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Safety Study Report on Simultaneous Parallel Instrument Landing System (ILS) and Area Navigation (RNAV) or Required Navigation Performance (RNP) Approaches – Phases 1B and 2B

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Flight Systems Laboratory
Flight Technologies and Procedures Division
Flight Standards Service

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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 Systems Laboratory (AFS-450) 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. An earlier report addressed dual and triple, independent and dependent approaches by Instrument Landing System (ILS), and RNP(GPS)/RNAV(GPS) aircraft flying with flight director guidance. This report will consider inclusion of aircraft with panel-mounted GPS (TSO-C129a) and Global Positioning System/Wide Area Augmentation System (GPS/WAAS) (TSO-C145b or TSO-C146b) receivers providing basic Course Deviation Indicator (CDI) and, in the WAAS case, Vertical Deviation Indicator (VDI) guidance for dependent and independent simultaneous approaches, TSO-C129a-equipped aircraft without flight director could only participate in dependent operations.

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, surveillance system, pilot, controller, etc.) and performs a Monte Carlo simulation in which all significant parameters are varied according to appropriate probability distributions.

All C145b and C146b certified receivers can operate in “vector to final” (VTF) mode which provides guidance equivalent to or better than ILS in the areas covered by the study. For aircraft not in VTF mode, several of the scenarios tested with independent approaches to both dual runways separated by 4,300 feet and triple runways separated by 5,000 feet did not meet the established test criteria. None of the scenarios for dependent approaches to runways separated by 2,500 feet experienced any separations less than 3,000 feet during the simulation. The study recommends that operational mitigations be developed to ensure that TSO-C146b receivers participating in independent simultaneous approaches to parallel runways will be using vector-to-final mode.

13. Key Words Simultaneous Parallel Approaches, RNAV/RNP, Blunder, WAAS	**14. Distribution Statement** Controlled by AFS-450
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Executive Summary

Federal Aviation Administration (FAA) Order 7110.65R, *Air Traffic Control*, paragraphs 5-9-6 through 5-9-8 contain the current provisions governing air traffic control 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 Operational Evolution Plan (OEP) benchmark airports (Houston-KIAH, Atlanta-KATL, and Pittsburgh-KPIT) to authorize such operations.

The Flight Systems Laboratory (AFS-450) (formerly 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 the Flight Technologies and Procedures Division (AFS-400), the RNAV/RNP Group (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. For convenience, the study was broken into several phases.

Some of the phases have two parts (identified as “A” and “B”). The part “A” studies focus on flight director-guided approaches using appropriate Flight Technical Error (FTE) values. This performance level also should represent a conservative worst case for autopilot performance and is expected to be representative of most air traffic likely to be engaged in simultaneous operations to major airports. A previous report *Safety Study Report on Simultaneous Parallel ILS and RNAV/RNP Approaches–Phases 1A and 2A* [12] addressed part A of Phases 1 and 2. The part “B” studies will address the limited portion of the fleet that will be using panel-mounted GPS receivers or equivalent equipment without flight director. These aircraft may have significantly greater FTEs due to the lack of flight director guidance and a much coarser scale on their instruments outside the Precision Final Approach Fix (PFAF). (Inside the PFAF, the Course Deviation Indicator [CDI] full scale reading is ±0.3 NM or less. At 2 NM outside the PFAF, it is increased to ±1.0 NM.)

There are two principal types of panel-mounted GPS receivers currently available: systems certified under either TSO-C129a or TSO-C146b. Those systems certified under TSO-C129a are un-augmented GPS systems with no vertical capability (independent simultaneous approach operations require vertical guidance). If the C129a system has a Barometric Vertical Navigation System (Baro-VNAV), it falls under AC 90-97, *Use of Barometric Vertical Navigation (VNAV) for Instrument Approach Operations Using Decision Altitude*, and is required to have a flight director to perform approaches with vertical guidance. Systems certified under TSO-C146b, *Stand-Alone Airborne Navigation Equipment Using the Global Positioning System (GPS) Augmented by the Wide Area Augmentation System (WAAS),* provide both lateral and vertical guidance. Inside the PFAF or when in Vector-to-Final (VTF) mode, this guidance should be equivalent to an ILS approach. (ILS equivalence assumes the approach has a valid Final Approach Segment (FAS) data block in the receiver database. This will be discussed in Section 1.4.) However, if not in VTF mode, the CDI sensitivity outside the PFAF is significantly degraded with a corresponding increase in FTE. This report addresses that situation, dual and triple independent and dual dependent approaches by ILS, RNP/RNAV and GPS or WAAS aircraft flying with CDI and VDI (Vertical Deviation Indicator)(WAAS only) guidance. Note that TSO-C145b, *Airborne Navigation Sensors Using the Global Positioning System (GPS) Augmented by the Wide Area Augmentation System (WAAS,)* also covers WAAS navigation systems that are subject to the same issues discussed here but it was assumed that that group of aircraft would also have flight director available. In the event of loss of flight director, a C145b aircraft should be subject to the same issues as the C146b aircraft.

AFS-450'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, surveillance system, 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, RNAV/RNP, and GPS/WAAS aircraft, both with and without flight director, performing simultaneous approach operations to parallel runways at user-defined separations and user-defined staggers.

Analysis of the results of the simulations indicated that, for the assumed performance levels (defined in Section 2.2.6), C146b-equipped aircraft without flight director and not operating in VTF mode were much more likely to experience a test criteria violation (TCV separation less than 500 feet) than ILS-directed aircraft. For small percentages of these aircraft (less than 10%), the overall risk of the operation may still meet the acceptance criteria, but when one of the aircraft in the blunder scenario was a non-flight director-guided aircraft, the TCV rate was well over the acceptance level.

The probability of a TSO-C145b/C146b WAAS-equipped aircraft without flight director flying an LPV or LNAV/VNAV approach at an airport conducting simultaneous operations is expected to be relatively low although difficult to estimate. Aircraft equipped with minimal C146b receiver installations (no flight director) are primarily going to be general aviation types that would be discouraged from participating in simultaneous operations at major airports due to significant speed differentials with most of the traffic.

The study did not consider ATC's interaction with the approaching aircraft. Any aircraft that is significantly off the approach course in a simultaneous approach operation would be directed by ATC to return to the approach track. If it is unable to do so, regardless of the quality of its navigation system, it would probably be removed from the approach stream and handled as a special case.

Based on the simulation, TSO-C145b or C146b-equipped aircraft flying the approach with CDI/VDI guidance in Vector-to-Final mode should be as safe or safer than current operations but aircraft in non-VTF mode should not be mixed with ILS or other RNAV traffic during independent simultaneous approach operations under Airport Surveillance Radar-Model 9 (ASR-9) level surveillance without additional mitigations (such as requiring them to be in VTF mode). The simulations indicate that they can participate in dependent dual operations without significant safety impacts..

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1.0 Introduction

This report presents the results of Phases 1B and 2B of a safety study conducted on simultaneous parallel Instrument Landing System (ILS) and Area Navigation (RNAV) and Required Navigation Performance (RNP) approaches. This phase specifically addresses the inclusion of aircraft using basic Global Positioning System (GPS) and Wide Area Augmentation System (WAAS) standalone equipment that are nominally considered RNAV. The safety evaluation was conducted by the Flight Systems Laboratory (AFS-450) 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

This study assessed the risk for simultaneous dependent and independent parallel approach operations involving mixed operations of ILS-equipped and GPS-equipped RNAV or RNP aircraft with flight director and GPS-equipped RNAV aircraft flying without flight director. Unless specifically stated otherwise, all RNAV or RNP aircraft referred to in this report are assumed to be GPS-equipped per the memorandum of agreement covered in the next section. The study used 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 examined a series of scenarios involving different combinations of ILS aircraft, RNAV or RNP aircraft with GPS and flight director, and RNAV(GPS) aircraft without flight director conducting approaches to various runway configurations. Some of the RNAV(GPS) aircraft without flight director were flying with ILS-like guidance on the final approach. This will be discussed in greater detail in section 1.4.

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 a previous report, *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 details the data collected during the Multiple Parallel Approach Program (MPAP) testing and explains the Probability Distribution Functions (PDFs) developed from that data. Appendix C: Air Traffic Controller Reaction Time Distribution Analysis includes a list of runway and sensor configurations tested and discusses the PDFs developed. Appendix D: Risk Analysis contains relevant excerpts from a previous report [6] deriving the acceptable risk parameters used in the simulation. 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 between the Flight Technologies and Procedures Division, the RNAV/RNP Group, and Avionics Certification Systems Branch is attached as Appendix H: Memorandum of Agreement. Appendix I: Radar Accuracy Parameters contains tables summarizing the principle error components.

1.2 Statement of the Problem

FAA Order 7110.65R, *Air Traffic Control* [4], paragraph 5-9-7 (Simultaneous Independent ILS/MLS [Microwave Landing System] 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). Simultaneous independent operations require a full ILS system for operation, i.e. both localizer and glideslope. To allow inclusion of RNAV aircraft in the mix, this has been interpreted as a requirement for vertical guidance capability, including a calculated descent angle.

These standards were developed in part 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 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 Systems Laboratory (AFS-450) was requested by the RNAV/RNP Group (AJR-37) to conduct a series of studies to determine what combinations of RNAV or RNP simultaneous approach operations could be authorized by ATC.

AFS-450'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 studies 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 dual or independent dual or triple), without the necessity of waivers. The studies may 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 that will be provided as needed:

- Phase 1 provides a study to show that inclusion of RNAV or RNP aircraft using certified GPS 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 or RNP aircraft using certified GPS complies with current standards for parallel dependent approaches, with runway separation less than 4,300 feet but greater than 2,500 feet (as in FAA Order 7110.65R, paragraph 5-9-6).

- Phase 3 provides a study to show that inclusion of RNAV or RNP aircraft using certified GPS 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 or RNP aircraft using certified GPS complies with current standards for Simultaneous Offset Instrument Approaches (SOIAs) 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 Orders 8260.3b, *United States Standard for Terminal Instrument Procedures (TERPS)*, or 7110.65R, *Air Traffic Control*, for inclusion of RNAV approaches into simultaneous operations.

Some of the phases have two parts (identified as "A" and "B"). The part "A" studies focus on flight director-guided approaches using appropriate Flight Technical Error (FTE) values. This performance level should also represent a conservative worst case for autopilot performance and is expected to be representative of most air traffic likely to be engaged in simultaneous operations to major airports. A previous report, *Safety Study Report on Simultaneous Parallel ILS and RNAV/RNP Approaches–Phases 1A and 2A* [12] addressed part "A" of Phases 1 and 2. The part "B" studies will address the small portion of the fleet that will be using panel-mounted GPS receivers or equivalent equipment without flight director. These aircraft may have significantly greater FTEs due to the lack of flight director guidance and a much coarser scale on their instruments outside the Precision Final Approach Fix (PFAF). (Inside the PFAF, the Course Deviation Indicator [CDI] full scale reading is ±0.3 NM or less. At 2 NM outside the PFAF, it may increase to ±1.0 NM unless the aircraft is TSO-C145b or TSO-C146b equipped and in Vector to Final mode, which will be discussed later.)

There are two principal types of panel-mounted GPS receivers currently available: systems certified under either TSO-C129a or TSO-C146b. Those systems certified under TSO-C129a, *Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS)* [17], are un-augmented GPS systems with no GPS-based vertical capability (independent simultaneous approach operations require vertical guidance[1]). If the C129a system has a Barometric Vertical Navigation System (Baro-VNAV), it falls under AC 90-97, *Use of Barometric Vertical Navigation (VNAV) for Instrument Approach Operations Using Decision Altitude* [19], and is required to have a flight director to perform approaches requiring vertical guidance. Systems certified under TSO-C145b, *Airborne Navigation Sensors Using the Global Positioning System (GPS) Augmented by the Wide Area Augmentation System (WAAS)* or TSO-C146b, *Stand-Alone Airborne Navigation Equipment Using the Global Positioning System (GPS) Augmented By the Wide Area Augmentation System (WAAS)* [18] provide both lateral and vertical guidance. Inside the PFAF or when in Vector-to-Final (VTF) mode (which is discussed in greater detail in Section 1.4), this guidance should be equivalent to an ILS approach. (ILS equivalence assumes the approach has a valid Final Approach Segment (FAS) data block in the receiver database. This will also be discussed in Section 1.4.) However, if not in VTF mode, the CDI sensitivity outside

[1] For independent simultaneous parallel ILS approaches, FAA Order 7110.65 requires that both the localizer and glide slope be operational. For RNAV/RNP aircraft that do not use the ILS, this has been interpreted as a requirement for both lateral and vertical guidance.

the PFAF is significantly degraded with a corresponding increase in FTEs. This report addresses that situation, dual and triple independent approaches by ILS or RNP/RNAV with flight director aircraft and WAAS aircraft flying with CDI/VDI (Vertical Deviation Indicator) guidance, as Phase 1B.

For Phase 1B, 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 from either an electronic glideslope or calculated descent angle) to parallel runways, when one of the aircraft deviates from the approach path towards the adjacent traffic.

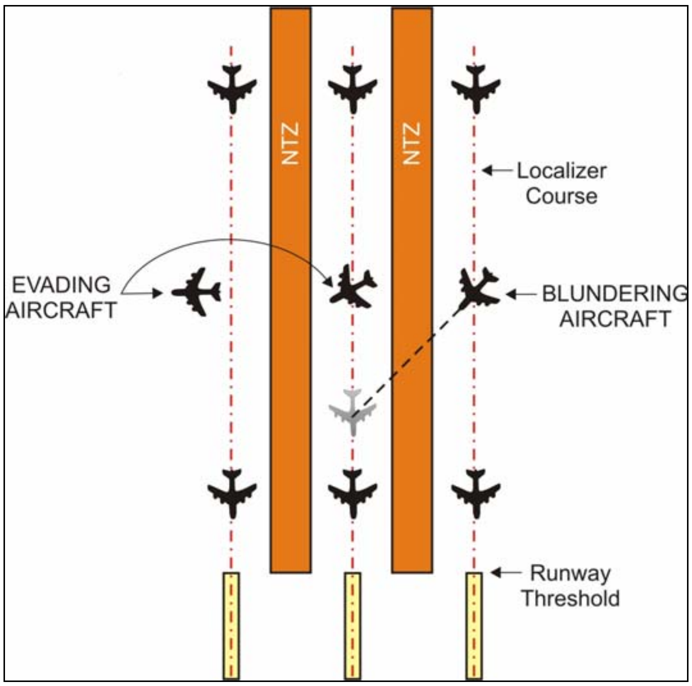

Figure 1: Triple Simultaneous Approach with Blunder

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* [20], 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.

The term "at-risk" implies that if no corrective action is taken, the aircraft's centers of mass 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).

Systems certified under TSO-C129a are considered in the evaluation of dependent parallel approaches in Phase 2B. Their lateral CDI full scale sensitivity is constant at ±0.3 NM from the FAF to threshold and the same as the C146b systems without VTF outside the PFAF. (A PFAF or precise final approach fix is only defined for an approach with a glide path. Non-precision approaches will only have a FAF. FAF's are fixed at a specific point. PFAF's move in and out along the approach course depending on the barometric altitude of the glide slope intercept points.)

With the lateral and longitudinal spacing required for dependent operations, it is very difficult to achieve an at-risk configuration but attempts are made to bring the two aircraft as close together as possible (in the simulation). For dependent operations to dual parallel runways, a single controller may be monitoring both streams.

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. A nuisance breakout occurs when an aircraft penetrates the NTZ, forcing the adjacent aircraft to be broken out of the approach pattern, and then returns to the approach course either on its own or with air traffic direction.

The Target Level of Safety (TLS) for approaches has been determined to be 4×10^{-8} fatal accidents per approach (see Section 3.1 or 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.

1.3 RNAV and 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 for aircraft equipped in accordance with AC 90-100, "U.S. Terminal and En Route Area Navigation (RNAV) Operations." In developing AC 90-100[2], industry partners and the FAA defined the minimum criteria for RNAV systems to operate on the RNAV routes and procedures.

For the purposes of this evaluation, an RNP aircraft is an aircraft with a approved 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 Systems Integrating Multiple Navigation Sensors"; TSO-C129a; or TSO-C145b or C146b. As mentioned previously, GPS must be an active component of the navigation position determination for the procedures evaluated in this study. In addition, RNAV and RNP aircraft approved for independent simultaneous approaches 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.". There must also be processes in place for monitoring Flight Technical Error, either automatically or manually, and making the pilot aware of excessive values. Because the approach operations are under continuous radar surveillance (by multiple controllers in the independent case), 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 to be 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 and RNP fleet, cross-track deviations that previously would have generated immediate attention for an ILS track may become routine. Therefore, in an RNAV and RNP environment, controllers may delay their decision to command an evasion to avoid nuisance breakouts.

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[2] 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).

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/08R and Runway 26R/08L 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 NSE 95% of the time, this is not expected to be an issue.

While TSO-C145b/C146b equipped aircraft are considered part of the RNAV fleet for the purposes of this report, it should be noted that manually flown approaches with CDI/VDI guidance will have ILS-like guidance on final rather than the linear guidance normally associated with most RNAV approaches. This is discussed in more detail in the next section.

1.4 TSO-C129a GPS and TSO-C145/C146b WAAS Receiver Considerations

The FAA bases GPS operations on an assumed constellation of at least 24 satellites continuously broadcasting time, ephemeris, and status messages that are used by a GPS receiver to calculate a position. The current constellation consists of 32 satellites but that number may decrease over time. (With maintenance and other planned outages, the average number of available satellites in the current constellation is about 29-30.) Based on actual collected data, the system typically provides navigation accuracies in the 15 to 20 meter range horizontally and 30 to 50 meter range vertically. A GPS receiver certified under TSO-C129a is a stand-alone panel-mounted unit that normally provides lateral guidance outputs in approach mode that could be provided to the pilot on a CDI. In approach mode, the lateral guidance supports a full scale sensitivity of ±0.3 NM inside the Final Approach Fix (FAF), which is a point normally located about 5 NM from the runway threshold along the approach path. The FAF can be located less than or much further than 5 NM from the threshold. Outside the FAF, the lateral guidance sensitivity degrades linearly to ± 1 NM full scale at 2 NM from the FAF. See Figure 2.

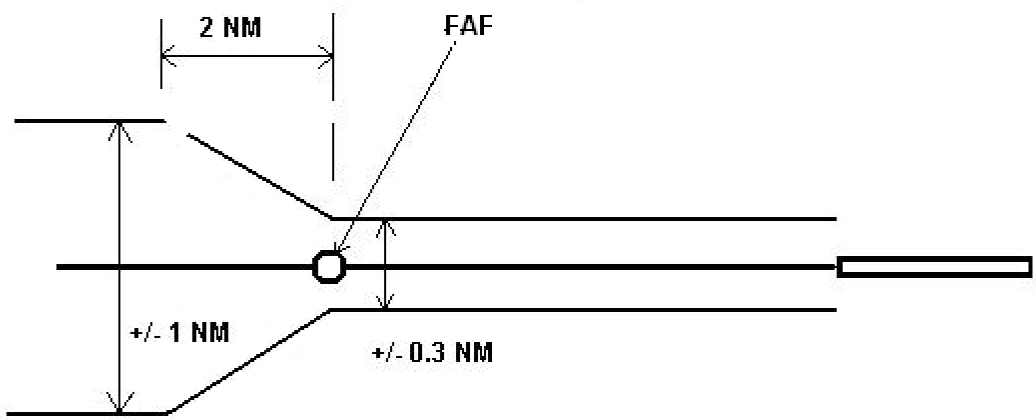

Figure 2: CDI Scaling for TSO-C129a Receiver

The WAAS uses several geo-stationary satellites to broadcast differential corrections and enhanced GPS status messages based on data collected by a ground-based monitoring infrastructure. It typically provides navigation accuracies in the 1 to 4 meter range. A WAAS sensor certified under TSO-C145b or a WAAS receiver certified under TSO-C146b normally provides both lateral and vertical guidance outputs in approach mode that could be provided to the pilot on a Horizontal Situation Indicator. This report generally refers only to C146b systems since most C145b installations will include a flight director.

LPV (Localizer Performance with Vertical Guidance) approaches currently support the lowest minima available for satellite based navigation systems. The approach path for an LPV approach is calculated from the parameters in a Final Approach Segment (FAS) data block stored in the receiver database. LPV approaches have been developed for most of the larger airports in the NAS and several hundred more are being added each year. If a FAS data block is not available for a particular approach, the receiver will revert to TSO-C129a lateral scaling as shown in Figure 2. This report assumes that an LPV FAS data block is available, i.e. an LPV approach is defined for the runways where simultaneous approaches are being performed, and that the receiver generates localizer-like deviations based on that approach path defined by the LPV FAS data.

On an LPV approach, the vertical guidance provided is very similar to that of an ILS glide slope. For LNAV/VNAV operations, the vertical alarm limits are larger and the vertical guidance may be of lower quality but is generally much better than barometric VNAV. In both modes, the lateral guidance is localizer-equivalent inside the PFAF (given that the FAS data block is available.). If the receiver is not in Vector-to-Final (VTF) mode, then outside the PFAF, the lateral guidance sensitivity will degrade linearly to ± 1 NM full scale at 2 NM from the PFAF. See Figure 3. Full scale sensitivity is limited to ± 0.3 NM inside the PFAF. So for long final approach segments (greater than 7 NM), the WAAS track distributions should be tighter than the ILS. For Final Approach Segments less than 7 NM, the convergence from ± 1 NM to the localizer-like angular splay will be variable but only over a fairly small range. The receiver may operate in a Vector-to-Final mode for either LPV or

LNAV/VNAV approaches where the lateral sensitivity remains angular (localizer-like) during the entire approach. See Figure 4. The VTF mode was intended for use when ATC is vectoring the aircraft off of a defined route or procedure to intercept the approach course. Implementation of VTF mode is somewhat manufacturer dependent and in some cases, certain waypoint information may be lost when it is engaged. This could create complications for ATC in certain situations. But use of VTF mode for simultaneous approaches would guarantee that guidance as good as or better than ILS was in use for the entire approach.

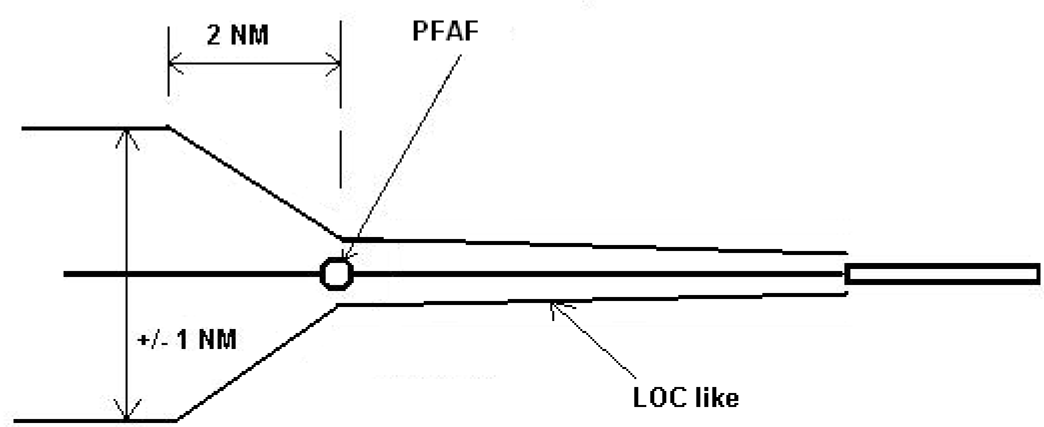

Figure 3: CDI Scaling for TSO-C145b/C146b Receiver in Non-VTF Mode

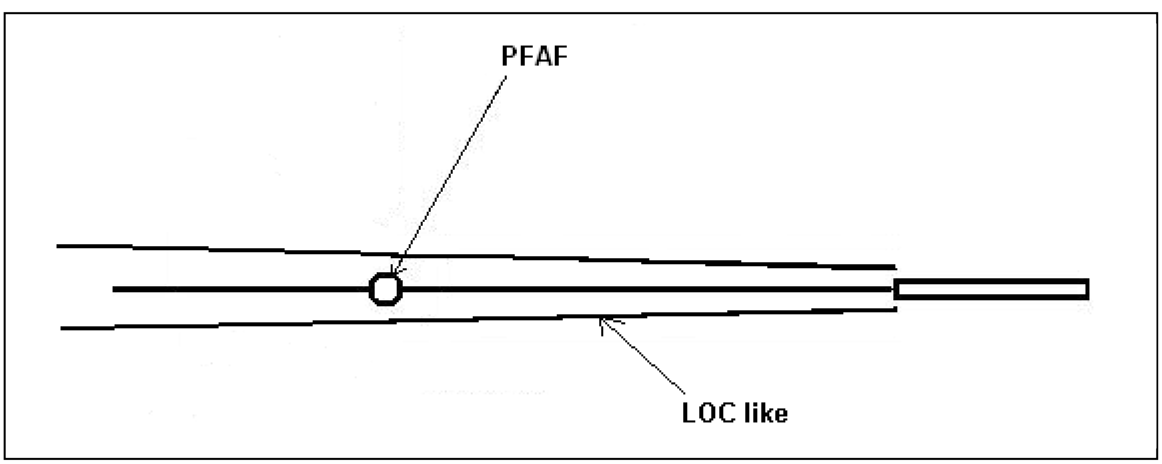

Figure 4: CDI Scaling for TSO-C145b/C146b Receiver in VTF Mode

One of the requirements for simultaneous independent operations (per 7110.65R *Air Traffic Control* [4]) is that the approaches maintain 1,000 feet of vertical separation until the aircraft are established on the approach course. This requires the Glide Path Intercept (GPI) points to be much farther from the threshold than for a single approach. For triple approaches, the GPIs are typically at altitudes of at 3,000; 5,000; and 4,000 feet (MSL) or 4,000; 6,000; and 5,000 feet, depending on airport elevation. (The highest GPI is almost always on the center runway to minimize crossing traffic.) This dictates that the approaching aircraft will be on the approach course 12 to16 NM from the threshold. This is important because it means that an aircraft with a WAAS receiver that is not in VTF mode could be flying a large portion of the approach with a CDI sensitivity of ± 1 NM. With the reduced sensitivity of the CDI, the FTE tends to be larger, which increases the probability that the aircraft will be off course and closer to the blundering aircraft, reducing the time available for performing an evasion.

1.5 Other Considerations

1. Most aircraft with C129a GPS or C146b WAAS receivers and no flight director are expected to be smaller general aviation aircraft. These types of aircraft have significantly slower approach speeds than commercial turbojets and will probably not be frequent participants in multiple simultaneous approach operations. The slower approach speeds also make them less likely to successfully evade a faster blundering aircraft.

2. If the C145b/C146b receiver is in VTF mode, it provides localizer equivalent scaling, leading to greatly reduced FTE. It is not clear at this point what percentage of equipped aircraft would be using VTF mode on the approach. There are flight plan issues since the pilot may no longer have all the procedure waypoints available so that he/she could accept any directions related to those waypoints from ATC) and pilotage issues. Ideally, ATC would not need to distinguish the WAAS aircraft from the other aircraft in the stream.

3. A pilot flying a CDI with ± 1 NM sensitivity is much more likely to enter the NTZ due to excessive FTE, triggering a nuisance breakout. The Practical Test Standards [14] for pilots only require that they remain within three-fourths full scale on their CDI, so they could potentially deviate more than 4,500 feet from course and still believe they were flying acceptably. This could be a serious problem where runways are separated by only 4,300 feet (the minimum separation for independent simultaneous dual approaches). There is a potential for increasing ATC workload due to having to frequently bring those aircraft back to the desired approach track or handling the nuisance breakouts caused by their entry into the NTZ.

2.0 Study Methodology

This 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, RNAV or RNP aircraft with flight director, and RNAV (GPS/WAAS) aircraft without flight director conducting approaches. This report considered only RNAV or RNP aircraft that were GPS-equipped. The primary output of the simulation was the percentage of TCVs (separation less than 500 feet) occurring during each scenario (combination of aircraft types, runway configurations, and fleet mix). Those percentages were compared to the pass/fail requirements mentioned in Section 1.2 and the scenarios were identified as acceptable or not acceptable.

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 5 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. "Heavy", "Large", and "Small" will be defined in the next section.) The Closest Point of Approach (CPA) between the blundering and evading aircraft was 1,276 feet slant range or 1,256 feet, ignoring vertical separation. As shown on the "36L" tab of the ASAT screenshot (in the lower left quadrant), the generic Heavy on Runway 36L was an RNP aircraft with an effective RNP level of 0.07. The derivation of this value is discussed in Section 2.2.6. The other two aircraft were both using the ILS for navigation. This would be seen on the respective tabs for "36C" and "36R".

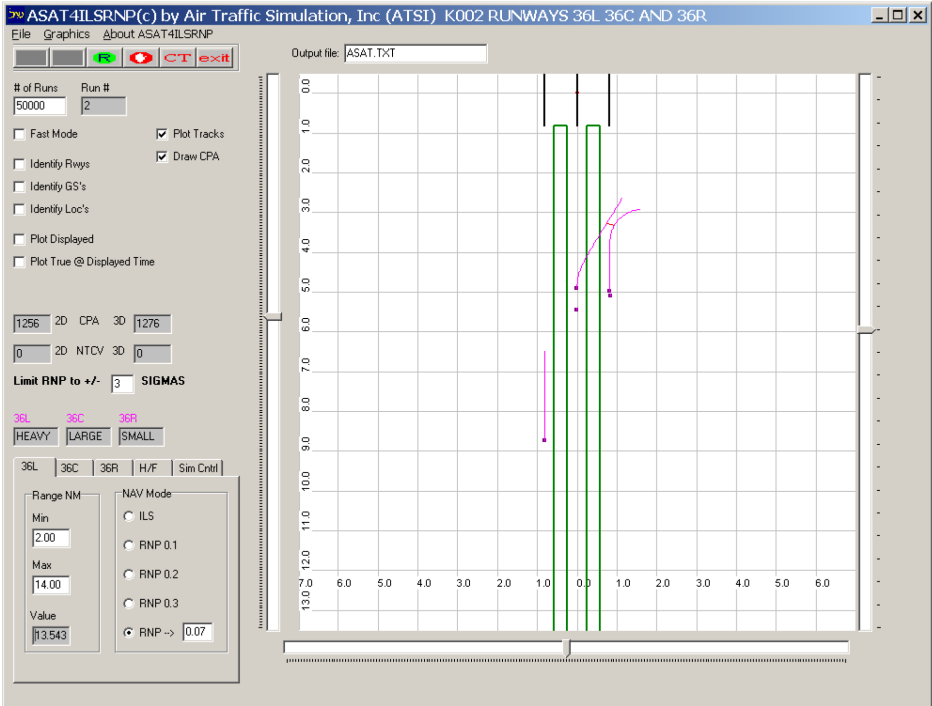

Figure 5: Typical ASAT Run

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 has landed before the blunderer could 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 (see Appendix A). 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 affected where the targets were depicted on the controller's screen and, hence, when it was perceived by the controller as being in or 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 amount of time was greater), 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 CPA.

  For the dependent cases, the simulation operated similarly except there was no NTZ to generate an alert, so no evasion instructions were issued nor was any maneuvering done. The simulation simply ran and reported the CPA experienced.

- 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 two-dimensional and three-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 two runway staggers: 0 and 2,000 feet; and four fleet mixes: 10% Heavies and 10% C146b (note that C146b could also include C145b systems without operative flight directors), 10% Heavies and 20% C146b, 20% Heavies and 10% C146b, and 20% Heavies and 20% C146b. The percentage of C146b aircraft was subtracted from the percentage of Small since that was the class closest to the expected aircraft types with WAAS panel-mounted receivers installed. This kept the ratio of Small to Large to Heavy the same as in the previous Phase 1A/2A study [12]. For the triple and dependent dual configurations, only the four fleet mixes were considered.

Each scenario was performed 100,000 times so that all reasonable combinations of aircraft types, performance parameters, radar update times, and pilot and controller response times were considered. For the dependent scenarios, the C146b aircraft were replaced by C129a aircraft since there was no requirement for vertical guidance on the dependent approaches and the basic GPS aircraft were a slightly more conservative fleet component than the WAAS-equipped aircraft.

Table 1: Navigation System/Runway Configurations*

TEST SCENARIO RUNWAY CONFIGURATIONS					
Phase	**Rwy Sep**	**Comments**	**Rwy 36L**	**Rwy 36C**	**Rwy 36R**
			DUALS		
1B	4,300	Baseline	ILS	ILS	N/A
1B	4,300		ILS	RNAV/C146b	N/A
1B	4,300		RNAV/C146b	RNAV/C146b	N/A
			TRIPLES		
1B	5,000	Baseline	ILS	ILS	ILS
1B	5,000		ILS	RNAV/C146b	ILS
1B	5,000		ILS	ILS	RNAV/C146b
1B	5,000		ILS	RNAV/C146b	RNAV/C146b
1B	5,000		RNAV/C146b	RNAV/C146b	RNAV/C146b
			DUALS		
2B	2,500	Dependent, Baseline	ILS	ILS	N/A
2B	2,500	Dependent	ILS	RNAV/C129a	N/A
2B	2,500	Dependent	RNAV/C129a	RNAV/C129a	N/A

*ILS=ILS/MLS; RNAV=RNAV or RNP with GPS; C129a or C146b=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 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.

This report uses class definitions partly based on weight classes 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 class that includes the heavier parts of the Small and the lighter parts of the Large classes 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 FAA Order 7110.65 *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 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 class 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.

This study also created two additional classes that were defined as C129a and C146b. These aircraft had the same performance parameters as the Small class but caused the simulation to use the appropriate track dispersion distributions based on the expected FTE.

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

2.2.3 Environmental Conditions

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

2.2.4 Pilot Response Times

The pilot response time was defined as 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 was defined as 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 encompassed a range of surveillance systems, displays, and runway spacings and collected response times for each. Appendix C lists 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. The baseline 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 the simulation begins, this phase of flight is very short, even for the evading aircraft.

For the RNAV/RNP aircraft with flight director considered for the earlier 1A/2A 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 observed GPS NSEs 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. This data was collected during the FAA Microwave Landing System testing of the mid-1980's [22], the Air Force GPS testing of the early 1990's [16], and a variety of other flight test programs [22] conducted by Flight Standards and the FAA Technical Center. 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 the 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 gave a 2σ, approximately 95%, value of 80 meters. Root-sum-squaring the NSE and FTE values translated to a lateral TSE of 0.07 NM 95% for flight director-guided RNAV/RNP approaches using GPS. Vertical navigation was based on typical glide path deviations around a glide slope whose ground point of intercept (GPI) was shifted due to the same Gaussian distribution. The aircraft then navigated along the adjusted path to the runway.

Appropriate values for the FTE of RNAV aircraft with panel-mounted GPS receivers driving a CDI were determined from existing test data, conversations with experienced pilots, and consideration of the *Instrument Rating Practical Test Standards for Aircraft, Helicopter, and Powered Lift* [14] for general aviation pilots. The Practical Test Standards were considered a minimal skills baseline for private pilots likely to be operating at large airports conducting simultaneous operations. For the part of the approach where the CDI sensitivity was lowest (±1.0 NM full scale), test data from previous GPS flight testing programs [15, 16] supported standard deviations on the order of 500 to 750 feet (approximately 155 to 230 meters). At the other end of the performance spectrum, the Practical Test Standards only required that a pilot on a precision approach stay within three-fourths of full scale on the CDI. Assuming that represented about a 3σ value, the standard deviation would be 1,519 feet (463 meters). Because runways separated by 4,300 feet only have a NOZ 1,150 feet wide, the latter case would translate to about 30% of the traffic being in the NTZ, resulting in an unacceptable number of nuisance breakouts.

Experienced general aviation pilots indicated that a more appropriate value would be somewhere between the two values. For this evaluation, a standard deviation of 1,012 feet was selected. This value was determined by using half-scale rather than three-fourths scale for the 3σ value. This value would also have resulted in an unacceptable number of nuisance breakouts (approximately 20%) but should have been an upper bound for general aviation pilots on precision approach to a busy airport.

The simulation used the same vertical navigation distributions for the C146b aircraft that were used for the ILS. This is consistent with data collected during the WAAS flight testing program.

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

RNAV aircraft that rely on DME (Distance Measuring Equipment)/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

[10] and the William J. Hughes Technical Center. Tables summarizing the principle error components are 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/WAAS aircraft across the runways, the runway separation and threshold stagger, and the fleet mix. One hundred thousand runs were performed for each scenario.

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 50,000 runs had the left aircraft blundering right and 50,000 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 50,000 interactions between the right and center runways and 50,000 interactions between the left and center.

The footnote on each table explains the terminology used, but in general, 'ILS' indicates that the aircraft landing on that runway are flying conventional precision approaches and 'RNAV' indicates that aircraft landing on that runway are flying either an RNP/RNAV approach (with vertical guidance) or a TSO-C145b/146b WAAS approach with calculated descent angle (and no flight director) for the 1B scenarios or a TSO-C129a RNAV(GPS) approach for the 2B scenarios. Lateral and vertical track distributions are based upon the navigation system being used as discussed in section 2.2.6.

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

Scenario #	Stagger	% Heavies	Display	36L Nav	36C Nav	36R Nav
1B	0	10	DEDS	ILS		ILS
2B	0	10	DEDS	ILS		RNAV
3B	0	10	DEDS	RNAV		RNAV
4B	0	20	DEDS	ILS		ILS
5B	0	20	DEDS	ILS		RNAV
6B	0	20	DEDS	RNAV		RNAV
10B	0	10	FMA	ILS		ILS
11B	0	10	FMA	ILS		RNAV
12B	0	10	FMA	RNAV		RNAV
13B	0	20	FMA	ILS		ILS
14B	0	20	FMA	ILS		RNAV
15B	0	20	FMA	RNAV		RNAV
19B	2,000	10	DEDS	ILS		ILS
20B	2,000	10	DEDS	ILS		RNAV
21B	2,000	10	DEDS	RNAV		RNAV
22B	2,000	20	DEDS	ILS		ILS
23B	2,000	20	DEDS	ILS		RNAV
24B	2,000	20	DEDS	RNAV		RNAV

Independent 5,000-Foot Triples

Scenario #	Stagger	% Heavies	Display	36L Nav	36C Nav	36R Nav
41B	0	10	DEDS	ILS	ILS	ILS
42B	0	10	DEDS	ILS	RNAV	ILS
43B	0	10	DEDS	ILS	ILS	RNAV
44B	0	10	DEDS	ILS	RNAV	RNAV
45B	0	10	DEDS	RNAV	RNAV	RNAV
46B	0	20	DEDS	ILS	ILS	ILS
47B	0	20	DEDS	ILS	RNAV	ILS
48B	0	20	DEDS	ILS	ILS	RNAV
49B	0	20	DEDS	ILS	RNAV	RNAV
50B	0	20	DEDS	RNAV	RNAV	RNAV

*ILS indicates a conventional precision approach; RNAV, an RNAV or RNP with GPS approach including those approaches flown by the WAAS-equipped aircraft

Table 2: Test Scenarios* (continued)

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

Scenario #	Stagger	% Heavies	Display	36L Nav	36C Nav	36R Nav
61B	0	10	DEDS	ILS		ILS
62B	0	10	DEDS	ILS		RNAV
63B	0	10	DEDS	RNAV		RNAV
64B	0	20	DEDS	ILS		ILS
65B	0	20	DEDS	ILS		RNAV
66B	0	20	DEDS	RNAV		RNAV

*ILS indicates a conventional precision approach; RNAV, an RNAV or RNP with GPS approach including those approaches flown by the C129a-equipped aircraft

When the blunderer in a triple runway configuration is on one of the outer runways, there is a potential for a secondary TCV between the evader on the center runway and the evader on the far outer runway. This case was 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 outer 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 defines the acceptability of the results for operational implementation and examines the results of the simulation.

3.1 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 TLS for midair collisions on simultaneous parallel approaches is 4×10^{-8}, or:

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

The MPAP test team adopted a method for determining a simulation's maximum acceptable Test Criteria Violation (TCV – Center of Mass separation less than 500 feet) rate from 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 TLS, 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% for dual approaches.

The MPAP test team also determined that the criterion for triple approaches is 5.1%. 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 TLS, 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 TLS. 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].

3.2 Summary of the TCV Probability Analysis

Table 3, Table 4, and Table 5 list the resultant TCV counts, number of runs for each scenario, and the associated TCV rate for each scenario. (A TCV or test criteria violation occurs when the aircraft's centers of mass come within 500 feet of each other.) The independent dual and triple parallel runway and dependent dual parallel runway results are discussed in separate sections. Note that throughout the following sections, references to TSO-C146b systems also include TSO-C145b systems operating without flight director.

The terminology in Tables 3-5 is the same as in Table 2: 'ILS' indicates that the aircraft landing on that runway are flying conventional precision approaches and 'RNAV' indicates that aircraft landing on that runway are flying either an RNP/RNAV approach (with vertical guidance) or a TSO-C145b/146b WAAS approach with calculated descent angle (and no flight director) for the 1B scenarios or a TSO-C129a RNAV(GPS) approach for the 2B scenarios. The 'Nav Config' column is the arrangement of approach types by runway. "ILS/RNAV" indicates a dual approach with one runway being a conventional ILS and the other an 'RNAV' as defined earlier in the paragraph. "RNAV/RNAV/RNAV" indicates a triple approach with all three using 'RNAV'.

3.2.1 Independent 4,300-Foot Dual Parallel Runway Scenarios

Table 3 shows the resultant TCV rates for the simulations of the independent simultaneous dual approaches to runways separated by 4,300 feet. The scenario numbers allow comparison with the 1A/2A report cases. The ".1" and ".2" notation are used to represent the 10% and 20% C146b or C129a cases, respectively. Note that the baseline scenarios for these runs are slightly larger than in the Phase 1A/2A report [12] due to some minor changes to the pilot reaction time distribution which were made to reflect additional data.

Table 3 shows that several scenarios for the 4,300-foot runway separation cases did not meet the TCV (CG separation less than 500 feet) rate criteria (<6.8%) when C146b-equipped aircraft in non-VTF mode were involved. Those TCV rates are highlighted in red. A more detailed examination of the C146b runs showed that approximately 90% of the TCVs involving C146b aircraft were more than 7 NM from threshold (where the CDI sensitivity was ± 1.0 NM). Considering the ranges at which blunders were allowed, the expected value should have been less than 60%. The examination also showed that the TCVs were significantly more likely if the C146b aircraft was the evader. The larger cross-track error (due to the reduced guidance sensitivity) 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. As noted earlier, many of the C146b aircraft penetrated the NTZ and would have caused nuisance breakouts.

Data from the staggered runway scenarios showed a decrease in TCV rate. This was expected based on the Phase 1A study [12]. With a runway stagger, the evader starts out with some vertical separation and thus requires less time to accomplish a successful evasion.

Adding proportionally more Heavy aircraft caused 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 (this impacts the rate of successful evasions).

No special scenarios were developed to model the C146b aircraft flying in Vector-to-Final mode. As stated earlier, the guidance and navigation system error provided in that mode is equal or superior to the ILS, so the baseline ILS/ILS cases should represent an upper bound on the risks for approaches involving those aircraft.

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

Scenario #	Stagger	%Heavies	Display	Nav Config	%C146b	#Runs	%TCV
1B	0	10	DEDS	ILS/ILS	0	100,000	5.095
2B.1	0	10	DEDS	ILS/RNAV	10	100,000	6.203
3B.1	0	10	DEDS	RNAV/RNAV	10	100,000	7.267
2B.2	0	10	DEDS	ILS/RNAV	20	100,000	7.276
3B.2	0	10	DEDS	RNAV/RNAV	20	100,000	9.246
4B	0	20	DEDS	ILS/ILS	0	100,000	5.731
5B.1	0	20	DEDS	ILS/RNAV	10	100,000	6.802
6B.1	0	20	DEDS	RNAV/RNAV	10	100,000	7.952
5B.2	0	20	DEDS	ILS/RNAV	20	100,000	7.370
6B.2	0	20	DEDS	RNAV/RNAV	20	100,000	9.154
10B	0	10	FMA	ILS/ILS	0	100,000	3.105
11B.1	0	10	FMA	ILS/RNAV	10	100,000	3.992
12B.1	0	10	FMA	RNAV/RNAV	10	100,000	4.633
11B.2	0	10	FMA	ILS/RNAV	20	100,000	4.508
12B.2	0	10	FMA	RNAV/RNAV	20	100,000	5.704
13B	0	20	FMA	ILS/ILS	0	100,000	3.551
14B.1	0	20	FMA	ILS/RNAV	10	100,000	4.361
15B.1	0	20	FMA	RNAV/RNAV	10	100,000	5.104
14B.2	0	20	FMA	ILS/RNAV	20	100,000	4.861
15B.2	0	20	FMA	RNAV/RNAV	20	100,000	6.029
19B	2,000	10	DEDS	ILS/ILS	0	100,000	4.697
20B.1	2,000	10	DEDS	ILS/RNAV	10	200,000	5.954
21B.1	2,000	10	DEDS	RNAV/RNAV	10	100,000	6.757
20B.2	2,000	10	DEDS	ILS/RNAV	20	200,000	6.590
21B.2	2,000	10	DEDS	RNAV/RNAV	20	100,000	7.829
22B	2,000	20	DEDS	ILS/ILS	0	100,000	5.276
23B.1	2,000	20	DEDS	ILS/RNAV	10	200,000	6.422
24B.1	2,000	20	DEDS	RNAV/RNAV	10	100,000	7.468
23B.2	2,000	20	DEDS	ILS/RNAV	20	100,000	7.008
24B.2	2,000	30	DEDS	RNAV/RNAV	20	100,000	8.702

The baseline system for the modeling and 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" 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 performed with no "Small" classes and a higher percentage of Heavies, and the resultant TCV rate was not acceptable.)

3.2.2 Independent 5,000-Foot Triple Parallel Runway Scenarios

Table 4 shows that several of the scenarios for the 5,000-foot separation case for independent simultaneous triple approaches did not meet the acceptable TCV rate criteria for triples defined above (5.1% - these scenarios are highlighted in red.) All the scenarios that failed involved RNAV traffic to two adjacent runways and there were a disproportionate number of C146b aircraft outside 7 NM in the TCV list. TCVs between the two embedded duals are included in Table 4. All the embedded duals met the established safety criteria (TCV rate < 6.8%). The potential mitigation (using FMA's) discussed in the previous section is equally valid here, but otherwise, 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 have been seen if only 5,000-foot duals were examined as explained in Section 2.3.

Table 4: Independent 5,000-Foot Triple Parallel Runway TCVs

				Left/Center			Center/Right			Total	
Scenario #	Nav Config	%C146b	%Heavies	TCVs	#Runs	%TCV	TCVs	#Runs	%TCV	#Runs	%TCV
41B	ILS/ILS/ILS	0	10	1,763	49,911	3.532	1,808	50,029	3.614	100,000	3.571
42B.1	ILS/RNAV/ILS	10	10	2,144	50,016	4.287	2,183	49,984	4.367	100,000	4.327
43B.1	ILS/ILS/RNAV	10	10	1,806	49,920	3.618	2,225	50,080	4.443	100,000	4.031
44B.1	ILS/RNAV/RNAV	10	10	2,051	50,125	4.092	2,493	49,875	4.998	100,000	4.544
45B.1	RNAV/RNAV/RNAV	10	10	2,530	50,138	5.046	2,527	49,862	5.068	100,000	5.057
42B.2	ILS/RNAV/ILS	20	10	2,279	50,091	4.550	2,437	49,909	4.883	100,000	4.716
43B.2	ILS/ILS/RNAV	20	10	1,792	50,085	3.578	2,462	49,915	4.932	100,000	4.254
44B.2	ILS/RNAV/RNAV	20	10	2,360	50,060	4.714	2,945	49,940	5.897	100,000	5.305
45B.2	RNAV/RNAV/RNAV	20	10	2,914	50,159	5.810	3,002	49,841	6.023	100,000	5.916
46B	ILS/ILS/ILS	0	20	2,008	50,009	4.015	1,995	49,991	3.991	100,000	4.003
47B.1	ILS/RNAV/ILS	10	20	2,281	50,421	4.524	2,327	49,579	4.694	100,000	4.608
48B.1	ILS/ILS/RNAV	10	20	1,927	49,838	3.867	2,383	50,162	4.751	100,000	4.310
49B.1	ILS/RNAV/RNAV	10	20	2,277	49,827	4.570	2,760	50,173	5.501	100,000	5.037
50B.1	RNAV/RNAV/RNAV	10	20	2,644	50,035	5.284	2,715	49,965	5.434	100,000	5.359
47B.2	ILS/RNAV/ILS	20	20	2,550	50,024	5.098	2,599	49,976	5.200	100,000	5.149
48B.2	ILS/ILS/RNAV	20	20	2,037	50,099	4.066	2,623	49,901	5.256	100,000	4.660
49B.2	ILS/RNAV/RNAV	20	20	2,549	49,991	5.099	3,097	50,009	6.193	100,000	5.646
50B.2	RNAV/RNAV/RNAV	20	20	3,051	50,281	6.068	3,101	49,719	6.237	100,000	6.152

3.2.3 Dependent 2,500-Foot Dual Parallel Runway Scenarios

For the dependent case, the different scenarios were examined without a controller-directed evasion maneuver. Normal ATC procedure would be to not initiate an evasion maneuver since the dependent spacing requirements were developed to eliminate the possibility of collision. Table 5 shows that the dependent case scenarios produced no TCVs. The table also lists the CPA for each of the scenarios.

While wake turbulence considerations were not part of this study, a small test case was run using the ASAT wake modeling capabilities. With 2,500-foot runway separations and track dispersions as described above for the trailing aircraft, wake encounters did occur at a rate between 2% and 5%.

Table 5: Dependent 2,500-Foot Dual Parallel Runway TCVs

Scenario #	%C146b	%Heavies	Nav Config	TCVs	CPA
61B	0	10	ILS/ILS	0	4,110
62B.1	10	10	ILS/RNAV	0	3,380
63B.1	10	10	RNAV/RNAV	0	3,860
62B.2	20	10	ILS/RNAV	0	3,550
63B.2	20	10	RNAV/RNAV	0	3,340
64B	0	20	ILS/ILS	0	4,220
65B.1	10	20	ILS/RNAV	0	3,370
66B.1	10	20	RNAV/RNAV	0	3,770
65B.2	20	20	ILS/RNAV	0	3,600
66B.2	20	20	RNAV/RNAV	0	3,050

The TCV rate driven pass/fail criteria for the independent operations is not strictly applicable here but since the minimum separation in 500,000 runs was 3,050 feet and considering the distribution shapes shown in the Phase 1A/2A report [12], it is reasonable to assume the safety level for the operation is acceptable.

4.0 Results and 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* [4], paragraphs 5-9-6 through 5-9-7. In particular, this study examined the inclusion of aircraft using GPS or GPS/WAAS sensors/receivers per TSO-C129a or TSO-C145b/C146b, respectively, flying without flight director. The study assumed that for C145b/C146b operations, the receiver database included an LPV Final Approach Segment data block for the runway involved, i.e. an LPV approach was available.

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, GPS-equipped RNAV/RNP with flight director and GPS C129a/WAAS C145b/C146b without flight director traffic. Scenarios involving WAAS systems assumed the receiver was not in VTF mode since receivers operating in VTF mode would have guidance equivalent to or better than ILS. Fleet mix is discussed in Appendix A. 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 FTEs determined from consideration of flight test data, experienced pilot opinions, and testing standards for general aviation pilots. It was assumed that the integrity, availability, and continuity functions inherent in RNP were covered for RNAV aircraft by the required ATC surveillance and by the other conservative assumptions.

4.1 Independent 4,300-Foot Dual Parallel Runways

The simulations suggest that aircraft operating with CDIs with ± 1.0 NM sensitivity (and no flight director) should not take part in independent simultaneous approach operations to runways separated by 4,300 feet (i.e., the minimum separation allowed by FAA Order 7110.65R *Air Traffic Control* [4]). Separations greater than 4,300 feet are addressed in Section 4.4. Aircraft with TSO-C145b/C146b WAAS sensors/receivers in non-VTF mode without flight director are currently the most likely members of this category. However, given the other capabilities of those receivers, some mitigation should be achievable, the simplest of which would just be to require participants so equipped to be in VTF mode for the approach. If the WAAS receiver is in VTF mode (or if the PFAF is moved out to the expected glide slope intercept point), the guidance provided will be equivalent to or better than a typical ILS and the safety criteria would be expected to be met. Consideration should be given to methods to assure that the WAAS receiver on approaching aircraft is in the VTF mode for the duration of the approach where altitude separation is not guaranteed.

4.2 Independent 5,000-Foot Triples

Several of the scenarios for C145b/C146b aircraft with WAAS receivers that were not operating in Vector-to-Final mode did not achieve the acceptable TCV rate (5.1%) and thus failed the test criteria. All of the unacceptable scenarios involved two or more runways with RNAV approaches and a disproportionate number of the TCVs involved the C145b/C146b-equipped aircraft at ranges greater than 7 NM from threshold (where the CDI sensitivity is ± 1 NM when not in vector-to-final mode). The same mitigations discussed in the previous paragraph should resolve this issue.

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 produced no TCVs and maintained more than 3,000 feet separation. However, wake turbulence issues may need to be further evaluated.

4.4 Conclusions

When the simulation examined C145b/C146b aircraft with WAAS receivers that were not operating in Vector-to-Final mode, several of the scenarios tested with independent approaches to both dual runways separated by 4,300 feet and triple runways separated by 5,000 feet did not pass the test criteria. Possible solutions to the problem include:

1. Develop an operational requirement for the C145b/C146b receivers to be in VTF mode when doing simultaneous approach operations. This could be accomplished by additional notes on the approach plate or something similar. This should be the best and simplest solution since many of the approaches will normally be flown in VTF mode.

2. Exclude TSO-C145b/C146b aircraft without flight director from these approaches. This might be the easiest solution but, given that the receiver is easily capable of flying the approach to ILS standards, it is probably not the best option.

   An alternative is to allow WAAS aircraft in the mix only to parallel runways separated by more than 4,300 feet. At 5,000 feet separation, the embedded duals in the triples scenarios met the safety criteria if one of the aircraft was on ILS guidance. But even at 5,000 feet separation, the expected frequency of nuisance alerts may be too high for a successful operation. Five thousand feet separation was still insufficient if both aircraft were C145b/C146b-equipped. Additional studies would need to be done to determine appropriate separations if this option is selected.

3. Move the PFAF out to the GPI when conducting simultaneous operations. This would force the C145b/C146b receiver into pseudo-ILS guidance mode, providing either ± 0.3 NM full scale CDI sensitivity or localizer equivalent angular sensitivity, whichever was tighter. The safety issues would be resolved. This solution would, however, involve redesigning approach plates, databases, etc. for every runway used for simultaneous operations in the NAS.

None of the scenarios for dependent approaches to runways separated by 2,500 feet experienced any TCVs and all of them maintained at least 3,000 feet separation during the simulations. It is reasonable to assume that inclusion of C129a/C145b/C146b-equipped aircraft is acceptable with regard to loss of separation considerations. Wake turbulence issues may need to be reconsidered (but not when a C145b/C146b aircraft is in VTF mode.)

Appendix A: Aircraft Mix and Performance Modeling

One of the ASAT initiation files contained a section where the number of each type of aircraft was given. It automatically set the frequency of occurrence for each aircraft type during the simulation. For this generic study, four fleet mixes were considered containing different percentages of Heavy and C129a/C145b/C146b aircraft: 10% and 10%, 10% and 20%, 20% and 10%, and 20% and 20%. The C129a/C145b/C146b aircraft were assumed to be Small and the percentage was just subtracted from the Small aircraft total. The percentages are shown in the table below. It is important to note that when a C129a/C145b/C146b aircraft was picked for a runway where the navigation system was set to ILS, it performed as an ILS approach, not an RNAV.

Table A-1: Fleet Mix Percentages Used in Simulations

ASAT Class	% in 10% mix		% in 20% mix	
C146b-C129a	10	20	10	20
Small	40	30	35	25
Large	40		35	
Heavy	10		20	

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 class 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 represented 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 nine of 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	Runways	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

Airport	2005			2006		
	% 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 separated by 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 was 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 shown in Table B-1. (Johnson distributions are discussed in Appendix E.)

Table B-1: Johnson S_L Distribution Parameters

Parameter	Value
Type	S_L
Delta	3.0
Gamma	0.0
Lambda	7.2
Xi	0.9
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.

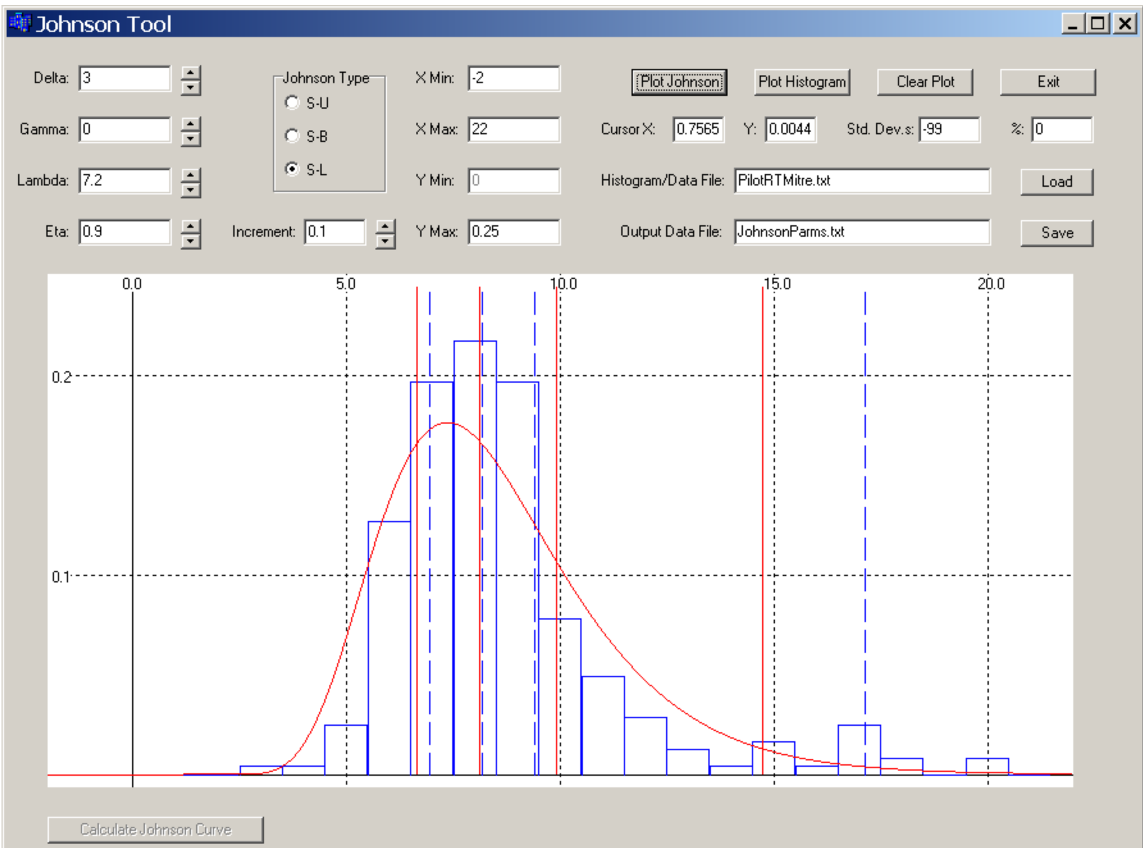

Figure B-1: Pilot Response Times Distribution

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 facilitiesworking 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.

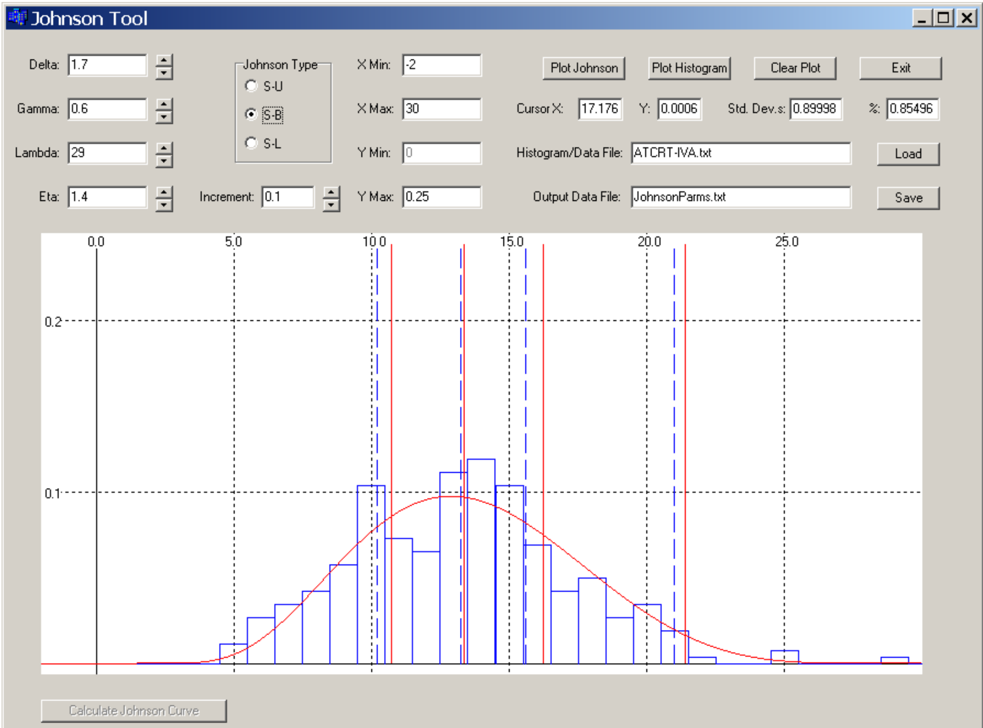

Figure C-1: ATC Response Time Distribution for 4,300-Foot Duals

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 degrees 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.

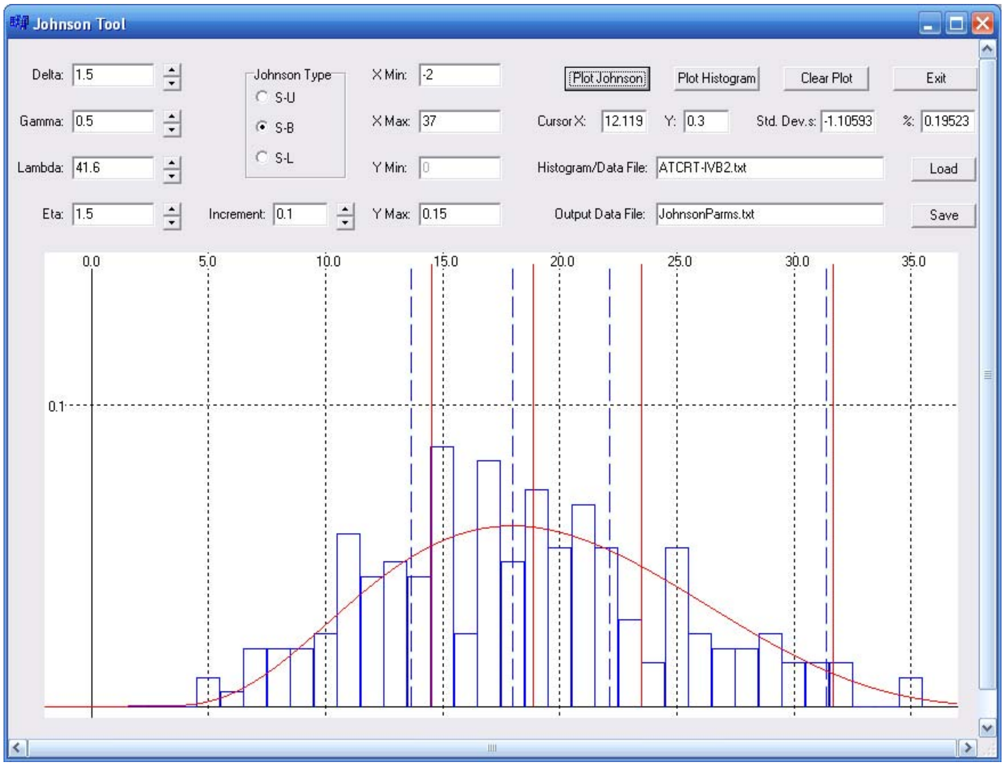

Figure C-2: ATC Response Time Distribution for 5,000-Foot Triples

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	No available documentation
Dual	15	6/6-6/17 1994	National Standards	3,000	FMA	E-Scan 1.0s	1º Localizer Offset	Not approved	No available documentation
Dual	16	7/11-7/22 1994	National Standards	3,000	FMA	E-Scan 1.0s	2.5º Localizer Offset		Published Report (DOT/FAA/CT-96/2)
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 available documentation
Dual and Triple (VA)	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	No available documentation
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

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
Triple	11	3/2-3/13 1992	Human Factors Study	3,400	FMA	E-Scan 1.0s	1 Mr Radar Accuracy	No recommendation	No available documentation
Triple	14	11/16-11/20 1992				ASR-9 4.8s	Field Elevation 5,431 ft	Not approved	Published Report (DOT/FAA/CT-94-36)
		11/30-12/17 1992	(DEN)	5,280	FMA			Approved	
Triple	17	8/14-8/25 1995	National Standards	4,000 5,300	FMA	E-Scan 1.0s		Not approved	Published Report (DOT/FAA/CT-TN02/16) Appendix
Triple	19	4/15-4/26 1996	National Standards	4,000 5,300	FMA	E-Scan 1.0s		Approved	No available 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:

$$P(\text{Accident}) = P(\text{TCV and At-risk and WCB and Blunder}) \times 2 \qquad \text{(D1)}$$

or

$$\begin{aligned} P(\text{Accident}) = {} & P(\text{TCV}|\text{At-risk and WCB and Blunder}) \times \\ & P(\text{At-risk}|\text{WCB and Blunder}) \times \\ & P(\text{WCB}|\text{Blunder}) \times \\ & P(\text{Blunder}) \times 2 \end{aligned} \qquad \text{(D2)}$$

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-degree blunder per 1,000 dual approach pairs or 1 30-degree blunder per 2,000 approaches. This is a conservative value that the MPAP researchers derived from the risk analysis conducted during the PRM demonstration program. Until a blunder rate estimate can be derived from field data of actual blunder occurrences or other evidence suggests using a different value, the TWG has agreed to use 1/1,000 30-degree blunders per dual approach pair. Researchers can show the rate for triple approaches to be 1/1,500 30-degree blunders per triple approach trio. (For two runways, there are four possible 30-degree blunders, only two of which place the other traffic at risk. For three runways, there are six possible 30-degree blunders, four 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 two. So P(Blunder-Dual) = 1 30° Blunder / 1,000 dual approaches × 1 dual approach / 2 approaches = 1 / 2,000 30° Blunder / approach and P(Blunder-Triple) = 2 30° Blunder / 1,000 triple approaches × 1 triple approach / 3 approaches = 1 / 1,500 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 Level of Safety 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:

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

or,

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

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

Substituting values from (D2) into (D3):

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

$$\frac{4 \times 10^{-8}}{1} \times \frac{17}{1} \times \frac{100}{1} \times \frac{1{,}500}{1} \times \frac{1}{2} = 5.1\%$$

Thus, if the simulation results support the assertion that the probability of a TCV, given that an at-risk WCB occurs (P(TCV|At-risk and WCB and Blunder)), is less than 5.1%, then the simultaneous approach procedure simulated should have an acceptable accident rate. For the embedded duals, the factor 1,500 was replaced by 2,000 and the allowable percentage became 6.8%.

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:

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

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:

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

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:

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

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.

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:

$$f_1(x) = \frac{\delta}{(x-\varepsilon)\sqrt{2\pi}} \exp\left\{-\frac{1}{2}\left[\gamma + \delta \ln\left(\frac{x-\varepsilon}{\lambda}\right)\right]^2\right\}, \ x \geq \varepsilon, \qquad \text{(E7)}$$
$$\delta > 0, -\infty < \gamma < \infty, \lambda > 0, -\infty < \varepsilon < \infty.$$

2. The Probability Density Function of a member of the Johnson S_B family has the following form:

$$f_2(x) = \frac{\delta\lambda}{(x-\varepsilon)(\lambda - x + \varepsilon)\sqrt{2\pi}} \exp\left\{-\frac{1}{2}\left[\gamma + \delta \ln\left(\frac{x-\varepsilon}{\lambda - x + \varepsilon}\right)\right]^2\right\}, \qquad \text{(E8)}$$
$$\varepsilon < x < \varepsilon + \lambda, \delta > 0, -\infty < \gamma < \infty, \lambda > 0, -\infty < \varepsilon < \infty.$$

3. The Probability Density Function of a member of the Johnson S_U family has the following form:

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

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

Sampling From a Johnson Curve

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

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

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

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

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:\ASAT4ILSRNAV\Airports & ASAT Projects\Generic Dual

RunNumber	AcType2	AcType1	CPA2D	CPA3D	BATCRT	BPRT	EATCRT
	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
2
3
4
5

Total Number of Runs : 5

TCV Range: 500[Ft]
NTCV2D(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

27 26L 26R.apf ASAT project input file

EPRT	TCV2D	TCV3D	BlunderStatus	TCV
3.1	0	0	C_Blunders_to_Left	0
6.9	0	0	L_Blunders_to_Center	0
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

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:

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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 (1/4,096 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.)

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