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

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December 1999

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16. Abstract

The Multiple Parallel Approach Program (MPAP), under the auspices of the FAA Secondary Surveillance Integrated Product Team, AND-450, was developed to evaluate the feasibility of conducting simultaneous parallel approaches using both current and advanced radar and display system technology. The program focused primarily on the capacity-enhancing benefits of a Precision Runway Monitor system with various airport configurations. MPAP conducted over 20 real-time, human-in-the-loop and fast-time modeling simulations since 1988. The purpose of these simulations was to develop procedures for independent approaches to quadruple, triple, and closely spaced dual parallel runways in instrument meteorological conditions. This report provides a history of all MPAP simulations conducted to date, including a description of the test criteria used to evaluate each test, the findings, and subsequent procedural and equipment recommendations.

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Executive Summary

The Multiple Parallel Approach Program (MPAP) conducted over 20 real-time, human-in-the-loop simulations since 1988 to evaluate proposed simultaneous operations to closely spaced parallel runways. The program established the MPAP Technical Working Group (TWG) to evaluate multiple parallel approaches in an effort to safely increase airport capacity. The MPAP TWG, with the support of Federal Aviation Administration William J. Hughes Technical Center personnel and contractors, conducted simulations of dual, triple, and quadruple parallel runway configurations. These simulations addressed issues at specific airports and established national standards for simultaneous approach operations.

The MPAP Team simulated various approach configurations using both current and new radar and display system technology. These systems included the Airport Surveillance Radar (ASR)-9, back-to-back Mode S, and Electronic Scanning Radar (E-Scan) systems, with their respective update rate capabilities. Simulated display systems included Fully Digital Alphanumeric Display System (FDADS) displays, Digital Entry Display Subsystem (DEDS) displays, and Final Monitor Aid (FMA) displays.

The team observed benefits and limitations of display and radar combinations with various parallel runway spacings in the simulations. Objective analyses of controller and aircrew performance measures provided reliable information about system performance with each simulation configuration. Based upon safety and capacity-related test criteria, the MPAP TWG recommended which proposed simultaneous approach procedures should be approved for the operational environment.

This paper summarizes the results of MPAP real-time simulation evaluations concerning simultaneous Instrument Landing System approaches to multiple parallel runways. It explains test criteria used in the evaluation of the real-time simulations and provides brief synopses of each MPAP simulation. In addition, it provides TWG recommendations for national standards and site-specific procedures. A summary of MPAP TWG radar and display system national standard recommendations for simultaneous approach operations is provided below.

a. For *straight-in* approaches to dual parallel runways spaced by

   1. *at least 5000 ft,* FDADS and/or DEDS displays and ASR-9 radar with a 4.8-second update rate are recommended,

   2. *less than 5000 ft and greater than or equal to 4300 ft*, FMA displays and ASR-9 radar with a 4.8-second update rate are recommended,

   3. *less than 4300 ft and greater than or equal to 3400 ft*, FMA displays and a high update radar with faster than or equal to a 1.0-second update rate (i.e., Precision Runway Monitor (PRM) System) are recommended.

b. For offset approaches to dual parallel runways spaced by

   1. *less than 3400 ft and greater than or equal to 3000 ft with no less than a 2.5-degree localizer offset and no greater than a 3-degree offset*, FMA displays and a high update radar with faster than or equal to a 1.0-second update rate (i.e., PRM System) are recommended,

c. For straight-in approaches to triple parallel runways spaced by

   1. *at least 5000 ft with an airport field elevation of less than 1000 ft*, FDADS and/or DEDS displays and ASR-9 radar with a 4.8-second update rate are recommended, and

   2. *less than 5000 ft and greater than or equal to 4300 ft with an airport field elevation of less than 1000 ft*, FMA displays and ASR-9 radar with a 4.8-second update rate are recommended.

1. Introduction

1.1 Background

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

The MPAP TWG, with the support of Federal Aviation Administration William J. Hughes Technical Center personnel and contractors, comprised a team who conducted a series of real-time simulations. These simulations evaluated air traffic control (ATC) system performance with proposed simultaneous parallel approach operations for specific airports and for the development of national standards. Airport runway configurations tested included dual, triple, and quadruple parallel runways at various spacings.

1.2 Program Objective

The main objective of the MPAP was to achieve capacity enhancements through the conduct of simultaneous approaches and in the process of doing so, maintain a specified, conservative target level of safety. Simultaneous approaches can yield up to 40% more arrivals than staggered approaches at high traffic-density airports. Figure 1 illustrates the difference between simultaneous and staggered approaches.

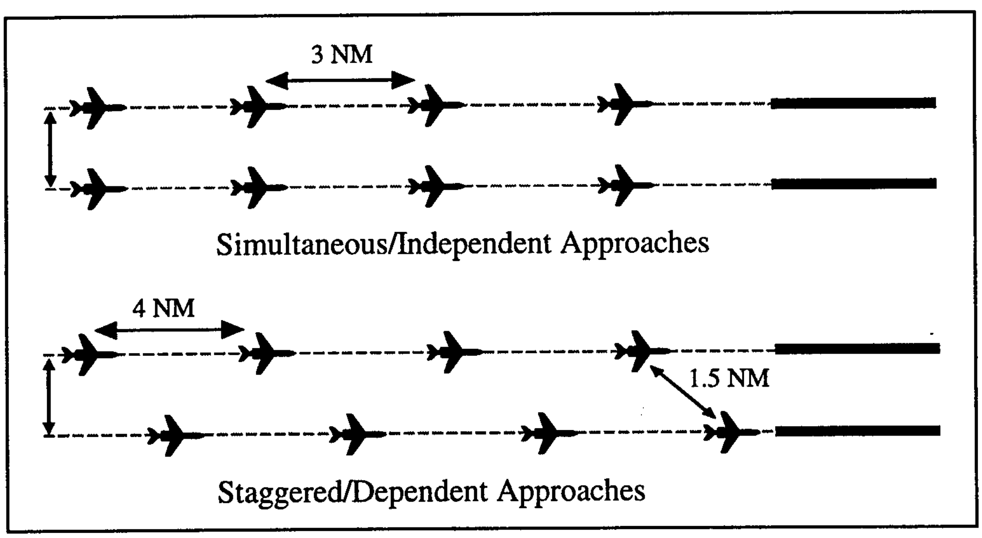

Figure 1. Simultaneous and staggered approaches.

One principal task of the MPAP was to determine the minimum acceptable spacings between parallel runways as a function of equipment/technology alternatives. When two airplanes are approaching parallel runways during instrument meteorological conditions, the controller needs to insure that each aircraft stays on its assigned approach course. In the event that an aircraft strays from course, the controller needs to be able to detect and redirect the deviating aircraft and also any adjacent aircraft on the approach. This was one of the major concerns in developing simultaneous parallel approach standards.

Extensive testing and analysis showed that runway spacing, however, is just one of several factors that can affect the safe execution of simultaneous parallel approaches. Radar and display systems including processors and sensors are also important for maintaining aircraft separation in the event of an aircraft deviation off course. The major features of radar and display systems important to simultaneous parallel ILS approaches are surveillance delay (including update interval), surveillance system accuracy (combined sensor accuracy and display resolution), automation aids (alarms and display enhancements), and system capacity (Crane & Massimini, 1995).

The MPAP Team tested various parallel runway configurations using both current and new radar and display system technology. Simulated radar systems included the Airport Surveillance Radar Model #9 (ASR-9), back-to back Mode S, and Electronic Scanning Radar (E-Scan) systems, with their respective update rate capabilities. Display systems tested included Fully Digital Alphanumeric Display System (FDADS) displays, Digital Entry Display Subsystem (DEDS) displays, and Final Monitor Aid (FMA) displays. The benefits and limitations of display and radar combinations with various parallel runway spacings were observed in the real-time simulations. Based on predetermined test criteria, the MPAP TWG evaluated the results of the real-time simulations and made recommendations to the FAA as to whether or not proposed parallel approach procedures were feasible, as tested.

1.3 Purpose

The purpose of this paper is to summarize the findings and recommendations for each simultaneous parallel approach real-time simulation conducted by the MPAP Team. By doing so, the paper will demonstrate which combinations of runway spacings, radar, and display systems are and are not feasible, based on simulation results, for conducting simultaneous approaches to closely spaced dual, triple, and quadruple parallel runway configurations.

2. Simulation Methodology

The development of the real-time simulation environment at the Technical Center has made the simulation method of analysis one of the most advanced for evaluating ATC procedures development. In MPAP simulations, full performance level ATC Specialists used operational ATC displays or display prototypes and issued commands to both computer-generated and flight simulator-controlled aircraft targets flying simultaneous approaches. Current and/or qualified airline flight crews participated as subjects, flying several different types of flight simulator aircraft at various locations around the country. By incorporating flight simulators into the simulations, the MPAP Team collected actual flight crew and aircraft performance data.

The test criteria used by the MPAP to evaluate parallel runway simulations evolved over the years since the program's inception. The following sections briefly describe the test criteria as they existed at the end of the program. For a more detailed explanation of the derivation of each criterion, see Ozmore and Morrow (1996). For information on earlier simulation test criteria, see the simulation final test report for the specific procedure in question.

2.1 Blunder Resolution Performance

To measure the ability of the ATC system to maintain adequate separation between aircraft on simultaneous final approaches, the MPAP Team introduced critical situations by initiating aircraft blunders. A blunder occurred when an aircraft, already established on an ILS approach, made an unexpected turn towards another aircraft on an adjacent approach, as depicted in Figure 2. Blunders presented the controllers with worst-case situations. Blundering aircraft turned at angles of 30 degrees and, in most cases, were non-responding, simulating an inability to comply with controller instructions.

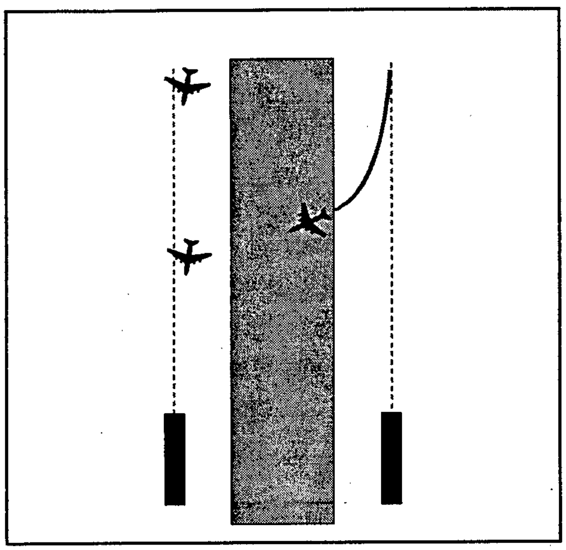

Figure 2. Aircraft blunder during parallel approach operations.

Controllers monitoring blundering aircraft and all adjacent aircraft issued commands as necessary to keep the aircraft apart. If the minimum slant range distance between the blundering aircraft and the evading aircraft was 500 ft or greater (adequate separation), the TWG considered the blunder resolved. A Test Criterion Violation (TCV) occurred if a blunder resulted in a miss distance of less than 500 ft between aircraft. The number of TCVs divided by the total number of blunders that would have resulted in TCVs if the controllers did not intervene (i.e., at-risk blunders) resulted in a TCV rate. The TWG based the decision to use 500 ft as the upper limit on the definition of a near mid-air collision, as found in the Aeronautical Information Manual (AIM), paragraph 7-6-3 (FAR, 1996).

Members of the MPAP Team computed maximum acceptable TCV rates for each simulation based on a target level of safety of no more than one fatal accident per 25 million approaches. The real-time TCV rate had to be equal to or below the maximum acceptable TCV rate to meet the blunder resolution test criterion. To ensure a more accurate measurement of the operational TCV rate, the team conducted a fast-time computer simulation or Monte Carlo simulation. The Monte Carlo simulation used data collected in the real-time simulation to model over 100 thousand at-risk blunders, thus reducing the range of the confidence interval to a very small size. The team compared the TCV rate estimate from the Monte Carlo simulation to the results of the real-time simulation to ensure consistency. For a complete explanation of the risk analysis and maximum acceptable TCV rate derivation, see the Precision Runway Monitor Demonstration report (Precision Runway Monitor Program Office, 1991), and for the latest revisions, see Morrow and Ozmore (1996).

2.2 No Transgression Zone Entries and Nuisance Breakouts

The final approach airspace for independent approaches is divided into two areas between runways, the Normal Operating Zone (NOZ) and the No Transgression Zone (NTZ). Aircraft are permitted to fly in the NOZ. The NTZ is a 2000-ft wide area equidistant between final approach courses where aircraft are not permitted to enter. If an aircraft enters the NTZ, regulations require the monitor controller to break that aircraft and any adjacent aircraft out of the approach. Because the NTZ is fixed at 2000 ft, the NOZ varies with runway separation. As separation between runways decreases, the NOZ decreases, providing less airspace for aircraft to fly along the ILS and a greater opportunity for aircraft to enter the NTZ.

As runways become more closely spaced, Total Navigation System Error (TNSE) becomes a concern. TNSE represents the difference between the actual flight path of an aircraft and its intended flight path. TNSE can be caused by flight technical error, avionics error, ILS signal error, and/or weather. TNSE may contribute to the occurrence of NTZ entries and nuisance breakouts (NBOs). In the MPAP simulations, an NTZ entry occurred when an aircraft entered the NTZ for reasons other than a blunder or breakout. An NBO occurred when an aircraft was broken out of its final approach course for reasons other than a blunder, loss of longitudinal separation, or lost beacon signal (i.e., aircraft target went into coast).

If an excessive number of NTZ entries and/or NBOs occurred in an MPAP simulation, a high communications workload on the controller resulted and capacity was reduced because of aircraft being broken out. The MPAP TWG evaluated the frequency of NTZ entry and NBO occurrences and the resultant impact on controller communications workload for each simulation and determined whether or not the rates were acceptable.

2.3 Operational Assessment

The MPAP TWG also drew from its own collective knowledge and expertise in forming an operational assessment for each proposed parallel approach procedure. The operational assessment reflected the TWG's overall evaluation of the simulated procedure and recommendation regarding the feasibility of implementing the procedure in the operational environment. They based the operational assessment on all test results, on MPAP TWG expertise and judgment, and on evaluations from subject controllers, pilots, controller technical observers, and pilot technical observers.

To fully understand the intricacies of controller and pilot performance with proposed procedures, the TWG considered all test results to form an operational assessment. Analyses of controller response times, pilot/aircraft response times, aircraft separation distributions, controller breakout instruction content, and controller and pilot questionnaire responses were reviewed and incorporated into the TWG's final recommendation.

3. Multiple Parallel Approach Program Simulations and Results

The MPAP Team conducted initial real-time simulations to evaluate proposed runway operations at the Dallas/Fort Worth International Airport (DFW). Following the DFW studies, the focus of the program shifted to the development of national standards for various parallel runway configurations, display systems, and radar systems. During the series of national standards tests, the program addressed a site-specific study of the Denver International Airport (DEN). Following the Denver study, the program resumed testing for national standards development and, at the same time, addressed site-specific issues for the following airports: Philadelphia International (PHL), John F. Kennedy International (JFK), Atlanta International (ATL), and Pittsburgh International (PIT) Airports.

Some detailed sources of information on these simulations are included in the following list:

a. CTA Incorporated (1990). *Dallas/Fort Worth simulation phase II - triple simultaneous parallel ILS approaches* (DOT/FAA/CT-90/2). Atlantic City International Airport, NJ: FAA Technical Center.

b. Fischer, T., Yastrop, G., & Startzel-Dehel, B. (1990). *Simulation of quadruple simultaneous parallel ILS approaches at D/FW - phase III* (DOT/FAA/CT-90/15). Atlantic City International Airport, NJ: FAA Technical Center.

c. Hitchcock, L., Fischer, T., Bensel, L. W., Yastrop, G., Jones, R., Luongo, R., Reardon, K., & Startzel-Dehel, B. (1991). *Evaluation of triple simultaneous parallel ILS approaches spaced 4300 feet apart-phase IV.a* (DOT/FAA/CT-91/6). Atlantic City International Airport, NJ: FAA Technical Center.

d. Hitchcock, L., Fischer, T., Bensel, L. W., Yastrop, G., Jones, R., Luongo, R., Reardon, K., & Startzel-Dehel, B. (1992). *Evaluation of triple simultaneous parallel ILS approaches spaced 5000 feet apart-phase IV.b* (DOT/FAA/CT-91/31). Atlantic City International Airport, NJ: FAA Technical Center.

e. Morrow, S. L. & Ozmore, R. E. (1999). *Evaluation of triple simultaneous instrument landing system approaches to runways spaced 4000 and 5300 ft apart using a precision runway monitor system.* Manuscript in preparation.

f. Ozmore, R. & DiMeo, K. (1994). *Simulation of triple simultaneous parallel ILS approaches at the new Denver International Airport using the final monitor aid display and a 4.8 second radar update rate* (DOT/FAA/CT-94/36). Atlantic City International Airport, NJ: FAA Technical Center.

g. Ozmore, R. E. & Morrow, S. L. (1996). *Evaluation of dual simultaneous instrument landing system approaches to runways spaced 3000 feet apart with one localizer offset using a precision runway monitor system* (DOT/FAA/CT-96/2). Atlantic City International Airport, NJ: DOT/FAA William J. Hughes Technical Center.

h. Paul, L., Shochet, E., & Algeo, R. (1989). *Dallas/Forth Worth simulation* (DOT/FAA/CT-TN89/28). Atlantic City International Airport, NJ: FAA Technical Center.

i. Precision Runway Monitor Program Office (1991). *Precision runway monitor demonstration report* (DOT/FAA/RD-91/5). Washington, DC: FAA Research and Development Service.

j. Yastrop, G., Bensel, L. W., Fischer, T., Jones, R., Luongo, R., Neiderman, E., & Reardon, K. (1992). *Evaluation of triple simultaneous ILS approaches spaced 4300 feet apart using the final monitor aid-phase V.a.1* (DOT/FAA/CT-92/16). Atlantic City International Airport, NJ: FAA Technical Center.

3.1 Dallas/Fort Worth International Airport Triple and Quadruple Approaches

The MPAP was initiated in 1988 to examine proposed operations at DFW. The parallel approach operations were tested using monochrome displays, which were configured to emulate DEDS displays. Three simulations were conducted to evaluate the proposed triple and quadruple approach operations. Table 1 shows the parameters tested in each DFW simulation.

Table 1. Dallas/Fort Worth Triple and Quadruple Approach Simulations

Purpose	Dates	Parallel Runways	Runway Spacing	Display	Simulated Radar	Other	Recommendation
DFW	5/16-6/10/88	Quadruple	5000 ft & 5800 ft & 8800 ft	DEDS	ASR-9 4.8-second update rate	Airspace Configuration	Approved
	9/25-10/5/89	Triple	5000 ft & 8800 ft	DEDS	ASR-9 4.8-second update rate		Approved
	11/29 2/9/90	Quadruple	5000 ft & 5800 ft & 8800 ft	DEDS	ASR-9 4.8-second update rate	Missed Approach Procedures	Approved

The "Other" column of Table 1 shows the difference between the May 1988 and the November 1990 DFW studies. In addition to evaluating simultaneous approaches, the May 1988 simulation examined airspace-configuration issues, and the November 1990 simulation examined missed approach procedures associated with the proposed quadruple parallel operation.

After consideration of the blunder resolution rates, NTZ entry rates, and the operational assessment, the MPAP TWG found that all three DFW simulations met the test criteria and recommended them for approval. The FAA subsequently granted authorization to conduct the simulated procedures. DFW began triple simultaneous parallel approach operations on October 10, 1996 using the FDADS, which provides better display quality than the tested monochrome DEDS displays and an ASR-9 system with a 4.8-second update rate. The FAA approved the DFW expansion to quadruple parallel approach operations pending runway construction.

3.2 Dual and Triple Approaches With DEDS Displays and ASR-9

The MPAP Team conducted the next set of real-time simulations to establish national standards for triple simultaneous approaches using monochrome DEDS displays and simulated ASR-9 with a 4.8-second update rate. Table 2 details the parameters tested in each real-time simulation.

Table 2. Dual and Triple Approach Simulations Using DEDS Displays and ASR-9

Purpose	Dates	Parallel Runways	Runway Spacing	Display	Simulated Radar	Other	Recommendation
National Standards	4/24-5/3/90	Dual and Triple	4300 ft	DEDS	ASR-9 4.8-second update rate		Not Approved
National Standards	9/17-9/28/90	Triple	5000 ft	DEDS	ASR-9 4.8-second update rate		Approved

After consideration of the blunder resolution rate and operational assessment, the MPAP TWG determined that both the results of the 4300-ft dual and triple approach simulations were not acceptable. The TWG cited the controllers' inability to detect and redirect deviating aircraft in a timely manner as the major contributing factor to the unsatisfactory results.

However, the MPAP TWG recommended that the 5000-ft triple approach operation be approved. The additional spacing between approach courses, as compared to the 4300-ft spacing, provided controllers with the necessary time to react to and resolve aircraft deviations. Subsequently, the FAA authorized simultaneous approaches to three parallel runways separated by at least 5000 ft.

3.3 Dual and Triple Approaches With FMA Displays and ASR-9

Three simulations evaluated simultaneous approach operations using FMA displays and ASR-9. FMAs are high-resolution color displays that are equipped with controller alert systems and expandable horizontal and vertical axes. FMAs provide controllers with tools for recognizing and resolving aircraft course deviations, a task that is critical when monitoring simultaneous approaches.

The FMA alert system includes algorithms that estimate future aircraft positions with predictor lines that are affixed to aircraft data tags. When an aircraft is predicted to enter the NTZ, the aircraft tag and data block change from green to yellow. If an aircraft enters the NTZ, the tag and data block turn red. In addition, a synthesized voice alert sounds when an aircraft is within a set parameter of entering the NTZ.

The FMA provides the capability to adjust the horizontal and vertical ratio of the display. Axes can be scaled independently to improve the controller's ability to detect aircraft movement away from the extended runway centerline during final approach. For all of the MPAP simulations, a 4:1, horizontal to vertical, expansion ratio was applied. MPAP simulations that investigated dual and triple approaches with FMA displays are detailed in Table 3.

Table 3. Dual and Triple Approach Simulations Using FMA Displays and ASR-9

Purpose	Dates	Parallel Runways	Runway Spacing	Display	Simulated Radar	Other	Recommendation
National Standards	5/15-5/24/91	Dual and Triple	4300 ft	FMA	ASR-9 4.8-second update rate		Approved
National Standards	9/24-10/4/91	Triple	4000 ft	FMA	ASR-9 4.8-second update rate		Inconclusive
National Standards	7/27-8/14/92	Dual and Triple	4000 ft	FMA	ASR-9 4.8-second update rate		Inconclusive

Based on the established test criteria, the MPAP TWG recommended the approval of both the 4300-ft dual and triple operations, and the FAA subsequently authorized the approaches. The FMA displays were effective in enabling successful operations. With expanded horizontal axes and color/voice alerts, controllers were able to detect aircraft blunders in sufficient time to resolve the situations and thus maintain the specified target level of safety.

The September 1991 4000-ft triple approach simulation provided positive results in terms of blunder resolution performance, however, the MPAP Team did not collect enough data over the course of the simulation to support a recommendation of the operation.

The team conducted the July 1992 4000-ft dual and triple approach simulations to supplement the data from the September 1991 study. A combination of the results from the simulations provided a larger sample of data. Analysis of the combined results showed that blunder resolution performance was not significantly better than the target level of safety. The results from the July 1992 simulations alone were unacceptable. The TWG attributed those results to changes in controller phraseology, which included new breakout terms and standardized 'climb only' breakout instructions. Because the validity of the combined data was questionable due to different ATC procedures that were employed between simulations, the TWG did not provide any recommendations on the procedures.

3.4 Denver International Airport Triple Approaches

The Denver simulation consisted of three parts. First, the MPAP TWG performed a generic study to gain information about the effects of density-altitude on aircraft performance at high-altitude airports, particularly as related to aircraft executing simultaneous approaches. They did not make a recommendation from the study. Second, they performed a real-time simulation to emulate the triple runway configuration of DEN. Controllers monitored aircraft arrivals using FDADS and a simulated ASR-9 with a 4.8-second update rate. Third, they tested the DEN triple runway configuration using FMA displays and an ASR-9 with a 4.8-second update rate. Table 4 details the test parameters for all of the high-altitude simulations.

Table 4. Denver Triple Approach Simulations

Purpose	Dates	Parallel Runways	Runway Spacing	Display	Simulated Radar	Other	Recommendation
High-Altitude	9/8-9/25/92	Triple	7600 ft & 5280 ft	DEDS	ASR-9 4.8-second update rate	Field Elevation 5431 ft	No Recommendation Made
DEN	11/16-11/20/92	Triple	7600 ft & 5280 ft	FDADS	ASR-9 4.8-second update rate	Field Elevation 5431 ft	Not Approved
DEN	11/30-12/17/92	Triple	7600 ft & 5280 ft	FMA	ASR-9 4.8-second update rate	Field Elevation 5431 ft	Approved

The high-altitude simulation provided valuable information about the effects of air density on aircraft performance at airports with high field elevations. Air density at high altitudes degrades performance because it reduces engine power output and aerodynamic lift. Another effect of high altitude is a higher true airspeed. Even though the indicated airspeed that the pilots see in the cockpit is unaffected by variations in air density, the true airspeed increases with increased altitudes/decreased densities. Nevertheless, aircraft fly the same indicated airspeeds at both high-altitude airports and sea level airports.

At high-altitude airports where simultaneous approaches are being conducted, reduced aircraft performance and higher true airspeeds could become critical factors in a pilot's ability to avoid a blundering aircraft. First, with a greater true airspeed, a blundering aircraft has a higher cross-track velocity. Second, the higher true airspeed of an evading aircraft would result in a larger turn radius and, therefore, a decreased probability of avoiding a blundering aircraft. The controller would have to detect blunders and issue breakout instructions almost immediately to resolve a blunder.

DEN planned to operate triple simultaneous approaches when it opened in February 1993. The runway spacings were above minimums, however, the field elevation classified the airport as a high-altitude airport. Therefore, the MPAP Team performed a simulation in November 1992 to determine if the high altitude and low air density would effect the safety of a triple simultaneous approach operation. For the test, controllers monitored aircraft using FDADS displays and an ASR-9 with a 4.8-second update rate.

The MPAP TWG determined that the results of the DEN simulation using the FDADS displays were unacceptable. Observations during the simulation by the TWG, Air Traffic representatives, and Northwest Mountain Region representatives were enough to conclude that the FDADS did not provide the controllers with the necessary resolution and features to detect and respond to deviating aircraft in timely manners. The blunder resolution performance criterion was not met. The simulation thus concluded, and a decision was made to test the procedure with FMA displays.

The DEN simulation using FMA displays was a success. After analysis of the blunder resolution rate, the NTZ entry and NBO rates, and the operational assessment, the MPAP Team found that the procedure had met all of the test criteria. The FMA displays were effective in alerting controllers to blundering aircraft in sufficient time for the controllers to react to and resolve the situations. The MPAP TWG, therefore, recommended the procedure for approval. With the stipulation that FMA displays be installed at DEN, the FAA subsequently granted authorization to conduct the triple approach procedure. DEN conducted triple simultaneous approaches under instrument weather conditions on their opening day in February 1995.

The knowledge gained from the high-altitude studies resulted in addenda to the approved 5000-ft and 4300-ft triple approach procedures. In addition to a minimum of 5000 ft between runways, airports executing these simultaneous triple approaches using FDADS or DEDS displays and ASR-9 must also have a field elevation of less than 1000 ft Mean Sea Level (msl). In addition, airports conducting triple simultaneous approaches to runways spaced 4300 ft apart using FMA displays with ASR-9 must also have field elevations of less than 1000 ft msl.

3.5 Dual Approaches With Precision Runway Monitor Systems

The Precision Runway Monitor (PRM) system was developed specifically for the monitoring of closely spaced parallel approaches in the late 1980s. The PRM consists of a high-resolution display system, such as the FMA, and a monopulse antenna system that provides high azimuth and range accuracy and higher update rates than the current terminal ASR systems. The electronically scanned antenna has an update interval that can be varied from 0.5 to 5 seconds, although computer-processing capacity generally limits the minimum update interval to 1.0 second (Crane & Massimini, 1995).

In 1990, the MPAP Team tested and recommended for approval a procedure for simultaneous parallel approaches to two runways spaced 3400 ft apart using FMA displays and a high-update radar system. The radar consisted of a back-to-back Mode S radar sensor with a 2.4-second update rate. The FAA, however, approved funding for PRM systems with E-Scan radar with a 1.0-second update rate only. The back-to-back Mode S radar with the 2.4-second update rate was not purchased to be part of the PRM system. Therefore, the TWG adopted the recommendation for 3400-ft duals to include the E-Scan 1.0-second update rate to coincide with the fielded PRM system specifications.

As explained in the PRM Demonstration Report (PRM Program Office, 1991), the 3400-ft dual procedure addressed operations at Raleigh-Durham International (RDU) and Memphis International (MEM) Airports, which were chosen as field sites for test and evaluation. Initial studies, however, conducted as part of the PRM Demonstration Program, indicated that the minimum runway spacing enabled by a PRM system would be approximately 3000 ft. The MPAP TWG investigated this possibility.

They performed a series of simulations to develop national standards for two parallel runways using the PRM. They designed the simulations to investigate the effects of the PRM on the controller's ability to monitor closely spaced approaches. All of the 3000-ft dual runway simulations included FMA displays and simulated E-Scan radar systems with 1.0-second update rates. As Table 5 depicts, two simulations tested the same parameters as two earlier simulations. The following paragraphs explain the impetus for each of those dual runway simulations.

The MPAP Team conducted the March 1991 simulation to test the feasibility of executing simultaneous approaches to two runways spaced 3000 ft apart. The results of the study did not meet the safety requirements defined by the TWG. They attributed the reason to a capacity issue, not to an aircraft separation issue. Controllers broke an excessive number of aircraft out of the approach because of aircraft navigational error, and, consequently, the procedure offered little to no capacity increases. In other words, as aircraft captured the localizers, their typical fan-shaped approaches caused predictor lines to enter the NTZ and alerts to sound (see Figure 3) due to the closely spaced approach configuration. Controllers responded correctly by breaking the aircraft off the approach. Consequently, the 3000-ft dual procedure was not recommended for approval.

Table 5. Dual Approach Simulations Using Precision Runway Monitor Systems

Purpose	Dates	Parallel Runways	Runway Spacing	Display	Simulated Radar	Other	Recommendation
National Standards	1990	Dual	3400 ft	FMA	Mode S 2.4-second update rate		Approved *
National Standards	3/18-3/27/91	Dual	3000 ft	FMA	E-Scan 1.0-second update rate		Not Approved
National Standards	9/16-9/23/91	Dual	3000 ft	FMA	E-Scan 1.0-second update rate	1-Degree Localizer Offset	No Decision Rendered See June 1994
National Standards	6/6-6/17/94	Dual	3000 ft	FMA	E-Scan 1.0-second update rate	1-Degree Localizer Offset	Not Approved
National Standards	7/11-7/22/94	Dual	3000 ft	FMA	E-Scan 1.0-second update rate	2.5-Degree Localizer Offset	No Decision Rendered See October 1995
National Standards	10/16-10/27/95	Dual	3000 ft	FMA	E-Scan 1.0-second update rate	2.5-Degree Localizer Offset	Approved

* A PRM Demonstration Program study, not an MPAP simulation

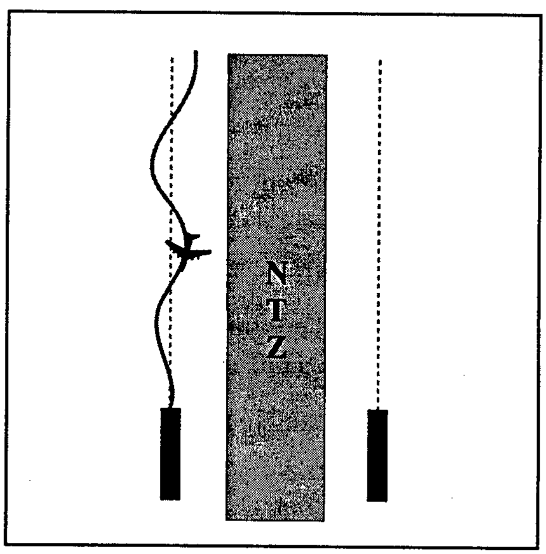

Figure 3. Pilot/aircraft navigation performance.

In an attempt to resolve the navigational precision issue, the MPAP Team conducted a 3000-ft simulation in September 1991 with one of the parallel approach courses offset by one degree. They added the offset to increase the spacing between approach courses as a function of distance from the localizer antenna. The anticipated effect of the offset was fewer alerts as aircraft captured the localizers and, thus, fewer breakouts. The FAA did not make a recommendation on the tested procedure, however, because insufficient data were collected during the simulation to support a recommendation.

The MPAP Team reevaluated the 3000-ft, one-degree offset procedure in June 1994. The offset localizer appeared to resolve the navigational error issue; however, the blunder resolution performance criterion was not met. The number of TCVs that occurred did not allow the procedure to meet the target level of safety. The TWG did not recommend the procedure for approval.

The team decided to investigate a procedure with a larger offset angle that would emulate proposed simultaneous approach operations at JFK and PHL. Both airports were interested in a 3000-ft dual parallel runway operation with one localizer offset by 2.5 degrees.

The team tested the 3000-ft, 2.5-degree offset procedure in July 1994 using FMA displays and a simulated E-Scan radar with a 1.0-second update rate. The results of the simulation showed that the NTZ entry and NBO criteria were met; however, the resultant TCV rate was just over the maximum acceptable TCV rate. Therefore, the blunder resolution criterion was not met and the TWG operational assessment was not supportive of the operation.

Through extensive analysis of simulation data, the TWG determined that training for both controllers and pilots was not adequate for the simulation. A large number of controllers were rotated through as subjects, and, as a result, individuals did not receive sufficient training on the PRM equipment prior to their participation. In addition, not enough emphasis was placed on the use of standardized phraseology for blunders, and, consequently, breakout phraseologies varied in content and duration during the test. Pilots, on the other hand, were not trained to perform breakout maneuvers and were unfamiliar with ATC-directed breakouts between glide slope intercept and decision height. To summarize, the TWG identified training as the contributing factor to the failure of the simulation, not the proposed procedure itself.

The MPAP Team took action to resolve the problem areas identified with the July 1994 simulation. They developed improved training packages for both controllers and pilots with the intent to develop training recommendations that could be applied in actual field operations. The 3000-ft, 2.5-degree offset procedure was re-tested in October 1995 and passed all of the test criteria unquestionably. No TCVs occurred throughout the entire test. Controllers familiarized themselves with the PRM equipment and delivered phraseology as prescribed. The pilots on the MPAP Team administered awareness training to subject pilots for flying closely spaced approaches. They instructed the pilots to execute only hand-flown breakouts, which were determined to be faster than autopilot breakouts in the July 1994 simulation. With the stipulation that similar controller and pilot training be required, the TWG unanimously agreed to recommend the 3000-ft, 2.5-degree offset procedure for approval.

3.6 Triple Approaches With Precision Runway Monitor Systems

The MPAP Team conducted a series of triple parallel runway simulations over the past several years using the PRM system. Table 6 details the test parameters for four triple approach simulations and the final recommendations for each.

Table 6. Triple Approach Simulations Using Precision Runway Monitor Systems

Purpose	Dates	Parallel Runways	Runway Spacing	Display	Simulated Radar	Other	Recommendation
National Standards	3/28-4/5/91	Triple	3000 ft	FMA	E-Scan 1.0-second update rate		Not Approved
National Standards	5/6-5/14/91	Triple	3400 ft	FMA	Mode S 2.4-second update rate		Inconclusive
National Standards	8/14-8/25/95	Triple	4000 ft & 5300 ft	FMA	E-Scan 1.0-second		No Decision Rendered
National Standards	4/15-4/26/96	Triple	4000 ft & 5300 ft	FMA	E-Scan 1.0-second update rate		Approved

The MPAP Team tested a 3000-ft triple approach procedure using FMA displays and an E-Scan radar directly following the 3000-ft dual approach simulation in March 1991. The MPAP TWG did not recommend the triple procedure for approval. As with the duals, they attributed the reason for the failure of the procedure to a capacity issue. Navigational error caused controllers to break out an excessive number of aircraft, and consequently, the procedure did not offer any capacity gains.

In May 1991, the team conducted a simulation to evaluate triple approaches to runways spaced 3400 ft apart using FMA displays and a back-to-back Mode S radar with a 2.4-second update rate. The TWG deemed the study inconclusive due to insufficient data collected during the simulation. They therefore made no recommendation on the procedure.

In August 1995, the MPAP Team simulated a procedure for three parallel runways spaced 4000 and 5300 ft apart using FMA displays and an E-Scan radar. The purpose of the simulation was to address proposed operations at Pittsburgh International (PIT) and Atlanta International (ATL) Airports. Results of the simulation showed that the NTZ entry and NBO rates were acceptable but the blunder resolution rates were not.

Similar to the July 1994 3000-ft dual, 2.5-degree offset simulation, the TWG identified training as a problem area. Specifically, they identified controller training as the major contributing factor to the outcome of the test. A large number of controllers rotated through as subjects. As a result, training with the PRM equipment on an individual level was not adequate prior to the test. The MPAP Team briefed breakout phraseology to the controllers before the simulation. Because of its length, however, controllers had problems issuing it during blunders.

The TWG believed that the 4000 and 5300-ft triple procedure would be operable if the team applied the improved controller training package that enabled a successful 3000-ft, 2.5-degree offset simulation. This package included a mandatory 8 hours of hands-on training with the PRM equipment, during which controllers could observe and respond to blunders and rehearse a new shortened standard breakout phraseology. Pilot training proved to be very effective in the August 1995 simulation, as demonstrated by pilot performance and, therefore, did not require any modifications. The MPAP administered the improved controller training packages and the same pilot training that was administered in the August 1995 simulation. The test passed all of the criteria.

The MPAP Team tested the 4000- and 5300-ft triple procedure again in April 1996 and it passed all of the test criteria. The test results demonstrated that the modified controller training and the employment of pilot training improved the procedure. Controllers delivered standard breakout phraseology during almost every blunder event, and the resulting TCV rate was well below the maximum acceptable TCV rate. The TWG therefore recommended the 4000 and 5300-ft triple procedure for approval at airports with field elevations of less than 1000 ft msl with the condition that similar controller and pilot training be applied as in the simulation.

4. Conclusions

The MPAP TWG observed and evaluated numerous simultaneous parallel approach procedures in the last decade, mostly with the use of advanced radar and display system technology. They gained a phenomenal amount of information about system performance with various simultaneous approach configurations, controller displays, and radar systems. MPAP research findings have been adopted by the United States and worldwide. Procedures have been incorporated into FAA Order 7110.65- *Air Traffic Control* (FAA 1996), FAA Order 8260.39- *Close Parallel ILS/MLS Approaches* (FAA, 1994) and the *Aeronautical Information Manual* (AIM) (FAA, 1996). Instrument approach path obstacle clearance requirements for PRM have been incorporated into FAA Order 8260.39. Many of these FAA standards have also been adopted by the International Civil Aviation Organization.

The MPAP designed these simulations to test and define operational limits of current systems and examine enhanced capabilities of new systems. The implementation of PRM systems to reduce minimum required runway spacings between parallel runways is one example of the milestones achieved through these endeavors. The simulations were also instrumental in identifying and correcting potentially hazardous operations such as with the proposed operations at DEN using FDADS. Through the MPAP TWG efforts, the FMA display system was proposed, tested, and installed prior to DEN going operational.

The MPAP TWG acquired a comprehensive understanding of the intricacies of simultaneous approach operations. The impact of simultaneous operations on controllers, aircrews, and the entire National Airspace System (NAS) was studied extensively. Based upon the information gained from the simulations and the collective knowledge of the MPAP, the TWG developed a set of recommendations, shown in Table 7.

Table 7. Summary of MPAP TWG National Standard Recommendations

	Parallel Runways Spaced by	Display	Radar	FAA Approved
DUAL *Straight-In* Approaches	Greater than or equal to **5000 ft**	FDADS & DEDS	ASR-9 4.8 seconds	Yes
	Less than **5000 ft** and greater than or equal to **4300 ft**	FMA	ASR-9 4.8 seconds	Yes
	Less than **4300 ft** and greater than or equal to **3400 ft**	FMA	E-Scan ≤ 1.0 second	Yes
DUAL *Offset* Approaches	Less than **3400 ft** and greater than or equal to **3000 ft with no less than a 2.5-degree localizer offset**	FMA	E-Scan ≤ 1.0 second	Yes
TRIPLE *Straight-In* Approaches	Greater than or equal to **5000 ft** with airport field elevation less than 1000 ft	FDADS & DEDS	ASR-9 4.8 seconds	Yes
	Less than **5000 ft** and greater than or equal to **4300 ft** with airport field elevation less than 1000 ft	FMA	ASR-9 4.8 seconds	Yes

For straight-in simultaneous ILS approaches to two parallel runways spaced apart by at least 5000 ft, the TWG recommended the use of FDADS or DEDS and ASR-9 with a 4.8-second update rate. The TWG recommended, however, that the installation of FMA displays be considered as a safety enhancement.

The TWG recommended that FMA displays be required with radar systems that have a 4.8-second update rate such as the ASR-9, for straight-in, simultaneous, ILS approaches to two parallel runways spaced apart by less than 5000 ft and greater than or equal to 4300 ft, (runway spacings below 4300 ft require FMAs and high update radar). This recommendation is significant in that a small number of airports currently conduct dual simultaneous approaches to two runways spaced 4300 ft apart using FDADS or DEDS displays, which are the current FAA standards.

The TWG recommended and the FAA approved a procedure requiring the use of a PRM system for straight-in, simultaneous, ILS approaches to two parallel runways spaced less than 4300 ft apart and greater than or equal to 3400 ft apart (FAA, 1996). FMA displays are required for these closely spaced operations, and the radar sensor must provide an update rate not exceeding 1.0 second.

The TWG recommended and the FAA approved a procedure requiring the use of a PRM system for offset, simultaneous, ILS approaches to two parallel runways spaced less than 3400 ft apart and greater than or equal to 3000 ft apart with one localizer offset by 2.5 degrees (FAA, 1997). FMA displays are required and the radar sensor must provide an update rate not exceeding 1.0 second. In addition, simultaneous approach procedural training must be given to all final monitor controllers and aircrews who plan to fly the approaches.

For straight-in, simultaneous, ILS approaches to three parallel runways spaced apart by at least 5000 ft at airports with field elevations of less than 1000 ft msl, the TWG recommended the use of FDADS or DEDS and ASR-9 with a 4.8-second update rate. The conduct of the DEN simulations highlighted the effects of high-altitude air density on aircraft performance. Thus, higher altitude airports need to be examined individually to determine the runway spacing requirements.

The TWG recommended and the FAA approved a procedure requiring the use of FMA displays and ASR-9 with a 4.8-second update rate for straight-in simultaneous ILS approaches to three parallel runways spaced less than 5000 ft apart and greater than or equal to 4300 ft apart at airports with field elevations of less than 1000 ft msl (FAA, 1996).

The MPAP TWG demonstrated that the conduct of simultaneous approach operations to parallel runways could increase the NAS capacity and reduce operational delays. Furthermore, simultaneous approach procedures can be incorporated into many airport operations with a minimal level of expenditure. In many cases, airports can be modified or use their existing runway layouts to allow simultaneous operations as opposed to having to build new runways or new airports. To enhance the safety of these simultaneous approach operations, the MPAP TWG advised adherence to the recommendations cited in this document.

Glossary

At-Risk Blunder - (As defined for the simulations) A blunder in which the two aircraft would have come within 500 ft of one another without controller intervention.

Blunder - (As defined for the simulations) An unexpected turn by an aircraft already established on the localizer toward another aircraft on an adjacent approach.

Breakout - A technique used to direct aircraft out of the approach stream. In the context of close parallel operations, a breakout is used to direct an aircraft away from a deviating aircraft while simultaneous operations are being conducted.

Controller Technical Observer - An individual who observes a monitor controller position during each simulation run. Duties include documenting discrepancies between issued control instructions and actual aircraft responses; assisting in alerting responsible parties to correct any problems which may occur during the test (e.g., computer failure, stuck microphone); assisting controllers in preparation of reports; and documenting their evaluation of the data in a Technical Observer report at the end of the simulation.

Final Monitor Aid (FMA) - A high resolution color display that is equipped with the controller alert system hardware and software used in the PRM system. The display includes alert algorithms providing the target predictors, a color change alert when a target penetrates or is predicted to penetrate the NTZ, a color change alert if the aircraft transponder becomes inoperative, synthesized voice alerts, digital mapping, and like features contained in the PRM system. (FAA, 1996; FAR, 1996)

Final Monitor Controller - Air Traffic Control Specialist assigned to radar monitor the flight paths of aircraft during simultaneous parallel and simultaneous close parallel ILS approach operations. Each runway is assigned a final monitor controller during simultaneous parallel and simultaneous close parallel ILS approaches. Final monitor controllers shall utilize the Precision Runway Monitor system (PRM) during simultaneous close parallel ILS approaches. (FAA, 1996)

Flight Technical Error (FTE) - (As defined for the simulations) The accuracy with which the pilot controls the aircraft as measured by the actual aircraft position with respect to the desired aircraft position. It does not include blunders.

Indicated Airspeed (IAS) - The speed shown on the aircraft airspeed indicator. This is the speed used in pilot/controller communications under the general term, airspeed. (FAA, 1996; FAR, 1996)

Instrument Landing System (ILS) - A precision instrument approach system which normally consists of the following electronic components and visual aids: localizer, glide slope, outer marker, middle marker, and approach lights. (FAA, 1996; FAR, 1996)

Instrument Meteorological Conditions (IMC) - Meteorological conditions expressed in terms of visibility, distance from cloud, and ceiling less than the minima specified for visual meteorological conditions. (FAA, 1996; FAR, 1996)

Localizer Offset - An angular offset of the localizer from the extended runway centerline in a direction away from the No Transgression Zone (NTZ) that increases the Normal Operating Zone (NOZ) width. An offset requires a 50-foot increase in decision height (DH) and is not authorized for CAT II and CAT III approaches. (FAA, 1996)

Multiple Parallel Approach Program Technical Work Group (MPAP TWG) - A group of FAA employees representing several different offices (e.g. Secondary Surveillance Product Lead, Office of System Capacity and Requirements) that assembles to make recommendations on multiple parallel approach procedures.

National Airspace System (NAS) - The common network of U.S. airspace; air navigation facilities, equipment and services, airports or landing areas; aeronautical charts, information and services; rules, regulations and procedures, technical information and manpower and material. Included are system components shared jointly with the military. (FAA, 1996; FAR, 1996)

No Transgression Zone (NTZ) - A 2000 foot wide zone, located an equal distance between parallel runway final approach courses, in which flight is not allowed. (FAA, 1996)

Normal Operation Zone (NOZ) - The operating zone within which aircraft flight remains during normal independent simultaneous parallel ILS approaches. (FAA, 1996)

Nuisance Breakout (NBO) - (As defined for the simulations) An event in which an aircraft is broken out of its final approach for reasons other than a blunder, loss of longitudinal separation, or lost beacon signal (i.e., aircraft goes into coast).

Pilot Technical Observer - A pilot who participates in the simulation as a flight simulator site coordinator. The pilot technical observer evaluates operational aspects of the simulation at the sites and is the conduit to the FAA Technical Center for that area/phase of the simulation.

Precision Runway Monitor (PRM) System - A system that provides air traffic controllers with high precision secondary surveillance data for aircraft on final approach to closely spaced parallel runways. High-resolution color monitoring displays (FMAs) are required to present surveillance track data to controllers along with detailed maps depicting approaches and the no transgression zone. (FAA, 1996; FAR, 1996)

Simultaneous ILS Approaches - An approach system permitting simultaneous ILS/MLS approaches to airports having parallel runways separated by at least 4,300 ft between centerlines. Integral parts of the total system are ILS/MLS, radar, communications, ATC procedures, and appropriate airborne equipment. (FAA, 1996; FAR, 1996)

Test Criterion Violation (TCV) - (As defined for the simulations) An event that occurs when the CPA between two aircraft after the initiation of a blunder is less than 500 ft.

Total Navigation System Error (TNSE) - (As defined for the simulations) The difference between the actual flight path of the aircraft and the path it is intending to fly. It is caused by FTE, avionics error, ILS signal error, and weather.

Acronyms

ASR-9	Airport Surveillance Radar Model #9
ATC	Air Traffic Control
ATL	Atlanta International Airport
DEDS	Digital Entry Display Subsystem
DEN	Denver International Airport
DFW	Dallas/Fort Worth International Airport
E-SCAN	Electronic Scanning Radar
FAA	Federal Aviation Administration
FDADS	Fully Digital Alphanumeric Display System
FMA	Final Monitor Aid
ILS	Instrument Landing System
JFK	John F. Kennedy International Airport
MEM	Memphis International Airport
MPAP	Multiple Parallel Approach Program
MSL	Mean Sea Level
NAS	National Airspace System
NBO	Nuisance Breakout
NOZ	Normal Operating Zone
NTZ	No Transgression Zone
PHL	Philadelphia International Airport
PIT	Pittsburgh International Airport
PRM	Precision Runway Monitor
RDU	Raleigh/Durham International Airport
TCV	Test Criterion Violation
TNSE	Total Navigation System Error
TWG	Technical Working Group

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