closely spaced parallel runways (i.e., where the runway separation is less than 4,300 feet) that require the use of a Precision Runway Monitor (PRM) system.

A PRM system consists of the following major components:

- High update rate radar - Typical approach radars provide a position report roughly every 5.0 seconds. Because of the reduced runway separation, the high update radar component of the PRM must provide updates at least every 2.4 seconds for parallel approaches to runways separated by 3,400 to 4,299 feet or at least every 1.0 seconds for approaches to runways separated by 3,000 to 3,399 feet with one localizer offset by 2.5°. This requirement is typically met by electronically scanned phased array (e-scan) radar.

- Final Monitor Aid (FMA) - An FMA is a large (not less than 20" x 20"), high resolution color monitor for use by dedicated final monitor controllers (one for each runway in a dual or triple runway configuration). The FMA must be capable of displaying the 2,000-foot wide No Transgression Zone (NTZ) located equal distance between the runway final approach courses. The purpose of the NTZ will be discussed later. In addition, the FMA is equipped with visual and/or audible alert algorithms which alert the final monitor controller when an aircraft is projected to enter or has entered the NTZ. STARS includes an FMA-like display that has essentially the same capabilities plus a number of other features.

For independent operations, there must be a separate controller monitoring each runway and the FMAs monitoring the simultaneous approaches must be adjacent consoles to facilitate communications between the controllers involved. If one controller sees anything amiss, such as a blunder, he or she can immediately call the other controllers' attention to it.

The FAA developed the multilateration PRM-A monitoring system as a means to provide the same capability as the e-scan PRM, combining the technology in the STARS and Airport Surface Detection Equipment-X (ASDE-X) systems. The multilateration system, referred to as PRM-A, measures when the aircraft's beacon transponder signal arrives to small, strategically placed sensors at an airport. The system uses the different delay times to triangulate the aircraft's position. The accuracy of the system's position reports can be adjusted by changing the number of sensors or their locations to meet operational requirements. The update rate is also adjustable by controlling how often transponder queries are issued. While the system normally operates at the highest update rate available, Radio Frequency (RF) spectrum availability may limit the rate at some locations.

Previous simulations determined acceptable combinations of these adjustable parameters when the multilateration system is used as a PRM system: (1) surveillance system update rate, (2) data display processing delay, and (3) position measurement accuracy. The previous study also evaluated the impact of using STARS instead of a direct connection from the surveillance system to a FMA display. Use of the STARS increases the display processing delay over the almost direct feed used in the e-scan PRM system, but not by a great amount. See reference *Safety Study Report for Multilateration/STARS FMA used as a Precision Runway Monitoring System to Parallel Runways Separated by 3,400 Feet* [6] for more information on this study.

1.4 Technical Approach

A computer-based Monte Carlo simulation was conducted using a modified version of AFS-440's Airspace Simulation and Analysis Tool (ASAT). ASAT is discussed in more detail in Section 2.1. During the previous study on multilateration requirements *Safety Study Report for Multilateration/STARS FMA used as a Precision Runway Monitoring System to Parallel Runways Separated by 3,400 Feet* [6], the basic ASAT blunder analysis routine was modified to allow statistical variation of the critical parameters bearing on the operational scenarios. Additional modifications were made to support modeling the offset localizers for this study.

The operation of interest is an independent simultaneous parallel approach procedure with an *at-risk* blunder. See Figure 2 for an illustration of a sample blunder scenario (not intended to represent the KDTW runway configuration). This blunder involves three aircraft established on approach (with vertical guidance) to parallel runways (although one course may be offset by a small amount, as at KDTW) where one of the aircraft deviates from the approach path towards the adjacent traffic. The ultimate requirement on the "system" is that 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, FAA Order 7110.65 requires a final monitor controller position for each runway *Air Traffic Control* [2]. These controllers maintain longitudinal spacing between landings and are responsible for attempting to return a blundering aircraft to the correct course. If the blundering aircraft fails to correct its course, the controllers direct the threatened traffic to evade, usually by giving them an immediate turn command.

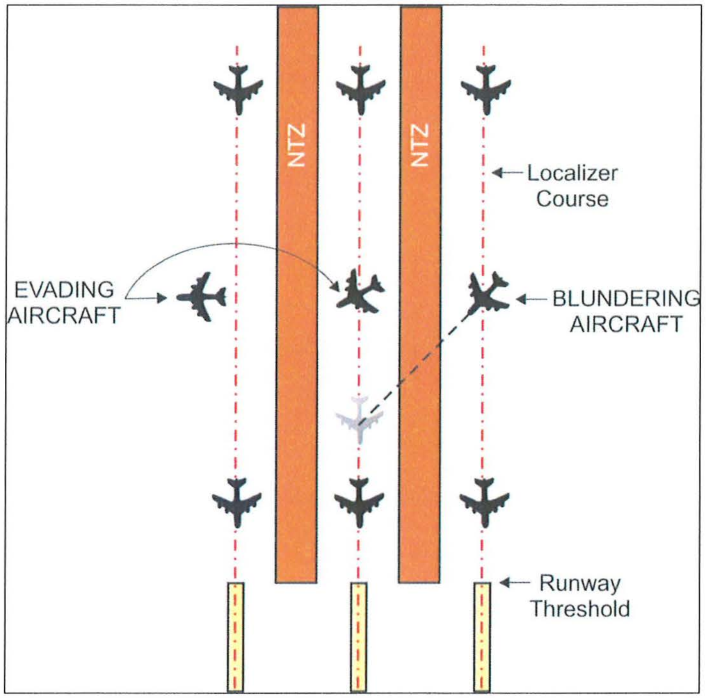

Figure 2: Triple Simultaneous Approach with Blunder

The "at-risk" term implies that if no corrective action is taken, the aircraft will come within 500 feet of each other and potentially collide. The simulation includes an algorithm to initially align the aircraft so that the blundering aircraft should collide with the adjacent aircraft if controller and pilot actions are not quick enough to move the threatened (evading) aircraft out of the way. The algorithm is less efficient when there is a significant stagger between the two runways (which provides a significant initial vertical separation), such as the 3,700-foot arrival threshold stagger between Runway 22L and Runway 22R and some adjustments to the results are required in those cases. Violation of the 500-foot separation is referred to as a Test Criteria Violation (TCV).

For independent operations, a 2,000-foot wide NTZ is located midway between adjacent pairs of approach paths to aid controllers in determining that an aircraft is blundering. The simulation maintained a "predictor" on each aircraft, which told the controller where the aircraft was expected to be 10 seconds later. The predictor is another capability required in the FMAs. When the blundering aircraft was determined by the surveillance system to be 10 seconds or less from penetrating the NTZ, a simulated "yellow" alert was issued to the final monitor controller. After a suitable response time to the yellow alert, simulated evasion instructions were issued by the final monitor controller to the pilot(s) of the at-risk evader aircraft. Controllers could determine that a blunder might be occurring even before the yellow alert, but the simulation did not allow any responses prior to the yellow alert. Controller actions were simulated and sampled from a statistical distribution based on data collected during the Multiple Parallel Approach Program

(MPAP), which will be discussed later. (Refer to Appendix A: Air Traffic Controller Response Time Statistical Distribution Analysis for more information concerning how the reaction times were determined.) Due to the time and fuel costs associated with a "nuisance" breakout, the final monitor controllers should be reasonably certain that the blundering aircraft cannot be returned to its intended course before breaking the threatened aircraft out.

The pilot reaction time to the controller instructions was sampled from another statistical distribution and then the aircraft models were commanded to begin the evasion maneuver, an immediate turn away from the blunderer, usually 90°. Aircraft performance parameters, such as roll rate, bank angle, and acceleration, were sampled from data sets collected over many flight and simulator test programs. Refer to Appendix B: Pilot Reaction Time Statistical Distribution Analysis for more information about how the reaction times were determined.

While the operational scenario was playing out, ASAT constantly monitored the distance between the blundering aircraft and the non-blundering aircraft and recorded the Closest Point of Approach (CPA) for each simulation run. If the CPA for a run was less than 500 feet, it was recorded as a TCV.

Risk evaluations performed during the MPAP identified acceptable TCV rates for dual and triple simultaneous approach operations. Refer to Section 2.4 for details of the evaluation. For this study, the safety requirements were satisfied if, for a given scenario (set of conditions), the frequency of blunders that resulted in a CPA of less than 500 feet (i.e., a TCV) was less than 5.1% overall and less than 6.8% for each of the embedded dual operations. This generates an unambiguous pass-fail criterion for each test scenario.

1.5 Standard Terminal Automation Replacement System (STARS) Considerations

The Standard Terminal Automation Replacement System (STARS) is a state-of-the art radar display for terminal airspace designed to replace older Automated Radar Terminal Systems (ARTS) at 172 FAA and 199 Department of Defense terminal radar approach control facilities and towers. STARS will be used by controllers to provide air traffic control services to aircraft in terminal areas. These services include separation and sequencing of air traffic, provision of alerts and weather advisories, and radar vectoring for departing and arriving traffic.

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 that there were no STARS artifacts that would affect the presentation of the targets. (Possibly the most significant attribute of STARS is its versatility.) It can operate in a large number of modes using various sensors. During the development cycle, the system has evolved considerably. 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 STARS is implemented as a FMA, it receives slant range data essentially directly from the radar, just as previous tests had assumed. While it is not totally clear whether the slant range data are extracted from system plane data (calculated from slant range data), any conversions to and from the radar's system plane involve a negligible amount of processing overhead and should 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 e-scan system. The red alert is based upon the target report being in the NTZ, not any tracking prediction artifact.

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. The testing process used to determine this latency was explained by researchers at the FAA William J. Hughes Technical Center and data were provided to support the lower value. In essence, the only change to the ASAT module for this analysis is replacing the 1.2-second surveillance system display latency/processing delay with a 1.0-second value based on the data provided by the STARS Program Office.

1.6 PRM-A Considerations

The Precision Runway Monitor-Alternate (PRM-A) target report data is sent to STARS through the Airport Surface Detection Equipment – Model X (ASDE-X) system. The ASDE-X system can process radar, multilateration (MLAT) and ADS-B sensor data. STARS will receive multilaterated target reports via a connection to an ASDE-X Target Processor (TP) subsystem which collects transponder reply data from all multilateration system Receiver Units (RUs) to compute target positions and track multilateration targets. These TP messages will be sent to STARS for track processing.

Primary radar surveillance operates by transmitting radio energy from an antenna and receiving the energy reflected back by a target. These reflections are then interpreted to form the images that can be displayed to an air traffic controller. Modern terminal area radars normally also have a Secondary Surveillance mode (SSR). A transponder on board the aircraft is interrogated by the SSR and the radar receives the reply. This allows the radar to update the aircraft positional data with not only range and azimuth data but also altitude and beacon code identification. This is done on every sweep (radar scan) and gives information corresponding to the accuracy of the radar.

The multilateration surveillance system to be used for PRM-A operations at the Detroit Metropolitan Wayne County Airport will include several RUs situated around the airport surface to provide good multilateration coverage geometry. Some units also contain interrogators called Receiver/Transmitter (RT) units that elicit transponder replies from aircraft. The times at which replies are received by the various RUs are fed to a central processing system, which calculates the position of the replying aircraft by measuring differences in times of arrival of the replies.

Multilateration surveillance system ground transmissions include SSR Mode S, Mode A, and Mode C interrogations that illicit replies from the Mode S and Air Traffic Control Radar Beacon System (ATCRBS) transponders in the aircraft. ADS-B Mode-S squitters are also used to compute a multilaterated target report.

Multilateration provides GPS-like aircraft latitude and longitude along with aircraft identification and altitude making it an important transition technology until all aircraft are ADS-B equipped. With a potential update rate of under once per second, a multilateration system can handle hundreds of transponder target reports per second.

2.0 Description of the Model

This section of the report provides information about how the ASAT was customized for the study, the phases of the operational scenario, the scenarios evaluated during the study, and a summary of the acceptable levels of risk.

2.1 Airspace Simulation and Analysis Tool (ASAT)

The primary analysis tool for this safety evaluation was a customized version of ASAT. ASAT is a multifaceted, highly adaptable computer-based tool for aviation-related simulations and safety evaluations. ASAT consists of high fidelity models and statistical data representing the major components of a typical real world operational aviation scenario.

In this study, the following components of ASAT were relevant:

- Aircraft models representing a wide range of aircraft types driven by statistical aircraft performance models

- Navigation models representing the statistical navigation accuracy of aircraft on final approach using the ILS

- Environmental model based upon the International Standard Atmosphere (ISA)

- Surveillance equipment models based on statistical characterizations of the critical parameters of the multilateration and STARS FMA systems

- Air traffic controller response times based on the statistical analysis of actual controller in-the-loop tests and evaluations

- Pilot response times to controller instructions based on the statistical analysis of actual pilot/controller in the loop tests and evaluations

For this study, the ASAT blunder analysis tool has been customized to allow user control of the three critical surveillance parameters: (1) update rate, (2) processing delay, and (3) target position accuracy. The ASAT blunder analysis tool has also been customized to support modeling of the KDTW runway layout including the offset localizers. Similar versions of ASAT have been used for numerous safety evaluations related to the study of aircraft blunder scenarios during simultaneous multiple approaches to parallel runways using ILS, Required Navigation Performance (RNP), or satellite-based (SATNAV) final approach navigation guidance. The model includes provision for modeling ATC surveillance using an Airport Surveillance Radar (ASR), an e-scan PRM system, or a multilateration system. The ASAT component used for this simulation contains navigation, surveillance, Air Traffic Controller models, and pilot models that act in concert for evaluating the safety of operational scenarios with respect to resolution of aircraft blunders to closely spaced dual or triple parallel runways.

Figure 3 shows a top level flowchart of the functions performed by the tool. In the initialization phase, ASAT loads all necessary databases as well as the data defining the operational scenario. User-selected inputs may also be entered via a Graphical User Interface (GUI) at this stage. The GUI is shown in Figure 4. In the Monte Carlo simulation phase, the tool executes a desired number of consecutive simulation runs of the operational scenario using the databases and data items defined in the initialization phase. The values of various parameters of interest are recorded for each completed simulation run. In the post-processing phase, the recorded data are statistically analyzed to evaluate the risk associated with the particular operational scenario. These three phases are discussed in more detail in the next section.

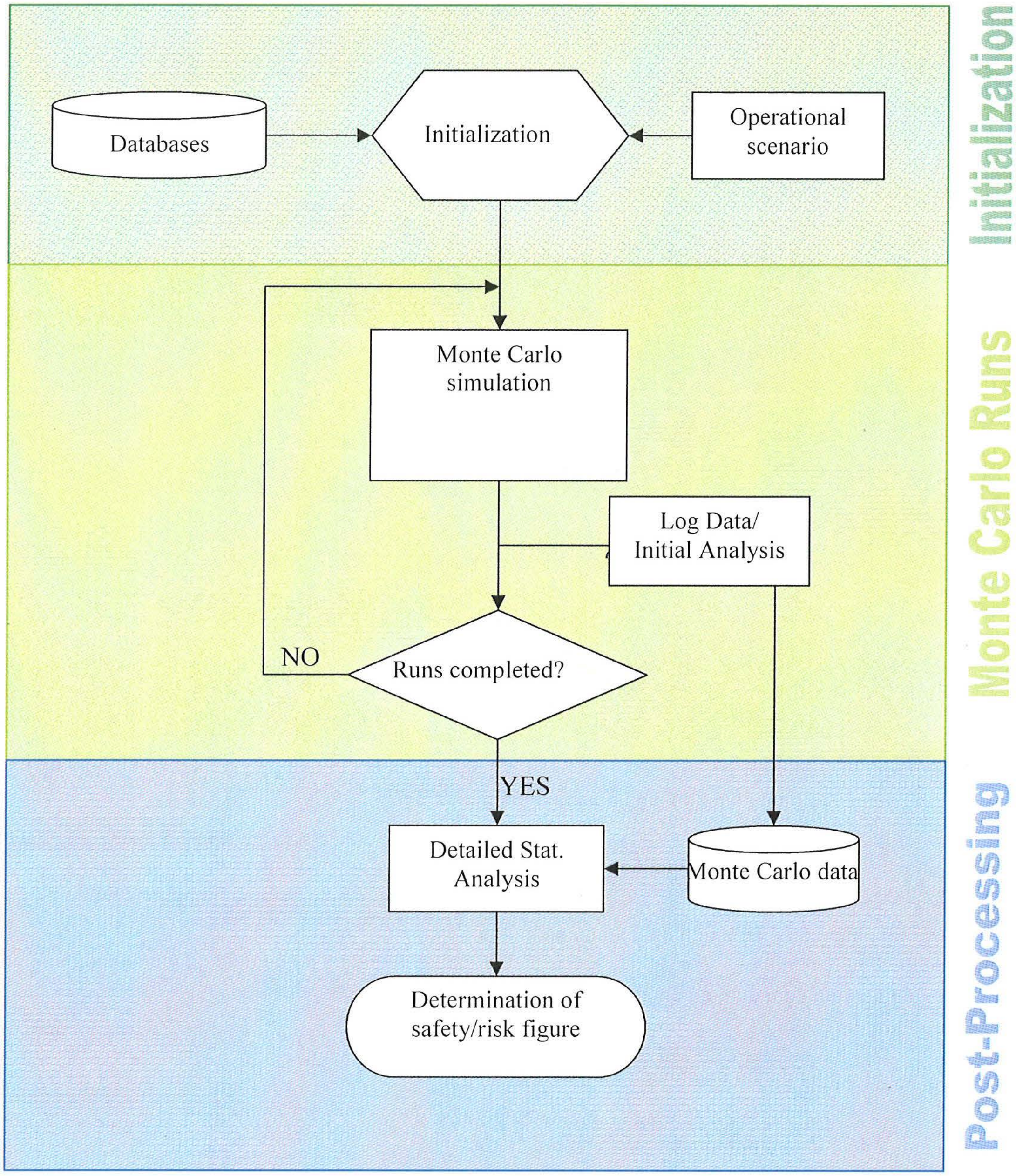

Figure 3: Top Level Flowchart of ASAT Operation

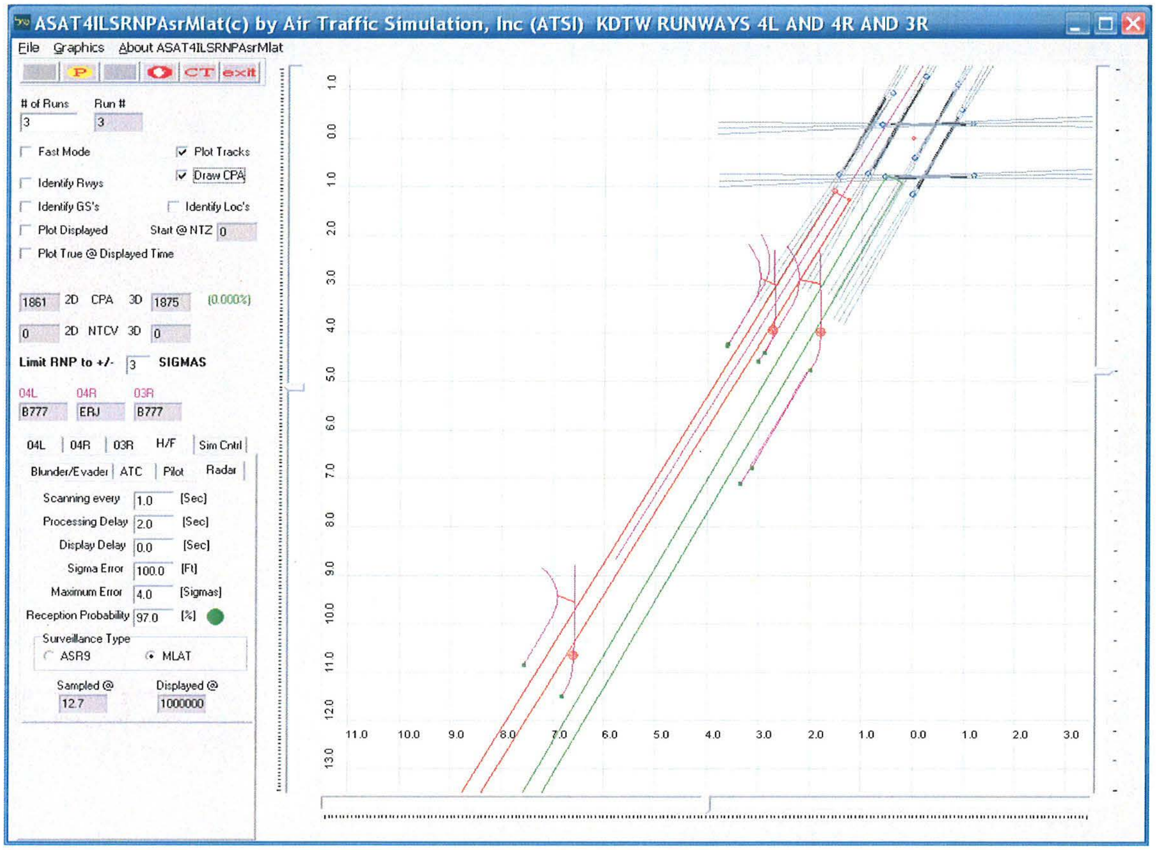

Figure 4: ASAT GUI for KDTW Triples Evaluation

Figure 4 shows a typical set of three runs. (All three happened to be blunders in the same direction.) The values shown on the GUI are for the last of the three runs and indicate that it involved an Embraer ERJ approaching Runway 4R blundering toward a Boeing 777 on the offset localizer to Runway 4L. A second Boeing 777 was not involved in the blunder. If an aircraft is not going to be involved in the blunder, it is randomly positioned along the approach track. The minimum slant range or CPA between the blunderer and evader was 1,875 feet. No TCVs occurred in the three runs. The scanning time for this run was set to 1.0 second with a processing delay of 2.0 seconds. Other parameters that can be input (some on panels that are hidden in the screen shot shown in Figure 4) include the range from threshold of interest (set here to 2 to 14 nautical miles for all runways), active runways, and the speed of the simulation.

2.2 Operational Scenario

The operational scenario of the ASAT run proceeds in three phases: initialization, performance, and reporting the run and analysis of the results.

Phase 1: Initialization - The aircraft types were selected randomly according to the fleet mix. Fleet mix information was provided by KDTW operations. (Refer to Appendix D for more information about how the fleet mix determinations were calculated for this study.) Aircraft types in the fleet mix were matched to the closest performance model in the types available to the simulation. (In addition to the provided fleet mix, scenarios were run that included 10% and 20% Heavy aircraft to ensure that future fleet changes would be considered. The percentage of Heavies may affect the outcome of the study since Heavy aircraft tend to respond more slowly and are less maneuverable, thus reducing the probability of a successful evasion.) The appropriate 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 the scenario-defined update time, 2 or 4 seconds. All parameters that were based on Probability Distribution Functions (PDFs), such as evader rate of climb, roll rate, and pilot and controller response times, 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° 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 affected where the targets were depicted on the controller's screen and, as a result, when it would trigger the yellow alert or be perceived by the controller as being in the NTZ. A small percentage of target reports were randomly dropped per the surveillance system specifications. When the yellow alert was issued or the ATC response time was reached, whichever was later, the evader was ordered to perform a 90° 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 react to collisions so that even if the slant range separation reached 0.0, the model kept running.

Phase 3: Reporting the run and analysis of results. For each run, critical parameters were recorded and saved to output files. These parameters included the aircraft types and runways involved, the pilot and controller 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. Generally, the success or failure of the scenario is determined by simply calculating the TCV rate, as discussed earlier. However, the analysis may examine other data to validate the performance of the model or identify potential mitigations or high-risk factors.

The only variables between scenarios were the selection of runway pairs (21/22 or 3/4), the update rate, processing delay, and fleet mix. 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. This resulted in a total of 1,800,000 ASAT runs.

Figure 5 shows the simulated operational scenario in flowchart format. In Figure 5, ATCt is the time at which the controller responded to the blunder event. ATCt was derived from the time at which the controller recognized the 10-second yellow alert plus the controller response time: $ATCt = Time_{yellow\ alert}$ + Statistical_ATC_Response_Time. In Figure 5, Pilott is the time at which the pilot of the at-risk aircraft initiated evasive actions. Pilott was derived from ATCt and the pilot response time sampled from a statistical distribution: Pilott = ATCt + Statistical_Pilot_Response_Time.

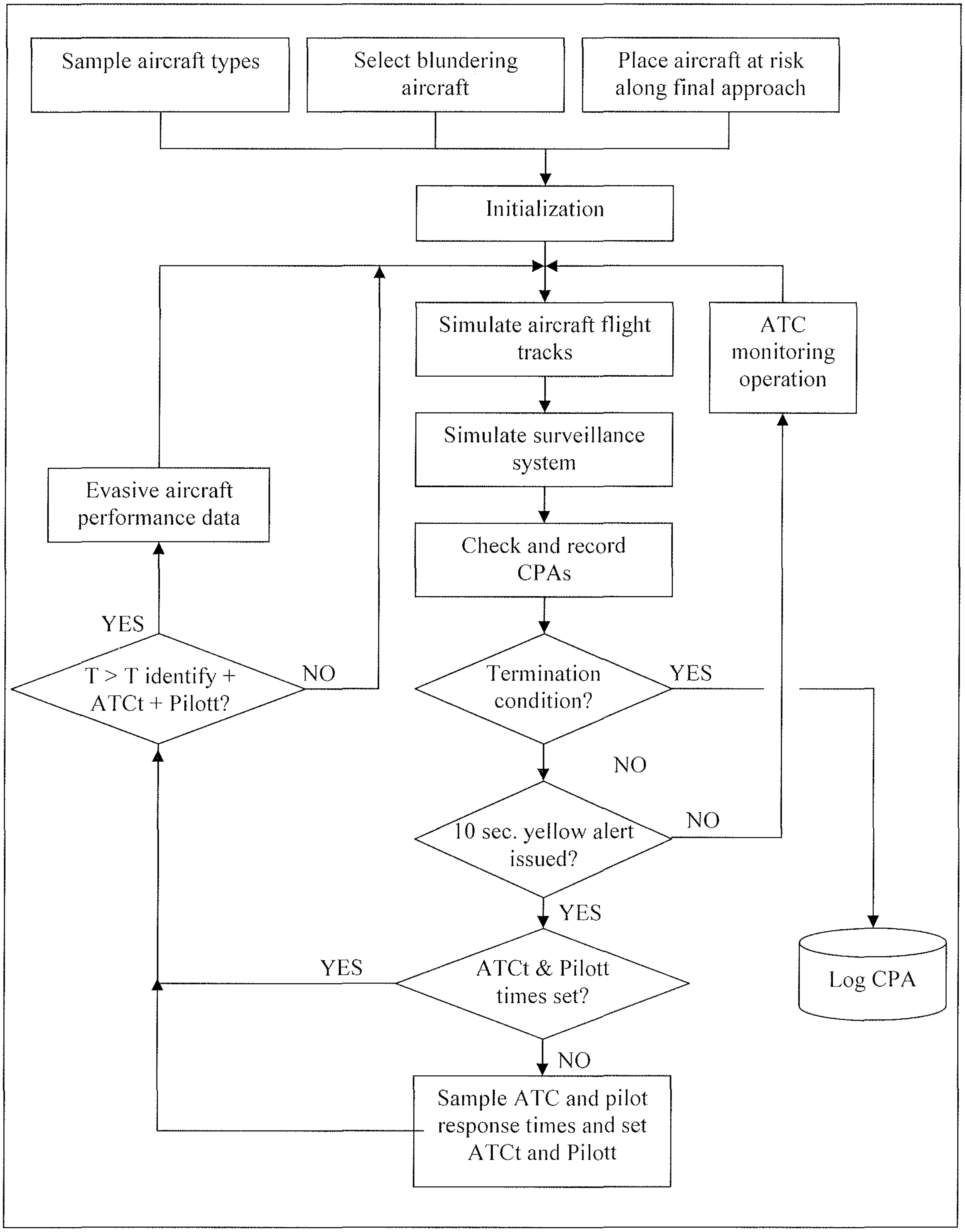

Figure 5: Flowchart of Simulation Module

2.3 ASAT Scenarios

Table 1 lists the 48 scenarios evaluated by this test. Fifty thousand runs were done for each scenario. The variables involved have been discussed earlier.

Table 1: ASAT Scenarios for KDTW Triples Evaluation

Scenario #	Runways	Fleet Mix	Update Rate	Processing Delay
1	4L-4R-3R	Default	1	1
2	4L-4R-3R	Default	1	2
3	4L-4R-3R	Default	1	3
4	4L-4R-3R	Default	2	1
5	4L-4R-3R	Default	2	2
6	4L-4R-3R	Default	2	3
7	4L-4R-3R	10% Heavies	1	1
8	4L-4R-3R	10% Heavies	1	2
9	4L-4R-3R	10% Heavies	1	3
10	4L-4R-3R	10% Heavies	2	1
11	4L-4R-3R	10% Heavies	2	2
12	4L-4R-3R	10% Heavies	2	3
13	4L-4R-3R	20% Heavies	1	1
14	4L-4R-3R	20% Heavies	1	2
15	4L-4R-3R	20% Heavies	1	3
16	4L-4R-3R	20% Heavies	2	1
17	4L-4R-3R	20% Heavies	2	2
18	4L-4R-3R	20% Heavies	2	3
19	21L-22L-22R	Default	1	1
20	21L-22L-22R	Default	1	2
21	21L-22L-22R	Default	1	3
22	21L-22L-22R	Default	2	1
23	21L-22L-22R	Default	2	2
24	21L-22L-22R	Default	2	3
25	21L-22L-22R	10% Heavies	1	1
26	21L-22L-22R	10% Heavies	1	2
27	21L-22L-22R	10% Heavies	1	3
28	21L-22L-22R	10% Heavies	2	1
29	21L-22L-22R	10% Heavies	2	2
30	21L-22L-22R	10% Heavies	2	3
31	21L-22L-22R	20% Heavies	1	1
32	21L-22L-22R	20% Heavies	1	2
33	21L-22L-22R	20% Heavies	1	3
34	21L-22L-22R	20% Heavies	2	1
35	21L-22L-22R	20% Heavies	2	2
36	21L-22L-22R	20% Heavies	2	3

2.4 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 evaluate multiple parallel approaches to safely increase airport capacity. 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 comprised 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 from 1983 to 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 Instrument Meteorological Conditions 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. The implementation of simultaneous parallel approaches creates a tenth possible accident cause, a collision with an aircraft on an adjacent approach. For simplicity of model development, the researchers assume that the risks of the ten potential accident causes are equal. Thus, the contribution of any one of the accident causes is one-tenth of the total accident rate. Based on this, the Target Level of Safety (TLS) for midair collisions on simultaneous parallel approaches is 4×10^{-8}, or:

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

The MPAP test team determined a simulation's maximum acceptable TCV rate during the PRM Demonstration Program. In the *Precision Runway Monitor Demonstration Report*, 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 TLS, provided that the overall 30° blunder rate did not exceed one 30° blunder per 2,000 approaches *Precision Runway Monitor Demonstration Report* [3].

The Monte Carlo simulation, however, measures a TCV rate based on at-risk WCBs, not the population of all WCBs. Therefore, for comparison purposes, the population TCV rate is 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 is 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 decision eliminates the situation where the criterion for the triple approach could be met but one of the proximate pairs of runways would not meet the criterion for dual approaches.

For this simulation, a Monte Carlo at-risk TCV rate confidence interval not exceeding 5.1% for the triple approach and an at-risk confidence interval not exceeding 6.8% for each proximate pair of dual approaches would indicate a fatal accident rate below the TLS and thus would be acceptable. 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 TLS. The confidence intervals on the results of the simulations are quite small (<0.1%) due to the large number of runs.

The risk analysis is covered in more detail in Appendix C, which is excerpted from Appendix C of the 1991 *Precision Runway Monitor Demonstration Report* [3].

3.0 Summary of Data Analysis

The output of the 1,800,000 simulation runs was analyzed to determine what combinations of parameters would satisfy the acceptable TCV rate based on the desired TLS. Table 2 and Table 3 present the results for all 36 scenarios, including the rates for the more closely embedded duals. All of the tested scenarios produced acceptable TCV rates.

The low TCV rates initially caused some concern but after a more thorough examination of the scenarios, several factors contributing to the low rates were identified:

- The 21L-22L and 3R-4R runway pairs essentially did not contribute any TCVs. Of the 1.8 million runs, there were less than 10 TCVs on those pairs and all occurred with the 20% Heavies fleet mix. The separation is significantly greater than what is allowed for duals with conventional terminal radar, lower resolution displays, and no predictors. With the more frequent updates, higher resolution, and the 10-second predictor more than compensating for any extra processing delays, the probability of a TCV becomes extremely small.

- The effect of the offset localizer is extremely significant. At the expected 2.5° offset, the separation between the closer approach paths is less than 3,400 feet for only the last 1.5 out of the 14 nautical miles of the scenario considered and less than 4,300 feet for nominally the last 5 nautical miles. A sensitivity analysis run on the localizer offset angle showed that the angle would be less than 1° before the TCV rate became unacceptable. This corresponds, not surprisingly, to the angle at which the average separation becomes less than 3,400 feet. Note that the sensitivity analysis did not address other operational considerations such as nuisance breakout rates.

- Other studies (see Reference [7] *Safety Study Report on Simultaneous Parallel ILS and RNAV/RNP Approaches – Phases 1A and 2A,* DOT-FAA-AFS-440-29.) have shown that a runway stagger reduces the TCV rate since the stagger provides an initial vertical separation for the evasion maneuver to build on. This reduction was especially noticeable for the 22L-22R runway pair with its 3,700 feet longitudinal difference in arrival thresholds. Due to the offset localizers, the stagger also affects the track separation. On the 22L-22R end, between the stagger and the offset angle and the simulation restriction of not permitting blunders within 2 nautical miles of the threshold, no blunders or evasions occur where the localizer centerlines are less than 3,400 feet apart.

Table 2: Summary of TCV Rate Results for KDTW for Runways 4L-4R-3R

Current fleet mix					
Scenario #	**Update rate**	**Processing Delay**	**# Runs**	**Overall %**	**4L-4R %**
1	1	1	50,000	0.5	0.9
2	1	2	50,000	0.7	1.3
3	1	3	50,000	0.8	1.6
4	2	1	50,000	0.7	1.5
5	2	2	50,000	0.9	1.8
6	2	3	50,000	1.1	2.3
10% Heavies					
Scenario #	**Update rate**	**Processing Delay**	**# Runs**	**Overall %**	**4L-4R %**
7	1	1	50,000	0.5	0.9
8	1	2	50,000	0.6	1.3
9	1	3	50,000	0.8	1.6
10	2	1	50,000	0.8	1.5
11	2	2	50,000	1.0	2.0
12	2	3	50,000	1.2	2.5
20% Heavies					
Scenario #	**Update rate**	**Processing Delay**	**# Runs**	**Overall %**	**4L-4R %**
13	1	1	50,000	0.6	1.2
14	1	2	50,000	0.7	1.4
15	1	3	50,000	1.0	2.0
16	2	1	50,000	0.8	1.5
17	2	2	50,000	1.4	2.7
18	2	3	50,000	1.3	2.7

Table 3: Summary of TCV Rate Results for KDTW for Runways 21L-22L-22R

Scenario #	Update rate	Processing Delay	# Runs	Overall %	22L-22R %
Current fleet mix					
19	1	1	50,000	0.4	0.7
20	1	2	50,000	0.5	1.0
21	1	3	50,000	0.6	1.2
22	2	1	50,000	0.5	1.0
23	2	2	50,000	0.7	1.4
24	2	3	50,000	0.9	1.7
10% Heavies					
Scenario #	**Update rate**	**Processing Delay**	**# Runs**	**Overall %**	**22L-22R %**
25	1	1	50,000	0.3	0.7
26	1	2	50,000	0.5	1.0
27	1	3	50,000	0.7	1.4
28	2	1	50,000	0.5	1.0
29	2	2	50,000	0.8	1.5
30	2	3	50,000	1.0	2.0
20% Heavies					
Scenario #	**Update rate**	**Processing Delay**	**# Runs**	**Overall %**	**22L-22R %**
31	1	1	50,000	0.4	0.8
32	1	2	50,000	0.5	1.0
33	1	3	50,000	0.7	1.4
34	2	1	50,000	0.6	1.2
35	2	2	50,000	0.8	1.6
36	2	3	50,000	1.1	2.1

4.0 Results and Conclusions

Based on the results of a Monte Carlo simulation performed on the ASAT, the proposed triple independent simultaneous approaches to KDTW runway sets 4L-4R-3R and 21L-22L-22R with offset localizers on 4L and 22R, with a PRM-A (multilateration based) surveillance system feeding STARS consoles meet the accepted safety standards for the blunder scenario. These results include evaluations of the current fleet mix and significant increases in the percentage of Heavies. While the results are based on assumed performance parameters for the multilateration system, the study covered a range of parameters that should easily be met by the system when fully deployed.

5.0 References

[1] FAA Handbook 8260.3B, *United States Standard for Terminal Instrument Procedures (TERPS)*. Change 19. May 15, 2002.

[2] FAA Order 7110.65, *Air Traffic Control*. February 19, 2004.

[3] Precision Runway Monitor Program Office. *Precision Runway Monitor Demonstration Report* (DOT/FAA/RD-91/5). Washington, DC: FAA Research and Development Service. 1991.

[4] Ozmore, Richard E., and Morrow, Sherri L. *Evaluation of Dual Simultaneous Instrument Landing System Approaches to Runways Spaced 3,000 Feet Apart with One Localizer Offset Using a Precision Runway Monitor System*. DOT/FAA/CT-96/2. September 1996.

[5] Magyarits, Sherri M. and Ozmore, Richard E. *Evaluation of Triple Independent Instrument Landing System Approaches to Runways Spaced 4,000 Feet and 5,300 Feet Apart Using a Precision Runway System*. DOT/FAA/CT-TN02/16. May 2002.

[6] McCartor, Gerry, Moore, Carl, and Ladecky, Shahar. *Safety Study Report for Multilateration/STARS FMA used as a Precision Runway Monitoring System to Parallel Runways Separated by 3,400 Feet*. DOT-FAA-AFS-440-21. May 2006.

[7] McCartor, Gerry, Moore, Carl, and Ladecky, Shahar. *Safety Study Report on Simultaneous Parallel ILS and RNAV/RNP Approaches – Phases 1A and 2A*. DOT-FAA-AFS-440-29. April 2007.

Appendix A: Air Traffic Controller Response Time Statistical Distribution Analysis

The final monitor controller response time to the yellow FMA alert was modeled in this study as a normal distribution with a mean (μ) of 1 second and a standard deviation (σ) of 1.5 seconds. However, the response time generated by the simulation cannot be earlier than the yellow alert. The controller response time represents the time from alert onset, i.e., the change in color of the FMA predictor line and aircraft data block from green to yellow, to the time the controller keyed the microphone to communicate with the pilot of the evading aircraft. The yellow alert is based on a 10-second software algorithm predictor of NTZ penetration. If actual NTZ penetration occurs, a red alert is issued.

The basis of the controller response time distribution is found in two similar evaluations using blunder scenarios of ILS approaches while using a PRM system. A previous study, *Evaluation of Dual Simultaneous Instrument Landing Approaches to Runways Spaced 3,000 Feet Apart with One Localizer Offset Using a Precision Runway Monitor System*, reports the statistical results of controller responses to 299 blunders using an offset ILS to one runway with runways separated by 3,000 feet *Evaluation of Dual Simultaneous Instrument Landing System Approaches to Runways Spaced 3,000 Feet Apart with One Localizer Offset Using a Precision Runway Monitor System* [4]. Response times ranged from -3 seconds to +3 seconds. (The negative response times were the result of controllers closely monitoring aircraft tracks and taking action prior to the actual yellow alert.) The mean response time of the 299 blunders was 0.5 seconds and the standard deviation was 1.1 seconds. As Figure A1 shows, the data correspond closely to a normal distribution.

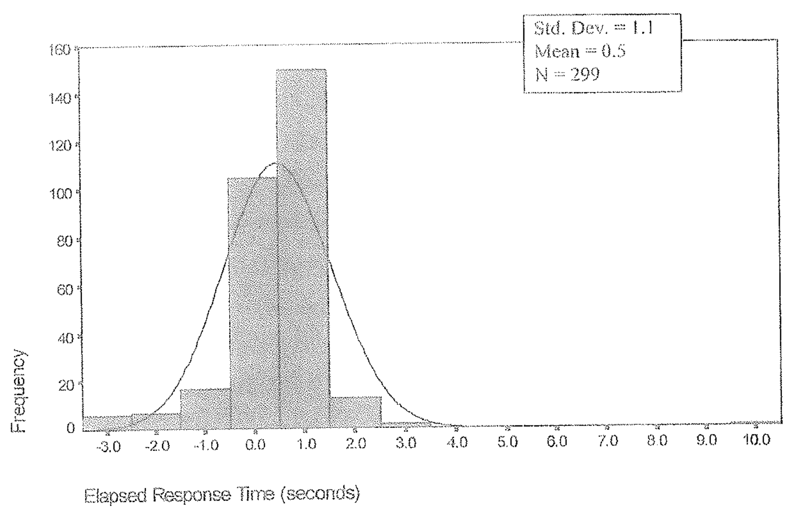

Figure A1: Controller Response Times[1]
(Offset ILS Approach, 3,000 Feet Runway Separation)

[1] This figure originally appeared as Figure 6 in *Evaluation of Dual Simultaneous Instrument Landing Approaches to Runways Spaced 3,000 Feet Apart with One Localizer Offset Using a Precision Runway Monitor System* [4].

Another study, *Evaluation of Triple Independent Instrument Landing System Approaches to Runways Spaced 4,000 Feet and 5,300 Feet Apart Using a Precision Runway System* [5] reports the results of 150 blunders using ILS approaches to triple runways spaced 4,000 feet and 5,300 feet apart. Response times ranged from -3 seconds to +9 seconds with a mean of 1.7 seconds and a standard deviation of 1.9 seconds. Again, examination of Figure A2 shows the histogram of the data conforms to a basic normal distribution shape. These values are considerably larger than those reported in *Evaluation of Dual Simultaneous Instrument Landing System Approaches to Runways Spaced 3,000 Feet Apart with One Localizer Offset Using a Precision Runway Monitor System*. [4] for more closely spaced runways. These results support a general trend of longer response times as the runway separation increases. This phenomenon can be explained by controllers taking a little more time, when runway separation distances allow, determining if the blundering aircraft will return to the ILS course.

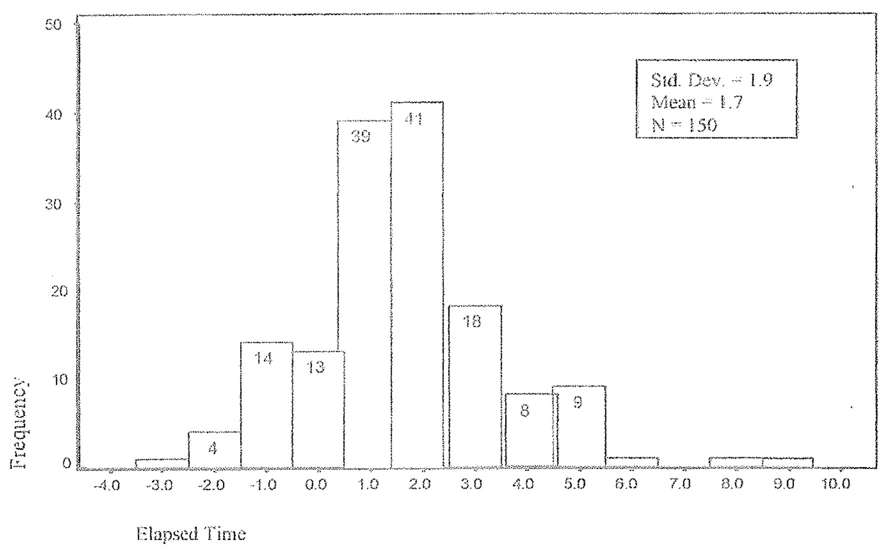

Figure A2: Controller Response Times[2]
(Triple ILS Approaches, 4,000 Feet and 5,300 Feet Runway Separation)

Since this study focused on runways separated by 3,400 feet, controller response times somewhere between the results from *Evaluation of Dual Simultaneous Instrument Landing System Approaches to Runways Spaced 3,000 Feet Apart with One Localizer Offset Using a Precision Runway Monitor System*. [4] (3,000 feet runway separation) and the results from *Evaluation of Triple Independent Instrument Landing System Approaches to Runways Spaced 4,000 Feet and 5,300 Feet Apart Using a Precision Runway System* [5] (4,000 feet minimum runway separation) were thought to be more

[2] This figure originally appeared as Figure 6 from *Evaluation of Triple Independent Instrument Landing System Approaches to Runways Spaced 4,000 Feet and 5,300 Feet Apart Using a Precision Runway System* [5].

representative of the operational scenario being evaluated. Thus, the values of $\mu = 1$ second and $\sigma = 1.5$ seconds were chosen.

Appendix B: Pilot Reaction Time Statistical 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 recorded during the testing was the time from the controller's initial evasion command until the aircraft achieved a 3° 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 PRM system to monitor closely spaced parallel runways led to the development of a training requirement to ensure 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 4,300 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 controllers' 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, FAA Order 7110.65R, provides only three phraseologies that include "immediate," two of those are associated with simultaneous approaches; the third is when collision with terrain appears imminent *Air Traffic Control* [2]. 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 includes pilots from both the trained and untrained groups. There was little difference in the bulk of the distribution between the two groups but the trained pilot's data set had no significant outliers as were seen in the untrained group. The data are 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.)

Table B1: Johnson S_L Distribution Parameters

Parameter	Value
Type	S-L
Delta	3.0
Gamma	0.0
Lambda	7.9
Xi	0.9
Truncation-Low	1.0
Truncation-High	17.0
Offset	1.0

The truncation points were chosen to reflect the empirical data. When the "trained" pilots were evaluated, no data points greater than 15.5 seconds were collected 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° 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 B1 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.

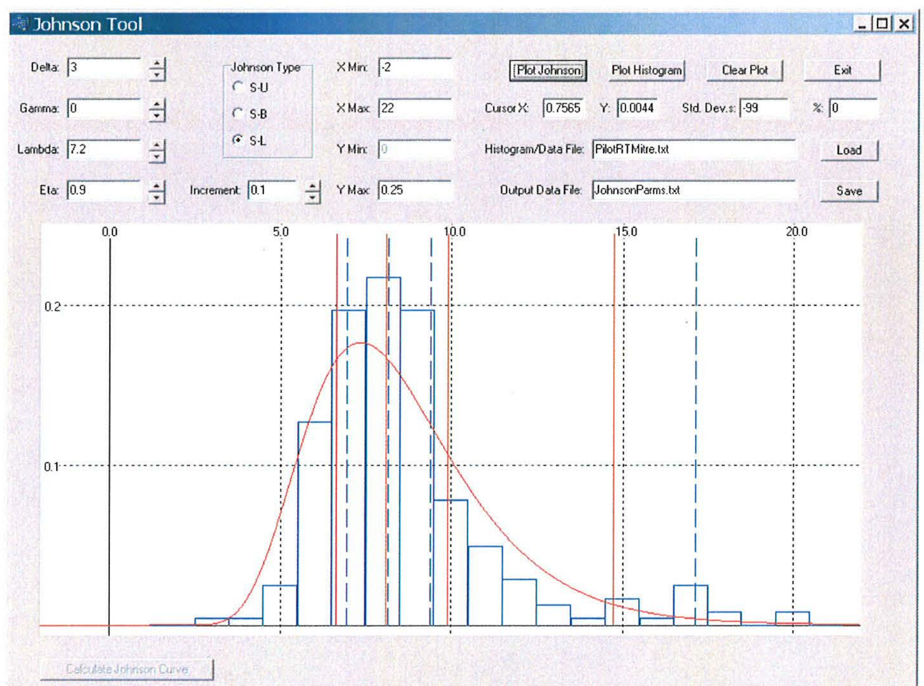

Figure B1: Pilot Response Times Distribution

Appendix C: Risk Analysis[3]

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 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 occurs 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 National Transportation Safety Board (NTSB).

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

$$P(\text{Accident}) = P(\text{TCV and At-risk and WCB and Blunder}) \times 2, \qquad \text{(C1)}$$

or

$$\begin{aligned} P(\text{Accident}) = {} & P(\text{TCV}|\text{At-risk and WCB and Blunder}) \times \\ & P(\text{At-risk}|\text{WCB and Blunder}) \times \\ & P(\text{WCB}|\text{Blunder}) \times \\ & P(\text{Blunder}) \times 2, \end{aligned} \qquad \text{(C2)}$$

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 nautical miles in-trail spacing.

[3] This appendix is excerpted from Appendix C of the 2002 *Evaluation of Triple Independent Instrument Landing System Approaches to Runways Spaced 4,000 Ft and 5,300 Ft Apart Using a Precision Runway Monitor System* [5].

- P(WCB|Blunder) is the probability that a blunder is a WCB. This probability is unknown, but is estimated to be approximately 1/100 per the *Precision Runway Monitor Demonstration Report* [3].

- 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 30° blunder per 1000 dual approach pairs or 1 30° blunder per 2,000 approaches. This is a conservative value the MPAP researchers 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 1/1,000 30° blunders per dual approach pair. Researchers can show the rate for triple approaches to be 1/1,500 30° blunders per triple approach trio. (For two runways, there are 4 possible 30° blunders, only two of which place the other traffic at risk. For three runways, there are 6 possible 30° blunders, 4 of which place the other traffic at risk. So there are twice as many possible at-risk blunders, but there are three aircraft involved rather than 2. So P(Blunder-Dual) = 1 30° Blunder / 1000 dual approaches × 1 dual approach / 2 approaches = 1 / 2000 30° Blunder / approach and P(Blunder-Triple) = 2 30° Blunder / 1000 triple approaches × 1 triple approach / 3 approaches = 1 / 1500 30° Blunder / approach.)

- 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 from 1983 to 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 Instrument Meteorological Conditions 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 TLS for midair collisions on simultaneous parallel approaches is 4×10^{-8}, or:

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

Maximum Allowable Test Criterion Violation Rate

Since the only undefined variable in Equation (C2), 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 TLS. Knowledge of this number would allow the TWG to quickly decide if the simulated operation would meet the TLS. The maximum allowable TCV rate may be found from following analysis.

Given the TLS, P(Accident) = 4×10^{-8}, then Equation (C2) 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,

$$P(TCV|\text{At-risk and WCB and Blunder}) = \qquad \text{(C3)}$$

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

Substituting values from Equation (C2) into Equation (C3):

$$P(TCV|\text{At-risk and WCB and Blunder}) = \qquad \text{(C4)}$$

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

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%, then the simultaneous approach procedure simulated should have an acceptable accident rate. For the embedded duals, the 1,500 is replaced by 2,000 and the allowable percentage becomes 6.8%.

Appendix D: Fleet Mix Considerations

Information was provided by the Wayne County Airport Authority (see Table D-1) on a representative fleet mix for the airport. Additional information was obtained from the FAA's Enhanced Traffic Management System Counts (ETMSC) database.

Table D-1. Representative Fleet Mix for KDTW (Feb. 2006)

Aircraft Type	Number of Operations*	%
CRJ-100/200	180	21.5%
DC-9	96	11.5%
A319	89	10.6%
A320	82	9.8%
Saab340	71	8.5%
DC-9-50	64	7.6%
B757-200	42	5.0%
B737-300	29	3.5%
MD-80	29	3.5%
Avro RJ	22	2.6%
ERJ	16	1.9%
CRJ-700	14	1.7%
B737-700	12	1.4%
B737-800	11	1.3%
A321	10	1.2%
B737-500	10	1.2%
ERJ-135	10	1.2%
A330-300	7	0.8%
B757-300	6	0.7%
B717	5	0.6%
B737-900	5	0.6%
B757-200	5	0.6%
B747-400	4	0.5%
Beechcraft	4	0.5%
DHC-8-100	3	0.4%
CRJ-900	2	0.2%
ERJ-170	2	0.2%
ERJ-145	2	0.2%
MD-83	2	0.2%
A330-200	1	0.1%
A340-200	1	0.1%
B767	1	0.1%
DHC-8-300	1	0.1%
Total	**838**	

Table D-2. Percentage Breakdown of ASAT Types Used

Representative ASAT Type	Percentage of Fleet
B777	2.7
B737-200	11.0
B737-800	3.4
A320	21.6
Saab 340	12.2
B727	2.0
ERJ	28.4
B757-200	7.0
MD88	11.7

Table D-2 shows the aircraft types and percentage of overall traffic used for the baseline Monte Carlo simulation. This mix is representative of DTW and contains relatively small turboprop aircraft such as the Saab 340 as well as large jet aircraft such as the B777. Each of the types shown is considered representative of a number of aircraft types-the Saab, for instance, is used as the closest available model for a variety of small turbo-prop aircraft. One of the ASAT initiation files contains a section where the number of each type of aircraft is given. Based on those numbers, 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, and achieved bank angle. Certain limits were applied to many of these parameters to eliminate extreme maneuvers from consideration during the simulation. For instance, banks of 40 degrees or more were seen during the MPAP tests, but the simulation limited the bank to 30 degrees.

The fleet mixes for the 10 per cent and 20 per cent heavies cases were generated by simply increasing the number of Boeing B777s until they represented 10 or 20 per cent of the fleet.

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, variates 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:

$$z = \gamma + \delta \ln\left(\frac{x-\varepsilon}{\lambda}\right), \quad x > \varepsilon, \qquad \text{(E1)}$$

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 bound on the left by ε and is unbound 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:

$$z = \gamma + \delta \ln\left(\frac{x-\varepsilon}{\lambda+\varepsilon-x}\right), \quad \varepsilon < x < \varepsilon + \lambda, \qquad \text{(E2)}$$

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 bound 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:

$$z = \gamma + \delta \sinh^{-1}\left(\frac{x-\varepsilon}{\lambda}\right), \quad -\infty < x < \infty, \qquad \text{(E3)}$$

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 unbound and unimodal. The parameters γ and δ are shape parameters, ε is a location parameter, and λ is a scale parameter.

To use the Johnson family of curves, it is necessary to invert Equations (E1), (E2), and (E3), i.e., each of the equations must be solved for x.

1. The S_L transformation after inversion is:

$$x = \varepsilon + \lambda \exp\left(\frac{z-\gamma}{\delta}\right), \; -\infty < z < \infty. \qquad \text{(E4)}$$

2. The S_B transformation after inversion is:

$$x = \varepsilon - \frac{\lambda}{1-\exp\left(\frac{\gamma - z}{\delta}\right)}, \; -\infty < z < \infty. \qquad \text{(E5)}$$

3. The S_U transformation after inversion is:

$$x = \varepsilon + \lambda \sinh\left(\frac{z-\gamma}{\delta}\right), \; -\infty < x < \infty. \qquad \text{(E6)}$$

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 (PDF) of a member of the Johnson S_L family has the following form:

$$f_1(x) = \frac{\delta}{(x-\varepsilon)\sqrt{2\pi}} \exp\left\{-\frac{1}{2}\left[\gamma + \delta \ln\left(\frac{x-\varepsilon}{\lambda}\right)\right]^2\right\}, \; x \geq \varepsilon, \qquad \text{(E7)}$$

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

2. The PDF of a member of the Johnson S_B family has the following form:

$$f_2(x) = \frac{\delta\lambda}{(x-\varepsilon)(\lambda - x + \varepsilon)\sqrt{2\pi}} \exp\left\{-\frac{1}{2}\left[\gamma + \delta \ln\left(\frac{x-\varepsilon}{\lambda - x + \varepsilon}\right)\right]^2\right\}, \qquad \text{(E8)}$$

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

3. The PDF of a member of the Johnson S_U family has the following form:

$$f_3(x) = \frac{\delta}{\sqrt{2\pi\left[(x-\varepsilon)^2+\lambda^2\right]}} \exp\left[-\frac{1}{2}\left(\gamma+\delta \ln\left\{\left(\frac{x-\varepsilon}{\lambda}\right)+\left[\left(\frac{x-\varepsilon}{\lambda}\right)^2+1\right]^{1/2}\right\}\right)^2\right], \quad \text{(E9)}$$

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

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 (E4) to obtain the random variate x. If the Johnson curve is of type S_B then substitute z into Equation (E5) to obtain the random variate x. If the Johnson curve is of type S_U then substitute z into Equation (E6) to obtain the random variate x.

AFS-420
Correspondence Control

Action

Subject:	Safety Study Report for Multilateration/STARS FAM Used as a Precision Runway Monitoring System for Triple Simultaneous Independent Approaches to Detroit Metropolitan Wayne County Airport (KDTW)

Tracking Number:	2007-118345-A	Document Date:	05/02/2007
Alternate Tracking Numbers:		Date Doc Received:	05/02/2007 11:00:00 PM
		Document Type:	Coordination
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The below comments were added by: Amy Diaz on 5/3/2007 10:15:22 AM.

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Gary Powell Recommends to concur w/out comments

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