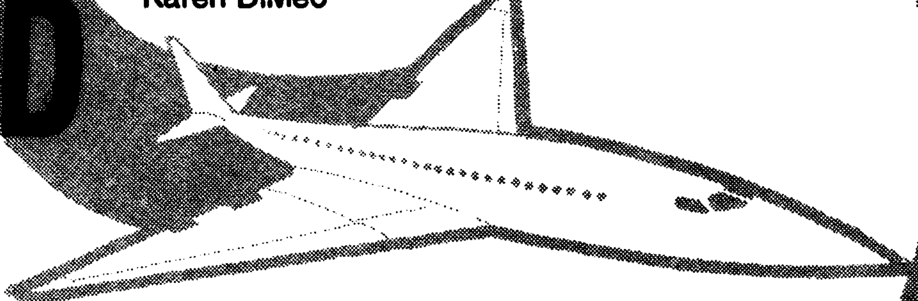
DOT/FAA/CT-94/36

FAA Technical Center
Atlantic City International Airport,
N.J. 08405

# 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



Richard Ozmore
Karen DiMeo



June 1994

Final Report



U.S. Department of Transportation
Federal Aviation Administration

## NOTICE

**Technical Report Documentation Page**

| | | |
|---|---|---|
| 1. Report No.<br>DOT/FAA/CT-94/36 | 2. Government Accession No. | 3. Recipient's Catalog No. |
| 4. Title and Subtitle<br>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 | | 5. Report Date<br>June 1994 |
| | | 6. Performing Organization Code<br>ACD-340 |
| 7. Authors<br>Richard E. Ozmore and Karen DiMeo, ACD-340 and ATC Simulation Team | | 8. Performing Organization Report No.<br>DOT/FAA/CT-94-36 |
| 9. Performing Organization Name and Address<br>CTA INCORPORATED<br>2500 English Creek Avenue, Suite 1000<br>Pleasantville, NJ 08232 | | 10. Work Unit No. (TRAIS) |
| | | 11. Contract or Grant No.<br>F2006D |
| 12. Sponsoring Agency Name and Address<br>U.S. Department of Transportation<br>Federal Aviation Administration<br>Research and Development Service<br>Washington, D.C. 20591 | | 13. Type or Report and Period Covered<br>Test Report<br>November 1992 - April 1994 |
| | | 14. Sponsoring Agency Code<br>ARD-100 |

15. Supplementary Notes

ATC Simulation Team: T. Fischer, R. Jones, E. Neiderman, S. Courington, J. Auflick, S. Morrow, CTA INCORPORATED

16. Abstract

This simulation tested controllers' ability to effectively resolve conflicts for the proposed triple simultaneous instrument landing system (ILS) approach operation at the new Denver International Airport (DIA). Controllers used Final Monitor Aid (FMA) displays. The radar sensor simulated had the performance of an Airport Surveillance Radar (ASR)-9 system enhanced to provide improved target resolution capabilities.

Aircraft blunders were used to test the controllers' ability to maintain a distance of 500 ft between aircraft during critical situations. Four criteria were developed by the Multiple Parallel Approach Program (MPAP) Technical Work Group (TWG) to evaluate the study: 1) the number of Test Criterion Violations (TCV's) relative to the total number of "at risk" blunders; 2) the frequency of nuisance breakouts (NBO's) and No Transgression Zone (NTZ) entries; 3) the operational assessments from participating controllers, technical observers, and MPAP TWG members; and 4) a risk analysis relative to one fatal accident per 25,000,000 approaches.

The MPAP TWG, technical observers, and participating controllers agreed that the triple simultaneous ILS approach operation at DIA was acceptable, as simulated.

| 17. Key Words | 18. Distribution Statement |
|---|---|
| Simultaneous Parallel ILS, ILS Approaches, Real-Time Simulation, Air Traffic Control, Final Monitor Aid, Denver International Airport | This documentation is available to the public through the National Technical Information Service, Springfield, Virginia 22161 |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 115 | |

Form DOT F 1700.7 (18_72) Reproduction of completed page authorized

# ACKNOWLEDGEMENTS

Contributions from the following organizations were indispensable and highly appreciated:

Multiple Parallel Approach Program Technical Work Group:

Gene Wong, Research and Development Service (ARD-100) and TWG Chairman; Brenda Mileski, Air Traffic Rules and Procedures Service (ATP-120); Robert Berlucchi, Office of Air Traffic System Management (ATM-120); Victor Smith, Air Traffic Plans and Requirements Service (ATR-120); D. Spyder Thomas, Flight Standards Service (AFS-405); David N. Lankford, Aviation System Standards (AVN-210); Dominic Johnson, Office of System Capacity and Requirements (ASC-205); Ron Uhlenhaker, Southwest Region (ASW-1C); Harold R. Anderson, National Air Traffic Controllers Association.

FAA Technical Center:

Engineering, Research, and Development Service, Directorate for Aviation Technology, ATC Technology Branch (ACD-340)

Engineering, Test, and Evaluation Service:
NAS Facilities Software Engineering Division (ACN-400);
NAS Facilities Hardware Engineering Division (ACN-500);
NAS Facilities Operations Division (ACN-600)

Other FAA:

Northwest Mountain Region (ANM)
Great Lakes Region (AGL)
Southern Region (ASO)

Contractors:

CRM
NYMA
TRW
MIT/Lincoln Laboratory
MITRE Corporation

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

APPENDIXES

## LIST OF ILLUSTRATIONS



## LIST OF TABLES

# EXECUTIVE SUMMARY

This simulation tested controllers' ability to effectively resolve conflicts for the proposed triple simultaneous instrument landing system (ILS) approach operation at the new Denver International Airport (DIA). A model of DIA with triple simultaneous parallel approaches, spaced 5280 and 7600 feet (ft) apart, and a field elevation of 5431 ft at an ambient temperature of 16°C, or 61°F, was incorporated into the simulation. Controllers used Final Monitor Aid (FMA) displays to monitor final approach traffic. The radar sensor simulated had the performance of an Airport Surveillance Radar (ASR)-9 system enhanced to provide improved target resolution capabilities.

Aircraft blunders were used to test the controllers' ability to maintain a distance of 500 ft between aircraft during critical situations. A blunder occurred when one aircraft (i.e., a Target Generation Facility (TGF) aircraft), established on an ILS approach, made an unexpected turn toward an aircraft on an adjacent approach, usually a flight simulator. Eighty percent of the blunders were 30-degree turns off of the localizer, 17 percent were 20-degree turns, and 3 percent were 10-degree turns. Pilots of 70 percent of the blundering aircraft were instructed to disregard controller communications, simulating an inability to correct the blunder. Statistical analyses evaluated the 30 degree, "no-response" blunders that were initiated into flight simulator targets. A test criterion violation (TCV) occurred when the separation between aircraft was less than 500 ft. Blunders that would have resulted in an aircraft miss distance of less than 500 ft without controller intervention were classified as "at risk."

Four criteria were developed by the Multiple Parallel Approach Program (MPAP) Technical Work Group (TWG) to evaluate the study:

1. The number of TCV's relative to the total number of "at risk" blunders;

2. The frequency of nuisance breakouts (NBO's) and No Transgression Zone (NTZ) entries;

3. The operational assessments from participating controllers, technical observers, and MPAP TWG members; and

4. A risk analysis relative to one fatal accident per 25,000,000 approaches.

During the simulation, two blunders resulted in TCV's. Analyses indicated that 186 blunders would have resulted in an aircraft miss distance of less than 500 ft without controller intervention. In total, controllers were able to successfully resolve 98.9 percent of all "at risk" blunders.

An evaluation of NBO's and NTZ entries was conducted to assess total navigation system error (TNSE). NBO's occurred in 0.2 percent of the non-blunder approaches. In addition, the DIA runway spacings were sufficiently large that aircraft did not enter the NTZ as a consequence of TNSE.

Participating air traffic controllers reported, "In this simulation the air traffic controller team believes they safely monitored triple simultaneous ILS approaches at the simulated new Denver Airport using the FMA." Technical observers unanimously agreed that controllers "had little difficulty detecting and resolving blunders." It was also noted that, "the controllers seemed so comfortable with the position that time was taken to evaluate options, even after a blunder had occurred."

The risk assessment indicated the operation meets the target risk of 1 fatal accident per 25,000,000 approaches.

The MPAP TWG evaluated the controllers effectiveness at resolving conflicts, the frequency of NTZ entries and NBO's, and the ability of the system to maintain the predetermined target level of risk (1 fatal accident per 25,000,000 approaches). Based upon their evaluations, the TWG concluded that the triple simultaneous ILS approach operation at DIA as simulated was acceptable.

## 1. INTRODUCTION.

The ability of the National Airspace System (NAS) to meet future air traffic demands has been a serious concern at the national level. With the growing number of aircraft in the NAS and increasing congestion at the nation's airports, the Federal Aviation Administration (FAA) has been developing programs to improve NAS capacity since the early 1980's. These programs have attempted to reduce air traffic delays by meeting the increasing demands on the NAS. Programs to redesign the existing airways structure include proposals to provide a more modern air traffic flow management capability and major programs to incorporate state-of-the-art automation technology throughout the system.

A major factor influencing system capacity has been the number of aircraft that can land at an airport during instrument meteorological conditions (IMC). Limitations imposed by current airport runway configurations and associated air traffic separation criteria contribute to the capacity problem, particularly as they relate to aircraft executing instrument landing system (ILS) approaches under IMC. Increases in the number of simultaneous ILS approaches during IMC will increase airport capacity and potentially improve traffic flow throughout the NAS.

The Denver-Stapleton International Airport was faced with the capacity problems mentioned above, as well as noise level and environmental concerns. To deal with these issues and to avoid potential future problems, the new Denver International Airport (DIA) is being constructed. The size, location, and design of the new airfield will help overcome capacity issues, such as congestion and delays, as well as protect surrounding environmental interests. DIA's high field elevation, however, will affect airport and aircraft operations in many ways, especially with respect to high density altitude. High density altitude is a concern, particularly during the final approach phase of flight, as it affects aircraft performance.

### 1.1 BACKGROUND.

Density altitude has been defined to be "a measure of air density used to determine aircraft performance" (Jeppeson Sanderson, 1983). Generally, as air density decreases (i.e., as a function of ambient temperature, altitude, and barometric pressure), density altitude increases. Any significant increase in density altitude can result in drastic reductions in engine power output, propeller efficiency, and aerodynamic lift (Jeppeson Sanderson, 1990). This degradation of performance occurs throughout the airplane's operational envelope, but is especially noticeable in takeoff and rate of climb performance (FAR/AIM, 1991).

One specific effect of high density altitude is higher true airspeed (TAS). TAS is the actual speed of an airplane through the air. As altitude or air temperature increases, the density of the air decreases. Indicated airspeed (IAS) is the reading taken directly from the airspeed indicator on an airplane. It does not reflect variations in air density as higher altitudes are reached. For a given IAS, this means the TAS increases with altitude (Jeppeson Sanderson, 1990). Aircraft fly the same indicated airspeed at both high density and sea level airports. Table 1 demonstrates the differences between indicated airspeed and true airspeed within varying high density altitudes.

TABLE 1. TRUE AIRSPEED VS. INDICATE AIRSPEED

| | True Airspeed | | |
|---|---|---|---|
| Indicated Airspeed | Density Altitude (Feet) 6000 | 9000 | 11,000 |
| 130 | 142 | 149 | 154 |
| 140 | 153 | 160 | 165 |
| 150 | 164 | 172 | 177 |
| 160 | 175 | 183 | 189 |
| 170 | 186 | 195 | 201 |
| 180 | 197 | 206 | 213 |
| 190 | 208 | 218 | 225 |
| 200 | 219 | 229 | 236 |
| 210 | 230 | 240 | 248 |
| 220 | 241 | 252 | 260 |

If an airplane on approach in a high density altitude environment must take evasive actions to avoid a blundering aircraft, the reduced aircraft performance caused by higher density altitude could become a critical factor in its ability to avoid a collision. High density altitude affects blunder resolution in two ways. First, the blundering aircraft has a higher TAS, therefore, a higher cross-track velocity. Second, the evading aircraft's higher TAS would result in a larger turn radius, therefore, a decreased ability to avoid the blundering aircraft.

If controllers could immediately detect blunders, there would be less potential for a conflict to occur. The high resolution and the computer generated controller alerts of the Final Monitor Aid

(FMA) display were designed to assist controllers in the early detection and resolution of blunders. Studies have shown that the FMA displays provide the controllers with increased time to either correct the course of a blundering aircraft or to issue conflict resolution instructions to the pilots of aircraft on adjacent parallel approaches (CTA, 1993 Report in progress). Quicker controller response times available with the FMA will be particularly useful in counteracting the effects of high density altitude.

### 1.1.1 Multiple Parallel Approach Program (MPAP).

The FAA established the MPAP Technical Work Group (TWG) to evaluate multiple parallel simultaneous ILS approaches. Previous simulations conducted by the MPAP have evaluated controller blunder detection and conflict resolution performance using both the Automated Radar Terminal System (ARTS) and the Precision Runway Monitor (PRM) System (see appendix A). A simulation completed in September of 1990 (Phase IV.b of the MPAP) examined triple simultaneous ILS approaches to runways spaced 5000 feet (ft) apart, near sea level (i.e., field elevation of 600 ft), with even runway thresholds. Controllers used current ARTS displays and a simulated Airport Surveillance Radar (ASR) system with a 4.8 second (s) update rate. Findings from this simulation indicated these operations are acceptable near sea level. The Phase IV.b study, however, did not address the effects of high density altitudes on the operation of multiple parallel approaches.

Using the above simulation as a baseline, the MITRE Corporation conducted analyses that evaluated blunder resolution performance at high runway elevations. These analyses found that high airport/runway elevation (5400 ft) can significantly degrade blunder resolution performance. An empirical examination of the effect of high density altitude became increasingly important as DIA, with a field elevation of 5431 ft, neared completion.

#### 1.1.1.1 Simulation Using the ARTS IIIA Display.

A study was conducted to evaluate controller blunder resolution performance and total navigation system error (TNSE) (based on the frequency of nuisance breakouts (NBO's) and No Transgression Zone (NTZ) entries). This simulation was conducted to yield data for an operational assessment and a risk assessment of parallel operations at a generic high density altitude airport. This simulation studied simultaneous ILS approaches to both triple and quadruple parallel runways at a field elevation (i.e., pressure altitude) of 5431 ft. Final monitor controllers used ARTS IIIA displays and a radar with a 4.8 second update rate.

The high density altitude simulation using ARTS IIIA displays was conducted from September 8 to September 25, 1992, at the FAA

Technical Center. Indicated air speeds of 180 knots (kn) were assigned for turbojets, 150 kn for turboprops, and 120 kn for twin engine piston aircraft. Preliminary data indicated that during the simulation, a total of 746 blunders were initiated, 376 for the triple approach configuration and 370 for the quadruple approach configuration. Approximately 74 percent of all blundering aircraft did not respond to air traffic control (ATC) commands.

Preliminary data analyses indicated that the test criterion violations (TCV's) (aircraft separated by less than or equal to 500 feet) exceeded the test criterion rate of 2 percent set to evaluate the operation. However, the number of NBO's and NTZ entries was acceptable based on the criteria set by the TWG.

Qualitative data from the controller questionnaires indicated that when the ARTS IIIA display was used, it was "very difficult" to perform the monitor controller task. The controllers also disagreed with the statement that "triple independent IFR approaches to runways spaced 5280 and 7600 ft apart can be safely conducted as simulated."

After reviewing the preliminary data, controller opinions, and technical observer comments, it was decided that an additional high density altitude simulation should be conducted using the Full Digital ARTS III Display System (FDADS) and data specific to DIA. To make this simulation site specific to DIA, additional information about air traffic and airport operations was requested from representatives from the Northwest Mountain Region and the Air Traffic Division of the FAA.

1.1.1.2 Simulation Using the FDADS.

A second simulation was conducted to evaluate the performance of controllers monitoring triple simultaneous approaches to parallel runways using the FDADS. In this simulation, assigned aircraft speeds were kept at 170 kn for all turbojet and turboprop aircraft. Additionally, twin-engine piston aircraft were assigned a 150 kn IAS. The three-week simulation began on November 16, 1992, but was terminated on November 18, 1992, because preliminary data indicated that the operation would not meet performance goals set by the TWG.

Preliminary data for aircraft separation, NBO's, and NTZ entries were reviewed daily. At the end of the second day of simulation, 1169 aircraft were handled, 87 blunders were initiated into flight simulators, and 5 TCV's were reported. Although the data for NTZ entries and NBO's appeared to be within the goals set by the TWG, this sample of data (5 TCV's out of 87 blunders = 5.7 percent TCV rate) exceeded the blunder resolution performance goal set by the TWG. Additionally, TWG members, simulation participants, and observers from FAA Headquarters and the

Northwest Mountain Region also agreed that the operation, as simulated (i.e., using the FDADS), would not meet the evaluation criteria. Documents supporting this decision can be found in appendixes B, C, and D.

Beginning November 18, 1992, the remainder of the simulation was conducted using the FMA with a radar update rate of 4.8 seconds. The FMA was used because the high resolution color display and the automated visual/aural alarms were shown to improve blunder resolution performance (Fabrizi, M., Massimini, S., and Toma, N., 1993).

## 2. SIMULATION DESIGN.

This study was a real-time ATC simulation to evaluate final approach operations at DIA. Controllers used FMA displays to monitor triple simultaneous parallel ILS approaches under IMC.

The following sections will discuss the parameters, equipment, personnel, and procedures used for the simulation.

### 2.1 SIMULATION PARAMETERS.

In order to assess the viability of the triple parallel runway configuration, certain operational parameters were defined and included in the DIA simulation. Parameters, including the pressure altitude, temperature, airport configuration, and aircraft mix, were derived from information provided by the Northwest Mountain Region.

#### 2.1.1 Density Altitude.

As explained in earlier sections, DIA will be located in a region where high density altitude can be a problem for aircraft on approach. To account for the potentially dramatic effect of high density altitudes on aircraft performance, all aircraft in this simulation were programmed to perform at a pressure altitude of 5431 ft on a 16°C day, which is equivalent to a 6500 ft mean sea level (M.S.L.) altitude at standard temperature and pressure. The temperature was based on a review of the 90th percentile surface temperature during instrument operations at Denver-Stapleton Airport.

#### 2.1.2 Airport Configuration and Flight Patterns.

DIA was modeled with three 12,000-ft parallel runways with staggered thresholds (figure 1). Runways 17L and 17R were spaced 5280 ft apart, while the 17R and 16 runways were spaced 7600 ft apart (centerline to centerline). Outer markers (OM), turn-on altitudes, and glide slope intercepts (GSI) for each runway are

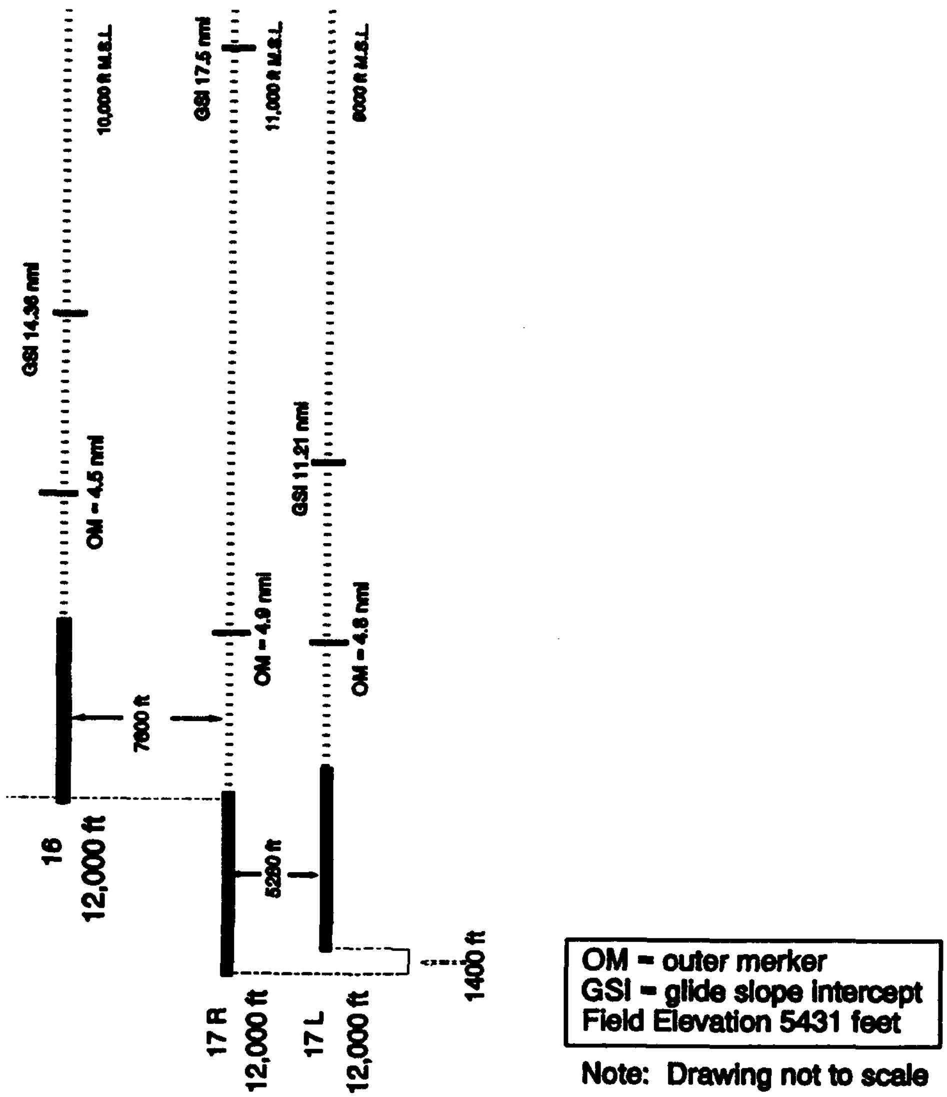



FIGURE 1. AIRPORT CONFIGURATION

presented in table 2. Aircraft executed 30-degree localizer intercepts approximately 3 nautical miles (nmi) from their respective GSI point.

TABLE 2. DIA ILS RUNWAY TURN-ON ALTITUDES

| Runway | Outer Marker (nmi) | Turn-On Altitude (ft) | Glide Slope Intercept (nmi) |
|---|---|---|---|
| 16 | 4.5 | 10,000 | 14.36 |
| 17R | 4.9 | 11,000 | 17.5 |
| 17L | 4.8 | 9,000 | 11.21 |

Although minor differences between touchdown zone elevations are planned for the runways at DIA, the simulation used a common touchdown zone altitude for all three runways because of current limitations in the simulation capabilities of the Target Generation Facility (TGF). GSI points also varied from the actual DIA operation due to the common touchdown zone elevation. The MPAP TWG and representatives from the Northwest Mountain Region and DIA concurred that the differences were minimal and would not affect controller performance.

Approach plates were produced based upon the simulated airport configuration (see appendix E). The approach plates included runway layouts, spacings, and arrival frequencies. All flight simulator approaches in the simulation were made using these approach plates.

<u>2.1.3 Blunders</u>.

Aircraft blunders were used to test the controllers' ability to maintain a 500 ft distance between aircraft during critical situations. During each run of the simulation, blunders transpired without warning to the controllers. A blunder occurred when one aircraft, established on the ILS localizer approach, made an unexpected turn towards a second aircraft on an adjacent approach course.

In normal operations, the controller detects the deviation of the blundering aircraft, issues instructions to resolve the situation, and the pilot verbally responds and complies as instructed. However, in some situations, the blundering aircraft may be unable to correct its deviation and may pass through the NTZ, and cross the adjacent approach course. This inability to correct the blunder can arise from several causes (e.g., communications, hardware failure, human error, etc.). To simulate this situation, pilots of blundering aircraft were sometimes instructed to disregard controller communications, thereby not correcting the blunder. A blunder with this condition will be referred to as a "no-response" blunder in this report.

2.1.3.1 Blunder Scripts.

Blunder scripts were developed from the traffic samples to assist the test director with creating potential TCV's. All blunders were initiated by TGF aircraft and occurred after vertical separation had been lost with aircraft on an adjacent approach. Sixty percent of the blunders were scripted to occur between the 17L and 17R runways, with the remaining 40 percent occurring between runways 17R and 16.

Eighty percent of the blunders were scripted to be 30-degree turns off of the localizer, 17 percent were scripted to be 20-degree turns, and 3 percent of the blunders were scripted to be 10-degree turns. In order to simulate worst case scenarios, 70 percent of the blunders were scripted as no-response blunders.

Only 30 degree, no-response blunders initiated into flight simulator targets were assessed in the statistical evaluation of the data. In previous simulations, controllers have been able to resolve 10 and 20-degree turns, and these blunders only contributed to about 1 percent of the total risk.

2.1.3.2 Closest Point of Approach (CPA) Prediction Tool.

The CPA Prediction Tool is a software tool used by the test director in creating potential TCV's. The software presented the call signs of the blundering and the evading aircraft in a window on the test director's display. For each aircraft pair, the CPA Prediction Tool used aircraft velocities, headings, and blunder degree in the real-time calculation of a predicted CPA. The time until the CPA would be reached, given an immediate execution of the blunder, was also calculated. This information was updated with each radar update, every 4.8 seconds, and was presented with the aircraft call signs.

The window had the capacity to accommodate four aircraft pairs at one time. The aircraft pairs which appeared in the window were determined by the scripted blunder scenarios; however, the test director had the capability to create blunders that were not designated on the blunder scripts. The test director also had the capability to delete aircraft pairs from the window.

2.1.4 Traffic Samples.

The traffic samples were based on actual arrival traffic into Denver-Stapleton Airport. Each of the samples was composed of a representative population of propeller-driven, turboprop, and turbojet aircraft. Sixty-four percent of each traffic sample were air carriers, 30 percent were commuters, and approximately 6 percent of each sample were general aviation aircraft.

All turbojet and turboprop aircraft were assigned an initial approach speed of 170 kn IAS, plus or minus 10 kn. Twin-engine piston aircraft were assigned a 150 kn IAS, plus or minus 10 kn. Additionally, each traffic sample included two to three speed overtakes during each run to provide additional realism to the controllers.

### 2.1.5 TNSE Model.

Aircraft position, with respect to the extended runway centerline, the NTZ, and to other aircraft, must be realistically presented on the radar display to accurately assess the controllers' ability to detect a blunder. In developing the navigational error model for TGF aircraft, two criteria were used. First, aggregate errors must accurately reflect the TNSE distribution of aircraft as they fly ILS approaches in the operational environment. Second, displayed flight paths of aircraft must look reasonable to the controllers; i.e., deviations from the localizer centerline should appear to be typical of aircraft flying an ILS approach during IMC. The navigational error model used for this simulation was based upon data collected at Chicago O'Hare International Airport (ORD) (Timoteo, D. and Thomas, J., 1989), Memphis International Airport (MEM) (PRM Program Office, 1991), Los Angeles International Airport (LAX) (DiMeo, K. et al, 1993, Report in progress), and data collected at the FAA Technical Center investigating TNSE at high density altitudes using flight simulators.

Review of the flight tracks collected at ORD and MEM indicated that the TNSE generally consisted of a combination of two elements. First, the aircraft often flew a course which was asymptotic with the actual runway centerline extended. Second, about this course there were often cyclic and periodic deviations. To simulate this pattern of flight, a system using "pseudoroutes" and "fans" about the pseudoroutes was developed. Further, preliminary LAX data supports the assumption of linearity of the TNSE model out to 20 nmi.

As shown in figure 2a, a pseudoroute was defined to be a straight line which simulated the asymptotic element of navigational error. It began at the center of the runway threshold and extended outward beyond 20 nmi. Starting at the runway threshold, pseudoroutes were offset from the ILS localizer centerline based upon a normal distribution with a mean of 0 degrees and a standard deviation of approximately 0.29 degrees.

A fan-shaped envelope was added on either side of the pseudoroute to accurately represent the deviations around the pseudoroute.

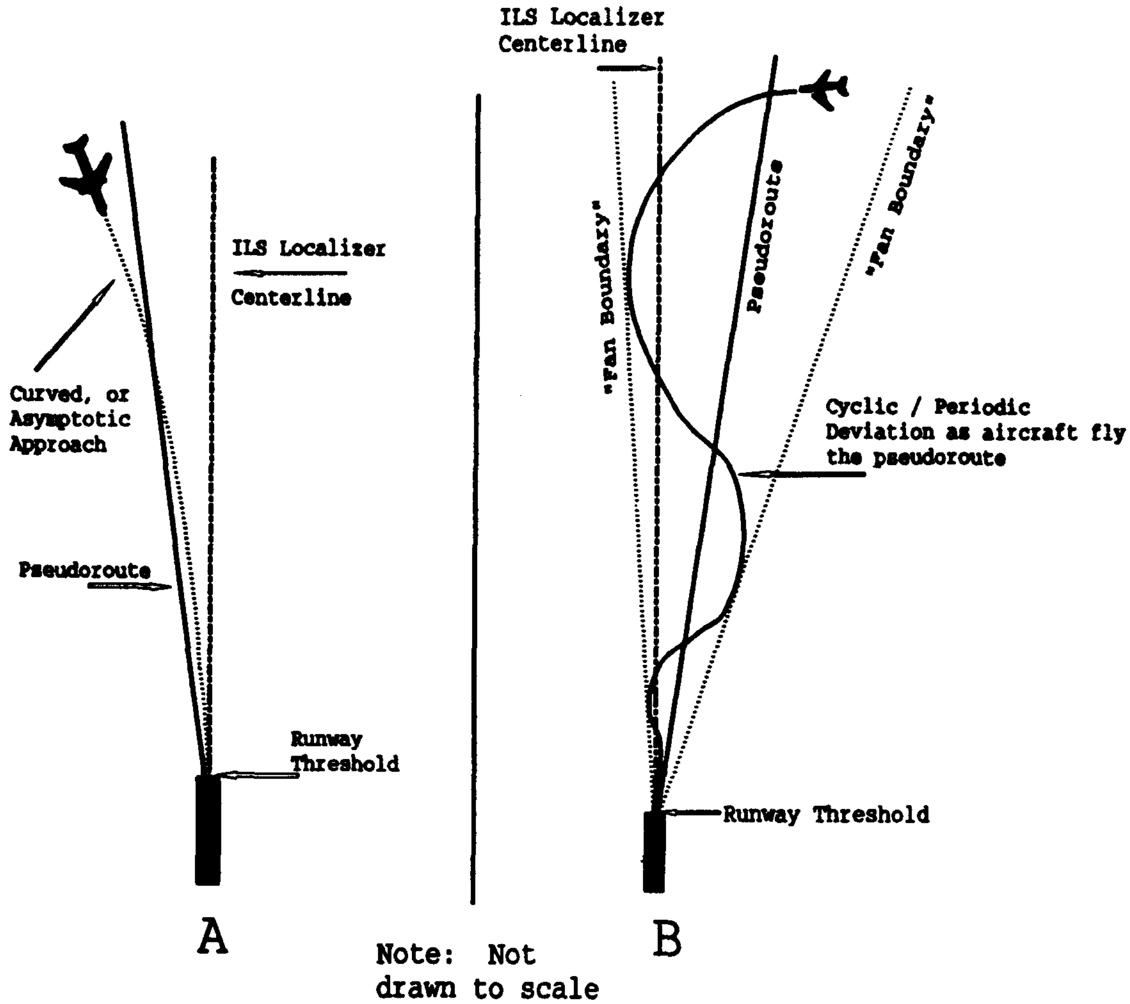



FIGURE 2. CURVED ASYMPTOTIC APPROACH (A) AND AIRCRAFT DEVIATIONS (B)

As seen in figure 2b, the fan began at the runway threshold and was bisected by the pseudo-route. As aircraft traveled along the pseudoroute, they flew between the fan boundaries. Individual aircraft began a half-standard rate turn (1.5 degrees per second) towards the opposite fan boundary after coming within plus or minus 2 seconds time of the fan boundary. As the aircraft approached the opposite fan boundary, it once again made a slow turn back towards the first boundary. This process was repeated throughout the approach until the aircraft landed or was given a heading change by the controller.

The resultant flight paths satisfied the first criteria by producing navigational error distributions that corresponded closely with those found in previous data. In addition, the new flight paths also satisfied the second requirement since they provided realistic visual targets for the controllers.

#### 2.1.6 Radar Error.

The representation of aircraft positions on controllers' displays may differ from the actual aircraft position due to inaccuracies in the radar system. Therefore, to accurately represent the operational environment, radar error was included as a parameter in the DIA simulation. The radar error model for this simulation as based upon the performance characteristics of an ASR-9 system enhanced to provide improved target resolution capabilities. The range error had a mean equal to zero and a standard deviation of 185 ft.

The DIA simulation assumed a radar system with 2.7 milliradians azimuth accuracy or better, and the capability to resolve two aircraft at 20 nmi separated by 0.9 degrees or more. Thus, the radar requirements were: 1) normal azimuth accuracy of 2.7 milliradians, and 2) resolution (resolving power) of 2 aircraft targets at the same range (20 nmi) separated by 0.9 degrees or more. The second requirement was equivalent to resolution of 2 targets slightly more than 2000 feet apart at 20 nmi.

## 2.2 EQUIPMENT.

This section describes the equipment that was used during the simulation.

### 2.2.1 TGF.

The TGF is an advanced simulation system designed to support testing of current and future ATC systems at the FAA Technical Center. The functionality of the TGF system is partitioned in three subsystems: Simulation Pilot, Target Generation, and Development and Support.

The Simulation Pilot Subsystem consists of both the Simulation Pilot Workstations (SPW's) and the Exercise Control Workstations (ECW's). Each workstation consists of a 386-based personal computer, running under DOS. The SPW's are mounted in pairs to a customized table, which contains a communication system that provides an audio interface with air traffic controllers. The Simulation Pilot Operators (SPO's) use the SPW's to "fly" the simulated aircraft and command them according to ATC instructions.

The Target Generation Subsystem consists of both a Target Generation (TG) chassis and External Interface (EI) chassis. Each chassis is based upon a VME architecture employing 68030 processor boards. The TG performs all modeling within the TGF and correlates dynamic data such as: aircraft state vectors, radar performance, weather vectors and states, with known flight plan and adaptable data. The EI is responsible for creating the exact form and content of the digitized radar messages sent to the ATC system under test. Controller-pilot voice communications are processed through an AMECOM voice communications system.

The Development and Support Subsystem is based on a SUN architecture that employs a SUN 3/470 as a file server, a set of peripherals, and the Sun 3/80 diskless computer as the Development and Support Workstation (DSW's). The Development and Support Subsystem provides the basic post-exercise data reduction and analysis capabilities. In addition, this subsystem provides the capabilities necessary to maintain and/or enhance the TGF software.

In total, the TGF models a logical view of the ATC environment, including long and short range radar sensors, controlled airspace, weather conditions, air traffic, and aircraft performance. The TGF configuration in respect to this simulation is shown in figure 3.

<u>2.2.2 FMA Displays</u>.

A digital video map of DIA was presented to controllers on three FMA displays located in the Systems Display Laboratory at the FAA Technical Center. The FMA is a high resolution color display that is equipped with the controller alert system hardware and software which is 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.

The graphics for the monitors were generated by a Metheus graphics driver, and the display system was driven by a micro-VAX computer. In addition to the mapping information currently

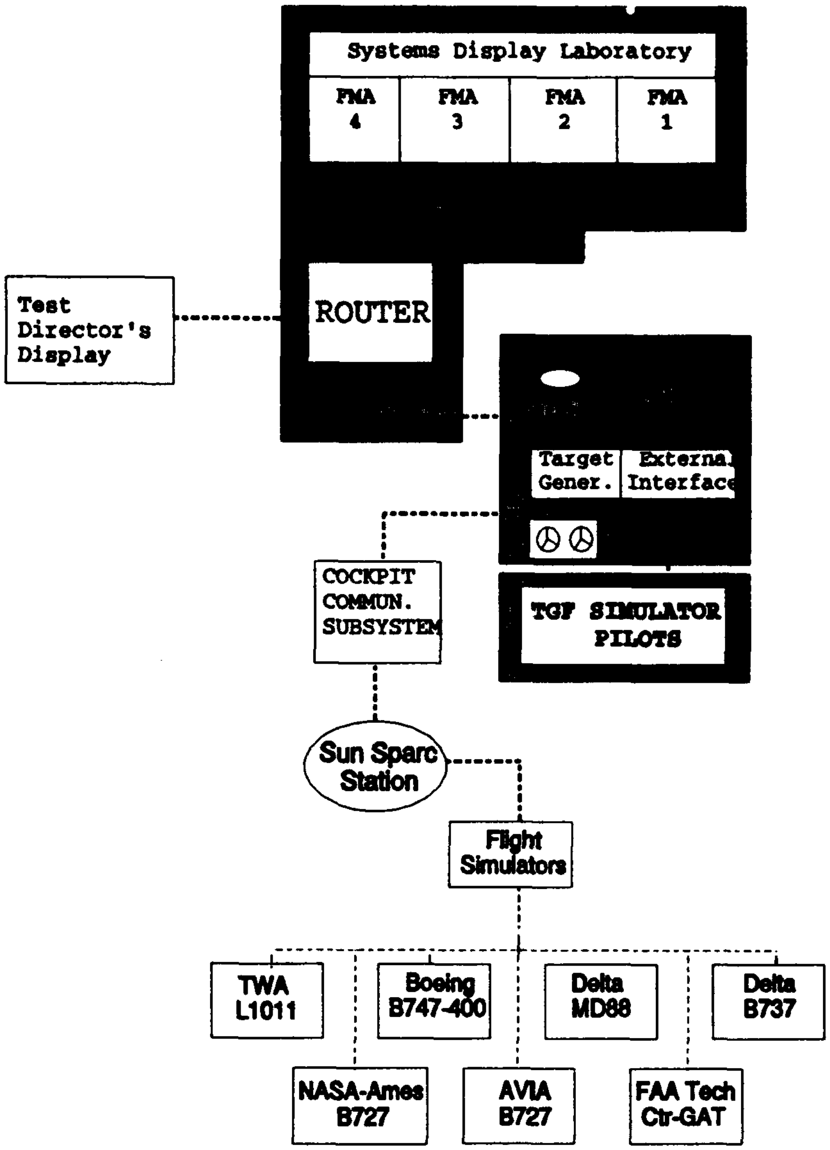



FIGURE 3. TARGET GENERATION FACILITY CONFIGURATION

provided by ARTS displays, FMA's provide controllers with features to aid them in the early detection of blunders and the control of airspace. These include independent axes expansion capabilities, color coding, aircraft predictor lines, and audio and visual warnings.

With FMA's, vertical and horizontal (Y-X) axes can be expanded independently, in accordance with site variable requirements, to improve the controller's ability to detect aircraft movement away from the extended runway centerline. For this simulation, the ratio for the horizontal axis was 6 times, while the vertical axis was 1.5 times on the controllers' displays.

For each of the three runways, ILS approach centerlines were displayed as dashed white lines, where each dash and each space between dashes were scaled to represent 1 nmi. Additional solid light blue lines were on each side of the ILS centerline to delineate 200 foot-deviations from the localizer. The 2000-ft wide NTZ, between extended runway centerlines, was outlined in red.

A predictor line was used in the generation of the audio and visual alerts. The predictor line, which was affixed to each aircraft target, indicated where the aircraft would be in 10 s if it continued on the same path. The predictor line provided the controller with advance notice of the path of the aircraft. The predictor line can be varied, but for this simulation it was set to 10 s.

Aircraft targets and alphanumeric data blocks were presented in green, as long as they maintained an approach within the normal operating zone (NOZ). When the predictor line indicated that an aircraft was within 10 s of entering the NTZ, the green aircraft target and data block changed to yellow. An auditory warning also sounded (e.g., "American 211") to notify the controller of the impending NTZ entry. If the aircraft entered the NTZ, the yellow aircraft target and data block immediately changed to red.

2.2.3 Flight Simulators and Simulator Parameters.

Six Part 121 aircraft simulators and one general aviation trainer (GAT) were integrated into the simulation. This group included simulators from: NASA-Ames, Moffett Field, CA; AVIA Inc., Costa Mesa, CA; Boeing Inc., Seattle, WA; Trans World Airlines, St. Louis, MO; Delta Airlines Inc., Atlanta, GA, and the FAA Technical Center, Atlantic City International Airport, NJ. Having the flight simulators as an integral part of the simulation increased the validity of the findings by providing a representative sample of NAS users (i.e., currently licensed airline pilots who staffed the simulators). It also generated more accurate data with respect to aircraft and pilot performance.

Flight simulators assumed the configuration of aircraft flying the localizer course and replaced TGF aircraft that were scheduled to enter the traffic. Crosswinds were introduced to flight simulator approaches to provide pilots with a realistic flight environment. Three wind conditions were assigned: no wind, wind from the east, or wind from the west. Winds were started at 25 kn and decreased to 10 kn at the outer marker. Flight simulator approaches were flown using autopilot, flight director, or raw data, in accordance with an individual captain's discretion and his respective company policy.

### 2.3 SIMULATION PERSONNEL.

The following section describes the various personnel involved in this simulation and their responsibilities.

#### 2.3.1 Controllers.

Ten air traffic controllers with experience in multiple parallel approaches participated as test subjects in the DIA simulation. Six of the controllers were selected from various Terminal Radar Approach Control (TRACON) facilities across the country, and four positions were filled by controllers from the existing Denver TRACON facility. Two of the Denver controllers participated the first week, and the other two participated the remainder of the simulation.

Controllers staffed the three final approach monitor positions. They monitored the flight path of the aircraft on their assigned runway and ensured aircraft maintained the required separation. In the event of a blunder or an NTZ penetration, controllers issued the appropriate control instructions to resolve the conflict situation. When controllers were not working the monitor position, they were often reassigned to perform the local tower control function in an attempt to generate realistic communications on the approach frequencies.

Individual controllers were scheduled to work as a monitor controller for half of each 2-hour run. A controller rotation period was scheduled at the midpoint of each two-hour run to simulate actual work rotations and to give monitor controllers a rest. Blunders were scripted to occur at any time during a run, including during the controller rotation periods. Controllers were not scheduled to work the monitor position for more than 2 consecutive hours at a time.

Monitor controllers completed a questionnaire after each run and at the conclusion of the simulation. After each run in which a potential TCV occurred, the controllers who monitored the blundering and evading aircraft completed a TCV Statement. These questionnaires can be found in appendix F.

Controllers also submitted a report documenting their experiences during the simulation. The controller report is included as appendix H of this report.

### 2.3.2 Simulation Pilot Operators.

SPO's operated the TGF aircraft within the various traffic scenarios. Throughout the simulation, SPO's responded to controller instructions by entering aircraft heading and altitude changes using their specialized computer keyboard and display. SPO's performed their task from the Simulation Pilot Complex in the TGF at the FAA Technical Center.

### 2.3.3 Test Director.

Simulation runs and aircraft blunders were under the direction of the simulation test director. Three individuals assumed the role of test director throughout the simulation. These individuals have extensive ATC experience and were trained to work with the CPA Prediction Tool. The test director was responsible for initiating blunders based upon the information provided by the blunder scripts, the CPA Prediction Tool, and his expert judgment.

### 2.3.4 Technical Observers.

Four technical observers participated in the DIA simulation. All technical observers had past ATC experience, and some had FAA supervisory experience. All technical observers were familiar with the current MPAP project. Technical observers monitored controller actions during each simulation run. Their duties included documenting discrepancies between issued control instructions and actual aircraft responses; assisting with alerting responsible parties to correct any problems that may have occurred during the test (e.g., computer failure, stuck microphone); assisting controllers with the preparation of incident reports; and preparing a Technical Observer Report at the end of the simulation. This report included their opinions and conclusions concerning the conduct of the simulation as well as any recommendations to the MPAP TWG. The report is included as appendix I to this report.

### 2.3.5 Simulation Observers.

Simulation observers recorded information from the simulation, such as occurrences of blunders, NBO's, lost beacon signals (i.e., aircraft that went into coast), and system problems (e.g., hardware/software failure, communications, etc.). One simulation observer was stationed in the Systems Display Laboratory, and another was located in the area of the test director.

#### 2.3.6 Site Coordinators.

A site coordinator was assigned to each flight simulator location to coordinate efforts with the test director at the FAA Technical Center and to support pilots during their participation in the simulation. Site coordinators acted as observers and did not aid the aircrews during their approaches. Their responsibilities included briefing aircrews, providing pilots with flight information prior to each approach, documenting approach information, and administering questionnaires to the pilots.

#### 2.3.7 Flight Simulator Pilots.

Sixty current air carrier and air taxi pilots were assigned to fly the flight simulators. Two pilots were assigned to each flight simulator during each run of the simulation. Pilots rotated between roles (i.e., captain, first officer, observer) throughout the day.

### 2.4 SIMULATION PROCEDURES.

The simulation was conducted November 18 through November 20 and November 30 through December 17, 1992. Three, 2-hour runs were scheduled for each day. During the final week of the simulation, an additional 1-hour run was conducted daily. Practice trials were scheduled for the entire first run on November 18 and the first hour of the first run on November 30 to acquaint controllers with the displayed triple approach operations and the radar/FMA configuration. Runs were not scheduled for Saturdays and Sundays.

Controllers staffed their positions and issued appropriate control instructions to maintain separation between blundering and evading aircraft. With the exception of the pilots of blundering aircraft during no-response blunders, pilots would verbally respond and comply as instructed. Aircraft that blundered, or were vectored off their ILS as a result of a blunder, were removed from the traffic.

## 3. DATA ANALYSIS.

This section discusses the various qualitative and descriptive statistical approaches that were used to analyze the DIA simulation data.

### 3.1 DATA COLLECTION.

The controllers' ability to resolve blunders, including factors that potentially affected their performance, was examined using descriptive statistical and qualitative analyses. Data files included the following:

a. NTZ transgression frequency;

b. NBO frequency;

c. Parallel conflict frequency (i.e., conflicts between aircraft on different approach courses); and

d. Parallel conflict slant range miss distances.

Any conflict that resulted in a CPA less than 500 ft was considered a TCV and was investigated to determine its operational impact. A comprehensive review of TCV's, including audio/visual information, controller-pilot communications, and computer data, was conducted to ascertain whether any single factor contributed to the severity of the conflict.

The communication frequencies of the blundering and evading aircraft and visual components of each run were recorded on a Super-VHS video cassette recorder. Complete audio recordings were made using a 20-channel DICTAPHONE audio recorder and a 9-channel IONICA audio recorder. Both the DICTAPHONE and the IONICA systems were recorded from the AMECOM system and operated independent of one another and the TGF operating system.

### 3.1.1 Questionnaires and Observer Logs.

After controllers participated as a monitor controller, they completed a Post-Run Controller Questionnaire. This questionnaire addressed the level of activity, stress, and mental effort they experienced during the run. When a TCV occurred, controllers described the incident on a TCV Statement. Controllers also completed a Post-Simulation Questionnaire at the conclusion of their participation in the simulation. The Post-Simulation Questionnaire addressed the operational viability of the display, the equipment, and the runway configuration. A copy of these questionnaires can be found in appendix F.

Technical observers, simulation observers, and site coordinators each recorded information using logs designed specifically for their task. In general, the logs were devised to permit observers to record information pertaining to blunders, TCV's, NBO's, simulation problems, and the like, without being distracted from their task. Site coordinator logs were developed more specifically to record approach information. A copy of these logs can be found in appendix J. Information provided by these logs was used, along with the controller questionnaires, to support computer data files.

## 3.2 ACCEPTANCE CRITERIA.

This simulation evaluated the ability of controllers using FMA displays to monitor final approach traffic at DIA. As stated in section 2, four criteria were selected by the MPAP TWG to evaluate the operations that were simulated:

a. The number of TCV's relative to the total number of "at risk" blunders, with a goal of 2 percent;

b. The frequency of NBO's and NTZ entries;

c. The operational assessments from participating controllers, technical observers, and MPAP TWG members; and

d. A risk analysis relative to one fatal accident per 25,000,000 approaches.

## 3.3 SAMPLE SIZE AND STATISTICAL TECHNIQUES.

### 3.3.1 "At Risk" Blunders.

Controller performance was measured by determining the proportion of successfully resolved conflicts relative to the blunders that would have resulted in a TCV. Specifically, the TWG was concerned with non-responding blunders toward flight simulator targets that would have resulted in a TCV if the controllers did not intervene. These blunders were identified and classified as being "at risk."

Two methods were used to determine whether a blunder was "at risk" for the simulation runs. The first method, no-controller intervention runs, were conducted prior to the simulation. In these runs, controllers did not participate, and if a blunder resulted in a TCV, it was classified as "at risk." No-controller intervention runs were conducted to determine the probability of "at-risk" blunders during the simulation. These data were used to estimate the total number of runs which needed to be executed to produce a sufficient sample size.

Due to variations in aircraft speeds and blunder timing, an "at risk" categorization for a specific blunder may vary between simulation runs. Therefore, a second method was used in the analysis of the simulation data.

The aircraft position data were analyzed post-hoc to determine whether the blunder was indeed "at risk." Aircraft position data and speed data at the beginning of the blunder were used to generate aircraft tracks as if the controller did not intervene. This provided an accurate method for determining "at risk" because actual position and speed data of the blundering and evader aircraft were used in the determination.

### 3.3.1.1 No-Controller Intervention Runs.

To determine the number of "at risk" blunders in the simulation, five no-controller intervention runs were conducted November 23 through November 25, 1992. Traffic samples from the simulation were run, and blunders were initiated without controllers present to maintain separation. The 30-degree blunders that resulted in a TCV were used to estimate the number of "at risk" blunders in the simulation.

Descriptive analyses were conducted for the five no-controller intervention runs. Overall there were 1225 approaches. There were approximately 38 approaches per runway per hour. Of the 167 blunders initiated, 101 were 30-degree blunders. The 30-degree blunders resulted in 23 TCV's. Thus, the test director created conflicts with CPA's less than 500 ft in an average of 22.8 percent of all blunders. This "at risk" percentage was considered a gross, conservative estimate used to calculate the number of blunders to initiate during the simulation.

### 3.3.1.2 Post-Hoc "At Risk" Categorization.

For every aircraft in the simulation, data were collected for its X, Y, and Z position on a second-by-second basis. Post-hoc analysis of this data provided an accurate measure of whether the aircraft pair would have resulted in a TCV had the controllers not intervened.

Analysis of the X, Y, and Z aircraft position data for the simulation runs indicated that 27 percent of all 30-degree, no-response blunders into flight simulators would have resulted in a CPA less than 500 ft. Therefore, of all the 30 degree, no-response blunders into flight simulators, 186 were determined to be "at risk."

### 3.3.2 Sample Size.

The TWG had previously determined that controller blunder resolution performance should be evaluated against a baseline of 200 "at risk" blunders. In the DIA simulation, 200 "at risk" blunders could not be accomplished due to limited simulation time. Therefore, the method of sequential sampling was used to determine an acceptable sample size for the DIA simulation that would yield the same net effect as a sample of 200 blunders and could be collected within time constraints.

This sequential sampling method was based on the assumption that a 2 percent TCV rate was acceptable for a sample size of 200 "at risk" blunders (e.g., with 200 "at risk" blunders, 4 TCV's would be acceptable). This technique was designed to result in a 99 percent confidence about the target TCV ratio (i.e., 2 percent TCV rate). Thus, if a test ran with 0 TCV's out of 86 "at risk" blunders, then the upper limit of the .99 confidence interval would agree with the results obtained from a test with 4 observed TCV's out of 200 "at risk" blunders.

Similar calculations were made assuming 1, 2, 3, or 4 observed TCV's. Table 3 presents the required number of "at risk" blunders, assuming 0 to 4 TCV's were observed during the DIA simulation.

In summary, the no-controller intervention runs were used as an estimate of the number of "at risk" blunders in the planning and execution of the simulation. This estimate was used in deriving the number of blunders that had to be initiated to yield an appropriate sample of "at risk" blunders. The aircraft position data were used, after the simulation, to validate the number of blunders "at risk" and to confirm that an adequate number of blunders had been initiated.

TABLE 3. REQUIRED SAMPLE SIZE

| Observed TCV's | Required "At Risk" Blunders |
|---|---|
| 0 | 86 |
| 1 | 119 |
| 2 | 151 |
| 3 | 179 |
| 4 | 200 |

## 4. SIMULATION RESULTS.

This section describes analyses of the data collected in the DIA simulation. Examination of CPA's, TCV's, NTZ entries, and NBO's is presented. CPA data are initially presented for all blunder angles and simulator types; however, the focus of all subsequent CPA analyses is for 30 degree, no-response blunders into flight simulators. Lastly, a risk assessment of the DIA simulation is detailed.

Prior to the simulation, the MPAP TWG determined that blunders with TGF aircraft evaders would not be included in the simulation analyses. This decision was due to differences between TGF aircraft and flight simulators, such as: 1) aerodynamic performance between TGF aircraft and flight simulators (these differences limited the generalizability of TGF "pilot" and "aircraft" performance to the operational environment); 2) the TGF interface for the SPO's was not representative of flight simulator controls and displays; and 3) SPO's were not trained pilots, they were keyboard operators. Therefore, the simulation analyses and the TWG operational assessment were based on data from blunders into flight simulators.

## 4.1 OVERVIEW OF AIR TRAFFIC.

The air traffic consisted of 11,787 approaches over 63 runs. Flight simulators made 1639 approaches, and TGF aircraft made 10,148 approaches.

### 4.1.1 Aircraft Speeds.

The speeds of both the blundering and evading aircraft are critical factors in the successful resolution of a blunder. Aircraft TAS is directly related to M.S.L. altitude (see table 1). Groundspeed is a function of TAS and wind. Since aircraft speeds were tantamount to the integrity of the simulation, they were examined for operational validity. Average groundspeeds of blundering and evading aircraft at the time of blunder initiation, from 5000 ft M.S.L. to 11,000 ft M.S.L., were examined. Speeds ranged from 140 to 180 IAS until the aircraft slowed to final approach speeds. These data indicated that flight simulator and TGF aircraft groundspeeds were consistent with the operational environment.

### 4.1.2 Blunders.

Approximately 14 blunders were initiated per hour. Blunders were 10 degrees in 54 blunders (3.8 percent), 20 degrees in 244 blunders (17.1 percent), and 30 degrees in 1132 blunders (79.1 percent). There was no response in 999 blunders (69.9 percent), and there was a response in 431 blunders (30.1 percent). Blundering and evading aircraft were in conflict if they came within 3 nmi horizontally and 1000 ft vertically. Table 4 presents the blunder degree, simulator type, and response data for the 1430 blunders that resulted in a conflict.

### 4.1.3 Evading Aircraft.

The evading aircraft was a flight simulator in 1170 of all the blunders (81.8 percent). Previous simulations indicated that flight simulator evasive maneuvers were executed with greater fidelity than those initiated by TGF aircraft. Therefore, cases with flight simulator evading aircraft were most like the operational environment. Thus, only data from blunders into flight simulators were analyzed and presented in the results. Evading flight simulator data are presented in table 5.

## 4.2 DIA SIMULATION ANALYSES.

The following section examines the simulation data for conflicts, "at risk" aircraft, and participant opinions. Analyses were conducted on the blunder resolution performance, NBO frequency, and NTZ entry frequency. A detailed operational assessment of each TCV was conducted by the TWG. Controller post-run and post-simulation questionnaire responses were qualitatively analyzed. These findings, as well as the risk assessment findings, are presented in the following sections.

TABLE 4. BLUNDERS THAT RESULTED IN A CONFLICT

| | Evading Aircraft/Blunder Degree | | | | | |
|---|---|---|---|---|---|---|
| | Flight Simulator (n = 1170) | | | TGF Aircraft (n = 260) | | |
| | 10 | 20 | 30 | 10 | 20 | 30 |
| Response n = 431 | 0.8% n=12 | 5.7% n=82 | 16.5% n=236 | 0.8% n=12 | 1.5% n=22 | 4.7% n=67 |
| No Response n = 999 | 1.4% n=20 | 8.0% n=115 | 49.3% n=705 | 0.7% n=10 | 1.7% n=25 | 8.7% n=124 |

TABLE 5. EVADING FLIGHT SIMULATOR DATA

| Flight Simulator | Number of Conflicts | Percent of Conflicts |
|---|---|---|
| MD-88 | 207 | 17.7 |
| B-727 | 457 | 39.0 |
| B-737 | 191 | 16.4 |
| B-747-400 | 79 | 6.8 |
| L1011 | 108 | 9.2 |
| GAT | 128 | 10.9 |

### 4.2.1 Conflicts.

Flight simulators were the evading aircraft in 1170 conflicts. The full range of CPA's for flight simulator evaders is shown in figure 4. The mean CPA for these conflicts was 3697 ft (s.d. = 1484 ft, range 280 ft to 10,357 ft). Table 6 presents CPA data for flight simulator evaders.

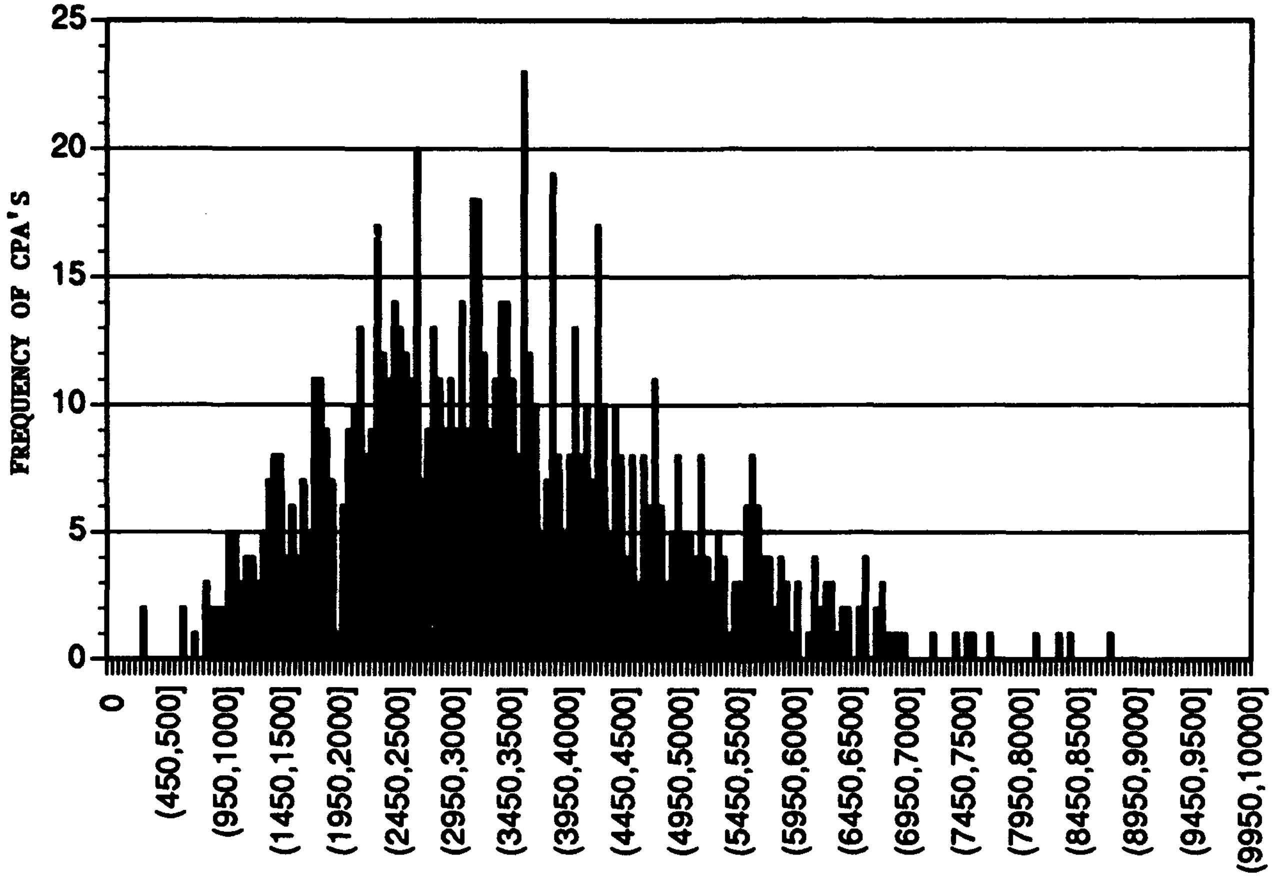



FIGURE 4. FULL RANGE OF CPA'S, FLIGHT SIMULATOR EVADERS

TABLE 6. EVADING FLIGHT SIMULATOR CPA DATA

| | | Runway Pair/Blunder Degree | | | | | |
|---|---|---|---|---|---|---|---|
| | | 16/17R (7600 ft) | | | 17R/17L (5280 ft) | | |
| Resp | | 10 | 20 | 30 | 10 | 20 | 30 |
| Yes | Avg.= | 6787 | 5763 | 4843 | 4390 | 3989 | 3196 |
| | s.d.= | 1226 | 663 | 1107 | 1487 | 776 | 991 |
| | n = | 6 | 32 | 82 | 6 | 50 | 154 |
| No | Avg.= | 4883 | 4865 | 4295 | 3460 | 3269 | 2748 |
| | s.d.= | 1760 | 1438 | 1470 | 990 | 1422 | 1129 |
| | n = | 13 | 41 | 292 | 7 | 74 | 413 |

### 4.2.2 Independent Variables.

The effects of blunder angle (10, 20, or 30 degrees), runway spacing (5280 ft or 7600 ft), and blundering aircraft response status (on or off) on the average CPA were examined.

As expected, 30 degree blunders resulted in controllers maintaining less aircraft separation than 10 or 20 degree blunders. Secondly, blunders that did not respond resulted in controllers maintaining less aircraft separation. Finally, blunders initiated between the runways spaced 5280 ft apart (17R and 17L) resulted in less separation.

As expected, the CPA data confirmed that 30 degree, no-response blunders were a worst-case situation. Therefore, the aircraft separation data from 30 degree, no response blunders into flight simulators were examined in greater detail. The distribution of CPA's for these blunders is presented in figure 5.

Thirty degree, no-response blunders into flight simulators produced conflicts with CPA's that ranged from 280 ft to 10,357 ft. The mean separation for these blunders was 3388.9 ft (s.d. = 1490.5 ft).

### 4.2.3 CPA Lower Distribution Analysis.

Analyses were conducted on the lower tail of the distribution resulting from 30 degree, no-response blunders into flight simulators. There were 13 conflicts in which the CPA came within

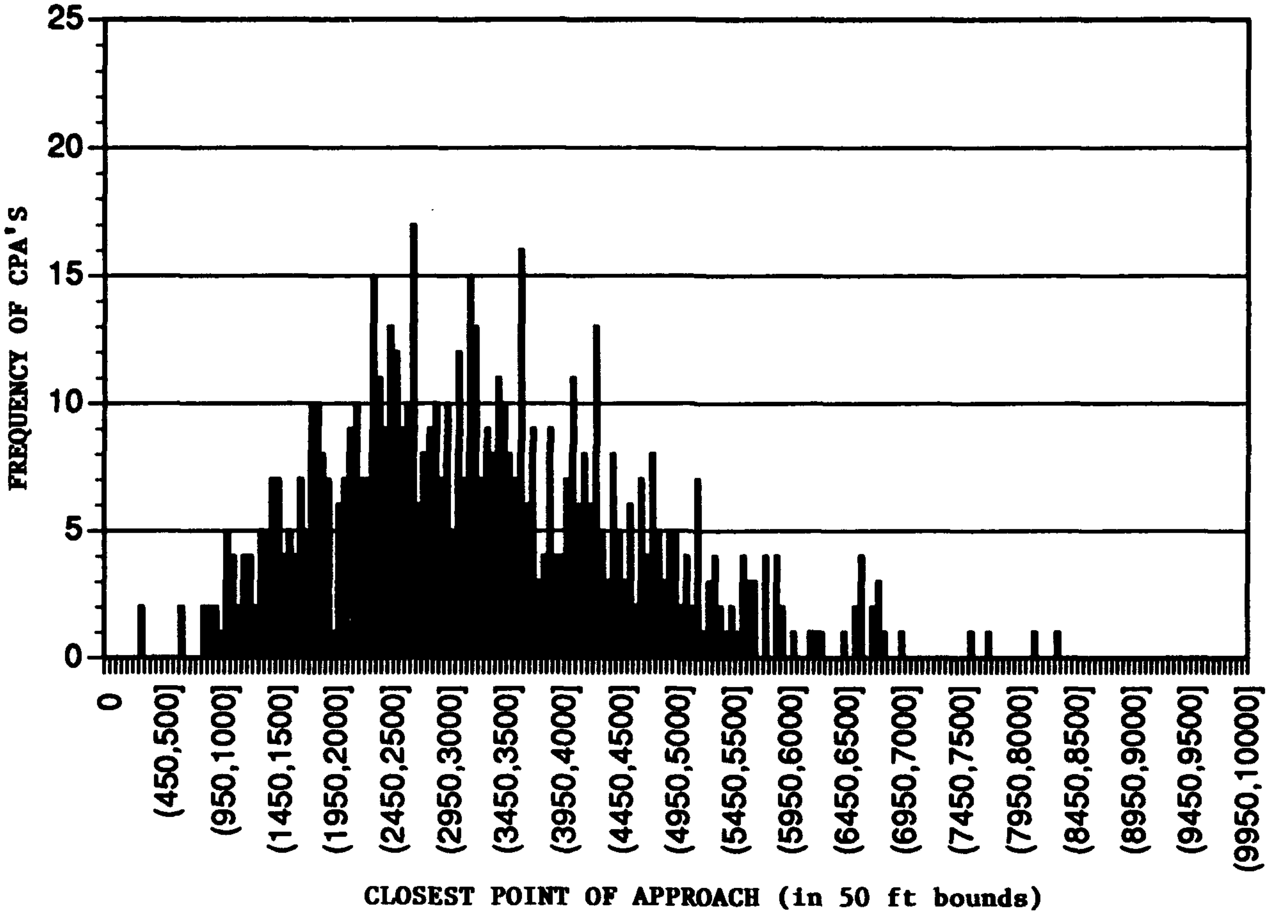



FIGURE 5. DISTRIBUTION OF CPA'S FOR 30-DEGREE, NO RESPONSE BLUNDERS INTO FLIGHT SIMULATORS

1000 ft. Table 7 presents these data. Qualitative analysis revealed that eight conflicts were between the closer spaced 17R and 17L (i.e., 5280 ft) runways.

4.2.4 Decision Tree Analysis.

A comprehensive review of the eight conflicts that resulted in a miss distance of less than 500 ft was conducted. This review analyzed video tapes, controller response times, controller message lengths, pilot response times, aircraft performance, site coordinator notes, technical observer logs, and controller incident reports. This review was performed to ensure that each TCV, a) was not the result of a simulation anomaly, and b) could have occurred in the operational environment.

Three of the eight TCV's had TGF aircraft evader's. The review further indicated that an additional three TCV's were the result of simulation anomalies. In one case, a flight simulator target was incorrectly located. In the second case, the blunder was initiated less than 2 nmi from the runway threshold, which violated procedures outlined in the test plan. In the third case, the blunder was initiated after the run was completed. These six cases were removed from further analysis.

Two TCV's were maintained to be valid. These two TCV's are described in the following section.

4.2.5 Test Criterion Violations.

The following is a description of the valid TCV's in the DIA simulation. Both TCV's were the result of 30-degree, no-response blunders.

4.2.5.1 Trans World Airlines 621 into American 204.

The first TCV occurred between Trans World Airlines 621 (TWA621) and American 204 (AAL204) in the first run on December 3, 1992 (run number 25). Approximately 17 minutes into the run, TWA621 on 17L blundered to the right towards AAL204, a flight simulator on 17R. The ATC message to the endangered aircraft (AAL204) began 7 seconds after blunder initiation.

AAL204 acknowledged and responded in a timely manner. The 14 second response time was within the normal range of aircraft response times (Hasman F. and Pratt, M., 1991; Hasman, F., Pratt, M., and Jones, A., 1991). The lowest horizontal separation was 235 ft, and the lowest vertical separation was 188 ft. The resultant slant range miss distance was 301 ft. Further data, including groundspeeds and altitudes at blunder initiation, can be found in table 8.

TABLE 7. CPA LOWER DISTRIBUTION DATA

| Evading Aircraft Type | Runway Spacing (ft) | Blundering Aircraft ALT | Blundering Aircraft GS(kn) | Evading Aircraft ALT | Evading Aircraft GS(kn) | CPA (ft) | Distance to Runway (nmi) |
|---|---|---|---|---|---|---|---|
| B-737 | 7600 | 8972' | 194 | 8769' | 184 | 280 | 10.3 |
| B-727 | 5280 | 8307' | 200 | 8457' | 184 | 301 | 7.9 |
| B-747/400 | 5280 | 7800' | 203 | 8000' | 203 | 631 | 7.0 |
| L1011 | 5280 | 7647' | 198 | 7735' | 148 | 635 | 6.1 |
| B-727 | 5280 | 8388' | 183 | 8569' | 214 | 748 | 8.8 |
| B-747/400 | 7600 | 7284 | 201 | 6595' | 171 | 810 | 4.8 |
| MD-88 | 5280 | 9400' | 192 | 10393' | 206 | 846 | 12.0 |
| B-747/400 | 7600 | 7526' | 200 | 7719' | 189 | 867 | 6.0 |
| B-747/400 | 5280 | 6716' | 164 | 6155' | 149 | 876 | 3.0 |
| MD-88 | 5280 | 8379' | 205 | 8491' | 192 | 886 | 5.9 |
| B-727 | 7600 | 9870' | 190 | 9636' | 184 | 923 | 12.9 |
| B-737 | 7600 | 9000' | 199 | 9990' | 208 | 950 | 8.3 |
| B-727 | 5280 | 10000' | 210 | 9034' | 210 | 974 | 14.0 |

Note: ALT and GS at blunder initiation.
DIST at time of CPA.

TABLE 8. TCV DATA, TWA621/AAL204

| | Blundering Aircraft | Evading Aircraft |
|---|---|---|
| Runway | 17L | 17R |
| Call Sign | TWA621 | AAL204 |
| Groundspeed at Blunder Start (kn) | 200 | 184 |
| Altitude at Blunder Start (ft) | 8307 | 8457 |
| CPA (ft) | 301 at 7.9 nmi from runway threshold | |

The pilot of the evading aircraft was flying by hand (i.e., raw data) at the time of the blunder. The site coordinator log indicated a "normal" breakout maneuver with a maximum observed bank angle of 30 degrees. The site coordinator noted that the initial ATC instruction was a turn to 270 and a climb to 11,000. A second heading of 320 was later given.

Table 9 is a record of the dialogue between the controllers and pilots during the conflict. Transmission times were extracted from the video tape of the run and reflect real-time minutes and seconds of the simulation clock.

One technical observer attributed the TCV to slow pilot and aircraft response. The observer wrote, "TWA 621, NORDO. 17R pilot slow to turn."

The controller for the 17R runway (i.e., evading aircraft runway) wrote that the blunder was self-identified. He noted that he saw the blundering aircraft right of the 17L localizer, but not in the NTZ. The controller stated that he immediately turned and climbed AAL204, before TWA621 entered the NTZ. The controller identified pilot action and a slow aircraft turn as the causal factors in the conflict. The controller also wrote that, "two factors contributed to the conflict: 1) speed overtake - blundering aircraft was flying 20 kn faster than the evading aircraft, and 2) the evading aircraft was slow in turning and climbing." It was recommended that to prevent a recurrence of this type of conflict, the evading aircraft should use a faster turn rate.

The controller for the blundering aircraft runway (i.e., 17L) noted that he self-identified the blunder when TWA621 deviated from course. The controller attempted to turn TWA621, but he did not get a response. The controller also identified pilot action and slow pilot response of AAL204 as the causal factor in the conflict. He wrote that, "AAL204 seemed slow in responding and breaking out."

TABLE 9. DIALOGUE FOR TCV, TWA621/AAL204

| Rwy | | Transmission Start | End |
|---|---|---|---|
| 17L | Controller: "TWA Six-Two-One, Turn Left Immediately, Heading Zero-Niner-Zero, Climb and Maintain One-One-Thousand." | 17:45 | 17:53 |
| 17R | Controller: "American Two-Zero-Four, Turn Right Immediately, Heading Two-Seven-Zero, Climb and Maintain One-One-Thousand." | 17:47 | 17:51 |
| 17R | Controller: "Turn to Two-Seven-Zero, Climb to One-One-Thousand, American Two-Zero-Four." | 17:51 | 17:53 |
| 17R | Pilot: "Climbing to One-One-Thousand, American Two-Zero-Four." | 17:54 | 17:55 |
| 17R | Controller: "Two-Zero-Four Expedite Turn and Climb." | 17:56 | 17:58 |
| 17R | Controller: "Two-Zero-Four, Turn Right Heading Three-Two-Zero." | 18:03 | 18:05 |
| 17L | Pilot: "Three-Two-Zero, American Two-Zero-Four." | 18:06 | 18:08 |

4.2.5.2 American West 234 into Northwest 893.

The second TCV involved American West (CACTUS) 234 (AWE234) and Northwest 893 (NWA893). It occurred in the second run on December 8, 1992 (run number 35). Crosswinds were from the west for flight simulator approaches. Approximately 16 minutes into the run, AWE234 on runway 17R turned towards NWA893, a flight simulator on runway 16. Emair 243 (EME243), a TGF aircraft, was traveling approximately 4 nmi behind NWA893 and was in potential danger. Information pertaining to the TCV, including groundspeeds and altitudes at blunder initiation, can be found in table 10.

The 17R controller began his message to the blundering aircraft approximately 10 seconds after blunder initiation. This response time was approximately two radar updates. Although it did not affect the outcome of the blunder (the blundering aircraft was directed not to respond), the 17R controller mistakenly called AWE234 "Air Wisconsin 234." Approximately one second later, the runway 16 controller gave an evasive instruction to NWA893. Without waiting for acknowledgement from NWA893 (NWA893 never acknowledged the transmission), the runway 16 controller gave EME243 an evasive instruction. After two transmissions, EME243 acknowledged. The runway 16 controller then repeated the evasive instructions for NWA893. NWA893 acknowledged and responded in a timely manner. When NWA893 responded, AWE234 had already come within 500 ft. The resultant slant range miss distance was 280 ft.

TABLE 10. TCV DATA, AWE234/NWA893

| | Blundering Aircraft | Evading Aircraft |
|---|---|---|
| Runway | 17R | 16 |
| Call Sign | AWE234 | NWA893 |
| Groundspeed at Blunder Start (kn) | 194 | 184 |
| Altitude at Blunder Start (ft) | 8972 | 8769 |
| CPA (ft) | 280 at 10.3 nmi from runway threshold | |

The 12 second response time from NWA893 was within the normal range of aircraft response times, as demonstrated by two experiments of ATC directed missed approaches at 6 miles from the runway threshold (Hasman, F. and Pratt, M., 1991; Hasman, F., Pratt, M., and Jones, A., 1991). These studies indicated that the B-727 took an average of 4.5 seconds to respond, with a range from 2 seconds to 16 seconds.

Table 11 is a record of the dialogue between the controllers and pilots during the conflict. Transmission times were extracted from the video tape of the run and reflect the real-time minutes and seconds of the simulation clock.

Comments recorded in the site coordinator log from NWA893 stated, "...the controller broke us out. We answered and broke out immediately." In addition, the log indicated the evading aircraft pilot was using the flight director at the start of the blunder.

TABLE 11. DIALOGUE FOR TCV, AWE234/NWA893

| Rwy | | Transmission Start | End |
|---|---|---|---|
| 17R | Controller: "Air Wisconsin Two-Thirty-Four, Turn Left Immediately, Heading One-Seven-Zero, Climb and Maintain One-Zero-Thousand." | 11:55 | 11:59 |
| 16 | Controller: "Northwest Eight-Ninety-Three, Turn Right Immediately, Heading Two-Seven-Zero, Descend Immediately, Maintain Seven Thousand." | 11:57 | 12:02 |
| 16 | Controller: "Emair Two-Forty-Three, Climb Immediately, Maintain One-One-Thousand, Turn Right Heading Two-Seven-Zero." | 12:06 | 12:10 |
| 16 | Controller: "Alright Gentlemen Listen Up. Emair Two-Forty-Three, Right Turn Two-Seven-Zero, Up to Eleven." | 12:14 | 12:17 |
| 16 | Pilot: "Two-Seven-Zero, Emair Two-Forty-Three." | 12:18 | 12:20 |
| 16 | Controller: "Northwest Eight-Ninety-Three, Right Turn, Two-Seventy,Descend to Seven." | 12:20 | 12:22 |
| 16 | Pilot: "Northwest Eight-Ninety-Three, Two-Seven-Zero, Heading Down to Seven Thousand." | 12:23 | 12:26 |

One technical observer attributed the TCV to slow pilot and aircraft response. It was indicated that ATC instructions were not followed. A second technical observer also cited slow pilot response as the cause of the TCV. The observer wrote, "AWE234 NORDO. 17R controller recognized blunder immediately. It appeared that there was a comm problem with 16 pilot."

The controller for runway 16 (i.e., evading aircraft runway) wrote that the blunder was self-identified with the aid of the alert system. To prevent a recurrence of a similar operational error, the controller suggested that, "pilots be trained for listening skills."

The controller for the blundering aircraft runway (i.e., 17R) cited "numerous slow pilot responses," and commented that "NWA893 on RWY 16 was extremely slow responding."

4.2.6 Blunder Resolution Performance.

Overall, the results indicated that controllers were able to maintain the test criterion miss distance of 500 ft in 184 out of 186 "at risk" blunders. Thus, the success rate was 98.9 percent for all "at risk" blunders. In the DIA simulation, blunder resolution performance, when evaluated against "at risk" blunders, exceeded the 98 percent success rate criterion set by the TWG.

4.3 AIRPORT ARRIVAL RATE.

Arrival rates are reduced when aircraft are broken out of the approach sequence. Breakouts from the approach can be due to several causes, such as blunders, nuisance breakouts, and NTZ entries. Blunder-induced breakouts were the most prevalent in the simulation. Nuisance breakouts occurred when an aircraft was broken out of its final approach for reasons other than a conflict, loss of longitudinal separation, or lost beacon signal (i.e., aircraft goes into coast). NTZ entries could also cause breakouts. Controllers are required to breakout aircraft in proximity of an aircraft that enters the NTZ (Federal Aviation Administration, 1992).

Two factors that contribute to NTZ entries and nuisance breakouts are: 1) TNSE and 2) runway spacing.

4.3.1 TNSE.

TNSE is the difference between an aircraft's actual and intended paths. TNSE is expressed as a statistical combination of all sources of navigation error. These sources include: navigation signal source, propagation, airborne system, and flight technical error.

To provide adequate vertical separation during turn-on, multiple parallel approaches require localizer intercepts farther from the runway threshold. Farther intercepts increase the effects of TNSE due to dispersion of the localizer signal. The increase in TNSE generally results in an increase in NTZ entries and NBO's.

4.3.2 NTZ Entry Analysis.

Analyses were planned to evaluate NTZ entries that were not the result of a blunder or breakout. Simulation results indicated that there were no NTZ entries by either flight simulators or TGF aircraft.

4.3.3 NBO Analysis.

NBO's occurred in 17 of the 8927 non-blunder approaches (0.2 percent). A chi square goodness-of-fit test indicated that the number of NBO's was nearly level across all runs of the simulation; therefore, there did not appear to be any systematic bias present due to training or fatigue. NBO data are presented in figure 6.

The data also indicated that 5 out of the 17 (29.5 percent) NBO's were on 17L, 8 out of the 17 (47 percent) were on 17R, and 4 out of 17 (23.5 percent) were on runway 16. Thus, aircraft that flew the more closely spaced approaches (i.e., 17L and 17R) were broken out about twice as frequently as aircraft that flew the less closely spaced 16 approach. In addition, most aircraft broken out were on the center runway (i.e., 17R). This runway had an increased incidence of NBO's due to the two adjacent approaches. Of all the NBO's that occurred, 3 out of 17 (18 percent) of the broken out aircraft were flight simulators. The NBO data are presented in table 12.

## 4.4 CONTROLLER QUESTIONNAIRE ANALYSIS.

The following sections describe the results of the analyses on the Post Run Controller Questionnaires and the Post Simulation Controller Questionnaires.

### 4.4.1 Post Run Controller Questionnaires.

Questionnaires were distributed to monitor controllers after their sessions during the simulation. Controllers rated their level of activity, stress, and mental effort throughout each run.

#### 4.4.1.1 Activity Level.

Activity level was rated on a scale ranging from 1 (minimal) to 5 (intense). Of 270 completed questionnaires, 98 percent of the responses were a 2 or 3. This indicated a minimal to moderate level of activity.

A one-way analysis of variance (ANOVA) indicated a significant effect ($p < .05$) of runway assignment (16, 17R, 17L) on controller activity. A Scheffe post-hoc pairwise comparison test showed that controllers had significantly more activity ($p < .05$) on runway 17R (i.e., center runway) than on runway 16 (i.e., 7600 ft spacing). A higher activity level was expected since the center runway was involved in each blunder.

#### 4.4.1.2 Stress Level.

Controllers rated their level of stress on a five point scale, ranging from 1 (minimal) to 5 (intense). The results paralleled the activity level ratings in that 96 percent of the responses were minimal or moderate.

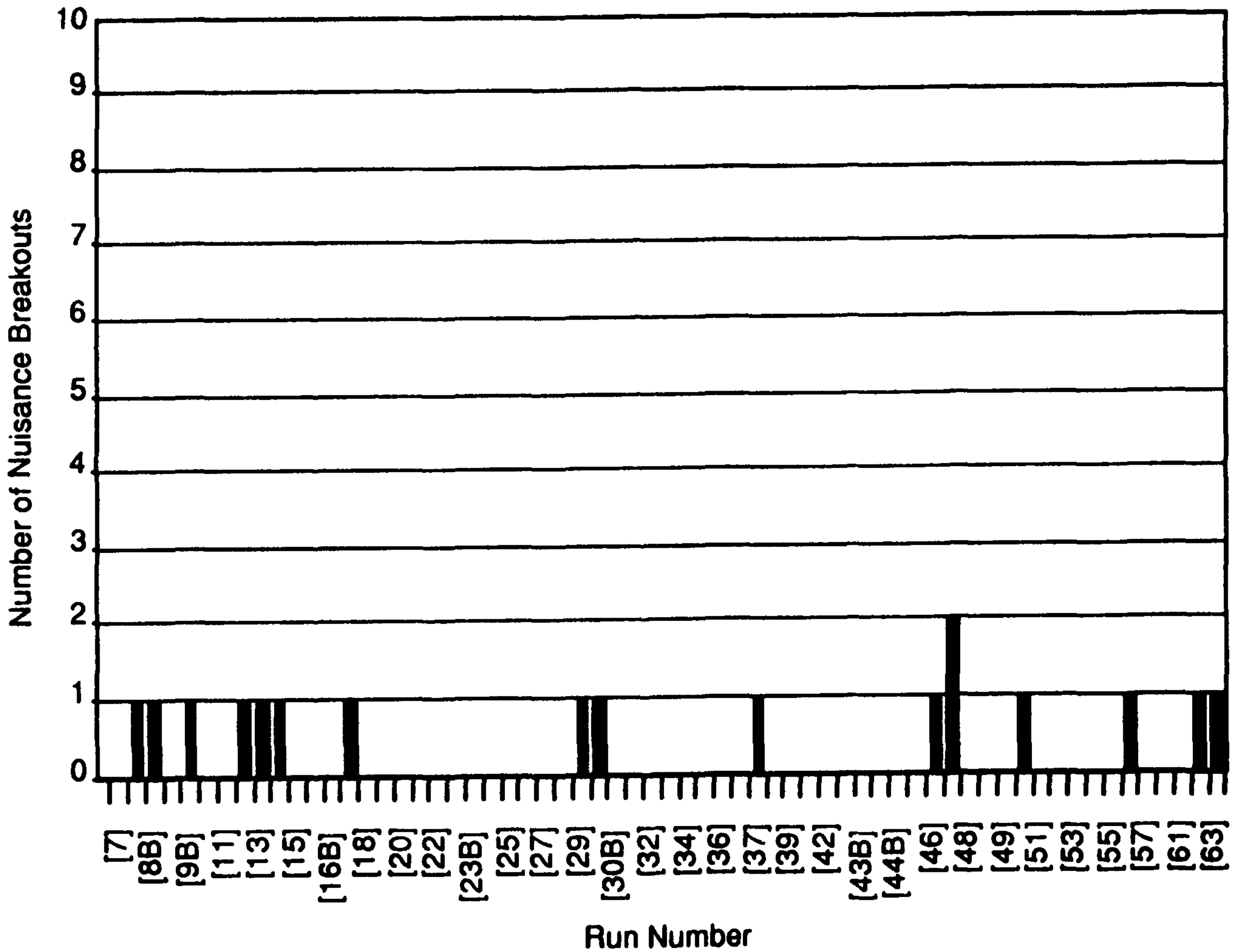



FIGURE 6. FREQUENCY OF NUISANCE BREAKOUTS

TABLE 12. NUISANCE BREAKOUT DATA

| Runway | Simulator Type | # of Cases | Percent |
|---|---|---|---|
| 16 | Flight Simulator<br>TGF | 0<br>4 | 0.0<br>23.5 |
| 17R | Flight Simulator<br>TGF | 1<br>7 | 6.0<br>41.0 |
| 17L | Flight Simulator<br>TGF | 2<br>3 | 12.0<br>17.5 |
| Totals | | 17 | 100.0 |

A one-way ANOVA was performed to detect any effects of runway assignment on stress levels. Runway assignment significantly affected stress level ($p < .05$). A Scheffe post-hoc pairwise comparison showed that controllers had significantly more stress ($p < .05$) on runway 17R (i.e., center runway) than on runway 16 (i.e., 7600 ft spacing). This relationship was expected since the center runway controller was involved in all blunder and breakout situations.

4.4.1.3 Mental Effort.

Mental effort was rated on a scale ranging from 1 (low) to 5 (maximum). Overall, 64 percent of the responses were twos (i.e., "acceptable"). Twenty-four percent of the responses were threes (i.e., "moderately high"). These percentages varied little over the course of the simulation. There were 39 ratings of fours and fives. Of these ratings, 36 (92.3 percent) were made by 1 controller. Thus, one controller consistently rated a high level of mental effort, indicating a rating bias toward the high end of the scale.

A one-way ANOVA was performed to determine if runway assignment (16, 17R, 17L) affected the level of mental effort to maintain traffic separation. No significant difference was found ($p > .05$). Thus, it appears that the mental effort required to detect and resolve blunders on all three runways was the same.

Overall, the situational factors associated with runway assignment (e.g., frequency of blunders, frequency of breakouts) required higher activity levels and produced more stress, but did not require any additional mental effort. Independent of runway assignment, the controllers' mental effort was generally moderate. Further, based on controller blunder resolution performance, the level of mental effort seemed appropriate for the task.

### 4.4.2 Post-Simulation Controller Questionnaires.

Each controller was given a post-simulation questionnaire at the end of their participation. The questions addressed the difficulty of the controllers' tasks performed during the simulation. Questions also asked about controller blunder resolution strategies and the authenticity of the simulation. Further, controllers were queried whether they believed triple independent instrument flight rules (IFR) approaches to runways spaced 5280 and 7600 ft apart could be safely conducted in the operational environment, as simulated. Nine out of the ten controllers completed the post-simulation questionnaires.

#### 4.4.2.1 Task Difficulty.

The scale for task difficulty using the FMA ranged from 1 (very difficult) to 5 (very easy). Controller ratings were evenly distributed from 3 (average difficulty) to 5 (very easy).

#### 4.4.2.2 Specific Strategies.

The most common "specific" strategy used for inter-controller coordination was a verbal warning and/or hand signal. Controllers also told each other the instructions that were given (e.g., descents, climbs, turns). Often, simply hearing another controller transmit instructions acted as an alert and coordination cue. One controller developed a strategy to scan the adjacent localizer. Three controllers maintained they did not employ a specific strategy.

#### 4.4.2.3 Central Strategies.

Six out of nine controllers claimed that no central strategies were developed due to the high density altitude environment. One controller asserted that when an evading aircraft was at a low altitude, it was best to keep the aircraft low and turn it 90 degrees off the localizer. On the center runway, however, this controller claimed it was better to climb the aircraft.

Another controller's central strategy was to either climb or descend aircraft when blunders occurred between runways 16 and 17R (i.e., 7600 ft spacing). Lastly, one controller stated that the central strategy used was to be "cognizant of higher speeds and reduced aircraft performance."

#### 4.4.2.4 High Density Altitude.

Controllers were asked to comment on any potential effects high density altitude had on the runway configuration, as simulated. Five controllers did not believe high density altitude was a factor that affected their work. One controller reported he would be uncomfortable working without the FMA's, and another controller reported faster speeds were the only noticeable differences in aircraft performance. Two controllers did not answer the question.

### 4.4.2.5 Simulation Reality.

The scale was from 1 (Not Realistic) to 5 (Very Realistic). There was one "1" rating, one "2" rating, one "3" rating, four "4" ratings, and one "5" rating.

The questionnaire also addressed the authenticity of the entire simulation as a whole. One controller commented that the simulation was as realistic as possible. Four controllers believed 30 degree blunders and the number of NORDO aircraft were unrealistic. Three controllers believed the groundspeeds were too fast. Two controllers commented on the poor communication between flight simulators and the controllers. One controller suggested finding a way to make flight simulator and SPO communications sound more alike to add to the realism. The controller also suggested simplifying the menus on the FMA displays.

All controllers agreed that triple independent IFR approaches to runways spaced 5280 and 7600 ft apart could be safely conducted, as simulated.

## 4.5 PILOT QUESTIONNAIRE ANALYSIS.

Participating flight simulator pilots were asked to complete a survey following the simulation. The survey consisted of six statements about the simulated operations and procedures. Pilots rated the first four statements on a scale ranging from 1 (strongly agree) to 5 (strongly disagree). Pilots also provided general comments and suggestions in response to two statements.

Sixty-two flightcrew opinion surveys were completed. The average years of experience for all of the participating pilots was 23 years. The range of experience was from 6 to 42 years.

### 4.5.1 Vertical Separation.

The first statement read: "In the event that one (or both) aircraft overshoot the localizer, 1000 ft of vertical separation would provide an acceptable safety margin provided aircraft maintain their assigned altitude until established on the localizer course." Eighty-seven percent of the pilot responses were "strongly agree" and "agree" (54 pilots). Four pilots were neutral, three pilots disagreed, and one pilot strongly disagreed.

### 4.5.2 Phraseology.

The second statement read: "To emphasize the importance of a quick response from the threatened aircraft, special phraseology should be used for the break-out maneuver." Ninety-five percent (59 pilots) of the responses were "strongly agree" and "agree." Two pilots were neutral on the issue, and one pilot disagreed.

### 4.5.3 Communications.

The third statement had two parts. The first part read: "An alternate communication frequency would be useful." Pilot responses tended not to be extreme on this issue. Thirteen percent (8 pilots) strongly agreed. Twenty-eight percent of the responses were "agree" (17 pilots), 23 percent were "neutral" (14 pilots), and 23 percent were "disagree" (14 pilots). Ten percent (6 pilots) strongly disagreed. Three pilots did not respond to this statement.

The second part of the statement read: "Breakout instructions should be broadcast simultaneously on the ILS frequency (voice on the localizer)." Twenty-five percent of the pilots agreed (15 pilots) and 36 percent disagreed (22 pilots) with this recommendation. Ten percent (6 pilots) strongly agreed, 13 percent (8 pilots) were neutral on the issue, and 16 percent (10 pilots) strongly disagreed. One pilot did not respond to the statement.

### 4.5.4 General Comments.

The survey also asked pilots to provide any suggestions on types of special terminology/phraseology and/or instructions that would be effective in initiating evasive maneuvers. The most popular suggestion was controller repetition of the aircraft call sign, at the beginning or the end of the instruction. The term "immediately" was acknowledged by more pilots as the effective term for instructing an escape maneuver rather than "escape."

Another common suggestion was to give the heading and altitude in one transmission, with the most urgent instruction first. Several pilots thought there should be no "descending" escapes. Several pilots favored a published escape procedure and an established standard terminology.

## 4.6 CONTROLLER STATEMENT.

In their controller report, the participating air traffic controllers concluded, "In this simulation the air traffic controller team believes they safely monitored triple simultaneous ILS approaches at the simulated new Denver Airport using the FMA."

## 4.7 TECHNICAL OBSERVER STATEMENT.

The technical observers unanimously agreed that controllers appeared to separate aircraft with relative ease. In their report, the technical observers stated that during the simulation, the controllers had little difficulty detecting and resolving blunders. In some cases, controller response times were actually slower, as the controllers took time to evaluate the situation prior to issuing instructions to the evading aircraft. Alert algorithms and runway spacings appeared to be factors which allowed controllers to take extra time when evaluating certain situations.

In conclusion, the technical observers unanimously agreed, "...triple simultaneous approaches at the DIA airport can be safely accomplished using the 4.8 second update radar and the final monitor aid."

## 4.8 RISK ASSESSMENT.

The analyses above have assessed the controllers' ability to resolve blunders during simultaneous parallel ILS approaches. It was observed that the controllers were not always able to maintain the test criterion miss distance of more than 500 ft between the blundering aircraft and aircraft on adjacent approaches. To properly evaluate the proposed operations, the effect of implementing the proposed operation on the level of risk found in today's operational environment must be determined.

Ideally, the probability of an accident during the approach operation could be computed and compared to an acceptable probability. However, since the majority of approach operations are conducted to single approaches, no recorded accident has ever been attributable to a blunder occurring during multiple approach operations. Accordingly, little effort has been made to record and track blunder occurrences.

A way to complete the risk analysis without operational blunder data is to determine a target risk value, and then to compute a blunder rate which would result in the target risk value. This would provide insight to the safety level of the operation, and allow the FAA to assess the acceptability of the operation. The computed blunder rate should not be used as the sole determining factor of whether the operation meets the target risk value.

The total number of air carrier accidents as well as the number of fatal accidents on final approach has been extracted from the National Transportation Safety Board (NTSB) data for the time period, 1983-1989. This number, together with the total number of ILS approaches during the time period, lead to an estimated fatal accident rate during ILS operations performed during IMC of $4 \times 10^{-7}$ fatal accidents (ACC) per approach (APP). 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 aircraft on an adjacent approach, is created with the implementation of parallel approaches.

For simplicity of model development, it is assumed that the risks of the 10 potential accident causes are approximately equal. Thus the contribution of any one of the accident causes would be approximately one-tenth of the total accident rate. Therefore, the target safety level for midair collisions on simultaneous parallel approaches is 4 x 10-8, or:

$$\frac{1\ \text{ACC}}{25\ \text{mill APP}}$$

To begin the evaluation, CPA analyses indicated that controllers had the greatest difficulty in maintaining a 500 ft spacing between aircraft in the event of a 30 degree blunder. Twenty (20) and 10 degree blunders were all resolvable. The simulation also demonstrated that only blunders which simulated a lack of response by the blundering aircraft were sometimes unresolvable. The pilot's inability to respond may be due to a conflict with another radio transmission, weather conditions, or a malfunction of the aircraft. Other studies (Precision Runway Monitor Program Office, 1991) have estimated that only one percent of the aircraft blundering 30 degrees off course would be unable to respond to controller commands.

It is assumed that pilots will be able to resolve conflicts during visual flight rules (VFR) conditions, therefore only IMC conditions are used in this analysis. Based upon these findings and assumptions, a worst case blunder (WCB) is defined as a 30 degree blunder, under IMC conditions, in which the blundering aircraft's pilot is unable to respond to the controller's directions and enters the NTZ.

A factor needed in the risk assessment is the probability of a 30 degree blunder in which the pilot of the blundering aircraft was unable to comply with ATC instructions (i.e., a WCB). As mentioned earlier, previous research estimated that the probability of a no-response blunder was 1/100. Therefore, the ratio of WCB's to 30 degree blunders is:

$$\frac{1\ \text{WCB}}{100\ \text{30-Degree Blunder}}$$

The longitudinal alignment of the aircraft, relative to the threshold, on adjacent ILS approaches, was found to be an important factor in conflict resolution. The probability of a blunder resulting in a TCV is highest when the blundering aircraft is slightly ahead (closer to the threshold) of the adjacent aircraft.

For analytical purposes, an alignment "window" will be defined for blunders which would result in a TCV if the controllers did not intervene. These blunders were considered to be "at risk" of resulting in a TCV. The length of the window depends on the ratio of the speeds and the blunder angle, and it can be shown analytically to be independent of the runway separation. The speeds used in the simulation ranged from 120 kn to 227 kn. The 120 kn was the slowest speed of a blundering aircraft, and the 227 kn was the fastest speed of an evading aircraft.

Assuming that either aircraft could be traveling at any speed between these two numbers, then the ratio of speeds ranged from 120/227 = .53 to 227/120 = 1.89. Using the maximum speed ratio (1.89) with a blunder angle of 30 degrees, the maximum window length was 2279 ft. Therefore, the probability of an "at risk" blunder, assuming 3 nmi longitudinal separation between aircraft on the same approach, is given by:

$$\frac{2279}{3 \times 6076} = .125 = \frac{1 \text{ "at risk" WCB}}{8 \text{ WCB's}}$$

Therefore, about one aligned approach occurs for every eight approaches executed.

A review of the data indicated that a total of 186 WCB's were initiated when the blundering aircraft was in the alignment window. Of the "at risk" WCB's, two resulted in an actual TCV. Using a 99 percent confidence interval to compute the upper bound for the probability of a TCV given an "at risk" WCB, the upper bound would be 0.049, or:

$$0.049 = \frac{5 \text{ TCV's}}{102 \text{ "at risk" WCB's}}$$

The NTSB would evaluate a mid-air collision as two accidents. Therefore, one TCV would equal two accidents:

$$\frac{1 \text{ TCV}}{2 \text{ ACC}}$$

Finally, using the data cited above, the number of blunders which could occur in the operational environment, before the target probability of 1 fatal accident in 25 million approaches, can be calculated. The calculation is shown on the following page:

$$\frac{1\ \text{ACC}}{25\ \text{mill APP}} \times \frac{8\ \text{WCB's}}{1\ \text{"at risk" WCB}} \times \frac{102\ \text{"at risk" WCB}}{5\ \text{TCV's}} \times \frac{3\ \text{APP}}{1\ \text{Triple APP}}$$

$$\times \frac{1\ \text{TCV}}{2\ \text{ACC}} \times \frac{100\ \text{30-Degree BL}}{1\ \text{WCB}} = \frac{9.8\ \text{30-Degree Blunder}}{10{,}000\ \text{Triple APP}}$$

Therefore, about ten 30-degree blunders per 10,000 triple parallel simultaneous approaches could be tolerated for the risk of the operation to meet the target risk level.

The occurrence of blunders during parallel approaches has remained undocumented. Anecdotal evidence has indicated that blunders do occur during simultaneous approach operations. Knowledgeable representatives from the FAA have indicated that blunders may occur as often as one or two times per 10,000 simultaneous approaches. Therefore, based upon the data collected in the simulation, the proposed triple parallel approach operation at DIA meets the current high level of safety found in approach operations. Additional detail about the risk analysis of blunders appears in appendix L.

## 4.9 MPAP TWG STATEMENT.

In their Operational Assessment (appendix K), the MPAP TWG stated, "Based on the established test criteria, the controllers met the simulation objective. The arrival monitor positions in the simulation proved to be operationally effective and feasible. The test controllers participated in the simulation as though they were controlling live traffic. Their attention and dedication was critical to the success of the simulation.

Based upon the results of the simulation, the TWG believes that the proposed triple simultaneous ILS approaches at DIA are acceptable, achievable, and safe with the final monitor aid (FMA) system and an appropriate radar system, such as a Mode S monopulse system or an ASR-9 radar system enhanced to provide improved target resolution capabilities."

# 5. DISCUSSION.

This discussion covers the simulation findings with respect to the criteria set for the DIA simulation: 1) the number of TCV's relative to the total number of "at risk" blunders; 2) frequency of NTZ entries and NBO's; 3) operational assessment; and 4) risk assessment.

## 5.1 TEST CRITERION VIOLATIONS.

During the simulation, only two "at risk" blunders resulted in TCV's. Since there were 186 "at risk" blunders generated during the simulation, the controllers were able to successfully resolve 98.9 percent of all "at risk" blunders. This 98.9 percent blunder resolution percentage exceeded the 98 percent criteria set by the TWG. Thus, the controller blunder resolution performance was satisfactory in the DIA simulation.

## 5.2 NBO'S AND NTZ ENTRIES.

An examination was conducted for NTZ entries that were not the result of a blunder or a breakout. Simulation data revealed that there were no NTZ entries by flight simulators or TGF aircraft. Therefore, the DIA runway spacings were sufficiently large that aircraft did not enter the NTZ as a consequence of TNSE.

NBO's were typically the result of TNSE. NBO's occurred infrequently in the DIA simulation. Data indicated that 0.2 percent of all non-blundering aircraft were broken out for reasons other than a conflict, loss of longitudinal separation, or loss of beacon signal (i.e., aircraft goes into coast). Overall, the low number of NBO's in the simulation indicated that controllers could accurately assess potential blunder situations.

## 5.3 OPERATIONAL ASSESSMENT.

The operational assessment of the DIA simulation was based on the opinions, conclusions, and recommendations of the participating controllers, technical observers, and the TWG.

### 5.3.1 Controller Assessment.

Controllers were asked to rate their stress level, activity level, and mental effort. Controllers rated their activity and stress levels as minimal to moderate. There was more stress and activity for controllers working the center runway. This was expected since the center runway was involved in all blunder and breakout situations.

Controllers rated their mental workload as acceptable to moderate throughout the simulation. The amount of mental effort was not related to runway assignment. Situational factors associated with runway assignment (e.g. frequency of blunders, frequency of breakouts) required higher activity levels and produced more stress, but did not require any additional mental effort. Throughout the simulation, based on blunder resolution performance, the level of mental effort seemed appropriate for the task.

The participating controllers agreed that they "safely monitored triple simultaneous ILS approaches at the simulated new Denver Airport using the FMA."

### 5.3.2 Technical Observer Assessment.

The technical observers concluded that the triple approach operation at DIA could be conducted safely, based upon their observations of controller and system performance. The technical observers reported that controllers had little difficulty detecting and resolving blunders for this operation. It was noted that the controllers used the FMA alerts to their advantage, and often used the additional lead time in determining the optimal evasion maneuver.

### 5.3.3 TWG Assessment.

Based on the established test criteria, the TWG concluded that the controllers met the simulation objective. The arrival monitor positions in the simulation proved to be operationally effective and feasible.

Based on the results of the simulation, the TWG concluded in its operational assessment (appendix K) that the proposed triple simultaneous ILS approaches at DIA are acceptable, achievable, and safe with the FMA system and an appropriate radar system, such as a Mode S monopulse system or an ASR-9 system enhanced to provide improved target resolution capabilities.

Based on their operational assessment, the MPAP TWG made three recommendations: 1) there should be one monitor controller for each runway; 2) monitor positions should be located adjacent to one another; 3) a radar system with 2.7 milliradians azimuth accuracy or better and the capability to resolve two aircraft at 20 nmi separated by 0.9 degrees or more should be used.

## 5.4 RISK ASSESSMENT.

A risk assessment was conducted on the data from the simulation. Since there is no recorded operational data about blunders, this analysis determined a target risk value, and then computed a blunder rate which would result in the target risk value. This assessment was based on NTSB data for the total number of air carrier accidents, as well as the number of fatal accidents on final approach. A risk model was developed, and it was determined that about ten 30-degree blunders per 10,000 triple parallel simultaneous approaches could be tolerated for the risk of the operation to meet the target risk level. Thus, the risk assessment indicated that the DIA operation meets the target risk of $4 \times 10^{-8}$ approaches.

# 6. CONCLUSIONS.

This simulation tested the controllers ability to effectively resolve conflicts for the proposed triple simultaneous instrument landing system (ILS) operation at the new Denver International

Airport (DIA). In addition, the simulation examined the influence of the runway spacing, 5280 and 7600 feet (ft), and the high density altitude, 5431 ft mean sea level, on no transgression zone (NTZ) entries and nuisance breakouts (NBO's). Controllers used final monitor aid displays to monitor approach traffic. The simulated radar sensor had the performance of an Airport Surveillance Radar (ASR)-9 system enhanced to provide improved target resolution capabilities. The Multiple Parallel Approach Program Technical Work Group (TWG) evaluated the controllers effectiveness at resolving conflicts, the frequency of NTZ entries and NBO's, and the ability of the system to maintain a predetermined target level of risk (1 fatal accident per 25,000,000 approaches). Based upon their evaluations, the TWG concluded that the triple simultaneous ILS approach operation at DIA was acceptable.

# BIBLIOGRAPHY

Bilicki, H. W., TGF and the Future of Air Traffic Control Simulation, AS&T Corporation, Mays Landing, New Jersey, 1992.

CTA INCORPORATED, Evaluation of Triple Simultaneous Parallel ILS Approaches Spaced 4300 Feet Apart Using The Final Monitor Aid and a Simulated Radar with a 4.8 Second Update Rate, DOT/FAA/CT-92/16, Pleasantville, New Jersey, 1993 (Report in Progress).

DiMeo, K., Melville, B., Churchwell, T., and Hubert, L., LAX Instrument Landing System Approach, Phase 2 and 3, DOT/FAA/CT-93/61, Atlantic City International Airport, 1993 (Report in Progress).

Fabrizi, M. A., Massimini, S. V., and Toma, N. E., Development of National Standards for Multiple Independent Parallel Approaches, WP920000126, April 1993.

Federal Aviation Regulations/Airman's Information Manual (FAR/AIM), Renton, WA: Aviation Supplies and Academics, Inc., 1991.

Federal Aviation Administration, Air Traffic Control, DOT/FAA/Order 7110.65G, March 1992.

Hasman, F. D. and Pratt, M. F., B-727 Missed Approach Crew Performance Simulator Project, DOT/FAA-AVN-500-52, FAA Standards Development Branch, Oklahoma City, Oklahoma, 1991.

Hasman, F. D., Pratt, M. F., and Jones, A. B., DC-10 Missed Approach Crew Performance Simulator Project, DOT/FAA-AVN-500-54, FAA Standards Development Branch, Oklahoma City, Oklahoma, 1991.

Hitchcock, L., Fischer, T., Bensel, L. W., Yastrop, G., Jones, R., Luongo, R., Reardon, K., Startzel-Dehel, B., Evaluation of Triple Simultaneous Parallel ILS Approaches Spaced 5000 Feet Apart - Phase IV.b, DOT/FAA/CT-91/31, McKee City, January 1992.

Jeppeson Sanderson, Private Pilot Manual, Englewood, CO: Jeppeson Sanderson Inc., 1990.

Jeppeson Sanderson, Aviation Fundamentals, Englewood, CO: Jeppeson Sanderson Inc., 1983.

Jeppeson Sanderson, Aviation Fundamentals, Englewood, CO: Jeppeson Sanderson Inc., 1992.

Precision Runway Monitor Program Office, Precision Runway Monitor Demonstration Report, DOT/FAA/RD-91/5, FAA Research and Development Service, Washington, DC, February 1991.

Thomas, J., Timoteo, D., and Hoang, P., Los Angeles International Airport Instrument Landing System Approach Data Collection and Reduction (Phase I) Final Report, FAA ATC Technology Branch, Atlantic City International Airport, New Jersey, 1993.

Timoteo, D. and Thomas J., Chicago O'Hare Simultaneous ILS Approach Data Collection and Analysis, FAA Technical Center, Concepts and Analysis Division, October 1989.

TRW Systems Division, Target Generation Facility, TGF-SY01-F03, December 1990.

## GLOSSARY

Airport Surveillance Radar (ASR) - Approach control radar used to detect and display an aircraft's position in the terminal area. ASR provides range and azimuth information but does not provide elevation data. Coverage of the ASR can extend up to 60 miles.

Automated Radar Terminal System (ARTS) IIIA - The modular, programmable ARTS which detects, tracks, and predicts primary as well as secondary radar-derived aircraft targets. This sophisticated computer driven system upgrades the existing ARTS by providing improved tracking, continuous data recording, and failsoft capabilities.

Blunder - An unexpected turn by an aircraft already established on the localizer toward another aircraft.

Closest Point of Approach (CPA) - The smallest slant range distance between two aircraft involved in a conflict. The distance is measured from the center of each aircraft involved.

Chi square - A statistical test for determining goodness-of-fit. Goodness-of-fit is an expression of how well any set of observed data conforms to some expected distribution. Tests for evaluating goodness-of-fit are based on the sum of squared deviations between the observed and expected values.

Conflict - Occurs whenever two or more aircraft approach each other with less than the minimum allowable airspace separation. A conflict occurs if there is less than a minimum of 1000 ft vertical and a minimum distance of 3 nautical miles (nmi) between aircraft.

CPA Prediction Tool - Presents a window of aircraft alignments for predicting separation between aircraft.

Final Monitor Aid (FMA) - A high resolution color display that is equipped with the controller alert system hardware/software which is used in the precision runway monitor (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 no transgression zone (NTZ), a color change alert if the aircraft transponder becomes inoperative, synthesized voice alerts, digital mapping, and like features contained in the PRM system.

Flight Technical Error (FTE) - The accuracy with which the pilot controls the aircraft as measured by the indicated aircraft position with respect to the indicated command or desired position. It does not include procedural blunders.

Glide Slope Intercept (GSI) - The minimum altitude to intercept the glide slope during a precision approach. The intersection of the published intercept altitude with the glide slope, designated on Government charts by the lightning bolt symbol, is the precision Final Approach Fix (FAF); however, when ATC directs a lower altitude, the resultant lower intercept position is then the FAF.

Groundspeed (GS) - The actual speed of an airplane over the ground. It is true airspeed adjusted for the wind. A headwind decreases GS while a tailwind increases it.

Indicated Airspeed (IAS) - The reading taken directly from the airspeed indicator on an airplane. IAS does not reflect variations in air density as higher altitudes are reached.

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.

Missed Approach - A maneuver conducted by a pilot when an instrument approach cannot be completed to a landing. The route of flight and altitude are shown on instrument approach procedure charts. A pilot executing a missed approach prior to the Missed Approach Point (MAP) must continue along the final approach to the MAP. The pilot may climb immediately to the altitude specified in the missed approach procedure.

Monitor Controller - A controller who continuously monitors aircraft conducting parallel instrument landing system (ILS) approaches.

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.

No Transgression Zone (NTZ) - A critical 2000 ft wide zone between parallel runways where aircraft are prohibited from entering. It is established equidistant between extended runway centerlines.

Nuisance Breakout (NBO) - Occurs when 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).

Outer Marker (OM) - A marker beacon at or near the glide slope intercept altitude of an ILS approach. It is keyed to transmit two dashes per second on a 400 Hertz (Hz) tone, which is received aurally and visually by compatible airborne equipment. The OM is normally located 4 to 7 miles from the runway threshold on the extended centerline of the runway.

Parallel Instrument Landing System (ILS) Approaches - Approaches to parallel runways by aircraft flying under Instrument Flight Rules (IFR) which, when established inbound toward the airport on the adjacent final approach courses, are radar-separated by at least 2 miles.

Scheffe Test - A statistical procedure for determining which specific comparisons in a multi-factor experiment are significant. These comparisons, which are run after the experiment is complete, are used only when a preliminary analysis has shown overall significance.

Simulation Pilot Operator (SPO) - A person who operates a Target Generation Facility (TGF) position and controls the trajectory of TGF aircraft by computer input messages. The SPO will usually communicate via voice circuits to ATC controller personnel in the laboratory which is being used to simulate an operational facility.

Simultaneous Instrument Landing System (ILS) Approaches - An approach system permitting simultaneous ILS approaches to airports having parallel runways separated by at least 4,300 feet between centerlines. Integral parts of the total system are ILS, radar, communications, ATC procedures, and appropriate airborne equipment.

Target Generation Facility (TGF) - An advanced simulation system designed to support testing of current and future ATC systems at the FAA Technical Center. The TGF is capable of modeling a logical view of the ATC environment (airspace volume including geographic data, weather data, navigation aids, radar sensors, airport data, and air routes) as well as simulate dynamic data associated with the movement and control of aircraft through the selected airspace.

Target Generation Facility (TGF) Aircraft - Targets generated by the TGF at the FAA Technical Center. TGF aircraft were used to provide additional traffic and to initiate blunders.

Technical Observer - An individual who monitors each control position visually and aurally during each simulation run. Their 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 assisting in final evaluation of data in order to prepare a Technical Observer report at the end of the simulation.

Test Criterion Violation (TCV) - Occur when two aircraft come within 500 ft of one another after the initiation of a blunder.

Test Director - Individual responsible for determining the occurrence of blunders through the use of the Closest Point of Approach (CPA) Prediction Tool and by assessing the blunder scripts. The test director is the liaison between the FAA Technical Center and the flight simulator sites during the simulation. The test director also coordinates the response condition with the target generation facility (TGF) aircraft operators.

Total Navigation System Error (TNSE) - Represents the difference between the actual flightpath of the aircraft and the path it is intending to fly. It is caused by flight techincal error (FTE), avionics error, instrument landing system (ILS) signal error, weather, and pilot performance.

True Airspeed (TAS) - The true speed of an airplane through the air. As altitude or air temperature increase, the density of the air decreases. For a given indicated airspeed (IAS), this means the TAS increases with altitude.

# APPENDIX A

## MULTIPLE PARALLEL APPROACH PROGRAM SUMMARY

# MULTIPLE PARALLEL APPROACH PROGRAM SIMULATIONS

| Phase | Dates | Purpose | Approach | Runway Spacing | Display | Simulated Radar | Other |
|---|---|---|---|---|---|---|---|
| I | 5/16-6/10 88 | DFW | Quadruple | 5000 & 5800 ft 8800 ft | SANDERS/ DEDS | ASR-9 4.8s | |
| II | 9/25-10/5 89 | DFW | Triple | 5000 & 8800 ft | SANDERS/ DEDS | ASR-9 4.8s | |
| III | 11/29-2/9 90 | DFW | Dual and Quadruple | 5000 & 5800 ft 8800 ft | SANDERS/ DEDS | ASR-9 4.8s | |
| IV.a | 4/24-5/3 90 | National Standards | Triple | 4300 ft | ARTS III | ASR-9 4.8s | |
| IV.b | 9/17-9/28 90 | National Standards | Triple | 5000 ft | ARTS III | ASR-9 4.8s | |
| V.a.1 | 5/15-5/24 91 | National Standards | Dual and Triple | 4300 ft | FMA | ASR-9 4.8s | |
| V.a.2 | 9/24-10/4 91 | National Standards | Triple | 4000 ft | FMA | ASR-9 4.8s | |
| V.a.2.2 | 7/27-8/14 92 | National Standards | Dual and Triple | 4000 ft | FMA | ASR-9 4.8 s | |
| V.b.1 & V.b.2 | 3/18-4/5 91 | National Standards | Dual and Triple | 3000 ft | FMA | E-Scan 1.0s | |
| V.b.3 | 9/16-9/23 91 | National Standards | Dual | 3000 ft | FMA | E-Scan 1.0s | 1-Degree Localizer Offset |
| V.c | 5/6-5/14 91 | National Standards | Triple | 3400 ft | FMA | Mode S 2.4 s | |
| V.d | 3/2-3/13 92 | Human Factors Study | Triple | 3400 ft | FMA | E-Scan 1.0 s | 1 Mr Radar Accuracy |
| V.a.2.2 | 7/27-8/14 92 | National Standards | Triple | 4000 ft | FMA | ASR-9 4.8 s | |
| n/a | 9/8-9/25 92 | Density Altitude Study | Triple and Quadruple | 7600 ft 5280 ft 5348 ft | ARTS III | ASR-9 4.8 s | Field Elevation 5431 ft |
| n/a | 11/16-11/20 92 11/30-12/17 92 | DIA | Triple | 7600 ft 5280 ft | FDADS FMA | ASR-9 4.8 s | Field Elevation 5431 ft |

# APPENDIX B

# SIMULATION USING THE FDADS

# CONTROLLER REPORT

ASSESSMENT OF TRIPLE SIMULTANEOUS PARALLEL ILS APPROACHES AT THE NEW DENVER INTERNATIONAL AIRPORT USING THE FDADS AND 4.8 SECOND RADAR UPDATE RATE.

Bargaining unit controllers from the Denver TRACON and airports around the country were asked to participate in a real-time air traffic control simulation. This simulations was scheduled from November 16, 1992 to December 15, 1992. The controllers involved in this study were tasked to provide air traffic control separation service for a high density altitude airport. The airport configuration is similar to the new Denver Airport. Field elevation in this simulation was 5431 feet. The radar monitoring equipment used a 4.8 second update rate source displayed on the FDADS. Aircraft used in this simulation were provided by five flight simulators, the FAA Technical Center's general aviation trainer, and the target generation facility. Aircraft flew approach speeds of 170 knots for jet and turboprops and 150 knots for light twin aircraft.

This simulation evaluated the FDADS equipment during the first two days of the simulation. The remaining three weeks of the simulation was directed by upper management levels to evaluate the Final Monitor Air (FMA) as the display tool.

The controllers cited the system's effectiveness to display information as a causal factor for inadequate blunder detection. The controller's comments best illustrate this statement. "Trend information makes it difficult to discern blunders." "Slow target update. There are times with a blunder of thirty degrees and the blundering aircraft goes NORDO as in this case, not enough time to escape." "Slow target update, not enough time to see the blunder and escape." "Slow target update, this hinders the controller to see the blunder in time to correct the situation." "Equipment is unable to display information accurately enough for controllers to do their job."

In many of the blunders, the controllers also listed pilot response as a causal factor for a blunder. In one instance a controller reported that after the pilot acknowledged the breakout instruction, the aircraft traveled 1 1/2-2 miles before the aircraft was observed to turn away from the final approach course. However, another controller's description of his observation in a three airplane escape indicates the difference in pilot/aircraft systems reactions times. The controller wrote, "AAL745 did an excellent job escaping and turning away from MTR435. UAL53's immediate turn and climb did not escape AAL745." The controller further wrote, "UAL53 was slow responding to instructions and AAL745 was all over him."

Inconsistent aircraft/pilot response rates coupled with inadequate FDADS clarity aggravated safe resolution of these blunders. There were 1169 aircraft handled with 87 blunders generated into with the flight simulators. Five blunders resulted in a Test Criterion Violation (TCV). A TCV occurred when controllers could not prevent two aircraft from coming within 500 feet of each other.

Thus, the controller,s ability to detect and provide adequate and safe resolution instructions was inadequate in this simulation. This does not reflect as a negative aspect of the controllers' abilities. However, it indicates the influence of the equipment and simulation guidelines on blunder resolution performance.

In this simulation configuration air traffic controllers could not safely monitor triple simultaneous instrument landing system approaches using simulated 4.8 second data and FDADS equipment at a simulated high density altitude report.

Harold R. Anderson

National Air Traffic Controllers Association
Multiple Parallel Approach Program Representative

# APPENDIX C

## SIMULATION USING THE FDADS

## TECHNICAL OBSERVERS REPORT

# TECHNICAL OBSERVERS REPORT
# DIA SIMULATION, FDADS

The following is a consensus opinion of the technical observers concerning the new Denver Airport simulation which began on November 16, 1992.

The simulation began, as planned, using the Full Digital ARTS III Display System (FDADS). From the initial run, it was quite evident that the controllers were experiencing difficulty recognizing and subsequently resolving aircraft blunders. Although the clarity of the indicators and the definition of the targets were satisfactory, determining movement around the localizer course was extremely difficult. The spacing between Runways 17L and 17R (5280 feet) and the radar update rate (4.8 seconds), appeared to be the two most prominent factors responsible for the controller difficulty. The slightly increased speeds, due to the density altitude, may also have given the controllers some problems. The spacing between runways 17R and 16 (7600 feet), did allow the controllers extra time in which to recognize and take action to resolve blunders.

Although the controllers continued to be extremely vigilant, many blundering aircraft penetrated the No Transgression Zone (NTZ) before control instructions were issued by the monitor controllers. The controllers appeared to be anxious and somewhat frustrated in their efforts to monitor these runs.

We unanimously agreed with the decision that terminated this phase of the simulation and restarted using the Final Monitor Aid (FMA) in place of the FDADS.

Richard B. Herschmann
SATCS, IAH ATCT

Chester W. Anderson
Special Projects Officer
AGL-507

Joel A. Forrest
SATCS, ATL ATCT

Wallace F. Watson
ATM, HSV ATCT

# APPENDIX D

# SIMULATION USING THE FDADS RISK ASSESSMENT

## FDADS SIMULATION AT DENVER

A demonstration simulation of the Full Digital Automated Radar Terminal Display System (FDADS) was conducted November 16 and 17, 1992. Thirty-six 30° blunders were simulated, of which 12 were shown by later analysis to be at-risk. Three TCV's were found among the 12 at-risk blunders, resulting in an observed TCV rate of 1/4. After two days of simulation, the decision was made by FAA management to discontinue the FDADS simulation in favor of the FMA. The analysis presented here will support that decision. The analysis will show that the TCV rate for the FDADS simulation is significantly larger than the TCV rate for the FMA simulation. The analysis will also show that the larger TCV rate of the FDADS simulation could lead to an unacceptably large risk.

Although the sample size is small, some conclusions regarding the data may be drawn. Since the number of at-risk, worst-case blunders was much larger for the FMA simulation, the observed Bernoulli ratio for the FMA simulation may be regarded as much more accurate than that for the FDADS simulation. The observed ratio for the FMA simulation was 2 TCV's per 186 at-risk blunders, or 1/93. Since binomial probabilities are easily computed, the null hypothesis that the probability of a TCV during the FDADS simulation is the same as that for FMA, $H_O{:}p = 1/93$, may be tested against the alternate hypothesis, $H_1{:}p > 1/93$, directly from the binomial distribution. A significance level of 0.05 will used to lessen the likelihood of a type II error.

If the probability of a TCV during the FDADS simulation was also $p = 1/93$, then the probability P of observing 3 TCV's in a sample of 12 at-risk blunders would be given by:

$$P = \binom{12}{3}\left(\frac{1}{93}\right)^3\left(\frac{92}{93}\right)^9 = 0.000248.$$

The probability of 3 or more TCV's in a sample of 12 may also be computed and is found to be P = 0.000254. Since the probability of 3 or more TCV's in a sample of 12 is smaller than 0.05, the alternate hypothesis, that the probability of a TCV using FDADS is larger than the probability of a TCV using FMA, is accepted as being true.

If the upper confidence limit for the FMA simulation, 5 TCV's per 102 at-risk blunders, is used for the estimate of the probability of a TCV given an at-risk blunder, then the null hypothesis would be $H_O{:}p = 5/102$ and the alternate hypothesis would be $H_1{:}p > 5/102$. The probability of 3 TCV's in a sample of 12 at-risk blunders, assuming p = 5/102 is computed as follows:

$$P=\binom{12}{3}\left(\frac{5}{102}\right)^{3}\left(\frac{97}{102}\right)^{9}=0.0165.$$

The probability of 3 or more TCV's in a sample of 12 at-risk blunders may also be computed and is found to be P = 0.0186. Since this probability is less than the chosen level of significance, the alternate hypothesis, that the probability of a TCV using FDADS is larger than the probability of a TCV using FMA, is accepted as true.

Assuming a binomial distribution and a 0.99 confidence interval, the actual TCV rate could be as high as 0.66. This rate means that about 100 TCV's per 151 worst case blunders could be expected while using the FDADS for monitoring purposes. The length of a confidence interval is dependent on sample size and will decrease as sample size is increased. An observed rate of 1/4 and a much larger sample size would result in an estimate of the upper confidence interval which would be smaller than 0.66. However, a larger sample could also result in a larger observed ratio which would in turn produce a large upper confidence interval limit. Therefore, the decision was made to use the upper confidence interval limit as an estimate of the ratio of TCV's to worst case blunders.

The formula which has been developed to predict the acceptable blunder rate which would result in an operational risk no larger than the target risk value of $4 \times 10^{-8}$, would become:

$$\frac{1\ \text{ACC}}{25\ \text{mill app}}\times\frac{8\ \text{WCB}}{1\ \text{algn WCB}}\times\frac{151\ \text{algn WCB}}{100\ \text{TCV}}\times\frac{3\ \text{app}}{1\ \text{triple}}\times$$
$$\frac{1\ \text{TCV}}{2\ \text{ACC}}\times\frac{100\ 30^{\circ}\ \text{Bl}}{1\ \text{WCB}}=\frac{1\ 30^{\circ}\ \text{Blunder}}{13{,}797\ \text{triple app}}$$

Because of the current lack of knowledge of the blunder rate, this blunder rate should be considered questionable and therefore, unacceptable. If, as has been suggested, the rate of WCB's to 30° blunders could be as high as 1/10, the result of the formula above would be:

$$\frac{1\ 30^{\circ}\ \text{Blunder}}{137{,}970\ \text{triple app}}$$

The actual blunder rate is generally assumed to be much larger than this rate and therefc -e, this rate should also be considered unacceptable. In either .ise, the simulation using the FDADS system should be considered to have resulted in an unacceptable operational risk.

In contrast to the FDADS simulation was the FMA simulation. The FMA simulation was conducted over 17 days and resulted in 186 at-risk blunders, but only 2 TCV's. The actual TCV rate was only 0.011. The 0.99 confidence interval indicated the TCV rate could be as high as 0.049 or 5 TCV's per 102 worst case blunders. Using the estimate of 1 worst case blunder per 100 30° blunders, the acceptable blunder rate for the FMA simulation becomes:

$$\frac{1\ 30^{\circ}\ \text{Blunder}}{1{,}021\ \text{triple app}}$$

If it is assumed that the ratio of worst case blunders to 30° blunders is 1/10, then the acceptable blunder rate for the FMA becomes:

$$\frac{1\ 30^{\circ}\ \text{Blunder}}{10{,}210\ \text{triple app}}$$

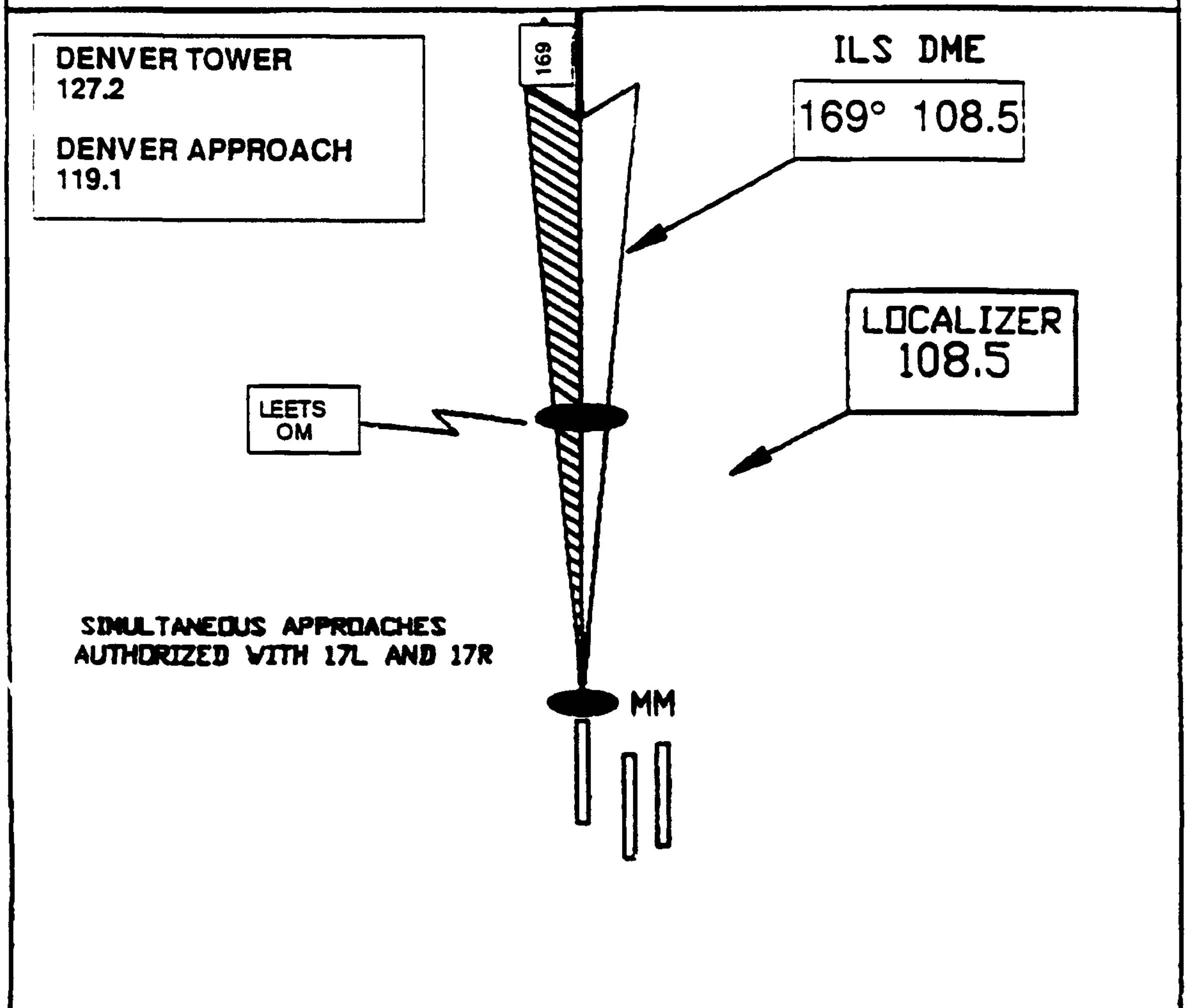
In either case, the acceptable rate for the FMA is about 13.5 times larger than the acceptable rate for the FDADS, thus indicating that the use of the FMA will result in an operation with less risk than the FDADS.

# APPENDIX E

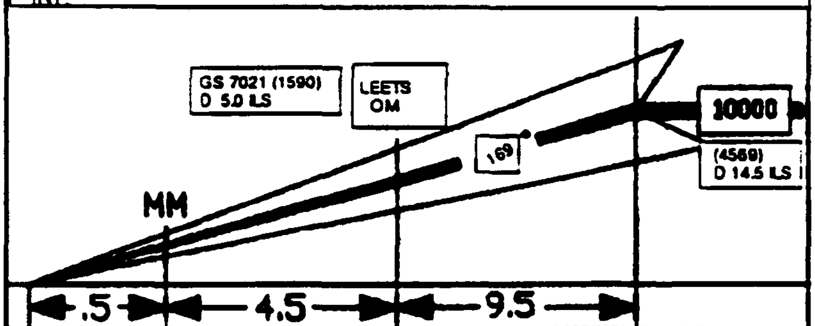
# APPROACH PLATES

ILS 16L

DENVER INTERNATIONAL AIRPORT (DVX)

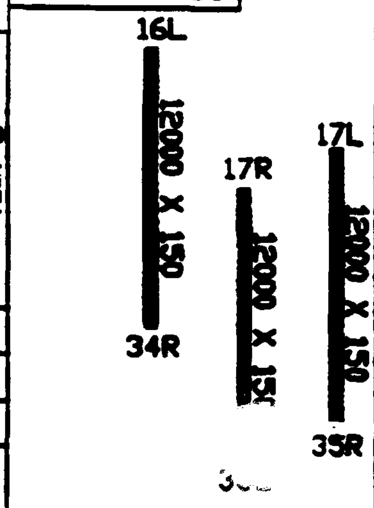



MISSED APPROACH: CLIMB TO 5900, THEN CLIMBING RIGHT TURN TO 8000 VIA HEADING 250° AND DVV R233° TO SLOPE INT.




| CAT. | A | B | C | D | E |
|---|---|---|---|---|---|
| S-ILS | 5631 1/2 (200) | | | | |
| S-LOC | | | | | |
| CIRCLING | | | | | |

ELEV 5431

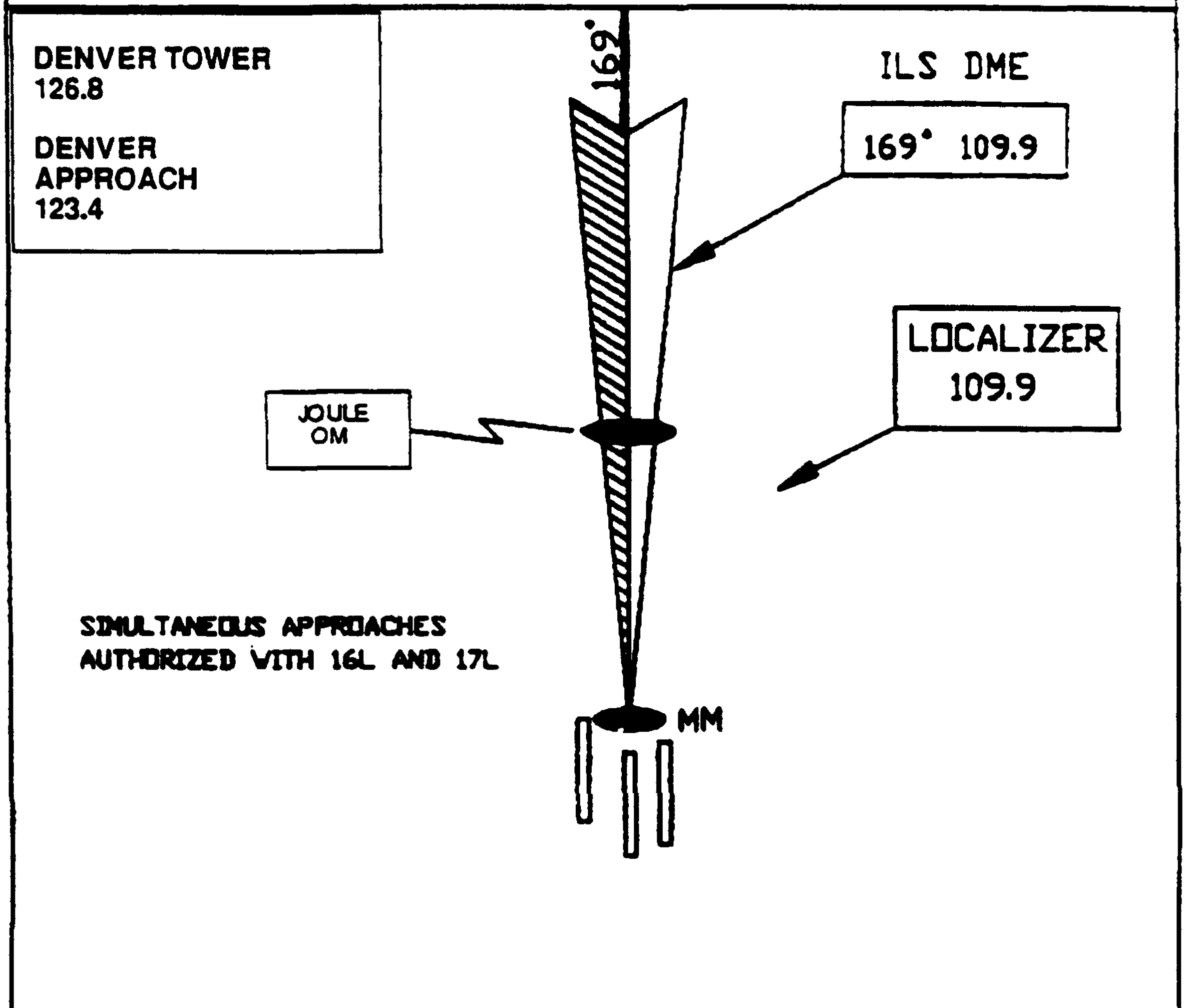



FAF TO MAP 5.0 NM

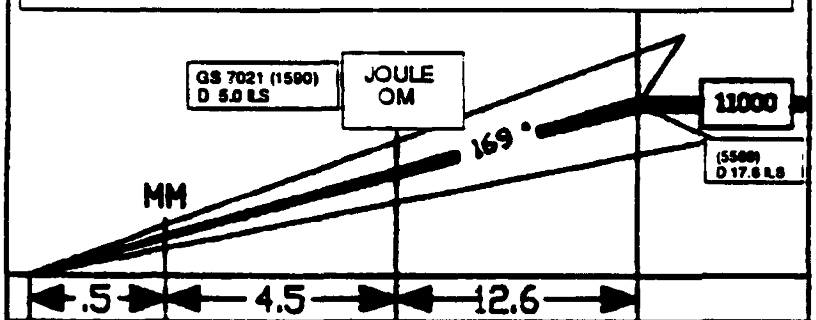
| KNOTS | 60 | 90 | 120 | 150 | 180 |
|---|---|---|---|---|---|
| MIN:SEC | [illegible] | [illegible] | [illegible] | [illegible] | 1:40 |

# ILS 17R

DENVER INTERNATIONAL AIRPORT (DVX)

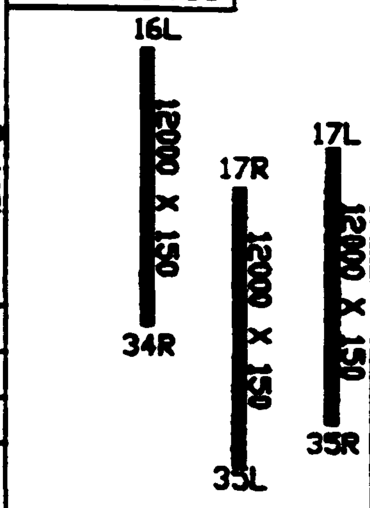



MISSED APPROACH: CLIMB TO 6500, THEN CLIMBING LEFT TURN TO 8000 DIRECT FQF VORTAC.




| CAT. | A | B | C | D | E |
|---|---|---|---|---|---|
| S-ILS | 5631 1/2 (200) | | | | |
| S-LOC | | | | | |
| CIRCLING | | | | | |

ELEV 5431

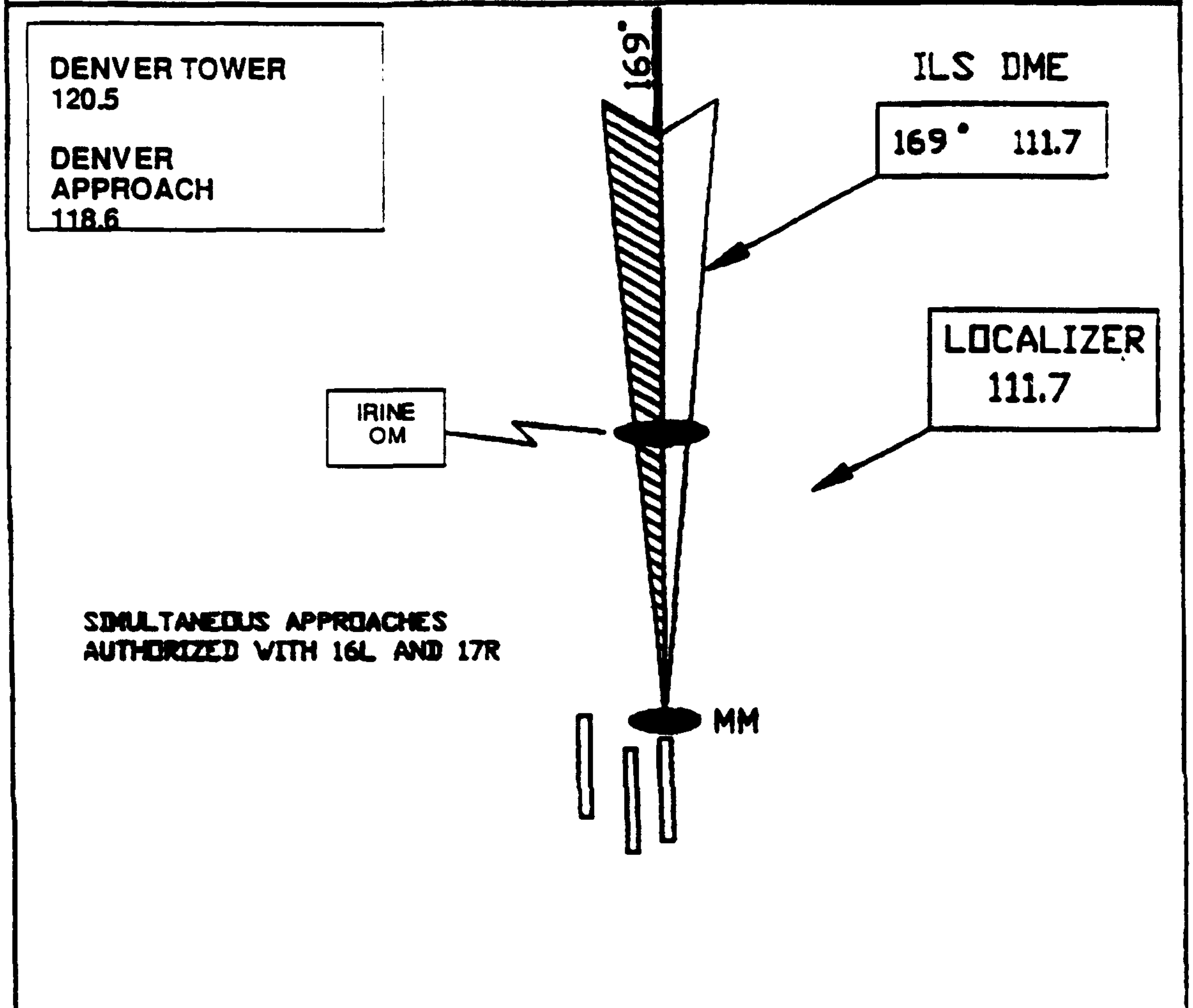



FAF TO MAP 5.0 NM

| KNOTS | 60 | 90 | 120 | 150 | 180 |
|---|---|---|---|---|---|
| MIN:SEC | 5:00 | 3:20 | 2:30 | 2:00 | 1:40 |

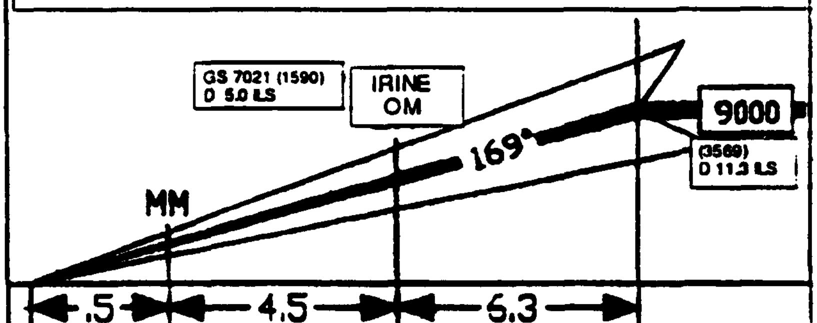
ILS 17L

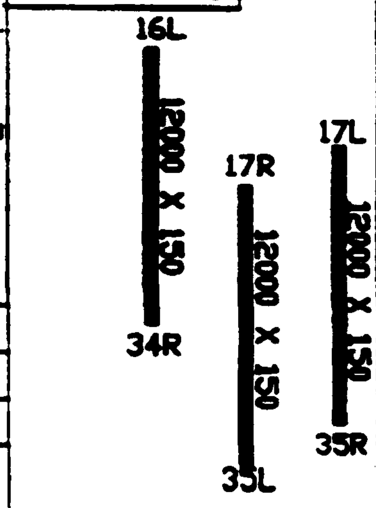
DENVER INTERNATIONAL AIRPORT (DVX)




MISSED APPROACH: CLIMB TO 5900 THEN CLIMBING LEFT TURN TO 8000 VIA HEADING 090° AND DVV R133° TO HOKER INT.

ELEV 5431




| CAT. | A | B | C | D | E |
|---|---|---|---|---|---|
| S-ILS | 5631 - 1/2 (200) | | | | |
| S-LOC | | | | | |
| CIRCLING | | | | | |

| FAF TO MAP 5.0 NM | | | | | |
|---|---|---|---|---|---|
| KNOTS | 60 | 90 | 120 | 150 | 180 |
| MIN:SEC | 5:00 | 3:20 | 2:30 | 2:00 | 1:40 |

# APPENDIX F

# CONTROLLER QUESTIONNAIRES

POST-RUN CONTROLLER QUESTIONNAIRE

DIA SIMULATION

PARTICIPANT CODE _______ DATE _______

PARTNER'S CODE ____ ____ ____ ____ TIME _______

RUN NUMBER ___________ RUNWAY _______

Please fill out this brief questionnaire on the run you have <u>just completed</u>.

---

1. Rate the level of activity required during this run.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Minimal | | Moderate | | Intense |

---

2. Rate the level of stress experienced during this run.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Minimal | | Moderate | | Intense |

---

3. Rate the mental effort required during this run.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Low | Acceptable | Moderately High | High | Maximum |

---

4. Please describe any unusual occurrences (problems with visuals, communications, aircraft performance, etc.) from the last hour. Please note any unusually long delays or incorrect pilot responses.

# POST-SIMULATION CONTROLLER QUESTIONNAIRE

## DIA SIMULATION

NOTE: All responses provided from the following questionnaire will be reported as an aggregate. Individual responses will not be reported. To ensure complete anonymity, please do not write your name or controller letter on the questionnaire. Thank you.

# POST-SIMULATION CONTROLLER QUESTIONNAIRE

## DIA SIMULATION

*************************************

1. Using the Final Monitor Aid (FMA), how difficult was it to perform the Monitor Controller task? Explain and identify any additional information needed, if any, to perform the Monitor Controller task?

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Very Difficult | | Average Difficulty | | Very Easy |

2. Triple independent IFR approaches to runways spaced 5280 and 7600 ft apart can be safely conducted as simulated. Explain.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Disagree | | Neutral | | Agree |

3. Except for deliberately introduced blunders, how realistic was this traffic (aircraft types, density)? Explain.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Not Realistic | | Borderline | | Very Realistic |

4. What specific strategy or agreement did you develop regarding inter-controller coordination? Please describe briefly below even if the arrangement was unspoken. Be specific and include controller letter codes.

5. What specific central strategies, if any, did you develop due to the high density altitude environment?

6. Based on your experiences during this simulation, please comment on any potential effects high density altitude may have on the runway configuration simulated?

8. Please describe any items in the simulation which you believe were not realistic or whose realism could have been improved upon (include any comments i.e equipment, displays, communication, etc.):

CONTROLLER TEST CRITERION VIOLATION STATEMENT
DIA Simulation

Controller ________ Runway ________ Run # ________

Blunder ID/Rwy ____________ Evader ID/Rwy ____________

============================================================

1. Were you aware a blunder situation was developing?

( ) Yes ( ) No

Explain ______________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

2. Did you contemplate taking corrective action?

( ) Yes ( ) No

Explain ______________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

3. Did you attempt to take corrective action?

( ) Yes ( ) No

Explain ______________________________________________

______________________________________________________

______________________________________________________

______________________________________________________

4. Identify which of the following alerted you to the occurrence:

( ) Self-Identified ( ) Pilot

( ) Other Controller ( ) Other ______________

5. Were you distracted by anything which influenced the occurrence (presence of visitors, speaker volume, loud talking from others, etc.)?

( ) Yes ( ) No

Explain ______________________________________

6. Brief explanation of traffic complexity: ______________

II. CAUSAL FACTORS/RECOMMENDATIONS: Identify any of the following which you believe contributed to the incident:

1. Operational Factors:

( ) Equipment ( ) Pilot Action ( ) Oversight

( ) Traffic Volume ( ) Lack of Cooperation ( ) Other

Explain all the items checked: ______________________

III. STATEMENT:

1. From your knowledge of the incident, provide a narrative summary:

____________________________________________________________
____________________________________________________________
____________________________________________________________
____________________________________________________________

2. To prevent recurrence of a similar operational error/deviation, I recommend the following:

____________________________________________________________
____________________________________________________________
____________________________________________________________
____________________________________________________________

# APPENDIX G

# PILOT QUESTIONNAIRES

PILOT BREAK-OUT QUESTIONNAIRE

DIA Simulation

1. WAS THE BREAK-OUT INSTRUCTION COMMUNICATED CLEARLY AND CONCISELY? (e.g., rate of speech, clarity, volume, etc...)

   Yes ________ No ________

   If no, state reason: ____________________________________

   ____________________________________________________________

2. HOW WAS THE BREAK-OUT INSTRUCTION GIVEN?

   1 - Heading, Altitude (in one transmission)
   2 - Altitude, Heading (in one transmission)
   3 - Heading, Altitude (in two separate transmissions)
   4 - Altitude, Heading (in two separate transmissions)
   5 - Other

   If 5 - Other, please describe: __________________________

   ____________________________________________________________

3. WAS A SECOND TRANSMISSION REQUIRED IN ORDER TO RECEIVE A COMPLETE BREAK-OUT INSTRUCTION?

   Yes ________ No ________

   If yes, state reason: ___________________________________

   ____________________________________________________________

4. GIVEN THE CONTROLLER INSTRUCTION, AIRCRAFT CONFIGURATION, AND FLIGHT REGIME, RATE THE DIFFICULTY OF THE BREAK-OUT MANEUVER.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Not Difficult | | Average | | Very Difficult |

   Please explain: _________________________________________

   ____________________________________________________________

5. WHAT, IF ANY, ADDITIONAL COMMENTS DO YOU HAVE?

   ____________________________________________________________

   ____________________________________________________________

FLIGHTCREW OPINION SURVEY
DIA Simulation

DATE: __________

SITE: AVIA BOEING DELTA/B737 DELTA/MD88 FAATC NASA TWA

PILOT LETTER: _____

TOTAL NUMBER YEARS FLIGHT EXPERIENCE: _______

Answer each question to the best of your ability using the scoring scheme shown. You are invited to provide additional comments on any item in the space provided at the end of the survey form. Please reference the item number.

1 - strongly agree
2 - agree
3 - neutral
4 - disagree
5 - strongly disagree

1.0 SURVEY ITEMS

1.1 Current parallel runway procedures require 1000 ft of vertical separation at the localizer turn-on for separation.

In the event that one (or both) aircraft overshoot the localizer, 1000 ft of vertical separation would provide an acceptable safety margin provided aircraft maintain their assigned altitude until established on the localizer course. 1 2 3 4 5

1.2 To emphasize the importance of a quick response from the threatened aircraft, special phraseology should be used for the break-out maneuver. 1 2 3 4 5

1.3 Given the premise that the resolution of a conflict situation is primarily dependent on monitor controller to pilot communications, please respond to the following statements.

An alternate communication frequency would be useful. 1 2 3 4 5

Breakout instructions should be broadcast simultaneously on the ILS frequency. (voice on the localizer) 1 2 3 4 5

## 2.0 GENERAL COMMENTS

2.1 Please provide any suggestions on types of training to be required, types of certification (etc.) that you think would enable the operation of multiple simultaneous parallel ILS approaches to be a safe and effective procedure.

2.2 Please provide any suggestions on types of special terminology/phraseology/instructions for an evasive maneuver (e.g., "Immediately," "Escape," call sign emphasis by repeating callsign 2 times, altitude instruction before heading instruction, published escape maneuver).

**THANK YOU FOR YOUR PARTICIPATION AND ALL COMMENTS GIVEN.**

IF YOU WOULD LIKE A COPY OF THE
DIA SIMULATION FINAL TEST REPORT,
PLEASE COMPLETE THE FOLLOWING:

NAME: ____________________

ADDRESS: ____________________

____________________

PHONE: ____________________

NOTE: IT TAKES APPROXIMATELY 1 YEAR FOR A TEST REPORT TO BE PUBLISHED AFTER A SIMULATION HAS BEEN COMPLETED.

## APPENDIX H

## CONTROLLER REPORT

SIMULATION REPORT FOR TRIPLE SIMULTANEOUS PARALLEL ILS APPROACHES FOR THE NEW DENVER INTERNATIONAL AIRPORT USING THE FINAL MONITOR AID.

This simulation involved air traffic controllers from the Denver TRACON as well as controllers from other airports that conduct Simultaneous Instrument Landing System (ILS) approaches. Conditions of the new Denver International Airport were simulated. The evaluation period was from November 18, 1992 to December 15, 1992 at the Federal Aviation Administration Technical Center (FAATC). This simulation evaluated the effects of high density altitude on an air traffic controller's ability to detect and resolve blunders for the final monitor position. A blunder is defined from the simulation documents as an unexpected turn by an aircraft already established on the localizer toward another aircraft. The monitor equipment was the Final Monitor Aid (FMA). The FMA description from the same documents is a 20x20 inch, high resolution color display specifically designed for the monitor controller position. These displays utilize 2048-line by 2048-pixel resolution television raster scan technology. They incorporate the controller alert system hardware/software which is used in the precision runway monitor (PRM) system. FMA alert features are a voice activated warning and data block color change on the display. This feature is activated when an aircraft approaches and/or enters the NTZ.

Controller resolution was considered adequate if the resolution did not result in a Test Criteria Violation (TCV). A TCV is when controllers could not prevent two aircraft from coming within 500 feet of one another. This simulation had two TCV's which gave the simulation results of 98.9% air traffic controller accuracy in resolving blunders.

The FMA greatly reduced controller workload by enhancing the controllers ability to resolve blunders and often discuss different control instructions as they were able to coordinate control actions with each other.

In this simulation configuration the effects of high density altitude were negligible on the controllers ability to detect and provide adequate resolution instructions. As a result, the air traffic controller team could safely monitor triple simultaneous ILS approaches for the simulated conditions of the new Denver International Airport with the FMA.

Harold R. Anderson ATCS
National Air Traffic Controllers Association Representative
to the Multiple Parallel Approach Program

# APPENDIX I

# TECHNICAL OBSERVER REPORT

## Technical Observers Report

This report is the consensus of the Technical Observers concerning the DIA triple simultaneous approach simulation. It contains general conclusions concerning the conduct of the simulation, as well as our recommendations to the Technical Work Group.

The simulation was to triple runways spaced 7,600 feet and 5,280 feet apart with a simulated radar system including a 4.8 second update rate and the Final Monitor Aid (FMA). FMA is the Sony 20 x 20 high resolution color display with controller alerts.

During the simulation, the controllers had little difficulty detecting and resolving blunders. The relative ease in which the controllers were able to maintain required separation became more evident as they grew accustomed to the equipment and procedures. In fact, as controllers gained experienced with the FMA, they were able to wait longer to evaluate the situation and then initiate action to resolve the blunder. Alert algorithms and runway spacings appeared to be the factors which allowed the controllers to take extra time when evaluating these situations. The slower response time did not appear to cause any "close calls" or test criterion violations (TCV). As the simulation progressed, it appeared that some controllers grew bored as they monitored approaches. Although the time spent on position monitoring simultaneous approaches varies facility to facility, controllers would never be required to perform this function for such long periods in reality. The ease in which blunders can be detected with the equipment tested and the monotony of the task, are factors which may possibly influence a controllers ability to maintain separation between aircraft. Whether a controller is bored or not is of course impossible to observe, however the Technical Observers agree this area may need some additional study through human factors testing.

All but two controllers who participated had prior experience in the procedures and equipment used for this test. Early in the simulation the experience level of the new controllers was evident. Even though a briefing was conducted to all personnel and practice runs were performed prior to the actual simulation, the Technical Observers believe that more time should be devoted to training of controllers new to these simulations. The practice runs were conducted until the new controllers indicated they felt comfortable with equipment and procedures. The Technical Observers believe the training should be conducted for a predetermined period decided by the TWG and not left up to the discretion of the new controllers. This training could effect the early portion of the simulation. As an example, there were several nuisance breakouts during the early portion of the simulation due to the new and returning controllers adjusting to the equipment.

The Technical Observers believe that consideration should also be given to rotating new controllers into the simulations. Reaction time could be affected due to their familiarity of the process. We believe that half of the controller work force should be new to each simulation.

Communications between the simulator pilots and the controllers was a factor as the TCV statements will reflect. The pilots flying the simulators may have flown for a particular carrier for a long period of time but during the simulation they were assigned another carrier call sign. This resulted in a missed communication and possibly a TCV. Data will be reviewed to determine if this was actually the case. There were other problems associated with communications between the controllers and the pseudo pilots due to inexperience of the pseudo. These problems were discussed as practical on an individual basis and should be considered when evaluating simulation results.

Aircraft types and performance characteristics were always a concern to the controller during a blunder situation. These concerns seemed to be amplified when a lower performance aircraft was involved and on the center runway approach. Although a TCV may not have resulted due to this situation, the Technical Observers suggest that lower performance aircraft be assigned runway 16L at DVX when practical because of the additional space between runways. This would allow more time for the lower performance aircraft to evade should it become necessary.

## CONCLUSION

The Technical Observers agree that triple simultaneous approaches at the DVX airport can be safely accomplished using the 4.8 second update radar and the Final Monitor Aid (FMA).

Richard B. Herschmann
SATCS, IAH ATCT

Chester W. Anderson
Special Projects Officer
AGL-507

Joel A. Forrest
SATCS, ATL ATCT

Wallace F. Watson
ATM, HSV ATCT

# APPENDIX J

## OBSERVER LOGS

# TECHNICAL OBSERVER LOG

OBSERVER: RUN #: CONTROLLERS: (16L) (17R) (17L)

DATE: TRAFFIC SAMPLE:

| SIM TIME | TCV | BLUNDER ID | RWY | EVADER ID | RWY | EVADER ID | RWY | NBO | P/S | Slow Turn Rate (P/A) | Slow Response Time (P/C/A) | Wrong Call Sign (P/C) | Instructions Not Followed | Other Factor |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | |

Additional Comments:

| SIM TIME | TCV | BLUNDER ID | RWY | EVADER ID | RWY | EVADER ID | RWY | NBO | P/S | Slow Turn Rate (P/A) | Slow Response Time (P/C/A) | Wrong Call Sign (P/C) | Instructions Not Followed | Other Factor |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | |

Additional Comments:

| SIM TIME | TCV | BLUNDER ID | RWY | EVADER ID | RWY | EVADER ID | RWY | NBO | P/S | Slow Turn Rate (P/A) | Slow Response Time (P/C/A) | Wrong Call Sign (P/C) | Instructions Not Followed | Other Factor |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | |

Additional Comments:

| SIM TIME | TCV | BLUNDER ID | RWY | EVADER ID | RWY | EVADER ID | RWY | NBO | P/S | Slow Turn Rate (P/A) | Slow Response Time (P/C/A) | Wrong Call Sign (P/C) | Instructions Not Followed | Other Factor |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | |

Additional Comments:

DATE: CONTROLLERS: RUN #:

OBSERVER: (16L) (17R) (17L) TRAFFIC SAMPLE:

| Clock Time | Sim Time | System Start/Fail | TCV | NBO | CST | Blunder ID | Rwy | Evader ID | Rwy | Evader ID | Rwy | DME | COM | CPA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | |

Controller Message/Additional Comments:

| Clock Time | Sim Time | System Start/Fail | TCV | NBO | CST | Blunder ID | Rwy | Evader ID | Rwy | Evader ID | Rwy | DME | COM | CPA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | |

Controller Message/Additional Comments:

| Clock Time | Sim Time | System Start/Fail | TCV | NBO | CST | Blunder ID | Rwy | Evader ID | Rwy | Evader ID | Rwy | DME | COM | CPA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | |

Controller Message/Additional Comments:

| Clock Time | Sim Time | System Start/Fail | TCV | NBO | CST | Blunder ID | Rwy | Evader ID | Rwy | Evader ID | Rwy | DME | COM | CPA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | |

Controller Message/Additional Comments:

SIMULATION OBSERVER LOG, DVX SIMULATION

## SITE COORDINATOR LOG

DATE: RUN: TRAFFIC SAMPLE: WIND:

SITE: AVIA BOEING DELTA/B737 DELTA/MD88 FAATC NASA TWA

| INDEX | AIRCRAFT ID | PILOT ID | TYPE OF APPROACH | | | LAND | BREAK-OUT MANEUVER | | BANK ANGLE | QUESTIONNAIRE | | | | OBSERVER/PILOT COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Raw Data | Flt Dir | Auto-Pilot | | Normal | Abnormal (1-6) | Maximum Observed | Q1 (Y/N) | Q2 (1-5) | Q3 (Y/N) | Q4 (1-5) | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |

ABNORMAL BREAK-OUT MANEUVER:

1 - Computer Problem/Computer Froze
2 - Message Clarity (speech rate, pronunciation, clipped transmission)
3 - Message Content (wrong call sign, missing altitude, missing heading)
4 - Radio Reception (stepped-on transmission, background noise)
5 - Difficulty While Executing Break-out Maneuver (disconnecting autopilot, MCP or flight director mode control selector difficulties, flight crew coordination)
6 - Other

# APPENDIX K

## OPERATIONAL ASSESSMENT

## MULTIPLE PARALLEL APPROACH PROGRAM TECHNICAL WORK GROUP (MPAP TWG) OPERATIONAL ASSESSMENT

The simulation of simultaneous approaches to the proposed triple parallel runway configuration at the new Denver International Airport (DIA) was conducted at the Federal Aviation Administration (FAA) Technical Center, Atlantic City International Airport, New Jersey, from November 18-20, 1992, and November 30-December 17, 1992. The goals were to demonstrate the safety and feasibility of conducting triple simultaneous instrument landing system (ILS) operations to triple parallel runways.

The simulation included approximately 11,800 ILS approaches in which two conflicts resulted in less than a 500-foot (ft) slant range distance. A total of 705 conflicts of 30-degree turns generated into flight simulators involved incommunicado blundering aircraft. One hundred eighty-six of these 705 conflicts were "at risk" if the controller did not intervene. Detailed evaluation was conducted on the two situations which resulted in 500 ft or less slant range distance. The closest point of approach was computed to have a 187-ft slant range distance.

Based on the established test criteria, the controllers met the simulation objective. The arrival monitor positions in the simulation proved to be operationally effective and feasible.

The test controllers participated in the simulation as though they were controlling live traffic. Their attention and dedication was critical to the success of the simulation.

Based upon the results of the simulation, the TWG believes that the proposed triple simultaneous ILS approaches at DIA are acceptable, achievable, and safe with the final monitor aid (FMA) system and an appropriate radar system, such as a Mode S monopulse system or an ASR-9 radar system enhanced to provide improved target resolution capabilities.

## RECOMMENDATIONS

The Multiple Parallel Approach Program Technical Work Group (MPAP TWG) recommends:

1. There shall be one monitor controller for each runway. Personnel and equipment shall be provided to support the procedure.

2. All monitor positions should be located together and near their respective arrival and departure positions.

3. A radar system with 2.7 milliradians azimuth accuracy or better, and the capability to resolve two aircraft at 20 nmi separated by .9 degrees or more.

# APPENDIX L

# RISK ANALYSIS OF BLUNDERS

## RISK ANALYSIS OF BLUNDERS

### 1.0 INTRODUCTION

The implementation of multiple parallel approaches will introduce the risk of collision of aircraft on adjacent approaches. Other possible risks are conflicts during the turn on procedure and possible runway deviations after landing. Historically the risk of collision of aircraft on adjacent approaches has been considered the most important. The risk of turn on conflicts is deemed acceptably small due to large altitude and lateral separations as well as positive radar guidance. The risk of runway deviations is also deemed acceptably small from the absence of large runway deviations from historic accident data.

The risk of collision of aircraft on adjacent approaches is due to a phenomenon called a blunder. Although it is well known that aircraft, during normal operations, display a distribution of lateral movement left and right of the course centerline, this distribution is understood well enough that the probability of the aircraft being so far off course during normal operations to cause a collision is considered negligible. This already small probability is made even smaller by the presence of air traffic controllers, equipped with state of the art radar, whose task is to monitor only the final approach segment. Thus the primary risk of collision is due to a previously unimportant rare event called a blunder.

A blunder can be defined as any significant deviation from the course centerline resulting from pilot error and/or equipment failure. Blunders are usually thought of as deviations of 10° or more from centerline and can be caused by a variety of reasons ranging from pilot error in the selection of the proper ILS frequency to failure of an outboard engine on an aircraft with wing mounted engines. Although no historical documentation of blunders exists, conversations with controllers affirm that blunders do occur as rare events. One known incident, which was caused by the simultaneous failure of two engines on the same side of a four engine aircraft, resulted in an estimated 30° blunder from the course centerline. This knowledge resulted in an agreement between the Multiple Parallel Approach Procedures Technical Work Group and industry representatives to test blunder angles up to and including 30°. However, simulations have indicated that blunders through 20° are easily resolvable and therefore pose minimal risk to the operation. Therefore this study will concentrate on the risk posed by a 30° blunder.

## 2.0 BASIC RISK COMPUTATION

### 2.1 DEFINITION OF A TCV

Although the definition of a collision of two aircraft is obvious, a definition which can be used in mathematical analysis is not as obvious and could be considered by some to be subjective. Since aircraft are basically long tubular structures with various protuberances, it is possible that two aircraft could pass very close to one another without touching. On the other hand, the aircraft could simply touch wing tips with the centers of gravity far removed. For this reason it was decided to simply place the evading aircraft in the center of a hypothetical sphere and determine whether or not the center of gravity of the blundering aircraft penetrates that sphere. It will be assumed that such a penetration would result in a collision. Obviously not all such penetrations would result in collisions, but in mathematical analysis some simplifying assumptions must be made. The choice of the radius of this sphere is somewhat subjective. It must be at least as large as the wingspan of the largest aircraft which will be involved in parallel approach operations, and it must be at least as large as the wingspan of aircraft in the foreseeable future. For these reasons the radius of the sphere was chosen to be 500 feet. Since an incursion of the blundering aircraft into the 500 foot sphere of the evader aircraft does not guarantee a collision, it will be called a Test Criterion Violation or TCV.

### 2.2 DEFINITION OF WORST CASE BLUNDER

Previous studies as well as the current study indicate that blunders in the 30° range are the most likely to result in a TCV. The probability of a TCV during a 20° or less blunder is considered to be remote. Not all 30° blunders will result in a flight by the blundering aircraft through the NTZ into the path of the evading aircraft just as not all swerves by automobiles toward the center median result in a crossing of the median. Simulations have shown that if the pilot of the blundering aircraft is able to return the aircraft to the course centerline because of controller intervention or personal initiative, the risk of collision is negligible. Therefore, a worst case blunder (WCB) is defined to be a 30° blunder in which the pilot of the blundering aircraft is unable to respond to a controller direction to return to course. The reason why the pilot may not respond could be a communications failure, a mechanical failure, a severe weather problem such as a thunderstorm, or a physiological problem of some member of the crew. For the purposes of this study, the reason will be simply referred to as no response.

### 2.3 BASIC RISK EQUATION

A TCV will occur when two aircraft are aligned in such a way that a TCV is possible and simultaneously a WCB occurs. Intuition suffices to prove that an alignment window exists during which a TCV is possible if a worst case blunder occurs. If the aircraft are not within this alignment window then the blundering aircraft would pass harmlessly ahead or behind of the evading aircraft without any evasive movement of the evading aircraft. Likewise, it is obvious that a TCV can only occur when a blunder turns into a worst case blunder. Hence a TCV can only occur when the aircraft are properly aligned during a blunder which results in a worst case blunder. In mathematical set theory, this means that the set of TCV's is a subset of the intersection of the set of aligned approaches with the set of 30° blunders and the set of no response blunders.

Although a TCV does not necessarily result in a collision, for simplicity and in order to equate the probability of a TCV to the existing accident rate, it will be assumed that a TCV will result in a collision and that a collision will result in the loss of both aircraft. Therefore, in order to simplify the analysis, a TCV will be assumed to result in two fatal accidents.

Using the notation P(event) to indicate the probability that an event will occur and P(event 1 | event 2) to indicate the probability that event 1 will occur given that event 2 has already occurred, the discussion above indicates that the probability of a collision may be written as:

$$
\begin{aligned}
P(\text{collision}) &= P(\text{TCV}) \\
&= P(\text{TCV and aligned and WCB and blunder}) \\
&= P(\text{TCV} \mid \text{aligned and WCB and blunder}) \times \\
&\quad P(\text{aligned} \mid \text{WCB and blunder}) \times \\
&\quad P(\text{WCB} \mid \text{blunder}) \times P(\text{blunder}).
\end{aligned}
$$

In order to compute the probability of a collision or TCV it is necessary to compute or estimate four factors. The first factor, P(TCV | aligned and WCB and blunder) may be estimated from data collected during the simulation of this study. The simulation is designed to determine the probability that a TCV will occur when an aligned WCB occurs. The second factor, P(aligned | WCB and blunder) may be estimated by analytical means. The third factor, P(WCB | blunder) is not easily estimated, but bounds may be placed on its possible variation. The fourth factor, P(blunder) is even more difficult to estimate since it is extremely small. Since P(TCV) depends on two factors whose estimation is in doubt, it is desirable to eliminate at least one of the doubtful factors. From historical data the probability of a fatal accident during an approach under instrument meteorological conditions may be determined and used to find an acceptable risk of a TCV. In this way, the only missing variable in the equation would be P(blunder). The formula could then be used to solve for P(blunder). Thus P(blunder) is given by:

$$P(\text{blunder}) = P(\text{TCV}) / (P(\text{TCV} \mid \text{aligned and WCB and blunder}) \times P(\text{aligned} \mid \text{WCB and blunder}) \times P(\text{WCB} \mid \text{blunder})).$$

The value, P(blunder) would not represent the actual value of a blunder since that value is unknown, instead, it would represent a blunder probability which the system could tolerate and which would provide an acceptable level of risk represented by P(TCV). A large value of P(blunder) would be desirable since it would indicate the system could tolerate a large blunder probability and still meet the acceptable risk level, P(TCV). A very small value of P(blunder) would be undesirable since it is known that the actual blunder rate is small, but the order of magnitude is in question.

## 3.0 DETERMINATION OF ACCEPTABLE RISK

### 3.1 PHASES OF FLIGHT

In order to find an acceptable probability of an accident due to a collision of aircraft on adjacent approaches, a general systems approach to the overall flight operation is discussed first. The flight operation is defined to be the entire sequence of events in a flight from starting the engine(s) in preparation for departure to shutting down the engine(s) at the destination. The sequence of events can be defined with varying degrees of detail; however, for the purposes of this discussion, the following sequence of events seems appropriate:

1. Start and taxi
2. Take-off
3. Climb to cruise altitude
4. Cruise en route
5. Descent and initial approach
6. Final approach
7. Landing, roll-out, taxi, shutdown.

This sequence was chosen because historical accident data is reported using this sequence.

### 3.2 ESTIMATING PHASE RISKS

Using data made available by the National Transportation Safety Board (NTSB) and the FAA, the fatal accident rates by departure for air-carrier operations for the years 1983 - 1988 have been made and are shown in Table 1. The accident count from which these rates were determined includes all reported air-carrier accidents. The accidents reported by NTSB may or may not be due to system failures or pilot errors; for example, a fatal accident involving a ground crew member during the push back from the jetway is reported. For this reason, only accidents caused by system failures or pilot errors are used in the determination of the phase rates. From data supplied by the FAA, the number of air carrier operations or departures is estimated to be about 33.3 million. The phase rate is determined by dividing the number of fatal accidents by the number of departures.

| Phase of Flight | Reported Fatal Accidents | Fatal Accident Rate (per Approach) |
|---|---|---|
| Start and Taxi | 1 | $2.9998 \times 10^{-8}$ |
| Take-off | 6 | $1.7999 \times 10^{-7}$ |
| Climb | 0 | - |
| Cruise | 3 | $8.9995 \times 10^{-8}$ |
| Descent | 1 | $2.9998 \times 10^{-8}$ |
| Approach | 2 | $5.9997 \times 10^{-8}$ |
| Landing | 1 | $2.9998 \times 10^{-8}$ |
| Total | 14 | $4.1998 \times 10^{-7}$ |

Table 1.

### 3.3 ESTIMATING FINAL APPROACH RISK

Since the NTSB reported two fatal accidents during the approach phase, the estimated rate for the final approach segment is $6 \times 10^{-8}$ fatal accidents per departure. Since most approaches are flown in visual flight conditions using visual flight rules (VFR) it is necessary to adjust the rate to reflect the number of approaches under instrument meteorological conditions using instrument flight rules (IFR). The number of instrument approaches is no longer recorded by the FAA; however, using data available in the FAA Statistical Handbook of Aviation, 1970, the percentage of precision approaches is estimated to be about 15%, the percentage of non-precision approaches is estimated to be about 2%, and the number of visual approaches is estimated to be about 85%. Since average weather conditions are assumed to be constant through the years, these percentages are assumed to still be accurate.

Since about 33.3 million operations were recorded for the years 1983 - 1988, the number of precision approaches is about 15% of 33.3 million or 5 million precision approaches. The two fatal accidents reported in the time period both occurred during precision approaches. This leads to an estimated fatal accident rate for precision approaches during the same period of time of $4 \times 10^{-7}$ or about 1 fatal accident per 2.5 million approaches.

### 3.4 ESTIMATING COLLISION RISK

The final approach, whether precision, non-precision, or VFR is not just a single operation, but is composed of several operations requiring certain systems for their successful completion. In order to determine the risk of collision with an aircraft on the adjacent glidepath, it is necessary to determine each operation which must be performed and each system which must function to successfully complete the approach without an accident. The following is a list of events which could produce an accident during an instrument approach:

1. Collision with an obstacle during the instrument portion of the approach.
2. Collision with an obstacle during the visual portion of the approach.
3. Pilot failure due to mental or physiological malfunction.
4. Failure of aircraft systems except engine, structures, electronic.
5. Aircraft structural failure.
6. Engine failure.
7. Failure of approach guidance electronics, ground and air.
8. Natural environmental phenomenon.
9. Midair collision.
10. Midair collision with an aircraft on an adjacent approach.

Event 9 represents a collision with another aircraft which is not established on an adjacent, parallel approach, while event 10 represents a collision with an aircraft which is, or has been (in case of a blunder),established on a parallel approach.

Using these events as the ones which could produce an accident if they occur, then the probability of an accident on the ILS approach, P(A), would be:

$$P(A) = 1 - P(A').$$

The probability that an accident will not occur, P(A') is the probability that event 1 does not occur, P(1'), and event 2 does not occur, P(2'), ... , and event 10 does not occur, P(10'). Assuming that the events are independent, the probability that an accident does not occur is:

$$P(A') = P(1')P(2')P(3') \ldots P(10').$$

The probability of an accident is then given by:

$$P(A) = 1 - P(1')P(2')P(3') \ldots P(10').$$

$$P(A) = 1 - (1 - P(1))(1 - P(2)) \ldots (1 - P(10)).$$

$$= P(1) + P(2) + \ldots + P(10) + Q,$$

where Q represents a sum of terms each involving products of probabilities, P(1) through P(10). Since each individual probability is very small, at most $4 \times 10^{-7}$, each term of Q must be of the order $10^{-15}$ or less. Neglecting these terms, the probability of an accident, P(A), is given by:

$$P(A) = P(1) + P(2) + \ldots + P(10).$$

Although enormous amounts of time and money are spent on accident investigations, it is extremely difficult to pinpoint the exact cause of an accident. Therefore, it is extremely difficult in many cases to determine which of the ten causes referred to above should be assigned to a particular accident. Furthermore, because of the rarity of accidents due to each of the causes, much more data than that currently available would be necessary to estimate the risk of each of the ten causes. Therefore, it is apparent that estimates of the ten risks are, for practical purposes, impossible and that a different approach to the problem is necessary.

This same problem is encountered in the design of an aircraft. According to FAR 25.1309, it was assumed arbitrarily that there are 100 potential failure conditions in an airplane which could contribute significantly to the cause of a serious accident. Since test data, historical data, or even theoretical estimates are unavailable for most of the causes, the allowable overall risk of a serious accident was apportioned equally among these conditions, resulting in an allowable risk for each of the failure conditions equal to 1/100 of the total risk.

Since ten causes of a fatal accident during a parallel approach can be defined, it is reasonable to assign an equal probability to each of the causes. Since the overall probability of a fatal accident during a parallel approach is the sum of the probabilities of the component causes, each cause should be allocated 1/10 of the total probability. This leads to an allowable probability of $4 \times 10^{-8}$ or 1 fatal accident per 25 million approaches. This approach should lead to a conservative risk allowance for collision since the risk of some of the ten causes may be so small as to be insignificant. This means that there are possibly fewer than ten significant causes so that the total risk could have been divided by a smaller number resulting in a larger allowable risk for collision.

4.0 DETERMINATION OF ALIGNMENT WINDOW

Since a TCV occurs when the two aircraft approach within 500 feet of each other it seems obvious that the evading aircraft need not be in an exact position relative to the blundering aircraft, but it could be in a number of places which could all result in a TCV. If the aircraft are traveling at the same speed, then it also seems obvious that the evading aircraft must be several feet behind the blundering aircraft. Therefore, there must be a minimum distance the evading aircraft may be behind the blundering aircraft and a maximum distance the evading aircraft may be behind the blundering aircraft which may result in a TCV. If the evading aircraft is between these two limits, it is said to be at-risk and an at-risk blunder is said to have occurred.

In order to obtain a solution, some assumptions are necessary. The aircraft will be assumed to only travel in the plane defined by the two glide slopes. In other words, the vertical component of travel will be neglected. The blundering aircraft will be assumed to be already established on the fixed blunder heading and the speeds of the two aircraft will be assumed to be constants. The evading aircraft will be assumed to travel straight along its glide path with no deviations. When determining whether two aircraft are aligned or at risk, the assumption of an immediate turn to the blunder heading can be alleviated by computing the position of the blundering aircraft after a standard rate turn to the blunder heading (see section 4.1).

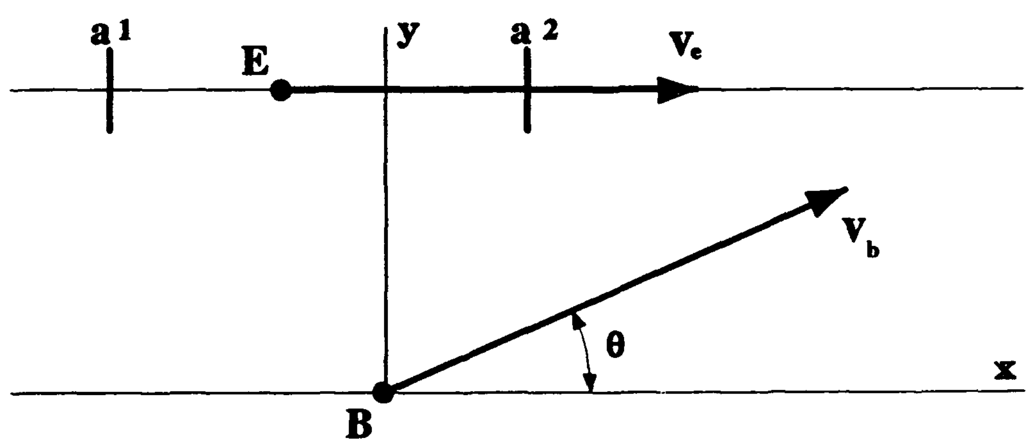



Figure 1

To begin the solution, refer to figure 1. The figure shows two lines, the upper line is the glide path of the evading aircraft while the lower line is the glide path of the blundering aircraft. The view is from above looking down toward the earth. The x-axis will be assumed to be the glide path of the blundering aircraft and the origin will be located at the point where the blunder begins. The vertical line is the y-axis and passes through the blundering aircraft. The direction of travel of both aircraft is in the direction of the positive x-axis. The evading aircraft will be assumed to be located a distance "a" behind the blundering aircraft. The runway separation will be denoted by "b", the speed of the blundering aircraft will be denoted by "$v_b$", the speed of the evading aircraft will be denoted by "$v_e$", the blunder angle by "θ", and the TCV radius will be denoted by "R". If the time, in seconds, measured from the point of the blunder is denoted by "t", then the vector equations of the paths of the two aircraft may be written as follows:

$$\mathbf{P_e} = ( v_e t - a)\mathbf{i} + b\mathbf{j}$$
$$\mathbf{P_b} = ( v_b \cos\theta )t\mathbf{i} + (v_b \sin\theta)t\mathbf{j}$$

The two vectors thus defined will each have their tails located at the origin while the heads will trace out the path of the respective aircraft. The path of the blundering aircraft will be a straight line inclined at an angle θ with the x-axis and the path of the evading aircraft will be a straight line parallel to the x-axis at a distance "b" from the x-axis. A TCV will occur if the heads of the vectors come within "R" feet of each other. Mathematically, this will happen if

$$| \mathbf{P_b} - \mathbf{P_e} | \le R.$$

This is equivalent to the following inequality:

$$((v_b\cos\theta - v_e)t + a)^2 + (v_b t\sin\theta - b)^2 \le R^2.$$

After expansion and simplification the inequality becomes:

$$t^2(v_b^2 + v_e^2 - 2v_b v_e\cos\theta) + 2t(a(v_b\cos\theta - v_e) - 2v_b b\sin\theta)$$
$$+ (a^2 + b^2 - R^2) \le 0.$$

This inequality is quadratic in t and the discriminant must be non-negative if there are to be values of t which satisfy the inequality. The discriminant results in the following inequality:

$$4(a(v_b\cos\theta-v_e)-v_b b\sin\theta)^2-4(v_b^2+v_e^2-2v_b v_e\cos\theta)(a^2+b^2-R^2) \ge 0$$

Expansion and simplification of this inequality leads to the following inequality:

$$a^2 v_b^2(\cos^2\theta - 1) - 2a[v_b b\sin\theta(v_b\cos\theta - v_e)]$$
$$+ v_b^2 b^2\sin^2\theta + (v_b^2 + v_e^2 + 2v_b v_e\cos\theta)(R^2 - b^2) \ge 0.$$

This inequality is quadratic in a and since the coefficient of $a^2$ is clearly negative, its solution is the interval between the two roots of the quadratic equation.

The roots of the quadratic equation may be solved with the quadratic formula. Substitution into the quadratic formula yields the following equation for the roots:

$$a = \frac{b(r - \cos\theta) \pm R\sqrt{r^2 - 2r\cos\theta + 1}}{\sin\theta}$$

where $r = v_e/v_b$. Note that by using the ratio of the two speeds, the units in which the speeds are expressed is unimportant beyond the fact that they must be expressed in the same units. Note also that the roots correspond to fixed values of $\theta$ and r. This means that the two roots which may be obtained by using either the "+" or the "-" in the place indicated by the symbol "$\pm$" mark the ends of the TCV window for one value of $\theta$ and r. For example, if $\theta = 30°$, r = 1.2, b = 3000 ft, and R = 500 ft, the two roots will be $a_1$ = 1402.57 ft and $a_2$ = 2605.13 ft. This means that if the evading aircraft is somewhere between 1402.57 ft and 2605.13 ft behind the blundering aircraft, a TCV will occur unless action is taken by the controller and the pilots. However, this window only applies to $\theta = 30°$ and r = 1.2. If the blunder angle is different or the speed ratio is different, then different roots will be computed giving a different window.

The length of the interval, L, is given by:

$$L = \frac{2R\sqrt{r^2 - 2r\cos\theta + 1}}{\sin\theta}$$

and is found by subtracting the smaller value $a_1$ from the larger value $a_2$. The only variables present in the equation for L are R, the radius of the TCV sphere, r, the ratio of evader speed to blunderer speed, and $\theta$, the blunder angle. Since the runway separation distance b is not present in the equation, the length of the interval is independent of the value of runway separation. This means that for a given speed ratio and blunder angle, the length of the alignment window is constant regardless of the runway separation. Therefore, widely spaced runways and closely spaced runways have the same chance for alignment of the two aircraft for a given blunder angle and a given speed ratio.

Analysis of the equation for L indicates that for a fixed blunder angle, the value of L increases as r is increased. Analysis also indicates that for a fixed value of r, the value of L increases as $\theta$ is increased. Therefore, in order to estimate the maximum value of L that would be encountered during parallel runway operations, it is only necessary to estimate the largest blunder angle and the largest speed ratio that would be experienced. If the greatest approach speed of the evading aircraft is expected to be about 227 knots and the smallest approach speed of the blundering aircraft is expected to be about 120 knots then the maximum value of r would be 1.89, and if the largest blunder angle is assumed to be 30°, then the longest alignment window would be 2279 feet.

## 4.1 CORRECTION FOR THE TURN

The analysis above assumes that the blundering aircraft turns instantaneously to the blunder heading. In order to compensate for this assumption, a correction is made to the blund ng aircraft position at the point where the blunder is ir ted. The blundering aircraft is assumed to turn at 3° per se d until the blunder heading is established. The radius of turn is computed from the speed of the blundering aircraft and the amount of movement of the blundering aircraft is determined during the turn. This movement, together with the movement of the evading aircraft (assumed to be straight along its original course since no instruction has been received from the controller) allows the computation of the relative positions of the two aircraft following the turn of the blunderer. The corrected relative position is used to predict whether the evader is aligned correctly for a TCV.

## 5.0 ESTIMATION OF TCV PROBABILITY

If a blunder occurs while two aircraft are aligned properly so that a TCV could happen, the avoidance of the TCV depends upon the reaction time of the pilot and controller as well as the update rate and accuracy of the surveillance radar. With adequate data obtained from real time simulations, probability distributions of each of the components could be determined with some degree of confidence and combined analytically to estimate the probability of a TCV. However, the simulation which would provide distributions for an indirect computation of the probability of a TCV can also be used for a direct computation of the probability.

Whether the goal is an indirect or direct computation of the probability of a TCV, the number of simulated blunders which actually occur while the evading aircraft is in the alignment window must be determined. In other words, the actual number of at-risk blunders must be counted. This may be computed as indicated above by knowing the speeds, relative positions, and blunder angle at the time the blunder is initiated. Since the window of alignment is relatively short and longitudinal separation distances are reasonably constant the probability of a TCV during an at-risk blunder may be assumed to be very nearly constant. If the probability of a TCV is constant then the TCV process may be modeled as a Bernoulli process.

In a Bernoulli process, there are only two outcomes to an experiment, usually called success and failure. The probability of either success or failure is simply the ratio of the event to the total number of observations during the experiment. Therefore, the probability of a TCV during an at-risk blunder may be estimated as the ratio of the number of TCV's to the total number of at-risk blunders. However, when an experiment is performed from a known Bernoulli process, such as flipping a coin or rolling a die, it is known that the observed estimate of the probability will differ from the theoretic or underlying probability and that different experiments will produce different estimates of the same underlying probability. Thus the ratio of TCV's to at-risk blunders should not be used directly as the estimate of the underlying probability.

From the theory of Bernoulli processes, confidence intervals of the underlying probability may be determined from the observed data. A confidence interval gives a measure of the variation from the underlying probability that may be observed in experimental data. Confidence intervals always have a probability or confidence level associated with them. A confidence interval might be termed a 0.99 interval. This would mean that if 100 different experiments were performed to estimate the underlying probability, then it would be expected that about 99 of the confidence intervals computed from the observed data would contain the underlying probability.

Formulae exist for the computation of confidence intervals of Bernoulli probabilities. Since the probability of a TCV is very small, the appropriate formulae for the upper and lower limits of a 0.99 confidence interval are as follows:

$$\sum_{y=0}^{k} c(n,y)p^{y}(1-p)^{n-y} = 0.005$$

$$\sum_{y=k}^{n} c(n,y)p^{y}(1-p)^{n-y} = 0.005$$

The value of the probability, p, must be found using numerical methods such as Newton's method or the bisection method.

Since in a computation of risk conservatism is extremely important, the value associated with the upper limit of the confidence interval is the only one of interest. The upper limit of a 0.99 confidence interval represents a value which is almost certainly larger than the actual underlying probability. Thus use of the upper confidence interval bound will provide a conservative estimate of the actual probability.

## 6.0 DETERMINATION OF ACCEPTABLE BLUNDER RATE

With the determination of a target risk, a method of determining the window of alignment, and a method of estimating the probability of a TCV during an aligned blunder, the acceptable blunder rate may be computed. The speeds used in the simulation ranged from 120 kts to 227 kts. The 120 kts was due to a blundering aircraft and the 227 kts was due to an evading aircraft. If is assumed that either aircraft could be traveling at any speed between these two numbers, then the ratio of speeds ranges from 120/227 = .53 to 227/120 = 1.89. Using these two ratios as the minimum and maximum speed ratios and using a maximum blunder angle of 30°, the maximum window length is 2279 feet. This occurs at the 1.89 ratio. Therefore, the probability of correct alignment, assuming 3 miles longitudinal separation, is given by

$$\frac{2279}{3 \times 6076} = 0.125 = \frac{1}{8}$$

Analysis of the data using the equations derived for the window of risk, indicated that the number of at-risk aircraft was 186 with two resultant TCVs. Using a .99 confidence interval to compute the upper bound for the binomial probability, the upper bound would be 0.049. This would lead to the following ratio of TCV's to at-risk aircraft:

$$0.049 = \frac{49}{1000} = \frac{5}{102}$$

Another factor needed is the ratio of Worst Case Blunders to 30° blunders. This really means, the ratio of 30° blunders in which the pilot of the blundering aircraft is unable to respond to instructions by the controller. In previous studies, the ratio of worst case blunders to 30° blunders, based on conversations with controllers and pilots, has been estimated to be 1/100. Recent conversations with controllers indicate that the 1/100 ratio may be too large and that the actual rate may be significantly lower. A more conservative approach would be to increase the 1/100 ratio, already considered conservative by the responding controllers, to 1/10. Because of the uncertainty of the ratio, both conservative estimates will be considered. Since the target risk is given in accidents per approach, factors must be introduced to correct for the number of approaches taking place during a triple approach and for the fact that one collision is equivalent to two accidents. The equation will be displayed with appropriate units for the convenience of the reader.

Using 1/100 as the estimate, the number of acceptable blunders to achieve the target probability of 4 x 10 or 1 fatal accident in 25 million approaches, becomes

$$\frac{1\ \text{ACC}}{25\ \text{mill app}} \times \frac{8\ \text{WCB}}{1\ \text{algn WCB}} \times \frac{102\ \text{algn WCB}}{5\ \text{TCV}} \times \frac{3\ \text{app}}{1\ \text{triple}} \times \frac{1\ \text{TCV}}{2\ \text{ACC}} \times \frac{100\ 30^{\circ}\ \text{Bl}}{1\ \text{WCB}} = \frac{1\ 30^{\circ}\ \text{Blunder}}{1021\ \text{triple approaches}}$$

This is a very high rate, which would not be approached in actual operations. Since the actual blunder rate seems to be much smaller, the risk of the operation may be assumed to be much smaller than the target, acceptable risk.

If it is assumed that 1/10 is the ratio of Worst Case Blunders to 30° blunders the ratio would become

$$\frac{1\ 30^{\circ}\ \text{Blunder}}{10{,}210\ \text{triple approaches}}$$

This rate may be the same order of magnitude as the actual, but unknown, blunder rate. However, since this rate represents an acceptable rate which will result in an accident rate no larger than the target rate, the risk of the operation is still deemed acceptable.

## 7.0 SUMMARY AND CONCLUSIONS

Historical accident data indicate that the current probability or risk of a fatal accident during an ILS approach in instrument meteorological conditions is about $4 \times 10^{-7}$. Since ten primary causes of a fatal accident during the approach may identified, including a midair collision with an aircraft on an adjacent approach, the target or acceptable risk rate may be determined to be $4 \times 10^{-8}$ or 1 fatal accident per 25 million instrument approaches.

The window of risk may be determined analytically for two aircraft on adjacent approaches from knowledge of their relative positions, their speeds, and the blunder angle. Using this information, the number of at-risk blunders from simulated flight track data was determined to be 186.

Analysis of the simulated flight track data also indicated that two TCV's occurred. Confidence intervals for the Bernoulli probability parameter were used to conservatively estimate the probability of a TCV given an at-risk blunder to be 0.049.

Conversations with controllers were used to estimate the ratio of worst case 30° blunders to 30° blunders to be between 1/100 and 1/10. Using the ratio, 1/100, the acceptable blunder rate was determined to be 1 30° blunder per 1021 triple approaches. Using the ratio, 1/10, the acceptable blunder rate was determined to 1 30° blunder per 10,210 approaches. In either case, the operation would meet the target risk rate.

*U.S. GOVERNMENT PRINTING OFFICE: 1994-504-078-00067