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Atlantic City International Airport
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Dallas/Fort Worth Simulation Phase II - Triple Simultaneous Parallel ILS Approaches

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March 1990

Final Report

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NOTICE

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16. Abstract

A dynamic, real-time simulation was conducted at the Federal Aviation Administration (FAA) Technical Center, September 25 - October 5, 1989, to evaluate triple simultaneous independent parallel approach operations for the Dallas/Fort Worth (D/FW) Airport. The simulation was part of an ongoing effort to evaluate plans for increasing air traffic capacity in the D/FW area and to evaluate multiple parallel approaches in general. An additional parallel runway (16L), with centerline 5,000 ft east of the existing 17L runway, was simulated in a triple simultaneous parallel operation conducted under Instrument Meteorological Conditions (IMC).

The results of the study indicated that controllers were able to maintain miss distances, between blundering aircraft and nonblundering aircraft, in the proposed D/FW triple simultaneous parallel Instrument Landing System (ILS) approach operation, that were statistically equivalent to the miss distances maintained in the approved dual approach condition. None of the blunders in the triple or dual approach conditions resulted in a slant range miss distance of less than 1,000 ft. Finally, controllers, controller observers and ATC management observers concluded that the triple simultaneous ILS approach operation at D/FW is acceptable, achievable, and safe.

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A dynamic, real-time simulation was conducted at the Federal Aviation Administration (FAA) Technical Center, September 25 - October 5, 1989, to evaluate triple simultaneous parallel Instrument Landing System (ILS) approach operations for the Dallas/Fort Worth (D/FW) Airport. The simulation was part of an ongoing effort to evaluate plans for increasing air traffic capacity in the D/FW area and to evaluate multiple parallel approaches in general. An additional parallel runway (16L), with centerline 5000 ft east of the existing 17L runway, was simulated in a triple simultaneous ILS operation conducted under Instrument Meteorological Conditions (IMC).

Both dual and triple simultaneous parallel ILS approaches were simulated, and controllers monitored air traffic on the localizers. Blunders were introduced, according to predetermined scenarios, by having simulated aircraft deviate off the localizer at 10, 20, and 30 degree angles. Some of the blundering aircraft also simulated loss of radio communication with the controllers. The ability of the controllers to cope with the blunders under the different parallel runway conditions was the central issue in the study. Three questions were to be answered:

a. Are the miss distances, between blundering aircraft and non-blundering aircraft, in the triple simultaneous parallel ILS approach operation at least statistically equivalent to the miss distances achieved in the dual simultaneous parallel ILS approach operation as indicated by the Aircraft Proximity Index (API) and Closest Point of Approach (CPA) metrics?

b. Can the controllers intervene in the event of a blunder to provide a miss distance greater than 500 ft between the affected aircraft? (A slant range of not less than 500 ft was the test criterion established by the executive committee of the FAA Multi-Parallel Simultaneous ILS Approach Program. This committee consists of representatives from Air Traffic, Flight Standards, Aviation Standards, and Research and Development.)

c. Do the controllers and other participants in the simulation view the proposed triple simultaneous parallel ILS configuration as acceptable with regard to achievability, acceptability, and safety?

The results of the study indicated that controllers were able to maintain miss distances, between blundering aircraft and nonblundering aircraft, in the proposed D/FW triple simultaneous parallel ILS approach operation, that were statistically equivalent to the miss distances maintained in the approved dual approach

condition. None of the blunders in the triple or dual approach conditions resulted in a slant range miss distance of less than 1000 ft. Thirdly, controllers, controller observers, and ATC management observers concluded that the triple simultaneous ILS approach operation at D/FW is acceptable, achievable, and safe.

1. INTRODUCTION.

1.1 PURPOSE.

This simulation was conducted to evaluate, using real-time simulation, triple simultaneous ILS approach operations at the Dallas/Fort Worth (D/FW) International Airport during Instrument Metecrological Conditions (IMC). Specifically, the simulation helped to determine whether triple simultaneous ILS approach operations are comparable to current dual approach operations.

1.2 BACKGROUND.

1.2.1 Airport Capacity.

Substantial increases in aviation traffic have been projected over the next two decades. In order to meet this anticipated increase, long-term efforts are under way to increase the capacity of the National Airspace System (NAS).

As part of this effort, a five phase airport capacity improvement program is being conducted. The first three phases of the program evaluate triple and quadruple independent parallel runway approach configurations and scenarios at D/FW. This is followed by the development of national separation standards for application to other airports based on existing and upgraded equipment (Phases IV and V, respectively). This report covers Phase II.

One means of expanding NAS capacity is to create additional airports. Although some are planned, new airports are costly, require a long time to plan and build, and often face political and social obstacles. Adding runways to existing airports is more timely and less expensive if space is available, and the required standards can be maintained for aircraft separation. Making the most efficient use of existing facilities provides near-term payoffs at minimal cost.

The number of aircraft that can land at a facility is subject to special restrictions under IMC. Permitting more than two (the current limit) simultaneous ILS approaches can increase the number of landings which may occur under these conditions.

1.2.2 Safety.

At a minimum, triple and quadruple simultaneous ILS approaches, at least 4300 ft apart, would be subject to the same limitations as dual simultaneous ILS approaches. Special requirements for simultaneous ILS approaches are described below. [1]

a. Provide a minimum of 1000 ft vertical or a minimum of 3 nautical miles (nmi) radar separation between aircraft during turn-on to parallel final approach. Provide minimum applicable radar separation between aircraft on the same final approach course.

b. Separate monitor controllers, each with transmit/receive and override capability on the local control frequency, shall ensure aircraft do not penetrate the depicted No Transgression Zone (NTZ).

c. Aircraft established on a final approach course are separated from aircraft established on an adjacent parallel final approach course provided neither aircraft penetrates the depicted NTZ.

Numerous studies by the FAA have addressed these requirements and operations research based models of the system have been employed to study safety restrictions and capacity limits [2, 3, 4, 5, 6, 7, 8, 9, and 10]. Any change in standard procedures requires rigorous testing to ensure that safety is not compromised.

1.2.3 Multiple Parallel Runway Studies Previous to the D/FW Series.

Several studies involving parallel runway approaches and related issues have already been completed. Some of these have investigated the effects of reducing separation between aircraft during parallel approaches. The minimum acceptable separation depends, in part, on aircraft navigational accuracy.

In 1975, a thorough study was conducted of aircraft navigational accuracy under normal operating conditions [4]. A simulation conducted in 1984 was the first to investigate navigational accuracy in the context of parallel instrument approaches. This investigation considered runways spaced 3000, 3400, and 4300 ft apart, employing both standard and modified radar displays using three levels of radar accuracy and update rates [11]. The results of the 1984 study have been questioned because 1) the navigational accuracy of the traffic samples may have been poor and 2) some of the analyses did not conform to the analytical models cited [6, 7]. However, the 1984 study did establish the importance of navigational accuracy in determining system capacity and showed the relationships between a number of system parameters and the controllers' abilities to cope with blunders.

Since the 1984 simulation was carried out, a major navigation survey was completed at the Chicago O'Hare facility [12]. This study and another study conducted at the Memphis International Airport [13] have provided additional data for refining the navigational error model in Phase II and future simulations in the D/FW series. It is important that the navigational error model used in ATC simulation of parallel runways operations provide both an accurate statistical representation of approaches on the localizer and visually realistic target movement to the controllers. Navigational accuracy also affects blunder detection. If all simulated aircraft were to fly visually perfect ILS approaches, then blundering aircraft would be easier to detect than they would be when navigational error is modeled in the simulation.

Additional real-time air traffic control (ATC) simulations have been conducted at the FAA Technical Center [14, 15] to investigate parallel runway questions. These studies are an important complement to the models cited previously since they generate estimates of the model parameters and, more importantly, allow direct observation of controller performance and recording of criterion measures related to safety and capacity. The 1988 D/FW and Atlanta Tower simulations are of direct interest to this study since they addressed most of the issues unique to multiple runway operations and shared some of the methodology of the 1984 simulation.

The Atlanta simulation evaluated two alternative runway configurations. The first configuration included the addition of a third parallel runway; the second included a 30 degree converging runway. The additional parallel runway was situated 3000 ft south of the existing runway - less than the current required separation distance for simultaneous approaches (i.e., 4300 ft). Three technological changes were employed for the purpose of improving controller performance in monitoring simultaneous approaches: 1) a 1-second update rate, high resolution radar, 2) an automated alert to permit controller detection of aircraft entering the NTZ, and 3) an expanded scale on the radar display. Aircraft blunders of 10, 20, and 30 degrees were executed, some with loss of radio communication. All approaches were flown with minimal navigational error.

The results of the Atlanta study projected an increase in capacity of up to 40 percent with the addition of either the parallel or converging runway, depending on weather conditions. The extent of runway separation, degree of blunder, and number of runways threatened all had significant impacts on safety related criterion measures.

The Atlanta simulation and the first simulation in the D/FW series both used a metric called the Aircraft Proximity Index (API) to measure the severity of a parallel conflict situation between two aircraft [see Appendix A]. The API, which ranges from 0 to 100, is a weighted measure of the smallest lateral and vertical separation distances reached in each conflict, with vertical separation being given more weight. While not to be considered an absolute measure of safety or risk, the API does provide a useful tool in quantifying conflicts. An alternative measure of aircraft proximity is Closest Point of Approach (CPA), which is the smallest slant range separation achieved between two aircraft. This measure also was used in the Atlanta study, as well as in the D/FW series of simulations.

1.2.4 D/FW Phase I.

During the 1990s, traffic in the D/FW terminal area is projected to increase by as much as 100 percent [16]. To help meet this anticipated growth, the D/FW Task Force was created. The Task Force produced the D/FW Metroplex Air Traffic System Plan. Its purpose was to provide procedures for the D/FW terminal area for the period 1995 through 2005. The D/FW Phase I simulation was a two-part study designed to test selected aspects of the plan. The first part of the simulation evaluated concepts for using additional routes, navigational aids, runways, and en route and Terminal Radar Approach Control Facility (TRACON) traffic flows in the initial implementation of the plan. The second part of the D/FW Phase I study focused on the proposed use of quadruple simultaneous approaches.

The D/FW Phase I study simulated two additional arrival runways with turbojet aircraft on the existing runways and props and turboprops on the proposed outer runways.

As in the Atlanta study, analysis for the D/FW Phase I study was based largely on a detailed review of individual conflict situations. The results of this analysis indicated that blunders threatening two or more approaches were no more dangerous than those threatening only one other approach. The evaluation team concluded that quadruple approaches could be "conducted without incident even when the system was repeatedly challenged by aircraft blundering 30 degrees off course without communications."

1.3 SIMULATION OVERVIEW.

Unlike Phase I, the present study focused exclusively on the multiple simultaneous approach operation. The Phase II D/FW simulation was designed to examine the safety issues relative to the addition of a third independent parallel approach to the D/FW facility.

The controllers manned the approach or departure monitor positions. Aircraft entered the simulator, already on the ILS, approximately 20 nmi from the threshold. The aircraft flew at 180 knots (+ or - 4 knots) until intercepting the glide slope. The aircraft began the approach with the standard aircraft separation distance as determined by aircraft type. Every 1 to 5 minutes an aircraft was randomly chosen to execute a blunder. A blunder was a deviation of 10, 20, or 30 degrees from the ILS heading toward the adjacent ILS. The controllers issued vector changes to aircraft affected directly or indirectly by the blundering aircraft. The controllers' task was to maintain adequate distances between aircraft at all times. The D/FW Phase II simulation had other features which distinguished it from previous studies. These are described in the following sections.

1.3.1 D/FW Airport Configuration.

The current D/FW airport configuration is shown in figure 1. Runways 17L and 18R, having centerlines separated by 8800 ft, were used for the simulation, along with a proposed 8500 ft runway, 16L, with its centerline located 5000 ft east of the runway 17L centerline. For the dual runway airport conditions, an east and a west airport were simulated. The east airport consisted of runways 17L and 16L, separated by 5000 ft. The west airport consisted of runways 17L and 18R, separated by 8800 ft. There are no major geographical or architectural obstructions at D/FW airport requiring special traffic handling procedures.

1.3.2 Flightpaths.

All aircraft started on the localizers and maintained the altitude at which they were cleared to the localizer until intercepting the glide slope. The following table shows the glide slope intercepts for each runway.

TABLE 1. TURN ON ALTITUDES AND GLIDE SLOPE INTERCEPTS FOR THE D/FW PHASE II SIMULATION

Runway	Turn on Altitude	Glide Slope Intercept
16L	5000 ft	15.7 nmi
17L	7000 ft	22.0 nmi
18R	6000 ft	18.8 nmi

1.3.3 Traffic Samples.

Traffic samples consisted of turbojets only and identifiers that were based on information developed from flight strips and computer printouts from the D/FW TRACON. Three traffic samples were used for the triple runway conditions and three for the dual runway conditions. No longitudinal conflict speed overtakes were programmed for the Phase II simulation.

1.3.4 Aircraft Turn Rate.

When aircraft had to be turned off the localizer (i.e., in the event of an aircraft blunder or a longitudinal conflict), the aircraft's rate of turn had to look realistic to the controller. In the Phase II simulation, the turn rate for a 20 degree turn or less was 1.5 degrees/second. For a 30 degree turn, the turn rate was 3.0 degrees/second. Maximum rate turns at 6.0 degrees/second were available for the first 28 simulation runs when the pilot was instructed to turn "immediately." Thereafter, the maximum turn rate was decreased to 3.0 degrees/second.

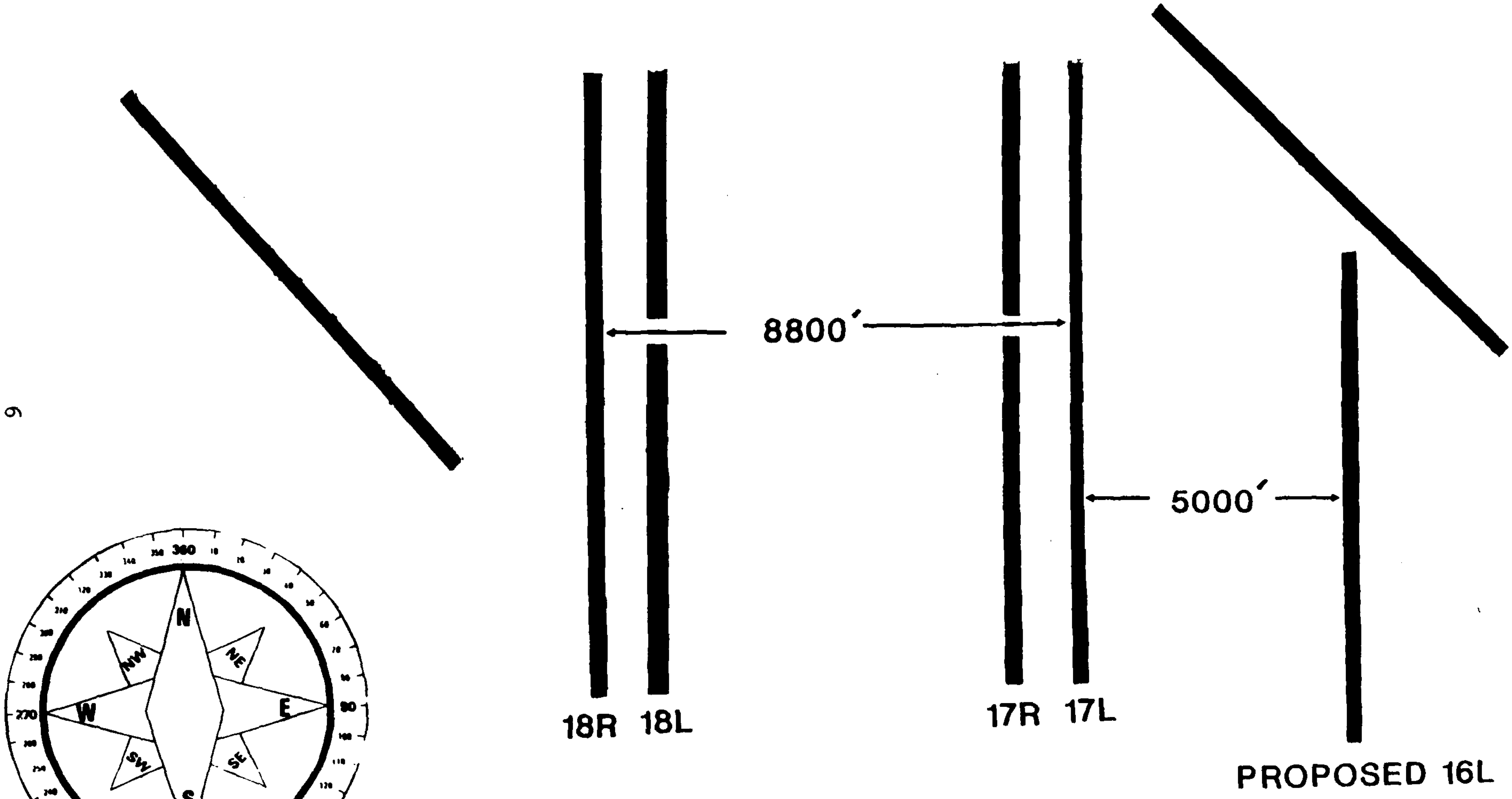

FIGURE 1. D/FW AIRPORT CONFIGURATION

1.3.5 Blunder Scenarios.

The test director and his assistant initiated blunders by directing simulator pilots to turn a particular aircraft away from the localizer. All blunders were scripted. Ten different scripts were used for the triple approach condition, and five scripts were used for each of the dual runway airports. Representative scripts are shown in Appendix B. The scripts or scenarios specified 1) the run time at which the blunder was to occur (TIME), 2) the runway assignment of the blundering aircraft (RW), 3) the blundering aircraft, by position (e.g., second from the bottom of the radar scope) (A/C#), 4) the direction (LR) and degree of turn (AMT), 5) continuation or loss of radio communication with the controller (COMM), and 6) the time between the initiation of each successive blunder (INTERVAL). The scripts were created in accordance with the following guidelines:

a. The time for the initiation of the blunder was selected from a random distribution of intervals having an average of 3 minutes, a minimum of 1, and maximum of 5 minutes.

b. The runway to which the blundering aircraft was assigned was selected at random so that each of the runways being used had an equal probability of being selected.

c. The direction of turn was chosen so that aircraft on outside localizers were always turned inward toward the other localizer(s); aircraft on the middle localizer were given an equal probability of blundering either to the right or to the left.

d. The size of the turn away from the assigned localizer was 10, 20, or 30 degrees. Degree of turn was randomly assigned to each aircraft, with the restriction that 60 percent of the aircraft would make a 30 degree turn, 20 percent would make a 20 degree turn, and 20 percent would make a 10 degree turn.

e. Some blundering aircraft were directed on a random basis to cease communication with the controller after the blunder was initiated. The probability of a scripted communications failure following a blunder was 50 percent.

Approximately 2 weeks prior to the simulation, members of the EX-COM viewed one of the traffic samples with a blunder scenario, in order to determine the number of blunders which would result in a slant range of 500 ft or less between aircraft if a controller did not intervene to rectify the situation. It was the opinion of the EX-COM that the number observed (3-4) was sufficient and that no changes would be required in the scenarios prior to the start of the study.

1.3.6 Questions Addressed in This Study.

The simulation addressed three questions for the proposed triple simultaneous ILS approach configuration:

a. Are the miss distances, between blundering aircraft and non-blundering aircraft, in the triple simultaneous ILS approach operation at least statistically equivalent to the miss distances achieved in the dual simultaneous ILS approach operation as indicated by the API and CPA metrics.

b. Can the controllers intervene in the event of a blunder to provide a miss distance (greater than 500 ft) between the affected aircraft.

c. Do the controllers and other participants in the simulation view the proposed triple simultaneous ILS configuration as acceptable with regard to achievability, acceptability, and safety.

2. APPROACH.

The principal goal of this study was to determine whether the proposed triple approach operations are as safe as the existing dual approach operation. The minimum requirement for modifying ATC standard procedures is the demonstration of undiminished safety. Evidence supporting undiminished safety as a result of proposed system changes can be obtained in a number of ways:

a. Demonstrate, through the collection and analysis of operational data, that present standards are unnecessarily restrictive.

b. Conduct flight tests supporting the feasibility and safety of proposed changes.

c. Conduct operations research, math modeling, or fast-time simulation and examine the impact of proposed changes on a variety of operational parameters and contingencies.

d. Conduct real-time ATC simulation studies of the changed system, introducing errors and failures, and compare the results with those of present operations.

These methods are neither independent nor mutually exclusive. Reliable field data are essential for successful modeling and for simulation. Real-time ATC, flight simulation, and flight testing are needed to generate estimates of the operational parameters used for modeling and fast-time simulation. Modeling provides a framework for collecting and analyzing field data. The D/FW Phase II study, a real-time ATC simulation, can, therefore, be viewed as part of an ongoing process of gathering, analyzing, and evaluating data to investigate the feasibility and acceptability of multiple simultaneous approach operations.

Three approaches were used in this study to evaluate the proposed simultaneous approach operation. One was based on the direct and indirect comparison of the three-runway operation with the present standard of two-runway operations. This was called the "Experimental Approach." The second consisted of an assessment of system performance against a set of predetermined criteria. This was called the "Operational Assessment Approach." The third was based on observations and reports from industry representatives and participating controllers concerning the conduct and implications of the simulation. This was termed the "Administrative Approach."

The focus of this report is the Experimental Approach. The other two approaches are summarized in the discussion section and are used to help explain experimental results, relate them to the observational data, and draw conclusions about their meaning. Although this report emphasizes the Experimental Approach, all three approaches are described in the following sections.

2.1 EXPERIMENTAL APPROACH.

The Experimental Approach involved the comparison of system performance when only two runways were involved (today's operation) with the outcome of comparable events involving three runways. It compared two-runway airports with three-runway airports and further analyzed the three-runway airport data, comparing events that are typical of two-runway operations with those that are unique to three-runway operations. Data for these comparisons came from the introduction of scripted blunders into the simulation runs. Blunders of 10, 20, and 30 degrees were initiated at various points during the simulation runs and the controllers' ability to handle the blunder situations by maintaining adequate distance between aircraft was the main criterion measure. This approach focused on statistical analyses of data on the distance between aircraft involved in conflict situations as measured by API and CPA. Results were interpreted in light of the safety related questions posed in the study.

2.2 OPERATIONAL ASSESSMENT APPROACH.

The Operational Assessment Approach evaluated each incident that met criteria outlined in figure 2, Operational Assessment Decision Tree, as if it had occurred in an operational environment. A determination was made of its seriousness and cause. The operational assessment approach differed from the Experimental Approach in two ways. First, only a small subset of data was considered, specifically, data for those occurrences which would have major safety implications if they occurred in the operational environment. Second, each occurrence of this type was considered

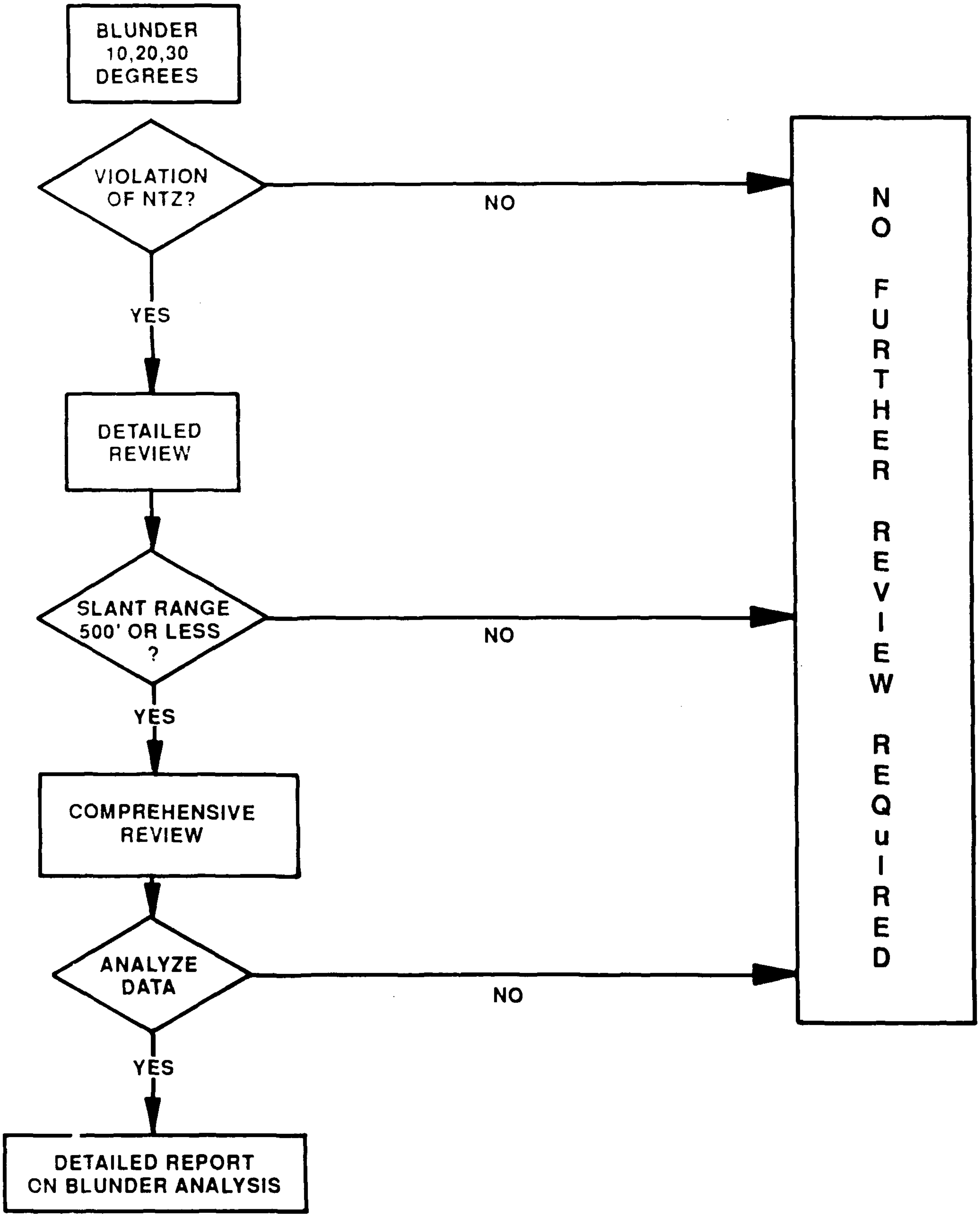

FIGURE 2. OPERATIONAL ASSESSMENT DECISION TREE

individually, and was subjected to a detailed analysis by an executive committee (EX-COM). The analysis of each event utilized data from many sources, including controller and technical observer reports, computer data, and video and audio tape materials.

2.3 ADMINISTRATIVE APPROACH.

The Administrative Approach consisted of observations and reports from the controllers who participated in the study and from representatives from industry and the aviation community who witnessed the simulation. Overview analysis provided in a report by EX-COM was also part of this approach. The views of participating controllers concerning the simulation came from two sources: 1) comments provided in the controller questionnaire administered following each run, and 2) a controller report including evaluations and recommendations, produced after the completion of the simulation. A questionnaire was also distributed to industry observers, providing the opportunity to collect their insights into the simulation as well as related issues of broader scope.

3. METHOD.

3.1 DESCRIPTION OF THE NATIONAL AIRSPACE SYSTEM SIMULATION SUPPORT FACILITY (NSSF).

This study took place at the FAA Technical Center, Atlantic City International Airport, New Jersey, using the NSSF. The NSSF houses a general purpose ATC simulator designed to provide a realistic test bed for developing, testing, and evaluating advanced ATC concepts, airspace management plans, and procedures. The simulator consists of three subsystems: 1) the Controller Laboratory, 2) the NSSF Simulator Pilot Complex, and 3) the Central Computer Facility.

The Controller Laboratory simulates an en route or terminal control room and contains eight digital, random write displays and associated keyboard entry and communication equipment (see figure 3). The radar displays are similar to standard Automated Radar Terminal System (ARTS) and en route plan view displays (PVDs). They provide track history by showing "≡" marks at each of the aircraft's last three target positions, rather than through the use of phosphor persistence as in ARTS (see figure 4). The laboratory is realistically configured permitting participating controllers to function with little or no acclimation. A communications system provides controller-to-controller, controller-to-pilot (NSSF simulator operator), and pilot-to-controller communication.

The NSSF Simulator Pilot Complex houses the individuals who "pilot" the simulation aircraft and the equipment they use to accomplish this task. NSSF simulator pilots are in voice contact with controllers and respond to controller instructions by entering keystrokes onto a specialized keyboard. These actions result in the simulated aircraft changing course, altitude, or speed. Each

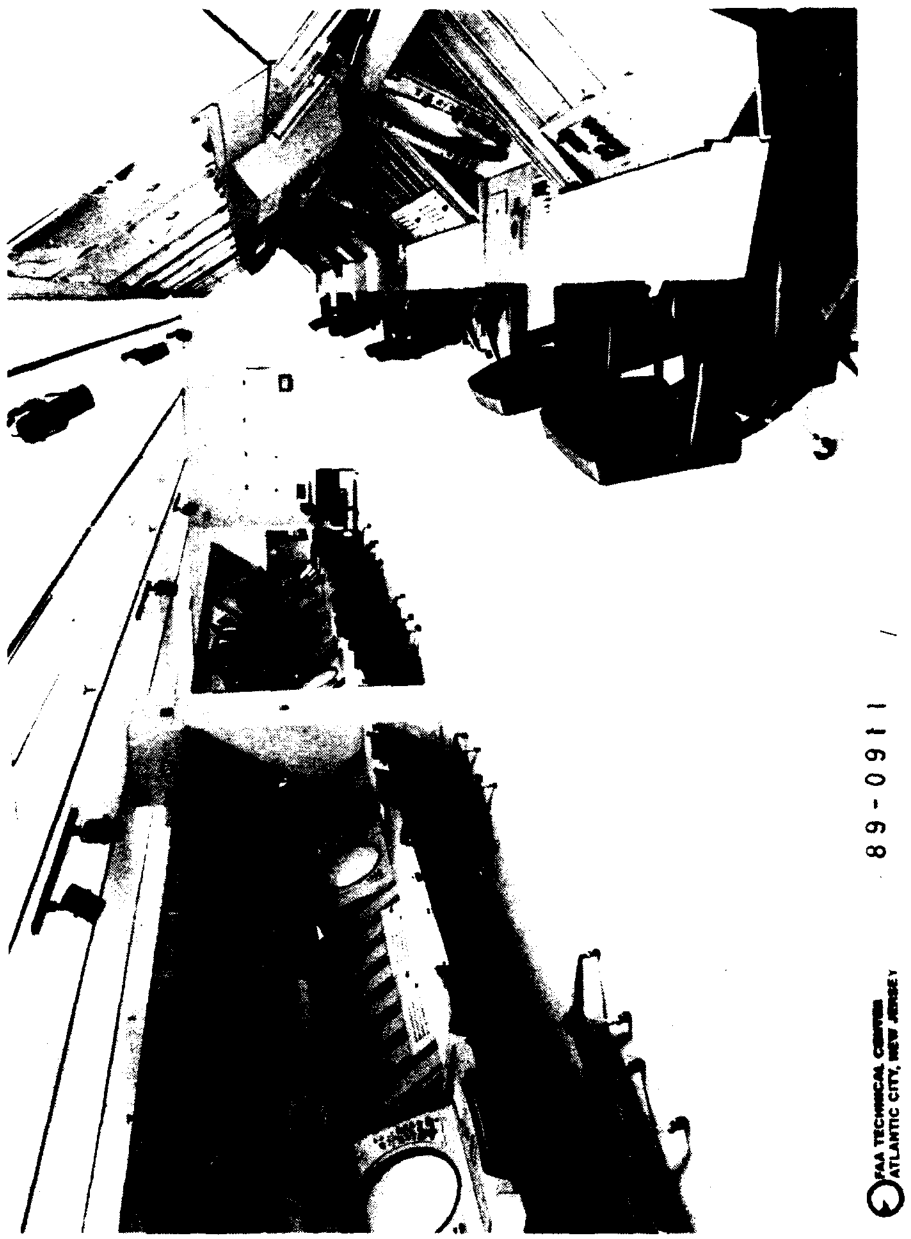

FIGURE 3. NSSF CONTROLLER LABORATORY

FIGURE 4. NSSF RADAR DISPLAY

NSSF simulator pilot can control as many as 10 aircraft. Aircraft responses are programmed to be consistent with the type of aircraft being simulated.

The NSSF computer in the Central Computer Facility generates the simulation targets and records data on aircraft position and status.

3.2 DESCRIPTION OF THE SIMULATION.

3.2.1 Video Map Presentation.

Monitor positions were the only ones represented in the Phase II simulation. The video map presented to the controllers (see figure 5) displayed the localizer course from a point, 20 nmi from each runway threshold. Range marks were placed at each 1-mile point along the localizer with each 5-mile point emphasized. Boundaries of the NTZ were also displayed for each localizer course.

3.2.2 Navigational Error Model.

Navigational error, in this context, is the discrepancy between the aircraft flightpath and the localizer. It is the sum of pilot error, avionics error, and navigational aid error. It is also referred to as Flight Technical Error (FTE). The D/FW Phase I study used a navigational error model that produced a standard deviation of approximately 200 ft around the localizer beyond 10 nmi of the threshold. This model was based largely on the Resalab study [4]. The navigational error model used in the D/FW Phase II simulation incorporated the Chicago data [12] in an effort to achieve a more accurate representation of navigational error (see figure 6).

The navigational error model, as currently implemented, has three parameters: 1) the probability that an aircraft will be chosen to deviate from the localizer, 2) the angle of deviation, and 3) the duration of the deviation (i.e., the amount of time the aircraft will continue on its diverted course before returning to the localizer). The simulation program considered each aircraft currently on the localizer at regular intervals and determined whether to give it a deviation off the localizer. The decision to make an aircraft deviate was made on a random basis, with a fixed probability of 0.10 at each "look." When a deviation occurred, suited tables of random values were used to determine the angle and length of time the aircraft stayed on the deviated course before returning to the localizer. The selection of parameters for the frequency, size, and duration of deviations from the localizer was based on the navigation error actually observed in aircraft of the type used in the traffic sample, as enumerated in the studies cited previously. The flight of simulated aircraft on the localizer must not only statistically represent navigation in the real world but

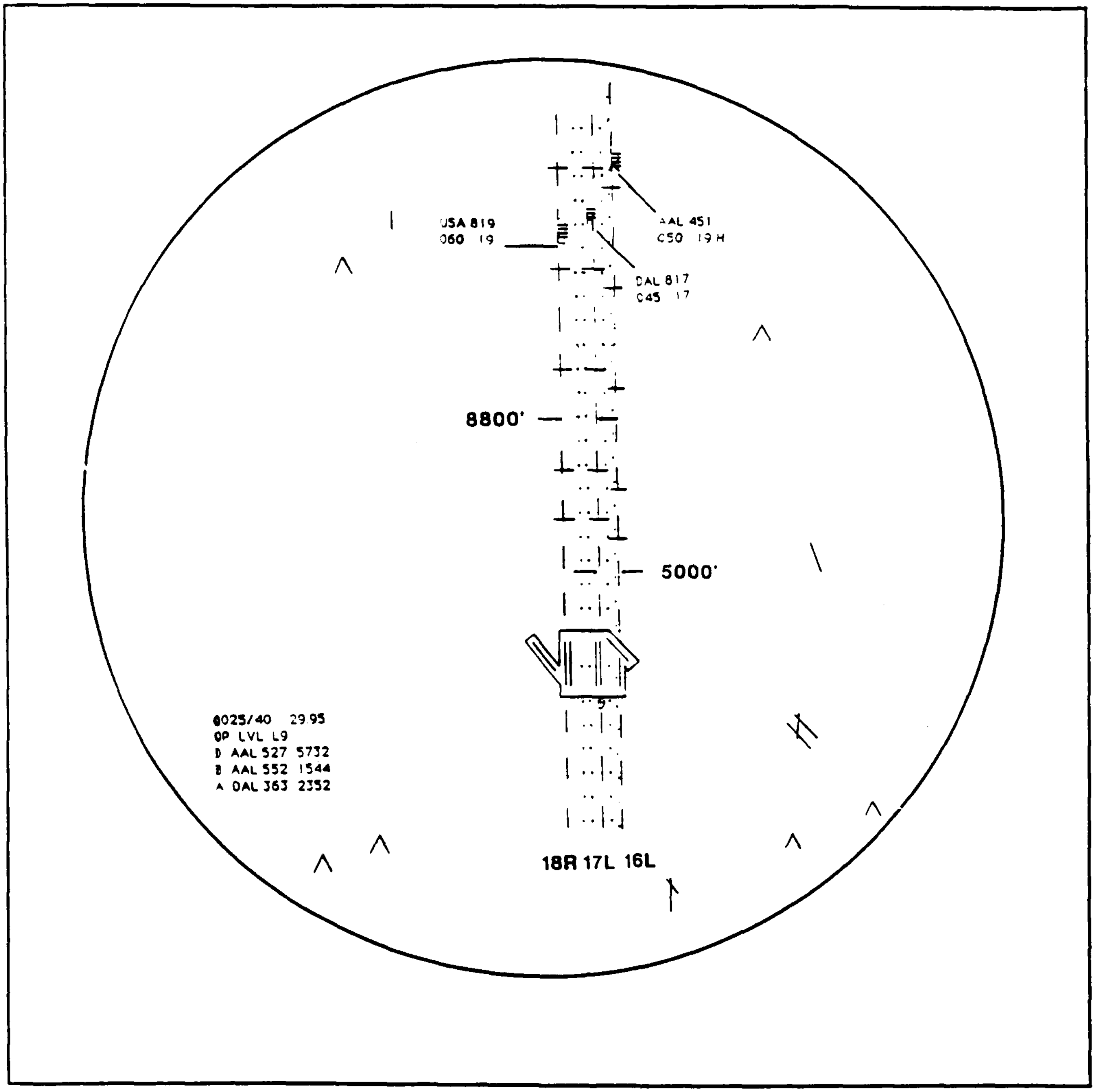

FIGURE 5. VIDEO MAP DISPLAY

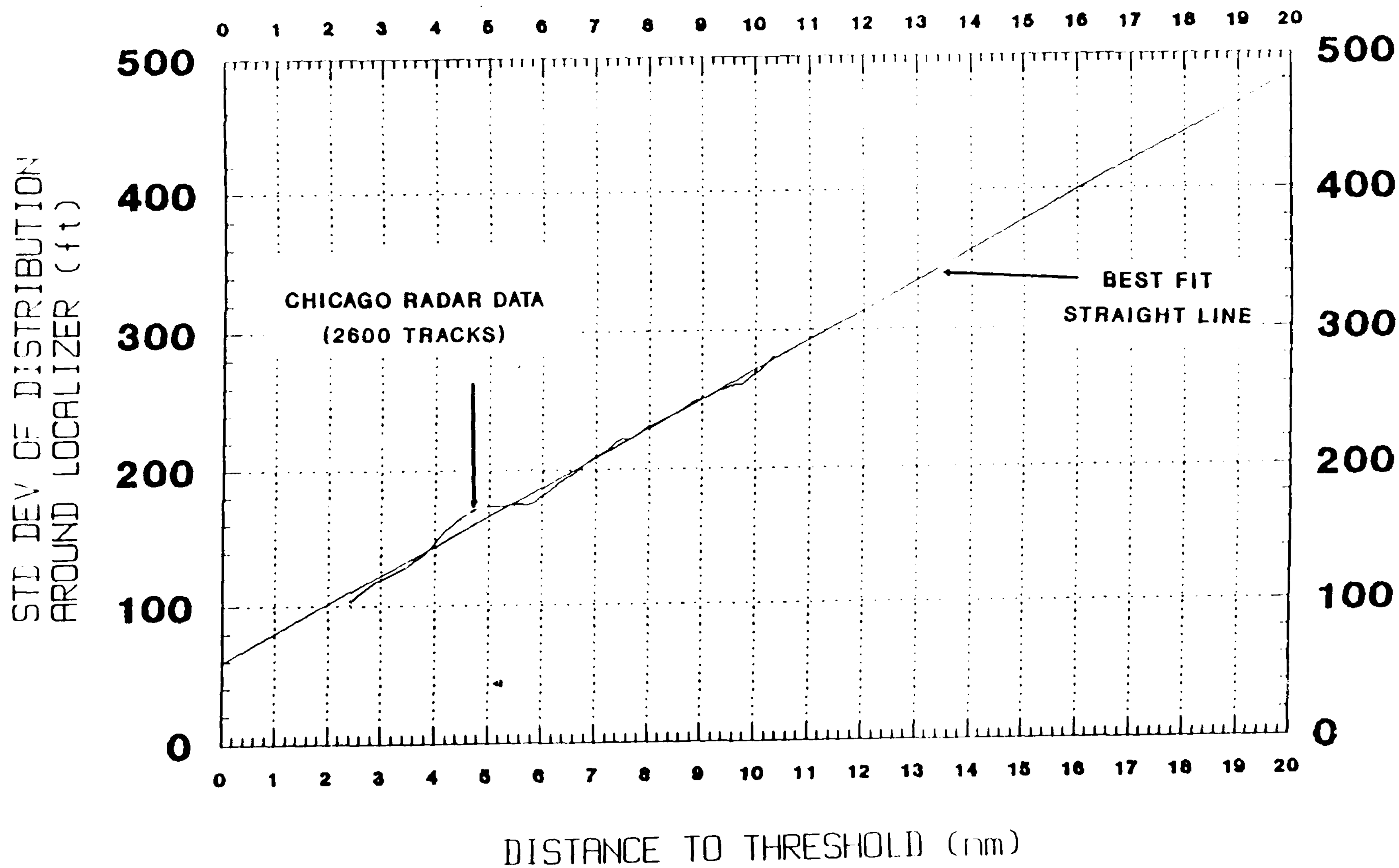

FIGURE 6. STANDARD DEVIATION OF AIRCRAFT FROM LOCALIZER (FT) AS A FUNCTION OF DISTANCE TO THRESHOLD (NMI)

must also provide controllers with visually realistic target motion. The D/FW Phase II navigational model was a product of these two constraints.

As in the Phase I simulation, controllers were permitted to direct straying aircraft to return to the localizer. If no action was taken, the aircraft would return to the localizer on its own.

3.2.3 Questionnaires and Other Written Materials.

A questionnaire was administered to the controllers after the completion of each run. The questionnaire assessed the level of difficulty, realism, and controllability of the task on a scale of 1 to 10. A mental workload rating scale, the Modified Cooper-Harper Scale, was also attached to the questionnaires. This scale has been validated and employed in a variety of applications. The scale consists of a decision tree which is used by the subject to rate the level of difficulty and mental workload associated with a given task. A copy of the questionnaire and the Modified Cooper Harper Scale (with instructions) are provided as Appendix C. As part of the Administrative Approach to this study, representatives from industry were to observe the simulation and provide their objective views of the test and its implications. Accordingly, a questionnaire was prepared to solicit the assessments of these observers (see Appendix D). The questionnaire included two rating-scale questions concerning the degree of realism in the simulation and the feasibility of triple simultaneous ILS approaches. A third question sought additional comments and suggestions.

A log book was used by experimenters as an aid in recording their observations of controller actions, blunders, and any unusual events constituting deviations from the Test Plan. The log book also served as a checklist for ensuring correct controller-runway pairings and operating the audio and video equipment. Signs were prepared for placement at the top of each radar workstation for each run. The signs indicated the runway number to be monitored at that workstation, as well as a letter code (A-E) used to identify the controller assigned to the workstation during the run.

3.2.4 Data Collection.

During the course of each simulation run, data were collected both manually and automatically. Automated data collection was provided by the NSSF computer which continuously recorded system variables such as aircraft position and speed once per second. The computer also recorded all simulator pilot inputs and the time at which each occurred.

Controller and simulator pilot voice communications were recorded using a 20-channel audio recorder. An S-VHS camcorder mounted on a tripod was used to make continuous video recordings of a radar display which was dedicated to that purpose. Video recordings were made of all triple approach runs and the east dual-runway airport runs. Controllers' voices were recorded on the video tape, using a pair of microphones above the controllers' displays.

The systematic video and audio recording of the entire simulation was performed as a means of augmenting analysis of individual blunders. The video and audio tape recordings of the simulation also provided a method by which controller response time could be more precisely estimated. This enabled experimenters to evaluate the relationship between blunder initiation time and controller response time, as well as the relationship between controller response time and the initiation of a change in the instructed aircraft's performance.

Manual data collection was provided by technical observers from D/FW who sat behind the controllers and took detailed notes for each blunder and its associated controller responses. As noted both industry observers and contractor personnel provided data through the completion of questionnaires and log books.

3.2.5 Data Reduction.

The data collected by the simulation computer were summarized on the same system at the end of each day and the files copied to floppy disk for eventual transfer to PCs for data analysis. A sample of each type of computer file generated is shown in Appendix E. Information contained in the computer summary files included the following:

a. number of NTZ transgressions;

b. number of parallel conflicts;

c. API and CPA values for parallel conflicts;

d. number of longitudinal conflicts;

e. API and CPA values for longitudinal conflicts;

f. response time to blunders (estimated from pilot message time);

g. number of blunder responses to nonblunders (i.e., false alarms);

h. number of communications;

i. number of speed changes;

j. number of nonblundering approaches aborted; and

k. number of aircraft landed.

Additional data reduction was performed using Lotus 1-2-3, a PC-based spreadsheet software program.

3.2.6 Data Analysis.

Data analysis was performed using the Complete Statistical System (CSS), release 2.1, a product of STATSOFT, Inc. CSS functions used in the analysis included Descriptive Statistics, T-tests, Analysis of Variance (ANOVAs), and Nonparametric Statistics (Mann-Whitney U).

In addition to the statistical analysis, technical and industry observer reports, comments from controller questionnaires and reports, and experimenters' log books were reviewed and summarized.

3.3 EXPERIMENTAL DESIGN.

3.3.1 Subjects.

The subjects were five air traffic control specialists and/or supervisors from the D/FW TRACON. The subjects were volunteers and were selected in accordance with the National Air Traffic Controllers Association (NATCA) D/FW local and the D/FW TRACON understanding on Employee Participation Group (EPG) participation. One of the air traffic control specialists was the NATCA D/FW area safety representative and the D/FW TRACON local representative for the project. The subjects had an average of 15.6 years of experience in ATC, with a minimum of 7 years and a maximum of 30 years. All had at least 4 years of experience working parallel approaches.

3.3.2 Design.

A total of 40 simulation runs over 9 working days were planned. The original simulation schedule, including controller runway assignments, is shown in Appendix F. Twelve runs were scheduled with dual approaches, with the dual runs distributed at the beginning, middle, and end of the 2-week test period. Two dual approach airports were set up during each of the dual approach runs, a west airport with runways 18R and 17L, and an east airport with runways 17L and 16L. Twenty-eight runs utilized triple runway approaches and were interspersed with the dual approach runs.

Assignments of controllers to runs and runway positions were made on a random basis with the following restrictions:

a. Controller assignments were balanced between dual and triple approach runs.

b. Runway assignments were balanced between left and right runways in the dual approach runs and the inner and outer runways in the triple approach runs.

c. Each controller participated in approximately the same number of runs on a given day.

Independent variables in this study consisted of the following:

a. the number of runways (2 or 3);

b. the direction of the blunder (to the left or right of the localizer);

c. the degree of turn of the blundering aircraft (10, 20, or 30 degrees); and

d. loss or maintenance of radio communications between blundering aircraft and controllers.

The main dependent variables of interest in this study relate to safety. The primary dependent measures related to safety were CPA and API. Other safety measures included the number of NTZ entries, the numbers of parallel and longitudinal conflicts, and the number of pilot warning messages.

Dependent measures derived from the controller questionnaire were the ratings of the level of realism, difficulty, and controllability for each of the runs, and the mental workload scores from the Modified Cooper-Harper Scale.

3.3.3 Procedure Used to Conduct the Simulation.

3.3.3.1 Orientation.

Prior to the start of the simulation, participating controllers were briefed on the procedures to be followed during the simulation. They were given the schedule of simulation runs and instructions for completing the questionnaires which were administered at the conclusion of each run. Each controller was informed of his assigned letter code (A-E) which was used in pairing the controllers and runways throughout the simulation. The controllers were informed that letter codes would be used in all subsequent data collection, analysis, and reporting in order to ensure anonymity. Controllers were also asked to complete a questionnaire providing information about their backgrounds in ATC and a consent form to confirm their willingness to participate in the simulation (see Appendix G). The controllers were told that they could withdraw from the simulation at any time. Following the briefing, D/FW controllers were given a tour of the FAA Technical Center and a demonstration of the equipment they were to use. No simulation runs were conducted on the day of the briefing.

3.3.3.2 Data Runs.

The following day, the test director and his assistant instructed the controllers on the use of the PVDs after which the simulation was initiated. Controllers participated in approximately five runs per day over the next 8 days (excluding weekends), with a 15-20 minute rest period between runs. Directly following each run the controllers completed the questionnaire and the Modified Cooper-Harper Scale.

4. RESULTS.

This section presents the findings of the simulation. Section 4.1 details the deviations from the Test Plan procedure which occurred in the Phase II simulation. Section 4.2 presents the results of the statistical analyses of the computer data. Time plots of selected blunders are described in Section 4.3, and the navigational model data is presented in Section 4.4. Section 4.5 describes the results of an ad hoc run (i.e., run 37). The controller questionnaire data are discussed in Section 4.6. Finally, Section 4.7 describes the results of the video and audio tape analysis of controller response time conducted.

4.1 DEVIATIONS FROM THE TEST PLAN.

A number of deviations from the Test Plan occurred during the simulation. Those deviations which had implications for the data analysis are enumerated in the following sections.

4.1.1 Changes of Schedule.

The schedule depicted in Appendix E was not strictly followed during the simulation runs. There were several reasons for this, including equipment malfunctions, major changes in the navigational model (see Section 4.1.3), and the loss of one controller's participation following run 26. As a result of these and other unavoidable events, the total number of valid runs conducted was 33. Of these, only 6 were dual approach runs; 27 were triple approach runs. Three of the 6 dual runs occurred at the beginning of the study and were subject to effects of practice and a number of simulator pilot errors. Analysis of the dual runs indicated no significant differences between runs even in the presence of the effects just described.

4.1.2 Variations in Simulation Run Time.

Simulation runs were to be 60 minutes in length. While this schedule was followed during the first half of the experiment, in the second half the simulation runs were often halted following the last blunder (i.e., at approximately 58 minutes into the run).

4.1.3 Adjustments in the Navigational Model.

Two adjustments were made to the navigational model during the simulation. The first occurred after the second run, the change was major, necessitating that the first two runs be eliminated from the data analysis. The second change, a relatively minor one, followed run 32 and is explained in Section 4.4. The data analyses presented in the following sections do not distinguish between the first 29 and the last 4 valid runs on the basis of navigational model. However, a discussion of the three models used and the resulting navigational error data are presented in Section 4.4.

4.2 COMPUTER DATA.

In addition to the descriptive statistics reported (e.g., means, standard deviations), the analyses of the computer data utilized a number of inferential statistics, including analysis of variance and t-tests for independent samples.

With regard to the analysis of variance technique, two types of effects are considered, main effects and interactions. A main effect is the effect of a variable considered in isolation. For example, the main effect of communication condition would consider the effect of having (or not having) radio communication between controller and simulator pilot, on a system performance measure, such as API. Other variables which might influence this effect (e.g., runway separation, degree of blunder) are ignored.

An interaction, on the other hand, represents the joint effect of two or more variables, considered together. A significant interaction occurs when either 1) a variable has disproportionate effects at different levels of the other variable(s), or 2) a variable has opposite effects at different levels of the other variable(s). As an example, if API values increased from the dual to the triple approach condition for the radio communication condition, but decreased from the dual to triple approach condition for the no radio communication condition, an interaction would exist in the data.

Main effects and interactions in an analysis of variance are denoted by F statistic values. The presentation of these values is exemplified by $F(1,21) = 19.05$, $MSE = 2.43$, $p. < .01$, where the numbers in parentheses following the F signify the numerator and denominator degrees of freedom. MSE stands for mean square error, the error term used in the F test.

Finally, t-tests are used in this report to compare the means of two independent samples. the format used to report the "t" is exemplified by ($t(5) = 2.14$, $p. < .01$), where the number in parentheses following the "t" signifies the degrees of freedom for the test. In those cases in which sample sizes differ for the two independent samples, the degrees of freedom value is aproximated.[1]

4.2.1 Dual Versus Triple Approach Comparisons.

The data analysis reported in this section compares dual and triple approaches with regard to airport safety issues.

4.2.1.1 Aircraft Activity Data.

The mean number of aircraft handled per runway was 38.92 (s.d. = .83, n = 24) in the dual approach condition and 38.54 (s.d. = 1.41, n = 81) in the triple approach condition. Because scripted blunders were included in the simulation, fewer aircraft were landed than were initially handled. The mean number of aircraft landed per runway was 22.46 (s.d. = 2.50, n = 24) for the dual approach condition and 23.91 (s.d. = 3.07, n = 81) for the triple approach condition. On the average, the number of aircraft landed during each 1-hour simulation was 45 for each of the dual runway configurations and 72 for the three-runway configuration.

4.2.1.2 Safety Data.

4.2.1.2.1 API Analysis.

A total of 554 of the 597 blunders generated during the Phase II simulation resulted in a conflict situation. Of these, 149 occurred under dual approach conditions, and 405 under the triple approach condition. The average of the API value was 20.18 (s.d. = 19.35, max = 70) for the dual approach condition and 19.49 (s.d. = 15.37, max = 86) for the triple approach condition. The cumulative distributions of API values for both conditions are shown in figure 7.

An ANOVA was performed to determine the effects of approach condition (dual versus triple), degree of blunder turn, and communication condition (radio contact or no radio contact following a blunder) on API. There were no significant main effects of approach condition, or degree of blunder turn on API.

There was a significant effect of communication condition on API ($F(1,542) = 11.20$, MSE = 261.24, $p. < .005$). The average API was lower in the radio communication condition ($X_c = 16.62$) than in the no radio communication condition ($X_{nc} = 21.89$).

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1 $$\left[df = \frac{[S_1^2/N_1 + S_2^2/N_2]^2}{\frac{(S_1^2/N_1)^2}{N_1} + \frac{(S_2^2/N_2)^2}{N_2}} \right] - 2$$

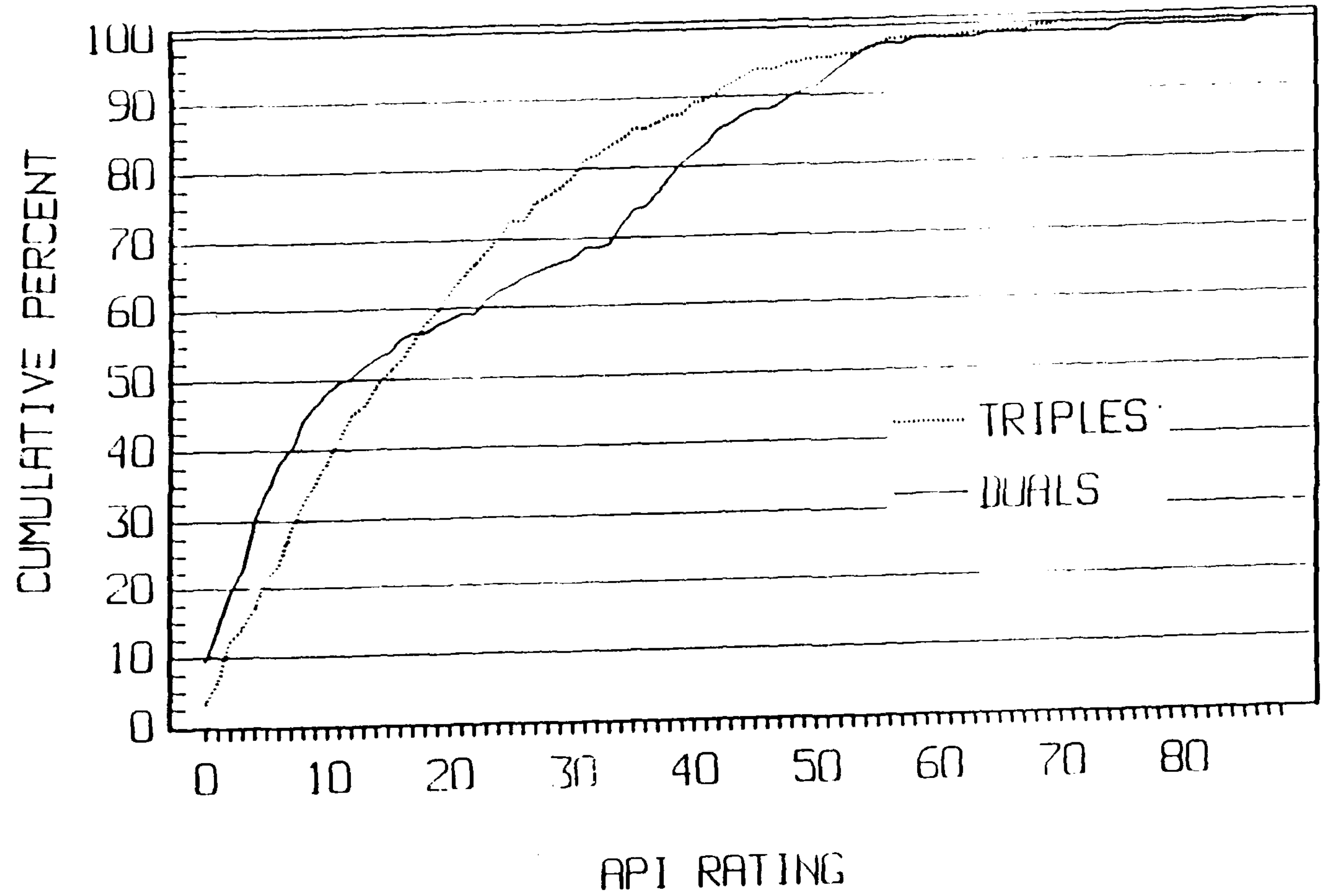

FIGURE 7. CUMULATIVE DISTRIBUTIONS OF API VALUES FOR DUAL AND TRIPLE APPROACH CONDITIONS

4.2.1.2.2 CPA Analysis.

The average CPA was 8484.22 ft (s.d. = 3878.45 ft, n = 149) for the dual approach condition and 8502.39 ft (s.d. = 3119.41 ft, n = 405) for the triple approach condition. The smallest CPA values achieved were 1103 and 1229 ft for the dual and triple approach conditions, respectively.

A second ANOVA was performed to investigate the effects of approach condition, degree of blunder, and communication condition on the CPA dependent measure. While the mean CPA value was more than one mile for all conditions, the statistical analysis revealed significant effects which largely paralleled those observed for the API measure.

The main effect of communication condition was again significant ($F(1,542) = 24.18$, MSE = .10E+08, $p. < .0001$). The average CPA value under the condition in which radio communication was maintained was 9268.09 ft. When communication ceased following a blunder, the average value dropped to 7542.45 ft.

The main effect of blunder degree was also significant in this analysis ($F(2,542) = 3.82$, MSE = .10E+.08, $p. < .05$). The average CPA value for 10 degree blunders (X_{10} = 9,257.38 ft, s.d. = 3,455.37 ft, n = 125) was greater than the averages for 20 degree blunders (X_{20} = 8,586.06 ft, s.d. = 3,197.66 ft, n_{20} = 207) and 30 degree blunders (X_{30} = 7,987.51 ft, s.d. = 3,322.10 ft, n_{30} = 222). The main effect of approach condition was not statistically significant, paralleling the API results.

The three-way interaction of approach, blunder degree, and communication variables was significant ($F(1, 542) = 3.03$, MSE = .10E+08, $p. < .05$). As can be seen in figure 8, the locus of the interaction appears to be in the differences between dual and triple approach conditions for 10 degree blunders. This interaction may be of limited practical importance since the CPA values for all conditions were within the prescribed limits of safe separation.

4.2.1.2.3 Other measures.

The number of NTZ entries per runway for the dual approaches was 4.96 (s.d. = 2.36), as compared to 5.30 (s.d. = 1.78) for the triple approach condition. The difference was not significant by t-test. The number of parallel conflict entries per runway was significantly different for the dual and triple approach conditions ($t(\simeq 25) = 5.626$, $p. < .0001$). The average for the dual condition was 19.83 (s.d. = 5.46) versus 31.88 (s.d. = 6.45) for the triple condition.

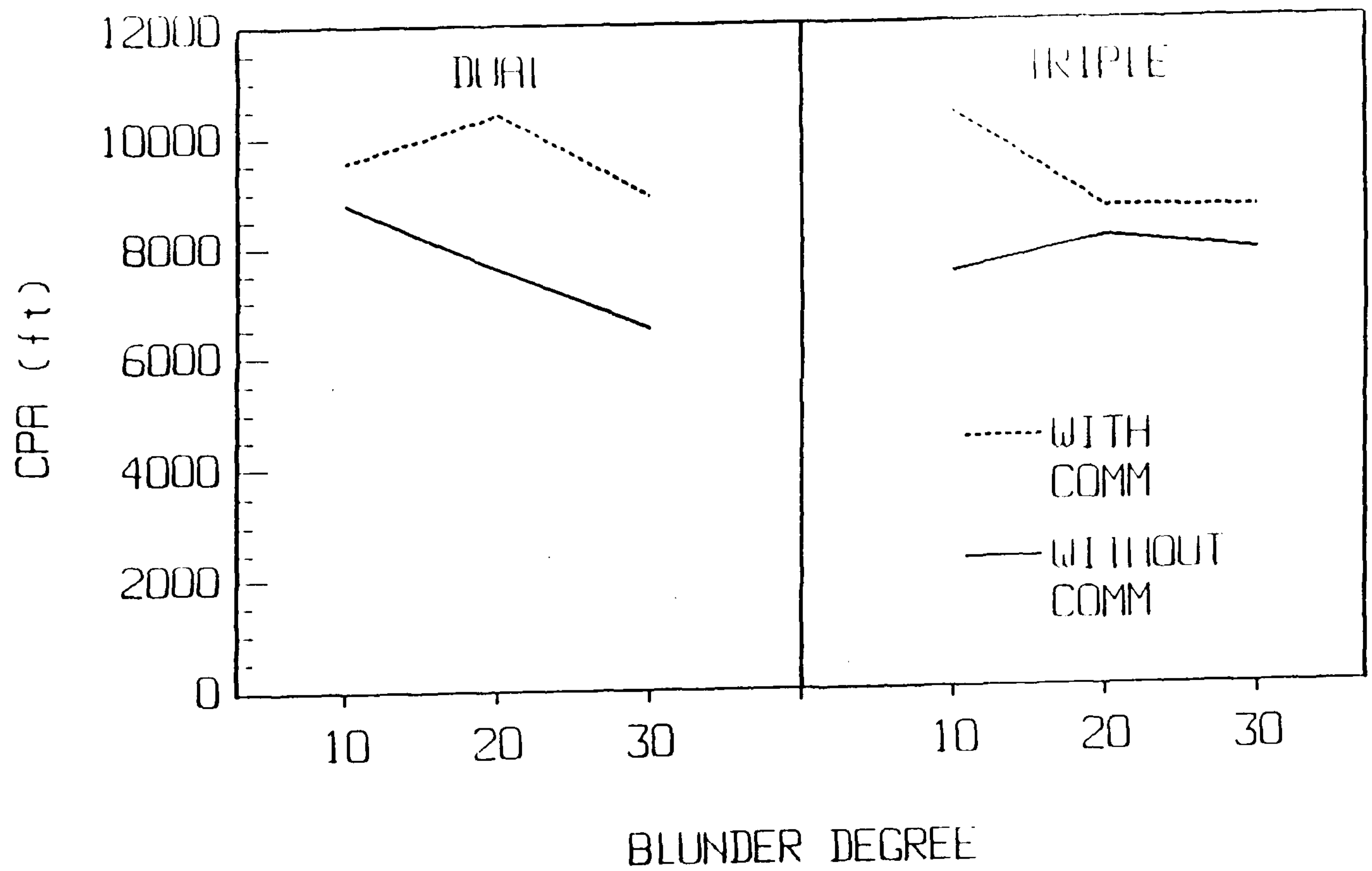

FIGURE 8. AVERAGE OF CPA VALUES AS A FUNCTION OF APPROACH CONDITION, DEGREE FO BLUNDER, AND COMMUNICATION CONDITION

The average number of warnings per runway was 33.71 (s.d. = 14.65) in the dual approach condition and 27.28 (s.d. = 7.87) in the triple approach condition. This difference was not significant by t-test. However, the number of pilot messages per runway did differ significantly between the dual and triple approaches ($t(\simeq 16) = 2.886$, $p < .01$). The average number of messages was 74.08 (s.d. = 17.18) in the dual condition and 60.22 (s.d. = 12.16) in the triple condition.

Neither dual nor triple approach conditions resulted in any occurrence producing a slant range distance 500 ft or less between target centers.

4.2.2 Analysis of Blunders Threatening One Versus Two Runways.

This section describes the analysis of blunders in the triple approach condition alone. Those which threatened two runways (i.e., blunders initiated from 16L or 18R) are compared with those initiated from 17L, which threatened only one runway.

4.2.2.1 API Analysis.

An ANOVA was performed to determine the effects of number of runways threatened, communication condition, and degree of blunder on API for the triple approach data. There was a significant main effect of the number of runways threatened ($F(1,393) = 4.76$, $MSE = 227.51$, $p < .05$). The average API value was greater when one runway was threatened ($X_1 = 21.12$, $n_1 = 134$) than when two runways were threatened ($X_2 = 17.61$, $n_2 = 271$). The effect of the communication condition was also significant in this analysis ($F(1,393) = 4.86$, $MSE = 227.51$, $p < .05$). The average API value was greater ($X_{nc} = 20.5$, $n_{nc} = 198$) when communication ceased between the pilot and controller than when communication was maintained ($X_c = 17.12$, $n_c = 207$).

4.2.2.2 CPA Analysis.

An analysis of variance was similarly conducted for the closest point of approach data. The main effect of number of runways threatened was significant ($F(1,393) = 6.43$, $MSE = .86E+07$, $p < .05$). The average CPA value was smaller for blunders threatening only one runway ($X_1 = 7941.10$ ft) than for those threatening two runways ($X_2 = 8779.93$ ft).

The effect of the communication condition was also significant in this analysis ($F(1,393) = 19.64$, $MSE = .86E+07$, $p < .0001$). The average CPA value for the no communication condition ($X_{nc} = 7856.01$, $n_{nc}=198$) was smaller than the average for the communication condition ($X_c = 9,120.666$, $n_c = 207$).

The interaction of the communication and blunder degree condition was significant ($F(2,393) = 4.05$, $MSE = .86E+07$, $p. < .05$) as shown in figure 9. The locus of the interaction appears to be the large disparity between communication conditions for 10 degree blunders.

Although significant, this interaction may be of limited practical importance, given the high CPA averages observed for all of the conditions.

Finally, the interaction between the number of runways threatened and the degree of blunder was significant ($F(2,393) = 8.43$, $MSE = .86E+07$, $p. < .0005$), as shown in figure 10. An explanation for this effect is not obvious. While this is a statistically significant result, it may be of limited practical importance given that all values shown in the figure far exceed the acceptance criteria.

4.2.3 Comparison of Comparable Conditions within the Dual and Triple Approach Runs.

This section compares blunder data from each of the dual approach airports with its analogous data from the triple approach condition. Therefore, the west dual approach airport data (blunders from runways 18R and 17L) are compared with data from 17L right turn blunders within the triple approach runs. Similarly, data from the east dual approach airport (runways 17L and 16L) are compared with triple approach data from 17L left turn blunders. These comparisons are depicted in figure 11. The analysis is performed on east and west airport data separately to control for differences in runway separation (east airport runway separation = 5000 ft; west airport runway separation = 8800 ft).

4.2.3.1 West Airport Comparisons.

ANOVAs were conducted to compare west airport dual data and triple approach data for 17L turning right. Independent variables in these analyses were degree of blunder, communication condition, and dual versus triple approach conditions. Dependent measures were API and CPA.

The degree of blunder was the only significant effect ($F(2,114) = 3.67$, $MSE = 157.01$, $p. < .05$) in the API analysis. Interestingly, 10 degree blunders resulted in the largest average API (16.29 ($n = 21$)). The 30 and 20 degree blunders resulted in smaller average API values, 15.69 ($n = 52$) and 9.77 ($n = 53$), respectively.

The CPA analysis indicated that degree of blunder had a significant effect on controller performance ($F(2,114) = 5.92$, $MSE = .95E+07$, $p. < .05$). The average CPA value for the 30 degree blunders was the smallest ($X_{30} = 9{,}128$ ft, $n_{30} = 52$). The 10 degree blunders resulted in a slightly larger average CPA ($X_{10} = 9{,}556$ ft, $n_{10} = 21$.

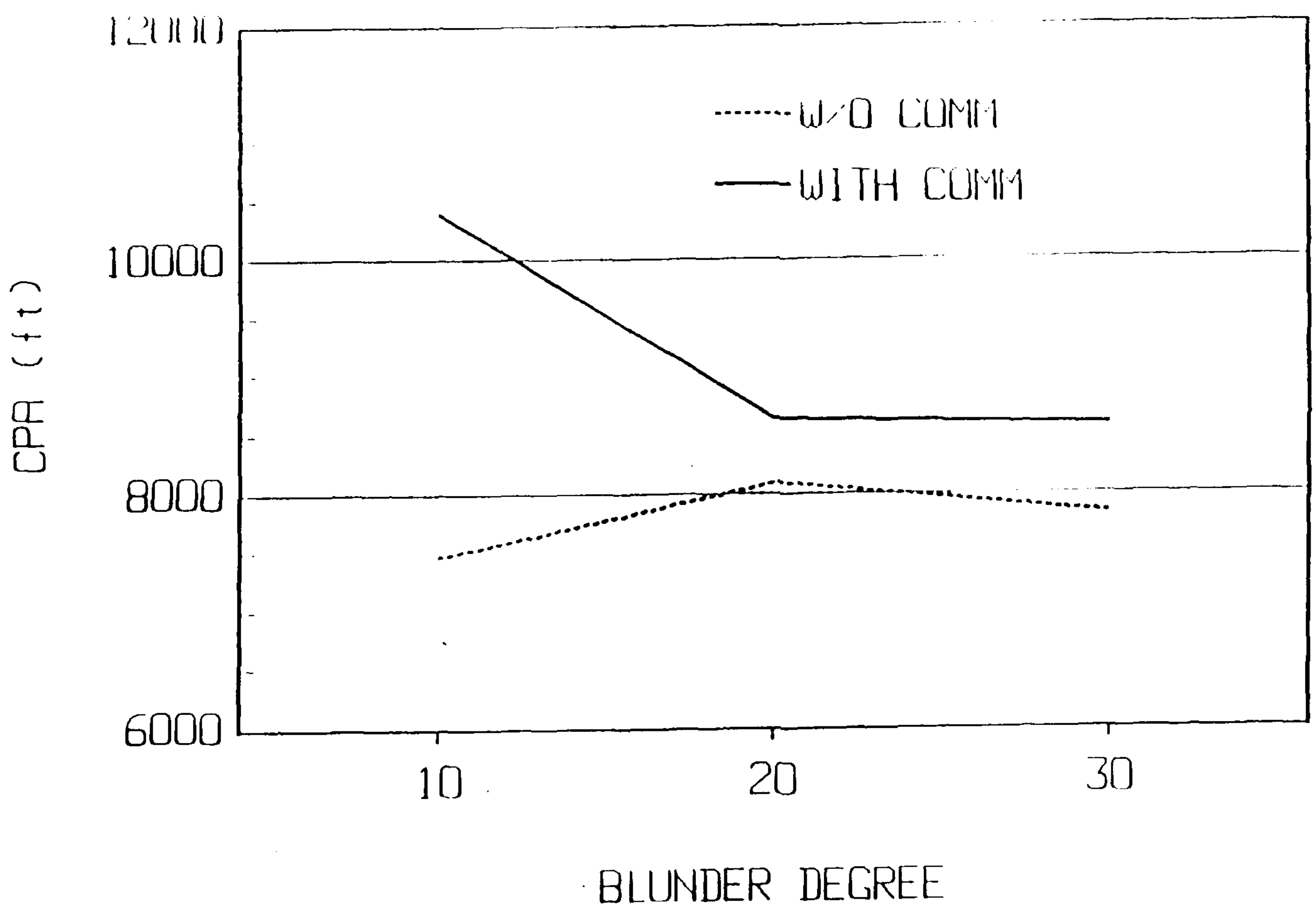

FIGURE 9. AVERAGE CPA VALUE (FT) AS A FUNCTION OF DEGREE OF BLUNDER AND COMMUNICATION CONDITION

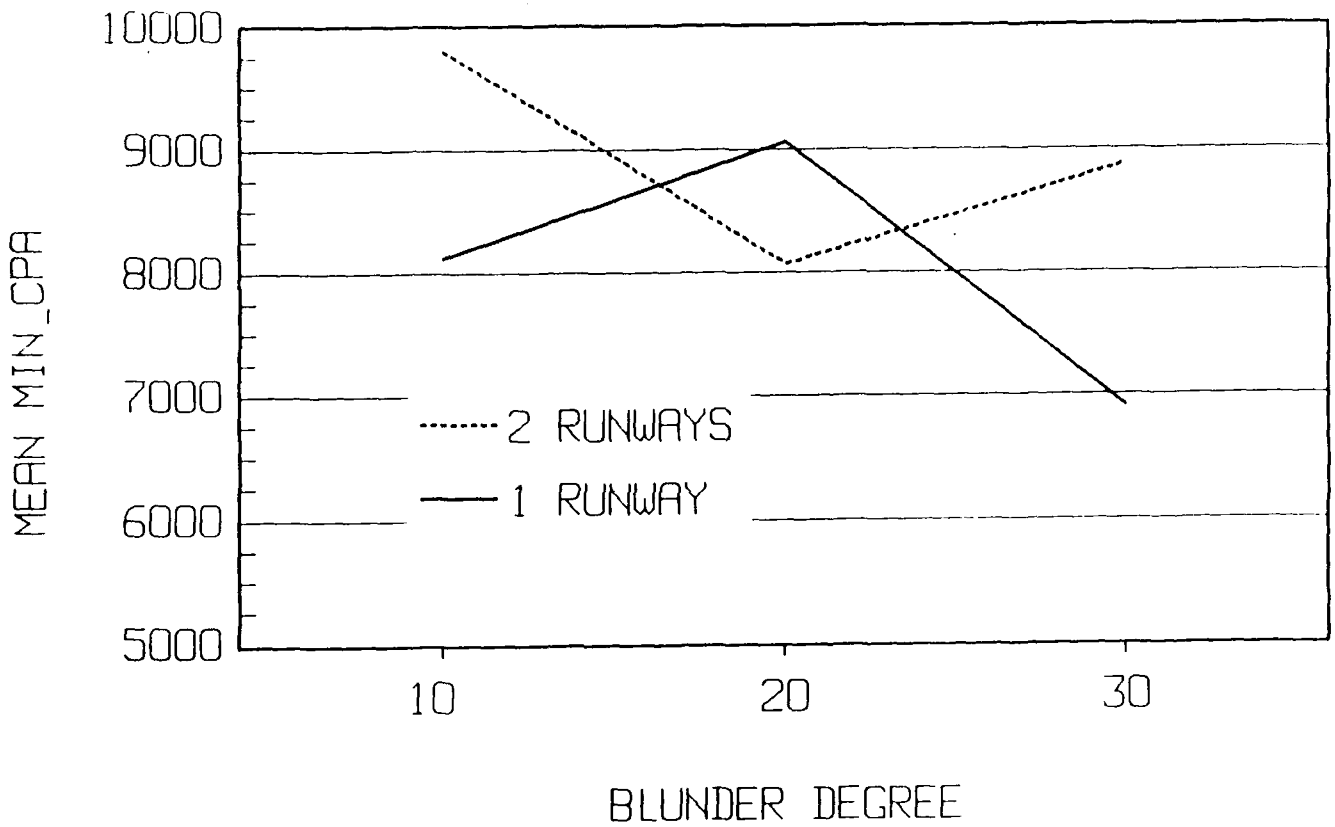

FIGURE 10. AVERAGE CPA VALUES AS A FUNCTION OF THE NUMBER OF RUNWAYS THREATENED AND THE DEGREE OF BLUNDER

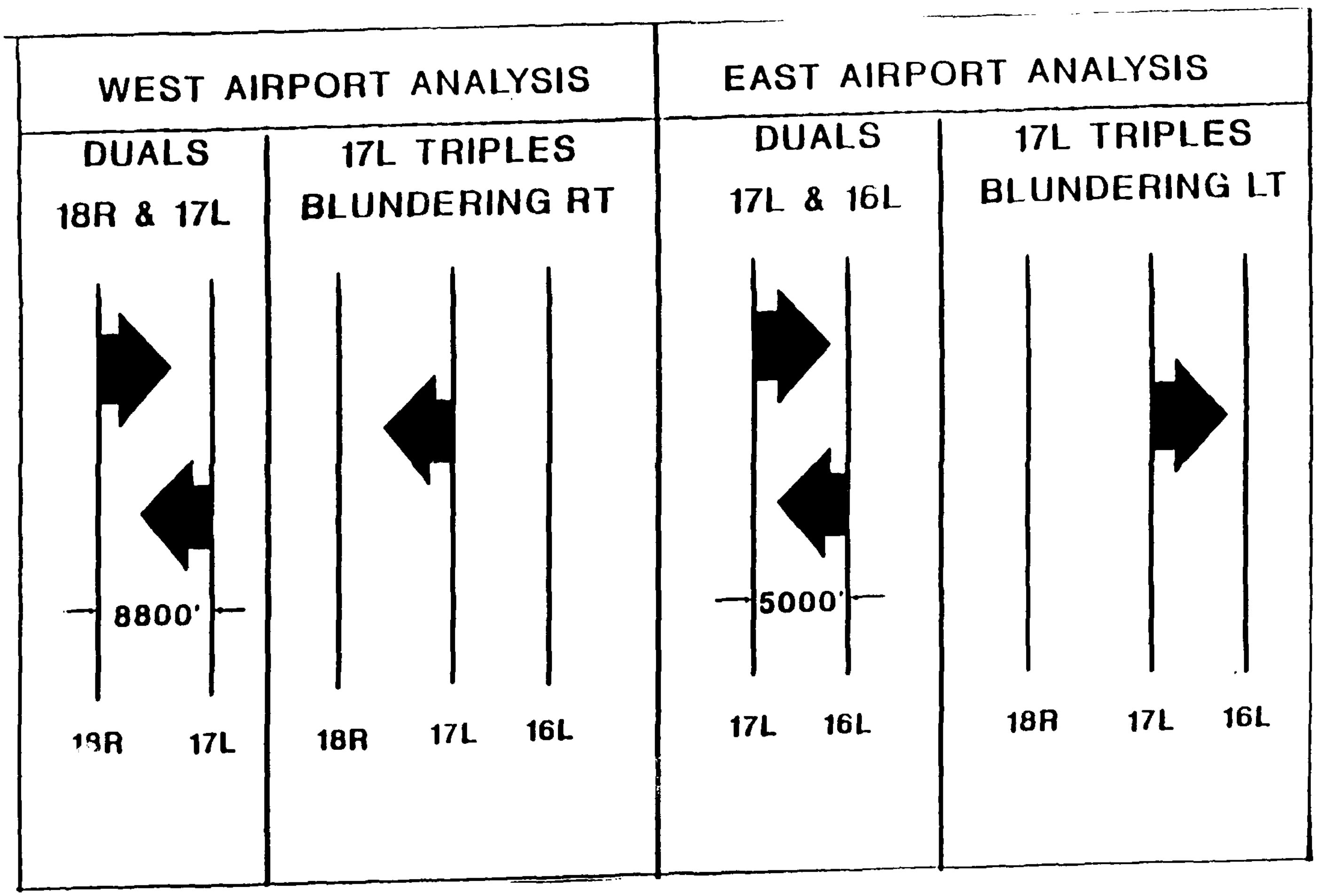

FIGURE 11. GRAPHIC REPRESENTATION OF COMPARABLE CONDITIONS WITHIN THE DUAL AND TRIPLE APPROACH RUNS

while 20 degree blunders resulted in a much larger average CPA (X_{20} = 11,000 ft, n_{20} = 53).

4.2.3.2 <u>East Airport Comparisons</u>.

In the analyses to follow, the east airport dual approaches 17L and 16L are compared with the triple approach data for 17L aircraft blundering toward the 16L localizer. The ANOVAs in these analyses had degree of blunder, communication condition and approach condition as independent variables and API and CPA as dependent variables.

The API ANOVA for the east airport comparisons indicated no significant effects of degree of blunder, communication condition, or approach condition. Conversely, the ANOVA on the CPA data indicated a significant effect of blunder degree ($F(2,145) = 5.28$, MSE = .93E+07, $p. < .01$) and communication condition ($F(1,145) = 8.23$, MSE = .93E+07, $p. < .005$). The average CPA for the 30 degree blunder condition (X_{30} = 5,906 ft, n_{30} = 71) was less than the average CPAs for 20 degree (X_{20} = 7,038 ft, n_{20} = 47) and 10 degree (X_{10} = 8,198 ft, n_{10} = 39) blunder conditions. The average CPA for the no communication condition (X_{nc} = 5,942 ft, n_{nc} = 91) was less than the average CPA for the communication condition (X_c = 8,016 ft, n_c = 66).

4.2.4 <u>Comparison of the Dual Runway Airports</u>.

The final analysis performed on the computer data compared the two dual runway airports which differed, primarily, in terms of runway separation. The east airport approaches were separated by 5000 ft and the west airport approaches were separated by 8800 ft.

The data for the two dual approach airports differed in a number of ways. First, the number of aircraft handled was significantly greater for the east airport (approaches 17L and 16L) than for the west airport (approaches 18R and 17L) ($t(5) = 5.721$, $p. < .001$). An average of 78.83 aircraft was handled for the east airport during each run, in comparison to 76.83 aircraft for the west airport. Second, although more aircraft were handled for the east airport, significantly more were <u>landed</u> for the west airport ($t(5) = 2.909$, $p. < .025$). An average of 48 aircraft landed at the west airport during a run, while approximately 42 landed at the east airport.

A number of measures indicated that the east airport was more difficult to control than the west airport. For example, the number of NTZ entries was much higher, on the average, for the east airport than for the west airport ($t(5) = 14.7$, $p. < .001$). There was an average of 5.5 NTZ entries per run for the west airport, in contrast to an average of 14.33 NTZ entries for the east airport. More warnings and more pilot messages were issued per run for the east airport than for the west airport ($t(5) = 2.711$, $p. < .025$ and t(5) = 2.966, p. < .025, respectively). The number of pilot messages averaged 125.67 per run for the west airport, and 170.67 for the east airport. Similarly, the number of warnings for the west airport averaged 49.17 per run while the east airport average was 85.67. Finally, API values were much higher, on the average, for the east airport runs than for the west airport runs (t(5) = 3.701, p. < .005). The average API values were 27.41 (s.d. = 21.01, n = 81) and 11.57 (s.d. = 12.74, n = 68) and for the east and west airports, respectively.

4.2.5 Concluding Remarks Concerning the Computer Data.

Given the large volume of data collected, it is not surprising that a number of statistically significant effects were observed. However, it should be noted that the practical significance of the observed differences is minimal in many cases.

The low API values and high CPA values cited consistently throughout the result section indicate that all of the conditions of this study resulted in acceptable performance from the standpoint of the safety measures.

4.3 TIME PLOTS OF SELECTED BLUNDERS.

Graphic plots served as a useful tool in the analysis of some of the more serious blunders. The graphic plots represent the aircraft's lateral movement along the localizer. As shown in figure 12, the localizers are indicated by vertical dashed lines and the aircraft tracks are solid lines that follow and eventually deviate from the localizer lines. The horizontal (x) and vertical (y) axes are marked in nautical miles from an imaginary origin. Simulation time (recorded along the aircraft tracks) is marked in 10 second increments. The aircraft identification is indicated at the beginning of each track. Table 2 provides an example of the digital data associated with a graphic plot. The data include increment time (from the plot), simulation time (seconds), x coordinate, y coordinate, altitude, ground speed, track status (1000 = Off-Flight-Plan on Vectors, 1060 = Flying ILS Approach, 1061 = Homing to ILS Approach, 1068 = Deviating from ILS Approach), and the distance the aircraft traveled since the plot was initiated. The following are descriptions of three blunders with their associated graphic plots and digital data.

The first example, shown in figure 12, had the smallest CPA value of all the blunders in which a pilot error was not detected. It involved AAL555 inbound on 17L and AAL344 inbound on 16L. At 2139 simulation time (between 213 and 214 on the graphic plot), AAL555 began a 30 degree blunder to the left and ceased communication with the controller. The controller for 16L vectored AAL344 immediately left to heading 080 and instructed AAL344 to climb and maintain 4000 ft. This vector change was initiated by AAL344 at approximately 2159 simulation time (between 215 and 216 on the

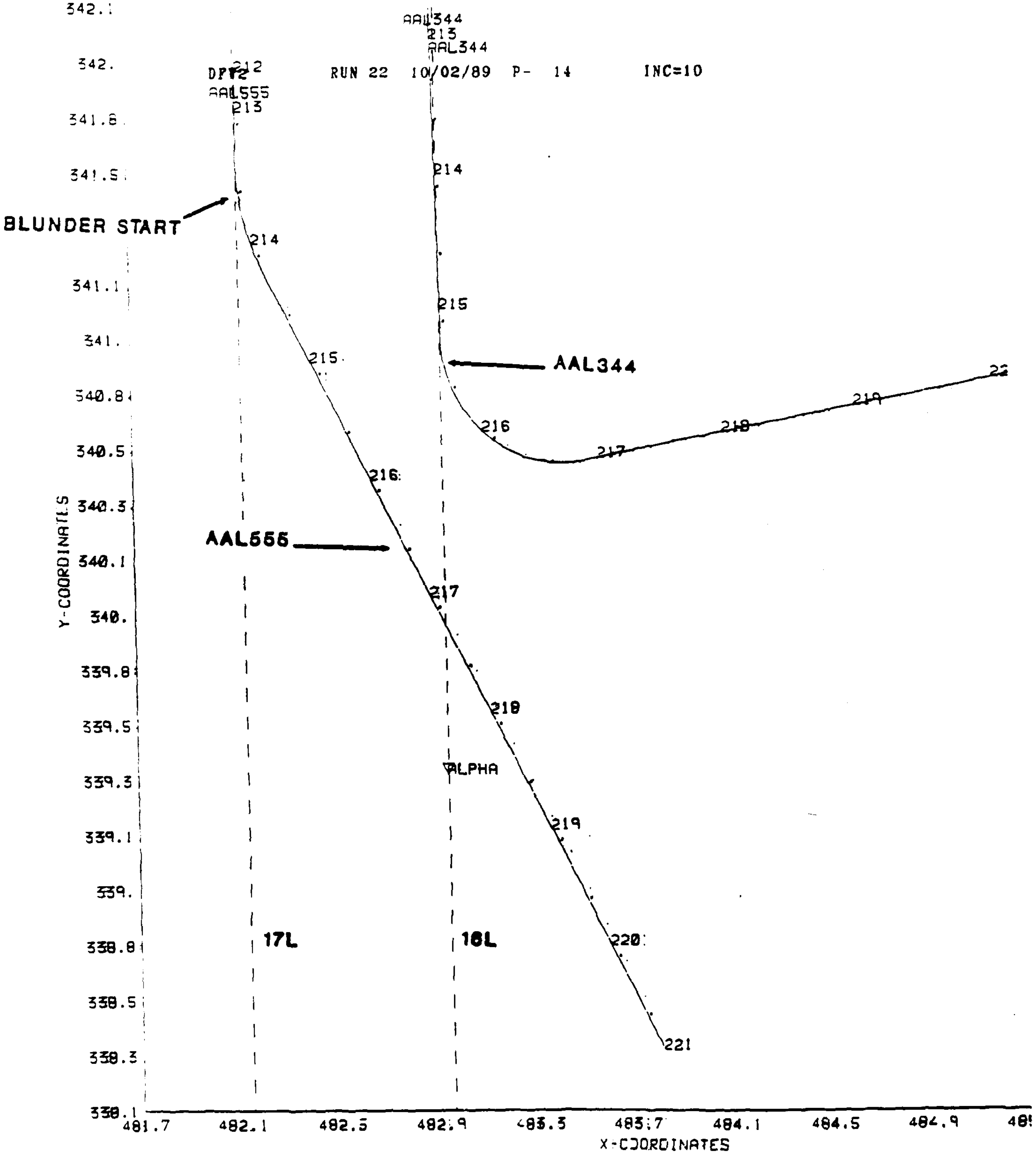

FIGURE 12. GRAPHIC PLOT FOR EXAMPLE 1

TABLE 2. DIGITAL DATA FOR EXAMPLE 1

DFW2

DATE OF RUN 10/02/89 RUN - 22 PLOT- 14

AAL555

INC	TIME	X	Y	ALT	SPEED	TRACK	DISTANCE
212	2126	482.254	341.973	2834.	177.	1060	.00
213	2129	482.252	341.826	2787.	177.	1060	.15
214	2139	482.304	341.344	2632.	176.	1000	.63
215	2149	482.532	340.914	2477.	176.	1000	1.12
216	2159	482.767	340.490	2322.	175.	1000	1.61
217	2169	483.002	340.065	2167.	175.	1000	2.09
218	2179	483.236	339.642	2011.	175.	1000	2.58
219	2189	483.470	339.220	1856.	174.	1000	3.06
220	2199	483.705	338.799	1701.	174.	1000	3.54
221	2209	483.914	338.421	1562.	174.	1000	3.97

AAL344

INC	TIME	X	Y	ALT	SPEED	TRACK	DISTANCE
212	2126	483.045	342.231	2729.	177.	1060	.00
213	2129	483.048	342.084	2690.	177.	1060	.15
214	2139	483.056	341.595	2560.	177.	1060	.64
215	2149	483.063	341.106	2430.	176.	1060	1.12
216	2159	483.222	340.665	2300.	176.	1000	1.61
217	2169	483.691	340.571	2440.	196.	1000	2.11
218	2179	484.198	340.660	2937.	197.	1000	2.63
219	2189	484.739	340.756	3436.	209.	1000	3.19
220	2199	485.300	340.854	3936.	212.	1000	3.75

graphic plot). At simulation time 2156 the two aircraft came within approximately 2795 ft laterally at approximately the same altitude. The API rating for this blunder was 68. Additional review of the video tape and the technical observer comments indicated that there were no unusual delays in controller response times or any pilot errors.

The second example shows one of the worst pilot errors that occurred during the simulation (see figure 13). AAL944 was inbound on 18R (simulation time 1149) when it began a 20 degree blunder to the left and the pilot ceased communication with the controller. As shown in the graphic plot, AAL944 made a left turn of approximately 200 degrees. The controller for 17L vectored AAL218 to 6000 ft in a maximum rate climb at simulation time 1166. Fifteen seconds later, the controller vectored AAL218 left to heading 080. The digital data (see table 3) indicated that at simulation time 1189 the aircraft were separated by 1460 ft laterally and 1372 ft vertically. The CPA between these two aircraft was 1684 ft with an API rating of 1. Two other aircraft, AAL101 and N756N, were vectored off the localizer as a result of this blunder, but neither aircraft came closer to AAL944 than AAL218 did.

A final example (see figure 14) shows one of the most serious blunders for the dual runway condition. AAL893 was inbound on 16L at simulation time 2672 when the pilot ceased communications with the controller and began a 30 degree blunder to the right. The aircraft inbound on 17L, AAL554, was vectored right to heading 270 descending to 2000 ft approximately 20 seconds after the beginning of the blunder. The controller on 16L then told controller on 17L that AAL893 was below 17L's AAL554. Ten seconds after the initial vectoring, AAL554 was again vectored right to heading 270 but was told to climb to 4000 ft. Review of the video tape and the digital data (see table 4) confirmed AAL893 was approximately 300 ft below AAL554 and 3350 ft away laterally. The CPA these aircraft attained was 2169 ft. The API rating was 62. Review of the video tape indicated, AAL554 responded timely to both ATC commands.

These examples serve to illustrate the value of the graphic plots and video/audio tapes in interpreting blunder data. For the interested reader, the Technical Observer Report, included as Appendix H, provides a detailed description of all blunders for which a slant range of 3000 ft or less was observed.

4.4 NAVIGATIONAL ERROR MODEL PERFORMANCE.

It was noted previously that the navigational error model used in Phase II underwent two changes during the simulation runs. The nature of these changes and the resulting navigational accuracy data are described in this section.

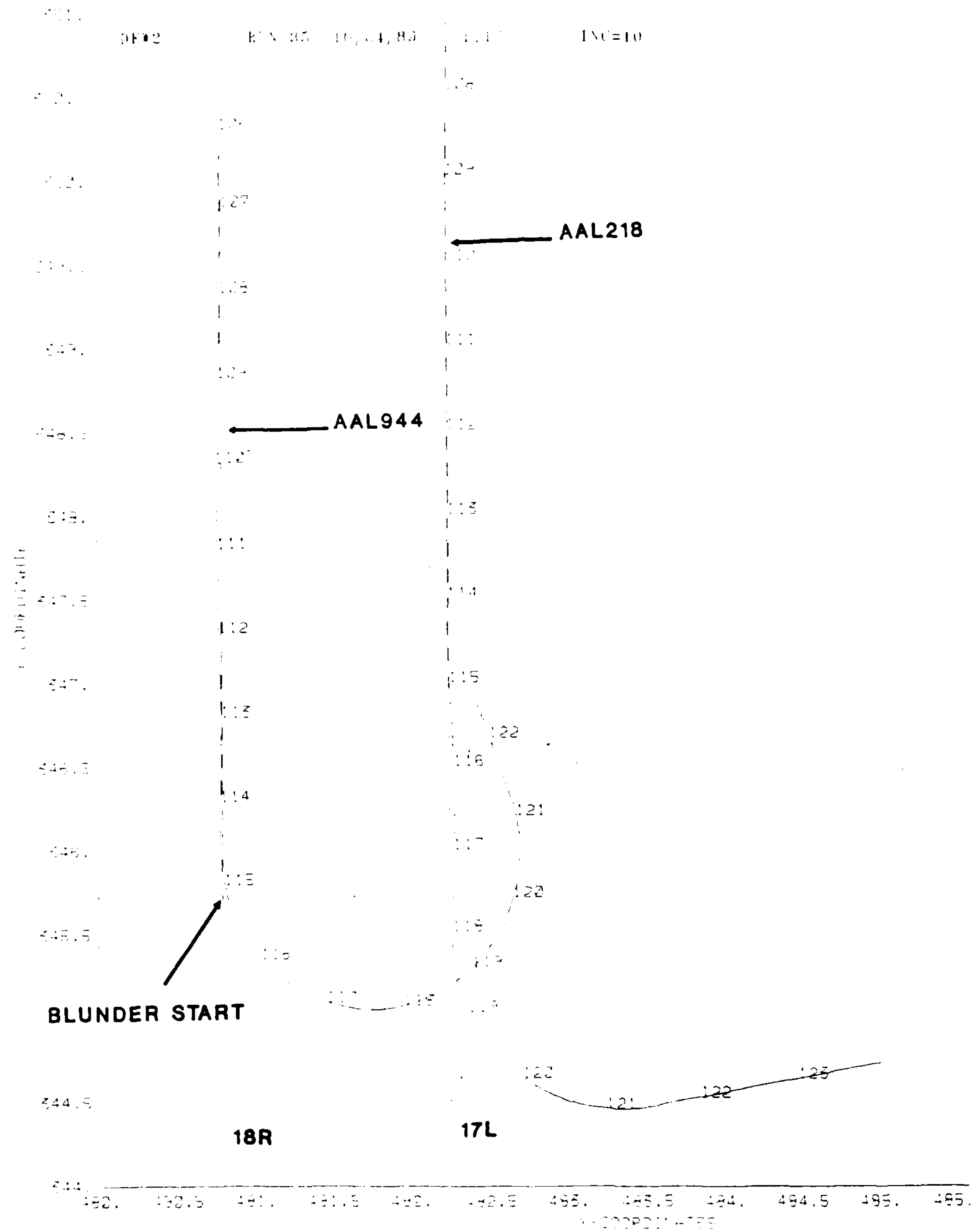

FIGURE 13. GRAPHIC PLOT FOR EXAMPLE 2

TABLE 3. DIGITAL DATA FOR EXAMPLE 2

AAL944 ACTUAL FLIGHT:

INC	TIME	X	Y	ALT	SPEED	TRACK	DISTANCE
106	1060	480.300	350.307	5739.	185.	1060	.00
107	1069	480.809	349.846	5594.	185.	1060	.46
108	1079	480.798	349.335	5433.	184.	1060	.97
109	1089	480.783	348.826	5272.	184.	1068	1.48
110	1099	480.766	348.318	5111.	184.	1060	1.99
111	1109	480.777	347.810	4951.	183.	1060	2.50
112	1119	480.737	347.305	4791.	183.	1060	3.00
113	1129	480.797	346.799	4632.	182.	1068	3.51
114	1139	480.791	346.296	4473.	182.	1068	4.01
115	1149	480.815	345.795	4315.	181.	1000	4.51
116	1159	481.048	345.357	4156.	181.	1000	5.02
117	1169	481.467	345.095	3998.	181.	1000	5.52
118	1179	481.960	345.078	3839.	180.	1000	6.02
119	1189	482.396	345.309	3681.	180.	1000	6.51
120	1199	482.656	345.725	3523.	179.	1000	7.01
121	1209	482.673	346.215	3364.	179.	1000	7.51
122	1219	482.503	346.679	3206.	178.	1000	8.00

AAL213 ACTUAL FLIGHT:

INC	TIME	X	Y	ALT	SPEED	TRACK	DISTANCE
106	1060	482.243	351.514	5852.	185.	1060	.00
107	1069	482.252	351.055	5706.	184.	1060	.46
108	1079	482.251	350.545	5544.	184.	1060	.97
109	1089	482.245	350.037	5382.	184.	1068	1.48
110	1099	482.245	349.530	5221.	183.	1068	1.98
111	1109	482.245	349.024	5076.	183.	1060	2.49
112	1119	482.245	348.519	4916.	182.	1060	3.00
113	1129	482.245	348.016	4756.	182.	1068	3.50
114	1139	482.245	347.513	4596.	181.	1068	4.00
115	1149	482.254	347.012	4436.	181.	1068	4.50
116	1159	482.281	346.513	4277.	181.	1068	5.00
117	1169	482.277	346.014	4178.	180.	1061	5.50
118	1179	482.268	345.524	4553.	181.	1061	5.99
119	1189	482.364	345.042	5053.	191.	1000	6.49
120	1199	482.710	344.646	5552.	203.	1000	7.02
121	1209	483.245	344.463	5962.	216.	1000	7.59
122	1219	483.849	344.533	6000.	224.	1000	8.20
123	1229	484.477	344.644	6000.	234.	1000	8.84

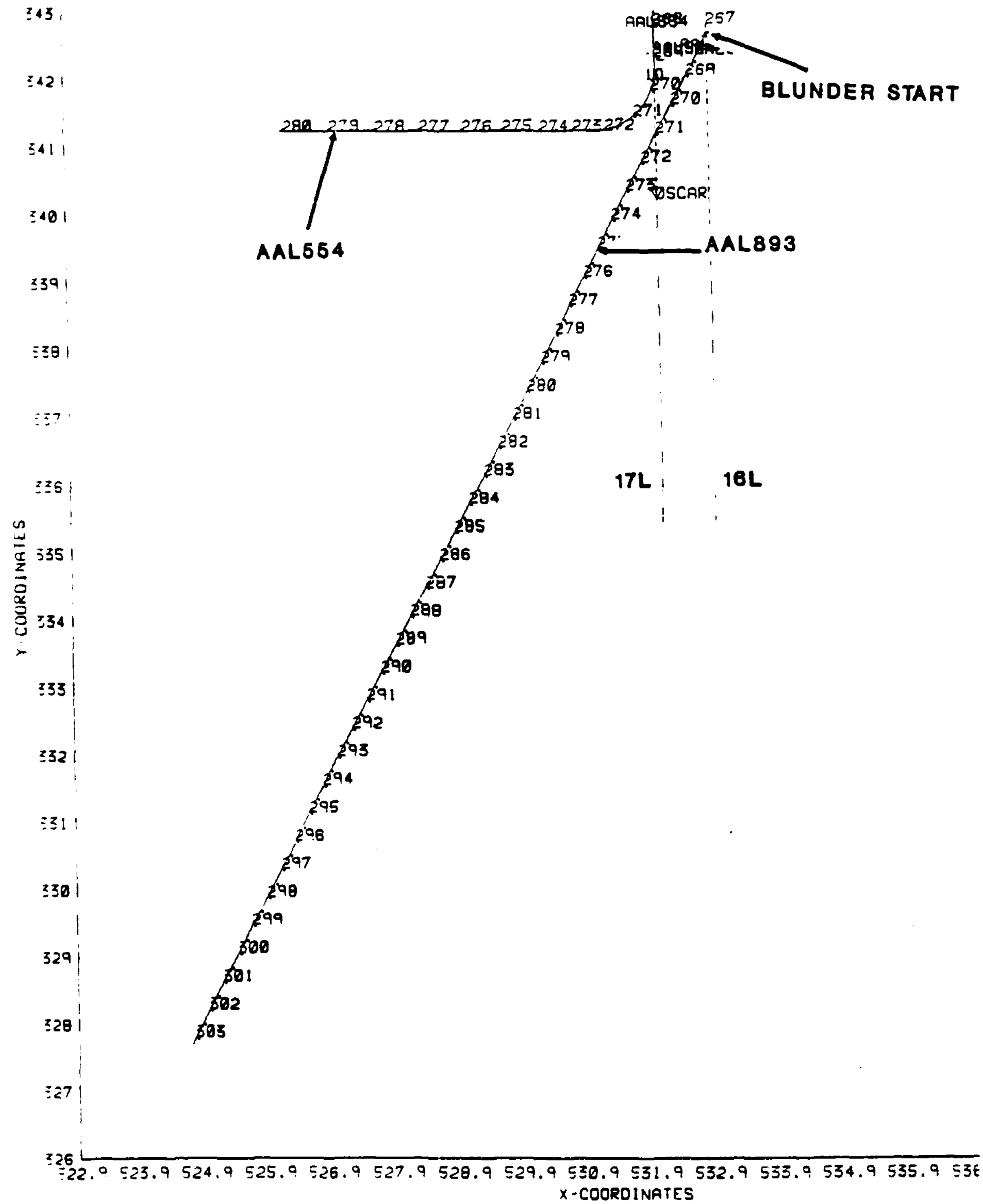

FIGURE 14. GRAPHIC PLOT FOR EXAMPLE 3

TABLE 4. DIGITAL DATA FOR EXAMPLE 3

AAL893

INC	TIME	X	Y	ALT	SPEED	TRACK	DISTANCE
267	2672	533.056	342.822	2890.	177.	1000	.00
268	2679	532.965	342.432	2799.	177.	1000	.34
269	2689	532.728	342.035	2668.	177.	1000	.83
270	2699	532.491	341.638	2538.	176.	1000	1.32
271	2709	532.254	341.210	2407.	176.	1000	1.81
272	2719	532.017	340.786	2277.	176.	1000	2.30
273	2729	531.783	340.361	2146.	175.	1000	2.78
274	2739	531.549	339.936	2016.	175.	1000	3.27
275	2749	531.314	339.513	1885.	175.	1000	3.75
276	2759	531.080	339.091	1755.	174.	1000	4.23
277	2769	530.845	338.669	1624.	174.	1000	4.72
278	2779	530.613	338.249	1494.	174.	1000	5.20
279	2789	530.381	337.829	1363.	173.	1000	5.68
280	2799	530.149	337.409	1233.	173.	1000	6.15
281	2809	529.917	336.991	1102.	173.	1000	6.63
282	2819	529.685	336.573	972.	172.	1000	7.11
283	2829	529.453	336.156	841.	172.	1000	7.59
284	2839	529.224	335.740	711.	172.	1000	8.06
285	2849	528.993	335.323	641.	171.	1000	8.54
286	2859	528.763	334.906	603.	171.	1000	9.02
287	2869	528.534	334.489	603.	171.	1000	9.49
288	2879	528.304	334.071	603.	171.	1000	9.97
289	2889	528.075	333.654	603.	171.	1000	10.44
290	2899	527.845	333.236	603.	171.	1000	10.92
291	2909	527.616	332.819	603.	171.	1000	11.40
292	2919	527.386	332.401	603.	171.	1000	11.87
293	2929	527.157	331.984	603.	171.	1000	12.35
294	2939	526.927	331.566	603.	171.	1000	12.83
295	2949	526.698	331.149	603.	171.	1000	13.30
296	2959	526.468	330.731	603.	171.	1000	13.78
297	2969	526.239	330.314	603.	171.	1000	14.26
298	2979	526.009	329.896	603.	171.	1000	14.73
299	2989	525.780	329.479	603.	171.	1000	15.21
300	2999	525.550	329.061	603.	171.	1000	15.69
301	3009	525.321	328.644	603.	171.	1000	16.16
302	3019	525.091	328.226	603.	171.	1000	16.64
303	3029	524.862	327.809	603.	171.	1000	17.11

AAL534

INC	TIME	X	Y	ALT	SPEED	TRACK	DISTANCE
267	2672	532.226	343.156	2994.	176.	1060	.00
268	2679	532.234	342.814	2994.	176.	1060	.34
269	2689	532.243	342.326	2951.	176.	1060	.83
270	2699	532.191	341.850	2707.	175.	1000	1.31

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271	2709	531.921	341.464	2374.	174.	1000	1.79
272	2719	531.475	341.257	2371.	185.	1000	2.29
273	2729	530.967	341.244	2907.	197.	1000	2.80
274	2739	530.429	341.244	3532.	209.	1000	3.33
275	2749	529.846	341.244	3990.	221.	1000	3.92
276	2759	529.224	341.244	4000.	228.	1000	4.54
277	2769	528.576	341.244	4000.	238.	1000	5.19
278	2779	527.898	341.244	4000.	249.	1000	5.86
279	2789	527.191	341.244	4000.	259.	1000	6.57
280	2799	526.439	341.244	4000.	265.	1000	7.30

The initial navigational error model was designed to produce an average deviation from the ILS of zero ft at 20 nmi from the threshold with a standard deviation of 400 ft. The model parameters were 1) a probability of .10, that an aircraft would deviate from the localizer during any given second of the simulation run, 2) a turn angle randomly selected from a rectangular distribution with a mean equal to zero and a range of ± 10 degrees, and 3) the number of seconds the aircraft would deviate from the localizer, which was set equal to the number of nmi the aircraft was from the threshold at the initiation of the deviation, plus 4 seconds. This model produced the level of FTE exemplified by run 2-2 in figure 15, and was used during the first two runs of the simulation. However, the controllers and technical observers indicated that the amount of aircraft deviation was unrealistically large in these two runs. This model was modified to reduce deviation from the localizer.

The second model used the same principal components as the first model except the duration of the deviation was reduced. The number of seconds an aircraft would deviate in the second model was set equal to one half the number of nmi the aircraft was from the threshold. This adjustment to the model effectively reduced the FTE to less than 200 ft at the point 20 nmi from the threshold. This can be seen in figure 15 for runs 29 to 32. The second model was used for runs 3 through 32.

The navigational error model was further improved in run 33. This revision included changes to both the deviation angle distribution and the deviation duration. The deviation duration set in the original model - the number of nmi from the threshold plus 4 seconds - was again used in this final version. The angle of deviation was randomly selected from a normal distribution with a mean of zero degrees and a standard deviation of 3.4 degrees. Negative angles were designated as left turns off the localizer and positive angles as right turns.

The third model produced deviations greater than those found in the second model but less than the original model, as shown for runs 33 - 36 in figure 15. The third model proved to produce both visually realistic and the statistically correct flight paths.

4.5 DESCRIPTION OF THE AD HOC RUN (RUN 37).

An ad hoc run (run 37) was introduced to reexamine previous runs and to create new blunders for examination. To achieve this goal a typical traffic sample was run in the simulation. Variations in aircraft speed were introduced to produce overtakes. Additionally, blunders were created inside the final approach fix. The blunders were generated by personnel from AFS-400 and AVN-540 to create the greatest potential for conflict.

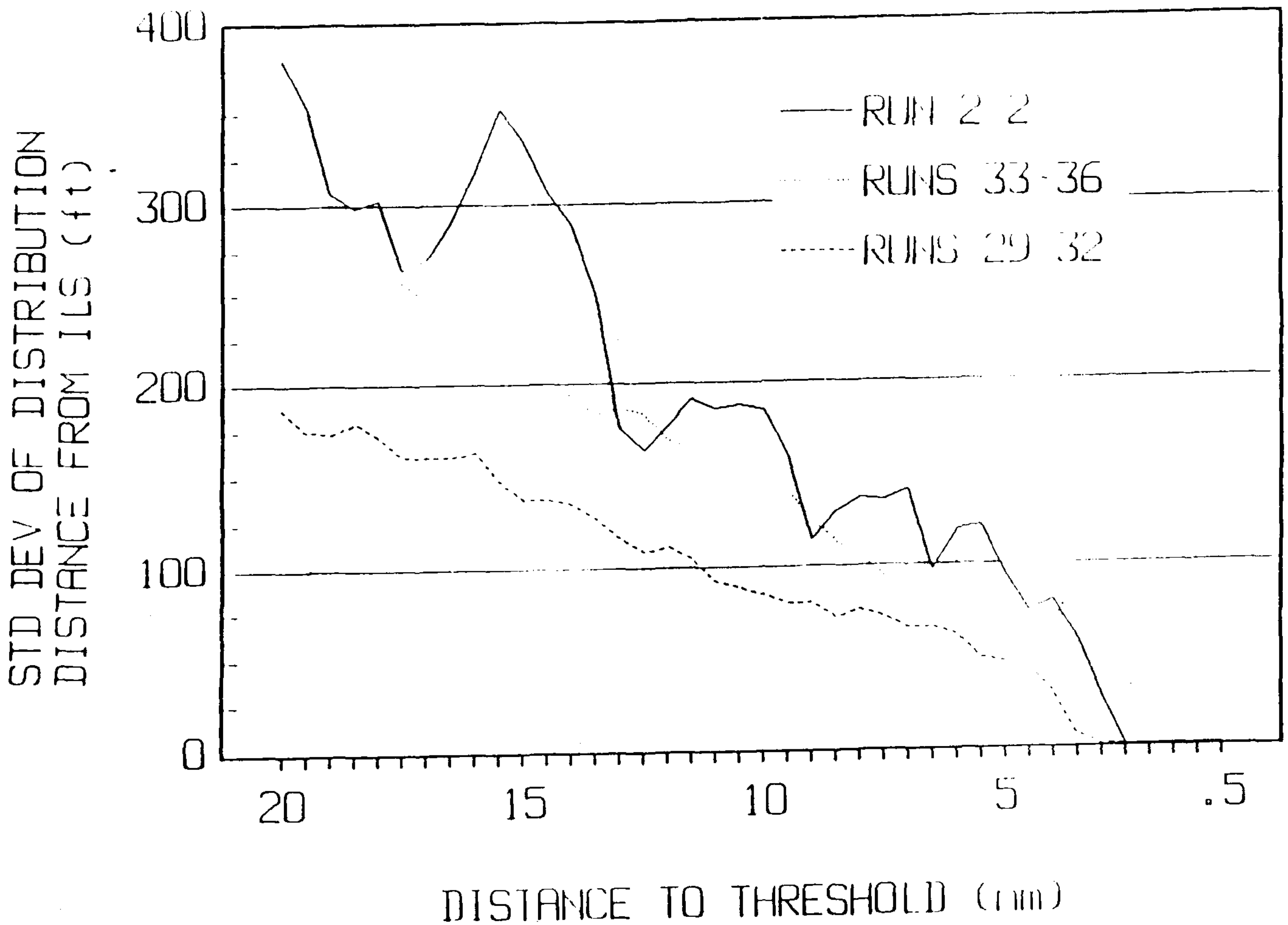

FIGURE 15. FLIGHT TECHNICAL ERROR FOR THE THREE NAVIGATIONAL MODELS USED IN D/FW PHASE II

Eighteen blunders were initiated in run 37. Ten of those involved cessation of communications between controllers and pilots. Twelve of the blunders originated from 17L, four from 16L, and two from 18R. Thirteen had blunder angles of 30 degrees, three had 10 degree blunder angles, and two had 20 degree angles.

The observed APIs ranged from 6 to 54 with an average of 36.75 (s.d. = 14.65), and the CPAs ranged from 1863 to 9590 ft with an average of 4662 ft (s.d. = 2409 ft). The results of this run indicated that controllers were able to adequately control the traffic under all of the conditions created.

4.6 CONTROLLER QUESTIONNAIRE DATA.

4.6.1 Controller Performance.

The first question in the questionnaire required controllers to rate their performance during the preceding run. The rating scale ranged from 1 (poor) to 10 (superior). Controllers rated their performance as good or superior in both the dual (X_2 = 8.4, s.d. = 1.2, n_2 = 24) and triple (X_3 = 8.3, s.d. = 1.3., n_3 = 81) approach conditions. An ANOVA performed on the data indicated no significant differences in the ratings attributable to either the approach condition or the runway assignment of the controller.

An ANOVA was performed to compare the ratings for the dual approach airports which differed, primarily, in terms of runway separation. Separation was greater for the west airport than for the east airport. Controllers rated their performance as better ($F(1,22) = 5.42$, MSE = 1.30, $p. < .05$) for the west airport (X_W = 8.91) than for the east airport (X_E = 7.83).

4.6.2 Activity Level.

Controllers were asked to rate the level of activity required for each run. The scale for this question ranged from 1 (minimal) to 10 (intense). The average rating for both the dual and triple approach conditions was 5.0, indicating a moderate level of workload throughout the study. However, there was a significant effect of runway assignment ($F(2,99) = 12.9$, MSE = 3.62, $p. < .05$). Controllers viewed their activity levels as higher when working runway 16L (X_{16} = 5.70) than when working either 17L (X_{17} = 4.90) or 18R (X_{18} = 4.51).

Ratings also differed between the east and west airports. Activity levels were viewed as much higher for the east airport (X_E = 6.17, s.d. = 1.11) than for the west airport (X_W = 3.92, s.d. = 1.62).

4.6.3 Stress Level.

Perceived level of stress was rated in the third question on a scale ranging from 1 (slight) to 10 (extreme). The average rating for both dual and triple approach conditions was 4.0, indicating a low to moderate level of perceived stress throughout the study. There were no differences attributable to runway assignment. Controllers perceived a higher level of stress ($F(1,22) = 11.14$, $MSE = 1.81$, $p. < .05$) when working the east airport ($X_E = 4.92$, s.d. = 1.31) than when working the west airport ($X_W = 3.08$, s.d. = 1.38).

4.6.4 <u>System Workability</u>.

The fourth question addressed the issue of system workability, using a scale ranging from 1 (strong yes) to 10 (strong no). Although an ANOVA indicated that the dual approach condition ($X_2 = 1.8$) was viewed as significantly more workable ($F(1,99) = 4.62$, $MSE = .67$, $p. < .05$) than the triple approach condition ($X_3 = 2.3$), both conditions were viewed as highly workable.

Workability ratings differed for the three runways ($F(2,99) = 3.86$, $MSE = .67$, $p. < .05$), with runway 18R ($X_{18} = 1.94$) viewed as more workable than 17L or 16L ($X_{17} = 2.22$ and $X_{16} = 2.27$, respectively). There was a significant interaction of approach condition and runway assignment ($F(2,99) = 5.39$, $MSE = .67$, $p. < .05$). In general, the 16L runway in the dual approach condition was seen as less workable ($X_{2,16} = 2.67$) than all of the other runway assignments.

Finally, an ANOVA performed for the dual approach airport data alone indicated that controllers viewed the west airport as more workable than the east airport ($F(1,22) = 21.56$, $MSE = .38$, $p.< .05$). The average ratings for the east and west airports were 2.33 and 1.17, respectively.

4.6.5 <u>Modified Cooper-Harper Scale Ratings</u>.

The Modified Cooper-Harper Scale was used to assess the mental workload of the controllers during the simulation runs. The rating scale ranged from 1 (very easy to perform with minimal mental effort) to 10 (impossible to perform). An ANOVA indicated no differences in mental workload for the dual and triple approach conditions, for which the average workload ratings were 2.3 and 2.4, respectively.

Mental workload was perceived as higher ($F(1,21) = 11.09$, $MSE = .60$, $p. < .05$) for the east airport dual approach condition ($X_E = 2.91$) than for the west airport ($X_W = 1.83$).

In summary, mental workload was rated as low in all of the conditions tested during the simulation.

4.7 CONTROLLER RESPONSE TIME.

With the addition of systematic video and audio taping in the Phase II simulation, it was possible to obtain direct measures of controller response time. Nevertheless, because the video and audio tape information is not linked directly with data in the computer files, the analysis of controller response time is a tedious, time consuming process. The results presented in this section represent data from the one run which has been analyzed. A number of relationships can be specified as a result of the analysis of controller response time, as follows.

a. The amount of time between the onset of a blunder and the controller's perception of the blunder, and the effect of degree of blunder on perception time.

b. The amount of time between the controller's verbal instruction and the related NSSF simulator pilot entry.

c. The amount of time between the controller's instruction and the first visible indication of an aircraft status change on the radar display.

Sixteen blunders were initiated in east airport dual approach run chosen for this analysis. There were seven 30 degree blunders, seven 20 degree blunders, and two 10 degree blunders. Although the sample size is small, the following results provide a preliminary indication of two of the three relationships denoted above.

The time between an aircraft's initiation of a blunder and controller response time was measured for all of the blunders. There appears to be an inverse relationship between degree of blunder and controller response time. The average response time to 10 degree blunders was 16 seconds (s.d. = 4.24 s, $n_{10} = 2$). For 20 degree blunders the average controller response time was 13.29 seconds (s.d. = 4.42 s, $n_{20} = 7$). Finally, the controller response time for 30 degree blunders averaged only 9.29 seconds (s.d. = 4.15 s, $n_{30} = 7$).

The time between a controller's instruction and a corresponding simulator pilot entry was also measured. To do this, controller instructions were divided into two types: 1) warning messages, which require only a single keystroke response by the simulator pilot, and 2) vector/altitude instructions, which require multiple keystroke responses by the simulator pilot. There were 47 warning messages and 32 vector/altitude instructions in the sample. The average time between controller instruction and simulator pilot response was 6.11 seconds (s.d. = 2.12 s) for warning messages and 10.66 seconds (s.d. = 4.8 s) for vector/altitude instructions.

Finally, the time between the controller's instruction and the first visible change in aircraft vector or altitude was measured.

This analysis paralleled the pilot response analysis just discussed. The average time between controller instruction and visible display change was 8.22 seconds (s.d. = 2.6 s, n = 9) for warning messages and 15.22 seconds (s.d. = 4.6 s, n = 23) for vector/altitude instructions.

5. DISCUSSION.

5.1 SUMMARY OF THE RESULTS.

The results of the Phase II simulation support the conclusion that triple simultaneous parallel ILS approaches can be conducted safely at the D/FW facility.

Although statistically significant differences were observed in a number of the computer data analyses, the degree of observed differences was generally small. The differences have few, if any, implications for the operations to be conducted at D/FW.

API values were generally low and none of the blunders resulted in a slant range of less than 1000 ft between two aircraft. Therefore, no special investigations were necessary in conjunction with the Operational Assessment Approach (see Section 2.1.2).

A significant difference was detected between dual and triple approach conditions in only one of the various analyses performed on the computer data. A difference in CPA values between approach conditions was detected in a second order (three way) interaction between blunder degree, communication condition, and approach conditions. This finding may be of limited significance since the CPA values were all within the prescribed limits of safe operation.

Additionally, none of the analyses favored dual over triple approaches. Overall, the worst performance in this study occurred in the east airport dual approach condition, for 20 degree blunders in which radio contact was not maintained with the controller.

The lack of radio communications by the blundering aircraft produced more severe conflicts than occurred when the blundering aircraft maintained radio communications, as indicated by the significant differences in API values and CPAs. Additionally there was a significant effect of blunder degree on conflict severity, as indicated by the CPAs. This difference was not detected in the API analysis. The 30 degree blunders produced the smallest CPAs followed by 20 degree and 10 degree blunders.

The results of the data analysis for blunders threatening one runway versus two runways indicated that blunders threatening one runway created more serious conflict situations as indicated by the larger average API values and the smaller average CPA values.

An analysis of 50 blunders indicated that there were no significant differences between the one and two runway threatened conditions with respect to the time interval between blunder initiation and altitude/vector change entry. There was, however, a difference between conditions in the commands issued to the threatened aircraft. When one runway was threatened, the controller issued a vector change to the threatened aircraft. When two runways were threatened, the controller for runway 17L, the runway adjacent to the blundering aircraft, would immediately issue an altitude change to the threatened aircraft. Normally, this was a command to climb. The controller for the outside runway, farthest from the blundering aircraft's approach, would issue a vector change to any threatened aircraft. Once the outside runway's aircraft had achieved safe separation from the middle runway's aircraft, the middle aircraft would be issued a vector change. This procedure was followed for almost all of the blunders which threatened two runways.

The procedural differences cited in the previous paragraph may explain the superior system performance in the two runways threatened condition. Because blundering aircraft always maintained a uniform descent following the blunder, altitude change instructions to nonblundering, threatened aircraft would cause more rapid changes in both CPA and API values than would vector changes. Vector changes were normally issued in the one runway threatened condition, the API was higher in that condition than in the two runway's threatened condition, in which altitude change instructions rapidly decreased the API value. Likewise the CPA would increase in the two runways threatened condition faster than it would in the situation in which only one runway was threatened.

The analysis of comparable events in the dual and triple approach conditions indicated no significant differences between approach conditions. Differences were found in API and CPA values between blunder degree conditions. For the east airport comparable events analysis, the API analysis showed no significant effects, but the CPA analysis indicated that the 30 degree blunder condition was worst followed by 20 and 10 degree blunder conditions. For the analogous west airport comparison, the API analysis indicated that 10 degree blunders resulted in the largest average API. The 30 degree blunders resulted in a slightly smaller average API, and the 20 degree blunders resulted in the smallest average API. The CPA analysis differed in that 30 degree blunders had the smallest CPA followed closely by 10 degree blunders, and 20 degree blunders respectively.

The results of the dual approach airport comparisons indicated that runway separation did impact the safety measures in the predicted direction. In general, there were more NTZ entries, higher API values, and smaller CPA values for the east airport (runway separation = 5000 ft) than for the west airport (runway separation = 8800 ft).

The questionnaires indicated that controllers discriminated somewhat among the conditions employed in this study. The controllers, overall, found all of the conditions to be highly workable. The mental workload was considered to be low, and the activity and stress levels moderate and low, respectively. Controller self-ratings of performance were good to superior throughout the simulation.

Finally, the controller response time measures provided valuable insight concerning both controller and system performance. There was an inverse relationship between controller response time and degree of blunder. Additionally, the type of command issued had an effect on both simulator pilot response times and safety measures. Longer, more complicated, vector changes produced longer delays in simulator operator entry. Secondly, response time measurement analysis revealed that smaller APIs and larger CPAs could be produced by initially issuing an increase in altitude to nonblundering aircraft before issuing a vector change.

5.2 NAVIGATIONAL ERROR MODEL PERFORMANCE.

The navigational error model used at the end of the Phase II simulation appeared reasonable to the controllers and was consistent with the Chicago data [11]. However, further refinements of the model are likely to be made for the Phase III simulation.

5.3 CRITIQUE OF THE SIMULATION.

This section describes issues noted by researchers, observers, and controllers during the Phase II simulation. Section 7.1, suggests improvements in the simulation models and the procedures for possible implementation in Phase III of the D/FW series.

5.3.1 Limitations of the Simulation.

5.3.1.1 Navigational Error Model.

The navigational error model underwent 2 changes during the course of the simulation. The final model, in place for the last eight runs of Phase II, was accepted by controllers as realistic. However, there is still need for further refinements to the model in light of the Chicago data [12].

5.3.1.2 Aircraft Turn Rates.

The maximum aircraft turn rate of 6 degrees per second was available for most of the runs in Phase II and was viewed as unrealistic. In response to comments from the industry observers, the final nine runs of the simulation employed only the 3 degrees per second turn rate to provide a more realistic depiction of aircraft performance.

5.3.1.3 Speed Overtakes.

There were no longitudinal conflicts created by speed overtakes in the Phase II simulation except in the ad hoc run. Controllers commented that one of their most frequent activities is the handling of aircraft speed adjustments, and that speed overtakes should be included in the simulation.

5.3.1.4 Blunders.

Industry observers felt that the number of blunders that occurred within 2 nmi of the threshold was insufficient. They also noted that the continuing descent of blundering aircraft toward the threshold was not realistic. Controllers and some observers commented that the frequency of blunders (i.e., approximately every 3 minutes) was too high and, that blunders were, thus, too predictable.

5.3.2 Procedural Issues.

5.3.2.1 Simulation Run Schedule.

Controllers, because of equipment failures and other contingencies, were occasionally required to serve in more than three simulation runs in one day. Fatigue, therefore, was a concern expressed in simulation reports.

5.3.2.2 Practice Effects.

Practice effects were observed in simulator pilot performance. Most of the NSSF simulator pilot errors occurred in the early runs. In addition, measures such as the number of pilot messages showed decreases after the first few runs. Because acclimation does occur for both controllers and NSSF simulator pilots, predetermined practice runs should be incorporated into each simulation.

5.3.2.3 Measurement of 'ontroller Response Time.

Accurate and efficient measurement of controller response time is important for the understanding of both controller and system performance. Response time data should be "collected" in the same manner as the other computer data. This would also ensure data accuracy.

6. CONCLUSIONS.

The Phase II Dallas/Fort Worth (D/FW) simulation investigated the potential of triple simultaneous Instrument Landing System (ILS) approaches. Analysis of the Aircraft Proximity Index (API) and Closest Point of Approach (CPA) metrics indicated that triple simultaneous ILS approaches resulted in miss distances statistically equivalent to those which occurred in the dual simultaneous parallel ILS approaches for the given D/FW configuration.

No blunder in either the dual or triple configuration resulted in a slant range miss distance of 1000 ft or less.

Finally, controllers, controller observers, and Air Traffic Control (ATC) management observers concluded that the triple simultaneous ILS approach operation at D/FW is acceptable, achievable, and safe.

7. RECOMMENDATIONS.

7.1 RECOMMENDATIONS FOR THE PHASE III SIMULATION.

The Dallas Fort Worth (D/FW) Phase III simulation, to be conducted in the near future, will investigate quadruple simultaneous Instrument Landing System (ILS) approaches at the D/FW Airport. The methodology for Phase III will be similar to that of Phase II. Given the comments of the participants in the Phase II simulation, presented in Section 5.3, the following are recommendations with regard to Phase III and future simulations.

7.1.1 Proposed Changes in the Simulation.

7.1.1.1 Navigational Error Model.

While controllers viewed the navigational error model in place at the end of Phase II as realistic, there should be a continuing effort to improve the navigational error model so that a complete and accurate representation of flight technical error (FTE) will be achieved for the critical simulations to be conducted in Phases IV and V of the National Airport Capacity Enhancement Program. A number of enhancements have been proposed and should be further investigated for the Phase III simulation.

7.1.1.2 Aircraft Turn Rate.

Industry observers recommended that data from missed approach simulation studies conducted at the FAA in Oklahoma City, as well as data collected at the Chicago O'Hare facility, be used to assess the aircraft turn rate model before the Phase III simulation.

7.1.1.3 Speed Overtakes.

Since the maintenance of longitudinal spacing is an integral part of the monitor controller's work, it is recommended that some speed overtakes (i.e., one or two per run) be included in the Phase III simulation.

7.1.1.4 Blunders.

Because of suggestions by industry observers and other participants during the Phase II simulation, a number of recommendations are made with regard to the blunder scenarios for Phase III. More traffic samples and blunder scenarios should be developed, so that controllers will be less able to predict blundering aircraft.

7.1.1.5 Altitude Maintenance of Blundering Aircraft.

To achieve a more accurate representation of blundering aircraft performance in the simulation, it is recommended that blundering aircraft not uniformly descend toward the runway following the blunder. In actuality, aircraft would be more likely to maintain altitude after such an event. Therefore, it is further recommended that some blundering aircraft maintain altitude and others descend, to attain a more realistic representation.

7.1.1.6 Proximity of Blundering Aircraft to Threshold.

Finally, it is not infeasible that aircraft might blunder within 2 nautical miles (nmi) of the threshold. Therefore, it is recommended that one or two of the aircraft in each Phase III run initiate blunders within 2 nmi of the threshold.

7.1.2 Procedural Changes for Phase III.

7.1.2.1 Simulation Schedule.

It is recommended that controllers not be asked to serve in more than two consecutive runs or more than three runs per day. Otherwise, fatigue may become a relevant performance factor.

It is recommended that practice runs, which are not subject to formal analysis, be incorporated in the Phase III simulation for the benefit of both controllers and simulator pilots.

7.1.2.2 Controller Performance Measures.

The controller response time measure is a valuable one. It is, therefore, recommended that a means be found by which to measure response time "on-line" in upcoming simulations. In particular, the potential gains of new technologies such as high update radar and blunder alerting systems may be subject to the perceptual limitations of the controller. The measurement of controller response time is one means to assess the controller benefits derived from these new technologies.

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APPENDIX A

AIRCRAFT PROXIMITY INDEX (API)

THE EVALUATION OF CONFLICTS IN AIR TRAFFIC CONTROL SIMULATIONS

Lee E. Paul, ACD-340

BACKGROUND

Air Traffic Control (ATC) Simulation is an essential research tool for the improvement of the National Airspace System (NAS). Simulation can never offer all of the complexity and subtlety of the real world, with live radar, actual aircraft, full communications systems and the rest of the ATC environment, but it can provide an intensive exercise of key portions of the system -- with controllers in the loop.

Proper use of simulation starts with carefully defining the questions to be answered and then developing a simulation environment which includes the features that could influence the process under study. The selection of a simulation environment, the development of scenarios, the choice of data to be recorded, and the method of analysis are part science, part art.

An important benefit of simulation is that it permits the exploration of systems, equipment failures, and human errors that would be too dangerous to study with aircraft, or that occur so rarely in the system that they cannot be fully understood and evaluated. A current example of this use has to do with the introduction of blunders[1] in parallel runway instrument approaches.

The introduction of large numbers of system errors is a useful way to study safety, but the analysis of the outcomes of these incidents is not always simple or clear cut.

SAFETY EVALUATION

1. CONFLICTS

The occurrence of a conflict in normal ATC operations is considered prima facie evidence of a human or system error. Identifying (and counting) conflicts under a variety of conditions is one way to expose a system problem.

> A conflict is defined as the absence of safe separation between two aircraft flying IFR. At its simplest, safe separation requires: (a) The aircraft must be laterally separated by 3 nm or 5 nm, depending

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1. A blunder is defined as an unexpected turn towards an adjacent approach by an aircraft already established on the ILS.

on distance from the radar, (b) vertical separation by 1,000 or 2,000 feet, depending on altitude or flight level, OR (c) that both aircraft are established on ILS localizers.

There are refinements of the above rules that take into consideration the fact that one aircraft may be crossing behind another, or that an aircraft has begun to climb or descend from a previous altitude clearance. There are special "wakes and vortices" restrictions for aircraft in trail behind heavy aircraft.

Since actual conflicts are rare, every event leading up to them and all the information available on the onset and resolution is carefully analyzed. The emphasis is on the intensive investigation of the particular event.

In scientific investigation, the intensive study of a single individual or a particular event is called the **idiographic** approach. This is often contrasted with the **nomothetic** approach: the study of a phenomenon or class of events by looking at large numbers of examples and attempting to draw general conclusions through the application of statistics.

The idiographic approach is mandatory for accident or incident investigation where the goal is to get as much information as possible about an unique event in order to prevent future occurrences.

In a simulation experiment, where the goal is to make a comparison between two or more systems (2 vs 3 or 4 runways, 4300 vs 3000 foot runway spacing, etc.) **and to generalize beyond the simulation environment**, the nomothetic approach is most appropriate. This means generating a large numbers of events and statistically analyzing the outcomes with respect to the system differences.

There is much to be gained by studying the individual conflicts in a simulation as an aid to understanding the kinds of problems that occur and to generate hypotheses about how a system might be improved for subsequent testing. But the evaluation of the systems under test requires the use of all of the valid data, analyzed in as objective a manner as possible. Valid data in this context means that it was collected under the plan and rules of the simulation and was not an artifact, such as a malfunction of the simulation computer or distraction by visitors.

2. SLANT RANGE

If it is important to go beyond the counting of conflicts, measurement of the distance between the conflicting aircraft pair is required. The most obvious measure is slant range separation: the length of an imaginary line stretched between the centers of each aircraft. Over the course of the incident that distance will vary, but the shortest distance observed is one indication of the seriousness or danger of the conflict.

The problem with slant range is that it ignores the basic definition of a conflict and is insensitive to the different standards that are set for horizontal and vertical separation. A slant range distance of 1100 feet might refer to a 1000 feet of vertical separation, which is normally perfectly safe, to less than 0.2 nm of horizontal miss distance, which would be considered by most people to be a very serious conflict.

Slant range, per se, is too ambiguous a metric to have any real analytical value.

3. AIRCRAFT PROXIMITY INDEX (API)

The need exists for a single value that reflects the relative seriousness or danger. The emphasis here is on 'relative', since with the nomothetic or statistical approach, an absolute judgment of dangerous or safe is useful, but not sensitive enough. The requirement is to look at the patterns of the data for the different experimental conditions and determine whether one pattern indicates more, less, or the same degree of safety as another.

Such an index should have to have certain properties.

- It should consider horizontal and vertical distances separately, since the ATC system gives 18 times the importance to vertical separation (1,000 ft. vs 3 nm.)

- It should increase in value as danger increases, and go to zero when there is no risk, since the danger in the safe system is essentially indeterminate.

- It should have a maximum value for the worst case (collision), so that users of the index can grasp its significance without tables or additional calculations.

- It should make the horizontal and vertical risk or danger independent factors, so that if either is zero, i.e., safe, their product will be zero.

- It should be a non-linear function, giving additional weight to serious violations, since they are of more concern than a number of minor infractions.

The Aircraft Proximity Index (API) is designed to meet these criteria. It assigns a weight or value to each conflict, depending on vertical and lateral separation. API facilitates the identification of the more serious (potentially dangerous) conflictions in a data base where many conflictions are present. 100 has been chosen, somewhat arbitrarily, for the maximum value of the API.

APPROACH

During a simulation API can be computed whenever a conflict exists. For convenience, this is taken to be when two aircraft have less than 1,000 feet of vertical separation AND less than 3.0 miles of lateral separation. It is computed once per second during the conflict. The API of the conflict is the largest value obtained.

API considers vertical and horizontal distances separately, then combines the two in a manner than gives them equal weight; equal in the sense that a loss of half the required 3.0 NM horizontal separation has the same effect as the loss of half the required 1000 feet of vertical separation.

COMPUTATION

The API ranges from 100 for a mid-air collision to 0 for the virtual absence of a technical confliction. A linear decrease in distance between the aircraft, either vertically or laterally, increases the API by the power of 2.

Computation is as follows:

D_V = vertical distance between a/c (in feet)

D_H = horizontal distance (Naut. Miles (6,076'))

$$API = (1{,}000-D_V)^2 * (3-D_H)^2 / (90{,}000)$$

To simplify its use, API is rounded off to the nearest integer, i.e.,

$$API = INT((1{,}000-D_V)^2 * (3-D_H)^2 / (90{,}000) + .5)$$

The rounding process zeros API's less than 0.5. This includes distances closer than 2 nm AND 800 feet. The contour plot in Figure 1, page 7, demonstrates the cutoff for API = 1.

See Tables 1 and 2 on page 6 for typical values of API at a variety of distances.

Figure 2, page 8, is a 3-dimensional plot showing the relationship between API and vertical and horizontal separation graphically. Figure 3, page 9, shows the same information in a slightly different way. Anything outside the contour at the base is '0'. In figure 4, page 10, a contour plot of API for horizontal and vertical distances from 0 to 500 feet is shown, with 300-foot and 500-foot slant range distances superimposed.

DISCUSSION

The index is not intended as a measure of acceptable risk, but it meets the need to look at aircraft safety in a more comprehensive way than simply counting conflictions or counting the number of aircraft that came closer than 200 feet, or some other arbitrary value.

It should be used to compare conflicts in similar environments. I.e., an API of 70 in enroute airspace with speeds of 600 kts is not necessarily the same concern as a 70 in highly structured terminal airspace with speeds under 250 kts.

Since the API is computed every second, it may be useful to examine its dynamics over time as a means of understanding the control process.

TABLE 1. TYPICAL VALUES:

VERTICAL DISTANCE (D_V)	HORIZONTAL DISTANCE IN NAUTICAL MILES (1 NM = 6076')(D_H) IN FEET 3	2.5	2.0	1.5	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	.05	.01	-0-
1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
900	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
800	0	0	0	1	2	2	2	2	3	3	3	3	3	4	4	4	4
700	0	0	1	2	4	4	5	5	6	6	7	7	8	8	9	9	9
600	0	0	2	4	7	8	9	9	10	11	12	13	14	15	15	16	16
500	0	1	3	6	11	12	13	15	16	17	19	20	22	23	24	25	25
400	0	1	4	9	16	18	19	21	23	25	27	29	31	34	35	36	36
300	0	1	5	12	22	24	26	29	31	34	37	40	43	46	47	49	49
200	0	2	7	16	28	31	34	38	41	44	48	52	56	60	62	64	64
100	0	2	9	20	36	40	44	48	52	56	61	66	71	76	78	80	81
-0-	0	3	11	25	44	49	54	59	64	69	75	81	87	93	97	99	100

TABLE 2., ADDITIONAL VALUES

D_H	D_V	API	D_H	D_V	API	D_H	D_V	API
3.0	1000	0	1.0	667	5	.05	667	11
3.0	0	0	1.0	500	11	.05	500	24
0	1000	0	1.0	333	20	.05	333	43
2.0	667	1	1.0	250	25	.05	250	54
2.0	500	3	1.0	100	36	.05	100	78
2.0	333	5	1.0	0	44	.05	0	97
2.0	250	6	.5	667	8	.01	667	11
2.0	100	9	.5	500	17	.01	500	25
2.0	0	11	.5	250	39	.01	333	44
1.5	667	3	.5	100	56	.01	250	56
1.5	500	6	.5	0	69	.01	100	80
1.5	333	11	.1	667	10	.01	0	99
1.5	250	14	.1	500	23	0	667	11
1.5	100	20	.1	250	53	0	500	25
1.5	0	25	.1	100	76	0	333	44
			.1	0	93	0	250	56
						0	100	81
						0	0	100

A/C PROXIMITY INDEX (API)

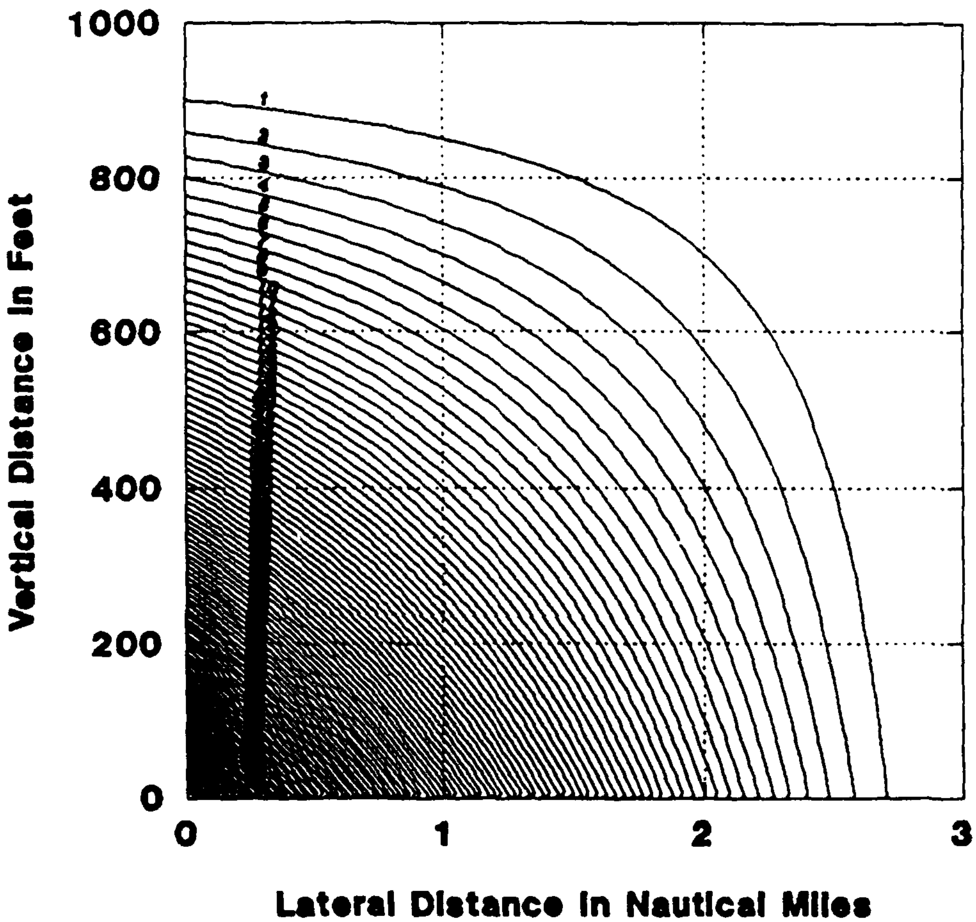


Figure 1. CONTOUR PLOT

This is a contour plot of API, showing the values of API for the horizontal separations of 0 to 3 nm, and vertical separation of 0 to 1,000 feet. Values less than API = .5 round to zero. This includes a/c separated by as little 1.6 nm horizontally AND 850 feet vertically.

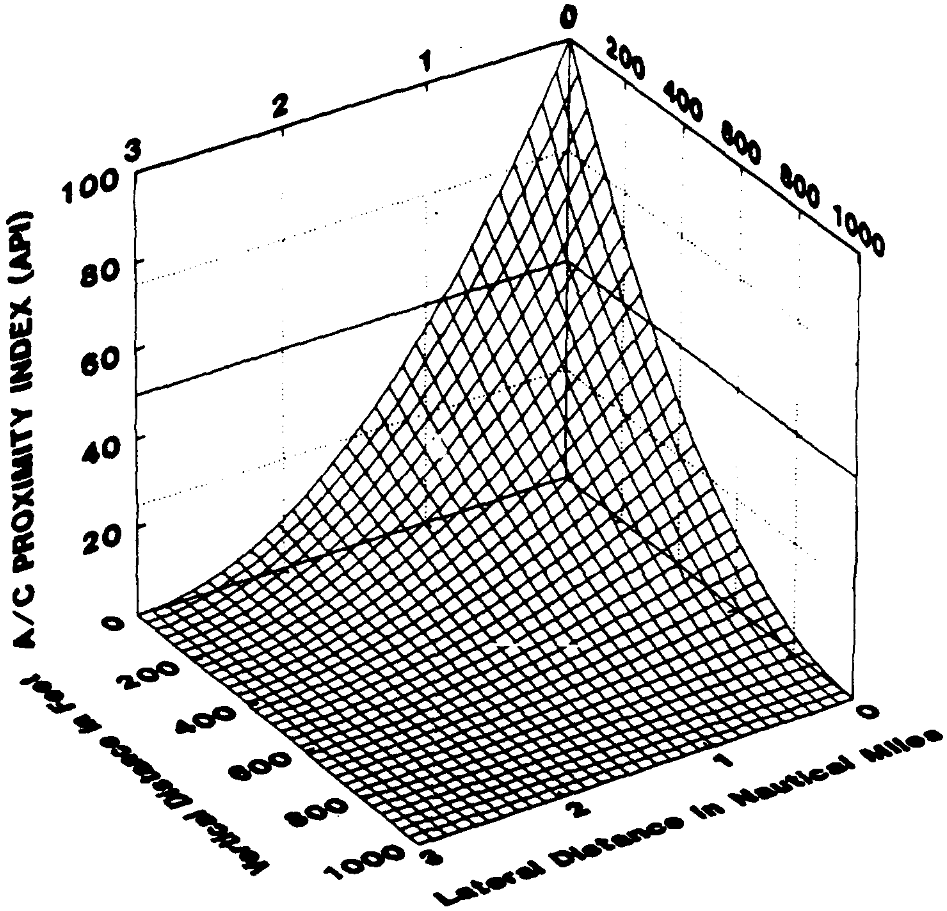


Figure 2. 3-DIMENSIONAL CONTOUR PLOT

3-dimensional contour plot of API, for horizontal separations of 0 to 3 nm, and vertical separations of 0 to 1,000 feet.

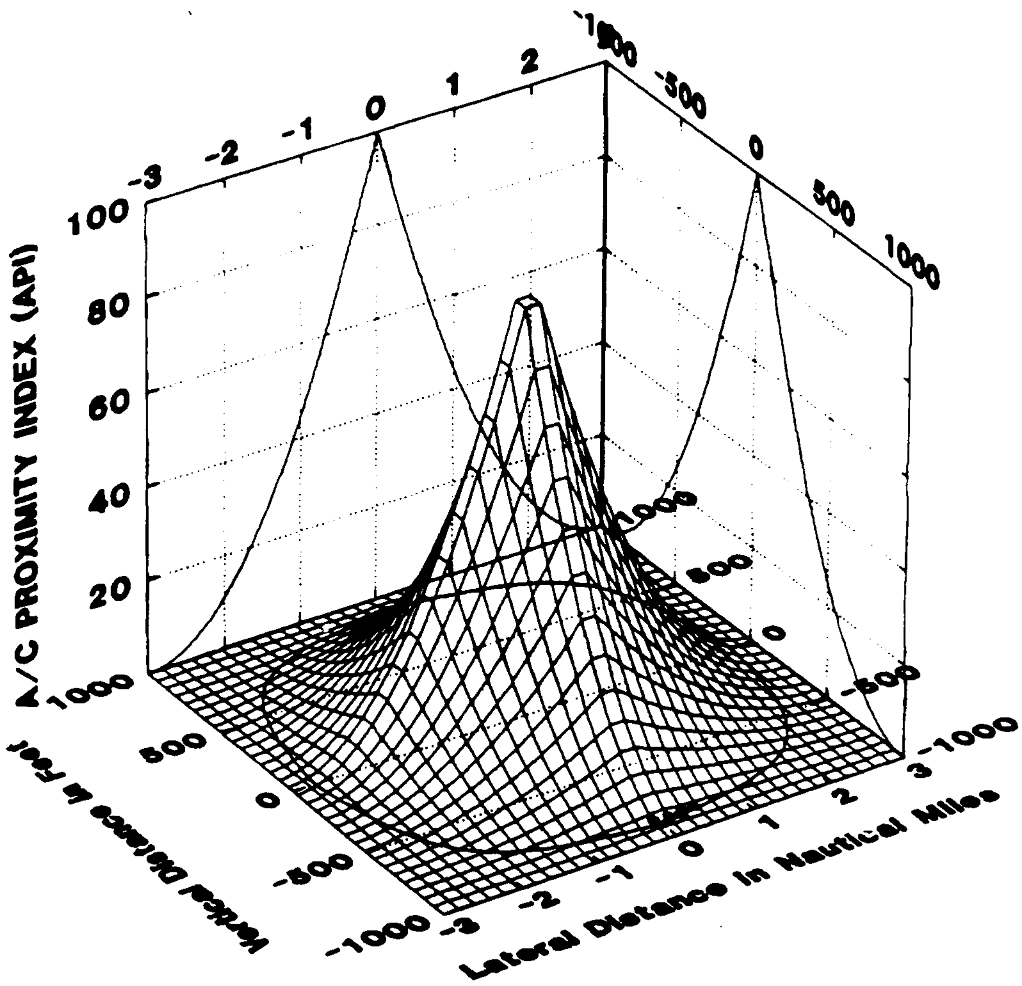


Figure 3. 3-DIMENSIONAL CONTOUR PLOT

Left vertical plane shows API vs horizontal distance with vertical distance=0. Right vertical plane shows API vs vertical separation with horizontal distance = 0.

Plot may be interpreted by considering one a/c at the center of the base plane, while the height of the figure shows the API for another a/c anywhere else on the base plane.

The contour on the base plane shows the boundary between API =0 and API=1.

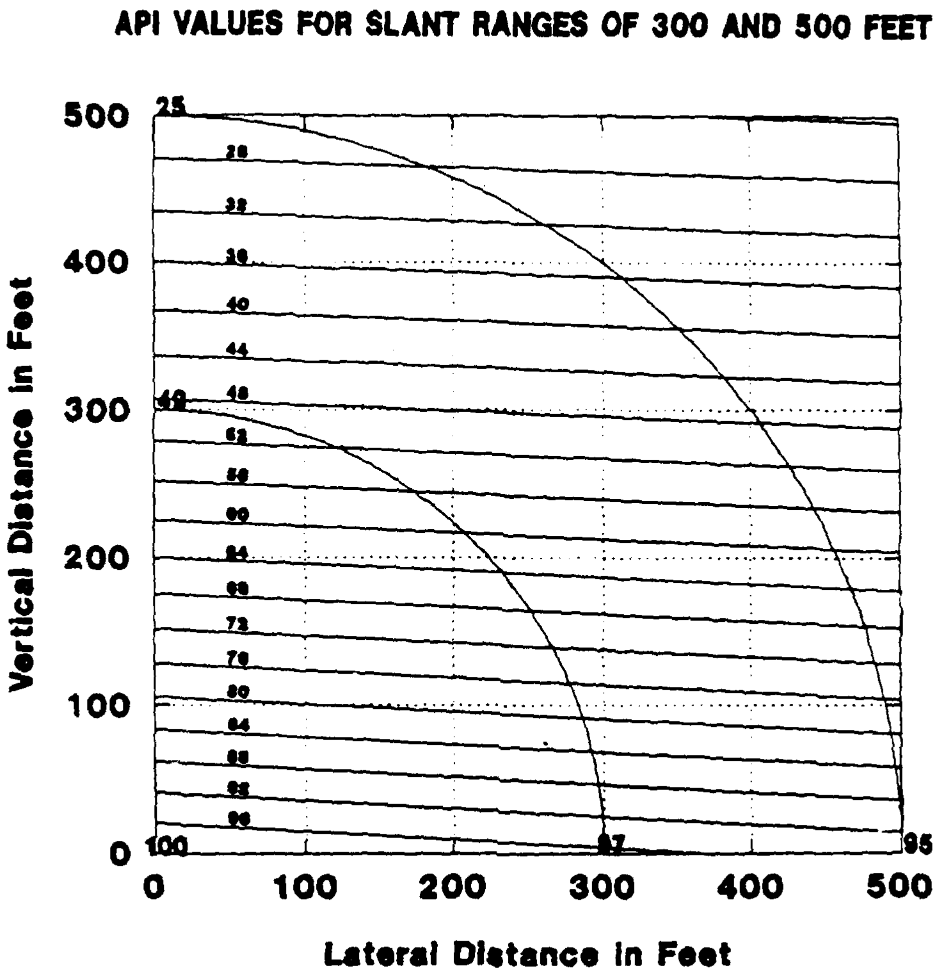


Figure 4. CONTOUR PLOT OF API FOR HORIZONTAL AND VERTICAL DISTANCES OF 0 TO 500 FEET, SHOWING SLANT RANGE CONTOURS OF 300 AND 500 FEET

This plot shows the API values (the small numbers, inside the square running from 25 at the top to 100 at the bottom) for equal API contours (the slightly sloping horizontal lines) for horizontal and vertical distances of 0 to 500 feet. API values range from 25 (500' vertical, 0 horizontal separation) to 100 (0/0).

The 500-foot slant range contour has API values ranging from 25 to 95, depending on amount of vertical component. The 300-foot slant range contour runs from API = 49 to 97. Using API as a criterion, 500-foot slant range can be more dangerous than 300-foot.

APPENDIX B

BLUNDER SCENARIOS USED FOR THE D/FW PHASE II SIMULATION

DFW TRIPS SCENARIO

DFW TRIP 1 START:00:02:00

TIME	RW	A/C#	LR	AMT	COMM	INTERVAL
00:05:03	17L	2nd	L	30deg	YES	00:03:03
00:08:26	17L	2nd	L	10deg	YES	00:03:23
00:10:29	16L	1st	R	20deg	NO	00:02:03
00:13:30	17L	2nd	L	10deg	YES	00:03:01
00:19:23	18R	2nd	L	30deg	YES	00:05:53
00:24:12	16L	1st	R	20deg	YES	00:04:49
00:28:37	17L	3rd	L	10deg	NO	00:04:25
00:30:43	17L	1st	R	30deg	NO	00:02:06
00:32:04	16L	3rd	R	10deg	YES	00:01:21
00:35:31	17L	1st	L	20deg	YES	00:03:27
00:39:48	16L	3rd	R	30deg	YES	00:04:17
00:43:35	18R	1st	L	20deg	YES	00:03:47
00:47:16	17L	3rd	R	30deg	YES	00:03:41
00:53:05	16L	1st	R	20deg	NO	00:05:49
00:54:32	18R	2nd	L	30deg	YES	00:01:27
01:00:21						00:05:49
01:02:35						00:02:14
01:03:58						00:01:23
01:07:05						00:03:07
01:09:32						00:02:27

FREQUENCY DISTRIBUTION OF BLUNDER PARAMETERS
BLUNDERS BEFORE 00:58:00

RUNWAY	#	SEQ	#	DIR	#	COMM	#	AMOUNT	#
16L	5	1ST	6	L	8	NO	4	10deg	4
17L	7	2ND	5	R	7	YES	11	20deg	5
18R	3	3RD	4					30deg	6

DFW TRIPS SCENARIO

DFW TRIP 2 START:00:02:00

TIME	RW	A/C#	LR	AMT	COMM	INTERVAL
00:05:12	18R	1st	L	20deg	NO	00:03:12
00:08:28	17L	2nd	L	30deg	YES	00:03:16
00:09:54	16L	1st	R	10deg	NO	00:01:26
00:11:05	18R	1st	L	30deg	YES	00:01:11
00:13:14	17L	3rd	R	10deg	NO	00:02:09
00:17:52	16L	3rd	R	20deg	NO	00:04:38
00:22:32	16L	3rd	R	20deg	NO	00:04:40
00:28:10	17L	1st	L	30deg	NO	00:05:38
00:32:35	16L	2nd	R	10deg	NO	00:04:25
00:35:14	16L	2nd	R	30deg	NO	00:02:39
00:38:42	16L	1st	R	20deg	YES	00:03:28
00:44:17	18R	2nd	L	30deg	NO	00:05:35
00:47:27	18R	2nd	L	30deg	NO	00:03:10
00:53:18	16L	3rd	R	30deg	NO	00:05:51
00:57:42	18R	2nd	L	30deg	NO	00:04:24
01:01:14						00:03:32
01:03:59						00:02:45
01:08:54						00:04:55
01:13:44						00:04:50
01:17:37						00:03:53

FREQUENCY DISTRIBUTION OF BLUNDER PARAMETERS
BLUNDERS BEFORE 00:58:00

RUNWAY	#	SEQ	#	DIR	#	COMM	#	AMOUNT	#
16L	7	1ST	5	L	7	NO	12	10deg	3
17L	3	2ND	6	R	8	YES	3	20deg	4
18R	5	3RD	4					30deg	8

DFW TRIPS SCENARIO

DFW TRIP 3 START:00:02:00

TIME	RW	A/C#	LR	AMT	COMM	INTERVAL
00:05:12	18R	2nd	L	30deg	NO	00:03:12
00:06:23	17L	3rd	R	20deg	YES	00:01:11
00:07:39	17L	2nd	R	30deg	YES	00:01:16
00:11:29	18R	1st	L	20deg	NO	00:03:50
00:14:21	18R	2nd	L	20deg	YES	00:02:52
00:18:08	17L	3rd	R	10deg	YES	00:03:47
00:20:14	17L	1st	R	30deg	YES	00:02:06
00:22:26	18R	3rd	L	10deg	YES	00:02:12
00:24:55	18R	2nd	L	20deg	YES	00:02:29
00:29:01	16L	1st	R	20deg	YES	00:04:06
00:30:29	18R	1st	L	30deg	YES	00:01:28
00:32:35	17L	3rd	R	20deg	YES	00:02:06
00:34:42	18R	1st	L	10deg	YES	00:02:07
00:36:10	16L	3rd	R	10deg	NO	00:01:28
00:38:50	18R	3rd	L	30deg	YES	00:02:40
00:42:13	17L	1st	L	20deg	NO	00:03:23
00:43:15	18R	2nd	L	20deg	NO	00:01:02
00:45:23	18R	3rd	L	20deg	YES	00:02:08
00:47:31	18R	1st	L	30deg	NO	00:02:08
00:48:33	16L	1st	R	20deg	YES	00:01:02

FREQUENCY DISTRIBUTION OF BLUNDER PARAMETERS
BLUNDERS BEFORE 00:58:00

RUNWAY	#	SEQ	#	DIR	#	COMM	#	AMOUNT	#
16L	3	1ST	8	L	12	NO	6	10deg	4
17L	6	2ND	5	R	8	YES	14	20deg	10
18R	11	3RD	7					30deg	6

DFW TRIPS SCENARIO

DFW TRIP 4 START:00:02:00

TIME	RW	A/C#	LR	AMT	COMM	INTERVAL
00:05:37	17L	3rd	R	20deg	YES	00:03:37
00:09:32	18R	2nd	L	30deg	YES	00:03:55
00:12:55	16L	3rd	R	30deg	NO	00:03:23
00:16:23	17L	3rd	L	20deg	NO	00:03:28
00:20:22	18R	2nd	L	10deg	NO	00:03:59
00:25:53	17L	1st	L	20deg	YES	00:05:31
00:29:04	18R	3rd	L	10deg	YES	00:03:11
00:33:48	18R	3rd	L	30deg	YES	00:04:44
00:39:34	16L	1st	R	10deg	YES	00:05:46
00:42:38	17L	3rd	L	30deg	NO	00:03:04
00:48:35	16L	1st	R	30deg	YES	00:05:57
00:51:15	16L	2nd	R	30deg	YES	00:02:40
00:52:18	18R	3rd	L	10deg	YES	00:01:03
00:55:02	18R	2nd	L	10deg	NO	00:02:44
00:58:16						00:03:14
01:00:42						00:02:26
01:06:41						00:05:59
01:09:15						00:02:34
01:10:35						00:01:20
01:13:27						00:02:52

FREQUENCY DISTRIBUTION OF BLUNDER PARAMETERS
BLUNDERS BEFORE 00:58:00

RUNWAY	#	SEQ	#	DIR	#	COMM	#	AMOUNT	#
16L	8	1ST	6	L	4	NO	8	10deg	3
17L	7	2ND	3	R	13	YES	9	20deg	3
18R	2	3RD	8					30deg	11

DFW TRIPS SCENARIO

DFW TRIP 5 START:00:02:00

TIME	RW	A/C#	LR	AMT	COMM	INTERVAL
00:03:08	18R	1st	L	20deg	NO	00:01:08
00:05:45	16L	3rd	R	20deg	NO	00:02:37
00:11:27	16L	2nd	R	10deg	NO	00:05:42
00:16:20	18R	2nd	L	30deg	NO	00:04:53
00:19:38	18R	1st	L	20deg	NO	00:03:18
00:23:34	17L	1st	R	30deg	YES	00:03:56
00:25:02	18R	2nd	L	20deg	NO	00:01:28
00:30:33	17L	2nd	L	30deg	YES	00:05:31
00:35:04	16L	2nd	R	10deg	NO	00:04:31
00:38:50	16L	3rd	R	10deg	YES	00:03:46
00:43:46	17L	1st	L	30deg	YES	00:04:56
00:45:14	17L	1st	R	30deg	NO	00:01:28
00:49:05	18R	2nd	L	20deg	NO	00:03:51
00:51:31	16L	3rd	R	30deg	NO	00:02:26
00:57:06	16L	3rd	R	10deg	NO	00:05:35
						00:04:21
						00:04:33
						00:01:10
						00:04:04

FREQUENCY DISTRIBUTION OF BLUNDER PARAMETERS
BLUNDERS BEFORE 00:58:00

RUNWAY	#	SEQ	#	DIR	#	COMM	#	AMOUNT	#
16L	8	1ST	6	L	7	NO	12	10deg	4
17L	4	2ND	6	R	10	YES	5	20deg	5
18R	5	3RD	5					30deg	8

DFW TRIPS SCENARIO

DFW TRIP 6 START:00:02:00

TIME	RW	A/C#	LR	AMT	COMM	INTERVAL
00:05:06	17L	2nd	L	30deg	NO	00:03:06
00:09:47	17L	2nd	L	30deg	NO	00:04:41
00:14:40	17L	2nd	L	30deg	NO	00:04:53
00:17:58	18R	3rd	L	20deg	YES	00:03:18
00:20:28	16L	1st	R	30deg	NO	00:02:30
00:22:39	18R	3rd	L	30deg	NO	00:02:11
00:27:19	16L	2nd	R	20deg	YES	00:04:40
00:31:19	16L	2nd	R	30deg	YES	00:04:00
00:34:08	18R	2nd	L	30deg	NO	00:02:49
00:37:41	18R	2nd	L	10deg	NO	00:03:33
00:40:39	18R	2nd	L	30deg	NO	00:02:58
00:43:14	17L	1st	R	20deg	NO	00:02:35
00:45:38	16L	3rd	R	10deg	YES	00:02:24
00:51:27	17L	3rd	L	30deg	NO	00:05:49
00:54:10	17L	1st	R	20deg	YES	00:02:43
00:56:23	16L	2nd	R	20deg	YES	00:02:13
00:58:47						00:02:24
01:02:54						00:04:07
01:05:15						00:02:21
01:09:21						00:04:06

FREQUENCY DISTRIBUTION OF BLUNDER PARAMETERS
BLUNDERS BEFORE 00:58:00

RUNWAY	#	SEQ	#	DIR	#	COMM	#	AMOUNT	#
16L	5	1ST	3	L	9	NO	10	10deg	2
17L	6	2ND	9	R	7	YES	6	20deg	5
18R	5	3RD	4					30deg	9

DFW TRIPS SCENARIO

DFW TRIP 7 START:00:02:00

TIME	RW	A/C#	LR	AMT	COMM	INTERVAL
00:05:38	17L	1st	R	20deg	YES	00:03:38
00:11:13	17L	2nd	L	10deg	YES	00:05:35
00:12:26	18R	1st	L	20deg	YES	00:01:13
00:17:09	18R	3rd	L	30deg	YES	00:04:43
00:18:20	18R	1st	L	20deg	NO	00:01:11
00:24:03	16L	3rd	R	10deg	NO	00:05:43
00:29:39	17L	3rd	L	10deg	NO	00:05:36
00:35:32	17L	1st	L	30deg	NO	00:05:53
00:39:56	17L	3rd	L	30deg	NO	00:04:24
00:44:14	18R	1st	L	30deg	NO	00:04:18
00:49:07	18R	2nd	L	10deg	YES	00:04:53
00:52:38	17L	2nd	R	20deg	YES	00:03:31
00:56:03	17L	1st	L	10deg	NO	00:03:25
00:58:40						00:02:37
01:04:29						00:05:49
01:09:07						00:04:38
01:12:48						00:03:41
01:16:01						00:03:13
01:20:12						00:04:11
01:22:13						00:02:01

FREQUENCY DISTRIBUTION OF BLUNDER PARAMETERS
BLUNDERS BEFORE 00:58:00

RUNWAY	#	SEQ	#	DIR	#	COMM	#	AMOUNT	#
16L	1	1ST	6	L	10	NO	7	10deg	5
17L	7	2ND	3	R	3	YES	6	20deg	4
18R	5	3RD	4					30deg	4

DFW TRIPS SCENARIO

DFW TRIP 8 START:00:02:00

TIME	RW	A/C#	LR	AMT	COMM	INTERVAL
00:03:13	16L	1st	R	20deg	YES	00:01:13
00:05:49	18R	2nd	L	10deg	YES	00:02:36
00:11:35	18R	2nd	L	20deg	NO	00:05:46
00:16:24	17L	2nd	L	10deg	NO	00:04:49
00:19:25	17L	3rd	L	20deg	YES	00:03:01
00:22:44	16L	3rd	R	20deg	YES	00:03:19
00:26:50	16L	3rd	R	20deg	YES	00:04:06
00:30:15	18R	2nd	L	20deg	YES	00:03:25
00:32:25	17L	1st	R	20deg	NO	00:02:10
00:35:06	18R	3rd	L	20deg	NO	00:02:41
00:39:13	17L	2nd	L	20deg	NO	00:04:07
00:44:02	18R	3rd	L	30deg	NO	00:04:49
00:47:52	18R	1st	L	10deg	YES	00:03:50
00:52:46	17L	1st	L	10deg	YES	00:04:54
00:55:12	17L	1st	R	20deg	NO	00:02:26
00:58:36						00:03:24
01:02:11						00:03:35
01:07:48						00:05:37
01:11:57						00:04:09
01:16:08						00:04:11

FREQUENCY DISTRIBUTION OF BLUNDER PARAMETERS
BLUNDERS BEFORE 00:58:00

RUNWAY	#	SEQ	#	DIR	#	COMM	#	AMOUNT	#
16L	3	1ST	5	L	10	NO	7	10deg	4
17L	6	2ND	5	R	5	YES	8	20deg	10
18R	6	3RD	5					30deg	1

DFW TRIPS SCENARIO

DFW TRIP 9 START:00:02:00

TIME	RW	A/C#	LR	AMT	COMM	INTERVAL
00:05:47	18R	2nd	L	20deg	NO	00:03:47
00:10:27	16L	3rd	R	10deg	YES	00:04:40
00:14:11	18R	1st	L	30deg	YES	00:03:44
00:19:06	18R	3rd	L	20deg	NO	00:04:55
00:22:32	18R	1st	L	30deg	YES	00:03:26
00:27:00	18R	2nd	L	10deg	YES	00:04:28
00:30:08	18R	2nd	L	30deg	NO	00:03:08
00:36:01	16L	2nd	R	20deg	YES	00:05:53
00:40:22	18R	3rd	L	30deg	NO	00:04:21
00:45:19	18R	2nd	L	20deg	NO	00:04:57
00:48:59	17L	1st	R	20deg	NO	00:03:40
00:54:35	17L	2nd	L	30deg	NO	00:05:36
00:55:47	18R	2nd	L	10deg	YES	00:01:12
00:59:36						00:03:49
01:04:11						00:04:35
01:05:34						00:01:23
01:09:11						00:03:37
01:13:24						00:04:13
01:16:36						00:03:12
01:20:37						00:04:01

FREQUENCY DISTRIBUTION OF BLUNDER PARAMETERS
BLUNDERS BEFORE 00:58:00

RUNWAY	#	SEQ	#	DIR	#	COMM	#	AMOUNT	#
16L	2	1ST	3	L	10	NO	7	10deg	3
17L	2	2ND	7	R	3	YES	6	20deg	5
18R	9	3RD	3					30deg	5

DFW TRIPS SCENARIO

DFW TRIP 10 START:00:02:00

TIME	RW	A/C#	LR	AMT	COMM	INTERVAL
00:05:34	17L	3rd	R	30deg	NO	00:03:34
00:08:17	18R	3rd	L	30deg	YES	00:02:43
00:09:37	18R	2nd	L	10deg	YES	00:01:20
00:11:37	16L	1st	R	30deg	YES	00:02:00
00:15:27	18R	3rd	L	30deg	NO	00:03:50
00:21:06	18R	2nd	L	20deg	NO	00:05:39
00:23:12	17L	1st	R	20deg	YES	00:02:06
00:26:36	18R	3rd	L	20deg	YES	00:03:24
00:32:27	18R	3rd	L	20deg	NO	00:05:51
00:34:37	17L	2nd	R	10deg	YES	00:02:10
00:40:30	16L	2nd	R	20deg	NO	00:05:53
00:42:53	16L	3rd	R	30deg	YES	00:02:23
00:46:48	17L	3rd	R	30deg	YES	00:03:55
00:49:38	18R	1st	L	20deg	NO	00:02:50
00:52:13	18R	3rd	L	30deg	NO	00:02:35
00:56:08	18R	1st	L	30deg	YES	00:03:55
00:58:45						00:02:37
01:02:48						00:04:03
01:06:09						00:03:21
01:11:48						00:05:39

FREQUENCY DISTRIBUTION OF BLUNDER PARAMETERS
BLUNDERS BEFORE 00:58:00

RUNWAY	#	SEQ	#	DIR	#	COMM	#	AMOUNT	#
16L	3	1ST	4	L	9	NO	7	10deg	2
17L	4	2ND	4	R	7	YES	13	20deg	6
18R	9	3RD	8					30deg	8

DFW DUAL-E 1 START:00:02:00
(16L/17L)

TIME	RW	A/C#	LR	AMT	COMM	INTERVAL
00:05:03	17L	1st	L	30deg	YES	00:03:03
00:08:26	16L	1st	R	10 deg	YES	00:03:23
00:10:29	17L	2nd	L	20deg	NO	00:02:03
00:13:30	17L	1st	L	10 deg	YES	00:03:01
00:18:23	16L	1st	R	30deg	YES	00:04:53
00:22:12	17L	2nd	L	20deg	YES	00:03:49
00:26:37	16L	3rd	R	10 deg	NO	00:04:25
00:28:43	17L	2nd	L	30deg	NO	00:02:06
00:30:04	17L	3rd	L	10 deg	YES	00:01:21
00:33:31	17L	2nd	L	20deg	YES	00:03:27
00:37:48	17L	3rd	L	30deg	YES	00:04:17
00:40:35	16L	2nd	R	20deg	YES	00:02:47
00:43:16	16L	3rd	R	30deg	YES	00:02:41
00:48:05	17L	2nd	L	20deg	NO	00:04:49
00:49:32	16L	1st	R	30deg	YES	00:01:27
00:54:21	16L	1st	R	20deg	NO	00:04:49
00:56:35	17L	3rd	L	10 deg	NO	00:02:14
00:57:58	17L	1st	L	20deg	YES	00:01:23
01:01:05						00:03:07
01:03:32						00:02:27

FREQUENCY DISTRIBUTION OF BLUNDER PARAMETERS

RUNWAY	#	SEQ	#	DIR	#	COMM	#	AMOUNT	#
16L	7	1ST	7	L	11	NO	6	10deg	5
17L	11	2ND	6	R	7	YES	12	20deg	7
		3RD	5					30deg	6

DFW DUAL-E 2 START:00:02:00
(16L/17L)

TIME	RW	A/C#	LR	AMT	COMM	INTERVAL
00:05:34	17L	3rd	L	30deg	NO	00:03:34
00:07:17	16L	3rd	R	30deg	YES	00:01:43
00:08:37	16L	1st	R	10 deg	YES	00:01:20
00:10:37	17L	2nd	L	30deg	YES	00:02:00
00:13:27	16L	3rd	R	30deg	NO	00:02:50
00:18:06	16L	1st	R	20deg	NO	00:04:39
00:20:12	17L	2nd	L	20deg	YES	00:02:06
00:23:36	16L	3rd	R	20deg	YES	00:03:24
00:28:27	16L	3rd	R	20deg	NO	00:04:51
00:30:37	17L	1st	L	10 deg	YES	00:02:10
00:35:30	17L	1st	L	20deg	NO	00:04:53
00:37:53	17L	3rd	L	30deg	YES	00:02:23
00:40:48	17L	3rd	L	30deg	YES	00:02:55
00:42:38	16L	2nd	R	20deg	NO	00:01:50
00:44:13	16L	3rd	R	30deg	NO	00:01:35
00:47:08	16L	2nd	R	30deg	YES	00:02:55
00:48:45	16L	2nd	R	20deg	YES	00:01:37
00:52:48	17L	3rd	L	10 deg	YES	00:04:03
00:56:09	16L	2nd	R	20deg	NO	00:03:21
01:00:48						00:04:39

FREQUENCY DISTRIBUTION OF BLUNDER PARAMETERS

RUNWAY	#	SEQ	#	DIR	#	COMM	#	AMOUNT	#
16L	11	1ST	4	L	8	NO	8	10deg	3
17L	8	2ND	6	R	11	YES	11	20deg	8
		3RD	9					30deg	8

DFW DUAL-E 3 (16L/17L) START:00:02:00

TIME	RW	A/C#	LR	AMT	COMM	INTERVAL
00:04:23	17L	3rd	L	10 deg	NO	00:02:23
00:09:09	16L	3rd	R	30deg	NO	00:04:46
00:12:31	17L	3rd	L	10 deg	NO	00:03:22
00:16:16	16L	2nd	R	30deg	NO	00:03:45
00:19:08	16L	3rd	R	10 deg	NO	00:02:52
00:22:59	17L	3rd	L	30deg	YES	00:03:51
00:25:53	17L	1st	L	20deg	YES	00:02:54
00:28:01	17L	2nd	L	30deg	NO	00:02:08
00:31:16	17L	3rd	L	20deg	NO	00:03:15
00:36:01	17L	1st	L	20deg	YES	00:04:45
00:40:39	17L	3rd	L	30deg	NO	00:04:38
00:41:56	16L	3rd	R	30deg	NO	00:01:17
00:43:08	17L	3rd	L	20deg	NO	00:01:12
00:48:03	17L	1st	L	20deg	YES	00:04:55
00:51:45	17L	2nd	L	20deg	NO	00:03:42
00:54:09	17L	3rd	L	30deg	YES	00:02:24
00:57:57	17L	2nd	L	30deg	NO	00:03:48
01:01:53						00:03:56
01:06:22						00:04:29
01:07:52						00:01:30

FREQUENCY DISTRIBUTION OF BLUNDER PARAMETERS

RUNWAY	#	SEQ	#	DIR	#	COMM	#	AMOUNT	#
16L	4	1ST	3	L	13	NO	12	10deg	3
17L	13	2ND	4	R	4	YES	5	20deg	6
		3RD	10					30deg	8

DFW DUAL-E 4 (16L/17L) START:00:02:00

TIME	RW	A/C#	LR	AMT	COMM	INTERVAL
00:07:57	16L	1st	R	30deg	NO	00:05:57
00:12:31	16L	2nd	R	30deg	NO	00:04:34
00:13:52	17L	1st	L	20deg	NO	00:01:21
00:16:31	16L	1st	R	30deg	NO	00:02:39
00:20:58	17L	2nd	L	10 deg	YES	00:04:27
00:25:52	16L	1st	R	10 deg	NO	00:04:54
00:28:55	16L	2nd	R	30deg	NO	00:03:03
00:31:28	17L	3rd	L	10 deg	YES	00:02:33
00:32:34	17L	1st	L	30deg	YES	00:01:06
00:37:16	16L	1st	R	30deg	NO	00:04:42
00:39:03	17L	1st	L	20deg	NO	00:01:47
00:43:22	17L	1st	L	30deg	NO	00:04:19
00:44:57	16L	1st	R	30deg	NO	00:01:35
00:46:04	16L	3rd	R	20deg	YES	00:01:07
00:50:33	17L	1st	L	30deg	YES	00:04:29
00:53:05	17L	3rd	L	20deg	NO	00:02:32
00:57:06	16L	1st	R	30deg	NO	00:04:01
01:02:05						00:04:59
01:06:39						00:04:34
01:08:57						00:02:18

FREQUENCY DISTRIBUTION OF BLUNDER PARAMETERS

RUNWAY	#	SEQ	#	DIR	#	COMM	#	AMOUNT	#
16L	9	1ST	11	L	8	NO	12	10deg	3
17L	8	2ND	3	R	9	YES	5	20deg	4
		3RD	3					30deg	10

DFW DUAL-E 5 START:00:02:00
(16L/17L)

TIME	RW	A/C#	LR	AMT	COMM	INTERVAL
00:05:42	16L	2nd	R	30deg	NO	00:03:42
00:10:10	16L	2nd	R	20deg	YES	00:04:28
00:14:55	17L	3rd	L	20deg	NO	00:04:45
00:18:02	16L	3rd	R	10 deg	NO	00:03:07
00:22:26	16L	2nd	R	30deg	NO	00:04:24
00:26:21	16L	2nd	R	30deg	NO	00:03:55
00:27:22	17L	1st	L	20deg	YES	00:01:01
00:31:36	17L	2nd	L	20deg	NO	00:04:14
00:34:44	16L	3rd	R	30deg	NO	00:03:08
00:36:40	17L	3rd	L	20deg	NO	00:01:56
00:39:11	17L	1st	L	20deg	YES	00:02:31
00:40:34	17L	3rd	L	20deg	NO	00:01:23
00:44:36	16L	2nd	R	30deg	NO	00:04:02
00:48:44	17L	1st	L	10 deg	YES	00:04:08
00:51:59	16L	3rd	R	30deg	YES	00:03:15
00:56:21	16L	1st	R	30deg	YES	00:04:22
01:01:16						00:04:55
01:02:46						00:01:30
01:04:22						00:01:36
01:08:51						00:04:29

FREQUENCY DISTRIBUTION OF BLUNDER PARAMETERS

RUNWAY	#	SEQ	#	DIR	#	COMM	#	AMOUNT	#
16L	9	1ST	4	L	7	NO	10	10deg	2
17L	7	2ND	6	R	9	YES	6	20deg	7
		3RD	6					30deg	7

DFW DUAL-W 1 START:00:02:00
(18R/17L)

TIME	RW	A/C#	LR	AMT	COMM	INTERVAL
00:05:59	18R	3rd	L	10 deg	NO	00:03:59
00:09:43	18R	1st	L	10 deg	NO	00:03:44
00:11:12	18R	2nd	L	30deg	YES	00:01:29
00:15:01	18R	3rd	L	10 deg	YES	00:03:49
00:19:47	17L	3rd	R	20deg	YES	00:04:46
00:23:52	18R	3rd	L	20deg	YES	00:04:05
00:26:28	18R	1st	L	10 deg	NO	00:02:36
00:29:16	17L	2nd	R	20deg	NO	00:02:48
00:30:22	18R	3rd	L	30deg	NO	00:01:06
00:34:19	17L	1st	R	10 deg	YES	00:03:57
00:40:08	17L	3rd	R	30deg	NO	00:05:49
00:42:09	17L	3rd	R	10 deg	YES	00:02:01
00:45:01	18R	2nd	L	20deg	YES	00:02:52
00:49:16	17L	3rd	R	10 deg	YES	00:04:15
00:51:42	17L	1st	R	30deg	NO	00:02:26
00:56:29	17L	3rd	R	20deg	YES	00:04:47
01:02:14						00:05:45
01:03:15						00:01:01
01:06:16						00:03:01
01:10:38						00:04:22

FREQUENCY DISTRIBUTION OF BLUNDER PARAMETERS

RUNWAY	#	SEQ	#	DIR	#	COMM	#	AMOUNT	#
16L	0	1ST	4	L	8	NO	7	10deg	7
17L	8	2ND	3	R	8	YES	9	20deg	5
18R	8	3RD	9					30deg	4

DFW DUAL-W 2 START:00:02:00

(18R/17L)

TIME	RW	A/C#	LR	AMT	COMM	INTERVAL
00:03:29	17L	2nd	R	30deg	NO	00:01:29
00:05:50	18R	3rd	L	20deg	NO	00:02:21
00:11:42	17L	2nd	R	30deg	YES	00:05:52
00:16:26	17L	3rd	R	30deg	YES	00:04:44
00:21:03	17L	1st	R	30deg	YES	00:04:37
00:22:06	17L	1st	R	30deg	YES	00:01:03
00:24:47	18R	2nd	L	20deg	YES	00:02:41
00:27:57	18R	2nd	L	20deg	YES	00:03:10
00:32:39	18R	3rd	L	30deg	YES	00:04:42
00:34:41	17L	3rd	R	10 deg	NO	00:02:02
00:39:32	18R	3rd	L	10 deg	NO	00:04:51
00:40:57	17L	1st	R	20deg	YES	00:01:25
00:46:43	17L	2nd	R	30deg	NO	00:05:46
00:51:16	17L	3rd	R	10 deg	NO	00:04:33
00:57:06	17L	2nd	R	20deg	YES	00:05:50
00:59:09						00:02:03
01:03:55						00:04:46
01:08:00						00:04:05
01:11:56						00:03:56
01:17:52						00:05:56

FREQUENCY DISTRIBUTION OF BLUNDER PARAMETERS

RUNWAY	#	SEQ	#	DIR	#	COMM	#	AMOUNT	#
16L	0	1ST	3	L	5	NO	6	10deg	3
17L	10	2ND	6	R	10	YES	9	20deg	5
18R	5	3RD	6					30deg	7

DFW DUAL-W 3 (18R/17L) START:00:02:00

TIME	RW	A/C#	LR	AMT	COMM	INTERVAL
00:04:13	18R	1st	L	20deg	YES	00:02:13
00:08:46	18R	2nd	L	30deg	NO	00:04:33
00:12:04	17L	2nd	R	30deg	YES	00:03:18
00:13:22	18R	3rd	L	20deg	YES	00:01:18
00:18:00	18R	2nd	L	10 deg	YES	00:04:38
00:20:52	18R	3rd	L	30deg	YES	00:02:52
00:21:52	18R	1st	L	30deg	NO	00:01:00
00:26:36	18R	3rd	L	20deg	YES	00:04:44
00:32:06	17L	3rd	R	30deg	NO	00:05:30
00:35:02	17L	3rd	R	20deg	NO	00:02:56
00:37:02	17L	3rd	R	30deg	YES	00:02:00
00:38:21	18R	1st	L	30deg	YES	00:01:19
00:39:30	17L	2nd	R	20deg	YES	00:01:09
00:43:01	17L	3rd	R	30deg	NO	00:03:31
00:46:18	18R	1st	L	20deg	YES	00:03:17
00:51:48	17L	3rd	R	30deg	YES	00:05:30
00:56:26	18R	3rd	L	20deg	YES	00:04:38
01:00:49						00:04:23
01:04:29						00:03:40
01:07:39						00:03:10

FREQUENCY DISTRIBUTION OF BLUNDER PARAMETERS

RUNWAY	#	SEQ	#	DIR	#	COMM	#	AMOUNT	#
16L	0	1ST	4	L	10	NO	5	10deg	1
17L	7	2ND	4	R	7	YES	12	20deg	7
18R	10	3RD	9					30deg	9

DFW DUAL-W 4 START:00:02:00
(18R/17L)

TIME	RW	A/C#	LR	AMT	COMM	INTERVAL
00:06:56	17L	2nd	R	20deg	YES	00:04:56
00:10:36	17L	1st	R	30deg	YES	00:03:40
00:14:10	18R	3rd	L	30deg	YES	00:03:34
00:16:56	17L	1st	R	20deg	YES	00:02:46
00:21:54	18R	2nd	L	10 deg	NO	00:04:58
00:26:12	17L	3rd	R	30deg	YES	00:04:18
00:30:00	17L	1st	R	10 deg	YES	00:03:48
00:34:42	18R	2nd	L	20deg	NO	00:04:42
00:36:57	18R	3rd	L	30deg	NO	00:02:15
00:40:10	17L	1st	R	30deg	YES	00:03:13
00:41:12	18R	3rd	L	20deg	NO	00:01:02
00:43:49	18R	2nd	L	20deg	NO	00:02:37
00:46:52	18R	1st	L	20deg	YES	00:03:03
00:50:41	18R	2nd	L	10 deg	YES	00:03:49
00:53:52	17L	1st	R	30deg	YES	00:03:11
00:58:25						00:04:33
01:04:08						00:05:43
01:08:09						00:04:01
01:09:21						00:01:12
01:13:43						00:04:22

FREQUENCY DISTRIBUTION OF BLUNDER PARAMETERS

RUNWAY	#	SEQ	#	DIR	#	COMM	#	AMOUNT	#
16L	0	1ST	6	L	8	NO	5	10deg	3
17L	7	2ND	5	R	7	YES	10	20deg	6
18R	8	3RD	4					30deg	6

DFW DUAL-W 5 START:00:02:00
(18R/17L)

TIME	RW	A/C#	LR	AMT	COMM	INTERVAL
00:07:57	17L	3rd	R	30deg	NO	00:05:57
00:13:54	18R	2nd	L	20deg	YES	00:05:57
00:18:09	18R	1st	L	30deg	NO	00:04:15
00:22:10	18R	1st	L	30deg	YES	00:04:01
00:25:08	17L	3rd	R	30deg	NO	00:02:58
00:28:05	18R	1st	L	20deg	YES	00:02:57
00:30:18	17L	2nd	R	30deg	YES	00:02:13
00:33:08	17L	1st	R	20deg	YES	00:02:50
00:37:59	18R	1st	L	30deg	NO	00:04:51
00:40:32	18R	2nd	L	10 deg	YES	00:02:33
00:44:51	18R	1st	L	30deg	YES	00:04:19
00:47:13	18R	3rd	L	30deg	NO	00:02:22
00:51:51	17L	2nd	R	30deg	NO	00:04:38
00:54:41	18R	1st	L	10 deg	YES	00:02:50
00:57:54	17L	2nd	R	10 deg	YES	00:03:13
01:00:33						00:02:39
01:05:19						00:04:46
01:09:31						00:04:12
01:11:34						00:02:03
01:14:01						00:02:27

FREQUENCY DISTRIBUTION OF BLUNDER PARAMETERS

RUNWAY	#	SEQ	#	DIR	#	COMM	#	AMOUNT	#
16L	0	1ST	7	L	9	NO	6	10deg	3
17L	6	2ND	5	R	6	YES	9	20deg	3
18R	9	3RD	3					30deg	9

APPENDIX C

CONTROLLER QUESTIONNAIRE AND MODIFIED COOPER-HARPER SCALE

RATING SCALE INSTRUCTIONS

Overview

After each of the following sessions, you will give a rating on a Modified Cooper-Harper Scale for workload. This rating scale and important definitions for using the scale are given below. Before you begin, we will review:

1. The definition of the terms used in the scale,

2. The steps you should follow in making your rating on the scale, and

3. How you should think of the ratings.

If you have any questions, as we review these points, please ask.

Important Definitions

To understand and use the Modified Cooper-Harper Scale properly, it is important that you understand the terms used on the scale and how they apply in this simulation.

First, "instructed task" is the ATC control task you will be doing in this simulation. It includes monitoring the aircraft along the localizer, maintaining the required separation distances, and doing all the duties associated with this task.

Second, the "operator" is you. Because the scale can be used in different situations, the person the rating is the operator. You will be operating the system and then using the rating scale to quantify your experience.

Third, the "system" is the complete group of equipment you will be using in doing the instructed task. For the present simulation, the system is the D/FW runways, localizers, and air traffic patterns. (Differences between the ATC suite simulator, its instruments, controls and radar displays, and the ATC suite in DFW are not a factor in the assessment of the system. Any difficulties arising due to differences between the simulation suite and DFW should be noted on the controller questionnaire.) The systems being compared in this simulation are the two parallel runway system and the three parallel runway system.

Fourth, "errors" include any of the following: loss of separation, near misses, and similar occurrences. In other words, errors are any appreciable deviation from the desired "operator/system" performance.

Finally, "mental workload" is the integrated mental effort required to perform the instructed task. It includes such factors as level of attention, depth of thinking, and level of concentration required by the instructed task.

Rating Scale Steps

On the Modified Cooper-Harper Scale you will notice that there is a series of decisions which follow a predetermined logical sequence. This logical sequence is designed to help you make more consistent and accurate ratings. Thus, you should follow the logic sequence on the scale for each of your ratings in the simulations.

The steps which you will follow in using the rating scale logic are as follows:

1. First you will decide if the instructed task can be accomplished all of the time. If the answer is no, move to the right and circle 10.

2. Second, you will decide if adequate performance is attainable. Adequate performance means that the errors are small and inconsequential in controlling the air traffic. If they are not, then there are major deficiencies in the system and you should proceed to the right. By reading the descriptions associated with numbers 7, 8, and 9, you should be able to select the one that best describes the situation you have experienced. You should then circle the most appropriate number.

3. If adequate performance is attainable your next decision is whether your mental workload for the instructed task is acceptable. If it is not acceptable, you should select a rating of 4, 5, or 6. One of these ratings should describe the situation you have experienced. You should circle the most appropriate number.

4. If mental workload is acceptable, you should then move to one of the top three descriptions on the scale. You should read and carefully select the rating 1, 2, or 3 based on the situation you have experienced.

Remember you are to circle only one number, and you should follow the logic of the scale. You should always begin at the lower left and follow the logic path to decide on a rating. In particular, do not skip any steps. Otherwise, your rating may not be valid and reliable.

How You Should Think of the Rating

Before you begin rating, there are several points that need to be emphasized.

First, be sure to try to perform the instructed task as instructed and make all your evaluations within the context of the instructed task. Try to maintain adequate performance as specified for your task.

Second, the rating scale is not a test of your personal skill. On all of your ratings, you will be evaluating the system for the general user population, not yourself. You should make the assumption that problems encountered are not problems you created. They are problems created by the system and the instructed task. In other words, don't blame yourself if the system is deficient, blame the system.

Third, try to avoid the problem of nit picking an especially good system, or saying that a system which is difficult to use is not difficult to use at all. Also, try not to overreact to differences between the simulated system and the actual system. Thus, to avoid any problems, just always try to "tell it like it is" in making your ratings.

If you have any questions, please ask the supervisor at this time.

POST RUN CONTROLLER QUESTIONNAIRE

PARTICIPANT CODE ______ DATE _____

PARTNER'S CODE(S) ______ ______ TIME _____

RUN NUMBER ______ RUNWAY _____

---

1. RATE YOUR PERFORMANCE CONTROLLING TRAFFIC DURING THE PAST SESSION. CIRCLE THE NUMBER WHICH BFST DESCRIBES YOUR PERFORMANCE.

1 2 3 4 5 6 7 8 9 10

POOR AVERAGE SUPERIOR

---

2. RATE THE LEVEL OF ACTIVITY REQUIRED DURING THE PAST SESSION.

1 2 3 4 5 6 7 8 9 10

MINIMAL MODERATE INTENSE

---

3. RATE THE LEVEL OF STRESS EXPERIENCED DURING THE PAST SESSION.

1 2 3 4 5 6 7 8 9 10

SLIGHT MODERATE EXTREME

---

4. ARE THE CONDITIONS OF THIS PAST SESSION (traffic volume, procedures, geography, separation requirements...) WORKABLE AT YOUR PRESENT FACILITY? CIRCLE YOUR RESPONSE.

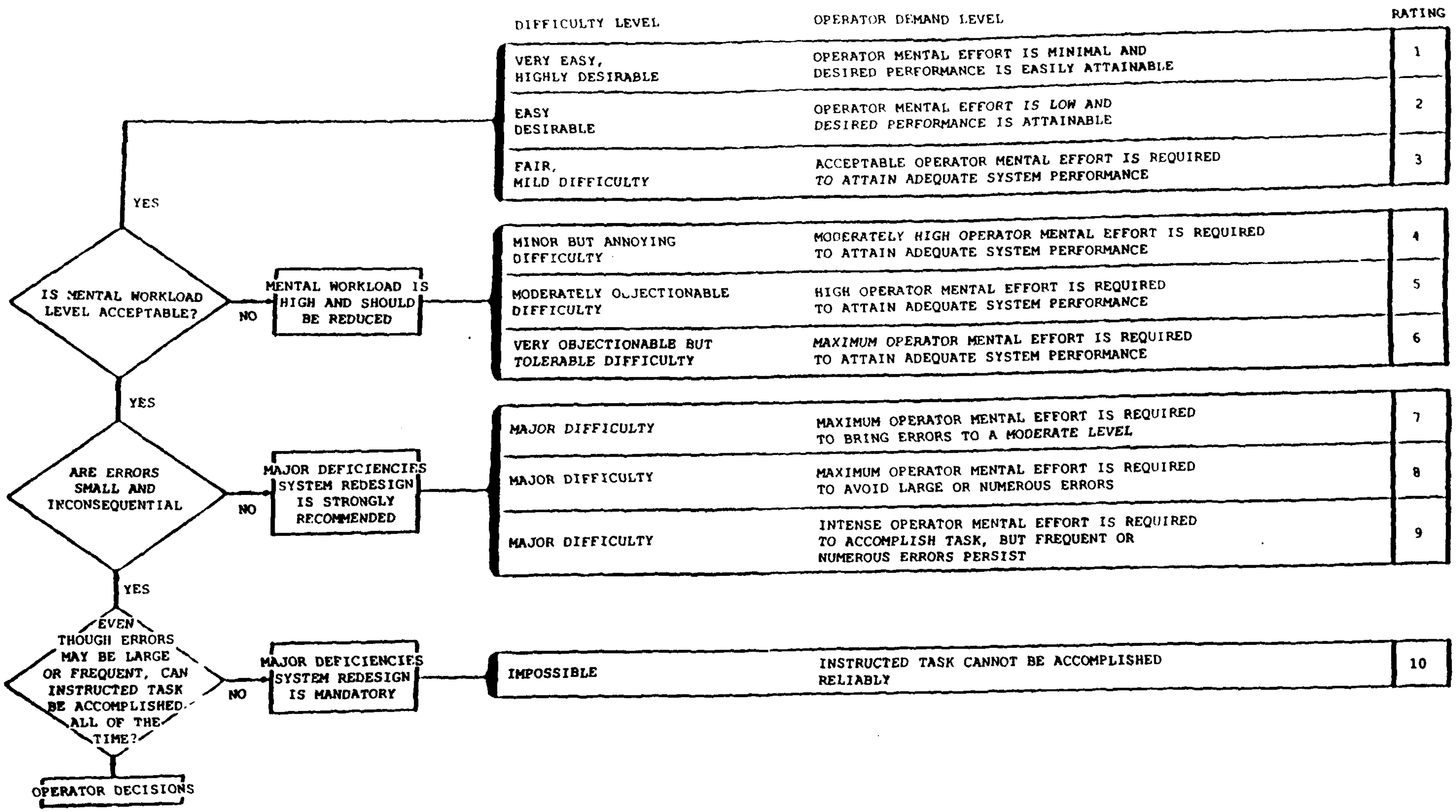
1 2 3 4 5 6 7 8 9 10

STRONG YES YES POSSIBLY NO STRONG NO

5. PLEASE DESCRIBE ANY UNUSUAL OCCURRENCES FROM THE LAST HOUR. ANY ADDITIONAL COMMENTS CONCERNING THE SESSION OR SIMULATION WOULD BE VERY WELCOME.

---

6. DID YOU AND YOUR PARTNER(S) FOR THIS PAST HOUR ESTABLISH, SPOKEN OR UNSPOKEN, ANY STRATEGY OR AGREEMENT ABOUT INDIVIDUAL DUTIES? IF YES, BRIEFLY DESCRIBE THE STRATEGY AGREEMENT? BE SPECIFIC ABOUT THE ASSIGNMENTS USING LETTER CODES.



DIFFICULTY LEVEL
OPERATOR DEMAND LEVEL
RATING
VERY EASY, HIGHLY DESIRABLE
OPERATOR MENTAL EFFORT IS MINIMAL AND DESIRED PERFORMANCE IS EASILY ATTAINABLE
1
EASY DESIRABLE
OPERATOR MENTAL EFFORT IS LOW AND DESIRED PERFORMANCE IS ATTAINABLE
2
FAIR, MILD DIFFICULTY
ACCEPTABLE OPERATOR MENTAL EFFORT IS REQUIRED TO ATTAIN ADEQUATE SYSTEM PERFORMANCE
3
MINOR BUT ANNOYING DIFFICULTY
MODERATELY HIGH OPERATOR MENTAL EFFORT IS REQUIRED TO ATTAIN ADEQUATE SYSTEM PERFORMANCE
4
MODERATELY OBJECTIONABLE DIFFICULTY
HIGH OPERATOR MENTAL EFFORT IS REQUIRED TO ATTAIN ADEQUATE SYSTEM PERFORMANCE
5
VERY OBJECTIONABLE BUT TOLERABLE DIFFICULTY
MAXIMUM OPERATOR MENTAL EFFORT IS REQUIRED TO ATTAIN ADEQUATE SYSTEM PERFORMANCE
6
MAJOR DIFFICULTY
MAXIMUM OPERATOR MENTAL EFFORT IS REQUIRED TO BRING ERRORS TO A MODERATE LEVEL
7
MAJOR DIFFICULTY
MAXIMUM OPERATOR MENTAL EFFORT IS REQUIRED TO AVOID LARGE OR NUMEROUS ERRORS
8
MAJOR DIFFICULTY
INTENSE OPERATOR MENTAL EFFORT IS REQUIRED TO ACCOMPLISH TASK, BUT FREQUENT OR NUMEROUS ERRORS PERSIST
9
IMPOSSIBLE
INSTRUCTED TASK CANNOT BE ACCOMPLISHED RELIABLY
10
IS MENTAL WORKLOAD LEVEL ACCEPTABLE?
YES
NO
MENTAL WORKLOAD IS HIGH AND SHOULD BE REDUCED
ARE ERRORS SMALL AND INCONSEQUENTIAL
YES
NO
MAJOR DEFICIENCIES SYSTEM REDESIGN IS STRONGLY RECOMMENDED
EVEN THOUGH ERRORS MAY BE LARGE OR FREQUENT, CAN INSTRUCTED TASK BE ACCOMPLISHED ALL OF THE TIME?
YES
NO
MAJOR DEFICIENCIES SYSTEM REDESIGN IS MANDATORY
OPERATOR DECISIONS

APPENDIX D

INDUSTRY OBSERVER QUESTIONNAIRE

INDUSTRY OBSERVER QUESTIONNAIRE

NAME ________________ DATE _________

ORGANIZATION ________

---

1. On which days did you observe the simulation?

   DATES:
   TIME:

---

2. How realistic was the simulation?

1	2	3	4	5	6	7	8	9	10
NOT REALISTIC AT ALL				AVERAGE					VERY REALISTIC

---

3. Based on your observations of this simulation, is the triple parallel runway operation workable?

1	2	3	4	5	6	7	8	9	10
STRONG NO		NO		POSSIBLY			YES		STRONG YES

---

4. Please provide any comments or observations.

APPENDIX E

DATA ANALYSIS COMPUTER FILES

D F W - 2   F I L E S

FILE LOCATION	BYTES	
@VCL050(DA.ARC)BLNDCNF	72244	Blunder Conflicts
@VCL050(DA.ARC)BLUNDERS	50122	Blunders and Next Message A/C
@VCL050(DA.ARC)CPAFILE	67935	Closest-Point-of-Approach
@VCL050(DA.ARC)SIMBLNDR	4360	Simultaneous Blunders
@VCL050(DA.ARC)SNAPCPA	103556	Pred. CPA after Blunder Turn
@VCL050(DA.ARC)SNAPSHOT	247440	Blunder and Surrounding A/C
@VCL050(DA.ARC)SUMFILE	14592	Summary Counts
@VCL050(DA.ARC)TRANFILE	87384	Trangressions into NTZ
@VCL050(DA.ARC)VECTFILE	94240	A/C deviated from ILS
@VCL050(DA.ARC)ACTFILE	1425032	Actions

ACTIONS:

```
ALTITUDE CANCEL   CLEARED  INFORM   LCNFEXIT LCNFNTRY
MISSED   NTZEXIT  NTZNTRY  PCNFNTRY PCNFEXIT SPEED
VECTOR   WARNING
```

LCNF = Longitudinal Conflicts (Same ILS)
PCNF = Parallel Conflicts (Adjacent ILS's)
NTZ = No-Transgression-Zone
MISSED = Missed Approach
INFORM = Information (very few of these)
CLEARED = Clearances

F I L E   F O R M A T S

Note: All TIMES are in seconds.

```
     CHARACTER*45 MSGM
     CHARACTER*3 ACTION
     CHARACTER*7 ID1,ID2
     CHARACTER*5 HSEP,VSEP,HORZ
     CHARACTER*4 RUNNBR
     CHARACTER*3 RWY1,RWY2
     CHARACTER*2 DEG3
     CHARACTER*1 DIRB,COMB,NRWYB,CID,STAR
     INTEGER*4 TIME1,TIME2,TIME3
     INTEGER*1 ILSFLG(2)
```

1. BLUNDERS

```
     READ('BLN','(X,A4,X,I5,X,A3,X,A7,X,A1,X,A2,X,A1,X,A1,X,I5,
   + X,A3,X,A7,X,A45)')
   + RUNNBR,TIME1,RWY1,ID1,DIRB,DEGB,COMB,NRWYB,
   + TIME2,RWY2,ID2,MSGM
```

2. BLNDCNF

```
     READ('BCF','(X,A4,X,I5,X,A3,X,A7,X,I5,X,I4,X,I5,X,A3,X,A7,X,
   + 2I1)') RUNNBR,TIME1 ,RWY1,ID1,TIME2 ,IAPI,TIME3,
   + RWY2,ID2,ILSFLG
```

3. SUMFILE

```
     READ('SF','(X,A4, X,A3, X,I4,2X,A1,X,
   + 19I6)')
   + RUNNBR,RWY1,ICONT,CID,
   + NHAND,NDEVTN,NBLUND,NWARN,
   + NTZER,NTZXR,NLCNE,MAXLAPI,
   + NPCNE,MAXPAPI,NSR500,NSR300,NSPD,NMISS,NCAN,
   + NLAND,NPILMSG
```

4. TRANFILE

```
      READ('TF','(X,A4,X,I5,X,A3,X,A8,X,A7,X,F5.2,
   +       2(X,F5.0),X,F6.0,X,A5, X,A45)')
   +   RUNNBR,TIME1,RWY1,ACTION,ID1,TDST,
   +   HDG1,SPD1,ALT1,HORZ,MSGM
```

5. SNAPSHOT

```
      READ('SSS','(X,A4,X,I5,2X,A3,X,A7,3X,A1,2X,A2,3X,A1,3X,I2,
     + 2(X,F7.2),X,I6,X,I4,X,F6.1,2X,A3,X,A7,2(X,F7.2),X,I6,X,I4,
     + X,F6.1,X,A1)')
     + RUNNBR,TIME1,RWY1,ID1,DIRB,DEGB,COMB,NRWYB,
     + BX,BY,IALT,ISPD,BDALT,RWY2,ID2,OX,OY,NALT,NSPD,ODALT,STAR
```

6. SNAPCPA

```
      READ('SCP','(X,A4,X,I5,2X,A3,X,A7,2X,A3,X,A7,X,I4,X,F7.2,X,
     +  F7.0,X,I3,X,F6.2,X,I3)')
     + RUNNBR,TIME1,RWY1,ID1,RWY2,ID2,TRACK,PHSEP,PVSEP,PAFI,PCPA,TCPA
```

7. VECTFILE

```
      READ('VF','(X,A4,X,I5,2X,A3,X,A7,2(X,F7.2),X,F6.0,X,F7.2,
     + X,F5.0,X,I4)')
     + RUNNBR,TIME1,RWY1,ID1,BX,BY,BALT,CLMBDESC,SPD,TRACK
```

8. CPAFILE

```
      READ('CPA','(X,A4,X,I5,X,A3,2(X,A7),2(X,F7.0))',END=80)
     + RUNNBR,TIME1,ACTION,ID1,ID2,API,CPAFT
```

9. SIMBLNDR

```
      READ('SB', '(X,A4,X,I5,X,A3,X,A7,X,A1,X,A2,X,A1,X,A1,X,I5,
     + X,A3,X,A7,X,A45)')
     + RUNNBR,TIME1,RWY1,ID1,DIRB,DEGB,COMB,NRWYB,
     + TIME2,RWY2,ID2,MSGM
```

10. ACTFILE

```
     READ('ACT','(X,A4,X,A3, X,I5, X,A7, X,A8,X,F5.2,2(X,A5),
     +        2(X,F5.0),X,F6.0,X,A3,X,A45)',END=100)
     +   RUNNBR,RWY1,TIME1,ID1,ACTION,TDST,HSEP,VSEP,HDG1,
     +   SPD1,ALT1,RWY2,MSGM
```

DFW-2 DATA DESCRIPTIONS

I. REPORTS

- .ILS Information (Controller, Runway, distances between Runways and distances to the No-Transgression-Zone (NTZ).
- .Flight Plan Information
- .Flight Event Times
- .List of Flights on an ILS and a Chart of Deviations from the ILS Center Line.
- .Controller Action Report
- .Pilot Messages
- .Conflict Entry and Exit Information
- .Parallel Events
- .Longitudinal Events
- .No-Transgression-Zone Entry and Exit Information
- .Conflicts - Parallel, Longitudinal
- .Flight Time History Chart
- .Minimum and Maximum A/C handled per Minute
- .Pilot Key Strike counts.

II. DATA FILES

- .Summary File Information
- .Blunders and associated Conflicts
- .Simultaneous Blunders (Blunders that occurred within one minute of each other).
- .Blunders and Aircraft keying next valid message.
- .Snapshot of Aircraft surrounding Blundering Aircraft
- .Blunders and Aircraft with a positive Predicted Time-to-CPA after Blundering Turn completed.
- .All Aircraft deviated (vectored) from the ILS.
- .Transgressions into the NTZ
- .CPA and associated API of conflicting A/C pairs.

Permanent Files (10):

- .ACTFILE - All Actions that took place during the Simulation Pilot Key Strikes, Conflicts, NTZ actions, etc.
- .BLUNDERS - Blundering A/C and the next A/C receiving a a Path Change Message.
- .SIMBLNDR - Blunders occurring within 60 seconds of each other. (Same Data as Blunders)
- .BLNDCNF - Blunders and associated Parallel Conflicts
- .SNAPSHOT - Snapshot of A/C within 3.5 miles of a planned Blunder.
- .SNAPCPA - Predicted CPA of SNAPSHOT Aircraft after Blundering Turn completed. If Blunder Time and CPA Time are the same, then the Predicted CPA is the Actual CPA.
- .SUMFILE - A Summary list of Selected Data Measures.
- .TRANFILE - A/C that entered the NO-TRANSGRESSION-ZONE (NTZ).
- .VECTFILE - All A/C that were diverted from the ILS.
- .CPAFILE - CPA and associated API of Conflicts.

REPORTS DESCRIPTIONS

The Parallel Runways Reports are listed in this section.

Please note that all Flight Times are internal simulation times (starting at Time 0).

1. ILS ENVIRONMENTAL INFORMATION

The ILS description contains the X,Y coordinates for the Runway, the Gate and the 25 mile (selectable) end-of-ILS, the Direction toward Threshold, the Parallel runways separation and the distance to the No-Transgression-Zone (feet, Left/Right of Center Line).

RUNWAY ...... ILS Runway Name
GATE .... ILS Gate Name
ILSEND ...... ILS extended end-point
DIRECTION ... Direction of ILS from ILSEND to RUNWAY
X .... X-Coordinate of Runway Threshold, Gate and ILS end
Y .... Y-Coordinate of Runway Threshold, Gate and ILS end
SEPL .... Distance to left ILS
SEPR .... Distance to right ILS
NTZL .... Distance to left NTZ
NTZR .... Distance to right NTZ

Note: Distance is in feet (0 indicates: no adjacent ILS)

2. FLIGHT PLANS

The Flight Plans are listed in chronological order.

The Aircraft size is determined by matching the Aircraft Type with Types listed in Small and Heavy Tables. If a match is not found it is assumed to be a Large Aircraft.

NO. .... flight number (order, in which, flight appears in the traffic sample)
ACID .... aircraft identity (operator and number)
TIME .... start time of flight
CAT .... aircraft category number
ACTYPE/E .... aircraft type and equipment code
ACSIZE .... size of the aircraft (SMALL, LARGE, HEAVY)
START-POINT . route start point
END-POINT ... route end point
DISTANCE .... total route distance (miles)

3. RUNWAY FLIGHT EVENT TIMES

The Aircraft are listed in Chronological Order by ON-ILS Time.
A Count of the Events follows each Listing.

```
NO. ....... flight number (Traffic Sample order)
IDENTITY .  aircraft identity (operator and number)
ACTYPE ...  aircraft type and equipment code
SIZE .....  size of the aircraft (S-small, L-large, H-heavy)
ON-ILS ...  time aircraft connected to the ILS
OFF-ILS     time A/C left the ILS (other than Land)
DEV-OUT ..  time aircraft Deviated away from the ILS
DEV-IN ...  time aircraft reconnected to the ILS
5-MI-PT ..  time aircraft was five miles from threshhold
            (inside the Outer Marker)
MISS-APR .  time aircraft executed a missed approach
CANCEL ...  time flight was canceled
LANDED ...  time aircraft Landed
RUNWAY ...  assigned runway
```

4.1 FLIGHT ILS POINT CROSSING

Aircraft connected to the ILS are tested for deviation from the Center Line. The ILS is extended 25 miles from the Runway through the Gate.

There are a total of 50 points along the ILS, starting at 25 miles from threshold and every .5 miles thereafter.

IDENTITY . flight identity
MEAN ..... average deviation from ILS center line
STDEV .... standard deviation of deviation from ILS center line
COUNT .... number of ILS point crossings
SUM ...... sum of deviations from ILS center line
SUMSQ .... sum-of-squares of deviations from ILS center line
STRTPT ... first ILS point crossed
ENDPT .... last ILS point crossed

4.2 ILS POINT FLIGHT DEVIATION DISTRIBUTION CHART

This is a measure of random noise introduced during the simulation. Only Aircraft connected to the ILS are included in this Report.

```
POINT ........ ILS crossing points
MEAN ......... average deviation from center line
STDEV ........ standard deviation from ILS center line
COUNT ........ number of flights that crossed point
SUM .......... sum of deviations from ILS center line
SUMSQ ........ sum-of-squares of deviations from ILS center line
DISTRIBUTION . number of deviations each 125 feet from
               ILS center line (-1250 to 1250)
               (0 point includes -124 to 124)
```

5. FLIGHT ACTION BY CONTROLLER

This Report lists Flight Actions that occurred after the initial ILS connection.

```
TIME .... time of action.
ACTION .. action concerning aircraft as follows:

  NTZNTRY  .. entry into NO-TRANSGRESSION-ZONE (NTZ)
  NTZEXIT  .. exit from NTZ.
  LCNFNTRY .. start of longitudinal conflict
  LCNFEXIT .. end of longitudinal conflict
  PCNFNTRY .. start of parallel runway conflict
  PCNFEXIT .. end of parallel runway conflict
Pilot Keybord Messages:
  ALTITUDE .. altitude change
  CANCEL .... cancel flight
  CLEARED ... clearance
  MISSED .... missed approach
  INFORM .... pilot information
  SPEED ..... speed change
  VECTOR .... heading change

RWY1 .... action runway
IDENT1 .. flight identity of aircraft perfoming action
TDST1 ... action A/C distance to threshold
HDG1 .... heading of action aircraft
SPD1 .... speed of action aircraft
ALT1 .... altitude of action aircraft
TRACK/SEP .. range and altitude separation of conflict
              (conflict exit - minimum separation during conflict)
                or
               A/C Tracking Code for Pilot or NTZ Actions
RWY2 .... Runway of second A/C
IDENT2 .. identity of second aircraft in confliction
TDST2 ... distance to threshold of second aircraft
HDG2 .... heading of second aircraft in conflict
SPD2 .... speed of second aircraft in conflict
ALT2 .... altitude of second aircraft in conflict
DEV ..... deviation from ILS center line (feet, L-left, R-right)
MX ...... maximum deviation during NTZ crossing (feet)
TDST .... distance flown along ILS during NTZ crossing (miles)
DUR ..... duration of NTZ crossing (seconds)
```

A SUMMARY of ACTIONS appears at the end of this report.
Those not discussed above are as follows:

LANDED ... Arrival Aircraft Landed
PILOTMSG . completed pilot keyboard messages
PILOTERR . pilot keyboard entry errors (these are not necessarily pilot errors, a controller may have given an incorrect command)
Every backspace is counted and if a CLR key is struck, every key in that message is counted as an error.
PKEYS .... pilot key strikes

6. PILOT MESSAGES

The Pilot Messages are extracted from the DEVFILE and Printed in Chronological Order.

Keyboard Key and Track Status Code definitions precede the Report.

```
  Pilot Keyboard - Key Definitions   Printed by: KEYDEFS
  Aircraft Track Codes               Printed by: PRTRKDEF

 TIME ..... Time of Message
 ACTION ... Type of Message
 RWY1 ..... Runway
 IDENT1 ... Operator and Flight Number
 TDST1 .... Distance to Threshold
 HDG1 ..... Heading
 SPD1 ..... Speed
 ALT1 ..... Altitude
 TRACK .... Track Status Code
 MESSAGE .. Pilot Message
```

7. EVENTS

The Events data are extracted from the OBVFILE.

The Parallel and Longitudinal Event Reports list only those actions which are most likely to be common with the Event. The NTZ Event Report lists the NTZ Entry/Exit information only.

```
 Conflicts:
  TIME ...... Time of Conflict Event
  ACTION .... PCNFNTRY (Parallel Conflict Entry)
              PCNFEXIT (Parallel Conflict Exit)
              NTZNTRY  (NTZ Entry)
              NTZEXIT  (NTZ Exit)
              VECTOR   (Heading Change)
              ALTITUDE (Altitude Change)
  ACTION .... LCNFNTRY (Longitudinal Conflict Entry)
              LCNFEXIT (Longitudinal Conflict Exit)
              SPEED    (Speed Change)
  IDENT1 .... Operator and Flight number of A/C-1
  TDST1 ..... A/C-1 distance to Threshold
  HDG1 ...... Heading of A/C-1
  SPD1 ...... True Air Speed of A/C-1
  ALT1 ...... Altitude of A/C-1
  TRACK/SEP . A/C Track Status or Horizontal Separation (Miles)
              Blank or             Vertical Separation (Feet)
  PILOT MESSAGE or the following:
  RWY2 ...... Blank or             Runway associated with A/C-2
  IDENT2 .... Operator and Flight of A/C-2
  TDST2 ..... A/C-2 distance to Threshold
  HDG2 ...... Heading of A/C-2
  SPD2 ...... TAS of A/C-2
  ALT2 ...... Altitude of A/C-2
```

Note: (1) For Longitudinal Conflicts (LCNFNTRY/LCNFEXIT), A/C-1 trails A/C-2.

(2) For Conflict Exits (LCNFEXIT/PCNFEXIT), HSEP and VSEP are the range and altitude separation at the closest SLANT RANGE during CONFLICT.

(3) The Asteriks (*****) in the Parallel Events indicate an intentionally Deviated Aircraft.

(4) A space is inserted before each Entry and after each Exit.

NTZ Events:

```
   TIME ....... Time of the Event
   ACTION ..... NTZENTRY (NTZ Entry)
                NTZEXIT (NTZ Exit)
   RWY ........ Runway
   IDENT ...... Operator and Flight Number of A/C
   TDST ....... Distance to Threshold
   HDG ........ Heading of A/C
   SPD ........ True Air Speed of A/C
   ALT ........ Altitude of A/C
   TRACK ...... A/C Tracking Status Code
   Deviation .  Deviation (feet, L-left, R-right), MX (maximum
                deviation in feet), TDST (distance flown toward
                threshold) and DUR (duration of deviation)
```

8. CONFLICTS

Conflicts are listed in two groups (1) Parallel (PCONFLCT) and (2) Longitudinal (LCONFLCT).

All Aircraft are tested for Vertical Separation of 1000 feet.

Parallel Horizontal Separation is 3 miles. The Test is conducted when one or both Aircraft are off the ILS.

Longitudinal Horizontal Separation is determined by the size of the two Aircraft using the following criteria:

Trail	Lead	Sep.	Trail	Lead	Sep.	Trail	Lead	Sep.
Small	Small	3	Large	Small	3	Heavy	Small	3
Small	Large	3	Large	Large	3	Heavy	Large	3
Small	Heavy	5	Large	Heavy	5	Heavy	Heavy	4

A Longitudinal Conflict Test is conducted when both Aircraft are on the same ILS.

The Greatest Risk is determined by an Algorithm develcped by Lee Paul, ACD-340 for this Project. The Routine returns an Aircraft Proximity Index (API) for Standard Conflicts (3 miles, 1000 feet).

Note: This was later modified by CRM to handle all Separation Standards.

TIME ...... Time of Conflict Event
ACTION .... PCONFLCT, LCONFLCT or SCONFLCT
RWY1 ...... Runway associated with A/C-1
IDENT1 .... Operator and Flight number of A/C-1
TDST1 ..... A/C-1 distance to Threshold
HDG1 ...... Heading of A/C-1
SPD1 ...... True Air Speed of A/C-1
RWY2 ...... Runway associated with AC-2
IDENT2 .... Pilot Message or Operator and Flight of A/C-2
TDST2 ..... A/C-2 distance to Threshold
HDG2 ...... Heading of A/C-2
SPD2 ...... TAS of A/C-2
HSEP ...... Horizontal Separation (Miles)
VSEP ...... Vertical Separation (Feet)
SLNTRSK ... Slant Range Risk (API) (1-least risk, 100-greatest)
RELATION .. Relationship of ILS's (B-1 side-by-side, B-2 an ILS between, B-3 Two ILS's between)

Note: For Longitudinal Conflicts (LCONFLCT), A/C-1 trails A/C-2.

9. FLIGHT TIME CHART

This is a Time plot of flight duration. The Aircraft are listed in Flight Plan Order and include all Aircraft that had a Start Time.

NO. .... flight number (order, in which, flight appears in the traffic sample)
ACID .... aircraft identity (operator and number)
START .... flight start time
END .... flight termination time
MINUTES-IN-PROBLEM . each plus (+) represents a portion of a minute the flight was in the problem

10. INSTANTANEOUS AIRCRAFT COUNT

The Instantaneous Aircraft count represents the Minimum and Maximum number of A/C handled simultaneously during each Minute.

11. PILOT KEY STRIKES

This report contains the number of key strikes entered by Pilots assigned to each Controller.

RWY .... Runway Name
CONT ...... Logical Controller Number
PVD .... Display Number
ALTITUDE .. altitude change
SPEED ..... speed change
HEADING ... heading change
BEACON .... beacon messages
CLEARED ... clearance
HOLD ...... hold messages
REPORT .... report messages
FREQXFER .. frequency transfers
MISSAPR ... missed approach
CANCEL .... cancel flight
PILOT-ER .. pilot keyboard entry errors (these are not necessarily pilot errors, a controller may have given an incorrect command)
Every backspace is counted and if a CLR key is struck, every key in that message is counted as an error
TOT-KEYS .. total key strikes by pilots assigned to controller

DATA FILES

1. BLNDCNF (Blunders and Associated Conflicts)

BLNDCNF contains Conflicts associated with Blunders.

COLUMN	ACRONYM	DESCRIPTION
2-5	RUNNBR	Run Number
7-11	STRTM	Start of Conflict
13-15	RWY1	Aircraft-1 Runway
17-23	ACID1	Aircraft-1 Identity
25-29	RISKTM	Highest Risk Time
31-34	API	Aircraft Proximity Index
36-40	ENDTM	End of Conflict
42-44	RWY2	Aircraft-2 Runway
46-52	ACID2	Aircraft-2 Identity
54-55	ILSFLAG	ILS Status of Aircraft-2

00-off ILS, Landed	10-on ILS, Landed
01-off ILS, did not Land	11-on ILS, did not Land
02-off ILS, Canceled	12-on ILS, Canceled

BLNDCNF Data Example:

RUN	STRT	RWY	ACID1	TIME	RISK	END	RWY	ACID2	ILSLFG
46	579	18R	TW906	621	13	643	16R	N5UMA	02
46	958	16L	EEC1240	988	5	1007	18R	AA365	10
46	958	16L	EEC1240	981	64	1020	17L	DL526	12
46	2103	16L	MEX3711	2133	28	2146	17L	AA286	01

```
2.    BLUNDERS and SIMBLNDR (Blunders with Next Message Aircraft)
                                          Generated by: FLAGBLND

   These Files contains all Blundering Aircraft and the next Aircraft
   on the blundering side to Key-in a path change message.

 COLUMN   ACRONYM      DESCRIPTION
 ------   -------      -----------
  2-5     RUNNBR ....... Run Number
  7-11    TIMEBA ....... Time of blunder
 13-15    RUNWAY1 ...... Runway associated with Blundering Aircraft
 17-23    IDENT1 ....... Blundering Aircraft Identity
    25    IDIR ......... Direction of blunder
 27-28    DEG .......... Heading change (degrees)
    30    COM .......... Blundering Aircraft communication Indicator
    32    NRWYT ........ Position of ILS affected (1) Side-by-Side,
                         (2) an ILS between, (3) two ILS's between, etc.
 34-38    TIMEMA ....... Time of Path Change Message
 40-42    RWY1 ......... Runway of Message Aircraft
 44-50    ID1 .......... Message Aircraft Identity
 52-96    MESG ......... Pilot Message

 Data Example - BLUNDERS File and SIMBLNDR File:

        BLUNDER:                 C R  MESSAGE:
RUN     TIME RWY ACID      VECT  M T  TIME RWY ACID     MESSAGE
---     ---- --- -----     ---- - -   ---- --- -----    --------
 60     1813 13R N756N     L 15  Y       0
 60     1826 13R N756N     R 15  N 1  1863 16R ASE2364 SPD  13C
 60     2019 17L AA215     R 15  Y 2  2021 16R ASE2444 SPD  13C
 60     2040 17L AA215     L 15  Y 1  2053 16L MTR876  CLMB 30  LEFT  HDG  0
 60     2318 18R DL443     L 20  Y 2  2332 16L MEX3711 SPD  11C

  Note: CM=Communications,  RT=Runway Threat
```

3. SNAPSHOT (Intentional Blunders)

Once an Aircraft has connected to the ILS, any change that causes it to disconnect is considered a deviation. This Report indicates the Aircraft, on Parallel Runways, that are within (+/-) 3.5 miles of the Threshold Distance of an Intentional Blunder. (Intentional Blunder - any Flight on the ILS that lists one of the Pilot Messages: LEFT 10,15,20,30 or RITE 10,15,20,30)

COLUMN	ACRONYM	DESCRIPTION
2-5	RUN	Run Number
7-11	BTIME	Time of the Blunder (seconds)
14-16	BRWY	Blundering A/C Runway
18-24	BID	Blundering A/C Identity
28	DIR	Direction of Blunder
31-32	AMT	Amount of Heading Change
36	COM	Blundering A/C Communication Indicator (Y or N)
41	THRT	Blundering A/C ILS proximity to Other A/C ((-) = Left)
43-49	BXCOORD ...	Blundering A/C X-Coordinate
51-57	BYCOORD ...	Blundering A/C Y-Coordinate
59-64	BALT	Blundering A/C Altitude
66-69	BSPD	Blundering A/C Speed
71-76	BDALT	Blundering A/C Climb/(-)Descend Rate
79-81	ORWY	Other A/C Runway
83-89	OID	Other A/C Flight Identity
91-97	OXCOORD ...	Other A/C X-Coordinate
99-105	OYCOORD ...	Other A/C Y-Coordinate
107-112	OALT	Other A/C Altitude
114-117	OSPD	Other A/C Speed
119-124	ODALT	Other A/C Climb/(-)Descend Rate
126	IND	(*) = Other A/C Trailing Blundering A/C

4. SUMMARY FILE (SUMFILE)

SUMFILE contains the Action Counts per Controller

COLUMN	ACRONYM	DESCRIPTION
2-5	RUN	Run number
7-9	RNWY	Runway
11-14	CONT	Logical Controller
17	CID	Controller ID
19-24	NHAND	Number of Aircraft Handled
25-30	NDEV	Number of Deviations from ILS
31-36	NBLND	Number of Blunders
37-42	NTZE	Number of NTZ Entries
43-48	NTZX	Number of NTZ Exits
49-54	LCNFE	Number of Longitudinal Conflict Entries
55-60	MLAPI	Maximum Longitudinal API
61-66	PCNFE	Number of Parallel Conflict Entries
67-72	MPAPI	MaximumoParallelaAPIonflict Exits
73-78	SR500	Number of Conflicts within 500 feet
79-84	SR300	Number of Conflicts within 300 feet
85-90	SPD	Number of Speed Messages
91-96	MISS	Number of Missed Approaches
97-102	CANCL	Number of Canceled Flights
103-108	LAND	Number of Number of Arrival Landings
109-114	PILOT	Number of Pilot Messages

5. TRANSGRESSION FILE (TRANFILE)

TRANFILE contains No-Transgression-Zone (NTZ) violations.

COLUMN	ACRONYM	DESCRIPTION
2-5	RUN	Run number
7-11	TIME	Internal Simulation Time (seconds)
13-15	RWY	Runway
17-24	ACTION	NTZ Entry (NTZNTRY) or NTZ Exit (NTZEXIT)
26-32	IDENT	Operator and Flight number of blundering A/C
34-38	TDST	Distance to Threshold at time of Exit
40-44	HDG	Heading of blundering A/C
46-50	SPD	True Air Speed of Blundering A/C
52-57	ALT	Altitude of Blundering A/C
59-63	TRACK	Track Status of Blundering A/C
77-82	DEV	Deviation (feet) upon Entering/Exiting NTZ
84	DIR	Direction of Deviation
89-93	MX=	Maximum Deviation
100-104	TDST=	Distance flown toward Threshold while in NTZ
110-113	DUR=	Duration of Transgression

6. VECTFILE (Deviated Aircraft)

This File contains all Aircraft that were deviated from the ILS.

COLUMN	ACRONYM	DESCRIPTION
2-5	RUN	Run Number
7-11	TIME	Vector Time (seconds)
14-16	RWY	Runway
18-24	ACID	Aircraft Identity
26-32	X	X-Coordinate
34-40	Y	Y-Coordinate
42-47	ALT	Altitude
49-55	CL/DSC	Climb/(-)Descend
57-61	SPD	True Air Speed
63-66	TRACK	Aircraft Tracking Status

Example - VECTFILE File:

RUN	TIME	RWY	ACID	X	Y	ALT	CL/DSC	SPD	TRACK
46	579	18R	TW906	480.79	343.67	3335.	-15.96	170.	1000
46	614	16R	N50MA	479.84	344.13	2785.	-13.80	180.	1000
46	747	18R	DL1028	480.79	352.76	4994.	-6.00	158.	1000
46	791	16R	ASE2446	479.84	353.52	3994.	-6.00	160.	1000
46	882	16R	MTR826	479.84	344.88	2987.	-7.08	169.	1000
46	958	16L	EEC1240	483.04	340.65	2212.	-12.94	170.	1000
46	1007	16R	N1626L	479.84	347.15	3585.	-13.19	170.	1000
46	1017	18R	DL698	480.79	343.11	3161.	-10.36	181.	1000
46	1029	16L	ASE2998	483.05	341.05	2316.	-12.96	170.	1000
46	1138	17L	AA199	482.21	335.52	5000.	.00	221.	1000

10. FLIGHT ACTION FILE (ACTFILE)

ACTFILE contains Actions taken by the Pilot due to controller commands. Since Actions include Pilot Messages, Entry/Exit into the No-Transgression-Zone and Entry/Exit of the Parallel and Longitudinal Conflicts, LINE is used to read the Data after the second Runway. HSEP contains the Aircraft Track Status for Pilot Messages and NTZ Actions.

```
COLUMN  ACRONYM   DESCRIPTION
------  -------   -----------
  2-5   RUN ..... Run Number
  7-9   RWY1 .... Action Runway
 11-15  TIME .... Time of Action
 17-23  IDENT1 .. Flight Identity of Aircraft performing Action
 25-32  ACTION .. Action concerning Aircraft as follows:
          NTZNTRY  .. Entry into NO-TRANSGRESSION-ZONE (NTZ)
          NTZEXIT  .. Exit from NTZ
          LCNFNTRY .. Start of Longitudinal Conflict
          LCNFEXIT .. End of Longitudinal Conflict
          PCNFNTRY .. Start of Parallel Runway Conflict
          PCNFEXIT .. End of Parallel Runway Conflict
        Pilot Keybord Messages:
          ALTITUDE .. Altitude Change
          CANCEL .... Cancel Flight
          CLEARED ... Clearance
          MISSED .... Missed Approach
          INFORM .... Pilot Information
          SPEED ..... Speed Change
          WARNING ... Controller NTZ Warning
          VECTOR .... Heading Change
 34-38  TDST1 ... Action A/C Distance to Threshold
 40-44  HSEP/TRACK . Horizontal Separation or Tracking Status
                     Conflict Exit - Minimum Separation during Conflict
                      or
                     A/C Tracking Code for Pilot or NTZ Actions
 46-50  VSEP ....... Vertical Separation or blank
 52-56  HDG1 .... Heading of Action Aircraft
 58-62  SPD1 .... Speed of Action Aircraft
 64-69  ALT1 .... Altitude of Action Aircraft
 71-73  RWY2 .... Runway of second A/C or blank
 75-119 LINE .... Pilot Message or the following:
         IDENT2 .. Identity of second Aircraft in Confliction
         TDST2 ... Distance to Threshold of second Aircraft
         HDG2 .... Heading of Second Aircraft in Conflict
         SPD2 .... Speed of Second Aircraft in Conflict
         ALT2 .... Altitude of Second Aircraft in Conflict
         DEV ..... Deviation from ILS Center Line (feet, Left or Right)
         MX ...... Maximum Deviation during NTZ crossing (feet)
         TDST .... Distance Flown along ILS during NTZ crossing (miles)
```

DUR ..... Duration of NTZ crossing (seconds)

APPENDIX F

ORIGINAL SIMULATION SCHEDULE

CONTROLLER ASSIGNMENT PLAN
SEPT. 21,1989

Five controllers will be randomly assigned letters A, B, C, D, or E. The controllers will rotate among the positions after each run, with one or two excused from the run.

DAY 1 MON SEPT. 25, 1989

---

two airports, dual runways

RUN#	18R	17L	17L	16L
1	A	B	C	E

DAY 2 TUES SEPT. 26, 1989

---

two airports, dual runways

RUN#	8R	17L	17L	16L
2	B	D	A	C
3	E	C	D	A
4	E	A	B	D

one airport, triple runways

RUN#	18R	17L	16L
5	A	B	E
6	D	A	C

DAY 3 WEDS SEPT. 27, 1989

---

one airport, triple runways

RUN#	18R	17L	16L
7	E	A	B
8	B	D	A
9	D	A	B
10	A	B	C
11	C	A	B

CONTROLLER ASSIGNMENT PLAN
SEPT. 21, 1989

DAY 4 THURS SEPT. 28, 1989

---

one airport, triple runways

RUN#	18R	17L	16L
12	C	E	B
13	B	C	D
14	E	A	D
15	D	E	A
16	E	C	D

DAY 5 FRI SEPT. 29, 1989

---

one airport, triple runways

RUN#	18R	17L	16L
17	D	E	B
18	E	B	C

two airports, dual runways

RUN#	18R	17L	17L	16L
19	C	B	A	E
20	D	E	B	C
21	B	A	E	C

DAY 6 MON OCT. 2, 1989

---

two airports, dual runways

RUN#	18R	17L	17L	16L
22	A	C	D	B

one airport, triple runways

RUN#	18R	17L	16L
23	C	D	B
24	B	E	A
25	B	C	E
26	C	E	A

CONTROLLER ASSIGNMENT PLAN
SEPT. 21, 1989

DAY 7 TUES OCT. 3, 1989

---

one airport, triple runways

RUN#	18R	17L	16L
27	A	C	D
28	E	A	C
29	E	B	D
30	B	C	A
31	D	B	C

DAY 8 WEDS OCT. 4, 1989

---

one airport, triple runways

RUN#	18R	17L	16L
32	A	D	E
33	D	E	C
34	C	D	A
35	A	C	E
36	B	D	E

DAY 9 THURS OCT. 5, 1989

---

two airports, dual runways

RUN#	18R	17L	17L	16L
37	D	A	B	E
38	B	C	E	D
39	C	D	A	B
40	E	B	C	A

APPENDIX G

CONTROLLER INFORMATION QUESTIONNAIRE AND CONSENT FORM

CONTROLLER BIOGRAPHICAL AND INFORMED
CONSENT QUESTIONNAIRE
SIMULATION OF TRIPLE PARALLEL RUNWAY APPROACHES

Part 1: Biographical Information

This questionnaire will help us to obtain relevant information with respect to your background as a controller, which may help us to better understand your performance in the simulation experiment. We would appreciate your taking the time to complete the few questions listed below. All information provided on this form will remain confidential, and the form itself will be destroyed following the completion of this project.

Date: ________________

1. How many years of experience do you have as an air traffic controller? _____________
2. How many years of experience have you had at your current facility? _______________
3. How many years have you worked parallel approaches? ________________

Part 2: Informed Consent

It is important to us that participating controllers in the simulation experiment 1) are fully informed with respect to the goals and procedures to be used in the experiment, and 2) have freely consented to participate in the simulation.

Please sign your name to indicate your agreement with the following statement:

"I have been fully briefed with respect to the goals of the simulation experiment and my role as a controller in the experiment. I further submit that I have freely chosen to participate in this study, and understand that I may withdraw from participation at any time, should I find it necessary to do so."

____

APPENDIX H

TECHNICAL OBSERVER REPORT

D/FW METROPLEX
AIR TRAFFIC SYSTEM PLAN

SIMULATION OF TRIPLE INDEPENDENT PARALLEL RUNWAYS OPERATIONAL ASSESSMENT

D/FW PROGRAM OFFICE

Sept. 25 - Oct. 6, 1989

Prepared by:
D/FW METROPLEX
AIR TRAFFIC SYSTEM PLAN
PROGRAM OFFICE

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U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL AVIATION ADMINISTRATION
SOUTHWEST REGION

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The goal of the triple, independent instrument landing system (ILS) simulation was to demonstrate the safety and feasibility of multiple parallel approaches to independent runways with all types of aircraft.

The D/FW Metroplex Air Traffic System Plan Program Office provided staff support and acted as observers throughout the simulation. During the simulation, the Program Office staff recorded the control instructions issued by the controllers and the estimated minimum slant range distance between blundering aircraft and the aircraft affected by the blunder. The records of the observers indicate two types of situations. The first type of situation was blunders--this includes turns of 30 degrees or less, with and without radio communications, which required aircraft on adjacent ILS courses be vectored to avoid the blundering aircraft. The second type of situation recorded the "turn left/right and rejoin the ILS" instructions issued to resolve the programmed navigation error.

The simulation included 16 dual ILS runs in which the observers recorded 207 blunders and 1,395 turn and join situations. The simulation also included 28 triple ILS runs in which the observers recorded 294 blunders and 2,094 turn and join situations.

The Triple Independent ILS Simulation Executive Committee determined that all situations which resulted in less than 500 feet slant range would receive an indepth analysis. The observers decided to analyze all situations in which less than 3,000 feet slant range was computed. In the simulation, duals produced 207 blunders of which 12 resulted in less than 3,000 feet slant range distance. In the simulation, triples produced 310 blunders of which 14 resulted in less than 3,000 feet slant range distance. Annexes 1 and 2 describe these situations.

During the dual simulation, the closest point of approach occurred in Run 4 - 2 and was estimated to be (0 ft - 0 NM) and computed to be 1,103 feet slant range. The slow response of the simulation operator pilot created this situation. A period of 15 to 20 seconds lapsed between the initial clearance response and the time the aircraft began to turn. In Run 4 - 2a, the controller called an aircraft by the wrong call sign. This may or may not have contributed to the creation of closest point of approach, estimated to be (200 ft - 1/4 NM), and computed to be 1,712 feet slant range. The closest point of approach in which the observers could not detect reaction delay by either pilot or controller occurred in Run 26 - 1. The miss distance was estimated to be (0 ft - 1 NM) and computed to be 2,279 feet slant range.

During the triple simulation, the closest point of approach occurred in Run 31, estimated to be (200 ft - 1 NM), and was computed to be 1,229 feet slant range. However, this distance occurred between two aircraft being vectored away from a blundering aircraft and **did not** involve a blundering aircraft. The closest point of approach involving a blundering aircraft occurred in Run 35, estimated to be (200 ft - 2 NM), and was computed to be 1,684 feet slant range. However, this slant range distance occurred after the pilot made a 90-degree left turn. The pilot continued the turn, resulting in a 180-degree left turn. The observers did not detect reaction delays by the controllers which resulted in less than 3,000 feet slant range miss distance during the triple simulation. The closest point of approach in which the observers did not detect reaction delays by the pilot occurred in Run 22, estimated to be (400 ft - 1/8 NM), and was computed to be 2,084 feet slant range.

The triple simulation had one run in which the blunders were not scripted. Representatives of Aviation Standards National Field Office (AVN) and Flight Standards Service (AFS) induced, on a random basis, blunders of 30-degree turns, with and without radio communications, during a 1-hour run. The intent of the run was to create situations which would result in a "worse case" condition. This was accomplished by arbitrarily manipulating an aircraft to a point where an aircraft was then either parallel or slightly behind on an adjacent ILS and approximately the same altitude before beginning the blunder. During the run, the observers recorded 17 blunders and 63 "turn and join" instructions being issued. The closest point of approach was observed to be (400 ft - 1/8 NM) and computed to be 1,863 feet slant range.

The simulation proved most emphatically the feasibility of implementing the triple ILS procedures at Dallas/Fort Worth International Airport without any degradation of safety.

INTRODUCTION

Implementation of the D/FW Metroplex Air Traffic System Plan will require new and innovative procedures to accommodate the increased volume of traffic projected for Dallas/Fort Worth International Airport.

Dallas/Fort Worth International Airport will construct two new parallel north/south runways on the east and west side of the airport. The east runway (16L/34R) will be approximately 8,500 feet long and 5,000 feet east of the center of Runway 17L. The west runway (16R/34L) will be approximately 8,500 feet long and 5,800 feet west of the centerline of Runway 18R. In order to gain full capacity of the new runways, procedures must be developed which allow multiple (more than two), simultaneous parallel ILS approaches be conducted during weather minimums of 200-foot ceiling and visibility of 1/2 NM.

The multiple, simultaneous parallel ILS approach simulations are being conducted in phases. Phase I was completed in June 1988. Phase II, triple independent ILS simulation, was conducted at the Federal Aviation Administration (FAA) Technical Center in Atlantic City, New Jersey, from September 25 through October 6, 1989.

Phase III, quadruple parallel ILS approach simulation, will be conducted at the FAA Technical Center January 29 through February 9, 1990.

The Dallas/Fort Worth TRACON/Tower provided five individuals--one supervisor, one traffic management specialist, and three controllers--to participate in the simulation. The D/FW Metroplex Air Traffic System Plan Program Office provided the staff support and acted as observers documenting the actions of the controllers throughout the simulation.

ANALYSIS

The simulation consisted of two separate scenarios with the runway layout unique to Dallas/Fort Worth International Airport. The first scenario studied dual parallel ILS approaches consisting of two separate runway layouts. One set of runways included Runways 18R and 17L with Runways 17L and 16L as the second set. The second scenario studied the triple, parallel ILS approaches using Runways 16L, 17L, and 18R. Simulation runs were made using the dual runways to compare the resulting data with the triple runway data.

Throughout the simulation, the controllers encountered unexpected situations and conditions to which they responded with excellent success, which provides further emphasis to our conclusions. The following paragraphs outline some of the general problems and situations. Annex 1 (Duals) and Annex 2 (Triples) explains the instances in which less than 3,000 feet slant range distance resulted between a blundering aircraft and an aircraft on an adjacent ILS.

BLUNDERS: The simulation included several types of scripted blunders, which were introduced at various times during a 1-hour run, without the prior knowledge of the controllers or observers. These blunders included 10, 20, and 30-degree turns with and without radio communication. Due to the navigational parameters set in the computer, the controllers and observers were unable to differentiate between 10 or 20-degree blunders and a navigational error in which the controller had radio communications with the aircraft. Further explanation of this is in the Navigation paragraph. Those blunders which involved nonradio conditions were detected immediately and the controllers issued instructions to turn/climb the aircraft on the adjacent ILS.

A 30-degree blunder in which the controller had radio communications, however, created a specific problem. When an aircraft on Runway 17L began a 30-degree left/right turn, the controllers would instruct the aircraft to turn right/left and join the ILS. The computer would then turn the aircraft back towards the ILS. However, the aircraft's angle of approach back to the ILS was such that the aircraft flew through the ILS course and then proceeded towards the No Transgression Zone (NTZ) before making another turn back to the ILS course (see figure 1). In several situations, the controllers would turn an aircraft on the outside ILS to separate it from the first 30-degree turn, and then the controller on the opposite, outside ILS would turn the aircraft in his control to separate it from the blundering aircraft when it flew through the ILS course the second time.

NAVIGATION: The navigation parameters programmed in the computer created a situation which eliminated the 10 and 20-degree blunders with radio communications. The navigation parameters allowed the aircraft to deviate either side of the centerline of the ILS along the entire final approach course. The amount of deviation did reduce as the aircraft came closer to the end of the runway. The controllers would detect the deviation and instruct the aircraft to turn left/right and join the ILS. The large volume of turn and join clearances completely eliminated the 10 and

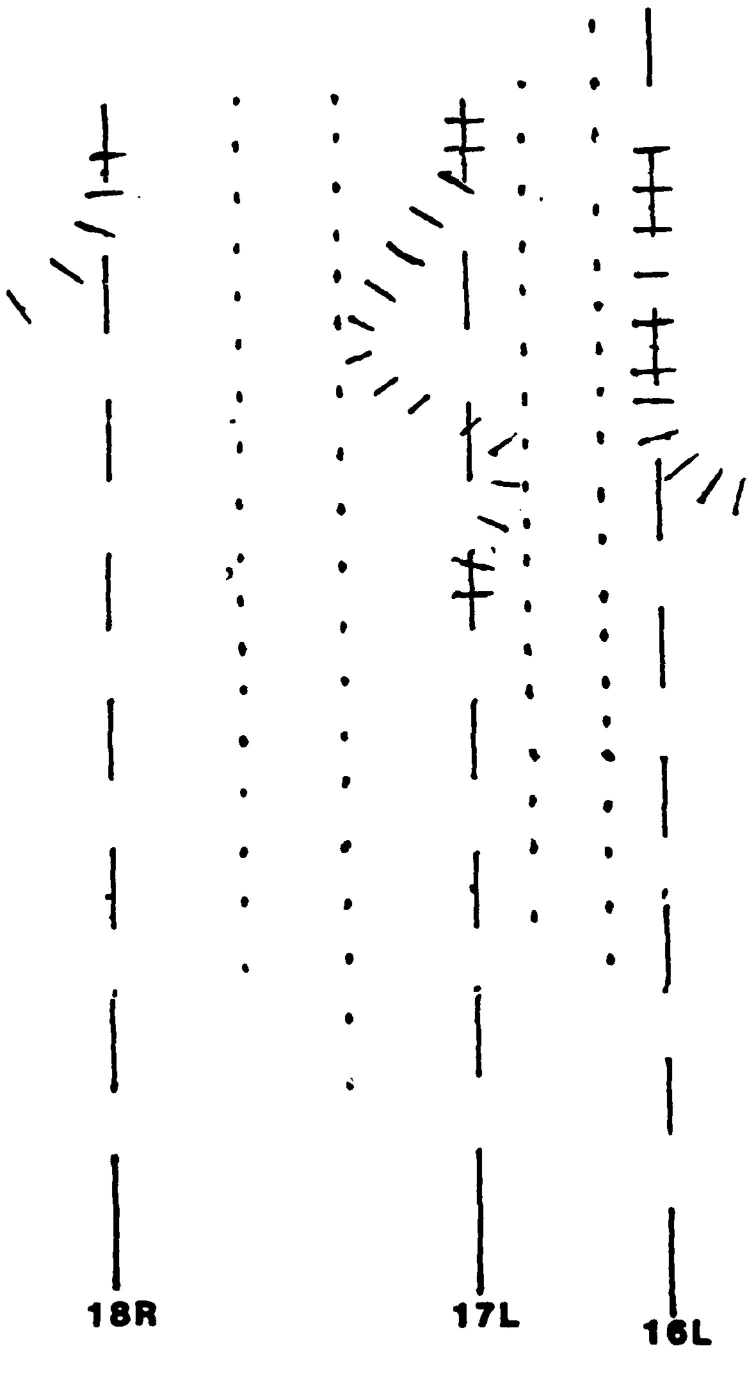

Figure 1

20-degree blunders with radio communications, which had been scripted into the simulation. In the vast majority of the 36 runs, these turn and join clearances were issued more than 25 times for each runway in a 1-hour run.

PILOTS: Simulation pilots were a major concern because simulation results could be greatly affected by the ability of the pilots. During the course of the simulation, pilot error fell into two categories.

a. Human Error - Slow response to aircraft calls and the entry of control instructions.

b. Computer Problems - Entry problems which were beyond the control of the pilots.

The controllers and observers were unable to determine the difference, and all the problems are combined under the general category of "pilot error."

Initially, the pilots were unfamiliar with the simulation scenarios and their response times reflect this. During the first several runs, the responses from the pilots improved dramatically. After the initial improvement, the pilots generally performed at a level of competence which allowed the simulation to achieve realistic results. Overall, the pilots performed in an outstanding manner and are to be commended.

EQUIPMENT: During the simulation, we encountered some minor computer problems and scope failures which were an inconvenience to the simulation.

However, the controllers were able to handle the indicator failures which occurred in the middle of two runs without any difficulty. The indicator failures were unplanned but added realism to the evaluation. The failures also provided support to the proposed final monitor equipment layout.

RUNS: The information contained in Annexes 1 (Dual) and 2 (Triple) provides a brief explanation of the occasions in which a blundering aircraft came within 3,000 feet or less slant range of an aircraft on the adjacent ILS courses. The following is a brief explanation of the information. The first sections contain run number, date, start time, runways used, and controller assignment. The second section outlines the blunder. The aircraft call sign that follows the time is the blundering aircraft. The aircraft call signs which follow are those aircraft which were affected by this blunder. Under each of these aircraft is the minimum estimated lateral distance as viewed by the observers. The last section is a brief overview of what control actions were initiated and the results.

The aircraft proximity index (API), developed by the Technical Center, is a single value that reflects the relative seriousness or danger of the situation. The API assigns a weight or value to each conflict, depending on vertical and lateral distance. API facilitates the identification of the more serious conflicts in a data base where many conflicts are present. A figure of 100 is the maximum value of the API. Therefore, the higher the API, the closer the aircraft. It should be noted that, in the dual runs, Run 4 produced the highest API of 77, but pilot error heavily influenced this figure. In the triple runway runs, Run 22 produced the highest

API of 68, and it should be noted that these aircraft had a slant range of 2,795 feet. If further explanation of the API is desired, it can be obtained from the Technical Center.

CONCLUSION

The D/FW Metroplex Air Traffic System Plan Program Office is thoroughly convinced that the triple, parallel ILS simulation was a complete success. The triple, parallel ILS simulation proved without a doubt that, with existing equipment and the runway layout available at Dallas/Fort Worth International Airport, these procedures are safe. The failure of the radar indicators during the simulation only serves to emphasis the controllers' ability to resolve the problems when they occur and supports the feasibility of triple parallel ILS approaches.

RECOMMENDATIONS

During the simulation, events occurred which created problems and delayed some of the runs. These events included both hardware and software problems with the computer, inexperience of the pilots, and the unfamiliarity of the participating controllers. The major problem was the result of the computer failures which delayed some of the runs and required overtime for the controllers to return to the prescribed schedule. The strain on the controllers created by the importance and visibility of this simulation was exhausting. The importance of these simulations is such that a failure due to fatigue should never occur. Therefore the D/FW Metroplex Air Traffic System Plan Program Office proposes the following changes in future simulations.

a. Makeup time should be scheduled during any simulation to resolve computer problems.

b. The maximum number of 1-hour runs should be five each day with no exceptions.

c. Additional controllers should be available.

d. The first full day should be devoted to indoctrination and familiarization for both the controllers and pilots.

ANNEX 1

(DUALS)

ANNEX 1 (DUALS)

RUN SUMMARY

RUN	BLUNDERS	TURN/JOIN
1 - 1	7	108
1 - 2	25	161
2 - 1	16	100
2 - 2	15	117
3 - 1	19	66
3 - 2	6	80
4 - 1	15	43
4 - 2	14	57
5 - 1	13	71
5 - 2	15	43
23 - 1	8	32
23 - 2	13	77
24 - 1	14	69
24 - 2	7	72
26 - 1	14	100
26 - 2	6	17
TOTALS 16	207	1,395

Blunders: less than 3,000 feet slant range distance - 12

less than 500 feet slant range distance - 0

NOTE: - 1 refers to Runway 16L and 17L

- 2 refers to Runway 17L and 18R

DUALS RUN ANALYSIS

RUN 1 - 2	9/26/89	09:15 LCL
RUN 1 - 2	9/26/89	09:15 LCL
RUNWAYS 16L	CONTROLLERS: C	
17L	E	

0009:00 DAL263 Rwy 16L Turned right - No radio

DAL815 Rwy 17L Turned right

(1,000 ft - ? NM)

The target of DAL263 disappeared; therefore, we were unable to give an estimate.

The closest point of approach was computed to be 1,575 feet slant range with an API of 1.

0054:00 AAL147 Rwy 17L Turned left - No radio

AAL1239 Rwy 16L Turned left and climbed

(500 ft - 1/4 NM)

The pilot of AAL1239 did not respond until the third call.

The closest point of approach was computed to be 2,748 feet slant range with an API of 2.

RUN 3 - 2		9/26/89	14:00 LCL
RUNWAYS	16L	CONTROLLERS:	D
	17L		A

0023:00	AAL694	Rwy 17L	Turned left - No radio
	DAL234	Rwy 16L	Turned left and climbed (400 ft - 1/4NM)

The pilot of DAL234 responded after the third call and reaction of the aircraft was slow.

The closest point of approach was computed to be 2,432 feet slant range with an API of 33.

RUN 4 - 1		9/26/89	15:20 LCL
RUNWAYS	17L	CONTROLLERS:	A
	18R		D

0032:00	DAL124	Rwy 18R	Turned right
	DAL182	Rwy 17L	Turned right and climbed

DAL124 was over the airport at 600 ft MSL when the aircraft turned right.

The closest point of approach was computed to be 1,771 feet slant range with an API of 39.

RUN 4 - 2		9/26/89	15:20 LCL
RUNWAYS	16L	CONTROLLERS:	E
	17L		B

0008:00	TWA906	Rwy 16L	Turned left - No radio
	AAL453	Rwy 17L	Turned right and climbed
			(300 ft - 1/10 NM)

The pilot of AAL453 was slow to climb the aircraft.

The closest point of approach was computed to be 1,858 feet slant range with an API of 31.

0038:00	AAL690	Rwy 16L	Turned right - No radio
	DAL375	Rwy 17L	Turned right and climbed
			(200 ft - 1/2 NM)

The pilot of DAL375 read back AAL375 and was slow to respond to the clearance.

The closest point of approach was computed to be 2,399 feet slant range with an API of 37.

0045:00 AAL893 Rwy 16L Turned right - No radio

AAL554 Rwy 17L Turned right and climbed

(200 ft - 1/4 NM)

The controller of AAL554 used the wrong call sign, he called AAL524; however, he corrected the call sign immediately.

The closest point of approach was computed to be 1,712 feet slant range with an API of 48.

0058:00 AAL356 Rwy 16L Turned right - No radio

DAL937 Rwy 17L Turned right and climbed

(0 ft - 0 NM)

The pilot of DAL937 acknowledged the turn and climb but did not respond to the clearance. Between 15 and 20 seconds lapsed between the initial clearance response and the time the aircraft began to turn. When the clearance was issued, AAL356 and DAL937 were approximately 300 feet and 3/4 NM apart. When the first action of DAL937 was observed, the distance had deteriorated to near collision conditions.

The closest point of approach was computed to be 1,103 feet slant range with an API of 77.

RUN 5 - 2		9/27/89	08:50 LCL
RUNWAYS	16L	CONTROLLERS:	C
	17L		E

0036:00	DAL375	Rwy 17L	Turned left - No radio
	AAL890	Rwy 16L	Turned left and climbed
			(500 ft - 1/4 NM)

The closest point of approach was computed to be 2,947 feet slant range with an API of 22.

0045:00	AAL893	Rwy 16L	Turned right - No radio
	AAL554	Rwy 17L	Turned right and climbed
			(100 ft - 1/8 NM)

The pilot of AAL554 did not respond to first call, and the second call resulted in a slow response.

The closest point of approach was computed to be 2,169 feet slant range with an API of 62.

RUN 26 - 1		10/2/89	14:30 LCL
RUNWAYS	16L	CONTROLLERS:	D
	17L		E

0012:51	AAL621	Rwy 16L	Turned right - No radio
	DAL626	Rwy 17L	Turned right and climbed (0 ft - 1 NM)
	AAL527	Rwy 17L	In front of DL626; AA621 passed behind.

The closest point of approach between AAL621 and AAL527 was computed to be 2,279 feet slant range with an API of 41.

RUN 26 - 2		10/2/89	14:30 LCL
RUNWAYS	17L	CONTROLLERS:	C
	18R		B

0044:20 AAL276 Rwy 17L Turned right - No radio

AAL570 Rwy 18R Turned right and descended

(200 ft - 1/4/NM)

The closest point of approach was computed to be 2,772 feet slant range with an API of 50.

ANNEX 2

(TRIPLES)

ANNEX 2 (TRIPLES)

RUN SUMMARY

RUN	BLUNDERS	TURN/JOIN
6	14	98
7	16	87
8	12	58
9	11	80
10	14	82
11	5	36
(Clocked stopped at 00:27)		
12	11	119
13	9	104
14	10	82
15	9	83
16	9	64
17	13	81
18	9	101
19	6	82
20	14	73
21	14	42
22	7	74
25	8	53
27	10	63
29	8	69
30	9	61
31	12	57
32	13	70

33	8	82
34	11	38
35	10	77
36	10	83
37	17	63
TOTALS 29	310	2,157

Blunders: less than 3,000 feet slant range distance - 14

less than 500 feet slant range distance - 0

TRIPLES RUN ANALYSIS

RUN 9		9/27/89	16:10 LCL
RUNWAYS	16L	CONTROLLERS:	C
	17L		B
	18R		E

0042:55	AAL556	Rwy 17L	Turned left - No radio
	AAL893	Rwy 16L	Turned left and climbed
		(400 ft - 1/2 NM)	

The closest point of approach was computed to be 2,511 feet slant range with an API of 27.

0048:51	AAL551	Rwy 16L	Turned right
	DAL1666	Rwy 17L	Turned right and climbed
		(300 ft - 1/4 NM)	
	UAL311	Rwy 18R	Turned right and climbed
		(1,000 ft - 3 NM)	

The pilot of DAL1666 turned left instead of right.

The closest point of approach between AAL551 and DAL1666 was computed to be 2,609 feet slant range with an API of 31.

RUN 22		10/2/89	09:00 LCL
RUNWAYS	16L	CONTROLLERS:	D
	17L		C
	18R		B

0035:48	AAL555	Rwy 17L	Turned left - No radio
	AAL344	Rwy 16L	Turned left and climbed (0 ft - 1/4 NM)

The closest point of approach was computed to be 2,795 feet slant range with an API of 68.

0040:14	TWA525	Rwy 17L	Turned left - No radio
	AAL445	Rwy 16L	Turned left and descended (400 ft - 1/8 NM)

The closest point of approach was computed to be 2,084 feet slant range with an API of 30.

RUN 25		10/2/89		13:20 LCL
RUNWAYS	16L	CONTROLLERS:	B	
	17L		A	
	18R		C	

0039:00	AAL295	Rwy 17L	Turned left - No radio
	AAL628	Rwy 16L	Turned left and climbed
		(300 ft - 1/8 NM)	

The pilot of AAL628 was slow to respond. AAL628 was given an immediate left turn and approximately 14 seconds later (3 updates) the aircraft turned.

The closest point of approach was computed to be 2,355 feet slant range with an API of 50.

RUN 28		10/3/89		10:10 LCL
RUNWAYS	16L	CONTROLLERS:	C	
	17L		B	
	18R		D	

0028:55 DAL1916 Rwy 17L Turned left - No radio

BNF524 Rwy 16L Turned left and climbed

(100 ft - 1/4/NM)

The closest point of approach was computed to be 2,846 feet slant range with an API 55.

0045:35 AAL1343 Rwy 18R Turned left - No radio

DAL179 Rwy 17L Climbed

(200 ft - 1/4 NM)

MID231 Rwy 16L Turned left and climbed

(200 ft - 3/4 NM)

The pilot of DAL179 required five calls to respond to the climb clearance.

The closest point of approach between DAL179 and AAL1343 was computed to be 2,469 feet slant range with an API of 3; between AAL1343 and MID231 was 15,268 feet slant range with an API of 1.

RUN 31		10/3/89		15:00 LCL
RUNWAYS	16L	CONTROLLERS:	B	
	17L		C	
	18R		A	

0045:38	DAL179	Rwy 17L	Turned left - No radio
	AAL424	Rwy 18R	Turned left and climbed
		(200 ft - 1 NM)	

The closest point of approach between DAL179 and AAL424 was computed to be 13,387 feet slant range with an API of 1.

The pilot of DAL179 continued the right turn and made a complete 90-degree turn. The controllers continued to vector aircraft away from DAL179, and the closest point of approach of 1,229 feet slant range was realized between AAL281 and AAL1343, which were aircraft being vectored away from DAL179. The closest point of approach between DAL179 and AAL1343 was computed to be 8,221 feet slant range with an API of 18. The closest point of approach between DAL179 and AAL281 was not computed; therefore, these aircraft never came closer than 1,000 feet and 3 NM.

RUN 32		10/4/89		08:05 LCL
RUNWAYS	16L	CONTROLLERS:	D	
	17L		B	
	18R		C	

0051:43	BNF580	Rwy 17L	Turned left - No radio
	AAL989	Rwy 16L	Turned left and descended
		(500 ft - 1/8 NM)	

The closest point of approach was computed to be 2,774 feet slant range with an API of 25.

RUN 35		10/4/89	11:30 LCL
RUNWAYS	16L	CONTROLLERS:	B
	17L		A
	18R		D

0019:00	AAL944	Rwy 18R	Turned left - No radio
	AAL218	Rwy 17L	Climbed
		(200 ft - 2 NM)	
	AAL101	Rwy 16L	Turned left and climbed
		(200 ft - 1 NM)	

The pilot of AAL944 turned the aircraft 90 degrees to the left and then continued the turn to a heading of 360.

The closest point of approach between AAL944 and AAL218 was computed to be 1,684 feet slant range with an API of 1. The closest point of approach between AAL944 and AAL101 was computed to be 11,877 feet slant range with an API of 1.

When AAL944 turned left to a heading of 360, N756N 16L was turned left and climbed. The closest point of approach between AAL944 and N756N was computed to be 14,520 feet with an API of 1.

0054:20 NWA401 Rwy 18R Turned left - No radio

This aircraft was 1/4 NM north of the approach end of the runway and approximately 200 feet above the ground. The aircraft continued to descend and made contact with the ground prior to entering the No Transgression Zone and no other aircraft were involved.

0054:45 AAL1237 Rwy 17L Turned left - No radio

AAL147 Rwy 16L Turned left and climbed (100 ft - 1/4 NM)

The closest point of approach was computed to be 2,546 feet slant range with an API of 55.

RUN 37		10/5/89		08:24 LCL
RUNWAYS	16L	CONTROLLERS:	A	
	17L		D	
	18R		B	

0028:36	AAL949	Rwy 18R	Turned left - No radio
	DAL796	Rwy 17L	Climbed
		(100 ft - 1 1/2 NM)	
	DAL881	Rwy 16L	Turned left and climbed
		(300 ft - 1/2 NM)	

The closest point of approach between DAL796 and AAL949 was computed to be 7,828 feet slant range with an API of 23. Between DAL796 and DAL881 there was 2,583 feet slant range with an API of 1.

0045:37	AAL1406	Rwy 17L	Turned left - No radio
	DAL193	Rwy 16L	Turned left and climbed
		(400 ft - 1/8 NM)	

The closest point of approach was computed to be 1,863 feet slant range with an API of 24.

APPENDIX I

CONTROLLER REPORT

D/FW METROPLEX
AIR TRAFFIC SYSTEM PLAN

SIMULATION OF TRIPLE INDEPENDENT PARALLEL RUNWAYS OPERATIONAL ASSESSMENT

Sept. 25 - Oct. 6, 1989

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U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL AVIATION ADMINISTRATION
SOUTHWEST REGION

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EXECUTIVE SUMMARY

Our task was to evaluate the feasibility of running triple independent instrument landing system (ILS) approaches to runways 18R, 17L, and 16L at Dallas/Fort Worth (D/FW) Airport. The test simulated jets on approach to all three runways. There were two questions we had to answer.

1. Is the proposed triple runway operation as safe as the dual runway operations?

2. How do the controllers view the triple runway operation with respect to safety, ease of operation, and capacity.

Our answer to the first question is a unified and emphatic, yes. As to the second question, it is believed that safety can be maintained with proper monitoring equipment and manning. Operations can be conducted without any degradation of safety while, at the same time, increase the capacity of the airport under instrument conditions approximately 33 percent. We found this phase to be completely successful in answering the assigned tasks.

INTRODUCTION

On September 25, 1989, a staff from DFW Terminal Radar Approach Control (TRACON) consisting of three air traffic controllers, one traffic management specialist and an area supervisor met at the Federal Aviation Administration's (FAA) Technical Center at Atlantic City International Airport, New Jersey. The purpose was to conduct the simulation of triple simultaneous approaches at D/FW Airport.

ANALYSIS

The principle concern of the controller test team was the frequency and number of blunders and wanderers did not realistically reflect simultaneous operations. There were numerous simulator pilot errors and software and hardware failures that created additional problems. One of the most challenging was the position indicators that failed during two separate scenarios. Although these problems were distracting we were still able to ensure adequate spacing at all times. As the evaluation continued some of these problems were resolved; however, others still existed.

Our operating guidelines were not to concern ourselves with airspace constraints. Our only objective was to maintain an acceptable margin of safety at all times between the center of targets. The lowest altitude we could use was 2000 feet. For each runway we developed our own pullout procedures to maximize safety of flight and decrease controller reaction times. We believe it was more stressful in this respect to perform the monitor function for runways 16L and 17L than runways 18R and 17L. The proximity of runway's 16L and 17L (5000 foot centerline separation) required quicker reaction times than that of runways 17L and 18R (8800 foot centerline separation). Staggered aircraft on the finals were easier to react to than a side by side operation.

The hardware and software problems necessitated the team to work 2 hours of overtime for 2 consecutive days to maintain the simulation schedule. On 1 of the 2 days six and one-half scenarios were completed with minimum turn around times The half completed scenario was the result of a computer failure.

CONCLUSIONS

After spending 9 days monitoring triple independent parallel approaches, we were able to overcome the obstacles of the pilot errors, software problems, indicator failures, and controller anxieties. In spite of all of these circumstances, we were able to ensure flight safety at all times.

We believe that the complexity and workload of triple instrument landing system (ILS) approaches will be as manageable as the dual ILS approaches are today with the proper manpower, equipment, and procedures. We believe that the Phase II simulation study on triple independent ILS approaches has been a total success.

RECOMMENDATIONS

FEDERAL AVIATION ADMINISTRATION TECHNICAL CENTER

1. In future tests more emphasis should be placed on overtake situations than on wandering and blundering aircraft. We believe this would more closely resemble real life situations.

2. The simulator pilots should modify or change the way they enter data. The present methods and equipment configurations make simulator pilot reaction times slow.

3. The fatigue factor is an important variable in the accomplishment of these tests. We recommend no more than five 1 hour scenarios a day. If practical, enough controllers should be provided to avoid having to work more than two consecutive problems.

DALLAS/FORT WORTH TERMINAL RADAR APPROACH CONTROL

1. To properly monitor the finals, the leader lines at DFW need to be available on all eight cardinal positions. Flight data information was often overlapped and unreadable without this option. The flight data information was obscured using only the four key cardinal points.

2. We recommend that future Enhanced Target Generator (ETG) controller training at DFW include the final monitor positions with these type scenarios.

3. We believe a task group should be formed at DFW to established local operating procedures and review any possible Automated Radar Tracking System (ARTS) changes that may be required to enhance safety.

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