Safety Study Report
DOT-FAA-AFS-440-29

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

Safety Study Report on Simultaneous Parallel ILS and RNAV/RNP Approaches – Phases 1A and 2A

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April 2007

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April 2007

Technical Report

Technical Report Documentation Page

1. Report No. DOT-FAA-AFS-440-29	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Safety Study Report on Simultaneous Parallel ILS and RNAV/RNP Approaches – Phases 1A and 2A		**5. Report Date** April 2007
6. Author(s) Gerry McCartor, AFS-440 Shahar Ladecky, ATSI		**7. Performing Organization Code**
8. Performing Organization Name and Address Federal Aviation Administration Flight Operations Simulation and Analysis Branch, AFS-440 P.O. Box 25082, Oklahoma City, OK 73125		**9. Type of Report and Period Covered** Technical Report
10. Sponsoring Agency Name and Address Federal Aviation Administration Flight Operations Simulation and Analysis Branch, AFS-440 P.O. Box 25082, Oklahoma City, OK 73125		
11. Supplementary Notes		

12. Abstract

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 separation for dependent and independent precision approach operations at airports with dual or triple parallel runway configurations. With the evolution toward performance-based navigation in the National Airspace System (NAS), Air Traffic Control (ATC) will increasingly be required to factor in Area Navigation (RNAV) and Required Navigation Performance (RNP) approaches to these operations. The Flight Operations Simulation and Analysis Branch (AFS-440) was requested by the RNAV/RNP Group (AJR-37) to conduct a study to determine what combinations of RNAV or RNP simultaneous approach operations could be authorized by ATC. This report addresses dual and triple, independent and dependent approaches by ILS, and RNP(GPS)/RNAV(GPS) aircraft flying with flight director guidance. 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 (e.g., aircraft, avionics, pilot, controller, etc.) and performs a Monte Carlo simulation in which all significant parameters are varied according to appropriate probability distributions.

Analysis of the results of the simulations indicated that, for the assumed performance levels and fleet mixes, GPS-equipped RNAV/RNP aircraft with flight director experienced a 15 to 20% increase in Test Criteria Violation (TCV) rate over the same simulation with only ILS-directed aircraft. The rate for mixed ILS and RNAV/RNP traffic was in between those two cases. The TCV rate for all simulations met the defined acceptance criteria.

13. Key Words Simultaneous Parallel Approaches RNAV/RNP Blunder	**14. Distribution Statement** Controlled by AFS-440
15. Security Classification of This Report Unclassified	**16. Security Classification of This Page**

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 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.

With the evolution toward performance-based navigation in the National Airspace System (NAS), Air Traffic Control (ATC) will increasingly be required to factor in Area Navigation (RNAV) and Required Navigation Performance (RNP) approaches to the operations referenced above. The Terminal Safety and Operations Support Director (ATO-T) has received waiver requests from three Operation Evolution Plan (OEP) benchmark airports (Houston-KIAH, Atlanta-KATL, and Pittsburgh-KPIT) to authorize such operations.

The Flight Operations Simulation and Analysis Branch (AFS-440) was requested by the RNAV/RNP Group (AJR-37) to conduct a study to determine what combinations of RNAV or RNP simultaneous approach operations could be authorized by ATC. The request resulted in a Memorandum of Agreement (MOA) among AFS-400, the Flight Technologies and Procedures Division (AJR-37), and the Avionics Certification System Branch (AIR-130) defining what cases were to be examined and their priorities. The results of the study will provide guidance for determining the allowable separation or operation of RNAV, RNP, and ILS approaches to parallel runways (dual and triple), without the necessity of waivers. The study would also address acceptable mitigations against which waiver requests would be considered. An important part of the MOA was an agreement that only Global Positioning System (GPS)-equipped RNAV aircraft would be considered.

The request was divided into several phases that covered both paragraphs in FAA Order 7110.65R. This report contains the results of Phase 1 and Phase 2. Additional studies will be provided as needed. The study is comprised of the following six phases:

- Phase 1 provides a study to show that inclusion of RNAV/RNP(GPS) aircraft complies with current standards for parallel dependent and independent approaches, runway separations of 4,300 feet for duals or 5,000 feet for triples (as in FAA Order 7110.65R, paragraphs 5-9-6 and 5-9-7).

- Phase 2 provides a study to show that inclusion of RNAV/RNP(GPS) aircraft complies with current standards for parallel dependent approaches, with runway separations less than 4,300 feet but greater than 2,500 feet (FAA Order 7110.65R, paragraph 5-9-6).

- Phase 3 provides a study to show that inclusion of RNAV/RNP(GPS) aircraft complies with current standards for parallel independent approaches for duals with high update radar (as in FAA Order 7110.65R, paragraph 5-9-8a).

- Phase 4 provides a study to show that inclusion of RNAV/RNP(GPS) aircraft complies with current standards for Simultaneous Offset Instrument Approaches (SOIA) as addressed in FAA Order 8260.49A, *Simultaneous Offset Instrument Approach (SOIA)*.

- Phase 5 provides studies or analyses to evaluate acceptable mitigations to support waiver requests to FAA Order 7110.65R standards.

- Phase 6 provides studies or analyses to support any changes required to FAA Order 8260.3b, *United States Standard for Terminal Instrument Procedures (TERPS)*, for inclusion of RNAV/VNAV (Vertical Navigation) approaches.

Each of the first four phases and most of the cases for Phase 5 will have two parts (identified as "A" and "B"). Initially, the study focuses on flight director guided approaches using appropriate Flight Technical Error (FTE) values (part "A"). This performance level should represent a conservative worst case for autopilot performance. This is considered to be representative of most air traffic likely to be engaged in simultaneous operations to major airports. However, a small portion of the fleet will be using panel-mounted GPS receivers or equivalent equipment that will have significantly greater FTEs due to the lack of flight director guidance and a much coarser scale on their instruments outside the Final Approach Fix (FAF). (The full scale Course Deviation Indicator (CDI) decreases from ±1.0 NM at 2 NM outside the FAF to ±0.3 NM at the FAF.) These part "B" studies will be completed when necessary modifications have been made to the tool.

This report addresses Phases 1A and 2A, dual and triple, independent and dependent approaches by ILS and RNP(GPS)/RNAV(GPS) aircraft flying with flight director guidance. Later reports will address the other phases.

AFS-440's 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 (e.g., aircraft, avionics, pilot, controller, etc.) and performs a Monte Carlo simulation in which all significant parameters are varied according to appropriate probability distributions. The ASAT allows examination of all combinations of ILS and RNAV/RNP aircraft performing simultaneous approach operations to parallel runways at user-defined separations and user-defined staggers.

Tracking performance for the ILS aircraft was based on International Civil Aviation Organization (ICAO) Collision Risk Model (CRM) data for both the lateral and vertical deviations from glide path. For the GPS-equipped RNAV/RNP aircraft considered for this study, the initial lateral deviation of the aircraft is based on a Navigation System Error (NSE) defined by a Gaussian distribution with zero mean and 50-meter standard deviation

plus a FTE distribution with zero mean and 40-meter standard deviation. The latter value was based on a number of flight director studies. Vertical tracking was offset by a position error in the glide slope origin generated by the same NSE distribution. For this report, sixty test scenarios were examined with 50,000 runs performed for each case.

The simulation tool can factor in an airport specific fleet mix but for these generic studies, representative models of the aircraft groups most likely to be participating in simultaneous operations (medium and large commuters, large turbojets, and heavy turbojets) were used in various ratios to examine 10, 20, and 30 percent heavy turbojet. The percentage of heavy turbojet aircraft, which tend to respond more slowly in the evasion maneuver, is a significant driver for the overall success or failure of a case. The fleet mixes used and the representative types are discussed in Appendix A: Aircraft Mix and Performance Modeling.

Pilot and controller response times were based on data collected during the Multiple Parallel Approach Program (MPAP) testing. Pilot response times were based on distributions collected from line pilots. ATC response times were selected from the closest MPAP test to the configuration being simulated. The various configurations available are listed in Appendix B: Pilot Reaction Time Distribution Analysis. Surveillance system errors and delays were based upon information obtained from MIT Lincoln Labs reports [10].

The Target Level of Safety (TLS) for the triple approach configurations was determined to be 4×10^{-8} (see Appendix D: Risk Analysis). From the TLS, a maximum acceptable Test Criteria Violation (TCV) rate can be derived (see Appendix D). The TCV rate for at-risk blunders for triples must be less than 5.1% overall and less than 6.8% for each of the embedded dual operations. The rate limit for duals is 6.8%.

Analysis of the results of the simulations indicated that, for the assumed performance levels (defined in section 2.2.6), GPS-equipped RNAV/RNP aircraft with flight director experienced a 15 to 20% increase in TCV rate over the same simulation with only ILS-directed aircraft. The rate for mixed ILS and RNAV/RNP traffic was in between the two "pure" cases. The TCV rate for all simulations met the acceptance criteria (although the 4,300 foot duals RNP/RNP case with 30% Heavies was just under the limit.).

It should be noted that none of the MPAP tests of 4,300 duals using the older Data Entry and Display Subsystem (DEDS) monitors were considered successful. Those tests, however, were all conducted with fleet mixes representative for that time period when almost all turbojets were what are now considered Large or Heavy and most were on the lower end of the modern performance spectrum. The current simulation used a more modern fleet mix with a significant percentage of regional and business jets classified as commuter aircraft and representative performance values for the modern aircraft of all categories.

Based on the simulation, GPS-equipped RNAV/RNP aircraft with flight director or autopilot could be mixed with ILS traffic in any configuration approved for ILS aircraft under Airport Surveillance Radar-Model 9 (ASR-9) level surveillance, i.e., independent duals down to

4,300 feet; independent triples down to 5,000 feet; and dependent duals down to 2,500 feet. All tested scenarios produced TCV rates that met the Target Level of Safety.

TABLE OF CONTENTS

1.0	Introduction	1
1.1	Purpose and Structure of the Report	1
1.2	Statement of the Problem	2
1.3	RNAV/RNP Considerations	5
2.0	Study Methodology	6
2.1	Description of the Model	7
2.2	Summary of Data Used	11
2.2.1	Geography	11
2.2.2	Aircraft	11
2.2.3	Environmental Conditions	12
2.2.4	Pilot Response Times	12
2.2.5	Air Traffic Controller Response Times	12
2.2.6	Navigation	13
2.2.7	Surveillance System	13
2.3	Simulation Performance	14
3.0	Summary of Data Analysis and Risk Evaluation	17
3.1	Summary of the TCV Probability Analysis	17
3.1.1	Independent 4,300-Foot Dual Parallel Runway Scenarios	17
3.1.2	Independent 5,000-Foot Triple Parallel Runway Scenarios	19
3.1.3	Dependent 2,500-Foot Dual Parallel Runway Scenarios	20
3.2	Summary of Acceptable Level of Risk	21
4.0	Results and Conclusions	22
4.1	Independent 4,300-Foot Dual Parallel Runways	22
4.2	Independent 5,000-Foot Triples	23
4.3	Dependent 2,500-Foot Duals	23
4.4	Conclusions	23
5.0	References	24

Appendix A. Aircraft Mix and Performance Modeling	26
Appendix B. Pilot Reaction Time Distribution Analysis	29
Appendix C. Air Traffic Controller Reaction Time Distribution Analysis	31
Appendix D. Risk Analysis	36
Appendix E. Johnson Distributions	39
Appendix F. ASAT Input Files	42
Appendix G. ASAT Output File	44
Appendix H. Memorandum of Agreement	46
Appendix I. Radar Accuracy Parameters	50

LIST OF ILLUSTRATIONS

Tables

Table 1.	Navigation System/Runway Configurations	10
Table 2.	Test Scenarios	15-16
Table 3.	Independent 4,300-Foot Dual Parallel Runway TCVs	18
Table 4.	Independent 5,000-Foot Triple TCVs	19
Table 5.	Dependent 2,500-Foot Dual TCVs	20
Table 6.	Minimum CPA for Selected Scenarios	20
Table A-1.	Fleet Mix Percentages Used in Simulation	26
Table A-2.	Parallel Runway Separations at 9 of the 15 Busiest Airports Between 4,300 and 6,000 Feet	27
Table A-3.	Fleet Mixes at 17 of the Busiest Airports 2005-2006	28
Table B-1.	Johnson S_B Distribution Parameters	29
Table C-1.	Johnson S_B Distribution Parameters	31
Table C-2.	Johnson S_B Distribution Parameters	32
Table C-3.	Multiple Parallel Approach Program 1988-1999	34-35
Table I-1.	Sensor Error Sources	50
Table I-2.	Transponder Error Sources	51

Figures

Figure 1.	Triple Simultaneous Approach with Blunder	4
Figure 2.	Typical ASAT Run	8
Figure 3.	CPA Distribution for Dependent Duals	21
Figure B-1.	Pilot Response Time Distribution	30
Figure C-1.	ATC Response Time Distribution for 4300 Foot Duals	32
Figure C-2.	ATC Response Time Distribution for 5000 Foot Triples	33

1.0 Introduction

This report presents the results of Phases 1A and 2A of a safety study conducted on simultaneous parallel Instrument Landing System (ILS) and Area Navigation/Required Navigation Performance (RNAV/RNP) approaches. The safety evaluation was conducted by the Flight Operations Simulation and Analysis Branch (AFS-440) of the Federal Aviation Administration (FAA) located at the Mike Monroney Aeronautical Center in Oklahoma City, Oklahoma. This section of the report describes the purpose and structure of this document, and provides a description of the problem.

1.1 Purpose and Structure of the Report

The purpose of this study is to provide a risk assessment for simultaneous dependent and independent parallel approach operations involving mixed operations of ILS-equipped aircraft and Global Positioning System (GPS)-equipped RNAV or RNP aircraft. The study uses a Monte Carlo simulation of the operation to evaluate the risk associated with a blunder in which one aircraft deviates 30 degrees from the final approach course toward the other aircraft. The simulation examines a series of scenarios involving different combinations of ILS and RNAV/RNP aircraft conducting approaches to various runway configurations. It only considers RNAV and RNP aircraft that are GPS-equipped and using GPS as their primary navigation source. RNP or RNAV systems using multiple Distance Measuring Equipment (DME) inputs may be addressed in a later report. Based on the results of this study, DME/DME RNAV-equipped aircraft are not expected to be acceptable for simultaneous approach operations to runways separated by less than 7,000 to 9,000 feet.

This report defines the problem (Section 1.2), explains the study methodology (Section 2.0), describes the structure of the Monte Carlo simulation involved (Section 2.1), details the inputs to the simulation (Section 2.2), and details the outputs used for validation of some of the new parts of the model (Section 2.3). The analysis of the results of the simulation (Section 3) is based on substantial work previously performed and summarized in *Terminal Air Traffic Control Radar and Display System Recommendations for Monitoring Simultaneous Instrument Approaches* [6]. Conclusions and recommendations are given in Section 4.

Appendix A: Aircraft Mix and Performance Modeling details the fleet mix composition and representative performance models. Appendix B: Pilot Reaction Time Distribution Analysis contains the data used during Multiple Parallel Approach Program (MPAP) testing. Appendix C: Air Traffic Controller Reaction Time Distribution Analysis includes a list of configurations tested. Appendix D: Risk Analysis contains relevant excerpts from a previous report *Terminal Air Traffic Control Radar and Display System Recommendations for Monitoring Simultaneous Instrument Approaches* [6]. Appendix E: Johnson Distributions discusses the Johnson distributions used in the study. Input and output files are listed in Appendix F: ASAT Input Files and Appendix G: ASAT Output File. The Memorandum of Agreement among Flight Standards Service, the RNAV/RNP Group, and Avionics Certification Systems Branch is attached as Appendix H: MOA.

1.2 Statement of the Problem

FAA Order 7110.65R, *Air Traffic Control* [4], paragraph 5-9-7 (Simultaneous Independent ILS/MLS Approaches – Dual and Triple) is the current Air Traffic Control (ATC) provision governing independent precision approach operations at airports with dual and triple parallel runway configurations having runway centerline separation of at least 4,300 feet for duals or 5,000 feet for triples and monitored by conventional ATC radar (Airport Surveillance Radar-Model 9 [ASR-9] or equivalent). These standards were developed from simulation exercises performed by the FAA based on ILS precision approach operations. FAA Order 7110.65R, paragraph 5-9-6 (Parallel Dependent ILS/MLS Approaches) is the current provision for dependent precision approach operations at airports with dual parallel runway configurations having runway centerline separation of at least 2,500 feet monitored by conventional radar (ASR-9 or equivalent).

With the evolution toward performance-based navigation in the United States National Airspace System (NAS), ATC will increasingly be required to factor in RNAV and RNP approaches to the operations referenced above. The Flight Operations Simulation and Analysis Branch (AFS-440) was requested by the RNAV/RNP Group (AJR-37) to conduct a study to determine what combinations of RNAV or RNP simultaneous approach operations could be authorized by ATC. AFS-440's 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 (e.g., aircraft, avionics, pilot, controller, etc.) and performs a Monte Carlo simulation in which all significant parameters are varied according to appropriate probability distributions. The results of the study should provide guidance for determining the allowable runway configurations (both runway centerline separation and threshold stagger), aircraft stagger (if any), surveillance requirements, and aircraft equipage for operation of RNAV, RNP, and ILS approach operations to parallel runways (dependent or independent, dual and triple), without the necessity of waivers. The final study results will also address acceptable mitigations against which any waiver requests could be considered.

The first case to be examined was George Bush Intercontinental Airport (KIAH) where ATC wanted to substitute RNAV approaches for ILS approaches when one of the ILSs was down for maintenance. That study examined generic RNP performance with the Total System Error (TSE) defined by the RNP level so that the track distributions for RNP 0.2 aircraft were Gaussian with a mean equal to zero and a standard deviation of about 0.1 nautical miles (NM). Because of the relatively large runway spacing and significant runway threshold staggers, approximately 5,000 feet separation between Runway 08L/26R and Runway 08R/26L with 1,200-foot and 1,650 foot threshold staggers respectively, and approximately 5,800 feet between Runway 08L/26R and Runway 09/27 with 6,600-foot and 7,300-foot threshold staggers, the study results were positive for most of the combinations. For details of the study, refer to DOT-FAA-AFS-440-16 [11].

As a result of that study, additional discussions were held with the RNAV/RNP Group (AJR-37), the Avionics Certification System Branch (AIR-130), and the Flight Procedure Standards Branch (AFS-420) to define the required equipment for conducting RNAV/RNP

simultaneous approach operations. It was apparent from the results of the KIAH study that "generic" RNP performance would not be sufficient to meet the current ILS simultaneous approach requirements in FAA Order 7110.65R. The discussions led to the creation of a Memorandum of Agreement (MOA) that identified GPS guidance as a requirement for participation in RNAV/RNP operations conducted simultaneously with ILS approaches to parallel runways. The MOA is attached as Appendix H. It also describes which cases were to be examined and their priorities. For the purposes of this study, the request was divided into the following phases that covered both the paragraphs in the FAA Order 7110.65R and additional studies will be provided as needed:

- Phase 1 provides a study to show that inclusion of RNAV/RNP(GPS) aircraft complies with current standards for parallel dependent and independent approaches, runway separation of 4,300 feet for duals or 5,000 feet for triples (as in FAA Order 7110.65R, paragraphs 5-9-6 and 5-9-7).

- Phase 2 provides a study to show that inclusion of RNAV/RNP(GPS) aircraft complies with current standards for parallel dependent approaches, with runway separation less than 4,300 feet but greater than 2,500 feet (FAA Order 7110.65R, paragraph 5-9-6).

- Phase 3 provides a study to show that inclusion of RNAV/RNP(GPS) aircraft complies with current standards for parallel independent approaches for duals with high update radar (as in FAA Order 7110.65R, paragraph 5-9-8a).

- Phase 4 provides a study to show that inclusion of RNAV/RNP(GPS) aircraft complies with current standards for Simultaneous Offset Instrument Approaches (SOIA) as addressed in FAA Order 8260.49A.

- Phase 5 provides studies or analyses to evaluate acceptable mitigations to support waiver requests to the applicable paragraphs of FAA Order 7110.65R.

- Phase 6 provides studies or analyses to support any changes required to FAA Order 8260.3b, *United States Standard for Terminal Instrument Procedures (TERPS)*, for inclusion of RNAV/VNAV (Vertical Navigation) approaches.

Each of the first four phases and many of the cases for Phase 5 will have two parts (identified as "A" and "B"). Initially, the study focuses on flight director guided approaches using appropriate Flight Technical Error (FTE) values (part "A"). The flight director performance should represent a conservative worst case for autopilot performance. Flight director or autopilot guided approaches are considered to be representative of most air traffic likely to be engaged in simultaneous operations to major airports. However, a small portion of the fleet may be using panel-mounted GPS receivers or equivalent equipment that will have significantly greater FTEs due to the lack of flight director guidance and a much coarser scale on their instruments outside the Final Approach Fix (FAF) (i.e., the full scale Course Deviation Indicator [CDI] increases from ± 0.3 NM at the FAF to ± 1.0 NM by 2

NM outside the FAF.) These Part B studies will be completed when necessary modifications have been made to the simulation system.

These reports addresses the results of studies for Phases 1A and 2A, dependent and independent simultaneous approaches to dual or triple parallel runways with conventional surveillance systems.

The operation of interest is an independent simultaneous parallel approach procedure with an *at-risk* blunder (see Figure 1 for an illustration). This blunder involves two or more aircraft established on approach (with vertical guidance), either ILS or RNAV/RNP, to parallel runways, when 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 7210.3, *Facility Operation and Administration*, requires a "final monitor controller" position for each runway. The final monitor 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. For dependent operations to dual parallel runways, a single controller may be monitoring both streams.

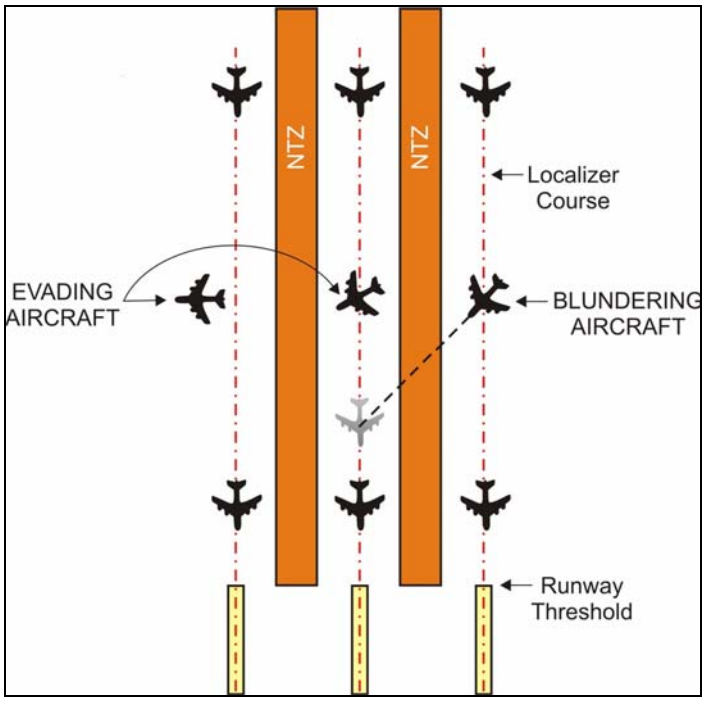

Figure 1 Triple Simultaneous Approach with Blunder

The term "at-risk" implies that if no corrective action is taken, the aircraft come within 500 feet of each other and potentially collide as shown by the shadowed aircraft on the center runway. Violation of the 500-foot separation is referred to as a Test Criteria Violation

(TCV). For independent operations, a 2,000-foot wide No Transgression Zone (NTZ) is depicted on the controller's monitor. The NTZ is located midway between adjacent pairs of approach paths to aid controllers in determining whether 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 take evasive action. Controllers may determine that a blunder is occurring before the aircraft penetrates the NTZ and act accordingly. However, due to the time and fuel costs associated with a "nuisance" breakout, 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 C). From the TLS, a maximum acceptable TCV rate can be derived for simultaneous operations (also Appendix C). The TCV rate for at-risk blunders in a dual approach must be less than 6.8%; the rate for a triple approach must be less than 5.1% overall and no more than 6.8% for each of the embedded dual operations. The TCV rate limit generates an unambiguous pass/fail criterion for each test scenario.

All scenarios will initially be run at the minimum runway spacing allowed by FAA Order 7110.65R. If any failures occur at these separations, the runway spacing will be increased in 200-foot increments until an acceptable TCV rate is achieved. If necessary, consideration can be given to improving controller response times via enhanced displays such as Standard Terminal Automation Replacement System (STARS) consoles.

1.3 RNAV/RNP Considerations

Advisory Circular (AC) 90-101, "Approval Guidance for RNP Procedures with SAAAR," defines RNAV as "a method of navigation which permits aircraft operation on any desired flight path within the coverage of station-referenced navigation aids or within the limits of the capability of self-contained aids, or a combination of these."

RNAV procedures are developed in accordance with AC 90-100, "U.S. Terminal and En Route Area Navigation (RNAV) Operations." In developing AC 90-100[1], industry partners and the FAA defined the minimum criteria for RNAV systems to operate on the RNAV routes and procedures.

For purposes of this evaluation, a RNP aircraft is an aircraft with a demonstrated RNP capability, as documented in the Aircraft Flight Manual (AFM) or AFM supplement. The demonstrated RNP capability must be equal to or less than the RNP value specified for the intended operation. An RNAV aircraft is one approved for instrument approach operations under FAA guidance such as AC 20-138, "Airworthiness Approval of Global Positioning System (GPS) Navigation Equipment for Use as a VFR or IFR Supplemental Navigation System"; AC 20-130, "Airworthiness Approval of Navigation or Flight Management

[1] The AC, along with additional RNAV supporting information, is available at the Web site of the FAA Flight Technologies and Procedures Division, Flight Operations Branch (AFS-410).

Systems Integrating Multiple Navigation Sensors"; or Technical Standard Order (TSO) C129, "Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS)." As mentioned previously, GPS must be an active component of the navigation position determination. In addition, approved RNAV/RNP aircraft must have an Instrument Flight Rules (IFR) Vertical Navigation capability as required in the AFM or AFM supplement.

An RNP navigation system differs from an RNAV system primarily in that it has additional algorithms for detecting and alerting when the navigation system information might be providing incorrect information. This process is referred to as "integrity monitoring." Because the approach operations are under continuous radar surveillance by multiple controllers, integrity was not considered a significant element of concern for the simulation (if the navigation system is providing significantly misleading information, ATC will detect the course error and act accordingly.)

The principal issue with RNAV and RNP aircraft on simultaneous approaches with other aircraft using ILS is that RNAV and RNP aircraft will not be following the localizer/glide slope guidance that the current ATC approach monitoring system has been built around. The navigation systems on the RNAV and RNP aircraft generate their own three-dimensional flight paths based on their onboard position solutions and stored navigation database information. Because of position solution errors and possible database errors, the course that the navigation system constructs may not completely correspond with the existing localizer/glide slope course and the aircraft may appear off the expected course on the ATC display. The extent to which ATC will tolerate significant cross-track deviations that are within the allowable range for the navigation system has yet to be determined. In a largely RNAV/RNP fleet, cross-track deviations that previously would have generated immediate attention for an ILS track may become routine. Therefore, in an RNAV/RNP environment, controllers may delay their decision to command an evasion to avoid nuisance breakouts.

Nuisance breakouts may also be caused by NTZ penetrations due to navigation errors. Purely as an example, an aircraft that exactly meets the RNP 0.3 containment requirement, i.e., 0.3 NM Total System Error (TSE) 95% of the time, could be in the NTZ 5.1% of the time on Runway 26L/R and Runway 08R/L at KIAH; that is, the aircraft could be more than 1,500 feet off course (the width of the Normal Operating Zone [NOZ]) and inside the NTZ while the aircraft's navigation system indicates that the aircraft is on the desired path. Given the MOA's requirement for GPS, with less than a 100-meter navigation error 95% of the time, this is not expected to be an issue for these studies.

2.0 Study Methodology

The study used a Monte Carlo simulation of the operation to evaluate the risk of collision. The simulation examined a series of scenarios involving different combinations of ILS and RNAV/RNP aircraft conducting approaches. This report considered only RNAV/RNP aircraft that were GPS-equipped and had at least a flight director providing guidance to the pilot. The primary output of the simulation was the percentage of TCVs occurring during

each scenario (combination of ILS and RNP/RNAV aircraft, runway configuration, and fleet mix). Those percentages, scaled as needed[2], were compared to the pass/fail requirements mentioned above and the scenarios were identified as acceptable or not.

2.1 Description of the Model

The ASAT consists 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, data provided by the manufacturer were used as a basis for 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. Figure 2 shows the ASAT screen for a typical run. The aircraft approaching Runway 36C (the middle runway on the screen), a generic Large aircraft, has blundered and the Runway 36R traffic, a generic Small (commuter aircraft), has successfully evaded. A generic Heavy was approaching Runway 36L and was not affected. (Since the simulation "knew" the Heavy aircraft would not be involved in the blunder, its position was totally random.) The Closest Point of Approach (CPA) was 1,276 feet slant range or 1,256 feet, ignoring vertical separation. Only the generic Heavy on Runway 36L was an RNP aircraft with an effective RNP level of 0.07. The derivation of this value will be discussed in Section 2.2.6.

[2] For certain scenarios, 100% at-risk could not be achieved, and the results were scaled by the actual percentage at-risk.

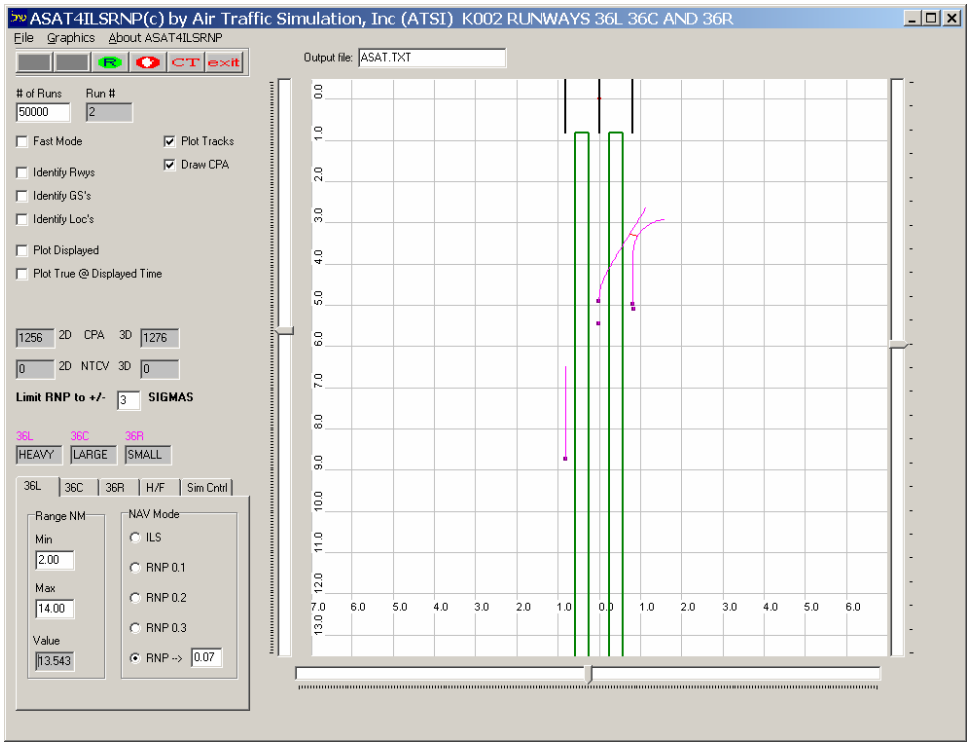

Figure 2 Typical ASAT Run

The simulation was set to initiate blunders between 2 and 14 NM from threshold. Outside 14 NM, there was at least 1,000-foot vertical separation per requirements for simultaneous operations. Inside 2 NM, the evader lands 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 the three following phases (not to be confused with the study phases):

- Phase 1: Initialization. The aircraft types were selected randomly according to the fleet mix. Their performance data were loaded and approach airspeeds were determined. They were assigned to a runway and the blunderer was selected. The blundering aircraft was positioned at a random distance from the airport (uniformly distributed within the 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 (PDFs), such as evader rate of climb, roll rate, pilot and ATC response times, etc., were selected.

- Phase 2: Performance. For the independent cases, 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 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 500 feet of 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 Closest Point of Approach [CPA]). The simulation does not detect collisions so that even if the slant range separation reached 0.0, the model keeps running.

  For the dependent case, the simulation operated similarly except there was no NTZ to generate an alert. Two sub-cases were examined, one where no evasion command was given, and one where the evasion command was given when the aircraft passed the halfway point across the runway separation.

- 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. For runs that included RNP aircraft, additional data were collected to verify that the track distributions matched the expected navigation performance for the RNP level involved. A sample output file is included as Appendix G.

The different runway configurations are shown in Table 1. For each independent dual configuration, there were three runway staggers: 0, 2,000, and 4,000; and three fleet mixes: 10, 20, and 30 percent Heavy. The duals case also considered the use of high resolution Final Monitor Aid (FMA) displays with their slightly shorter controller reaction times. For the triple configurations, only the three fleet mixes were considered. 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. Only the scenarios in bold were performed for this report.

Table 1 Navigation System/Runway Configurations*

TEST SCENARIO RUNWAY CONFIGURATIONS					
Phase	**Rwy Sep**	**Comments**	**Rwy 36L**	**Rwy 36C**	**Rwy 36R**
			DUALS		
1A	**4,300**	**Baseline**	**ILS**		**ILS**
1A	**4,300**		**ILS**		**RNP**
1A	**4,300**		**RNP**		**RNP**
1B	4,300		ILS		C129
1B	4,300		RNP		C129
1B	4,300		C129		C129
			TRIPLES		
1A	**5,000**	**Baseline**	**ILS**	**ILS**	**ILS**
1A	**5,000**		**ILS**	**ILS**	**RNP**
1A	**5,000**		**ILS**	**RNP**	**ILS**
1A	**5,000**		**ILS**	**RNP**	**RNP**
1A	**5,000**		**RNP**	**RNP**	**RNP**
1B	5,000		C129	ILS	C129
1B	5,000		C129	C129	C129
1B	5,000		C129	RNP	C129
			DUALS		
2A	**2,500**	**Dependent, Baseline**	**ILS**		**ILS**
2A	**2,500**	**Dependent**	**ILS**		**RNP**
2A	**2,500**	**Dependent**	**RNP**		**RNP**
2B	2,500	Dependent	ILS		C129
2B	2,500	Dependent	RNP		C129
2B	2,500	Dependent	C129		C129
			DUALS		
3A	3,400	PRM	ILS		RNP
3A	3,400	PRM	RNP		RNP
3B	3,400	PRM	ILS		C129
3B	3,400	PRM	RNP		C129
3B	3,400	PRM	C129		C129
			DUALS		
4A	750	SOIA	ILS		RNP
4A	750	SOIA	RNP		RNP
4B	750	SOIA	ILS		C129
4B	750	SOIA	RNP		C129
4B	750	SOIA	C129		C129

*ILS = ILS/MLS; RNP = RNAV(GPS)/RNP(GPS); C129 = Panel Mount/CDI Guidance

2.2 Summary of Data Used

The primary data components of the ASAT system are listed below. The data components allow extremely accurate representations of particular scenarios at particular airports but for the purposes of developing national standards, the system also supports a variety of generic elements.

2.2.1 Geography

Where an actual airport is being studied, ASAT uses the latest FAA databases to establish runway coordinates (including elevation), localizer and glide slope antenna positions, and relevant obstacle and terrain feature locations. For this study, generic airports were constructed with the desired runway separations and staggers.

2.2.2 Aircraft

Where a specific airport is being studied, aircraft fleet mix information is requested and incorporated into the simulation. For this study, generic aircraft models with typical performance values for commuter aircraft (referred to in the program as Small), Large turbojet, and Heavy turbojet aircraft types were used in various percentages to achieve the desired scenario. Note that because the Heavy turbojet aircraft tend to be less maneuverable and respond more slowly to pilot commands, the percentage of Heavy aircraft included in the scenario significantly affects the TCV rate.

This report uses class definitions partly based on weight categories established for wake turbulence purposes in *Air Traffic Control* [4] but separates the Large turbojet aircraft from the regional and business jet and commuter turboprops. This grouping effectively produces a new category that includes the heavier parts of the Small and the lighter parts of the Large categories that is intended to be more representative of commuter aircraft performance. For the ASAT routine, the three classes used are labeled as Heavy, Large, and Small based on the following criteria as defined in *Air Traffic Control* [4]:

- Heavy - Large turbojet aircraft capable of takeoff weights of more than 255,000 pounds whether or not they are operating at this weight during a particular phase of flight. It consists of Boeing 747, 767, and 777 models, Airbus A310, A330, A340, and some A300 models, and a handful of older types. Boeing 757 operations are also included in this class although the 757-200 is really on the light side for the class.

- Large - Turbojet aircraft of more than about 100,000 pounds, maximum certified takeoff weight, up to 255,000 pounds. This includes all Boeing 737, 727, and 707 models, Airbus A319, A320, and A321 models, and the DC-9/MD80/B717 family.

- Small - Primarily commuter aircraft with weights ranging from 10,000 to 100,000 pounds, intended to capture the regional jet and business jet categories as well as the commuter turboprops.

Details of fleet mix composition and representative performance models are discussed in Appendix A.

2.2.3 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 Multiple Parallel Approach Program (MPAP) studies have supported this assumption.

2.2.4 Pilot Response Times

The pilot response time is the period from the start of the ATC evasion command until the aircraft achieves 3 degrees of bank. These distributions are based on data collected during the MPAP testing and are discussed in more detail in Appendix B.

2.2.5 Air Traffic Controller Response Times

The air traffic controller response time is 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 spacing's and collected response times for each. Appendix C includes a list of the configurations tested. The test configurations that the MPAP examined included 4,300-foot duals and 5,000-foot triples with an ASR-9 radar and Data Entry and Display Subsystem (DEDS) displays. This represents the "baseline" ATC approach control system and is also the most conservative in terms of average controller response time, so the resultant times were selected for this simulation. Controller response times from the MPAP tests of 4,300-foot duals using FMAs were also used for the appropriate simulations. 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. (In the MPAP tests, the controllers frequently responded even earlier.) This was a conservative assumption to address the requirement in FAA Order 7110.65R, paragraph 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."

2.2.6 Navigation

Previous testing for evaluating ILS operations used the International Civil Aviation Organization (ICAO) Collision Risk Model to determine initial positions (lateral and vertical). The simulation proceeded along the localizer and glide slope using control filters to simulate FTE. Because the blunder is initiated immediately after simulation begins, this phase of flight is very short, even for the evading aircraft. For the RNAV/RNP aircraft considered for this study, the initial lateral position was selected based on a Gaussian distribution derived from the combination of the GPS Navigation System Error (NSE) (specified as 100 meters, 95%) and conservative FTE values. Actual GPS navigation errors are typically around 15 to 20 meters 99% of the time, so this represents a very conservative estimate for the NSE component. Historical flight test data were consulted to determine representative FTE values for flight director guided precision approaches. The standard deviations reported from these tests were up to 8 meters at Decision Height (DH) and no larger than 40 meters at 7 miles out from threshold. Data collected on RNAV approaches flown with GPS and flight director produced standard deviations of less than 20 meters. Using a standard deviation (σ) of 40 meters should represent a very conservative estimate. This gives a 2σ, approximately 95%, value of 80 meters. Root-sum-squaring the NSE and FTE values translate to a lateral Total System Error (TSE) of 0.07 NM 95% for flight director guided RNAV/RNP approaches using GPS. Vertical navigation was based on typical glidepath deviations around a glide slope whose ground path intercept was shifted due to the same Gaussian distribution. The aircraft then navigated along the adjusted path to the runway.

The difference between an RNP navigation system and an RNAV system has been discussed previously (section 1.3).

RNAV aircraft that rely on DME/DME/IRU (Inertial Reference Units) are extremely dependent on DME coverage and availability for their navigation solutions and, for an approach operation such as this, are flying into poorer coverage and decreasing signal quality as they descend. The expected performance of an RNAV/DME/DME/IRU aircraft would be marginally RNP 0.3 to 0.5 NM where good coverage is available. These types of aircraft were not considered for this study.

2.2.7 Surveillance System

An ASR-9 model, with appropriate errors and latencies was part of the simulation. The model was based on data provided by Lincoln Labs at Massachusetts Institute of Technology (reference 10) and the William J. Hughes Technical Center. A table summarizing the principle error components is included as Appendix I.

2.3 Simulation Performance

The runway configuration test scenarios are depicted in Table 2. As mentioned earlier, the variations between the scenarios are the arrangement of ILS and RNAV/RNP aircraft across the runways, the runway separation and threshold stagger, and the fleet mix. Fifty thousand runs were performed for each scenario. In discussion with Air Traffic during the program development, it was determined that there was no convenient way for ATC to sort different RNP-capable aircraft to particular runways, i.e., they could not route all RNP 0.3 aircraft to Runway X while allowing RNP 0.1 aircraft to land on Runways Y and Z. By assuming that all aircraft involved are GPS-equipped and have essentially the same navigation performance, per the MOA, this is no longer a significant concern.

For each scenario, the blunders were evenly distributed across the runways and only blunders toward other aircraft were considered, i.e., there were no runs where the aircraft on the left runway blundered left (away from the other traffic). For the dual runway case, approximately 25,000 runs had the left aircraft blundering right and 25,000 runs had the right aircraft blundering left. For the triple cases: from the outer runways, the blunder was always toward the other runways; from the center, it randomly went right or left. As a result, a typical set of runs involved 25,000 interactions between the right and center runways and 25,000 interactions between the left and center.

Table 2 Test Scenarios*
Phase 1A Test Scenarios
Independent 4,300-Foot Duals

Scenario #	Stagger	%Heavies	Display	36L Nav	36C Nav	36R Nav
1A	0	10	DEDS	ILS		ILS
2A	0	10	DEDS	ILS		RNP
3A	0	10	DEDS	RNP		RNP
4A	0	20	DEDS	ILS		ILS
5A	0	20	DEDS	ILS		RNP
6A	0	20	DEDS	RNP		RNP
7A	0	30	DEDS	ILS		ILS
8A	0	30	DEDS	ILS		RNP
9A	0	30	DEDS	RNP		RNP
10A	0	10	FMA	ILS		ILS
11A	0	10	FMA	ILS		RNP
12A	0	10	FMA	RNP		RNP
13A	0	20	FMA	ILS		ILS
14A	0	20	FMA	ILS		RNP
15A	0	20	FMA	RNP		RNP
16A	0	30	FMA	ILS		ILS
17A	0	30	FMA	ILS		RNP
18A	0	30	FMA	RNP		RNP
19A	2,000	10	DEDS	ILS		ILS
20A	2,000	10	DEDS	ILS		RNP
21A	2,000	10	DEDS	RNP		RNP
22A	2,000	20	DEDS	ILS		ILS
23A	2,000	20	DEDS	ILS		RNP
24A	2,000	20	DEDS	RNP		RNP
25A	2,000	30	DEDS	ILS		ILS
26A	2,000	30	DEDS	ILS		RNP
27A	2,000	30	DEDS	RNP		RNP
28A	4,000	10	DEDS	ILS		ILS
29A	4,000	10	DEDS	ILS		RNP
30A	4,000	10	DEDS	RNP		RNP
31A	4,000	20	DEDS	ILS		ILS
32A	4,000	20	DEDS	ILS		RNP
33A	4,000	20	DEDS	RNP		RNP
34A	4,000	30	DEDS	ILS		ILS
35A	4,000	30	DEDS	ILS		RNP
36A	4,000	30	DEDS	RNP		RNP

*ILS indicates a conventional precision approach; RNP, a GPS RNAV/RNP precision approach.

Table 2 Test Scenarios* (continued)
Independent 5,000-Foot Triples

Scenario #	Stagger	%Heavies	Display	36L Nav	36C Nav	36R Nav
41A	0	10	DEDS	ILS	ILS	ILS
42A	0	10	DEDS	ILS	RNP	ILS
43A	0	10	DEDS	ILS	ILS	RNP
44A	0	10	DEDS	ILS	RNP	RNP
45A	0	10	DEDS	RNP	RNP	RNP
46A	0	20	DEDS	ILS	ILS	ILS
47A	0	20	DEDS	ILS	RNP	ILS
48A	0	20	DEDS	ILS	ILS	RNP
49A	0	20	DEDS	ILS	RNP	RNP
50A	0	20	DEDS	RNP	RNP	RNP
51A	0	30	DEDS	ILS	ILS	ILS
52A	0	30	DEDS	ILS	RNP	ILS
53A	0	30	DEDS	ILS	ILS	RNP
54A	0	30	DEDS	ILS	RNP	RNP
55A	0	30	DEDS	RNP	RNP	RNP

Phase 2A Test Scenarios
Dependent 2,500-Foot Duals

Scenario #	Stagger	%Heavies	Display	36L Nav	36C Nav	36R Nav
61A	0	10	DEDS	ILS		ILS
62A	0	10	DEDS	ILS		RNP
63A	0	10	DEDS	RNP		RNP
64A	0	20	DEDS	ILS		ILS
65A	0	20	DEDS	ILS		RNP
66A	0	20	DEDS	RNP		RNP
67A	0	30	DEDS	ILS		ILS
68A	0	30	DEDS	ILS		RNP
69A	0	30	DEDS	RNP		RNP

*ILS indicates a conventional precision approach; RNP, a GPS RNAV/RNP precision approach.

When the blunderer in a triple runway configuration is on one of the outboard runways, there is a potential for a secondary TCV between the evader on the center runway and the evader on the far outboard. This case is not considered in this study. This situation is one of the reasons why the final monitor controllers for simultaneous approach operations are required to be at adjacent stations so that evasion operations can be coordinated and secondary TCVs avoided. When the blundering aircraft reaches the NTZ, it is generally on its 30-degree offset course and is 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 (triples at 5,000 feet separation between both pairs), the controller on the opposite outboard runway has more than a minute to extract his or her aircraft and avoid the other evader whose maneuvers are known.

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

Tables 3 through 5 list the resultant TCV counts, number of runs for each scenario, and the associated TCV rate for each scenario. The independent dual and triple parallel runway and dependent dual parallel runway results are discussed in separate sections.

The simulation included algorithms to longitudinally place evader aircraft relative to the blundering aircraft so that they were at-risk. However, for the 4,000-foot threshold stagger cases, the efficiency of this algorithm was reduced 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.

3.1.1 Independent 4,300-Foot Dual Parallel Runway Scenarios

Table 3 shows that all scenarios for the 4,300-foot runway separation case for independent simultaneous dual approaches met the TCV rate criteria although there was a perceptible increase in risk when RNAV aircraft were involved (under the performance parameters used in the simulation). This increase is presumably due to an increased likelihood that an RNAV aircraft will have a larger cross-track error than if it were tracking the ILS localizer, which effectively reduces the course separation and thus reduces the time available to resolve the blunder. The blundering aircraft may also be farther off the centerline but unless it is almost in the NTZ, its lateral deviation should not affect the controller response time which is measured from when the target is detected in or near the NTZ. For the assumed RNAV performance, the 95% lateral offset should be around 425 feet, still well inside the NOZ of 1,150 feet. The 425-foot offset on the evader side translates to about 4 seconds less time to complete an evasion maneuver.

As intuition would predict, the percentage of TCV rates consistently decreases with increasing runway stagger. As the stagger increases, the vertical separation between the two tracks increases, making it more likely that the evader will be able to maintain 500 feet separation from the blunderer. Likewise, adding proportionally more Heavy aircraft causes the TCV rate to rise. More massive aircraft, such as Boeing 747s, bank more slowly and, because of their higher speed, tend to achieve a lesser rate-of-turn for the same bank angle than do smaller aircraft and thus take longer to achieve a heading change.

Table 3 Independent 4,300-Foot Dual Parallel Runway TCVs

Scenario #	Stagger	%Heavies	Display	Nav Config	TCVs	# Runs	%TCV
1A	0	10	DEDS	ILS/ILS	4614	100,000	4.614
2A	0	10	DEDS	ILS/RNP	4886	100,000	4.886
3A	0	10	DEDS	RNP/RNP	5369	100,000	5.369
4A	0	20	DEDS	ILS/ILS	5250	100,000	5.25
5A	0	20	DEDS	ILS/RNP	5535	100,000	5.535
6A	0	20	DEDS	RNP/RNP	5981	100,000	5.981
7A	0	30	DEDS	ILS/ILS	5585	100,000	5.585
8A	0	30	DEDS	ILS/RNP	6201	100,000	6.201
9A	0	30	DEDS	RNP/RNP	6758	100,000	6.758
10A	0	10	FMA	ILS/ILS	2748	100,000	2.748
11A	0	10	FMA	ILS/RNP	3092	100,000	3.092
12A	0	10	FMA	RNP/RNP	3214	100,000	3.214
13A	0	20	FMA	ILS/ILS	3255	100,000	3.255
14A	0	20	FMA	ILS/RNP	3405	100,000	3.405
15A	0	20	FMA	RNP/RNP	3725	100,000	3.725
16A	0	30	FMA	ILS/ILS	3603	100,000	3.603
17A	0	30	FMA	ILS/RNP	3802	100,000	3.802
18A	0	30	FMA	RNP/RNP	4115	100,000	4.115
19A	2,000	10	DEDS	ILS/ILS	4364	100,000	4.364
20A	2,000	10	DEDS	ILS/RNP	4636	100,000	4.636
21A	2,000	10	DEDS	RNP/RNP	4987	100,000	4.987
22A	2,000	20	DEDS	ILS/ILS	4743	100,000	4.743
23A	2,000	20	DEDS	ILS/RNP	5263	100,000	5.263
24A	2,000	20	DEDS	RNP/RNP	5674	100,000	5.674
25A	2,000	30	DEDS	ILS/ILS	5336	100,000	5.336
26A	2,000	30	DEDS	ILS/RNP	5754	100,000	5.754
27A	2,000	30	DEDS	RNP/RNP	6147	100,000	6.147
28A	4,000	10	DEDS	ILS/ILS	3726	100,000	4.140*
29A	4,000	10	DEDS	ILS/RNP	3977	100,000	4.419*
30A	4,000	10	DEDS	RNP/RNP	4347	100,000	4.830*
31A	4,000	20	DEDS	ILS/ILS	4233	100,000	4.704*
32A	4,000	20	DEDS	ILS/RNP	4618	100,000	5.131*
33A	4,000	20	DEDS	RNP/RNP	4859	100,000	5.398*
34A	4,000	30	DEDS	ILS/ILS	4756	100,000	5.284*
35A	4,000	30	DEDS	ILS/RNP	5127	100,000	5.697*
36A	4,000	30	DEDS	RNP/RNP	5351	100,000	5.945*

* Indicates scaling applied

The baseline system for the modeling/simulation was the Automated Radar Terminal System (ARTS) IIIA driven by an ASR-9 radar with the Data Entry Display Subsystem (DEDS) console or the Full Digital ARTS Display System (FDADS). One of the results of the MPAP tests was identifying the superior performance of controllers using the Final Monitor Aid (FMA) which is a high resolution color display system. An equivalent monitor is part of the

Standard Terminal Automation Replacement System (STARS). Reaction time measurements for the FMAs were about two seconds shorter than the DEDS. Scenarios 10 through 18 reflect this improvement compared to Scenarios 1 through 9.

It should be noted that none of the MPAP tests of 4,300 duals using the older DEDS monitors were considered successful. Those tests, however, were all conducted with fleet mixes representative for that time period when almost all commercial turbojets would fall into the "Large" or "Heavy" ASAT classes defined earlier and most were on the lower end of the modern performance spectrum. The current simulation used a more modern fleet mix with a significant percentage of regional and business jets and representative performance values for the modern aircraft. (An additional simulation was done with no ASAT "Small" types and a higher percentage of heavies and the resultant TCV rate was not acceptable.)

3.1.2 Independent 5,000-Foot Triple Parallel Runway Scenarios

Table 4 shows that all scenarios for the 5,000-foot separation case for independent simultaneous triple approaches met the acceptable TCV rate criteria although there was a perceptible increase in risk when RNAV aircraft were involved (under the performance parameters used in the simulation). TCVs between the two embedded duals are included in Table 4. There is nothing of note in the results that was not discussed in the previous section. Given that secondary collisions were not considered, the results here are what would be seen if only 5,000-foot duals were examined as explained in section 2.3.

Table 4 5,000-Foot Triple TCVs

			Left/Center			Center/Right			Total		
Scenario	Nav	% Heavies	TCVs	Runs	TCV %	TCVs	Runs	TCV %	TCVs	Runs	TCV %
41A	ILS/ILS/ILS	10	965	49,971	1.931	1,000	50,029	1.999	1,965	100,000	1.965
42A	ILS/RNP/ILS	10	1,106	49,932	2.215	1,066	50,068	2.129	2,172	100,000	2.172
43A	ILS/ILS/RNP	10	927	49,962	1.855	1,111	50,038	2.220	2,038	100,000	2.038
44A	ILS/RNP/RNP	10	1,041	49,895	2.086	1,247	50,105	2.489	2,288	100,000	2.288
45A	RNP/RNP/RNP	10	1,182	49,839	2.372	1,211	50,161	2.414	2,393	100,000	2.393
46A	ILS/ILS/ILS	20	1,099	50,084	2.194	1,182	49,916	2.368	2,281	100,000	2.281
47A	ILS/RNP/ILS	20	1,272	49,918	2.548	1,268	50,082	2.532	2,540	100,000	2.540
48A	ILS/ILS/RNP	20	1,121	49,873	2.248	1,352	50,127	2.697	2,473	100,000	2.473
49A	ILS/RNP/RNP	20	1,229	49,893	2.463	1,416	50,107	2.826	2,645	100,000	2.645
50A	RNP/RNP/RNP	20	1,336	49,967	2.674	1,387	50,033	2.772	2,723	100,000	2.723
51A	ILS/ILS/ILS	30	1,270	50,013	2.539	1,216	49,987	2.433	2,486	100,000	2.486
52A	ILS/RNP/ILS	30	1,432	49,968	2.866	1,514	50,032	3.026	2,946	100,000	2.946
53A	ILS/ILS/RNP	30	1,298	50,029	2.594	1,391	49,971	2.784	2,689	100,000	2.689
54A	ILS/RNP/RNP	30	1,463	50,110	2.920	1,576	49,890	3.159	3,039	100,000	3.039
55A	RNP/RNP/RNP	30	1,526	49,927	3.056	1,640	50,073	3.275	3,166	100,000	3.166

3.1.3 Dependent 2,500-Foot Dual Parallel Runway Scenarios

For the dependent case, the different scenarios were examined with and without a controller directed evasion maneuver. Because there is no NTZ defined for dependent operations, the simulation assumed the controller would react if the blunderer passed the halfway point between the two runway centerlines extended. Normal ATC procedure would be to not initiate an evasion maneuver. Table 5 shows that the dependent case scenarios produced no TCVs. Table 6 lists the Closest Point of Approach (CPA) for several of the scenarios and suggests that the scenario is slightly safer, in that greater separation is maintained, if no controller action is taken, i.e., the standard procedure is the best choice. Wake turbulence considerations behind the deviating aircraft were not part of this study.

Table 5 Dependent 2,500-Foot Dual TCVs

Scenario #	% Heavies	Nav Config	TCVs-No ATC	TCVs-w/ATC
61A	10	ILS/ILS	0	0
62A	10	ILS/RNP	0	0
63A	10	RNP/RNP	0	0
64A	20	ILS/ILS	0	0
65A	20	ILS/RNP	0	0
66A	20	RNP/RNP	0	0
67A	30	ILS/ILS	0	0
68A	30	ILS/RNP	0	0
69A	30	RNP/RNP	0	0

Table 6 Minimum CPA for Selected Scenarios

Scenario	Nav	% Heavies	Min. CPA. (ft.) w/Evas.	Min. CPA. (ft.) w/o Evas
61A	ILS/ILS	10	3,070	3,910
63A	RNP/RNP	10	3,280	4,360
67A	ILS/ILS	30	3,120	4,050
69A	RNP/RNP	30	2,760	4,100

Figure 3 is a plot of frequencies of CPA values for the scenarios in Table 6. The TCV rate driven pass/fail criteria for the independent operations is not strictly applicable here but since there were no TCVs and the minimum separation for the no evasion case was 3,900 feet, it is reasonable to assume the safety level for the operation is acceptable.

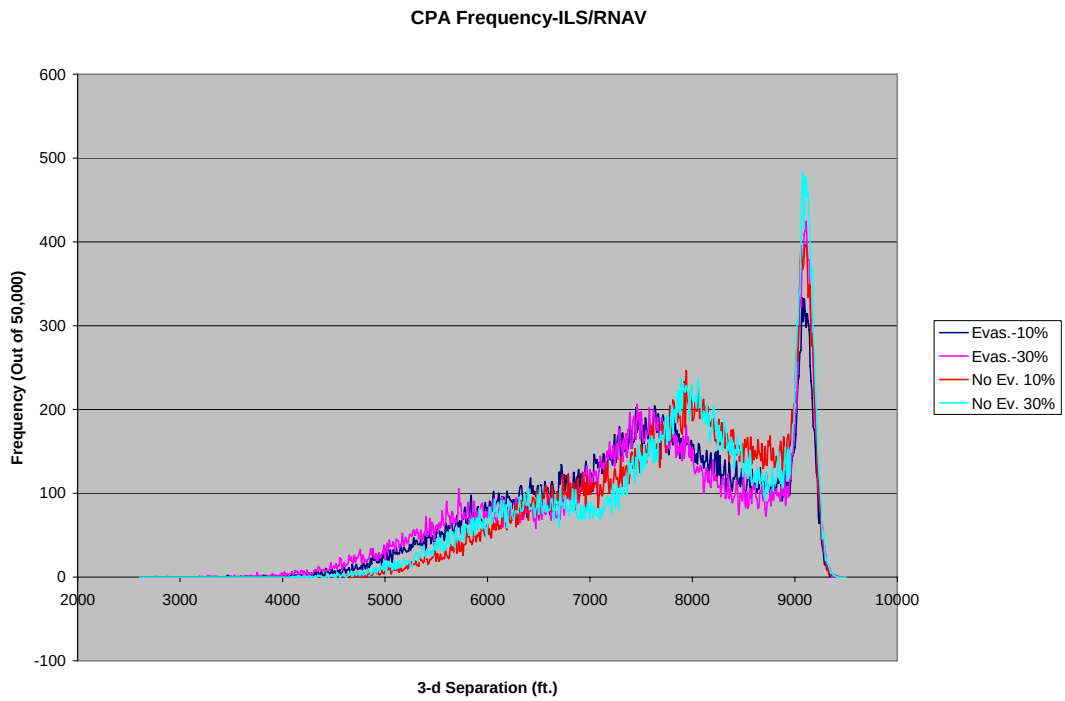

Figure 3 CPA Distribution for Dependent Duals

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 to evaluate 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 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, lead to an estimated fatal accident rate during ILS operations performed during Instrument Meteorological Conditions (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. Implementing 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 are equal. Thus, the contribution of any one of the accident causes would be one-tenth of the total accident rate. Based on this rate, 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 Precision Runway Monitor (PRM) Demonstration Program. In the *PRM Demonstration Report* [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, provided that 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 6.8 percent for dual approaches. The MPAP test team also determined that the criterion for triple approaches is 5.1 percent. 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 indicates 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 explained in more detail in Appendix D, which is excerpted from Appendix C of *Evaluation of Triple Independent Instrument Landing System Approaches to Runways Spaced 4,000 and 5,300 Feet Apart Using a Precision Runway Monitor System* [3].

4.0 Results and Conclusions

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

4.1 Independent 4,300-Foot Dual Parallel Runways

For all the scenarios examined, all combinations of GPS-equipped RNAV/RNP aircraft and ILS aircraft considered in the simulation achieved an acceptable TCV rate and passed the test criteria. A caveat was added noting that 4,300-foot ILS duals were never shown to meet the safety requirements during the MPAP test program. Although the current simulation

showed that the all-ILS case passed, the apparent discrepancy was believed to be due to changes in the fleet mix under evaluation and some modest improvements in aircraft performance. The simulation showed a small but significant increase in risk when the RNAV/RNP aircraft were added but the results still met the TCV rate criteria.

4.2 Independent 5,000-Foot Triples

For all the scenarios examined, all combinations of GPS-equipped RNAV/RNP and ILS aircraft considered in the simulation achieved an acceptable TCV rate and passed the test criteria.

4.3 Dependent 2,500-Foot Duals

For all the scenarios examined, all combinations of GPS-equipped RNAV/RNP and ILS aircraft considered in the simulation passed the test criteria.

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. This methodology was utilized to determine the acceptability of including RNAV and RNP aircraft in simultaneous independent dual and triple approach operations and simultaneous dependent dual approach operations as specified in FAA Order 7110.65R, *Air Traffic Control*, paragraphs 5-9-6 through 5-9-7. The study used a high fidelity simulation of the operation to perform a Monte Carlo analysis. The study examined 60 test scenarios that mixed ILS and GPS-equipped RNAV/RNP traffic and determined that all of them passed the test criteria. The simulation modeled RNAV/RNP performance as a Gaussian distribution with the RNP level equivalent to 1.96 standard deviations. The standard deviation was determined by root-sum-squaring approved GPS navigation error values with empirically determined FTEs for flight director guided approach operations. It was assumed that the integrity, availability, and continuity functions inherent in RNP were covered for RNAV aircraft by the required Air Traffic surveillance and by the other conservative assumptions.

This study did not address operations involving aircraft equipped with TSO C-129 panel mounted systems that rely on Course Display Indicator (CDI) guidance that may be considered RNAV. It is expected that these aircraft will only represent a small portion of the fleet involved in simultaneous approach operations. They will have significantly greater FTEs due to the lack of flight director guidance and the much coarser scale on their instruments outside the FAF discussed earlier.

The study also did not consider wake encounters with the vortices generated by the involved aircraft. These may create significant disturbances for other aircraft beyond the 500-foot TCV “bubble.”

5.0 References

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Appendix A: Aircraft Mix and Performance Modeling

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. For this generic study, three fleet mixes were considered containing different percentages of Heavy aircraft: 10, 20, and 30%. The percentages are shown in the table below.

Table A-1 Fleet Mix Percentages Used in Simulations

ASAT Class	% in 10% mix	% in 20% mix	% in 30% mix
Small	50	45	40
Large	40	35	30
Heavy	10	20	30

The Small aircraft class, intended to represent commuters, regional jets, and business jets has performance parameters similar to a Saab 340 turboprop. Based on comparisons between various performance parameters such as rate of climb and vertical acceleration, the Saab should be a conservative representative of the class. It is likely that the performance of many of the business and regional jets would be closer to the Large category model, but by using the Saab, the analysis should err on the conservative side.

The Large aircraft class, intended to represent large turbojets, such as Boeing 737s, MD-88s, and Airbus A320s was represented by the A320, which seemed to be at about the mid-point of the performance range.

The Heavy class, covering Boeing 747, 757, 767, and 777 models and Airbus A300, A310, A330, and A340 models, was represented by performance parameters similar to the Boeing 777. The 777 seemed to be about the middle of the performance range for the class. The 747 would have been a conservative representative but, in terms of percentage of operations, is only a significant player at one or two airports in the NAS.

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.

Overall fleet mix in terms of aircraft types and percentage of operations varies widely from airport to airport across the country. The Enhanced Traffic Management System Counts (ETMSC) tool was queried and traffic count by weight class and aircraft type was extracted for the 15 busiest commercial airports in the country for 2005 and 2006 (which came out to 17 different airports). Many of these airports run simultaneous approach operations. Table A-2 shows the runway pairs at these airports that have centerline separations between 4,300

and 6,000 feet. This table only addresses runway separations and is not claiming simultaneous operations are conducted for the listed pairs.

Table A-2 Parallel Runway Separations at 9 of the 15 Busiest Airports Between 4,300 and 6,000 Feet

Airport	Runway	Separation (ft)
ATL	08R/09L	4,500
ATL	26L/27R	4,500
ATL	09S/09L	5,254
ATL	27S/27R	5,254
ATL	08L/09L	5,500
ATL	26R/27R	5,500
ATL	08R/09R	5,600
ATL	26L/27L	5,600
BOS	15R/14	5,500
BOS	33L/32	5,500
CLT	36L/36R	5,000
CLT	18R/18L	5,000
DFW	18R/18C	6,000
DFW	36L/36C	6,000
DTW	03L/03R	5,750
DTW	21R/21L	5,750
IAH	08L/08R	5,000
IAH	26R/26L	5,000
IAH	08R/09L	6,000
IAH	26L/27R	6,000
LAX	06R/07L	4,500
LAX	24L/25R	4,500
LAX	06L/07L	5,200
LAX	24R/25R	5,200
LAX	06R/07R	5,300
LAX	24L/25L	5,300
LAX	06L/07R	6,000
LAX	24R/25L	6,000
ORD	09N/09L	5,500
ORD	27N/27R	5,500
ORD	09L/09R	5,500
ORD	27R/27L	5,500
PHX	08/07R	4,350
PHX	26/25L	4,350

Table A-3 lists the fleet mixes by the classes defined earlier at the 17 airports by year. It does not include data on the smallest classes or aircraft with undefined or unidentified weight classes so the totals do not add up to 100%. Note that the Heavy column includes Boeing 757 operations which were frequently more than all the other Heavy operations combined.

Table A-3 Fleet Mixes at 17 of the Busiest Airports 2005-2006

	2005			2006		
Airport	% Heavy	% Large	% Commuter	% Heavy	% Large	% Commuter
ATL	18.1	49.6	29.6	16.7	45.9	35.1
ORD	13.3	40.6	43.5	13.7	36.2	45.5
DFW	12.1	53.1	31.5	11.6	52.9	32.4
LAX	27.5	41.6	24.3	27.4	41.6	23.7
LAS	9.7	51.4	5.7	7.9	55.7	4.6
DEN	10.2	47.6	29.0	9.1	49.4	29.2
IAH	7.9	39.7	48.6	6.7	37.5	52.4
PHX	5.7	59.0	18.3	5.1	63.6	16.0
PHL	9.9	40.8	39.6	11.0	36.3	43.4
CLT	6.8	35.4	45.5	6.4	29.3	52.2
DTW	9.0	45.6	41.1	9.4	46.9	39.0
MSP	10.8	46.8	34.7	11.2	47.3	33.1
EWR	20.8	38.8	35.9	21.4	39.2	35.0
IAD	7.2	17.5	54.1	10.4	19.6	43.1
SLC	5.3	25.5	45.5	6.2	24.2	43.8
BOS	14.7	36.6	26.2	14.2	36.9	28.0
CVG	6.0	16.9	70.7	4.3	12.3	77.2

The fleet mixes selected for analysis in the simulation were intended to be generic, not representative of any particular airport. They are representative of a cross-section of the actual fleet mixes and, thus, should serve as a basis for national standards.

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 ensure that the pilots did not delay their response to a "traffic alert" message. Though not required, a significant part of the present pilot population has completed the training, which consists of a short video presentation. This training was not considered necessary for operations using conventional radar systems with runways spaced 4,300 feet or more.

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. 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.)

Table B-1 Johnson S_L Distribution Parameters

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 three 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.

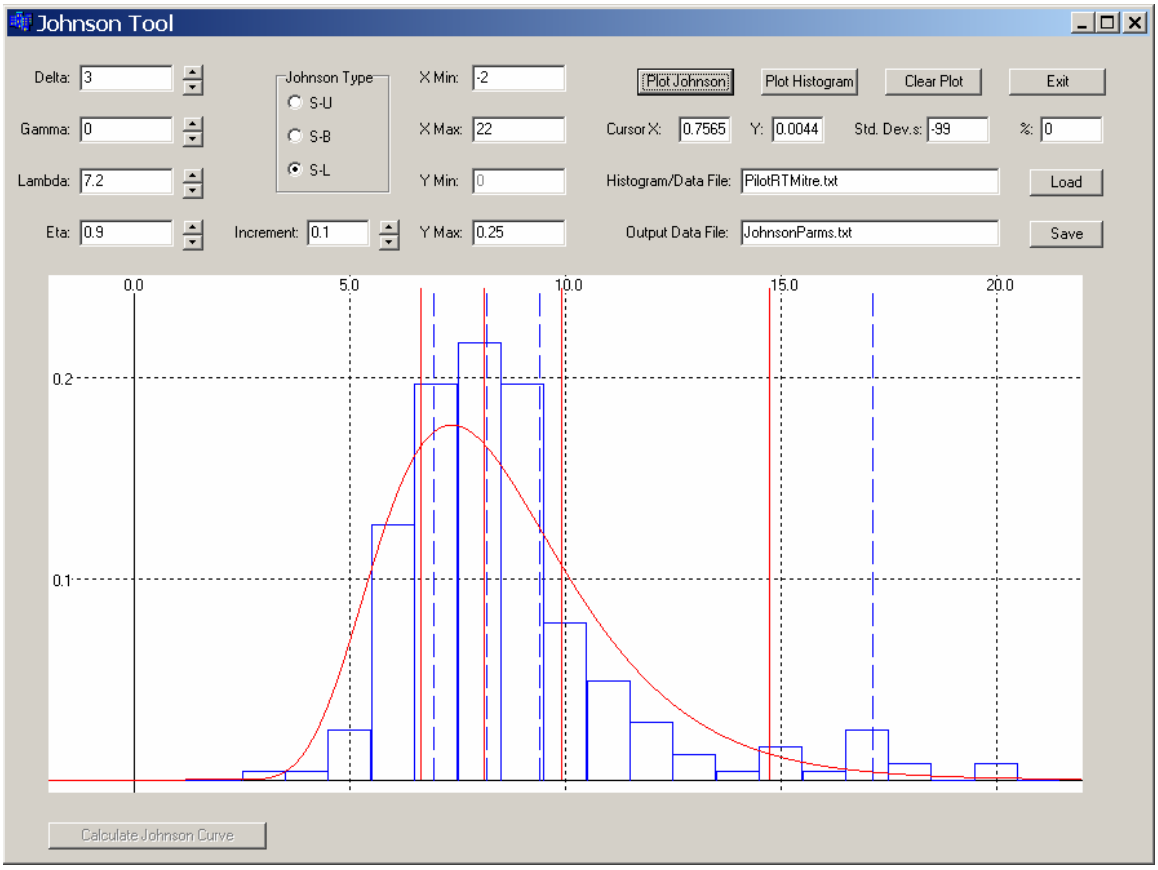

Figure B-1 Pilot Response Times Distribution

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-3 shows the configurations of systems used during the various MPAP tests.

The test program, identified as IVA in Table C-3, examined dual approaches to runways spaced 4,300 feet apart using standard ASR-9 radar and ASR/DEDS scopes (an ARTS III system). A histogram of the controller response times from that test was found in a draft document *Comparison of the Final Monitor Aid and The ARTS/DEDS Display Systems* [7]. The data were fitted with a Johnson S_B distribution resulting in the values shown in Table C-1. (Johnson distributions are discussed in Appendix E.)

Table C-1 Johnson S_B Distribution Parameters

Parameter	Value
Type	S-B
Delta	1.7
Gamma	0.6
Lambda	29.0
Xi	1.4
Truncation-Low	3.0
Truncation-High	30.0
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_B function fitted to the data. The distribution was truncated at three seconds on the low end.

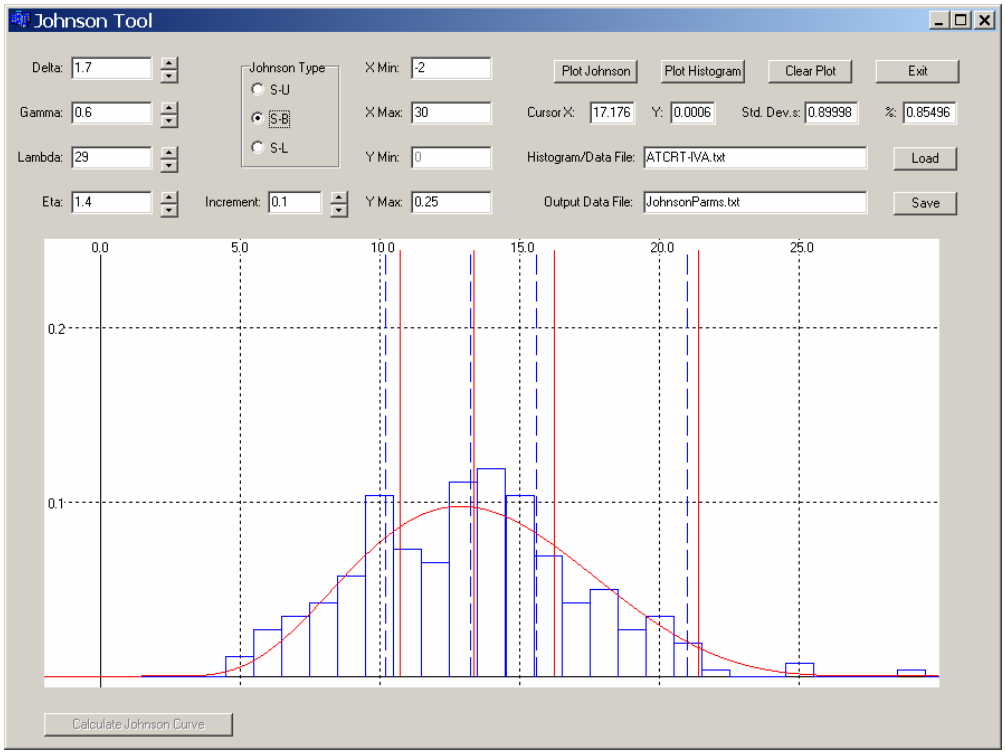

Figure C-1 ATC Response Time Distribution for 4,300-Foot Duals

Similar data was collected for the 5,000-foot triples test (IVB in the MPAP programs) and the Johnson curve fitted to that data is shown in Figure C-2. The values are shown in Table C-2. There were three very long controller response times collected during the 5,000-foot triples test that were not considered representative of performance for controllers in modern final monitor environments. For this reason, the distribution of controller response times was truncated at 30 seconds. A 30-second interval would include at least six radar target updates after the blunder initiation, three or four of which would occur after the 30-degree course deviation was attained (assuming a nominal 3 degree per second heading change on the blundering aircraft.).

Table C-2 Johnson S_B Distribution Parameters

Parameter	Value
Type	S-B
Delta	1.5
Gamma	0.5
Lambda	41.6
Xi	1.5
Truncation-Low	3.0
Truncation-High	30.0
Offset	0.0

Several goodness-of-fit tests were run on the Johnson curves and the histograms and did not produce significant agreement but the quartile fits indicate the distribution errors are on the conservative side.

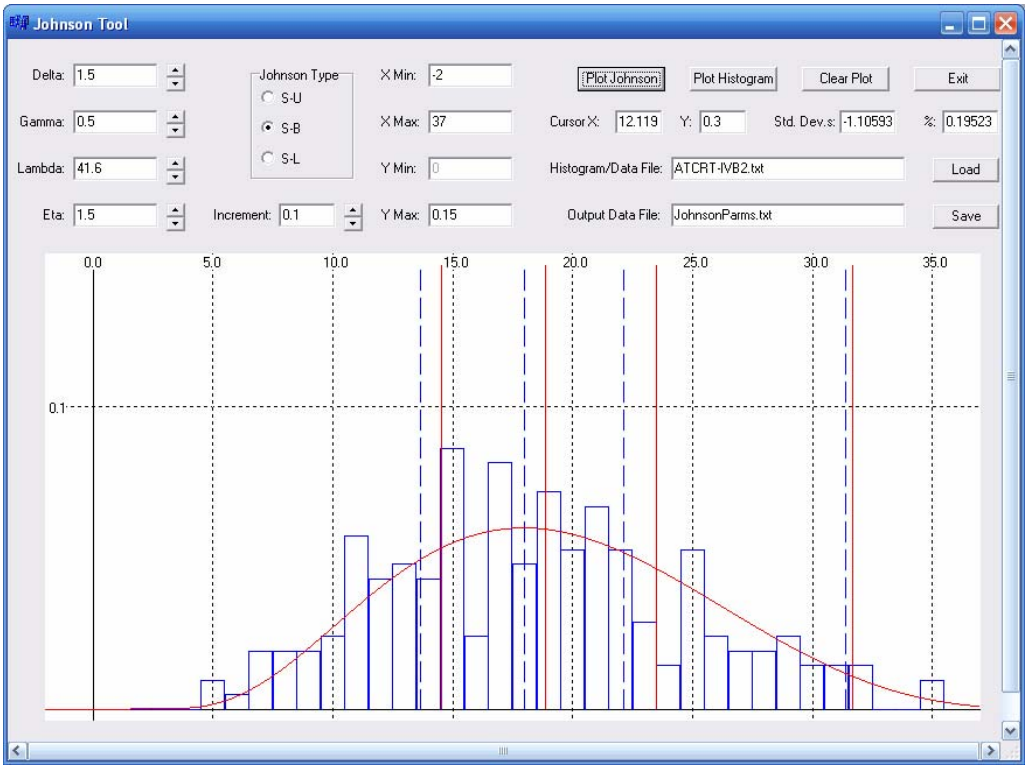

Figure C-2 ATC Response Time Distribution for 5,000-Foot Triples

Table C-3 Multiple Parallel Approach Program: 1988 - 1999

Approach	Sim Order	Dates	Purpose	Runway Spacing (ft)	Display	Simulated Radar	Other	TWG Recommendation	Documentation
Dual	N/A	6/1990	National Standards	3,400	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	3,000	FMA	E-Scan 1.0s	1º Localizer Offset	No Decision Rendered See June '94	
Dual	15	6/6-6/17 1994	National Standards	3,000	FMA	E-Scan 1.0s	1º Localizer Offset	Not Approved	
Dual	16	7/11-7/22 1994	National Standards	3,000	FMA	E-Scan 1.0s	2.5º Localizer Offset		
Dual	18	10/16-10/27 1995	National Standards	3,000	FMA	E-Scan 1.0s	2.5º Localizer Offset		
Dual and Triple (IVA)	4	4/24-5/3 1990	National Standards	4,300	ARTS III	ASR-9 4.8s		Not Approved	No Documentation
Dual and Triple (IVA)	8	5/15-5/24 1991	National Standards	4,300	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	3,000	FMA	E-Scan 1.0s		Not Approved	Memorandum
Dual and Triple	12	7/27-8/14 1992	National Standards	4,000	FMA	ASR-9 4.8s		Inconclusive	Memorandum
Triple	10	9/24-10/4 1991	National Standards	4,000	FMA	ASR-9 4.8s		Inconclusive	
Triple	2	9/25-10/5 1989	DFW	5,000 & 8,800	DEDS	ASR-9 4.8s		Approved	Published Report (DOT/FAA/CT-90-2)
Triple (IVB)	5	9/17-9/28 1990	National Standards	5,000	ARTS III	ASR-9 4.8s		Approved	Published Report (DOT/FAA/CT-91-31)
Triple	7	5/6/-5/14 1991	National Standards	3,400	FMA	Mode S 2.4s		Inconclusive	Memorandum
Triple	11	3/2-3/13 1992	Human Factors Study	3,400	FMA	E-Scan 1.0s	1 Mr Radar Accuracy	No Recommendation	
Triple	14	11/16-11/20, 11/30-12/17 1992	DIA (DEN)	7,600 5,280	FDADS FMA	ASR-9 4.8s	Field Elevation 5,431 ft	Not Approved Approved	Published Report (DOT/FAA/CT-94-36)
Triple	17	8/14-8/25 1995	National Standards	4,000 5,300	FMA	E-Scan 1.0s		Not Approved	TN02/16) Appendix
Triple	19	4/15-4/26 1996	National Standards	4,000 5,300	FMA	E-Scan 1.0s		Approved	

Table C-3 Multiple Parallel Approach Program: 1988 – 1999 (Continued)

Approach	Sim Order	Dates	Purpose	Runway Spacing (ft)	Display	Simulated Radar	Other	TWG Recommendation	Documentation
Quadruple	1	5/16-6/10 1988	DFW	5,000 5,800 8,800	DEDS	ASR-9 4.8s		Approved	Published Report (DOT/FAA/CT-90-15)
Dual and Quadruple	3	11/29/89-2/9 1990	DFW	5,000 5,800 8,800	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	7,600 5,280 5,348	ARTS III	ASR-9 4.8s	Field Elevation 5,431 ft	No Recommendation Made	Memorandum
MPAP Summary Report	20	12/ 1999	National Standard and Site-Specific Results	Published Report (DOT/FAA/CT-TN99/24)					

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: 30 degree blunder with lost communication) 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., the aircraft 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(Accident) = P(TCV and At-risk and WCB and Blunder) x 2 (D1)

or

P(Accident) = P(TCV|At-risk and WCB and Blunder) x (D2)
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 *Precision Runway Monitor Demonstration Report* [1].

- 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 30º blunders per dual approach pair. Researchers can show the rate for triple approaches to be 1/1,500 30º 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 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:

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

Maximum Allowable Test Criterion Violation Rate

Because the only undefined variable in Equation (D2) 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 (D2) becomes:

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

or,

$$P(\text{TCV}|\text{At-risk and WCB and Blunder}) = \qquad \text{(D3)}$$

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

Substituting values from (D2) into (D3):

$$P(\text{TCV}|\text{At-risk and WCB and Blunder}) = \qquad \text{(D4)}$$

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

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 1,500 was replaced by 2,000 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, 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:

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

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 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:

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

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 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:

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

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 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 (E1), (E2), and (E3); that is, 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:

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

Because 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:

$$f_2(x) = \frac{\delta\lambda}{(x-\varepsilon)(\lambda - x + \varepsilon)\sqrt{2\pi}} \exp\left\{-\frac{1}{2}\left[\gamma + \delta \ln\left(\frac{x-\varepsilon}{\lambda - x + \varepsilon}\right)\right]^2\right\},$$
$$\varepsilon < x < \varepsilon + \lambda, \delta > 0, -\infty < \gamma < \infty, \lambda > 0, -\infty < \varepsilon < \infty.$$

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 (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*.

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: K002 Runways 36L and 36R with 10% heavies and no stagger
;
;      Aircraft types and % of overall traffic
;      - - - - - - - - - - - - - - - - - - - -
Aircraft:    DATA\\SMALL.TXT
PercentageMix:      600                 ;      [-] out of TOTAL mix
;
Aircraft:    DATA\\LARGE.TXT
PercentageMix:      300                 ;      [-] out of TOTAL Mix
;
Aircraft:    DATA\\HEAVY.TXT
PercentageMix:      100                 ;      [-] out of TOTAL Mix
;
AirportFile: Airports & ASAT Projects\\GEN_DUAL_2000.out
;
;      Active runways (from LEFT to RIGHT)
;      - - - - - - - - - - - - - - - - - -
Runway:             36L
FlightMode:     REJECT
Runway:             36R
FlightMode:      REJECT
Runway:             36Z
FlightMode:      REJECT

;      Air Traffic Control Response Time Definition
;      - - - - - - - - - - - - - - - - - - - - - -
; GRM22 TC tests with 4300 foot duals & ARTs GRM PDF 12/19/06
AtcJohnsonType:         1
AtcXi:                  1.4
AtcLambda:           29.0
AtcDelta:               1.7
AtcGamma:               0.6
AtcMin:                 3.0
AtcMax:              30.0
AtcDeltaTime:           0.0
; GRM22

;      Pilot response type
;      - - - - - - - - - -
; GRM18
PilotJohnsonType:     2                   ;1:SB   2:SL    3:SU  pdf by grm
01/02/07
PilotXi:              0.9
PilotLambda:          7.2
PilotDelta:           3.0
PilotGamma:           0.0
PilotMin:             1.0
PilotMax:            25.0
PilotDeltaTime:        -1            ;roll time to 3 degrees which is what
;times are based on
; GRM18
;
CrmData:     DATA\\CAT1030.TXT                ;      CRM distributions
;
```

2. Air Description: Airport and runway coordinates. A third runway is included to meet requirements of the simulation tool.

```
AirportName        : GENERIC DUAL
AirportIdentifier  : K002
AirportLocation    : HOUSTON
AirportState       : TX
AirportLatLon      :  30 00 00.00,      100 00 00.00
AirportElevation   : 1000
AirportMagVarYr    : 1985
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;
RunwayName         : 36L
RunwayTrueBearing  : 0
RunwayLength       : 10000
RunwayThLatLon     :  29 58 50.88, 100 00 24.49
RunwayThElevation  : 1000

RunwayName         : 36R
RunwayTrueBearing  : 0
RunwayLength       : 10000
RunwayThLatLon     :  29 59 10.63, 099 59 35.51
RunwayThElevation  : 1000

RunwayName         : 36Z
RunwayTrueBearing  : 0
RunwayLength       : 3000
RunwayThLatLon     :  29 59 10.63, 099 57 0.00
RunwayThElevation  : 1000


-----------------------------------------------------------------------------------------------
```

Appendix G: ASAT Output File

```
ASAT Output file for C:\ASAT4ILSRNP\Airports & ASAT Projects\Generic Dual

                AcType2     AcType1       CPA2D       CPA3D      BATCRT        BPRT      EATCRT
RunNumber            ERJ        B732      4607.3      4614.6        15.4         3.2        13.6
                    B732        F100      2926.1      2932.8        27.8         3.1        17.4
                    B732         ERJ      1666.6      1666.7        18.7         3.1        25.2
                    F100        F100      3042.4      3042.6        15.1         2.4         9.7
                    B738         ERJ      2399.8      2431.7        10.7         5.0        19.1

1
2Total Number of Runs     : 5
3
4TCV Range: 500[Ft]
5NTCV2D(LCR): 0 / 5
NTCV3D(LCR): 0 / 5

NTCV2D(LC) : 0 / 3
NTCV3D(LC) : 0 / 3

NTCV2D(CR) : 0 / 2
NTCV3D(CR) : 0 / 2
```

Right half of output -----→
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
Rwy: Evader Runway
NAV: Evader Nav Mode (1=RNP 0.1, 2=RNP 0.2, 3=RNP 0.3)
Blunder Range: Range from thld when blunder initiated
Edev: Evader crosstrack deviation at ATC response to blunder

27 26L 26R.apf ASAT project input file

EPRT	TCV2D	TCV3D	BlunderStatus	TCV	Rwy	NAV	Blunder Rge	Edev
3.1	0	0	C_Blunders_to_Left	0	0	3	73016.4	-401.3
6.9	0	0	L_Blunders_to_Center	0	1	3	26372.5	789.4
2.5	0	0	C_Blunders_to_Right	0				
2.9	0	0	C_Blunders_to_Right	0				
3.6	0	0	L_Blunders_to_Center	0	1	3	89558.6	-335.8

Appendix H. Memorandum of Agreement

Federal Aviation Administration

MEMORANDUM OF AGREEMENT

between the

Flight Standards Service, Flight Technologies and Procedures Division, AFS-400

and

Area Navigation (RNAV)/Required Navigation Performance (RNP) Group, AJR-37

and

Avionics Certification System Branch, AIR-130

Article I. Purpose: The purpose of this agreement is to document the requirements for the analysis and subsequent criteria development for instrument landing system (ILS)/Microwave Landing System (MLS)/and RNAV(GPS) and RNAV (RNP) Dual Simultaneous dependent and independent approaches and ILS/MLS/and RNAV (GPS) and RNAV (RNP) Triple independent approaches to dual and triple parallel runways. The agreement is between the offices of AFS-400, AIR-130, and AJR-37.

Article II. Roles and Responsibilities: The Flight Operations Simulation and Analysis Branch, AFS-440, will conduct an analysis including the agreed to items listed in the Background paragraph, develop standards and write a technical report documenting analysis findings. Based upon the analysis findings, the Flight Procedure Standards Branch, AFS-420, will then develop instrument approach criteria for ILS/MLS/and RNAV Dual, Triple Simultaneous dependent and independent approaches to dual and triple parallel runways, as appropriate.

Background: The following is a summary of agreements with regard to the subject analysis issues and parameters discussed during our meeting on April 13, 2006.

We agree to the following:

- All RNAV operations considered must be based on Global Positioning System (GPS).
- The performance level studied will be RNAV/GPS where the navigation system error (NSE) will be 100 meters, based on a Gaussian distribution at the 95 percent probability level.

- The primary analysis first order of priority will be to consider Flight Management System (FMS), flight director and/or autopilot equipped aircraft where the greatest capacity and efficiency benefit to the National Airspace System (NAS) may first be realized. However, the need to consider incorporation of panel mounted GPS equipment into the model at some point in the future is acknowledged and will be coordinated at a later date. This panel mounted GPS equipment analysis would account for use of full scale deflection (FSD) in initial and intermediate segments where the FSD is equal to 1 nautical mile (NM) until 2 NM prior to Final Approach Fix (FAF). The FSD is greater in the initial and intermediate segments than in the final approach segment (FAS).
- Performance of barometric vertical navigation (Baro VNAV) may not be as accurate as ILS glide slope, but does not matter as separation is achieved based on lateral performance.
- There should be no need to model implementation of VNAV for the intermediate segment; however, AFS-410/420/430 and AIR-130 need to consider procedure coding, approach selection, and crew procedures for use of these procedures.
- This analysis may require amending United States Standard for Terminal Instrument Procedures (TERPS) as necessary to support inclusion of RNAV/VNAV approaches.

Order of Priority for Flight Standards analysis:

- First priority of analysis is to provide a policy to comply with current standards regarding the addition of RNAV(GPS) approaches to Parallel Dependent and Simultaneous Independent ILS/MLS Approaches - with runway spacing of 4,300 feet or greater for dual parallel approaches and 5,000 feet or greater for triple parallel approaches, as discussed in Federal Aviation Administration (FAA) Order 7110.65, Air Traffic Control, paragraphs 5-9-6 and 5-9-7.
- Second priority of analysis is to provide analysis to support development of a policy to comply with current standards regarding the addition of RNAV/GPS approaches to Parallel Dependent ILS/MLS Approaches with runway spacing greater than 2,500 feet and less than 4,300 feet, as discussed in FAA Order 7110.65, paragraph 5-9-6.
- Third priority of analysis is to provide analysis to support policy to comply with current standards regarding the addition of panel mounted GPS equipment as previously discussed.
- Fourth priority of analysis is to provide analysis to support development of a policy to comply with current standards regarding the addition of RNAV/GPS approaches to Simultaneous Independent Dual ILS/MLS Approaches - High Update Radars (i.e., PRM) at the runway spacing discussed in FAA Order 7110.65, paragraph 5-9-8a.
- Fifth priority of analysis is to provide analysis to support development of a policy to comply with current standards regarding the use of RNAV/GPS approaches during Simultaneous Offset Instrument Approach (SOIA) operations addressed in FAA Order 8260.49A, Simultaneous Offset Instrument Approach (SOIA).
- Sixth priority of analysis will be to provide analysis to support development of acceptable mitigations to support waiver requests to the FAA Order 7110.65 standards.

- Flight Standards analysis used to establish standards and policy may serve as input to future requirements under the FAA Safety Management System Manual.

- Any Air Traffic Organization (ATO) Document Change Proposal (DCP) with regard to this subject will be held in abeyance pending the outcome of these associated analyses.
- All issues and/or requests from the PARC, agency or any other industry group with regard to this subject or RNP/RNAV shall be vetted thru AJR-37.
- In the event of implementation of the requested policy resulting from this analysis, data will be collected for a period of one year to determine the actual tracking performance on the RNAV (GPS) equipped aircraft. This data will be used to validate any operational impacts.

Article III. Amendment: Any change in the provisions of this agreement must be formalized by an appropriate written amendment. This amendment must outline in detail the exact nature of the change.

Article IV. Effective Date: This agreement is effective upon signature of all parties.

Article V. Revocation: Any party may revoke this agreement in writing at any time.

APPROVED:

Bruce DeCleene
Navigation Lead, Avionics Certification System Branch, AIR-130

7/12/06
Date

Jeffrey T. Williams
Manager, RNAV/RNP Group, AJR-37

7/12/06
Date

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

7/12/06
Date

Appendix I

Radar Accuracy Parameters

Table I-1. Sensor Error Sources

		MSSR[1]		ATCRBS "Sliding Window"	
		Short Range	**Long Range**	**Short Range**	**Long Range**
Registration Errors	Location Bias	200 ft. (0.033 nmi.) Uniform in any direction ó = 115 ft. (0.019 nmi.) Note: this term was set to zero in the simulation based on modern survey capabilities.			
	Azimuth Bias	± 0.3º Uniform ó = 0.173º			
Range Errors	Radar Bias	± 30 ft. (0.005 nmi.) Uniform ó = 17 ft. (0.003 nmi.)		±1/32 nmi. Uniform[4] ó = 164 ft. (0.027 nmi)	
	Radar Jitter	25 feet rms Gaussian ó = 25 ft. (0.004 nmi.)		200 feet rms Gaussian[4] ó = 200 ft. (0.084 nmi.)	
Azimuth Error	Azimuth Jitter	Gaussian ó = 0.068º (0.8 ACP)[3]		Gaussian ó = 0.230º (2.6 ACP)[3]	
Data Dissemination Quantization CD format	Range	1/64 nmi. Uniform ó = 27 ft. (0.005 nmi.)	1/16 nmi. Uniform ó = 110 ft. (0.018 nmi.)	1/64 nmi. Uniform ó = 27 ft. (0.005 nmi.)	1/16 nmi. Uniform ó = 110 ft. (0.018 nmi.)
	Azimuth	360º/4096 Uniform ó = 0.025º			
Uncorrelated Sensor Scan Time Error[2]		4-5 sec. Uniform ó = 219 ft. (0.036 nmi.)	10-12 sec. Uniform ó = 536 ft. (0.088 nmi.)	4-5 sec. Uniform ó = 219 ft. (0.036 nmi.)	10-12 sec. Uniform ó = 536 ft. (0.088 nmi.)

[1]Note: MSSR handles both Mode S and ATCRBS transponders in a monopulse fashion.
[2]Note: For independent sensors tracking each aircraft. Same sensor scan time errors are deterministic.
[3]Note: ACP=Azimuth Change Pulse (1/4096 of a scan).
[4]Note: These values are for the primary radar only but were selected to provide a conservative baseline.

Table I-2. Transponder Error Sources

	Mode S	ATCRBS
Range Error	± 125 ft. (0.021 nmi.) Uniform ó = 72 ft. (0.012 nmi.)	± 250 ft. (0.041 nmi.) Uniform ó = 144 ft. (0.024 nmi.)