

**Evaluation of Blunder Detection
by Air Traffic Controllers
Using Two Different Display Types**

by

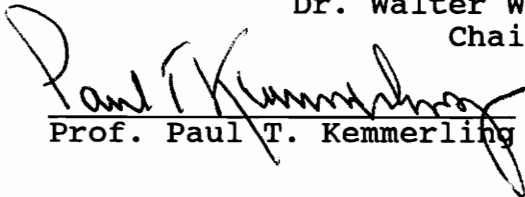
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ABSTRACT

One of the major problems plaguing the airline industry in recent years has been the steady increase in the number and duration of flight delays. Airports have not been able to keep pace with the increase in air traffic. Consequently, Congress has directed the Federal Aviation Administration (FAA) to initiate programs to reduce delays and improve airport capacity. One program the FAA has initiated evaluates the simultaneous use of three and four closely spaced parallel runways. These operations would allow cost efficient capacity increases through concurrent use of already constructed runways and through the construction of additional runways at existing airports.

Recent simulation studies have indicated that improvements in controller displays are required to safely conduct multiple parallel ILS approaches to runways spaced 4300 ft apart or less. This study was designed to quantify the ability of the Precision Runway Monitor (PRM) display to enhance controller performance over the current display, the Automated Radar Terminal System (ARTS) IIIA. Additionally, the effects of blunder degree and the number of simultaneous parallel approach operations (dual or triple approaches) on the controller's ability to detect aircraft blunders were also examined. A blunder is an unusually sharp turn by an aircraft off its ILS localizer course toward an adjacent ILS course.

The PRM display, a high resolution raster scan color monitor, enhanced the controller's ability to quickly detect aircraft blunders over the ARTS IIIA display (the current display system), a Plan Position Indicator (PPI). The average controller response times were smaller (4 seconds) and the average closest points of approach (CPAs) between the blundering and the evading aircraft were larger (776 ft) when the controllers used the PRM display.

As in earlier studies, the thirty degree blunders resulted in conflicts that were more severe than the conflicts associated with twenty degree blunders. Conversely, contrary to earlier studies, the controllers were able to detect the twenty degree blunders as quickly as they detected thirty degree blunders.

The controllers performed as well in the dual parallel approach operation as they did in the triple approach operation for all measures.

The results of this study generally agreed with those found in earlier studies on controller performance. Controller performance can be improved with the use of high resolution displays with alert systems. However, unlike earlier studies, this study provided a quantification of the benefit of a proposed system relative to the current system.

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INTRODUCTION

One of the major problems plaguing the airline industry in recent years has been the steady increase in the number and duration of flight delays. Airports have not been able to keep pace with the increase in air traffic. Consequently, Congress has directed the Federal Aviation Administration (FAA) to initiate programs to reduce delays and improve airport capacity. These programs include redesign of the airways, improved central flow management, automation of the air traffic control system and airport expansion and improvement plans.

The delay and airport capacity problem is intensified by the onset of inclement weather, especially for arrival traffic (DOT, 1969). Under Visual Flight Rules (VFR), airports can conduct independent approaches to two (dual) parallel runways spaced as close as 2500 ft apart. When inclement weather occurs and airports must operate under Instrument Meteorological Conditions (IMC), approaches to dual parallel runways must be sequenced to allow at least two nautical miles (nm) between aircraft on adjacent approaches. This can reduce capacity by as much as 50 percent. Additionally, under IMC, the runway spacing must be at least 4300 ft.

Major increases in airspace capacity can be achieved through the simultaneous use of three (triple) or four

(quadruple) parallel runways. These operations would allow cost efficient capacity increases through concurrent use of already constructed runways and through the construction of additional runways at existing airports.

Triple and quadruple parallel approach procedures have not been developed except for a few site specific operations. The site specific operations all have runway spacings well above the 4300 ft limit placed on dual approach operations.

Recent efforts to develop procedures for triple independent parallel approaches during Instrument Meteorological Conditions (IMC) have evaluated controller blunder detection and conflict resolution performance while using current Air Traffic Control (ATC) displays (Fischer, Yastrop, Startzel-Dehel, and Luongo, 1991). A blunder is an unusually sharp turn by an aircraft flying an approach toward an adjacent approach. The results of this effort indicated that the controllers had difficulty in detecting blunders by aircraft and that this could produce an unsafe operational situation for runways spaced 4300 ft apart. Subject matter experts concluded that monitor displays with higher resolution and aircraft course deviation alerts, such as the Precision Runway Monitor (PRM) display, would help enable controllers to detect blunders quicker and provide a safe operational environment.

The purpose of this thesis is to compare controller performance while using current Automated Radar Terminal System (ARTS) IIIA displays with controller performance using the new high resolution PRM displays and to quantify the benefit of using the PRM display system.

BACKGROUND

The Air Traffic Control (ATC) system of the United States is one of the most sophisticated command and control systems in the world. The detailed description of even a single component of this system represents a formidable task. Since the purpose of this thesis is to evaluate the controller's performance while monitoring the independent parallel instrument approaches, the background provided will be limited to historical, procedural and technical information pertinent to this topic.

Historical Background.

The application of parallel runway configurations to aircraft arrivals dates back to the late 1950's. The Federal Aviation Agency, the forerunner to the Federal Aviation Administration (FAA), sponsored several studies to analyze the ability of pilots to perform Instrument Flight Rules (IFR) approaches to parallel runways under Instrument Meteorological Conditions (IMC) (typically conditions with a measured or estimated ceiling of less than 700 ft or visibility of less than 2 miles). These studies (Fantoni and Rudich, 1961, and Federal Aviation Agency, 1962) provided evidence to allow the FAA to develop regulations in 1963 for simultaneous independent parallel approaches to runways with at least 5000

ft centerline spacings. The benefits of the regulations were felt most at Chicago O'Hare, Los Angeles, Atlanta (Hartsfield) and Miami airports which had existing parallel runways spaced accordingly (Haines and Swedish, 1981). By the late 1960's, rapid increases in the volume of air traffic necessitated a further reduction in the runway spacing requirements (DOT, 1969). Based on additional data (Resalab Inc., 1972) the FAA revised the regulations so that simultaneous parallel approaches could be performed to runways with centerline spacings of at least 4300 ft. This spacing was chosen to allow additional simultaneous approach configurations at Atlanta and Los Angeles (Haines and Swedish, 1981).

Technical and Procedural Background.

In addition to the 4300-ft centerline spacing, the following are additional requirements for the authorized use of independent parallel approaches (FAA, 1989):

1. The Instrument Landing System (ILS), surveillance radar, and two-way radio communications must be operable.
2. Aircraft must have radar separation of at least 3.0 nautical miles (nm) laterally and 1000 ft vertically until established on their respective localizer courses.

3. A monitor controller must be assigned to each approach to ensure aircraft do not penetrate the depicted No Transgression Zone (NTZ).

4. A 2000 ft wide NTZ shall be centered between the extended runway centerlines.

During IMC, a variety of procedures have been developed to guide aircraft safely during the approach sequence of flight. The Instrument Landing System (ILS) is the most precise system in common use. Radio navigation signals identify a precise flight path, laterally with the localizer signal (VHF) and vertically with the glideslope signal (UHF). The localizer radiates a horizontal fan shaped beam (3 to 6 degrees wide) that provides lateral guidance to aircraft on the final approach. The glide slope transmitter provides a vertically oriented fan shaped beam (1.4 degrees wide) that provides altitude guidance. The composite beam resulting from these signals defines a precise approach course for arriving aircraft (see Figure 1, obtained from Nolan, 1990).

The center of the localizer signal follows the imaginary path of the extended runway centerline and the glideslope signal projects upward at approximately 3 degrees from the runway threshold. A typical ILS also includes up to three additional marker transmitters which provide the pilot with information on the range from runway threshold. The ILS

approach procedures require that arriving aircraft be established on the localizer (capable of maintaining a course corresponding closely to the center of the localizer signal) prior to intersecting the outermarker (approximately 5 nm from the runway threshold). For simultaneous ILS approaches, the distance is extended typically to 10 nm (see Figure 1). It should be noted that each runway has its own ILS, independent from any other ILS which may be employed at that airport.

Aircraft executing an IFR approach are required to have an ILS receiver. The receiver provides the pilot with course tracking error. The ILS receivers range from the very simple Course Deviation Indicators (CDI), which indicates whether the pilot is left, right, above or below the prescribed course (see Figure 1), to the sophisticated receivers which couple with the navigational autopilot to provide automatic flight control down to the decision height.

The decision height (DH) is the distance above ground at which the pilot must be able to visually sight the landing runway. DH depends on the sophistication of the ILS transmitters and varies from 1000 ft above ground level (Category I ILS) to ground level (Category IIIC ILS). IFR approach procedures require that if the pilot is not able to see the runway indicator lights at DH, or if the aircraft is misaligned, the pilot must execute a missed approach. For parallel approaches, the missed approach procedures generally

require a climb in altitude and a turn away from adjacent approach courses. Exact missed approach procedures vary depending on the airport and the type of aircraft involved.

The operation of independent parallel ILS approaches requires the use of an additional controller position for each approach. The additional controller position is the monitor controller position. The monitor controllers are responsible for the aircraft only after the following has been accomplished by the final controller (who is responsible for vectoring the aircraft to the appropriate ILS courses):

1. The pilot has received and confirmed the local controller's radio frequency.
2. The pilot has received and confirmed the localizer and glideslope frequency.
3. The aircraft has intercepted the ILS, usually from 10 to 16 nm from the runway threshold.

The monitor controllers use the same radio frequency as the local controller (who is responsible for all flights in the terminal area to which visual separation can be applied). The monitor controller's role is to ensure that adequate separation is maintained between aircraft on the same approach course and between aircraft on adjacent approach courses.

Since the monitor controllers interact with each other, their positions are located adjacent to each other. As shown in the Graphical Representation of a Monitor Display, Figure 2, the monitor controllers are responsible for keeping their aircraft within their Normal Operating Zone (NOZ) and out of the No Transgression Zone (NTZ).

Generally, the airborne avionics enable the pilot to accurately navigate the aircraft along the ILS centerline and within the NOZ. However, if an aircraft is traveling toward the NTZ, the monitor controller responsible for that aircraft is required to advise the pilot of his deviation and direct him toward the ILS centerline (Buckanin, Guishard, and Paul, 1984). If an aircraft enters the NTZ, monitor controllers on adjacent approaches are required to resolve conflicts by vectoring threatened aircraft away from the deviating aircraft (FAA, 1989). The threatened aircraft are vectored off the ILS course instead of the deviating aircraft for two principal reasons:

1. The pilot of the deviating aircraft has demonstrated an inability to adequately navigate and/or control the aircraft (possibly due to an inflight emergency).
2. To increase the airspace between the two conflicting aircraft and thereby enhance the probability that they will not merge.

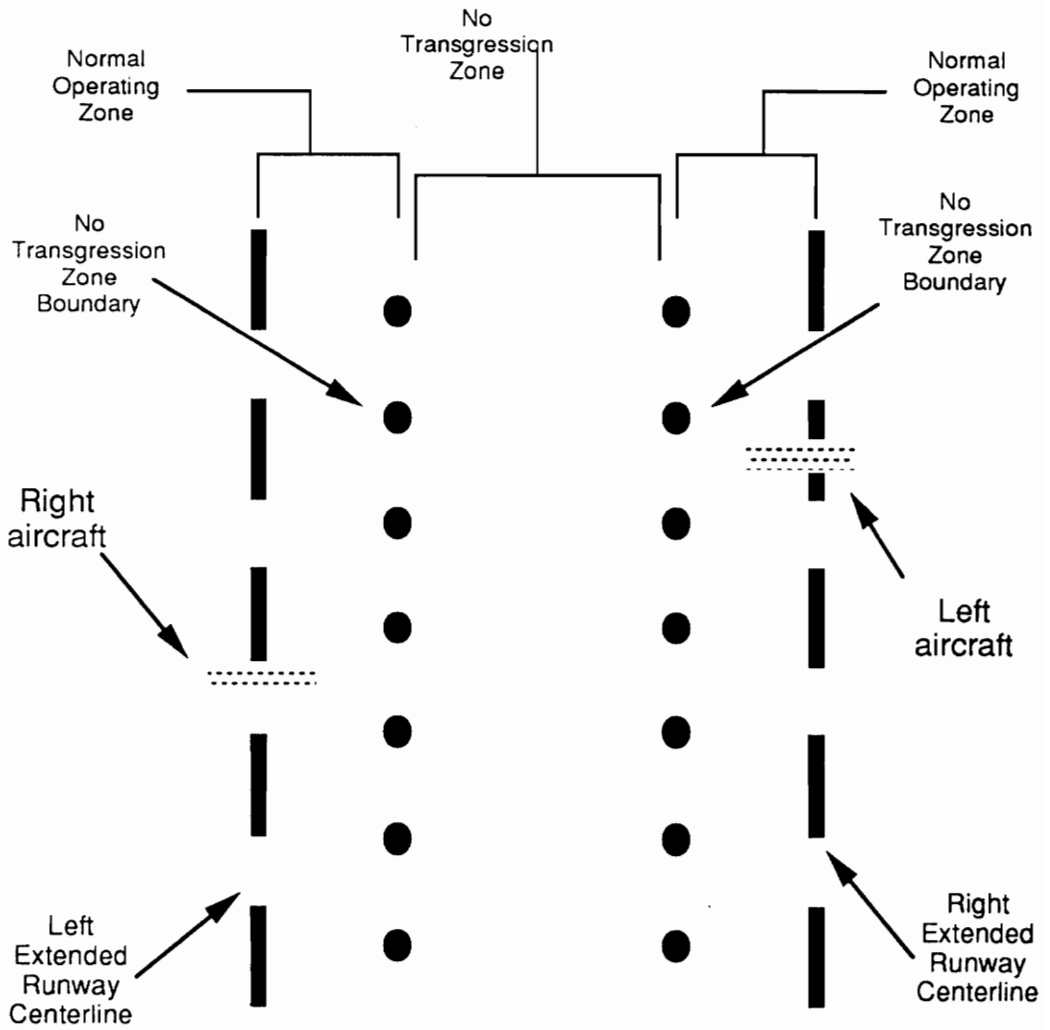


Figure 2. Graphical Representation of a Radar Display

Since aircraft usually navigate the ILS with minimal Cross Track Deviation (CTD), most of the monitor controller's time is spent ensuring longitudinal separation between aircraft on the same approach. This is accomplished through the issuance of speed advisories. The minimum longitudinal separation between aircraft on the same ILS approach (single or parallel) is 3 nm. For heavy jet aircraft, such as a DC-10 or B747, at least 6 nm separation is required for trailing aircraft.

Throughout the approach operation, control responsibility remains with the local controller and not with the monitor controller. The monitor controllers' normally passive function requires no communications with the pilot except during infrequent situations when warning, advisory, or vectoring action is deemed necessary. Since the monitor controller shares the frequency with the local controller, judicious use of the frequency is required. The judgement and techniques of the monitor controller critically impacts the safety and efficiency of the overall operation (Buckanin et al., 1984).

REVIEW OF LITERATURE

The purpose of this section is to provide a detailed survey of the literature concerning the assessment of simultaneous Instrument Landing System (ILS) approaches and triple simultaneous ILS approaches. The evaluation of simultaneous ILS approaches was initiated in the late 1950's. The research can be classified into four distinct types:

1. Data Collection and Analysis Studies,
2. Probabilistic Conflict Rate Studies,
3. Parametric Blunder Resolution Studies, and
4. Real Time Simulation.

The research types differ significantly in terms of the assumptions used, the variables considered, and the means by which the output is obtained. However, there is a considerable amount of similarity within each type.

Data Collection and Analysis Studies.

This type of research includes the collection and analysis of data taken by direct observation of aircraft executing Instrument Flight Rules approaches. Descriptive statistics of lateral position of aircraft relative to the extended runway centerline are used to determine the shape of

the probability distribution at fixed points along the Instrument Landing System (ILS). The end result is a determination of the frequency with which aircraft may come into conflict with aircraft on the adjacent approach course.

In the late 1950's McLaughlin (1959, 1960) collected data from ten U.S. airports conducting single ILS approaches. He grouped the data by range from threshold, aircraft type, ceiling height, wind speed and direction, visibility, and height at which the pilot spotted the runway. McLaughlin found that the proximity to the runway was the only factor to have a significant effect on the navigational error variance data.

Noncommercial test flights were used by Fantoni (1961) in order to establish a data base for the performance of aircraft on simultaneous ILS approaches to runways spaced 2700 ft apart. Data were also collected for commercial flights to both single approaches and parallel runways spaced 6510 ft apart. The pilot and controller questionnaires used in this study provided critical insight to the optimal level of monitor controller interaction for the approach. Based upon the test results, Fantoni recommended:

1. The operational procedures and the equipment configurations necessary for simultaneous ILS approaches spaced 6510 ft apart to Chicago O'Hare airport,

2. The feasibility and operational use of simultaneous ILS approaches spaced 2700 ft apart, and
3. The future data collection and analysis requirements toward developing minimum runway separation criteria.

Specifically, Fantoni determined that simultaneous ILS approaches to runways spaced 5000 ft apart were operationally feasible if altitude separation at ILS intercept (turn-on) and the use of monitor controllers were provided. As a result the Federal Aviation Administration (FAA) enacted an order in 1963 permitting the operation of simultaneous ILS approaches to runways separated by at least 5000 ft.

In 1972, Resalab Inc. presented the results of a data collection effort that examined both lateral and vertical course tracking capabilities of aircraft conducting single runway approaches to Charleston International Airport. These data allowed the FAA to reduce the minimum runway spacings for simultaneous ILS approaches from 5000 ft to 4300 ft in 1974. Resalab found that the navigational error variance decreased with proximity to runway threshold. They determined that the reduction in navigational error variance was due to both the angular spread of the ILS signal and the increase in the ILS beam's signal-to-noise ratio associated with the decreased distance from the transmitter.

Aircraft flight tracks were recorded for dependent ILS approaches to parallel runways at the Memphis, TN airport (Buckanin and Biedrzycki, 1987). Rules for dependent ILS approaches differ slightly from the rules for simultaneous ILS approaches (FAA, 1989) and are described below:

1. Monitor controllers are not used. All control after the ILS intercept rests with the final controllers.
2. Two mile radar separation is required between aircraft on adjacent approaches. This results in a staggered separation.
3. Dependent operations may be employed on parallel runways separated by as little as 2500 ft. Consequently, the capacity of the dependent approach operation is significantly less than the simultaneous ILS approach operation.

The data were collected using more sophisticated and accurate recording techniques than were available at the time of the Resalab data collection. The data were collected for use in the assessment of simultaneous ILS approaches. The results indicated that pilots conducting approaches to parallel runways often maintained a course away from the adjacent approach course. Based upon the findings of the data collection, the authors concluded that a database of flight

tracks from simultaneous ILS approaches would be more appropriate for analyzing simultaneous ILS approaches.

The FAA Advanced Concepts Division (ACD-340) at the FAA Technical Center recently completed a data collection of simultaneous ILS approaches at Chicago O'Hare (Thomas and Timoteo, 1990). The authors stated that, based upon aircraft navigational performance, the ILS and current radar systems could support runway spacings closer than 4300 ft. The results indicated that 98% of the aircraft would be able to maintain a course within the Normal Operating Zone (NOZ), 550 ft, of runways spaced 3100 ft apart. They further indicated that Cross Track Deviation (CTD) was only one of the parameters determining overall safety. Additional analyses of simultaneous ILS approaches were recommended using their data in collision risk models and real time simulation efforts.

Probabilistic Conflict Rate Studies.

This type of research can be used to determine the conflict risk associated with simultaneous ILS approaches. The probability density functions of the CTD distributions of adjacent approach courses is statistically manipulated to determine the conflict risk associated with various runway spacings. Most of this type of research has not explicitly considered the influence of the pilot or the ATC system; these

factors are implied in the estimation of the CTD distributions for aircraft navigating the ILS.

Using data collected for his earlier paper, McLaughlin (1960) was able to convolute the density functions of two approach courses to determine the probability of a collision at discrete ranges. Taylor (1960) expanded Mclaughlin's work and incorporated aircraft dimensions as inputs into his model. Among the results of Taylor's research was the conclusion that a 2700 ft runway separation should be adequate if vertical separation is applied at turn-on.

In 1966, Faison conducted a risk analysis which examined runway separation, aircraft dimensions, standard deviation of navigational errors, aircraft velocity, time spent on final approach, and separation between laterally adjacent aircraft. Faison's results indicated that dependent ILS approaches could be conducted to runways spaced 2700 ft apart and between aircraft (adjacent approaches) spacing of 2.5 nm as safely as simultaneous ILS approaches with 5000 ft runway spacings.

Parametric Blunder Resolution Studies.

This type of research provides an answer to the question of whether controllers will be able to resolve a blunder. The turn is defined as the worst conceivable excursion from the assigned course that an aircraft could experience, usually resulting from pilot and/or equipment failure. After

executing the turn, the blundering aircraft is assumed to maintain a straight-line course until the controller and pilot can resolve the situation.

Review of the literature shows two techniques of blunder resolution that have been considered (see Figure 3.a and 3.b). The first resolution technique has the blundering aircraft executing a corrective maneuver. The blundering aircraft is assumed to deviate toward the adjacent approach at some angle relative to its original course. The aircraft enters a wave-off zone and after detection, pilot and response delays, the aircraft is returned to a heading parallel to its original course.

The second resolution technique involves an evasive maneuver by the threatened aircraft. The pilot of the blundering aircraft is assumed to have lost communications and/or navigational control. The situation is considered resolved when the threatened aircraft has been vectored off the ILS course to a course parallel to the heading of the blundering aircraft. For both blunder resolution techniques, the slant-range miss distance, at the time the conflict is considered resolved, is the miss distance. Due to the conservative assumption that the blundering aircraft is completely out of control, the latter resolution technique has gained more acceptance among current researchers and FAA policy makers.

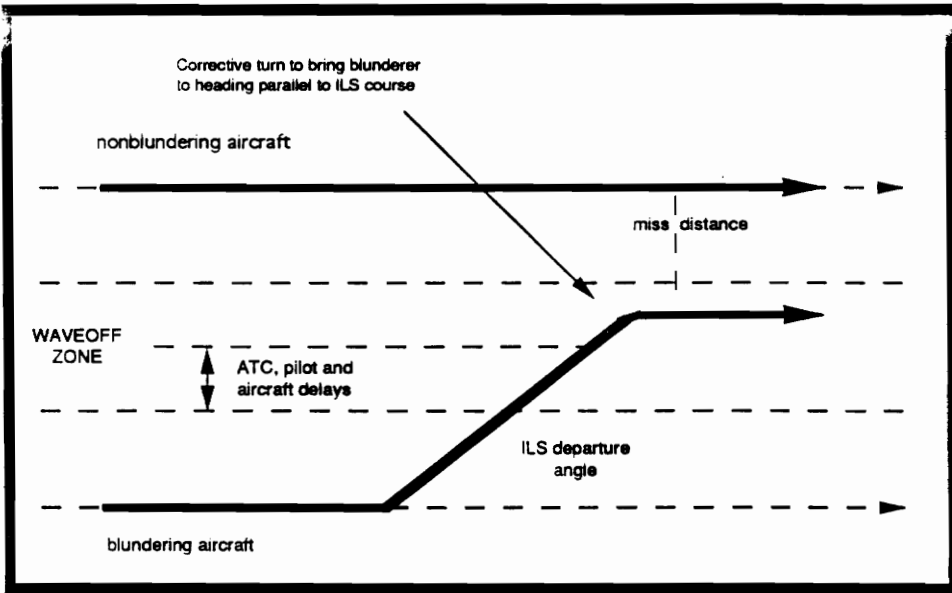


Figure 3.a. Corrective maneuver by blundering aircraft only

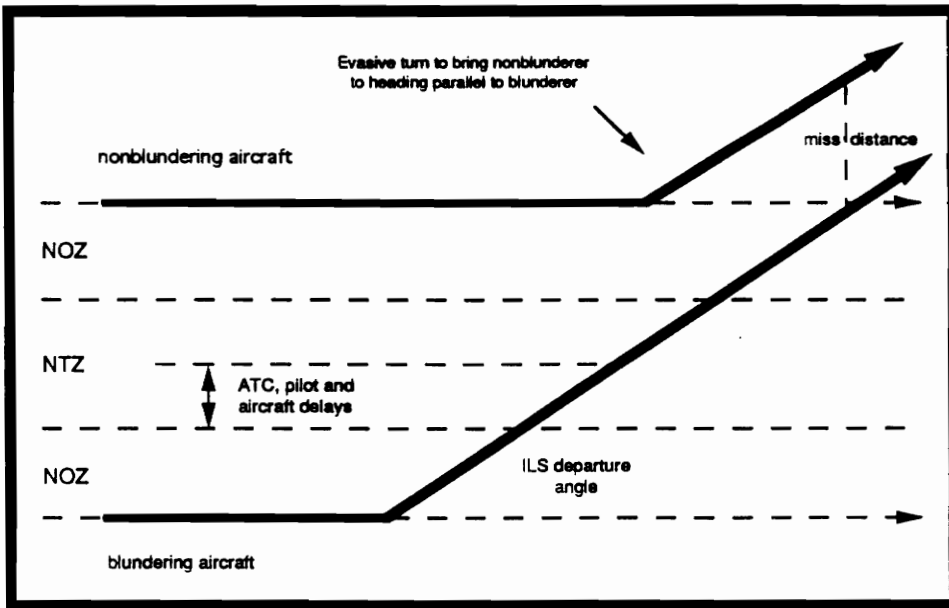


Figure 3.b. Evasive maneuver by evading aircraft only

Figure 3. Blunder Resolution Techniques

The input to these studies is for the most part deterministic. Geometric and trigonometric principles are applied in the calculation of analysis parameters. Since much of the input is parametric, the user of the models can employ sensitivity analyses to evaluate the effectiveness of the ATC system with respect to equipment, procedures and controller performance.

Koetsch (1961) examined blunder resolution using the first technique and the airport geometry shown in Figure 4. Aircraft were assumed to be under pilot control until crossing the wave-off zone boundary line. The controller would then advise the pilot to turn back toward the localizer as required. No evasive maneuver of the threatened aircraft was considered. Koetsch examined the distance between the wave-off zone boundary line and the extended runway centerline. The wave-off zone was to be wide enough to allow the pilot to correct the errant course prior to crossing the No Trespassing Line. As a result, Koetsch's model provided for safe resolution of simultaneous aircraft blunders.

Faison (1966) studied the blunder resolution as a combination of the time available to the controller to issue resolution commands and the time required for the threatened aircraft to execute an evasion maneuver. Also included in this study was pilot/aircraft reaction time. Unlike Koetsch, Faison assumed ATC blunder resolution techniques similar to

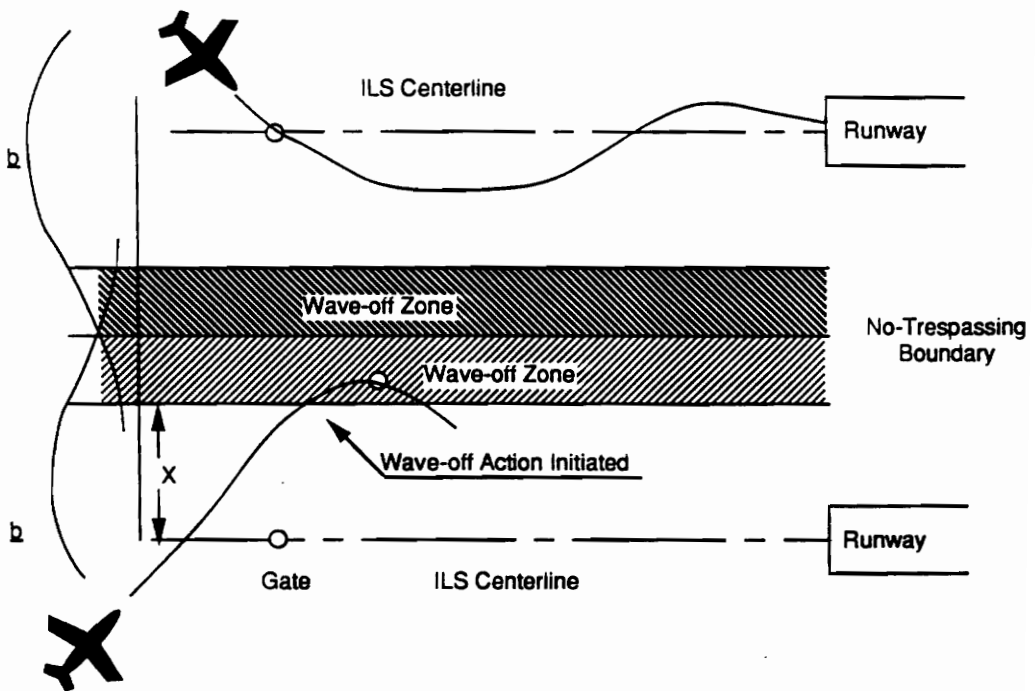


Figure 4. Geometry for the Dual Buffer Zone

those depicted in Figure 3.b, a No Transgression Zone (NTZ) and an evasive maneuver by the threatened aircraft. In addition, Faison compared the results from this system to a system in which no evasive maneuver is necessary or performed because separation between aircraft on adjacent runways already existed (dependent approaches). Faison was able to conclude that the critical parameters in assuring safe blunder resolution are:

1. The controller's display accuracy,
2. The controller's ability to assess, predict, and communicate,
3. The controller, pilot and aircraft reaction times,
4. The no transgression zone width,
5. The aircraft turn rates, and
6. The nature of the blundering aircraft's velocity (e.g. constant, descending, etc.).

Blake and Smith (1969) developed a model that was more sophisticated than that of Koetsch in that they considered three different alert strategies that could be used by controllers:

1. Position only (where the determination to issue a command to a blundering aircraft is based only on the position of that aircraft).

2. Position, heading, and velocity (same as above except that heading and velocity are also used as inputs).

3. Position, heading, velocity, and presence of aircraft on adjacent runway (this most accurately reflects the actual decision strategy of the controllers, but is the most difficult to model analytically).

Blake and Smith developed the "position only" strategy most thoroughly. Parameters used in this study included:

1. Aircraft velocity,
2. Data Acquisition System (DAS) position error,
3. DAS update period,
4. Turn rate of blundering aircraft away from the ILS course,
5. Turn rate of blundering aircraft during recovery maneuver (to a direction parallel to ILS course), and
6. Time spent in turn-away and recovery maneuvers.

As with Koetsch, the threatened aircraft did not execute an evasive maneuver. The purpose of this study was to assess the DAS requirements for use with parallel approaches; consequently, blunder detection by the controller was not examined. The study determined the distance required between

the extended runway centerlines and no trespassing line (see Figure 4).

Holt (1970) considered deterministic parameters such as:

1. Angular turn rate of blundering aircraft,
2. Absolute velocity of blundering aircraft,
3. Data sampling delay,
4. Data processing and analysis delay,
5. Communication delay,
6. Pilot/aircraft response delay,
7. Correction turn rate,
8. CTD by blundering aircraft when blunder began, and
9. CTD for aircraft on adjacent approach.

Holt assumed that controllers would detect and issue corrective actions to pilots as quickly as a deviation was displayed. Holt concluded that separation standards could be reduced below 5,000 ft if the total time consumed by all sources of delay could be held to less than 10 seconds. In addition, Holt recommended that the deterministic inputs should be treated as probabilistic in future studies -- determined empirically, analytically, or through simulation.

Kullstam (1972) further enhanced the blunder resolution technique of Figure 3.a. In addition to the NOZ (sized for a controller intervention rate of 1 in 100 landings), Kullstam

divided the Wave-off Zone (which he referred to as the Intervention Zone, IZ) into two sections:

1. Detection Zone (DZ): width based on a predetermined probability that, given an Intervention Zone violation, the blundering aircraft will be detected prior to the complete penetration of this zone.
2. Recovery Maneuver Zone (RMZ): width based on the requirement that, should detection of a blunder take place at the DZ/RMZ boundary, a corrective maneuver can be safely executed by the blundering aircraft prior to violation of the forbidden airspace (the NOZ of the adjacent approach).

Parameters considered by Kullstam were

1. Predetermined intervention probability;
2. Predetermined penetration probability (the probability that an aircraft will completely penetrate the DZ without being detected);
3. Data acquisition interval (update rate);
4. ILS departure angle (blunder angle);
5. Probability distribution (assumed normal) for DAS measurement errors;
6. Aircraft velocity;
7. Bank angle of aircraft during recovery maneuver;

8. Controller-to-pilot command time; and
9. Pilot/aircraft reaction time.

Kullstam claimed that the predetermined penetration probability depended on aircraft velocity and heading, DAS accuracy, and DAS update rate. Based upon his analyses, Kullstam concluded that the probability of collision was based on the conditional probability of collision given an IZ violation. Using sensitivity analysis, Kullstam found that a sizable reduction of IZ width could be obtained through the favorable selection of data acquisition rate or aircraft speed, and through reduction in the delay times for communication, and aircraft response.

Allen and Denlinger (1972) developed a model to investigate surveillance system requirements for simultaneous ILS approaches for controllers using a position, heading, and velocity control strategy. The complexity of this strategy enabled consideration of two types of blunder: turn-away blunders (blunders by an aircraft after intercepting the ILS), and straight line blunders (blunders due to a missed ILS intercept). Since the blunder recovery technique and geometry were very similar to that employed by Koetsch, the control system provided for the resolution of simultaneous blunders. The parameters considered were:

1. Aircraft velocity,

2. Normal turn rate,
3. Recovery maneuver turn rate,
4. Aircraft roll rate,
5. Pilot response time,
6. Wind,
7. Surveillance update interval,
8. Data-link delay,
9. Surveillance range accuracy, and
10. Surveillance azimuth accuracy.

Allen and Denlinger found that aircraft speed and surveillance update rate were the parameters to which runway separation was most sensitive. In addition, the authors concluded that turn-away blunders impose substantially greater spacing requirements than straight line blunders.

As with Allen and Denlinger, the model by Resalab (1972) also considered two types of blunders: those which occur during ILS intercept and those which occur after the aircraft is established on the ILS. In addition, Resalab considered a blunder recovery technique in which both aircraft were assumed to take evasive actions. This technique assumes that the blundering aircraft is not out of control and would respond to controller commands. The blunder was considered resolved when the blundering aircraft and threatened aircraft were brought to the same heading.

The Resalab model also differed from that of Allen and Denlinger in that a "position only" control strategy was assumed. Important parameters in this study were:

1. ILS departure angle,
2. DAS range accuracy,
3. DAS azimuth accuracy,
4. DAS update delays,
5. Aircraft velocities,
6. Aircraft bank angles,
7. Pilot/aircraft reaction times, and
8. Communication times.

Unique to this study was the fact that the DAS errors were determined analytically, instead of empirically, using variables such as aircraft ground range to touchdown, aircraft CTD, aircraft attitude, DAS antenna ground range from touchdown, DAS antenna lateral location from the runway centerline, and DAS antenna altitude. The analysis was designed to determine the lateral distance traveled into the NTZ by the blundering aircraft prior to resolution. Unlike the previous analyses which considered the departure angle as an independent variable, Resalab considered this variable parametrically. As a result, Resalab concluded that runway separation, was more sensitive to larger blunder angles.

Haines (1973 and 1975), and Haines and Swedish (1981) developed a set of blunder resolution models collectively known as the MITRE model. The MITRE model used the resolution technique depicted in Figure 3.b making the worst case assumption that the blundering aircraft was out of control and could not be corrected. The MITRE model is similar to that of Kullstam (1972) in that MITRE model divided the airspace between the two runways into several adaptive zones (see Figure 5):

1. Normal Operating Zone (NOZ): sized so for an acceptable rate of controller intervention.
2. Detection Zone (DZ): sized so that only a small percent of the blundering aircraft would not be identified before completely transgressing the DZ.
3. Delay Zone (DEL): sized to represent the additional spacing required to accommodate delays due to controller response, controller to pilot communications, and pilot response.
4. Correction Distance for Blundering Aircraft (CA): sized to represent the continued lateral encroachment while the threatened aircraft is undertaking an evasive maneuver.

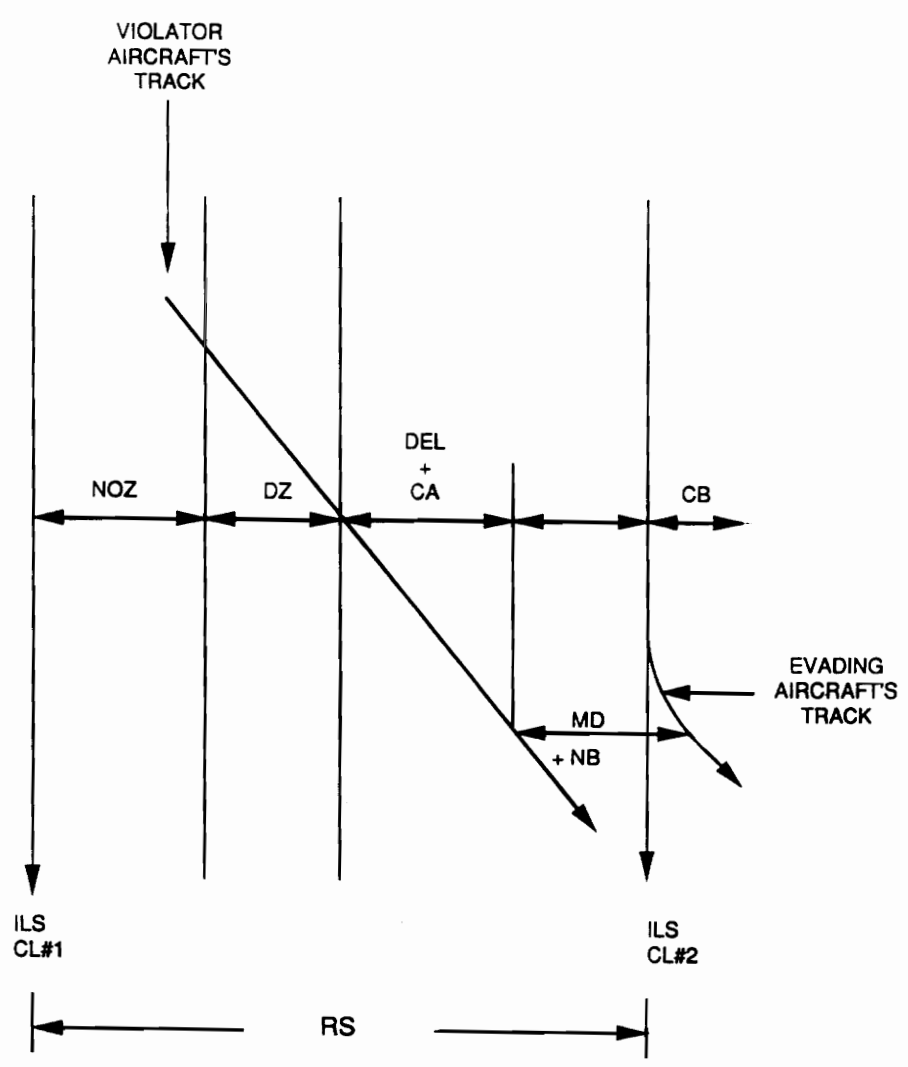


Figure 5. Spacing Nomenclature for the MITRE Model

5. Correction Allowance for Threatened Aircraft (CB): sized to represent the gain in lateral separation attained by the threatened aircraft during its evasive maneuver.

6. Navigation Buffer (NB): an allowance which was provided for the possibility that the threatened aircraft might have been slightly left or right of course at the commencement of its evasive maneuver.

7. Miss Distance (MD): the final lateral separation between the two aircraft at the point at which the blunder could be considered resolved.

Important inputs for the MITRE model were:

1. CTD distribution,
2. Blundering aircraft velocity and deviation angle,
3. Delay (controller, pilot, and aircraft) times,
4. Threatened aircraft turning performance,
5. Surveillance system error distribution,
6. Surveillance system update rate,
7. Controller intervention rate,
8. Non-detection rate, and
9. Required miss distance.

Based on the analyses results, MITRE concluded that separation could be reduced from 4,300 feet to 3,000 feet with improvement in surveillance system performance.

Real Time Simulation.

Real time simulation is the testing of some or all portions of the ATC system using real controllers in a simulated operational setting. Controllers observe aircraft flight tracks generally based on the results of Data Collection and Analysis studies. The controllers use displays that are typically found in the operational ATC environment or displays designed to closely represent those displays. The controllers issue commands to pilots flying test aircraft, aircraft simulators or simulator pilots that enter aircraft course changes into the simulation computer via specialized keyboards. Voice communications between the controllers and the pilots are transmitted through a simulated radio network.

Real time simulation offers benefits over the other three methods previously described. First, the simulations can accurately account for blunder detection delays by controllers. Secondly, by incorporating test aircraft or flight simulators into the simulations, pilot and aircraft performances can be accurately measured in the simulation. Finally, the real time simulation environment provides an

environment for FAA and industry representatives to observe and evaluate the performance of proposed systems.

Buckanin et al., (1984) created one of the first significant simulations specifically designed to evaluate simultaneous ILS approaches. The study examined the effects of the following variables on the controller's ability to control traffic:

1. Runway separation,
2. NOZ width,
- 3 Radar accuracy,
4. Radar update interval, and
5. Differential display magnification.

The experimenter was able to adjust the monitor controller's display so that the lateral direction is scaled differently than the longitudinal direction. The display was scaled such that 1 nm of lateral distance (between runways) was equal to 2 nm of longitudinal distance (along approach courses). The target sizes and approach course indicator lines remained the same size. This provided the controllers with an enhanced ability to detect CTDs. Aircraft blunders were randomly induced to the system at a much higher rate than what occurs operationally to keep the total simulation time to a reasonable length.

For each set of test conditions, the following output was obtained:

1. Average number of NTZ entries per hour,
2. Average number of parallel conflicts (minus the number of NTZ entries since longitudinal proximity did not always exist between adjacent flight tracks),
3. The Aircraft Proximity Index (API), a weighted metric based upon the smallest vertical and horizontal aircraft miss distance (see appendix B),
4. Time to first action (first pilot keyboard entry),
5. Time to first controller communication,
6. Time to first controller warning,
7. Average number of controller communications per hour,
8. Average number of controller warnings per hour,
9. Number of pilot actions, and
10. Number and type of missed approaches.

The results of this study showed that increased radar accuracy and radar update rate would enable reduced runway spacings. The study recommended that to improve controller performance, the magnification feature be incorporated into the controller's displays and an automated alert system be developed to detect and warn controllers of imminent NTZ entries. The worst case blunder scenarios (30 degree no

communication blunders) created for this study produced unacceptably small miss distances even at the present spacing standard. The authors reasoned that this blunder scenario was probably unrealistic and too severe for use as a test or design consideration.

Additional real-time ATC simulations have been conducted at the FAA Technical Center to investigate triple and quadruple simultaneous ILS approach proposals (Paul, Shochet, and Algeo, 1989; CTA Inc, 1990; Fischer, Yastrop and Dehel, 1990; and Fischer et al., 1991). These simulations are part of a multiple phase program designed to examine a proposed quadruple parallel approach operation at Dallas/Fort Worth International Airport (DFW) and to develop standard procedures for triple and quadruple simultaneous ILS approaches.

The DFW Phase I simulation (Paul et al., 1989) was conducted as a two-part study designed to test selected aspects of the quadruple simultaneous ILS approach operation. The first part of the simulation evaluated the concepts for using additional routes, navigational aids, runways, en route and Terminal Radar Approach Control Facility (TRACON) traffic flows necessary for the implementation of quadruple approach operations at DFW.

The second part of the simulation focused on the quadruple simultaneous ILS approach operation. The runway configuration consisted of the two existing runways which had

a centerline separation of 8800 ft, 18R and 17L, and two new runways. One additional runway was 5800 ft west of the 18R centerline, and a second runway, 16L, was 5000 ft east of the 17L centerline (see Figure 6). Aircraft with approach speeds of 160 knots or less (turboprops and reciprocating engine propeller) were restricted to landing only on the new outboard runways.

The controllers monitored approach traffic using digital displays with their associated data entry and communication equipment. The displays and consoles were configured similar to the Automated Radar Terminal System (ARTS) IIIA displays but did not provide track histories. The radar signal was developed to imitate the Airport Surveillance Radar No.9 (ASR-9) which has an update rate of 4.8 seconds and 4 milliradian azimuthal accuracy.

The traffic samples were developed to provide four different levels of traffic load, 125%, 150%, 175%, and 200% of normal traffic load. The aircraft types were chosen based upon DFW's normal traffic mix.

The evaluation of the TRACON traffic flow concentrated on analyses of controller questionnaires completed following each simulation run. The questionnaires indicated that controller workload increased with additional air traffic. Overall the controllers rated their workload as moderate even when handling twice the normal traffic load.

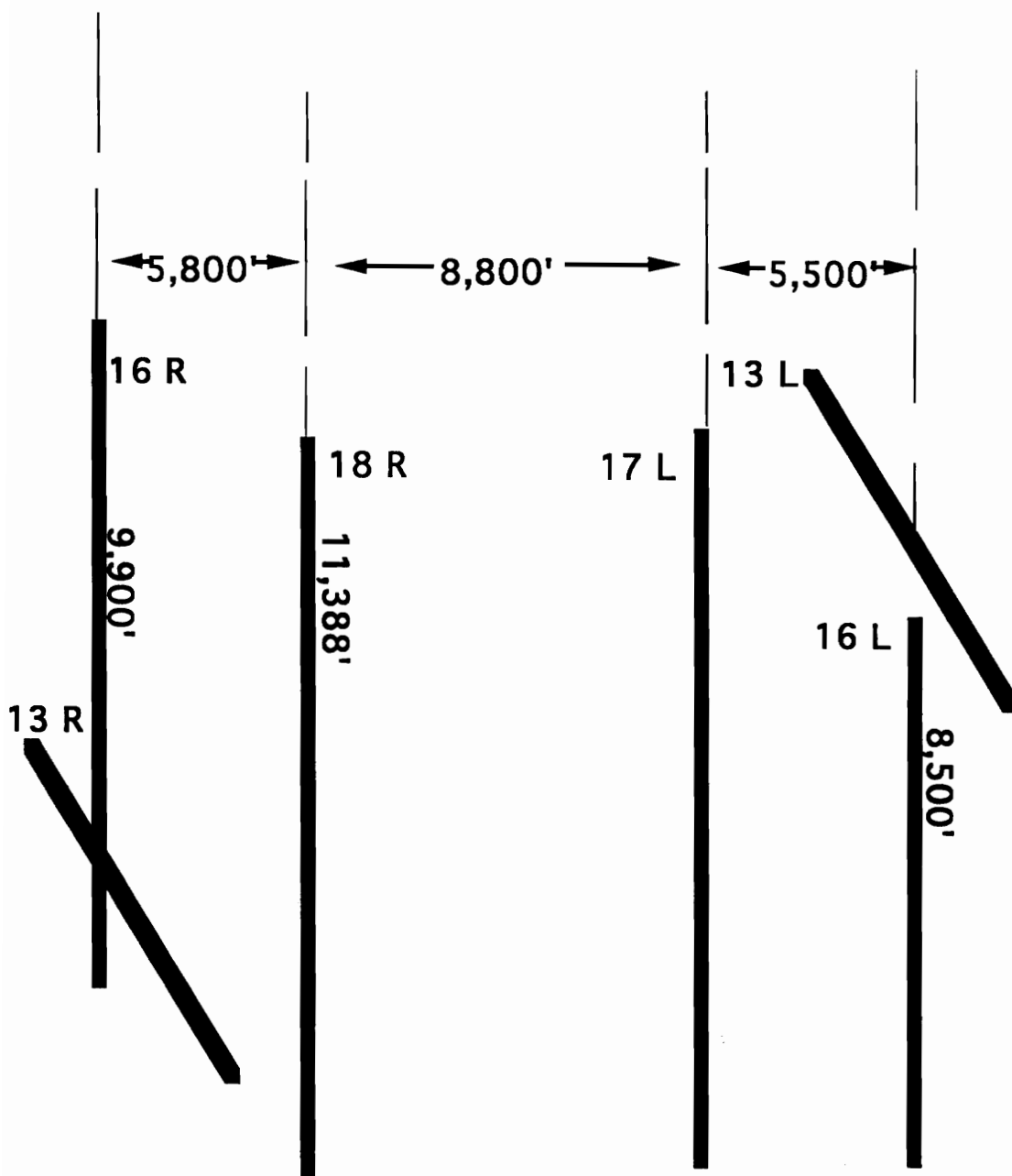


Figure 6. Dallas/Fort Worth's Proposed Airport Configuration

The analysis of the simultaneous ILS approaches concentrated on the conflict severity induced through the introduction of 10, 20, and 30 degree blunders. The blunders were observed and "problem" blunders (blunders which were predicted to result in less than 500 ft vertical separation and the controller had less than 30 seconds to resolve the conflict) were evaluated on a second-by-second basis. Only 2 out of 175 blunders were judged to be "problem" blunders and they both resulted in a Closest Point of Approach (CPA) of greater than 1400 ft.

The API (API = 100 corresponds to a collision and API = 0 corresponds to no conflict) ratings for each blunder were classified by runway spacing (between the blundering aircraft's and the threatened aircraft's approach), blunder degree, and communication loss. Analyses of the API ratings indicated that:

1. API ratings increased with decreases in runway spacings,
2. API ratings increased with increases in blunder degree, and
3. API ratings increased when controller-pilot communication was lost.

The controllers and the DFW evaluation team enthusiastically endorsed the proposed arrival route structure and the quadruple simultaneous ILS approach procedures. Based upon this simulation, triple parallel ILS approaches were approved for DFW with only turboprop and reciprocating engine propeller driven aircraft landing on 16L.

A second simulation was conducted for DFW that assessed triple simultaneous ILS approaches (CTA Inc., 1990). The simulation hardware and procedures were similar to those in Paul et al., 1989. One difference in this simulation was that only the simultaneous ILS approach operations were examined. Secondly, the airport configuration used the current parallel runways 17L and 18R (8800 ft spacing) and a proposed runway 16L, located 5000 ft east of the runway 17L centerline. Thirdly, there were no restrictions concerning aircraft type to any runway. Finally, dual simultaneous ILS approaches were simulated to runways spaced 8800 ft and 5000 ft apart to be used as a baseline for assessing the triple simultaneous ILS operation.

Additional programming was conducted to provide increased realism in the simulation. Aircraft track histories were simulated by representing the four previous aircraft positions by a small line (see Figure 7). The flight navigational error model was altered to closely match the probability distribution function of aircraft tracks found in the Chicago

data collection study (Thomas et al., 1990). Finally, data collection efforts were increased to include controller response time measures.

Analyses were conducted on the CPA and API data to determine the effects the following variables on controller performance.

1. Runway spacing,
2. Blunder degree,
3. Communication loss,
4. The number of runways threatened, and
5. Approach condition (dual or triple); .

The analyses indicated that runway spacing, blunder degree and communication loss all affected the controller's ability to resolve blunder induced conflicts. In the triple approach operation, blunders which threatened two other approaches (an aircraft blundering from 16L or 18R toward 17L) resulted in larger CPAs than those that threatened only one other approach. Finally, there were no significant differences in conflict severity between the triple approach and dual approach operations. No blunder, in either the dual or triple approach operation, resulted in a slant range miss distance of less than 1100 feet.

Measurements of controller response times to blunder initiation and pilot response times to controller messages

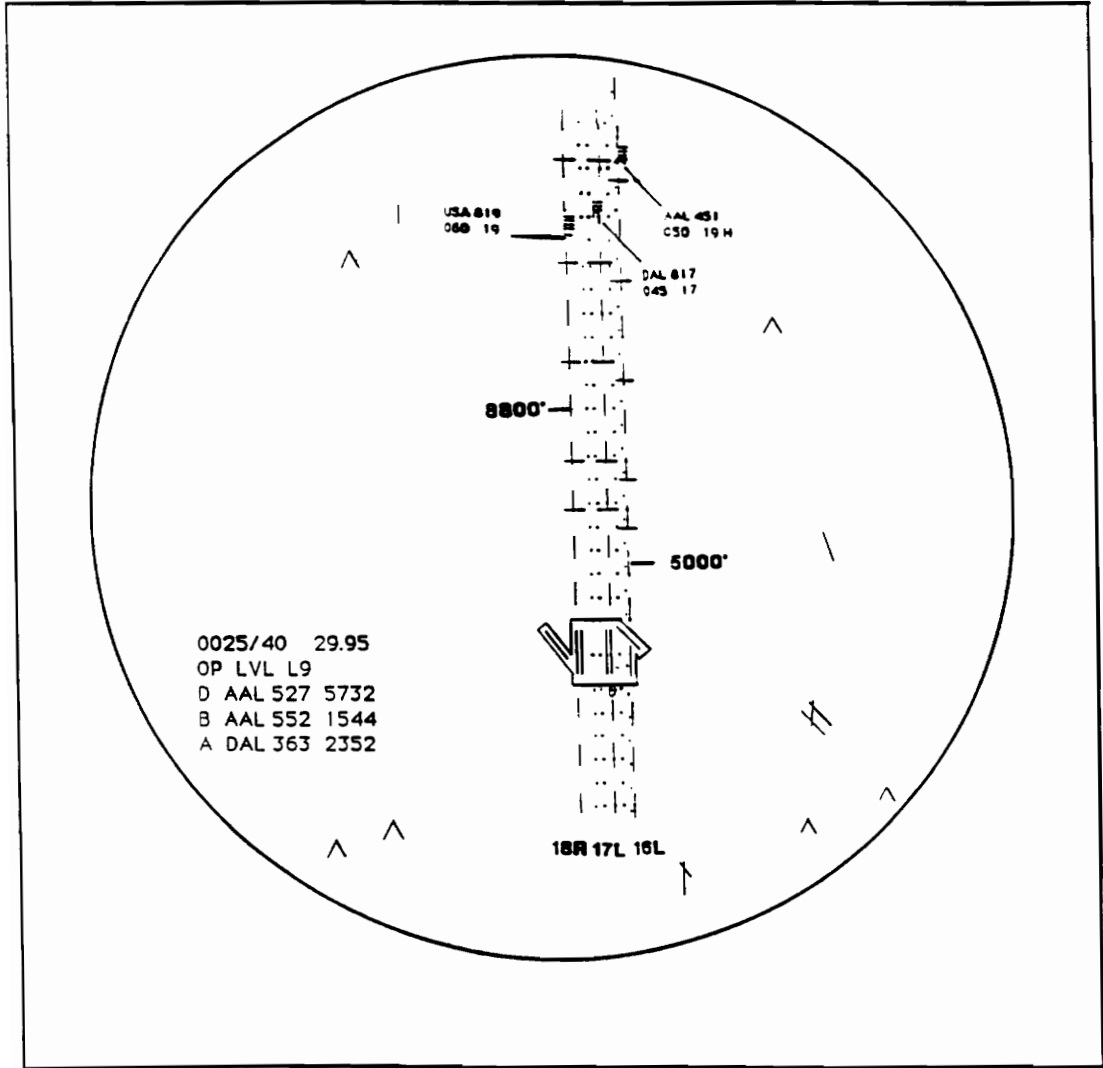


Figure 7. DFW Phase II Controller Display

were collected for one run in this simulation. Two relationships were specified as a result of the analysis of controller response time:

1. The amount of time between the onset of the blunder and the controller's perception of the blunder, and the effect of blunder degree on the controller's ability to detect a blunder; and
2. The amount of time between the controller's verbal message and the associated National Airspace System Simulation Support Facility (NSSF) simulator pilot entry.

Controller response times were measured from blunder initiation until the beginning of the controller message. As expected, the results indicated that the controller response time to blunder initiation was inversely related to blunder degree. Thirty degree blunders resulted in the smallest average response time (9.29 s) followed by 20 degree and 10 degree blunders (13.29 and 16.0 s, respectively).

The time between the controller's message delivery and the corresponding NSSF pilot's keyboard entry (threatened aircraft) was also measured. For this analysis, messages were divided into 2 classifications: warning messages, which only require 5 keystrokes, and vector/altitude change messages, which require 10 to 14 keystrokes. The average time for

warning message entry was 6.11 seconds and 10.66 seconds for vector/altitude changes. Some of the parametric blunder resolution analyses also included pilot delays in their analyses.

The controllers, controller observers (e.g., ATC supervisors) and ATC management observers, concluded that the proposed triple approach operation at DFW was acceptable, achievable, and safe. Results from this simulation supported the approval of turbojets operating on three parallel runways at DFW.

The DFW Phase III simulation (Fischer et al., 1990) reconsidered the DFW quadruple simultaneous ILS approach and departure operations assessed in Phase I. Changes were made in runway lengths to allow turbojets to land on the outer runways. The simulation used the same methodology and procedures of the DFW Phase II simulation (CTA, 1990).

As in the earlier DFW simulations, blunder degree and communications loss had significant effects on the controller's ability to resolve conflicts. The 30 degree blunders resulted in the smallest average CPAs. But the 20 degree blunders resulted in a higher average CPA than the 10 degree blunders. Post Hoc tests indicated that there were no significant differences between the CPAs for 10 and 20 degree blunders and that there was a significant difference between

the CPAs for the 30 degree blunders and both 10 and 20 degree blunders.

The controller response time to blunders was measured for 58 blunders in this simulation. The 30 degree blunders resulted in the smallest average controller response times (9.29 s) and the 20 degree blunders resulted in the highest average controller response times (22.0 s).

The National Standards Phase IV.a simulation evaluated dual and triple simultaneous ILS approaches to runways spaced 4300 ft apart. The simulation signified an advancement in simulation realism by using operational ARTS IIIA displays and incorporating two full motion flight simulators in the simulation.

The National Standards Phase IV.a simulation was used in the assessment of dual and triple simultaneous ILS approach operations using the ASR-9 radar and the ARTS IIIA display. The simulation data are currently being evaluated and will be used in this project for comparison with the Precision Runway Monitor (PRM) display data. Initial analyses and technical observer opinions indicated that the display and radar combination tested would not support the safe operation of triple simultaneous ILS approaches to runways spaced 4300 ft apart.

An equipment development and demonstration program for the PRM was conducted in 1990 at the Raleigh-Durham, NC (RDU),

and Memphis, TN (MEM), airports (PRM Program, 1991). The PRM consists of new high update rate radars and a 28 inch (diagonal) high resolution (2048-lines) raster scan color display.

The display had three unique features which may have enhanced the monitor controller's performance. The display had an aircraft position predictor line associated with each aircraft. The 10-second predictor provided an indication of the aircraft's future position based upon its instantaneous heading and velocity.

The display also had a visual and audio warning system that informed the controller of predicted NTZ entries. When an aircraft was predicted to enter the NTZ, the aircraft tag turned yellow. At the MEM site, the displays had a verbal message that identified the violating aircraft. The RDU site had a warning tone that sounded for impending NTZ entry. Additionally, when an aircraft entered the NTZ, the aircraft's tag turned red without an additional audio warning.

Finally, the display had independent zoom capabilities in the lateral and longitudinal directions (up to 12X). Therefore the controller had the capability of expanding the display between approaches relative to the distance along approaches. This magnification enabled the controllers to detect CTDs more rapidly.

Although the display systems were functionally equivalent at RDU and MEM, the radars were not. An electronic scanning radar antenna capable of an update rate of 0.5 seconds was evaluated at RDU. The radar at MEM was two mechanically rotating ASR-9 radar antennae mounted back-to-back. Their radar signals were dove-tailed thereby producing a 2.4 second update rate. The simulation also incorporated full motion flight simulators (B727 and DC-10) and a live test aircraft (B727).

The major objective of this program was the determination of the update rate requirements for various runway spacings. The demonstration program used three criteria to determine the PRM's success:

1. Participating controllers and pilots must judge the system as safe;
2. Five hundred ft minimum separation must be maintained between aircraft in scripted blunder scenarios; and
3. A risk analysis must show that the overall risk associated with closely spaced simultaneous ILS approaches was very low.

The simulation evaluated controller performance when monitoring traffic to simultaneous ILS approaches spaced 3400

ft (MEM) and 3500 ft (RDU) apart. MEM also conducted a small number of trials using a 4300 ft between runway spacing with a simulated 4.8 second update rate to be used as standard for comparing the different radar equipment.

Controller and pilot judgements were obtained through post participation questionnaires. The controllers (95%) and pilots (82%) liked the PRM equipment and most believed it could be used to safely reduce standard runway spacings to 3400 ft. The controllers that did not favor the PRM indicated that they would prefer additional time to evaluate the system before making a decision. Of the pilots that did not approve the PRM, 15% were undecided and 3% disapproved.

The separation was measured for flight simulators and test aircraft. In all but a few cases, the controllers were able to maintain miss distance above the 500 ft criterion. The blunders that resulted in less than 500 ft miss distances were examined and the conflict severity was accounted for by equipment problems, communication problems, or very slow pilot responses.

A risk assessment simulated 100,000 blunders with values for the relevant variables (radar update interval, display predictor lead time, controller and pilot response times, communication blockage, and initial spacing between the aircraft) selected from those measured during the demonstration. For each of the blunders executed, the closest

point of approach (CPA) was calculated. CPAs that were less than 500 ft were considered an unacceptably close encounter and the probability of their occurrence as the result of a blunder was calculated.

The time from when the controller begins to break out the threatened aircraft until the blundering aircraft enters the NTZ is defined as the net lead time. The net lead time is a function of the controller alert which in turn is affected by the radar update rate. The simulation results indicated that quicker update rates will result in a larger average net lead time thereby resulting in a safer system.

The alert response times did not vary significantly as a function of display update rate. Alert response is the time interval from the caution alert until the controller's breakout response. The alert response was however affected significantly by the blunder angle. It was found that, on the average, controller's reacted approximately 1 second quicker to 30 degree blunders (3.4 s) than they did to 15 degree blunders (2.5 s).

Summary.

The Data Collection and Analysis studies have an obvious advantage in that there is little need for the simplifying assumptions required for the other research techniques. The results, which are based on collected data have been

traditionally more convincing to the policy makers, as supported by the fact that the two major simultaneous ILS regulation changes were based on data collection studies.

Extensive data collection programs are required to determine the probability of collision (or some similar statistic) since a collision is an extremely rare event (Steinberg, 1969 and 1970). Complicating the data collection efforts may be regulations (i.e. restrictions on parallel approaches) or equipment availability.

The major advantage of the Probabilistic Conflict Rate analyses is that collision probability is usually a direct output of the research. If the track-keeping error is assumed to be normal, then the only parameters required are the mean and the standard deviation of the CTD. Inputs to this type of research can be obtained through the results of past and present Data Collection and Analysis studies. This type of analysis generally does not account for controller intervention in blunder situations. Parametric sensitivity analysis of controllable design parameters (such as surveillance update rate) are not possible with this type of study. Accordingly, very little development has been achieved since 1974.

The major advantage of the Parametric Blunder Resolution studies is that by specifying a system which is protected against the worst-case blunder scenario, the collision risk

theoretically reduces to zero. Also, since these models support parametric analysis of controllable design parameters, sensitivity analysis can be used to make reliable comparisons among competing systems. Among the disadvantages of this research is that some parameters, such as ILS departure angle and missed detection probability, are extremely difficult to estimate reliably. Also, since the analysis is deterministic and since a "worst case" scenario is difficult to define, errors in parameter estimation may result in needlessly large (non-optimal) separations. Finally, if it is desired to study blunder scenarios less severe than "worst case", the determination of the resulting risk would be virtually impossible. However, despite these disadvantages, this research (especially the MITRE model) continues to play an active role in current simultaneous ILS research.

Real Time Simulation offers a tremendous advantage in that reliable estimates of human factors parameters such as blunder detection delays, pilot response delays, and false breakout frequencies can be empirically obtained. Real time simulation provides an environment for analysis of controller blunder resolution techniques that would not be available in the operational environment. As with the Parametric Blunder Resolution studies, the controllable design parameters can be varied, thus allowing for sensitivity analyses. Regrettably, this research suffers from the basic question as to how well

the simulation duplicates the operational ATC environment. Often, unrealistic scenarios must be simulated to evaluate system performance in the event of a worst case situation. Additionally, real time simulations suffer from long development periods and costly setup.

RESEARCH OBJECTIVES

The primary purpose of this research was to quantify the benefit of fielding the high resolution color Precision Runway Monitor (PRM) displays with aircraft course deviation alert capabilities in the operational ATC environment. The studies presented in the literature survey often concluded that controller performance and consequently airport capacity could be improved through the development of better radar sensors and/or better controller displays. Two simulations (Paul et al., 1989 and PRM Program Office, 1991) tested controller performance with enhanced display systems and drew conclusions that the new display features would enable increases in capacity and safety. This study compared controller performance using the current Automated Radar Terminal System (ARTS) IIIIA display with controller performance using the PRM display. The results should quantify the benefits derived by fielding the PRM display in terms of safety measures (blunder detection times, API ratings, and CPAs).

MATERIALS AND METHODS

Experimental Design.

The experimental design for this study was a 2 x 2 x 2 repeated measures design. The factors were display type, blunder degree, and airport configuration. All three factors had two levels as described below. Figure 8 shows the overall experimental design.

Display type. Two different display types were evaluated in this study. The first display type was the Automated Radar Terminal System (ARTS) IIIA. It is the display type currently used in most high traffic TRACONS. The second, the Precision Runway Monitor (PRM) display, is a new display system undergoing evaluation for implementation.

Blunder angle. Two levels of blunder degree were examined in this study. Blunders of 30 and 20 degrees were initiated toward aircraft on adjacent approaches. The blunders were initiated after vertical separation had been lost between aircraft on adjacent approaches and before the aircraft had reached the Missed Approach Point (MAP).

Approach operation. Approach operation represented the number of parallel runways to which independent approaches were being conducted. The airport had a generic layout with three parallel runways having even thresholds. For the triple simultaneous parallel approach operation, approaches were conducted independently to all three runways. The dual

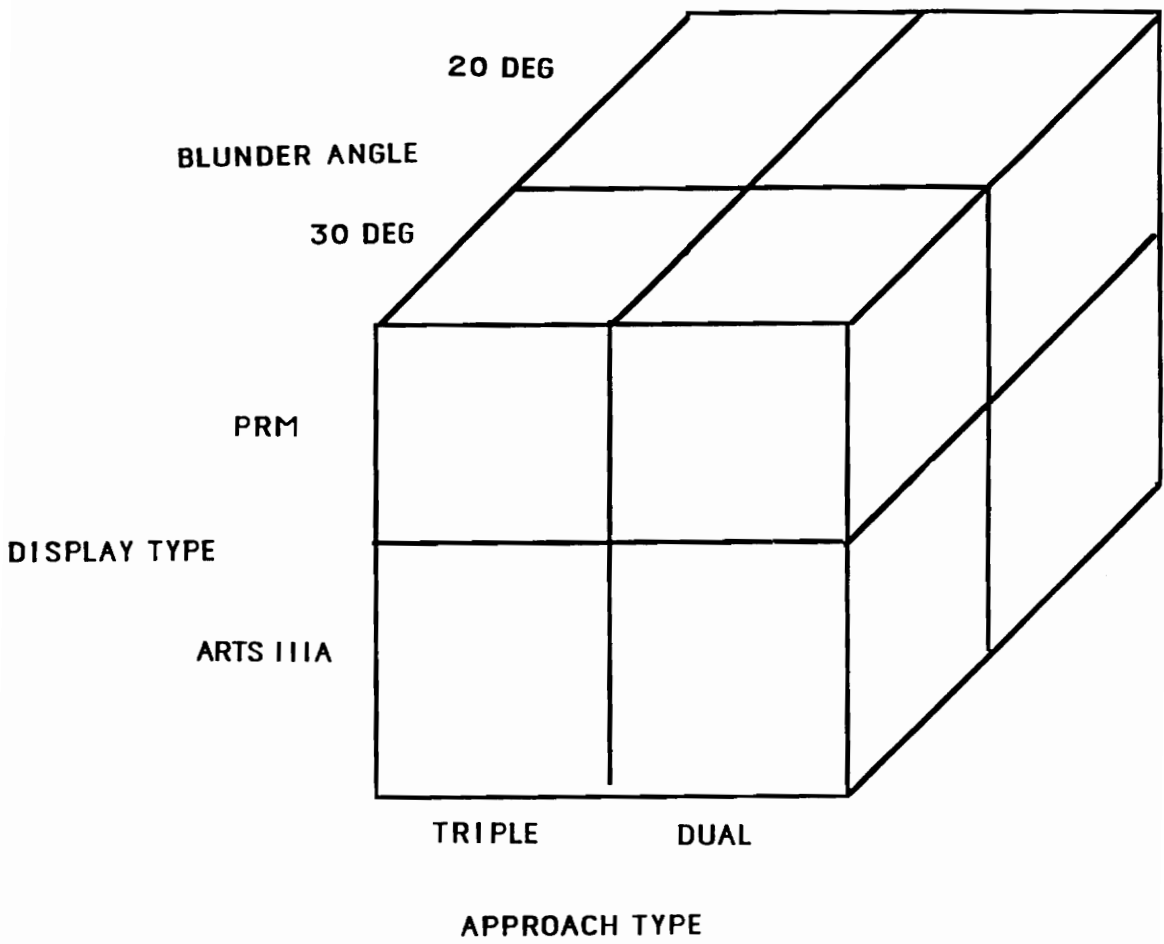


Figure 8. Experimental Design

approach operation had independent approaches conducted to only the center and the left runways. There were no air aircraft conducting approaches to the right runway for the dual approach operation. This in essence simulated a single set of parallel runways.

Potential conflict severity. Potential conflict severity is a measure of how close the blundering aircraft and a threatened aircraft would have come if the controllers did not intervene. The Predicted Closest Point of Approach (PCPA) and the Predicted Aircraft Proximity Index (PAPI) are both measures of the potential conflict severity. These are calculated by taking a "snapshot" of the blundering and evading aircraft's positions, speeds, headings, and descent rate at the beginning of a blunder. Based upon this information, the flight paths of both aircraft were projected. The CPA and the API were then calculated for the corresponding positions of the aircraft along their flight paths. The lowest CPA and the highest API were retained as the PCPA and PAPI.

It was difficult to produce similar PCPA and PAPI distributions between runs within each simulation and also between simulations. The controller issued speed changes and variations in flight simulator pilot performance resulted in differences in aircraft alignments between runs of the same traffic sample. This variation necessitated using the PCPAS

and PAPIs as covariates in the analyses of the CPA and API data, respectively. This helped control the error variance found between the initial conditions.

Dependent measures. Controller response times were collected to assess the controller's ability to detect aircraft blunders. Response times were measured from the blunder onset until the controller of the blundering aircraft identified the blundering aircraft and relayed a message to that aircraft. This was identified by the controller pressing the push-to-talk key of his headset.

The Closest Point of Approach (CPA), and Aircraft Proximity Index (API) were collected for each blunder evaluated in the simulation. During a conflict, the CPA and the API were updated every second. The smallest CPA and the largest API were recorded for each blunder. Although a blundering aircraft may have been involved in several conflicts, only the worst conflict, as indicated by CPAs, was retained for the assessment. The CPA and the API measures were used to assess the effectiveness of the controller in resolving the blunder.

Apparatus.

ARTS IIIA display. The ARTS IIIA was a radar and beacon tracking system that displays both primary and secondary surveillance echoes. The ARTS IIIA system displayed information on the plan position indicator (PPI) of the data

entry and display subsystem (DEDS). The PPI was a 36 inch diameter circular tube that used two types of phosphor, a low-persistence/high-intensity blue phosphor and a high-persistence/low-intensity orange phosphor. Targets and information on the display appeared as green. The PPIs were equipped with a filter over the display to equalize the intensity and color of the light. The ARTS system overlaid alphanumeric information provided by the data processing system on the primary and secondary radar information. Figure 9 shows the airport configuration as it appeared on the ARTS IIIA display.

PRM display. The second display type was the PRM display. The PRM display was a 20 x 20 inch (28 inch diagonal), high resolution (2048 raster scan lines), color monitor. The runway and the extended runway centerline were displayed in white on a black background. The NTZ was outlined in red. Additionally, light gray lines were displayed parallel to the extended runway centerline to mark 200 ft intervals between the NTZ and the ILS course. Figure 10 shows the PRM display console displaying the triple parallel approach configuration with 3000 ft runway spacing.

The PRM had two additional unique features. First, the display had independent x-y (lateral-longitudinal) range magnification. This allowed the controller to magnify lateral runway spacings independently of the longitudinal distances.

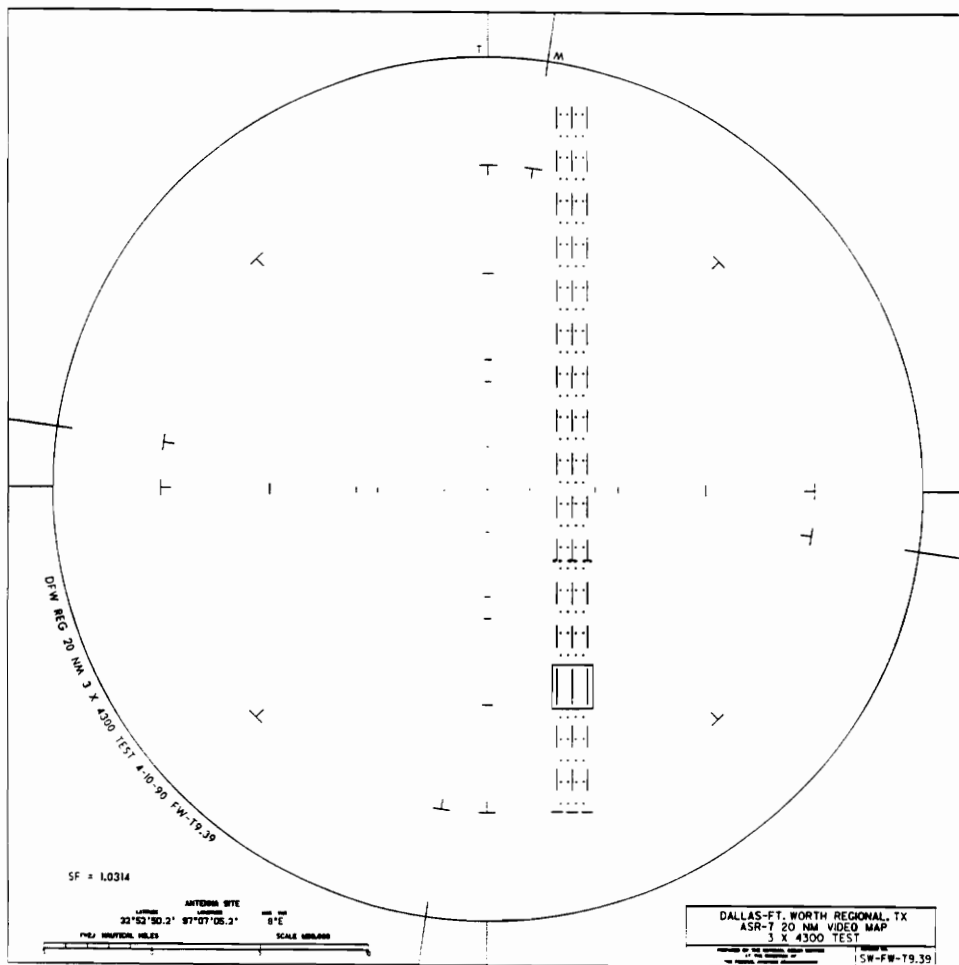


Figure 9. The Airport Configuration as Displayed on the ARTS IIIA Display



Figure 10. The PRM Display

Secondly, this display provided the controllers with both visual and audio alerts of impending NTZ entry and NTZ entry. The aircraft target and tag changed from green to yellow and an auditory warning which identified the aircraft ID was given when an NTZ entry was predicted to occur within 10 seconds. The prediction was based upon prior aircraft position and movement. If an aircraft proceeded and entered the NTZ, the target and the tag changed from yellow to red.

National Airspace Simulation Support Facility (NSSF). The NSSF was physically divided into three components, the air traffic controller laboratory (ATCL), the pilot simulation complex (PSC), and the central computer facility (CCF). Each of these three components is described below.

Air Traffic Controller Laboratory (ATCL). The NSSF provided a realistic environment for simulating the TRACON environment in the ATCL. The ATCL housed eight ARTS IIIA consoles and three PRM consoles. For this study, the three consoles being used in each phase of the study were placed abutting each other. This configuration allowed direct controller-to-controller voice communication.

Voice communications to the pilot simulation facility was provided via a simulated radio communication system. Communication lines to the pilot simulation facility simulated individual radio frequencies. This enabled a controller to communicate only with those pilots within his control. The

controller used a headset for controller-to-pilot communication exactly as he would in the operational environment.

Pilot Simulator Complex (PSC). The PSC housed individuals that controlled the computer generated aircraft targets. These pilots were in voice communication with the controllers. The simulator pilots verbally responded to the controller's message and converted the controller's verbal messages into data entry messages via a specialized keyboard. The message was then transmitted to the central computer facility where the appropriate response was generated. Each simulator pilot could have controlled up to ten aircraft. For this study, simulator pilots were required to control no more than three aircraft at any given time.

Central Computer Facility (CCF). The CCF generated simulated aircraft targets and simulated other aspects of the air traffic system. The CCF consisted of a Gould/SEL 32/8750 and a Gould/SEL 32/7780. The Gould/SEL 8750's programs performed all of the functions required to simulate aircraft within the ATC environment. The Gould/SEL 32/8750 interfaced with the pilot simulator displays and keyboards, and interfaced with the ATCL via the Gould/SEL 32/7780.

Targets were generated by using an aircraft model that dynamically updated each aircraft's position based upon its last position and current status, i.e., turning, climbing, and

accelerating. An aircraft's status was constantly monitored to reflect changes caused by predetermined flight plans and controller messages input by the pilot. The aircraft model included performance profiles unique to the aircraft types simulated to provide realistic aircraft-pilot response characteristics.

Procedure. Specific simulation procedures used to measure controller performance while monitoring traffic using the ARTS IIIA display are described in Appendix D (Phase IV.a.1 Test Plan). The simulation procedures for measuring controller performance while monitoring traffic using the PRM display are described in Appendix C (Test Plan Phases V.a.1 and V.c).

Instructions and Informed Consent. The controllers were briefed about the intent of the simulation and their tasks prior to participation in each phase of the simulation. Experimenters answered any questions the controllers had pertaining to the briefing. Controllers were asked to complete a biographical information questionnaire and sign an informed consent form before participating in the simulation. The Controller Briefing for Phase V.a.1 and V.c is included as appendix E and the Informed Consent Form is included as appendix F.

Subject Selection. Requests were sent to the National Air Traffic Controllers Association (NATCA) offices from six regions in the continental U.S. for participation in the

simulation conducted in March 1990 (Phase IV.a.1). The request asked for volunteer controllers that had more than 5 years experience monitoring traffic in parallel approach operations. NATCA provided individuals from each of the six regions for participation in the simulation. Nine controllers were chosen based upon availability and seniority of the volunteers. Controllers were compensated for their participation according to the standard rate for travel pay. Pretesting of controller vision or performance as a selection criteria was not permitted by the NATCA offices. Additionally, analysis of individual controller performances was not permitted.

The controllers that participated in the Phase IV.a.1 simulation were requested to participate in the Phase V.a.1 simulation. Only six of the original 9 controllers were available for retesting.

Controller Training. Because the ARTS IIIA display is currently used operationally the controllers were proficient using it prior to participation in the first simulation. To ameliorate order effects associated with the display type, the controllers were trained to proficiency using the PRM display prior to participating in the second simulation.

DATA REDUCTION

The Gould/SEL 32/7780 recorded the raw simulation data for each run on an 800 bpi magnetic tape drive. The raw data included individual aircraft status (position, velocity, heading and descent rate) and event occurrences (controller push-to-talk, pilot message entry, conflicts) at the rate of once per sec (1 Hz).

Trained observers monitored the simulation and recorded unusual occurrences. The observers recorded the occurrence of each blunder and logged the controller's message to the pilot. Subjective comments concerning the pilot response times and aircraft performance were often included in the observations.

Controllers completed post run questionnaires and workload ratings during both simulations. The questionnaire data however was not used in the analysis of controller performance for this study.

Video tape recordings were made of the controller's monitor via a S-VHS video camcorder. The audio track of the video recorder was used to record controller voice communication that was not transmitted via the simulated radio system (intercontroller conversation). The controller and pilot voice messages were recorded via the AMDECK 20-channel audio recording system.

After the simulation was completed the raw data were processed to provide data files containing the following information about each blunder:

1. Run number,
2. Blunder time,
3. Controller response time,
4. Blundering aircraft ID,
5. Blunder degree (20 or 30),
6. Blunder path (maintain altitude or continue descent),
7. Pilot communication capabilities (yes or no)
8. Lateral distance between blundering and evading aircraft (4300 ft or 8600 ft),
9. Closest Point of Approach (CPA in ft),
10. Predicted Closest Point of Approach (PCPA in ft),
11. Aircraft Proximity Index (API), and
12. Predicted Aircraft Proximity Index (PAPI).

The reduced file was then hand checked for erroneous data points, such as controller issued heading changes which were interpreted as a blunder by the reduction software. Blunders which resulted in CPAs or PCPAs of greater than 5000 ft were eliminated from the simulation analyses. The 5000 ft distance was chosen because it represented the slant range distance of

approximately one runway spacing plus and additional 2500 ft of either longitudinal or vertical spacing.

Additionally, the observer logs were reviewed and blunders which were identified as questionable were examined. The video and audio recordings were used to examine the questionable blunders. Subject matter experts, the Multiple Parallel Approach Technical Working Group, reviewed the blunders and assisted in judging the validity of the blunder consequences. Seven of the 49 blunders reviewed were eliminated from the analyses. The reasons for eliminating the blunders included incorrect heading change input by NSSF simulator pilots (4), unreasonably long pilot response delays (2), and no response by the threatened aircraft.

After all the data had been checked for validity, there were 285 blunders remaining for evaluation. There were 114 from the ARTS IIIA simulation and 171 from the PRM simulation. A breakdown of the blunder frequencies by display, approach operation, and degree is given in Table 1.

Table 1. Summary of Blunder Types

	ARTS IIIA		PRM	
	DUAL	TRIPLE	DUAL	TRIPLE
<u>20°</u>	6	7	8	36
<u>30°</u>	47	54	31	96

RESULTS

Controller Response Times. Controller response times were classified according to blunder degree, airport configuration, and display type. Figure 11 shows the distribution of controller response times for both display types. A Kolmogorov-Smirnov two-sample test was conducted to assess the normality of the controller response distributions. The distribution of the response times for the controllers using the Automated Radar Terminal System (ARTS) IIIA display was not significantly different from a normal distribution centered at 14.6 s with a standard deviation of 4.5 s ($d = 0.09$, $n = 114$). Similarly, the distribution of response times for controllers using the PRM display was not significantly different from a normal distribution centered at 10.0 s with a standard deviation of 3.7 s ($d = 0.10$, $n = 171$).

The ANOVA used to detect differences in controller response times between levels of the independent variables is shown in Table 2. It was shown that display type significantly affected the controller's ability to detect blunders, $F(1,277) = 24.86$, $p < 0.00002$). The average response time for controllers using the PRM radar display was 10.5 s (s.d. = 3.8 s, $n = 171$) and the average response time for controllers using the ARTS IIIA radar display was 14.6 s (s.d. = 4.2 s, $n = 114$). The blunder degree and approach

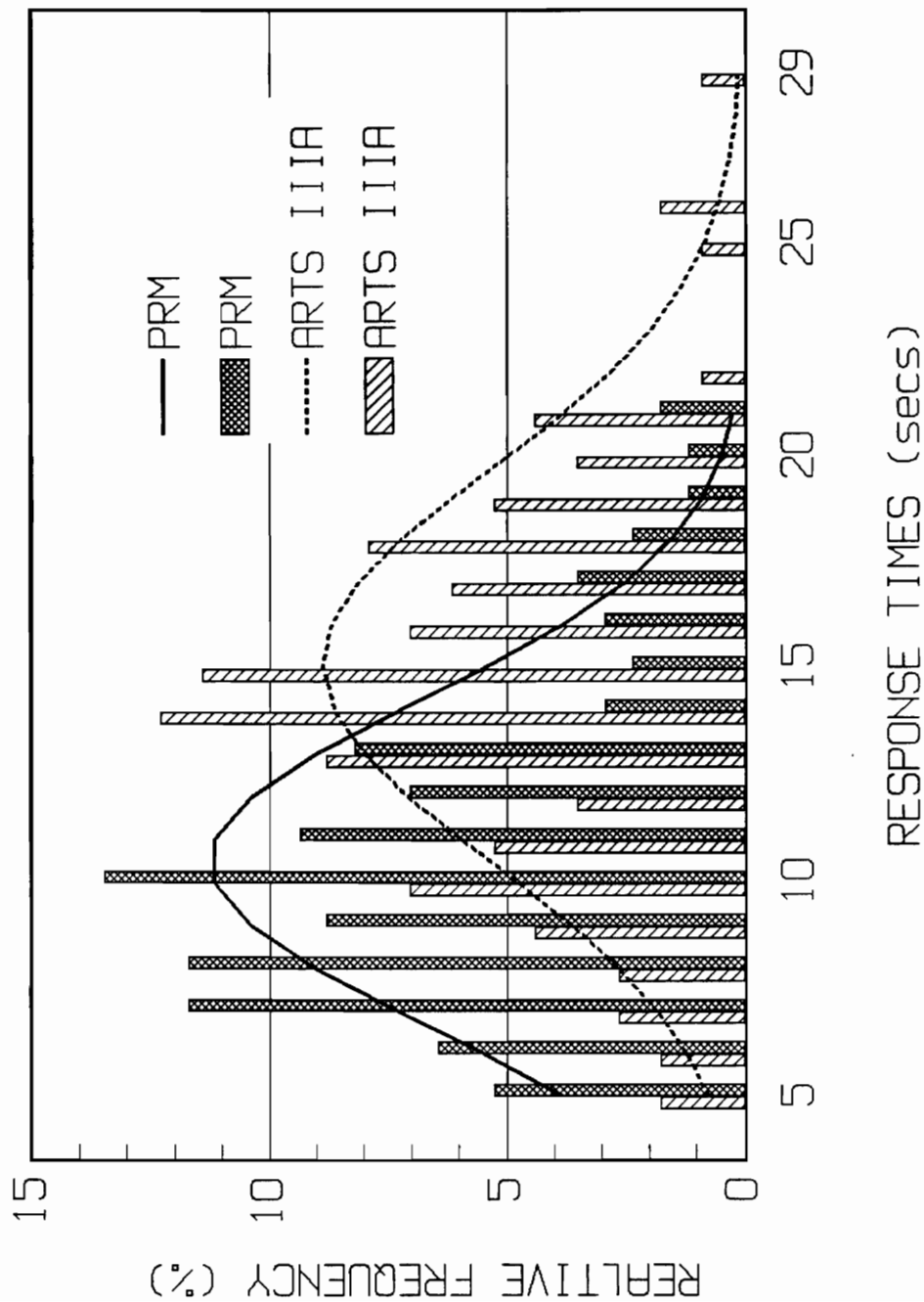


Figure 11. Controller Response Time Distributions

Table 2. Overall ANOVA for Controller Response Time

ANALYSIS OF VARIANCE

Effect	SS	df	MS	F	p
(A): DISP	408.511	1	408.5113	24.86431	0.00002
(B): AP OP	1.407	1	1.4068	0.08563	0.76288
(C): DEG	38.609	1	38.6090	2.34996	0.12234
A x B	4.467	1	4.4669	0.27188	0.60895
A x C	6.313	1	6.3127	0.38423	0.54311
B x C	0.734	1	0.7342	0.04468	0.81513
A x B x C	18.366	1	18.3656	1.11783	0.29135
Within	4551.006	277	16.4296		

operation did not significantly affect controller response time as indicated by the ANOVA.

Figure 12 illustrated the combined effect of display type, approach operation, and blunder degree on the average controller response time. There appeared to be an overall reduction in response times between 20 and 30 degree blunders (see Figure 13). Pos Hoc analyses (Fisher's Least Significant Difference) indicated that there was a significant difference between the response times for 20 and 30 degree blunders when the controllers were using the PRM display while monitoring triple approach operations ($p < 0.0018$)

Closest Point of Approach (CPA).

The evaluation of the CPA data was preceded by an examination of the Predicted Closest Point of Approach (PCPA) data for the two simulations. It was felt that differences in traffic scenarios may confound the analysis of the CPA data. Additional discussions with the Test Director indicated that there were differences in blunder execution strategies. In the ARTS IIIA simulation the Test Director attempted to execute the blunders to result in all conflicts to potentially result in a CPA of less than 500 ft. In the PRM simulation, the Test Director attempted to execute blunders such that the aircraft were within 1/4 nm longitudinally. Consequently the PRM simulation may have resulted in a lower potential for

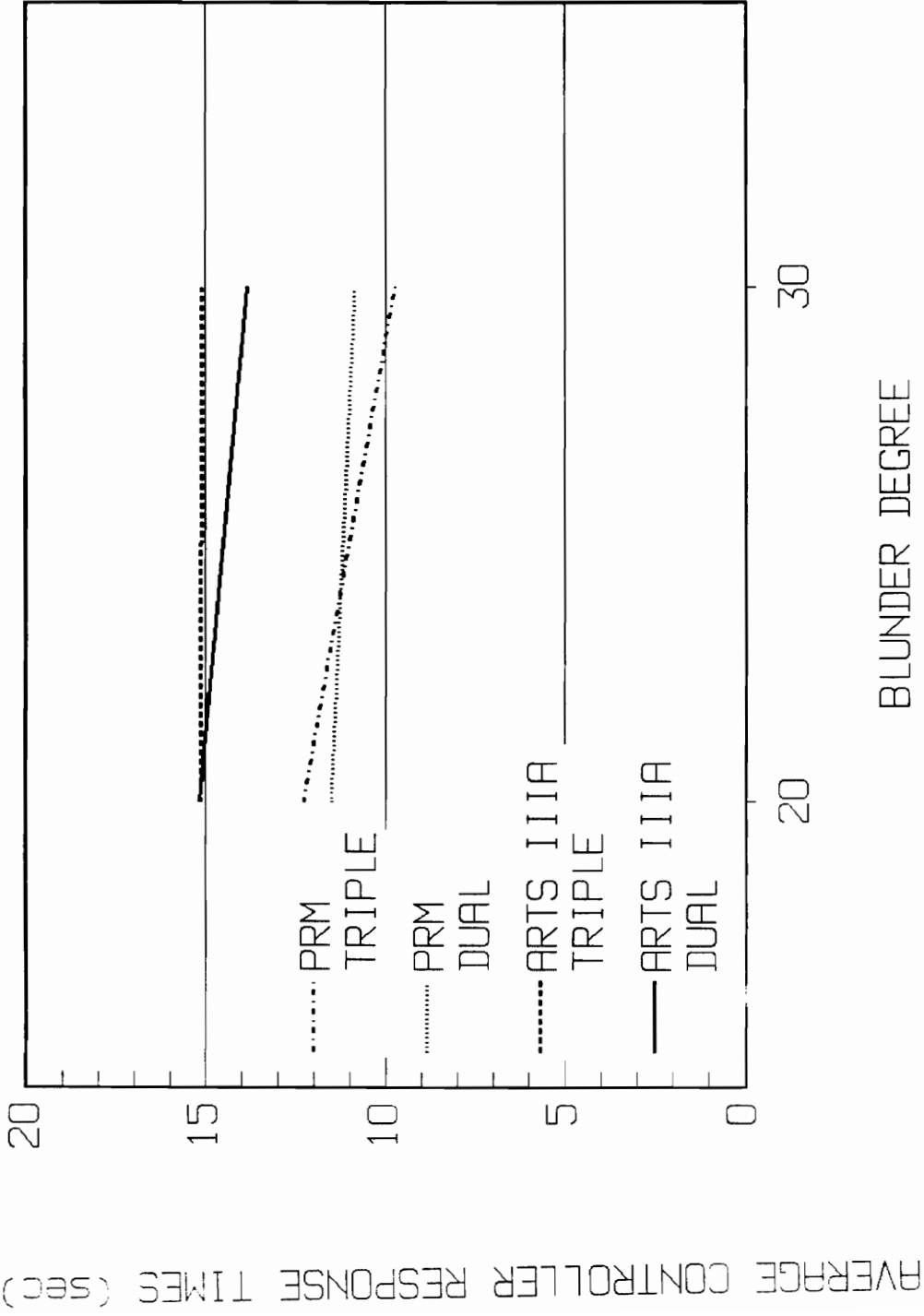


Figure 12. The Combined Effect of Display Type, Approach Operation and Blunder Degree on Controller Response Times

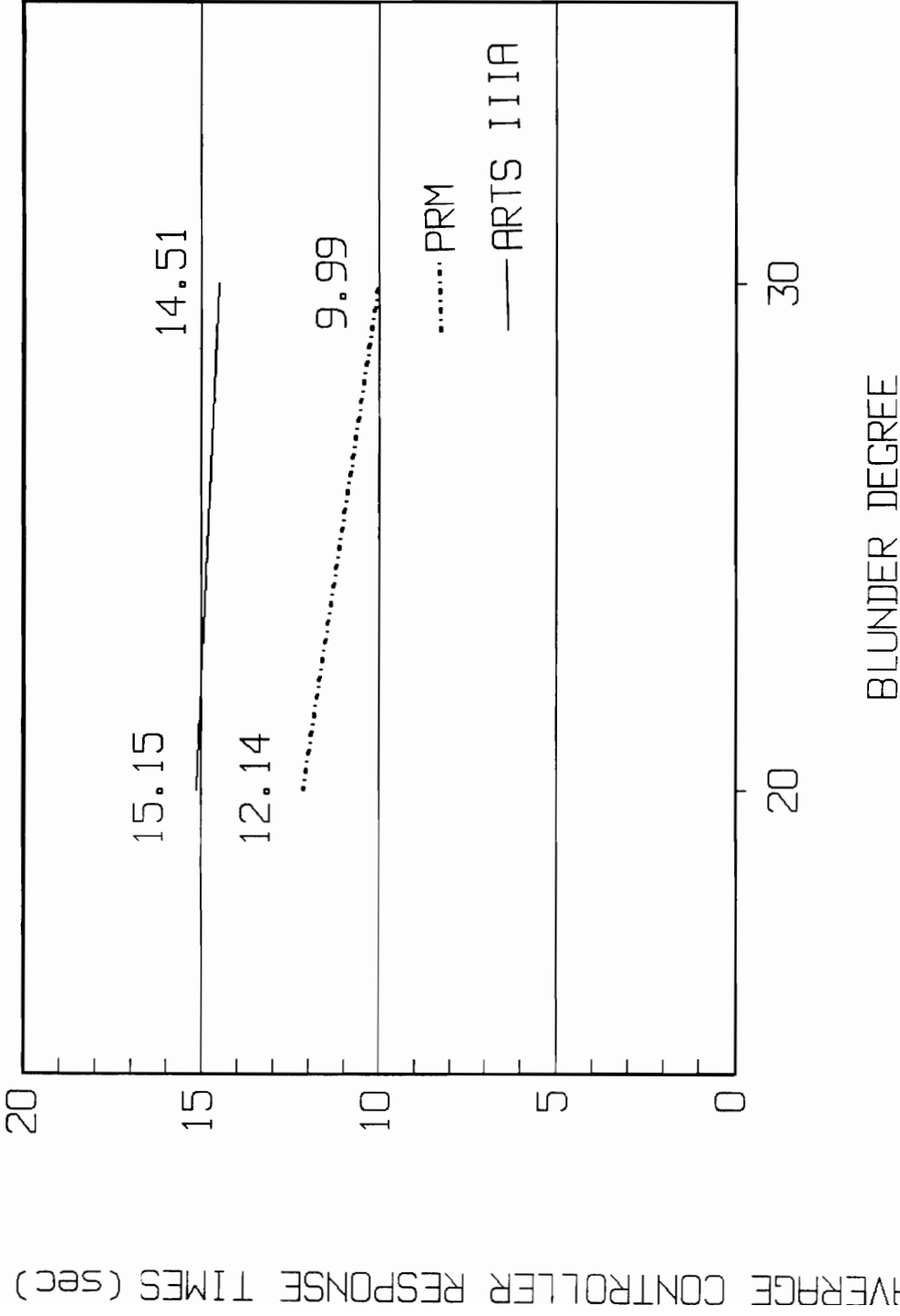


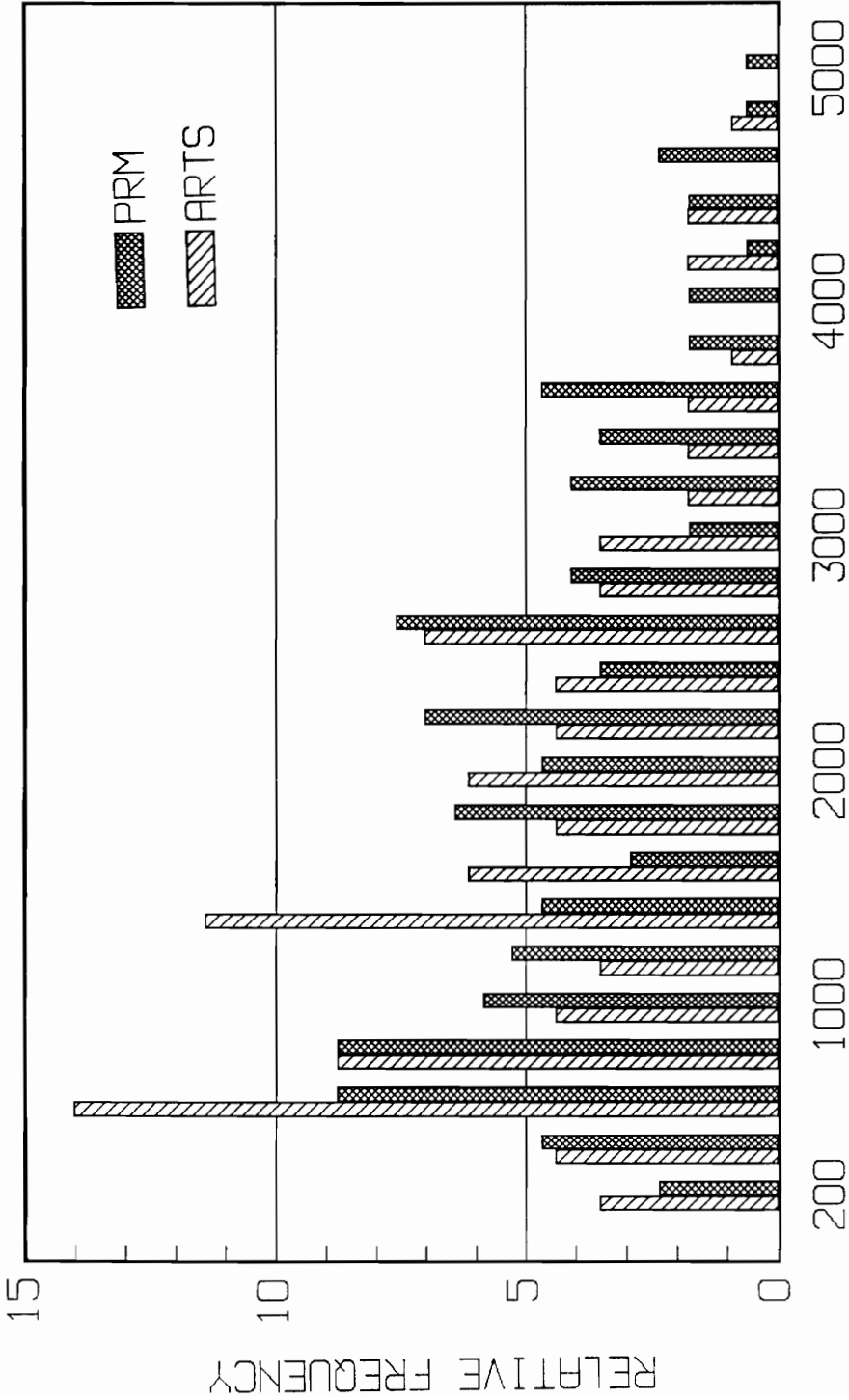
Figure 13. The Effect of Display Type and Blunder Degree on Average Controller Response Times

severe conflicts. Comparison of the PCPA data provided an assessment of the potential confound.

Figure 14 showed the relative frequency of PCPA values for the two simulations. As can be seen in this figure there were some small differences in the PCPA distributions. An ANOVA conducted on the PCPA data indicated there were significant differences ($F(1,283) = 4.667, p < 0.02962$) in the PCPAs between the simulations. The average PCPA was 1611.4 ft (s.d. = 1074 ft) for the simulation using the ARTS IIIA display and the average PCPA was 1912 ft (s.d. = 1201 ft) for the simulation using the PRM display.

Overall analyses (both simulations) indicated that a high level of correlation ($r = 0.638$) was present between the PCPAs and the CPAs. The correlation between the PCPA and the CPA for the simulation using the ARTS IIIA was $r = 0.724$. For the simulation using the PRM display, there was a correlation of $r = 0.611$. The CPA was plotted as a function of the PCPA for the two simulations and is presented in Figures 15 and 16.

Based upon the high correlation and the apparent linear trend in the relationship between PCPA and CPA, regression analyses were conducted on the simulation data. The regression analysis on the ARTS IIIA simulation data showed a slope of 0.8277 at a significance level of $p < 0.0001$ ($F(1,112) = 123.4$). The regression line intercept, 580 ft,



PCPA (200 ft intervals)

Figure 14. Relative Frequency of PCPAs

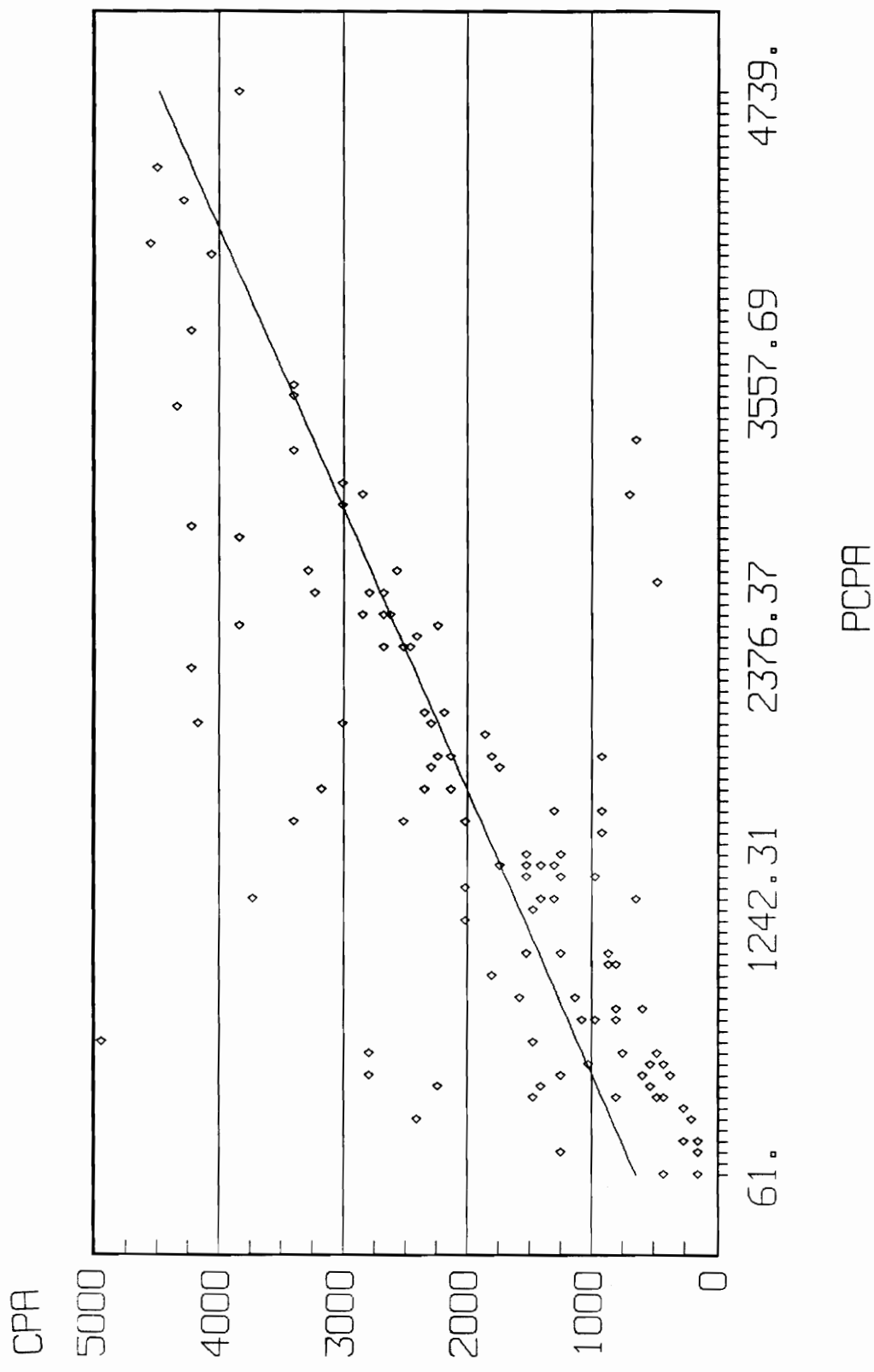


Figure 15. CPA Plotted as a Function of PCPA for the ARTS IIIA Simulation

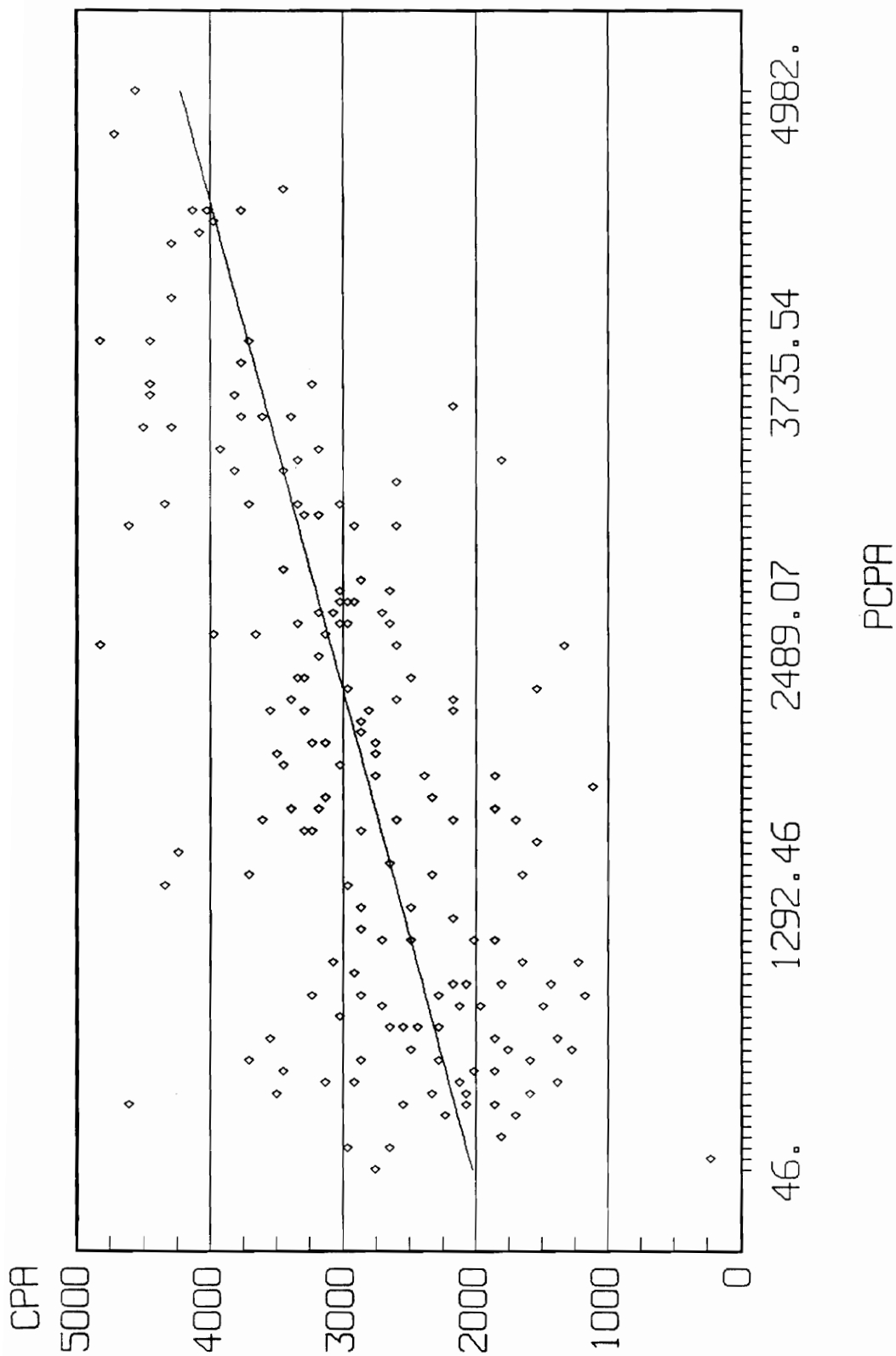


Figure 16. CPA Plotted as a Function of PCPA for the PRM Simulation

was shown to be significantly different from 0 ($t(112) = 11.11, p < 0.00001$).

The regression analysis on the PRM simulation data showed a slope of 0.4503 at a significance level of $p < 0.0001$ ($F(1,169) = 100.9$). The regression line intercept, 1994 ft, was also shown to be significantly different from 0 ($t(169) = 10.04, p < 0.00001$).

The analyses cited above have indicated that the distribution of PCPAs generated in the simulation using the ARTS IIIA display were significantly different from the distribution of PCPAs generated in the simulation using the PRM display. The linear regressions indicated that the CPA for both simulations increased linearly as a function of the PCPA. Finally, analyses also indicated that the CPA was highly correlated with the PCPA for both simulations. Based upon these findings the PCPA was recognized as an uncontrolled quantitative independent variable. It was deemed that the PCPA should be taken into account by analyzing the CPA using an Analysis of Covariance (ANCOVA). The objective of the ANCOVA was to adjust the CPAs for differences in the covariate, PCPA.

The summary ANCOVA table for the CPA data is shown in Table 3. The independent variables analyzed in the ANCOVA included the display type, approach condition, blunder degree, and communication. Communication was included because the

Table 3. Overall ANCOVA for the Closest Point of Approach Data

ANALYSIS OF VARIANCE

Effect	SS	df	MS	F	p
Cov: PCPA	0.11E+09	1	0.11E+09	185.5536	0.00000
(A): DISP	0.72E+07	1	0.72E+07	12.6803	0.00075
(B): AP OP	0.21E+06	1	0.21E+06	0.3692	0.55122
(C): DEG	0.72E+07	1	0.72E+07	12.6820	0.00075
(D): COMM	0.92E+06	1	0.92E+06	1.6191	0.20145
A x B	0.89E+05	1	0.89E+05	0.1562	0.69454
A x C	0.13E+07	1	0.13E+07	2.2867	0.12761
A x D	0.91E+06	1	0.91E+06	1.5976	0.20454
B x C	0.81E+06	1	0.81E+06	1.4353	0.22986
B x D	0.11E+07	1	0.11E+07	1.8820	0.16767
C x D	0.27E+03	1	0.27E+03	0.0005	0.93120
A x B x C	0.90E+06	1	0.90E+06	1.5790	0.20726
A x B x D	0.38E+05	1	0.38E+05	0.0673	0.78442
A x C x D	0.89E+06	1	0.89E+06	1.5682	0.20887
B x C x D	0.12E+07	1	0.12E+07	2.0662	0.14789
A x B x C x D	0.18E+06	1	0.18E+06	0.3177	0.58052
Within	0.15E+09	268	0.57E+06		

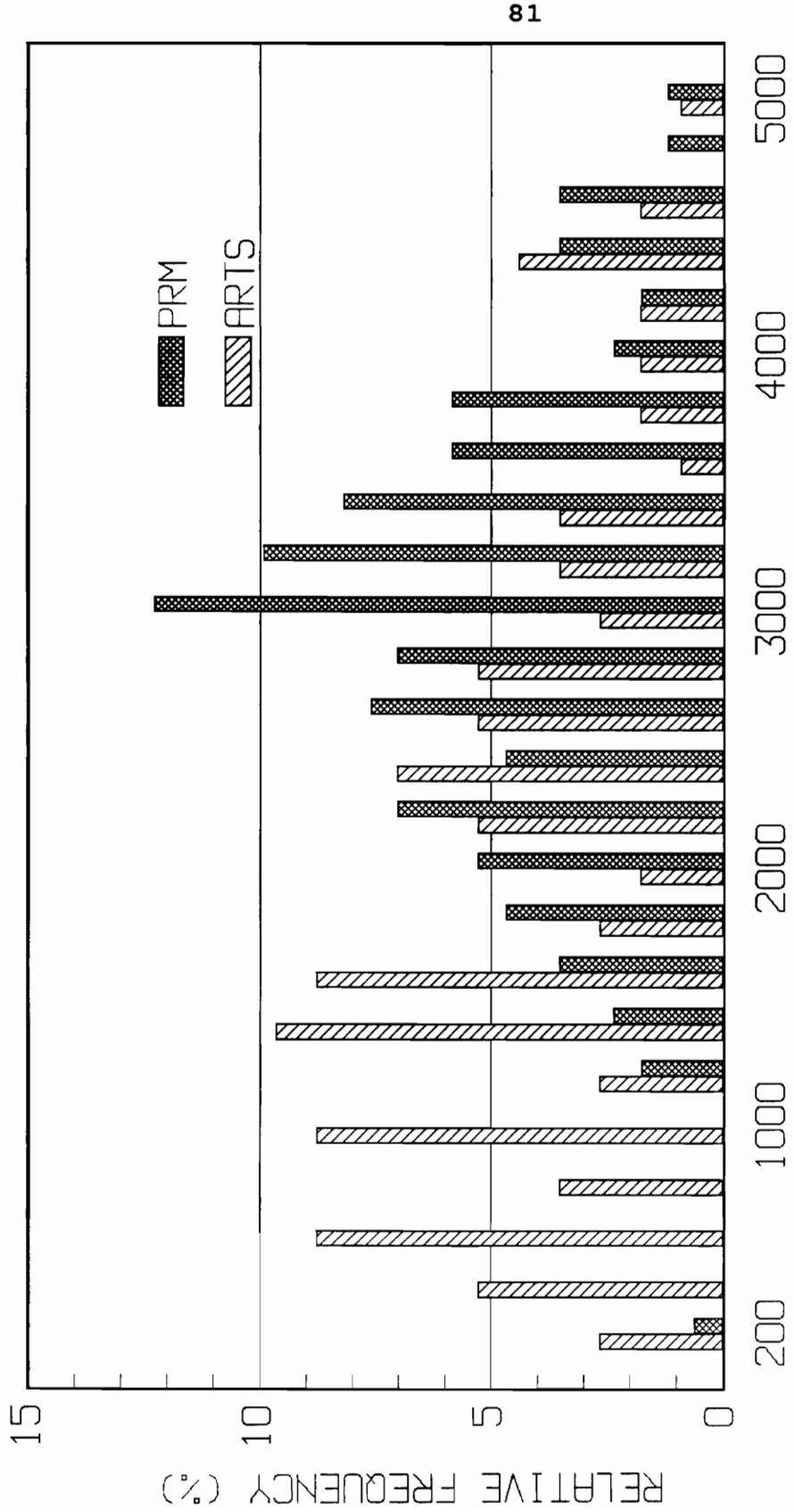
ability of the blundering aircraft to comply with the controller's resolution maneuvers would directly affect the CPA of the individual blunders.

As can be seen in the ANCOVA summary table, CPA was shown to vary significantly as function of the covariate, PCPA ($F(1,268) = 185.5536, p < 0.00001$). The only independent variables that were indicated to have a significant effect on the controller's ability to resolve blunders was the display type ($F(1, 268) = 12.6803, p < 0.00075$) and the blunder degree ($F(1, 268) = 12.6820, p < 0.00075$). There were no significant interactions between any of the independent variables. The distribution of CPA values was shown in Figure 17.

Figure 18 illustrated the combined effect of display type and blunder degree on the average CPA. Figure 18 also presented the average adjusted CPAs for the different combinations of display type and blunder degree. The adjusted CPAs were corrected for the difference in the PCPAs between treatment levels. The adjusted mean CPA for the ARTS IIIA display was 2014 ft and the adjusted mean CPA for the PRM display was 2789 ft.

Aircraft Proximity Index.

Similar to the CPA data, the evaluation of the API data was preceded by an examination of the PAPI data for the two simulations. Figure 19 shows the relative frequency of PAPI



CPA (200 ft intervals)

Figure 17. Distribution of CPA Values.

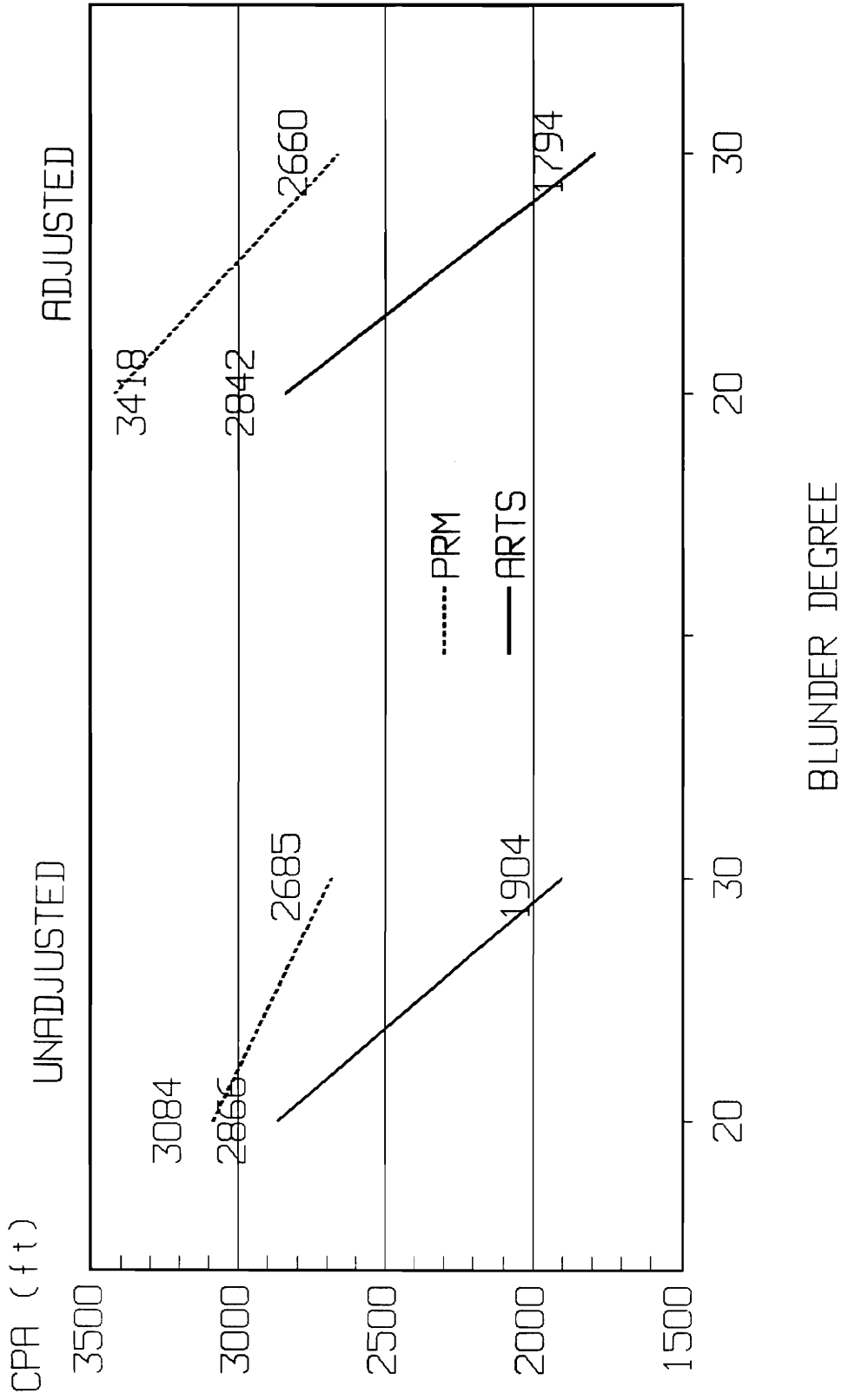


Figure 18. The Combined Effect of Display Type and Blunder Degree on The Average CPA.

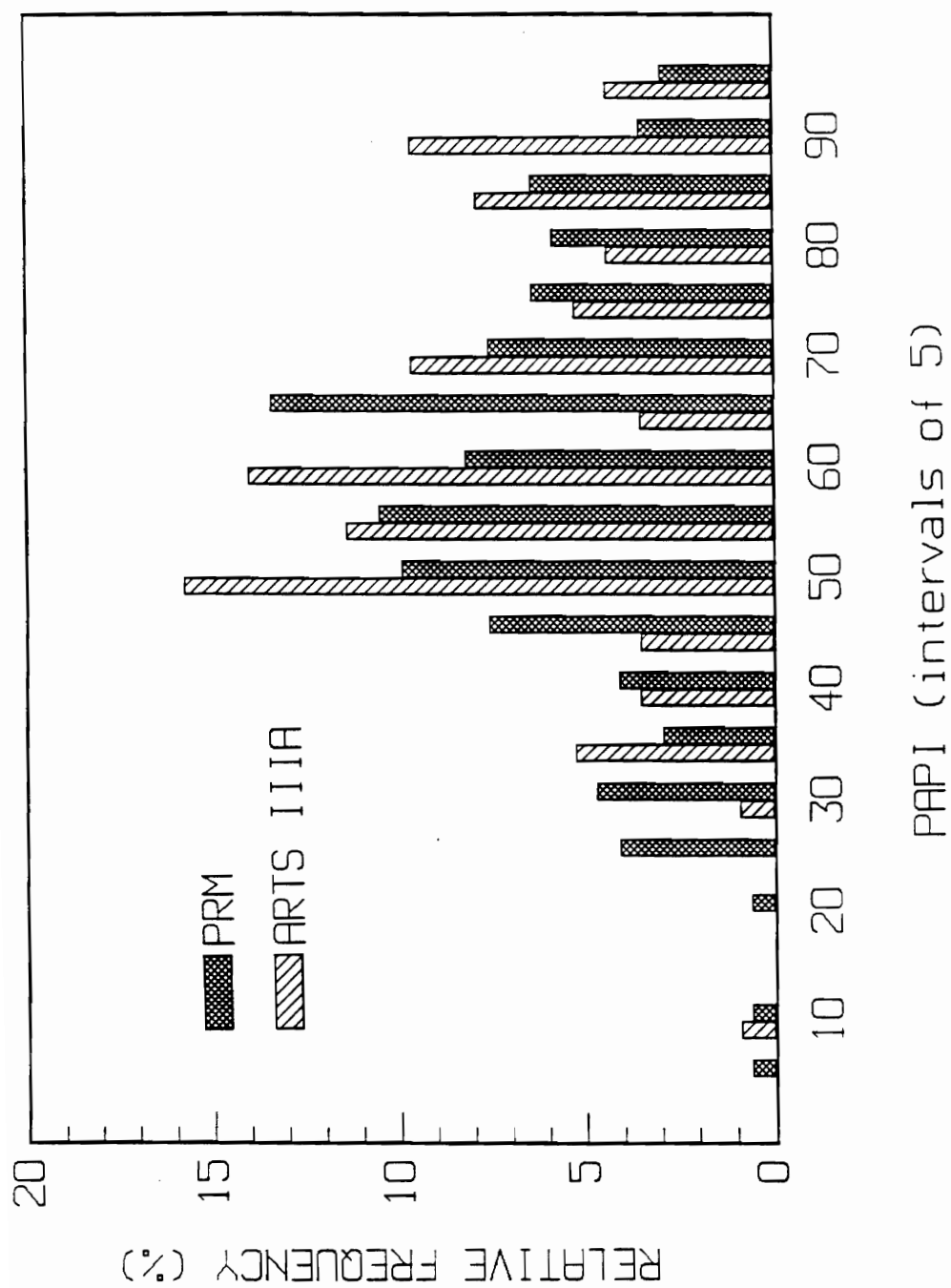


Figure 19. The Relative Frequency of PAPI Values.

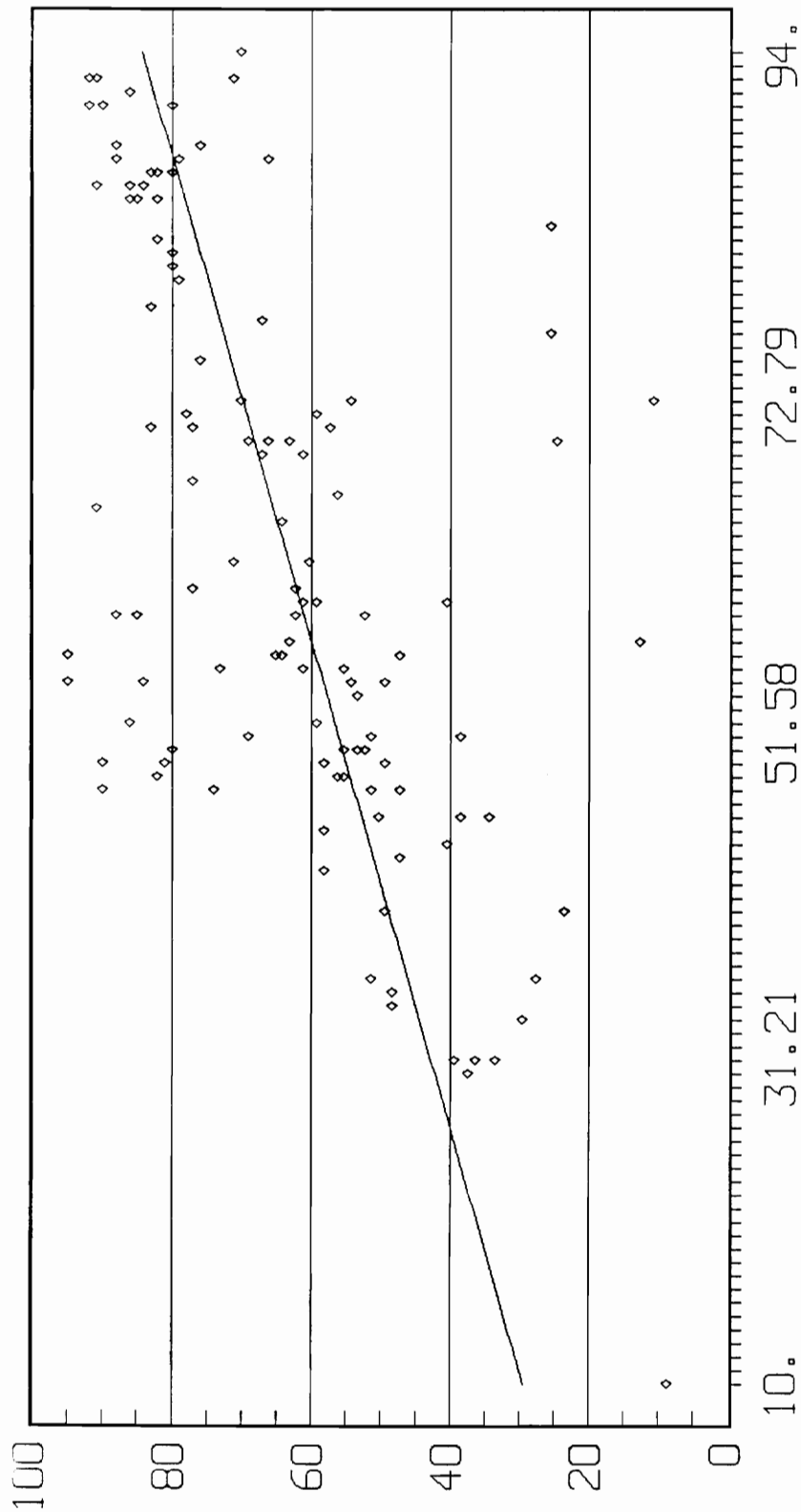
values for the two simulations. This figure indicated there may have been some differences in the PAPI distributions. An ANOVA conducted on the PAPI data indicated there were significant differences in PAPI ratings between the two display types ($F(1,283) = 3.97$, $p < 0.04437$). The average PAPI was 61.9 (s.d. = 17.8) for the simulation using the ARTS IIIA display and the average PAPI was 57.4 (s.d. = 18.9) for the simulation using the PRM displays.

Analyses indicated that a moderate level of correlation was present between the PAPIs and the APIs for both the simulation using the ARTS IIIA displays, $r = 0.575$ and the simulation using the PRM display, $r = 0.585$. The API was plotted as a function of the PAPI for the two simulations and is presented in Figures 20 and 21.

Regression analyses were conducted on the simulation data using the PAPI and API data. The regression analysis on the ARTS IIIA simulation data showed a slope of 0.658 at a significance level of $p < 0.0001$ ($F(1,112) = 55.24$). The regression line intercept, 22.7, was shown to be significantly different from 0 ($t(112) = 7.43$, $p < 0.00001$).

The PRM simulation data produced a regression line with a slope of 0.480 at a significance level of $p < 0.0001$ ($F(1,169) = 88.11$). The regression line intercept, 29.8, was also shown to be significantly different from 0 ($t(169) = 9.39$, $p < 0.00001$).

API



PAPI

Figure 20. The API plotted as a function of the PAPI for the ARTS IIIA display.

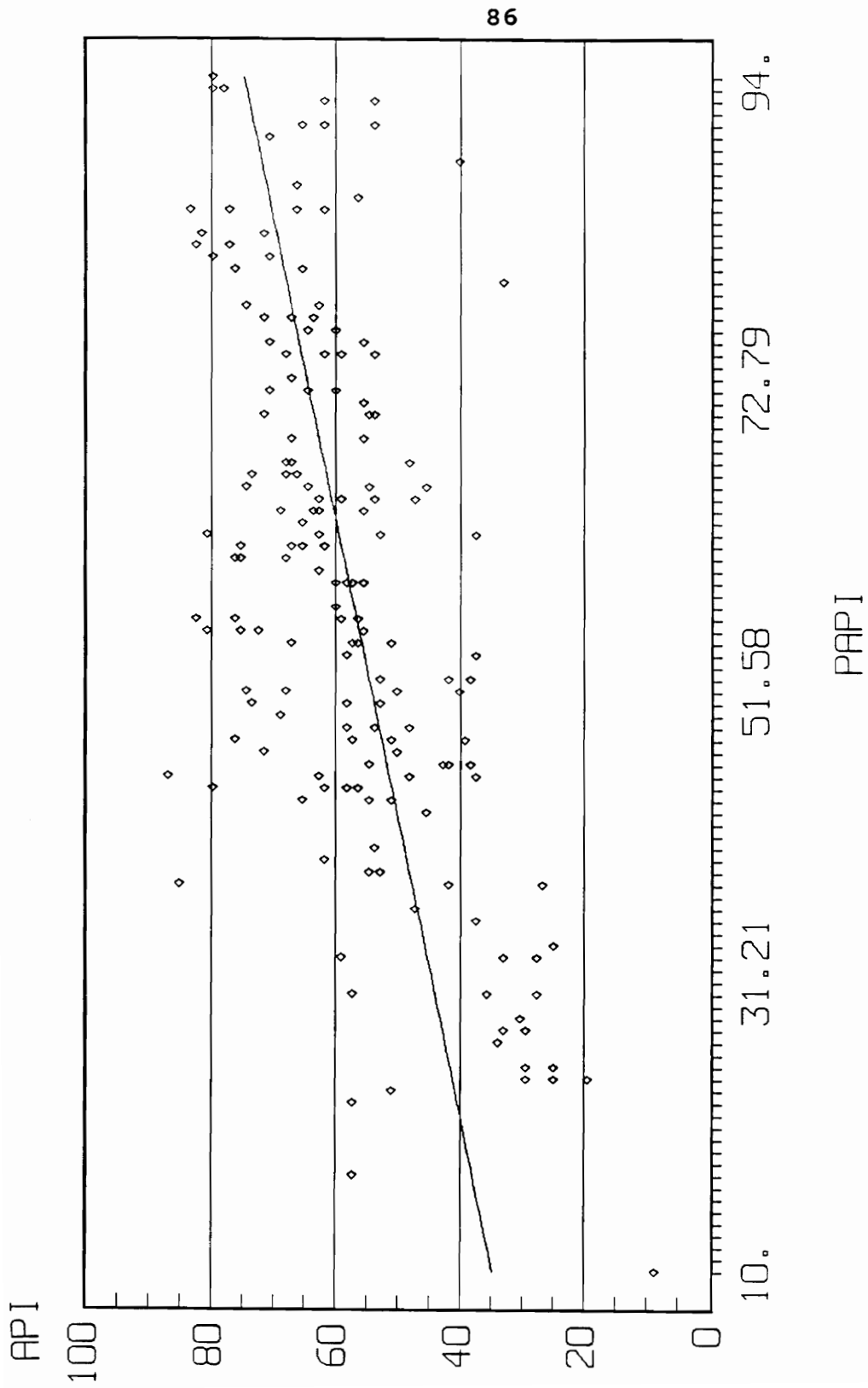


Figure 21. The API plotted as a function of the PAPI for the PRM display.

As in the CPA analyses, the value of API appeared to be highly dependent upon the PAPI. The analyses above also indicated that the distribution of PAPIs generated in the simulation using the ARTS IIIA display were significantly different from the distribution of PCPAs generated in the simulation using the PRM display. The PAPI was recognized as an uncontrolled quantitative independent variable, covariate. The PAPI was taken into account by using an Analysis of Covariance (ANCOVA) when the API data was assessed. The summary ANCOVA table for the API data is shown in Table 4. The independent variables analyzed in the ANCOVA included the display type, approach operation, blunder degree, and communication. API was shown to vary significantly as function of PAPI ($F(1,268) = 118.531, p < 0.00001$). Unlike the CPA analyses, there were no detectable differences in controller performance between levels of any of the independent variables.

Figure 22 showed the average API ratings by display type and blunder degree. As can be seen, there appeared to be a trend toward smaller APIs with the PRM display and 20 degree blunders. This trend was seen in both the average API and the average adjusted API.

Table 4. Overall ANCOVA for the Aircraft Proximity Index ratings.

ANALYSIS OF VARIANCE					
Effect	SS	df	MS	F	p
Cov: PAPI	23332.15	1	23332.15	118.5307	0.00000
(A): DISP	390.88	1	390.88	1.9857	0.15618
(B): DEG	322.33	1	322.33	1.6375	0.19884
(C): AP OP	51.57	1	51.57	0.2620	0.61547
(D): COMM	31.83	1	31.83	0.1617	0.68990
A x B	7.77	1	7.77	0.0395	0.82311
A x C	253.78	1	253.78	1.2893	0.25594
A x D	95.74	1	95.74	0.4864	0.49332
B x C	410.35	1	410.35	2.0846	0.14606
B x D	183.53	1	183.53	0.9324	0.33704
C x D	4.84	1	4.84	0.0246	0.84908
A x B x C	18.55	1	18.55	0.0942	0.75345
A x B x D	219.47	1	219.47	1.1149	0.29203
A x C x D	178.63	1	178.63	0.9074	0.34386
B x C x D	22.36	1	22.36	0.1136	0.73355
A x B x C x D	44.93	1	44.93	0.2283	0.63858
Within	52754.43	268	196.84		

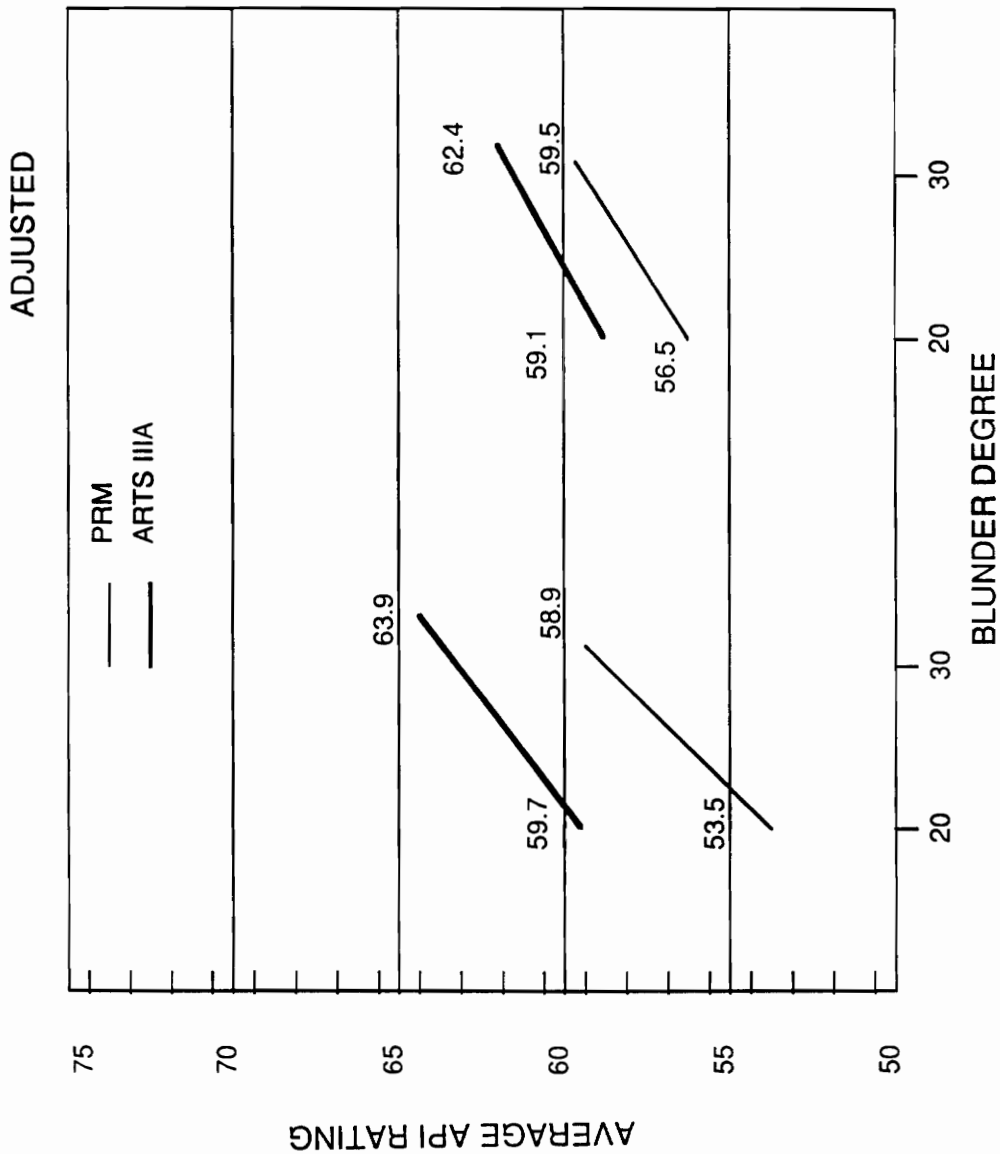


Figure 22. The Effect of Display Type and Blunder Degree on the Average API and the Average Adjusted API.

DISCUSSION

Overall, the analyses indicated that the PRM display enhanced controller performance over the performance found using the ARTS IIIA display. The effect of each of the independent variables on controller performance and the influence of the communication capability on the blunder resolution are discussed below.

Display Type. There were consistent differences in the controller's performance between the two displays. The controllers were able to detect blunders significantly quicker when using the PRM display for both approach operations. The average difference in controller response times between displays was 4.1 seconds. The average controller response time was 10.5 s for controllers using the PRM display and 14.6 s for controllers using the ARTS IIIA display.

The average controller response times using the PRM (10.5 s) and the ARTS IIIA (14.6 s) displays were slightly longer than the average response time found in the earlier Dallas/Ft. Worth (DFW) studies (9.29 s) cited in the review of literature. Like the PRM display, the display used for the DFW studies was of higher resolution than the ARTS IIIA display. This fact could explain the differences controller performance while using the ARTS IIIA and the display used in the DFW simulations.

It was reasoned that the differences in average controller response times between PRM display and the display used for the DFW simulations may have been due to differences in controller strategies. With the PRM display, the aircraft targets had predictor lines that provided controllers with additional information about the aircraft's direction of travel. Frequently when aircraft had entered the NTZ, the pilots realized that they were off course and were in the process of correcting their movement. Often controllers using the PRM display were observed to wait an additional radar sweep to view the predictor and determine whether an aircraft was a blundering aircraft or was just wandering into the NTZ.

The CPA analyses also indicated that controllers performed significantly better using the PRM display than they performed using the ARTS IIIA display. With the CPA scores adjusted for differences in PCPAs, through covariate analyses, the average CPA for controllers using the PRM display was 776 ft larger than the average CPA of controllers using the ARTS IIIA display.

An aircraft traveling 180 KTS and blundering thirty degrees travels toward the adjacent approach at about 140 ft/s. The controller could detect a blunder approximately 4 seconds quicker using the PRM display. Mathematics would indicate that the difference of 560 ft should be present in average CPA values between the PRM and the ARTS IIIA displays.

The actual difference of 776 ft supported the belief that controllers were able to use better conflict resolution strategies when using the PRM display.

The analyses of the API data did not indicate the presence of any significant differences in controller performance between the display types. The difference in the average API between display types was 3.3. The average API rating was higher for the ARTS IIIA display than for the PRM display.

Blunder Degree. Unlike earlier studies, analyses of the controller response times did not detect differences between controller performance for the twenty and thirty degree blunders. However, review of the data indicated that thirty degree blunders generally resulted in quicker response times. Earlier studies indicated that controllers typically detected thirty degree blunders 4 seconds quicker than they detected twenty degree blunders.

Two factors which could have contributed to the lack of significant differences in controller response times between twenty and thirty degree blunders include the disparity in sample sizes between twenty and thirty degree blunders and the display magnification. First, there were only 57 twenty degree blunders executed and there were 228 thirty degree blunders executed. Second, the differential expansion of the

display may have magnified the blunder so much that the twenty degree blunders were as easily detectable as the 30 degree blunders.

The lack of differences between controller response times for twenty and thirty degree blunders corresponded to the difference in CPAs found between twenty and thirty degree blunders. The rate of closure between the blundering and the evading aircraft is 46 percent greater for thirty degree blunders than twenty degree blunders.

Thirty degree blunders resulted in smaller CPAs than twenty degree blunders for both the PRM display and the ARTS IIIA display. When the CPA was adjusted for differences in the PCPA, the average CPA for thirty degree blunders, 2339 ft, was 695 ft smaller than the average CPA for twenty degree blunders, 3034 ft.

Analyses of the API ratings did not detect differences in controller performance between the twenty and thirty degree blunders. Review of the data showed that the thirty degree blunders resulted in a larger average API, 61, than the twenty degree blunders, 55.

Approach Operation. The approach operation did not significantly affect any of the dependent variables collected in this simulation. There were trends however that indicated

that controllers performed better in the triple approach operation than in the dual approach operation.

The average controller response time was 11.9 seconds for the triple approach operation and 12.7 seconds for the dual approach operation. The average adjusted CPA was 2566 ft for the triple approach operation and was 2296 ft for the dual approach operation. Finally, the average adjusted API was 58 for the triple approach operation and 64 for the dual approach operation.

Communication. The pilot of the blundering aircraft was directed not to respond to controller's instructions 72 percent of the time. The lack of response by the NSSF simulator pilot was analyzed for its influence on controller performance as indicated by the CPA and API data. The communication level, with response or without response, did not significantly affect the CPAs in this study. The average adjusted CPA for blunders in which the pilot did not respond was 2388 ft. The average adjusted CPA for the blunders in which the pilot did respond to the controller was 2707 ft.

The analyses of the API data did not indicate significant differences in controller performance between levels of the communication variable. The average adjusted API was 60 for the no response blunders and the average adjusted API was 58 for the blunders in which the pilots responded.

CONCLUSIONS

This study was designed to investigate the differences in controller performance between two types of controller displays. The influence of blunder degree and the number of simultaneous parallel approach operations on the controller's ability to detect aircraft blunders was also examined.

The Precision Runway Monitor (PRM) display, a high resolution raster scan color monitor, enhanced the controller's ability to quickly detect aircraft blunders over the Airport Radar Terminal System (ARTS) IIIA display, a plan position indicator (PPI). The controller response times were smaller and the closest points of approach (CPAs) between the blundering and the evading aircraft were larger when the controllers used the PRM display. The Aircraft Proximity Index (API) did not detect any differences between the two display types. There was however a trend in the API data toward smaller (better) ratings associated with the controller's performance while using the PRM display.

The controllers were not able to detect the thirty degree blunders any more quickly than they were able to detect twenty degree blunders. However, the 30 degree blunders resulted in more severe conflicts (smaller CPAs) than those associated with 20 degree blunders. The difference in CPAs between twenty and thirty degree blunders in the presence of a lack of

differences in response times is understandable due to the difference in the closure rates.

The controllers performed as well in the dual parallel approach operation as they did in the triple approach operation for all measures.

The study was unique because it has provided a quantification of the benefit of a proposed system relative to the current system. The information derived from the simulation concerning controller performance times to the different blunders can be used in Probabilistic Conflict Rate and Parametric Blunder Resolution studies.

RECOMMENDATIONS

As in the development of most new systems that require a man-machine interface, studies should be conducted to test the system's operating parameters. Studies should be performed to fully evaluate several of the variables in this study.

The differential expansion capability of the PRM display probably contributed to the improved controller performance more than any of the other advancements available in the PRM display. For the applications in which aircraft normally travel along the axes of expansion, the PRM display should be seriously considered. When aircraft are not normally flying along the axis of expansion the differential expansion could hinder the controller's ability to properly vector aircraft within the airspace. Based upon this observation, additional analyses are suggested to determine the influence of the differential magnification on controller performance.

Secondly, as the spacing between approaches is decreased, the algorithm for the aircraft position predictor will need to be examined. A predictor that responds quickly to small deviations is affected by random radar error. The errors may result in the predictor falsely entering the No Transgression Zone (NTZ) and triggering the warning alert. Conversely, conservative predictor algorithms are insensitive to random radar error but are slow in detecting heading changes.

Therefore, conservative algorithms may not alert controllers early enough to allow implementation of resolution maneuvers.

Finally, as radar sensors with quicker update rates are developed, additional studies will need to be performed to determine the affects of radar update rate on the variables studied in this simulation and those factors proposed for research cited above.

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Appendix A Simultaneous ILS Approach Procedures

5-126 SIMULTANEOUS ILS/MLS AP- PROACHES

TERMINAL

a. When parallel runways are at least 4,300 feet apart, authorize simultaneous ILS, MLS, or ILS and MLS approaches to parallel runways if:

(1) Straight-in landings will be made.

(2) ILS, MLS, radar, and appropriate frequencies are operating normally.

b. Prior to aircraft departing an outer fix, inform aircraft that simultaneous ILS/MLS approaches are in use. This information may be provided through the ATIS.

c. On the initial vector, inform the aircraft of the ILS/MLS runway number and the localizer frequency or the MLS channel.

Phraseology:

I-L-S RUNWAY (runway number) (left/right). LOCALIZER FREQUENCY IS (frequency).

M-L-S RUNWAY (runway number) (left/right). M-L-S CHANNEL IS (channel).

d. Clear the aircraft to descend to the appropriate glideslope/glidepath intercept altitude soon enough to provide a period of level flight to dissipate excess speed. Provide at least 1 mile of straight flight prior to the final approach course intercept.

5-126d Note. — Not applicable to curved and segmented MLS approaches.

e. Vector the aircraft to intercept the final approach course at an angle not greater than 30 degrees.

f. Provide a minimum of 1,000 feet vertical or a minimum of 3 miles radar separation between aircraft during turn-on to parallel final approach. Provide the minimum applicable radar separation between aircraft on the same final approach course.

5-126f Note. — 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.

g. When assigning the final heading to intercept the final approach course, issue the following to the aircraft:

(1) Position from a fix on the localizer course or the MLS azimuth course.

(2) An altitude to maintain until established on the localizer course or the MLS azimuth course.
5-126g(2) Reference. — Arrival Instructions, 5-123.

(3) Clearance for the appropriate ILS/MLS runway number approach.

Phraseology:

POSITION (number) MILES FROM (fix). TURN (left/right) HEADING (degrees). MAINTAIN (altitude) UNTIL ESTABLISHED ON THE LOCALIZER. CLEARED FOR I-L-S RUNWAY (number) (left/right) APPROACH.

POSITION (number) MILES FROM (fix). TURN (left/right) HEADING (degrees). MAINTAIN (altitude) UNTIL ESTABLISHED ON THE FINAL APPROACH COURSE. CLEARED FOR M-L-S RUNWAY (number) (left/right) APPROACH.

h. Monitor all approaches regardless of weather. Monitor local control frequency to receive any aircraft transmission. Issue control instructions and information necessary to ensure separation between aircraft and to ensure aircraft do not enter the "no transgression zone" (NTZ).

5-126h Note 1. — Separate monitor controllers, each with transmit/receive and override capability on the local control frequency, shall ensure aircraft do not penetrate the depicted NTZ. Facility directives shall delineate responsibility for providing the minimum applicable longitudinal separation between aircraft on the same final approach course.

5-126h Note 2. — An NTZ at least 2,000 feet wide is established equidistant between runway centerlines extended and is depicted on the monitor display. The primary responsibility for navigation on the final approach course rests with the pilot. Therefore, control instructions and information are issued only to ensure separation between aircraft and that aircraft do not penetrate the NTZ. Pilots are not expected to acknowledge those transmissions unless specifically requested to do so.

5-126h Note 3. — For the purposes of ensuring an aircraft does not penetrate the NTZ, the "aircraft" is considered the center of the primary radar return for that aircraft. The provisions of paragraph 5-71 apply also.

(1) When aircraft are observed to overshoot the turn-on or to continue on a track which will penetrate the NTZ, instruct the aircraft to return to the correct final approach course immediately.

Phraseology:

YOU HAVE CROSSED THE FINAL APPROACH COURSE. TURN (left/right) IMMEDIATELY AND RETURN TO LOCALIZER/AZIMUTH COURSE.

or

TURN (left/right) AND RETURN TO LOCALIZER/AZIMUTH COURSE.

(2) When an aircraft is observed penetrating the NTZ, instruct aircraft on the adjacent final approach course to alter course to avoid the deviating aircraft.

Phraseology:

TURN (left/right) HEADING (degrees) IMMEDIATELY, CLIMB AND MAINTAIN (altitude).

(3) Terminate radar monitoring when one of the following occurs:

(a) Visual separation is applied.

(b) The aircraft reports the approach lights or runway in sight.

(c) The aircraft is 1 mile or less from the runway threshold, if procedurally required and contained in facility directives.

(4) Do not inform the aircraft when radar monitoring is terminated.

(5) Do not apply the provisions of paragraph 5-180 for simultaneous ILS, MLS, or ILS and MLS approaches.

l. When simultaneous ILS, MLS, or ILS and MLS approaches are being conducted to parallel runways, consideration should be given to known factors that may in any way affect the safety of the instrument approach phase of flight, such as surface wind direction and velocity, wind shear alerts/reports, severe weather activity, etc. Closely monitor weather activity that could impact the final approach course. Weather conditions in the vicinity of the final approach course may dictate a change of approach in use.

Appendix B An Aircraft Proximity Index

AN AIRCRAFT PROXIMITY INDEX (API)

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 blunders¹ 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 under Instrument Flight Rules (IFR). At its simplest, safe separation requires: (a) the aircraft must be laterally separated by 3 or 5 nmi, depending 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.

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

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 a 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 1000 feet of vertical separation, which is normally perfectly safe, to less than 0.2 nmi 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. 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.

- a. 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 nmi).
- b. 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.
- c. 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.
- d. 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.
- e. It should be a nonlinear function, giving additional weight to serious violations, since they are of more concern than a number of minor infractions.

The 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) conflicts in a data base where many conflicts are present. One hundred 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 that gives them equal weight; equal in the sense that a loss of half the required 3.0 nmi 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 (nmi (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 nmi AND 800 feet. The contour plot in figure A-1, demonstrates the cutoff for API = 1.

See tables A-1 and A-2 for typical values of API at a variety of distances.

Figure A-2 is a three-dimensional plot showing the relationship between API and vertical and horizontal separation graphically. Figure A-3 shows the same information in a slightly different way. Anything outside the contour at the base is "0". In figure A-4 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 en route airspace with speeds of 600 knots is not necessarily the same concern as a 70 in highly structured terminal airspace with speeds under 250 knots.

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) (in feet)	HORIZONTAL DISTANCE IN NAUTICAL MILES (1 NM = 6076')(D _H)																
	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)

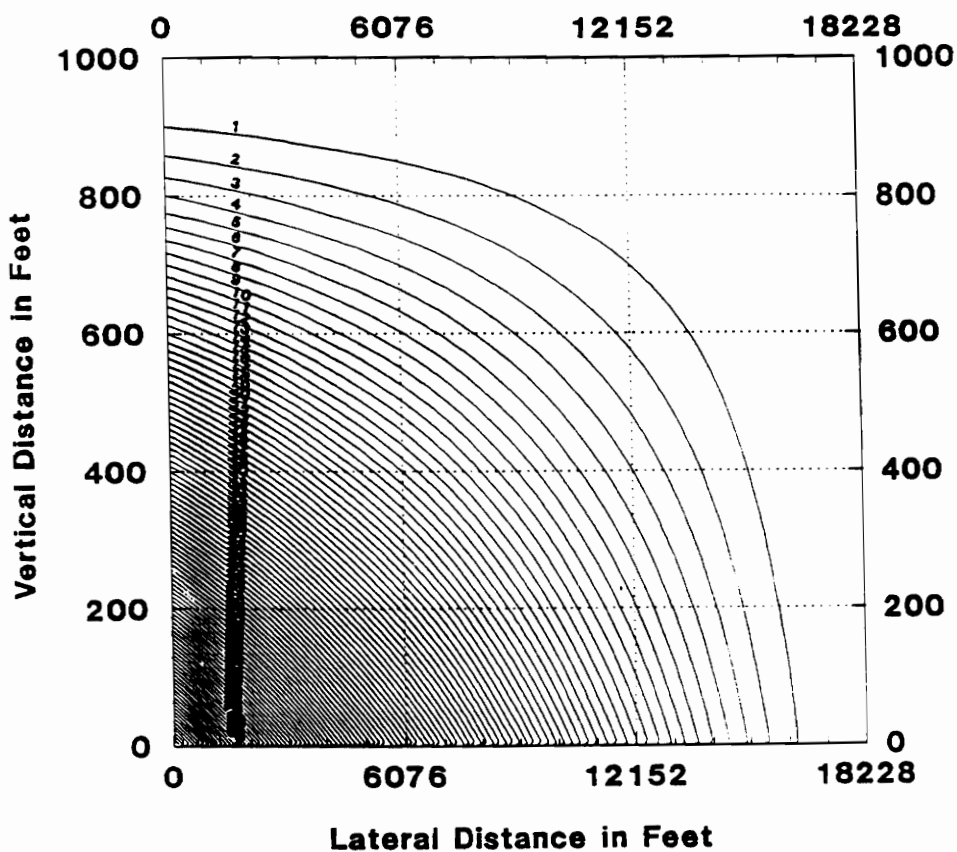


FIGURE A-1. CONTOUR PLOT

This is a contour plot of API showing the values of API for the horizontal separations of 0 to 3 nmi, and vertical separation of 0 to 1,000 feet. Values less than API = 0.5 round to zero. This includes a/c separated by as little 1.6 nm horizontally and 850 feet vertically.

AIRCRAFT PROXIMITY INDEX (API)

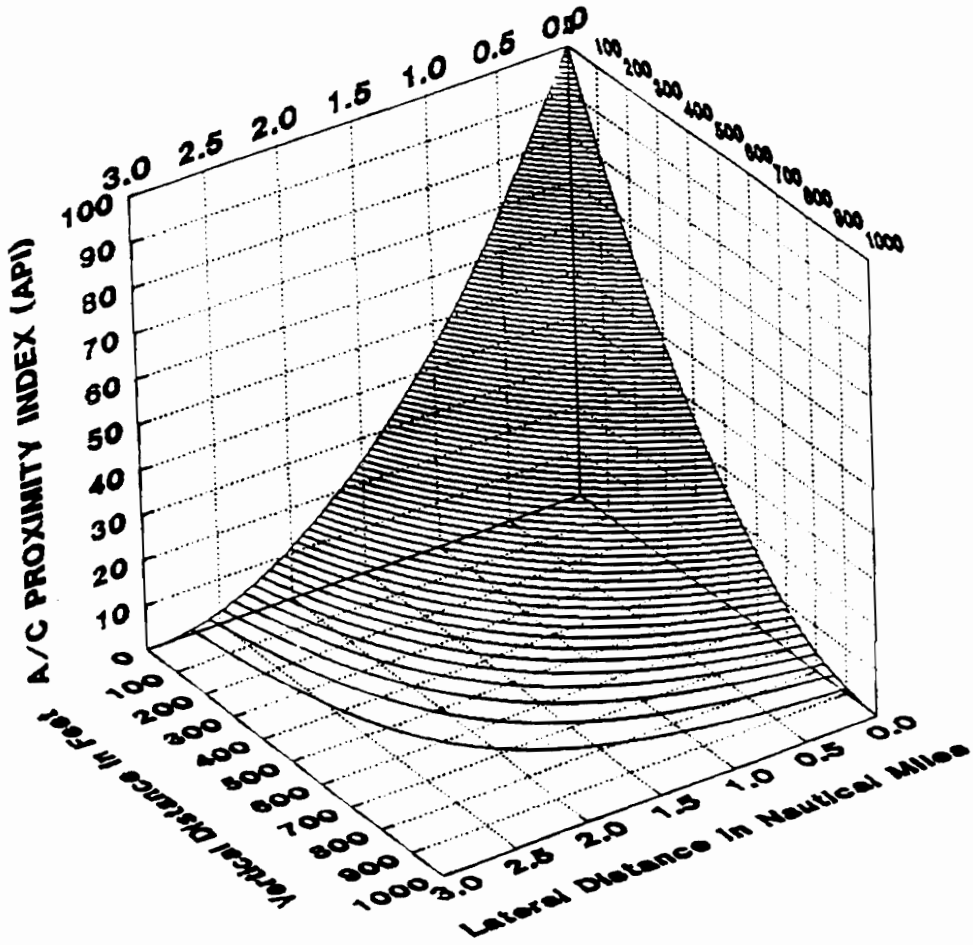


FIGURE A-2. THREE-DIMENSIONAL CONTOUR PLOT

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

AIRCRAFT PROXIMITY INDEX (API)

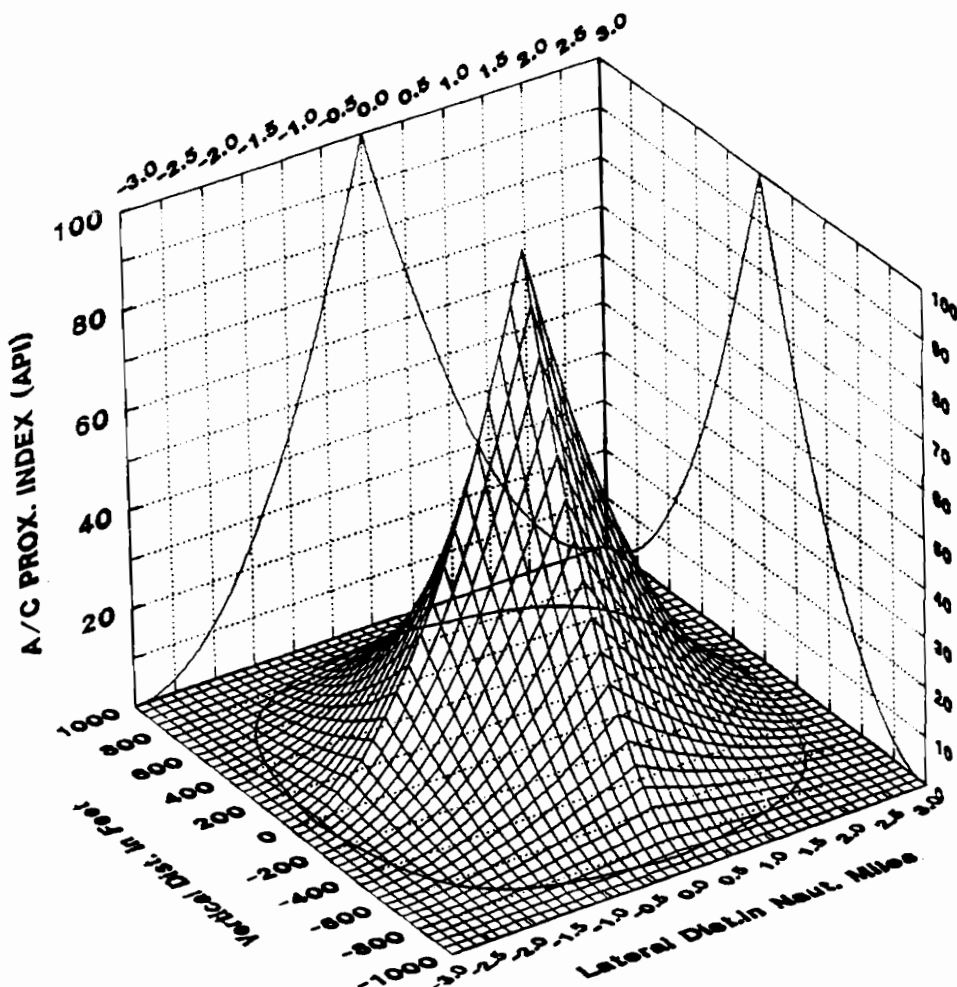


FIGURE A-3. THREE-DIMENSIONAL CONTOUR PLOT

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

A/C PROXIMITY INDEX (API)

API VALUES FOR SLANT RANGES OF 300 AND 500 FEET

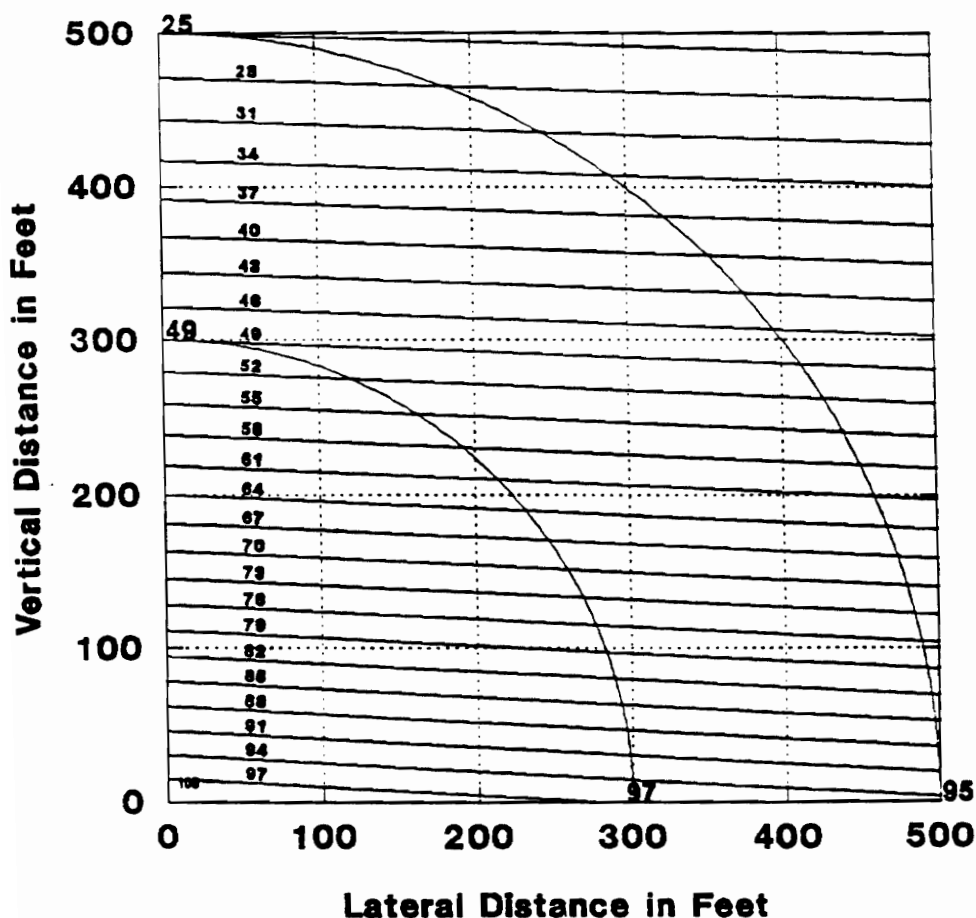


FIGURE A-4. CONTOUR PLOT OF API FOR HORIZONTAL AND VERTICAL DISTANCES OF 0 TO 500 FEET, SHOWING SLANT RANGE CONTOURS OF 300 AND 500 FEET

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 feet 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 C Test Plan Phase V.c and V.a.1 Simulation

Test Plan

Phases V.c and V.a.1

ATC SIMULATION OF SIMULTANEOUS PARALLEL
ILS APPROACHES WITH RUNWAYS SPACED 3400 FT APART
(TRIPLES)
and 4300 FT APART (DUALS AND TRIPLES) USING COLOR
DISPLAYS

19 April 1991

Engineering Research Psychology Services
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1. OBJECTIVE.

The overall objective of this program is to evaluate air traffic controller performance while monitoring multiple (dual, triple, and quadruple) simultaneous parallel Instrument Landing System (ILS) approaches during Instrument Meteorological Conditions (IMC). This study represents Phases V.c and V.a.1 of a six-phase program as described in section 2.5 of this document. This program addresses the ability of controllers to detect unsafe aircraft flight path deviations (blunders) and issue instructions in sufficient time to allow resolution of the blunder induced conflicts.

Specifically, this study will be a real-time air traffic control simulation designed to evaluate the performance of controllers monitoring triple simultaneous ILS approaches to parallel runways spaced 3400 feet (ft) apart, (V.c), and dual and triple simultaneous ILS approaches to parallel runways spaced 4300 ft apart, (V.a.1). The controllers will be using high resolution color monitors with audio conflict alerts and radar system update rates of 2.4 seconds (s) (V.c) and 4.8 s (V.a.1).

The study will be conducted under the auspices and the guidance of the Federal Aviation Administration (FAA) and the Multiple Parallel Technical Work Group (TWG). The TWG is composed of individuals from the Office of System Capacity and Requirements, Flight Standards, Aviation Standards, and Air Traffic organizations. The goal of the TWG is to develop national standards for implementing multiple simultaneous parallel ILS approaches using existing and new technology display and radar systems.

2. BACKGROUND.

The ability of the National Airspace System (NAS) to meet future air traffic demands is a serious concern at the national level. Programs to improve NAS capacity have been underway since the early 1980's, both to reduce air traffic delays and to accommodate the increased demand. Included in these programs are efforts to redesign the existing airways structure, projects that provide a more modern air traffic flow management capability, and major programs to incorporate state-of-the-art automation technology throughout the system.

Contributing to the capacity problem are the limitations imposed by current airport runway configurations and the associated air traffic separation criteria, particularly as related to aircraft executing ILS approaches under IMC. To alleviate these constraints, the FAA is investigating the use of triple, quadruple, and closely spaced dual parallel runway

configurations as a means of increasing airport capacity, while maintaining the high level of safety evident today.

2.1 AIRPORT LIMITATIONS.

The number of aircraft that can land at an airport during IMC is a major factor influencing system capacity. An increase in the number of simultaneous ILS approaches would significantly increase airport capacity during IMC and potentially improve traffic flow throughout the NAS.

At present, simultaneous approaches to parallel runways are limited to two approaches, and only when runways are spaced not less than 4300 ft apart. Approaches to runways spaced less than 4300 ft are restricted in IMC due to limitations in current radar and displays. Under such circumstances, air traffic control (ATC) must use dependently sequenced approaches. (McLaughlin, F., 1960)

The procedures currently required for simultaneous ILS approaches are described by Federal Aviation Administration, Air Traffic Control, (September 1989) FAA Order No. 7110.65F, Paragraph 5.126, quoted as follows: (Federal Aviation Administration, September 1989; Federal Aviation Administration, February 1989)

- a. Parallel runways that are at least 4300 ft apart.
- b. Straight-in landings will be made.
- c. Provide a minimum of 1000 ft vertical or a minimum distance of 3 nautical miles (nmi) between aircraft during turn-on to parallel final approaches.
- d. Provide the minimum applicable radar separation between aircraft on the same final approach course.
- e. Aircraft established on final approach course are considered separated from aircraft established on an adjacent parallel final approach course provided neither aircraft penetrates the No Transgression Zone (NTZ).
- f. Separate monitor controllers, each with transmit/receive and override capability on the local control frequency, shall ensure aircraft do not penetrate the depicted NTZ.

Interest in triple and quadruple approaches has been evident for more than 15 years. (McLaughlin, F., 1960; Haines, A.L., 1973) At a minimum, triple and quadruple simultaneous parallel ILS approaches would be subjected to the same limitations as dual simultaneous parallel ILS approaches.

Operations research based models of the system have been used to study various safety restrictions and capacity limitations. (McLaughlin, F., 1960; Resalab, Inc., 1975; ICAO, 1980; Haines, A.L., and Swedish, W.J., 1981; Shimi, T.N., et al., 1981; Romei, J., 1981; Steinberg, H.) Analyses have considered controller and pilot response times, navigational accuracy on the localizers, radar accuracy, and radar update rates. (Altschuler, S., and Elsayed, E., 1989)

2.2 ADDITIONAL RUNWAYS.

There are plans for both adding runways to existing airports and to build new airports. New airport construction is costly, requires a long time to plan and build, and has high social, environmental, and political impacts. Adding runways to existing airports is more timely and less expensive, if space is available to meet the required standards for runway separation. Making the most efficient use of existing facilities provides near-term payoffs at minimal cost.

2.3 PREVIOUS PARALLEL RUNWAY STUDIES.

Early studies of multiple runways concentrated on reducing separation between aircraft during simultaneous parallel approaches. (McLaughlin, F., 1960; Haines, A.L., 1973; Resalab, Inc., 1975; ICAO, 1980; Haines, A.L., and Swedish, W.J., 1981; Shimi, T.N., et al., 1981; Romei, J., 1981; Steinberg, H.) The results of the studies indicated that the amount of separation reduction that can safely be achieved is highly dependent upon aircraft navigational accuracy.

A simulation conducted in 1984 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. (Buckanin, D., et al., 1984) The results of this study have been questioned because 1) the navigational accuracy of the traffic samples may have been unrealistically poor and 2) some of the analyses did not conform to the analytical models cited. (Haines, A.L., and Swedish, W.J., 1981; Shimi, T.N., et al., 1981) However, the study established 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 completed, additional data have been collected at Memphis International Airport, and a major navigation survey has been completed at the Chicago O'Hare facility. (Buckanin, D., and Biedrzycki, R., 1987; Timoteo, B., and Thomas, J., 1989) The data from the Chicago survey, which directly considers simultaneous parallel approaches

under IMC, will be used in planning traffic for the present simulation.

Additional real-time air traffic control simulations have been conducted at the FAA Technical Center to investigate parallel runway proposals. (Hitchcock, L., et al., 1989 Art 1; Hitchcock, L., et al., 1989, Art 2; CTA Inc., 1990) These studies are an important complement to the models cited above since they generate estimates of the model parameters and, more importantly, they allow direct observation and recording of criterion measures related to safety and capacity.

The 1988 and 1989 Dallas/Fort Worth (DFW) simulations and the 1988 Atlanta Tower simulation are of direct interest to the ongoing effort since they addressed most of the issues unique to multiple runway operations and share some of the methodology of the current simulation.

2.4 PROOF OF CONCEPT: SIMULTANEOUS PARALLEL ILS APPROACHES.

Evidence that proposed system changes will not detrimentally affect air safety can be obtained in a number of ways. These include:

a. Demonstrate, through the collection and analysis of operational data, that new or improved standards can be developed.

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

c. Conduct operations research, mathematical 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 approaches are neither independent nor mutually exclusive. Ultimately it falls to experienced system users (e.g., controllers, pilots, operations personnel) to weigh the evidence and decide upon the proposed change, based on their understanding of daily operations, the knowledge and skills of the controllers, and the contingencies to which the system must respond.

2.5 MULTIPLE SIMULTANEOUS ILS APPROACH PROGRAM.

The Multiple Simultaneous ILS Approach Program was initiated to develop procedures for the safe execution of simultaneous

ILS approaches to triple and quadruple runway configurations. The program consists of the six phases described in sections 2.5.1 through 2.5.6, and is shown in figure 1.

2.5.1 Phase I.

The DFW Phase I simulation was conducted at the FAA Technical Center from May 16 to June 10, 1988. This two-part study was designed to test selected aspects of the quadruple approach operations. The first part of the simulation evaluated concepts for using additional routes, navigational aids, runways, Air Route Traffic Control Center (ARTCC) and Terminal Radar Approach Control Facility (TRACON) traffic flows in the implementation of quadruple approaches.

The second part was focused on the quadruple ILS parallel approach operation. The runway configuration consisted of the two existing 11,388 foot runways (17L and 18R), which have a centerline separation of 8800 ft, and two new 6000 ft runways. The first new runway, 16R, was 5800 ft west of the 18R centerline, and the second, 16L, was 5000 ft east of the 17L centerline.

The analyses indicated that blunders which threatened more than one approach were no more dangerous than blunders which threatened only one approach. Additionally, the controllers agreed that the new configuration maximized the use of en route airspace. (Hitchcock, L., et al., 1989, Art 2) Based upon this simulation, triple parallel ILS approaches were approved for DFW with the restriction that only turboprop aircraft land on 16L.

2.5.2 Phase II.

This simulation was conducted from September 25 to October 5, 1989, at the FAA Technical Center. The simulation assessed the DFW triple simultaneous ILS approaches, departures, and missed approach operations. The airport configuration used a new 8500 foot runway, 16L, located 5000 ft east of the runway 17L centerline.

Analyses indicated that controllers were able to intervene in the event of a blunder and provide distances between conflicting aircraft in the triple approach condition that were comparable to the distances achieved in the dual approach condition. No blunder in either the dual or triple approach condition resulted in a slant range miss distance of 1100 ft or less. Additionally, the controllers, controller observers and ATC management observers, concluded that the proposed triple approach operation at DFW was acceptable, achievable, and safe. (CTA, Inc., 1990) Results from this simulation

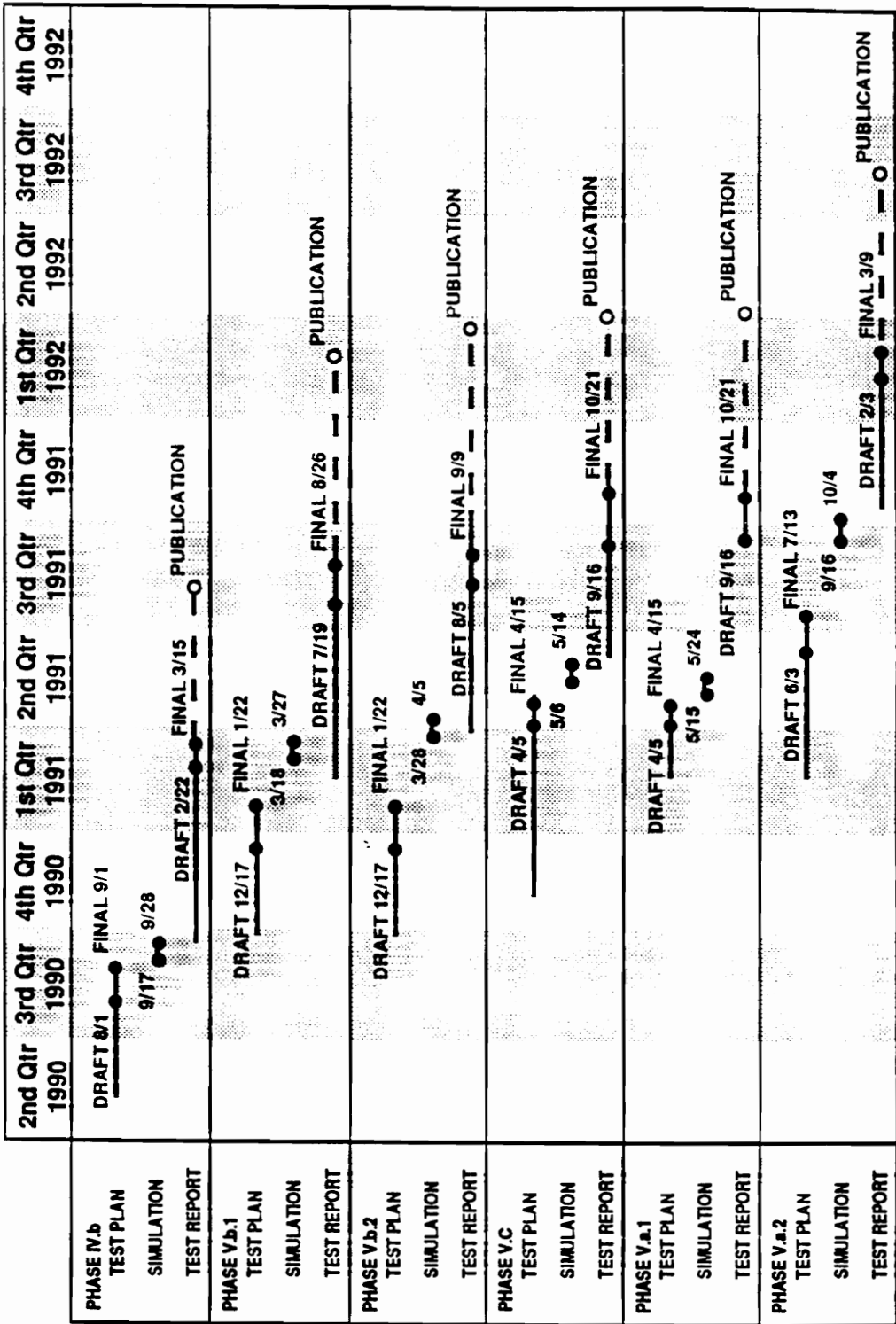


FIGURE 1. MULTIPLE SIMULTANEOUS ILS APPROACH SIMULATION SCHEDULE

supported the approval of turbojets operating on the three proposed parallel approaches.

2.5.3 Phase III.

The Phase III simulation reconsidered the DFW quadruple simultaneous ILS approach, departure and approach operation assessed in Phase I with changes in runway lengths and traffic samples. For this simulation, runway 16L was 8500 ft long and 16R was 9900 ft long. The traffic samples included propeller driven, turboprop, and turbojet aircraft on the outer runways and turbojet aircraft only on the inside runways.

The simulation found that air traffic controllers were able to maintain miss distances between aircraft in excess of the 500 foot criterion. There were no operational differences between the dual and quadruple approach conditions. Controllers, controller observers, and ATC management concluded that the quadruple approach operation is a "safe, efficient, and workable procedure." (Fischer, T., et al., 1990)

2.5.4 Phase IV.

The purpose of the Phase IV simulation was to develop national standards for triple simultaneous ILS approach operations using the Airport Surveillance Radar (ASR)-9, and the Automated Radar Terminal System (ARTS) IIIA. (Field Test and Evaluation of Airport Surveillance Radar (ASR-9), 1989) Phase IV was conducted at the FAA Technical Center in two simulations:

a. Phase IV.a was conducted April 24 to May 3, 1990 to assess triple simultaneous ILS approaches to runways spaced 4300 ft apart with even thresholds. This simulation included integration of a Phase II B-727 flight simulator and a General Aviation Trainer (GAT) flight simulator.

The analyses indicated that triple simultaneous parallel approaches to the cited runway configuration using the ASR-9 and the ARTS IIIA may decrease the level of safety found in current approach operations.

b. Phase IV.b was conducted from September 17 to 28, 1990 to assess triple simultaneous ILS approaches to runways spaced 5000 ft apart with even thresholds. This simulation included the integration of two Phase II B-727 and one GAT flight simulators. The results of this simulation are currently being analyzed.

2.5.5 Phase V.

Phase V simulations will incorporate the SONY 20X20 inch color displays with enhanced graphics capabilities and audio conflicts alert algorithms. Phase V will be assessed in five subphases as described below:

a. Subphase V.b.1. Assessed dual simultaneous parallel ILS approach operations to runways spaced 3000 ft apart using a radar with an update rate of 1.0 s. This subphase was conducted March 18 to 27, 1991.

b. Subphase V.b.2. Assessed triple simultaneous parallel ILS approach operations to runways spaced 3000 ft apart using a radar with an update rate of 1.0 s. This subphase was conducted March 28 to April 5, 1991.

c. Subphase V.c. Assess triple simultaneous parallel ILS approach operations to runways spaced 3400 ft apart using a radar with an update rate of 2.4 s. This subphase is scheduled to be conducted May 6 to 14, 1991.

d. Subphase V.a.1. Assess triple simultaneous parallel ILS approach operations to runways spaced 4300 ft apart from May 15 to 21, 1991 and assess dual simultaneous parallel ILS approach operations to runways spaced 4300 ft apart from May 22 to 24, 1991 using a radar with an update rate of 4.8 s.

e. Subphase V.a.2 Assess triple simultaneous parallel ILS approach operations to runways spaced 4000 ft apart using a radar with an update rate of 4.8 s. This subphase is scheduled to be conducted September 16 to October 4, 1991.

2.5.6 Phase VI.

Phase VI will address quadruple simultaneous parallel ILS approaches using technology varying from present day systems to advanced technology. Final criteria will be determined at a future date based largely on the results of Phases IV and V.

2.6 SIMULATION PARAMETERS.

In order to assess the viability of the closely spaced runway configuration, certain parameters must be defined. The parameters of particular relevance in the series of simulations are navigational accuracy, radar error, and blunders.

2.6.1 Navigational Accuracy.

Aircraft position with respect to the extended runway centerline, the NTZ, and to other aircraft must be realistically represented on the radar display to accurately assess the controllers' ability to detect a blunder. This requirement makes it essential that navigational error is modeled in the computer generated aircraft tracks. Navigational error, in the context of this study, is defined as the discrepancy between the aircraft flightpath and the extended runway centerline. The navigational error model to be used is based upon data collected at Chicago O'Hare Airport. (Timoteo and Thomas, 1989)

2.6.2 Radar Error.

The representation of aircraft on controllers' displays may differ from the actual aircraft position due to inaccuracies in the radar system. Therefore, to accurately represent the operational environment, radar error will be incorporated into the Phase V.c and V.a.1 simulations. The radar error model to be used is based upon the performance characteristics of the ASR-9 radar system.

The azimuth positional error at one standard deviation will be three milliradians. This value is equal to 18.24 ft/nmi. The range error will have a mean equal to zero and one standard deviation of 185 ft.

2.6.3 Blunders.

Blunders are used to test the controller's ability to maintain adequate distances between aircraft during critical situations. A blunder is an unexpected turn by an aircraft already established on the ILS localizer. Aircraft are suddenly turned toward traffic on adjacent approaches without warning to the controllers. Blunder turns are scripted to be either 20 or 30 degrees to the right or left of the nominal localizer course heading. Only computer generated targets will initiate blunders.

The blundering aircraft's pilots are instructed whether to acknowledge and respond to controller instructions. This effectively simulates a pilot's inability to correct the aircraft's deviation. The blundering aircraft will be randomly directed to maintain altitude or continue its descent. All blunders will occur after vertical separation has been lost with aircraft on an adjacent approach.

Previous simulations have indicated some degree of ambiguity when the term "immediately" is used. To potentially alleviate this problem during the Phase V.c and V.a.1 simulations, when

an immediate response is required from the pilots, the controllers will use the phrase "break";, i.e. "AAL205 BREAK LEFT HEADING 270 CLIMB AND MAINTAIN 5000 FT". This change in phraseology is for testing purposes only and does not constitute a permanent change in National Standards.

3. PHASES V.c AND V.a.1 ATC SIMULATION OF TRIPLE SIMULTANEOUS PARALLEL ILS APPROACHES (3400 FT SPACING) AND DUAL AND TRIPLE SIMULTANEOUS PARALLEL ILS APPROACHES (4300 FT SPACING).

This section describes the simulations to be performed from May 6 to 24, 1991. Simulation objectives, methodology, design, and procedures are presented in sections 3.1 through 3.4.

3.1 OBJECTIVES.

Phase V, Subphases V.c and V.a.1 simulations will address the following questions:

a. In the event of a 20 or 30 degree blunder, can miss distances, between aircraft, of 500 ft or greater be maintained?

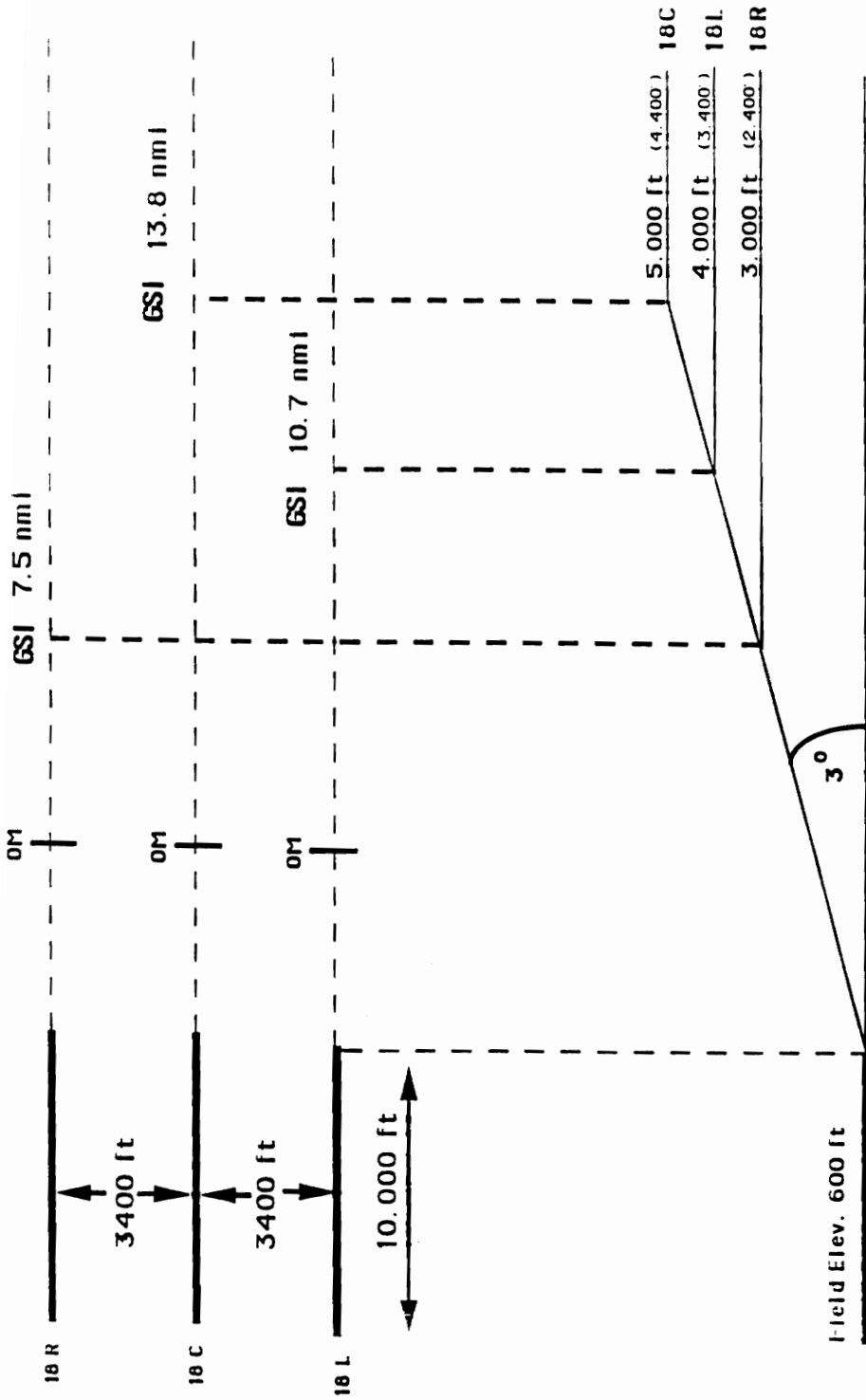
b. Do System Capacity and Requirements Office, Flight Standards, Aviation Standards, Research and Development, and Air Traffic personnel agree that the proposed operation of simultaneous parallel ILS approaches is acceptable, achievable, and safe?

Phase V.c will evaluate simultaneous ILS approaches to triple parallel runways with a minimum distance of 3400 ft between runway centerlines. Phase V.a.1 will evaluate simultaneous ILS approaches to dual and triple parallel runways with a minimum distance of 4300 ft between runway centerlines. In all cases, runway thresholds will be even. The airport configurations will be as shown in figure 2 and figure 3.

Aircraft target information will be provided by a simulated radar system that will update at a 2.4 s rate (V.c) or a 4.8 s rate (V.a.1). The monitor controller will use a high resolution 20x20 inch color display incorporating visual and audio controller alerts. ILS approaches will be made to all runways using propeller-driven, turboprop, and turbojet aircraft with a glide slope of 3 degrees.

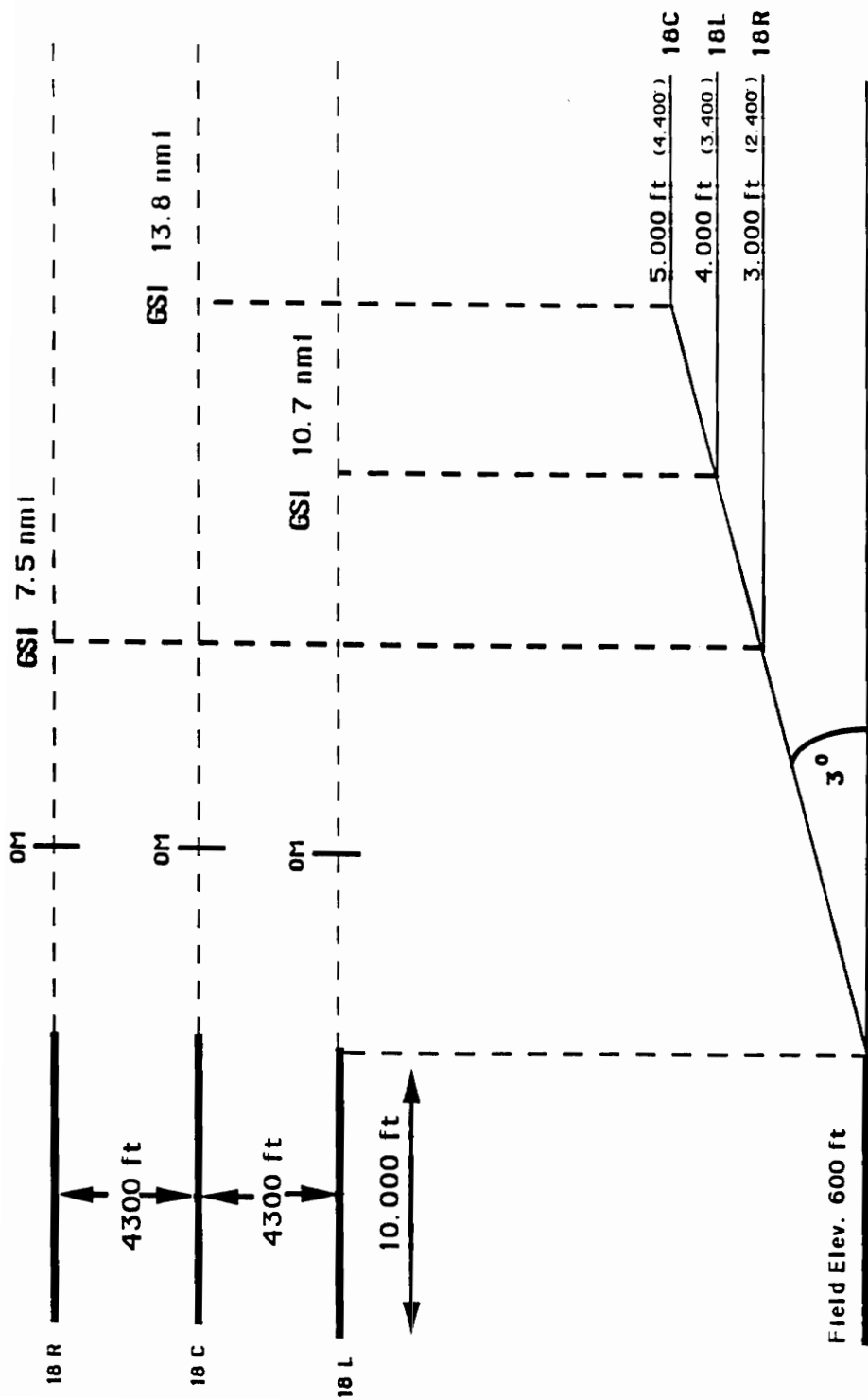
3.2 ASSESSMENT METHODOLOGY.

The ability of controllers to resolve blunders will be assessed by statistically analyzing the factors that affected their performance. Analyses will be conducted on the severity of blunder degree, loss of communication, and the number of



OM = outermarker at 5 nmi
 GSI = glide slope intercept

FIGURE 2. AIRPORT CONFIGURATION - 3400 FT



OM = outermarker at 5 nmi
 GSI = glide slope intercept

FIGURE 3. AIRPORT CONFIGURATION - 4300 FT

runways threatened to determine how these impact the ATC system. A risk assessment will then be performed to determine the impact of the proposed operation on the level of safety currently found in approach operations.

All blunders that result in a CPA of less than 500 ft will be investigated to determine its operational impact. A comprehensive review of the blunder including plots of aircraft position, controller-pilot communications, and computer data will be conducted to determine the factors contributing to the conflict severity.

The TWG will then evaluate all simulation results and develop recommendations. The TWG will draw upon their operational knowledge and experience in reaching their decisions.

3.2.1 Metrics.

Two indices are utilized to evaluate aircraft conflicts i.e., Aircraft Proximity Index (API) and the Closest Point of Approach (CPA). The API is a weighted metric computed from the horizontal and vertical separation distances between conflicting aircraft that result from a blunder. The index ranges from an API of 0, indicating that aircraft are not in conflict, to an API of 100, indicating that a collision will occur. The CPA is the smallest slant range distance between two aircraft that are involved in a blunder. A CPA of less than 500 ft will require an indepth analysis of the conflict.

3.2.2 Controller/Pilot Response Time.

Maintaining adequate distances between aircraft in the event of a blunder is a function of the controller's ability to detect the deviation, formulate, and issue appropriate control instructions in a timely fashion. Equally important, is the pilot's reaction time to the controller's instruction. Assessments of controller response times to blunders and pilot response times to controller messages will be performed.

3.3 SIMULATION DESIGN.

The simulation has been designed to determine whether air traffic controllers can provide miss distances of 500 ft or greater between blundering and evading aircraft. Data reflective of performance in the environment will be collected. To this end, the following study elements have been specifically controlled in the design:

a. To increase the validity of the findings, a number of flight simulators are integrated into the simulation. Maximizing the number of pilots enables a broader group of users to be evaluated while operating in the system. This

maximization also reduces error variance and increases result confidence.

b. Controllers will be drawn from a representative sample of different air traffic facilities enabling the data to be more representative of controllers' responses across the ATC system.

c. The data collection period is structured to provide a statistically valid data sample sufficient to conduct thorough analyses and allow accurate conclusions to be drawn.

d. Blunder scripts were developed in an unbiased manner across the conditions outlined in section 3.4.2.

3.3.1 Controllers.

Six air traffic control specialists from separate TRACONS will participate. All are volunteers selected in agreement with their National Air Traffic Controllers Association (NATCA) offices. The selected controllers each participated in the Phase V.b.1 and V.b.2 simulations and are experienced with simultaneous parallel approach operations. Controller schedule assignments are randomized and balanced as outlined in section 3.4.1.1.

3.3.2 Apparatus.

This section describes the pilot simulation facility, flight simulation facilities, monitor displays, airport configurations, flight patterns, traffic samples, navigational error model, and data collection equipment. The National Airspace System Simulation Support Facility (NSSF) configuration that will be used is shown in figure 4.

3.3.2.1 Pilot Simulation Facility.

The NSSF Pilot Complex houses the personnel and equipment necessary to "fly" the simulation. NSSF simulator pilots are in voice contact with the controllers and respond to controller instructions by entering aircraft heading and altitude changes using a specialized keyboard. These actions result in the simulated aircraft changing course, altitude, or speed. NSSF simulated aircraft responses are programmed to be consistent with aircraft being simulated.

3.3.2.2 Flight Simulator Facilities.

Flight simulators located at NASA Ames, Moffett Field, CA; Mike Monroney Aeronautical Center, Oklahoma City, OK; Delta

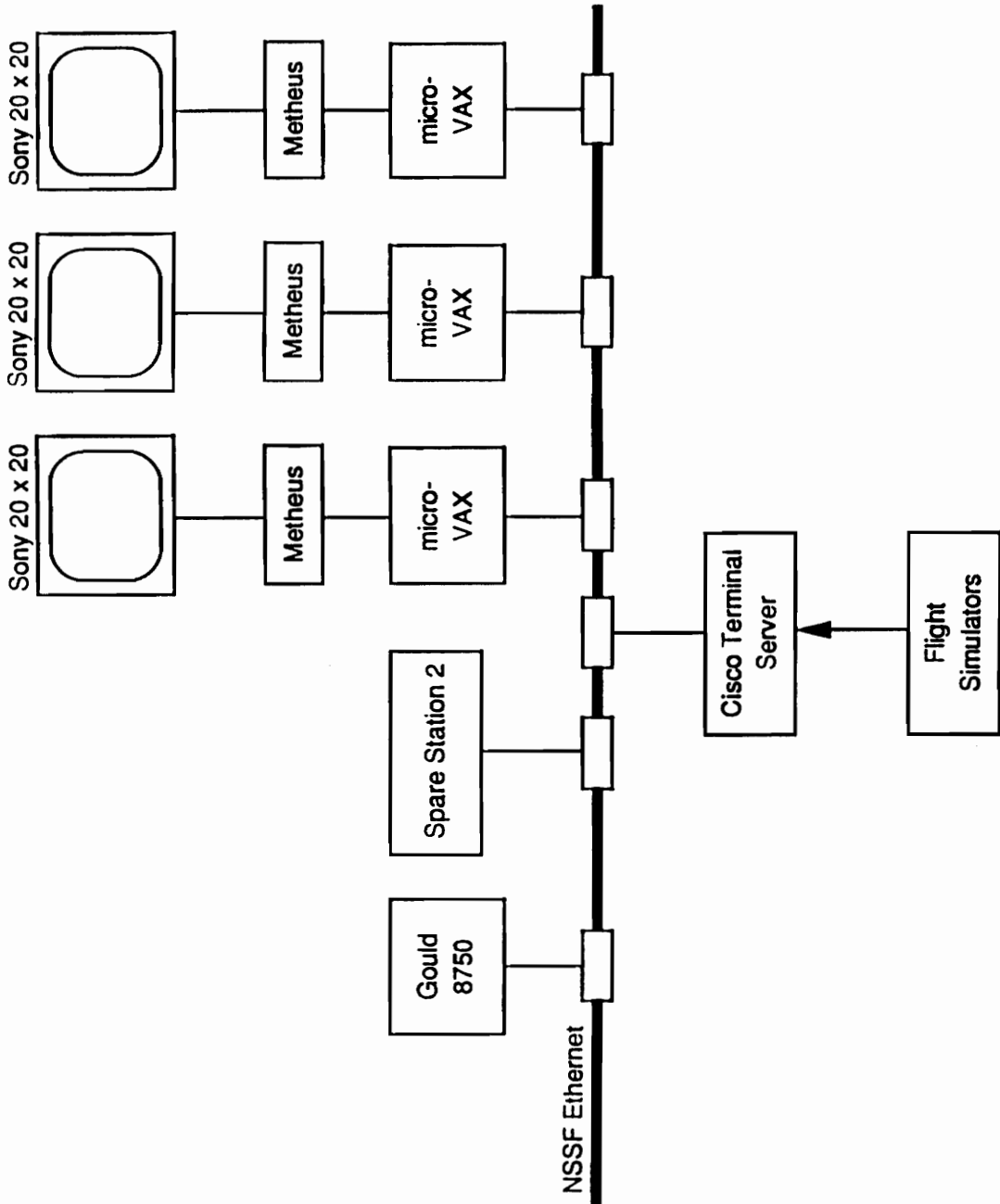


FIGURE 4. NSSF CONFIGURATION

Air Lines, Inc., Atlanta, GA; AVIA Inc., Costa Mesa, CA; and the FAA Technical Center, Atlantic City, NJ; will be integrated into the simulation to provide an assessment of the pilot and aircraft responses to controller commands. Flight simulators will be flown by air carrier and air taxi pilots. The flight simulators will be programmed to assume the configuration of aircraft flying the localizer course and will replace computer simulated aircraft that are scheduled to enter the simulation. In addition pilots will be required to execute 20 degree localizer intercepts. This will occur approximately 20 nmi prior to touchdown. At pilots' discretion approaches will be flown utilizing either autopilot, flight director and/or raw data.

The flight simulator pilots will be in voice communication with the controllers and with the simulator coordinator assigned to each site. The site coordinator will assist the pilots prior to and following each approach. Each flight simulator will perform approximately 10 to 12 approaches per simulation run.

3.3.2.3 Monitor Displays.

The display is a 20x20 inch high resolution color display specifically programmed to represent those proposed for controller monitor positions. These displays utilize 2000 line resolution television raster scan technology. The display scale can be expanded in the area between the runways to provide the controller with an improved capability to detect aircraft movement away from the extended runway centerline. The NTZ is outlined with a red border. ILS approach centerlines are displayed as dashed white lines. The dash and the space between the dash are scaled to represent one nautical mile. Lines to delineate 200 foot deviations from the ILS localizer course are displayed in light blue. Aircraft targets and alphanumeric data blocks are presented in green. When a potential NTZ entry is detected, the aircraft target and data block turn yellow and an aural warning sounds to notify the controller of the impending violation. When an aircraft has entered the NTZ, the aircraft target and data block change to red.

The high resolution of the display and the computer generated controller alerts will assist the controllers in early detection of blunders. Therefore, the displays may provide the controllers with increased time to either correct the course of the blundering aircraft or issue missed approach instructions to the pilots of aircraft on adjacent parallel approaches.

3.3.2.4 Airport Configurations and Flight Patterns.

The airport layout, runways, and arrival frequencies emulate a generic airport with even thresholds and glide slopes of 3 degrees. The distance between the centerlines will be 3400 ft, for Phase V.c, and 4300 ft for Phase V.a.1.

The airport configurations in the simulation will have three parallel runways (18R, 18C, and 18L) with an inbound course of 180. A mix of aircraft types will start on the localizers and maintain their turn-on altitude until glide slope intercept. Associated turn-on altitudes are provided in table 1 (for the dual approach condition, only 18C and 18L will be used). After passing the ILS Outer Marker, aircraft will complete the approach at the appropriate speed for the aircraft type.

TABLE 1. ILS RUNWAY TURN ON ALTITUDES

<u>Runway</u>	<u>Turn On Altitude (ft)</u>	<u>Glide Slope Intercept (nmi)</u>
18R	3000	7.5
18C	5000	13.8
18L	4000	10.7

3.3.2.5 Traffic Samples.

Traffic samples are based on actual air traffic from a combination of numerous high density airports (e.g., Atlanta, Chicago, Dallas/Fort Worth, Denver, Los Angeles, and other TRACON environments). This sample consists of a representative population of propeller-driven, turboprop, and turbojet aircraft including air carrier types such as DC9/MD80, DC10, B727, B737, B767, and B747. In addition, air carrier aircraft are identified with callsigns (e.g., TWA315, UAL242) obtained from the actual traffic. Seven traffic samples will be developed for each simulation subphase.

To provide additional realism, a crosswind condition will be introduced to the flight simulators. A wind of approximately 25 knots at 270 will be generated into the approach prior to the glideslope intercept. After the final approach fix but prior to approximately 1000 ft above ground level, the wind will be proportionately removed to arrive at a crosswind component not to exceed 10 knots at the runway threshold. Additionally, to maintain proper longitudinal spacing between

flight simulator targets and those manipulated by the NSSF pseudo pilots, a headwind component will be introduced to adjust flight simulator speeds after turn-on to final.

The traffic samples will produce a maximum through-put rate with start times that result in approximately 25 cases in which two or more aircraft are within a longitudinal distance of 1/4 nmi of one another to ensure frequent worse case situations. Simulations will also include two to three speed overtakes during each run.

3.3.2.6 Navigational Error Model.

A navigational model was developed to enable the realistic representation of aircraft on the controller display. Aircraft flying the approach segment of a flight typically deviate a nominal amount from the ILS course heading, as seen in the Memphis and Chicago surveys (Buckanin and Biedrzycki, 1987, Timoteo and Thomas, 1989). The deviations from the ILS course heading, navigational error, are produced by a number of sources including avionics error, ILS signal error, weather, and ordinary pilot performance. An accepted amount of navigational error exists with current navigational systems. The model developed for this simulation dynamically generates a unique flightpath for each aircraft in the simulation.

In order to accurately display navigational error two criteria must be met in the design of the model:

a. Flight paths of individual aircraft should look reasonable to the controllers; i.e., deviations from the localizer centerline should be typical of aircraft as they fly along the ILS approach.

b. Aggregate errors should reflect the accuracy typical of aircraft in the traffic sample, (e.g., the data collected at Chicago O'Hare).

Although pilots attempt to follow the ILS precisely, they often fly a course which is nearly asymptotic to the ILS course heading and intercept the ILS near the threshold. To model this part of the navigational error, a concept of pseudoroutes will be implemented. A pseudoroute is a straight line originating at the center of the runway threshold and extends outward beyond 20 nmi. Pseudoroutes are offset from the ILS localizer centerline based upon a normal distribution with a mean of 0 degrees and a standard deviation of 0.5 degrees. A deviation of 0.5 degrees equates to 53 ft per nmi.

There are also deviations from the asymptotic course, pseudoroute, described above. The deviations from the

pseudoroute are usually sinusoidal in behavior (i.e. the error is a side to side motion about the average). The size of this deviation also decreases as the aircraft approaches the threshold. To model this part of the navigational error a fan is defined. The fan width (angle) is randomly assigned with a mean of 0 degrees and a standard deviation of 0.24 degrees. The fan width is capped at 1.8 degrees. The fan begins at the threshold and is bisected by the pseudo-route.

As aircraft fly the ILS approach course, they fly between the fan boundaries. If the aircraft intercepts the fan boundary it executes a turn at half rate (1.5 degrees per second) which will direct them towards the opposite fan boundary. This is repeated throughout the approach until landing or given a heading change.

To facilitate the understanding of the navigational error model, an example is given in figure 5. Initially aircraft start their approach 25 nmi from the threshold on the ILS localizer centerline. Aircraft then turn to intercept their randomly assigned pseudoroute (0.7 degree offset = 179.3 heading in the example). The aircraft pass through the assigned pseudoroute centerline and approach the randomly assigned fan boundary (0.25 degree offset in the example). At the boundary, the aircraft commence a one-half standard rate turn (1.5 degrees per second) back towards the pseudoroute on a heading equivalent to the pseudoroute heading minus the 10 times the fan width ($179.3 - 10 * 0.25 = 176.8$ degrees). The process repeats until the aircraft reaches the runway threshold and lands. If the controller requests an aircraft to return to the localizer, the pseudoroute offset is reduced 20 percent.

This navigational error model produces navigational error distributions that correspond closely with those found in the Chicago data and provide visually realistic targets to the controllers.

3.3.2.7 Data Collection Equipment.

Data collection and reduction will be accomplished using NSSF computers. Data available for analysis from the computer summary files include, but are not limited to, the following:

- a. Number of NTZ transgressions;
- b. Number of parallel conflicts;
- c. API and CPA for parallel conflicts;
- d. Number of longitudinal conflicts;

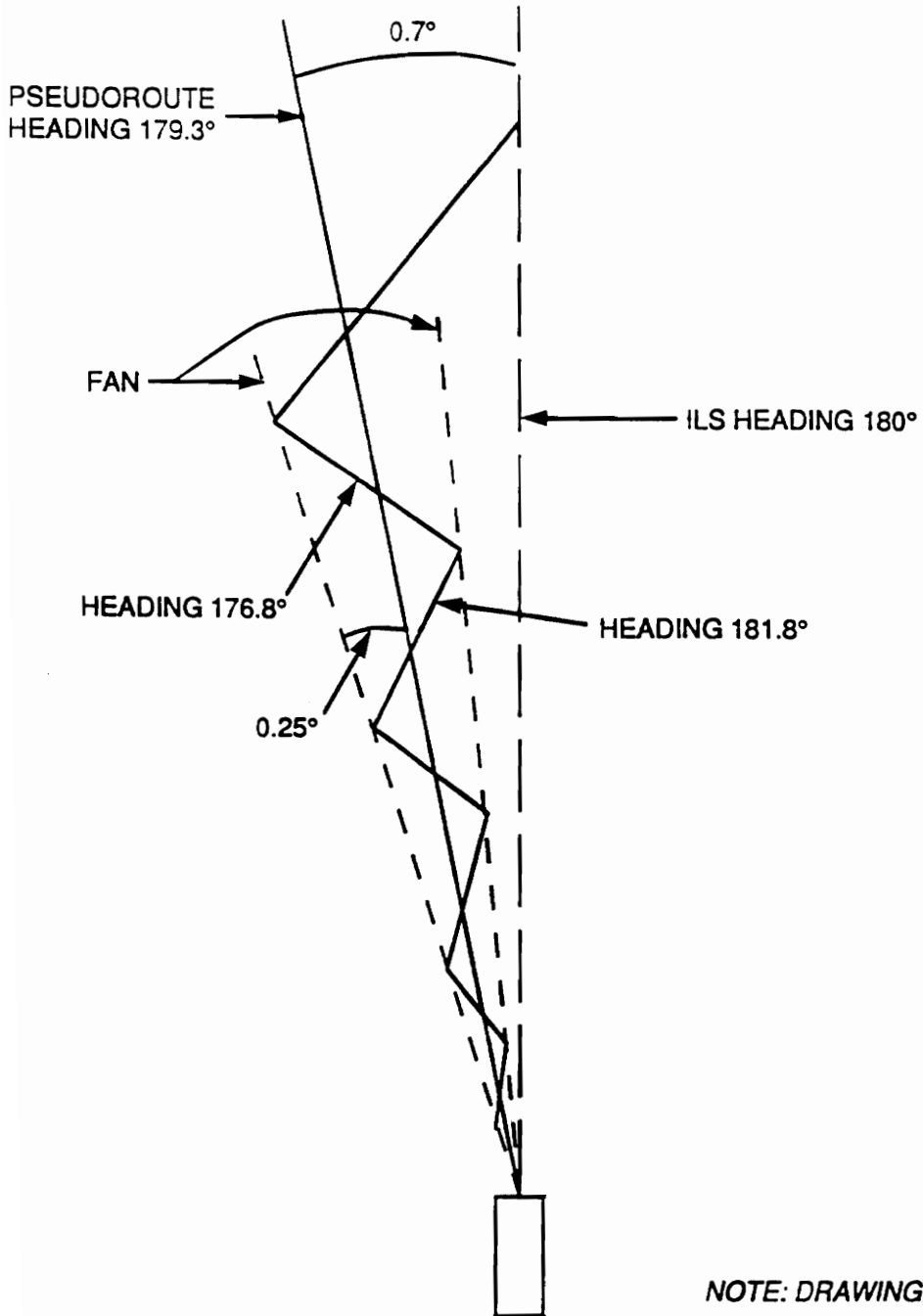


FIGURE 5. NAVIGATIONAL ERROR MODEL EXAMPLE

- e. API and CPA for longitudinal conflicts;
- f. Response time to blunders;
- g. Number of communications;
- h. Number of speed changes, and;
- i. Number of aircraft landed.

Controller, NSSF, and flight simulator pilot voice communications will be recorded using a 20-channel audio recorder available at the FAA Technical Center. Controller and NSSF simulator pilot verbal response times to blunders are extracted and statistically analyzed. Synchronization of the audio and computer data will be accomplished through the insertion of a "time hack", corresponding to simulator run time, onto the audio recordings.

Microphones will be used to record the controllers' conversations during each run to permit analysis of controller interaction.

3.4 SIMULATION PROCEDURE.

Controllers will man the approach monitor positions. Aircraft, on the approaches, will be sequenced to provide required separation. Controllers will monitor aircraft position and intervene if aircraft enter the NTZ. Aircraft blunders will be initiated by a Test Director to enable the assessment of the controller's traffic handling capabilities. Aircraft that successfully fly the ILS, intercept the glide slope, and are not involved in a blunder, eventually land. Aircraft that blunder, or are vectored off their ILS as a result of a blunder, are removed from the simulation.

3.4.1 Schedules.

The following sections 3.4.1.1 and 3.4.1.2 describe the subject and run scheduling.

3.4.1.1 Subject Scheduling.

Six controllers will participate in the simulation. Controller run assignments and runway positions are shown in tables 2 and 3. The Flight Simulator Schedule is provided as table 4.

Randomization of participant scheduling is carried out with the following restrictions:

a. Individual controllers' participation be limited to 1 hour per run. Controllers will participate in not more than 2 consecutive hours per day and a total of not more than 3 hours per day.

b. Controller assignments are balanced throughout the day.

c. Individual controller assignments are equally divided with respect to runways.

3.4.1.2 Run Scheduling.

The first run of the simulation, on May 6, 1991, will be used to refamiliarize controllers with the color display and associated equipment and to acquaint the controllers with the strategies involved in the control of aircraft for the radar/display configuration used in this phase of the simulation. The first run of Phase V.a.1, on May 15, 1991, will be used to familiarize the controllers with the strategies involved in controlling aircraft using the radar/display configuration used in this phase of the simulation. Data collected from these runs will not be formally analyzed.

Three, 2-hour runs will be conducted each day. Runs will not be scheduled for Saturdays and Sundays. Individual controllers will monitor only 1 hour of each 2 hour run. A controller rotation period will be scheduled at the midpoint of each run. Blunders may occur during the rotation period.

3.4.2 Blunder Scripting.

Blunders of 20 and 30 degrees will be scripted for aircraft on each runway. Approximately 25 percent of the blunders will be 20 degrees and 75 percent will be 30 degrees. Only 30 degree blunders will be implemented when a flight simulator target would be affected by the blunder.

Blundering aircraft will be turned toward an adjacent localizer course at a point following glide slope intercept and before reaching the runway threshold. Fifty percent of the blunders will occur after the aircraft has passed the outer marker.

Blunder scripts will dictate the actions of blundering aircraft as follows: 50 percent of the blundering aircraft will maintain altitude while 50 percent will continue their descent. To effectively simulate an uncontrollable aircraft, 50 percent of the blundering aircraft will not be permitted to respond to the controller instructions. Blundering aircraft

TABLE 2. PHASE V.c CONTROLLER/RUNWAY ASSIGNMENTS
FOR TRIPLES SPACED 3400 FT

DATE	RUN	18R	18C	18L	TRAFFIC SAMPLES
5/6	1a	A	E	C	304
	b	B	F	D	
	2a	C	A	E	305
	b	D	B	F	
	3a	E	C	A	306
	b	F	D	B	
5/7	4a	B	F	A	307
	b	D	E	C	
	5a	A	B	F	301
	b	E	C	D	
	6a	C	A	E	302
	b	F	D	B	
5/8	7a	D	C	A	303
	b	B	F	E	
	8a	E	B	D	304
	b	C	A	F	
	9a	F	D	B	305
	b	A	E	C	
5/9	10a	D	F	C	306
	b	E	B	A	
	11a	C	D	E	307
	b	F	A	B	
	12a	B	E	D	301
	b	A	C	F	
5/10	13a	F	E	D	302
	b	C	B	A	
	14a	E	A	C	303
	b	B	D	F	
	15a	A	F	E	304
	b	D	C	B	
5/13	16a	B	E	D	305
	b	A	C	F	
	17a	F	D	A	306
	b	E	B	C	
	18a	F	E	B	307
	b	D	A	C	
5/14	19a	C	A	F	301
	b	D	E	B	
	20a	F	B	E	302
	b	A	D	C	
	21a	E	C	D	303
	b	B	F	A	

a = 1 hour

b = 1 hour

TABLE 3. PHASE V.a.1 CONTROLLER/RUNWAY ASSIGNMENTS
FOR DUALS AND TRIPLES SPACED 4300 FT

DATE	RUN	18R	18C	18L	TRAFFIC SAMPLES
5/15	22a	A	D	F	304
	b	B	C	E	
	23a	C	E	D	305
	b	D	A	F	
	24a	C	B	A	306
	b	E	F	B	
5/16	25a	A	B	C	307
	b	F	D	E	
	26a	C	E	F	301
	b	D	A	B	
	27a	A	E	C	302
	b	D	B	F	
5/17	28a	B	E	D	303
	b	F	A	C	
	29a	C	F	E	304
	b	A	D	B	
	30a	E	C	A	305
	b	F	D	B	
5/20	31a	F	C	B	306
	b	D	A	E	
	32a	F	B	D	307
	b	A	C	E	
	33a	E	D	F	301
	b	B	A	C	
5/21	34a	C	F	E	302
	b	D	B	A	
	35a	E	A	C	303
	b	F	B	D	
	36a	C	F	B	304
	b	A	D	E	
5/22	37a		D	A	204
	b		E	C	
	38a		F	B	205
	b		A	E	
	39a		F	E	206
	b		B	C	
5/23	40a		D	B	207
	b		F	E	
	41a		A	C	208
	b		F	D	
	42a		E	B	202
	b		C	A	
5/24	43a		A	D	203
	b		B	E	
	44a		C	F	204
	b		D	A	
	45a		E	B	205
	b		F	C	

TABLE 4. FLIGHT SIMULATOR SCHEDULE

PHASE V.c

<u>DATE</u>	<u>RUNS</u>	<u>RUNWAY SPACING (ft)</u>
5/6	1 - 3	3400
5/7	4 - 6	3400
5/8	7 - 9	3400
5/9	10 - 12	3400
5/10	13 - 15	3400
5/13	16 - 18	3400
5/14	19 - 21	3400

PHASE V.a.1

<u>DATE</u>	<u>RUNS</u>	<u>RUNWAY SPACING (ft)</u>
5/15	22 - 24	4300 Triples
5/16	25 - 27	4300 Triples
5/17	28 - 30	4300 Triples
5/20	31 - 33	4300 Triples
5/21	34 - 36	4300 Triples
5/22	37 - 39	4300 Duals
5/23	40 - 42	4300 Duals
5/24	43 - 45	4300 Duals

permitted to respond to the controller will comply as instructed.

3.4.3 Questionnaire Administration.

Following each run, a short questionnaire and workload rating scale will be administered to the controllers to assess their opinions concerning run realism, difficulty, controllability, and their recommendations for operational use. Flight simulator pilots will also complete a questionnaire after each approach to record any unusual occurrences or controller instructions which may have affected their performance. Finally, information from technical and industry observers regarding the proposed system will be solicited using a technical observer questionnaire.

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GLOSSARY

Aircraft Proximity Index (API) - A weighted metric ranging from 0 to 100 computed from the horizontal and vertical separation distances between conflicting aircraft as a result of a blunder.

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

Automated Radar Terminal System (ARTS IIIA) - The Radar Tracking and Beacon Tracking Level (RT&BTL) of the modular, programmable automated radar terminal system. ARTS IIIA detects, tracks, and predicts primary as well as secondary radar-derived aircraft targets. This more sophisticated computer driven system upgrades the existing ARTS III system by providing improved tracking, continuous data recording, and failsoft capabilities.

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

Closest Point of Approach (CPA) - The smallest slant range distance between two aircraft in conflict.

Dependently Sequenced Approaches - When used in conjunction with parallel runways, ILS approaches conducted at many facilities in the United States where at least 2 nmi separation must be maintained between aircraft on the parallel approaches in addition to the standard radar separation required between aircraft on the same approach.

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

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

Instrument Meteorological Conditions (IMC) - Any weather condition which causes a pilot to navigate an aircraft solely via cockpit instrumentation. Meteorological conditions expressed in terms of visibility, distance from cloud, and

ceiling less than minima specified for visual meteorological conditions. Conditions which require a pilot to fly primarily with reference to the aircraft's instruments.

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

National Airspace System (NAS) - The National Airspace System is the United States' air traffic environment. The system is comprised of procedures, equipment, and the airway structure within the boundaries of the geographical United States.

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

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

Pseudo Pilots - Personnel, not necessarily pilots, trained to operate desk-top simulators at the FAA Technical Center NSSF complex.

Simultaneous ILS Approaches - An approach system permitting independent approaches using the Instrument Landing System in IMC to airports having parallel runways separated.

Technical Observer - An individual who monitors each control position visually and aurally during each simulation run. Their duties include: documenting discrepancies between issued control instructions and actual aircraft responses; assist in alerting responsible parties to correct any problems which may occur during the test (e.g., computer failure, stuck microphone); assist controllers in preparation of reports, and assist in final evaluation of data in order to prepare a Technical Observer report at the end of the simulation.

Appendix D Test Plan Phase IV.a.1 Simulation

Test Plan

Phase IV.a.1

ATC SIMULATION OF TRIPLE SIMULTANEOUS PARALLEL ILS
APPROACHES FOR THE DEVELOPMENT OF NATIONAL STANDARDS.

12 April 1990

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1. OBJECTIVE.

The FAA and the National Airspace Capacity Enhancement Executive Committee (EX-COM) are evaluating the capability of multiple (triple and quadruple) parallel runways to increase airport capacity in a safe and acceptable manner. The goal is to develop national standards for using multiple simultaneous parallel Instrument Landing System (ILS) approaches with both existing and/or new technology equipment. The objective of this study is to evaluate the traffic handling capability of triple simultaneous parallel ILS approaches with runways spaced 4300 ft. apart. Current technology radar systems will be examined using a real-time air traffic control (ATC) simulation. The results of this study will be used in the establishment of national standards using 4300 ft. runway spacing as a benchmark.

2. BACKGROUND.

The ability of the National Airspace System, (NAS) to handle the projected increase in air traffic with undiminished safety is a serious concern. Efforts to alleviate the concern include redesign of the airways, central flow management, and automation of the ATC system. There has been a long-term effort to increase the capacity of the NAS, both to reduce air traffic delays and to handle the anticipated increase in demand. The FAA is investigating the use of triple and quadruple parallel runways as one means to increase airport capacity while maintaining the high level of safety.

2.1 AIRPORT LIMITATIONS.

The number of aircraft that can land at an airport during Instrument Meteorological Conditions (IMC) is a significant limitation on system capacity. An area for improvement concerns the number of simultaneous approaches that can be made during IMC. The present limit is two, but there has been interest in triple and quadruple approaches for more than ten years [1, 2].

At a minimum, triple and quadruple simultaneous parallel ILS approaches, at least 4300 ft. apart, would be subject to the same limitations as dual simultaneous parallel ILS approaches. Special procedures required for simultaneous ILS approaches are described below [3]:

- a. Parallel runways that are at least 4300 ft. apart.
- b. Straight-in landings will be made.

c. Provide a minimum of 1000 ft. vertical or a minimum distance of 3 Nautical miles (NM) between aircraft during turn-on to parallel final approaches.

d. Provide the minimum applicable radar separation between aircraft on the same final approach course.

e. Aircraft established on final approach course are considered separated from aircraft established on an adjacent parallel final approach course provided neither aircraft penetrates the depicted No Transgression Zone (NTZ).

f. Separate monitor controllers, each with transmit/receive and override capability on the local control frequency, shall ensure aircraft do not penetrate the depicted NTZ.

These requirements have been studied by the FAA for a number of years. Operations research based models of the system have been used to study various safety restrictions and capacity limitations [1, 4, 5, 6, 7, 8, and 9]. Analyses have considered controller and pilot response times, navigational accuracy on the localizers, radar accuracy, and update rates, etc. [10].

2.2 ADDITIONAL RUNWAYS.

There are plans for adding runways to existing airports and building new airports. New airports are costly in dollars, require a long time to plan and build, and have high social and political costs, as well. Adding runways to existing airports is more timely and less expensive, if space is available to meet the required standards for runway separation. Making the most efficient use of existing facilities provides near-term payoffs at minimal cost.

2.3 ATC STANDARDS MODIFICATION REQUIREMENTS.

The absolute 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 proving 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 air traffic control (ATC) simulation studies of the changed system, introducing errors and failures, and comparing the results with those of present operations.

These approaches are neither independent nor mutually exclusive. Reliable field data are essential for successful modeling and simulation. Real-time ATC simulation, 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 desire to provide absolute certainty in the outcome of an extremely rare event may reduce system capacity below acceptable limits or, worse, produce new and higher risks in other areas now considered safe. Experienced system users (e.g., controllers, pilots, operations personnel) must weigh the sometimes conflicting evidence from these sources and make the decision about a proposed change, based on their understanding of 1) daily operations, 2) the knowledge and skills of the controllers, and 3) the contingencies to which the system must respond.

2.4 PREVIOUS MULTIPLE PARALLEL RUNWAY STUDIES.

Early studies of multiple runways concentrated on reducing separation between aircraft during simultaneous parallel approaches [1, 2, 4, 5, 6, 7, 8 and, 9]. The degree to which this can be done is dependent upon 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 this study have been questioned because 1) the navigational accuracy of the traffic samples may have been unrealistically poor and 2) some of the analyses did not conform to the analytical models cited [6, 7]. However, the 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 completed, additional data have been collected at Memphis International Airport [12], and a major navigation survey has been completed at the Chicago O'Hare facility [13]. The data from the Chicago survey directly considers simultaneous parallel approaches under IMC, will be used in planning traffic for the present simulation.

Additional real-time air traffic control simulations have been conducted at the FAA Technical Center [14, 15, and 16] to investigate parallel runway proposals. These studies are an important complement to the models cited above since they generate estimates of the model parameters and, more importantly, allow direct observation and recording of criterion measures related to safety and capacity. The 1988 and 1989 Dallas/Fort Worth (D/FW) simulations and the 1988 Atlanta Tower simulation are of direct interest to the ongoing effort since they addressed most of the issues unique to multiple runway operations and share some of the methodology of the current simulation.

The 1988 and 1989 D/FW simulations, which constitute Phases I and II of a five phase Airport Capacity Improvement Program are discussed in Section 2.5.

2.5 AIRPORT CAPACITY IMPROVEMENT PROGRAM.

The airport capacity improvement program consists of five phases. The schedule for the first four phases of the program is shown in Figure 1. The schedule for Phases IV.b and V will be determined later.

2.5.1 Phase I.

Simulation runs were conducted for D/FW quadruple simultaneous parallel ILS approaches with prop/turboprop aircraft on the two outer runways and only turbojets on the inner runways. The runway configuration employed consisted of the two existing runways, 17L and 18R, which have a centerline separation of 8800 ft., a new runway, 16R, with centerline 5800 ft. west of the 18R centerline, and a new runway, 16L, with centerline 5000 ft. east of the 17L centerline. The new runway lengths were 6000 ft.

2.5.2 Phase II.

This simulation considered D/FW triple simultaneous parallel ILS approaches, using a new 8500 ft. runway, 16L, having a centerline located 5000 ft. east of the runway 17L centerline. Aircraft consisted of turbojets on all runways. This simulation has been completed and results will be available in Spring of 1990. Missed approach procedures were not included in this simulation. Missed approaches for triple simultaneous

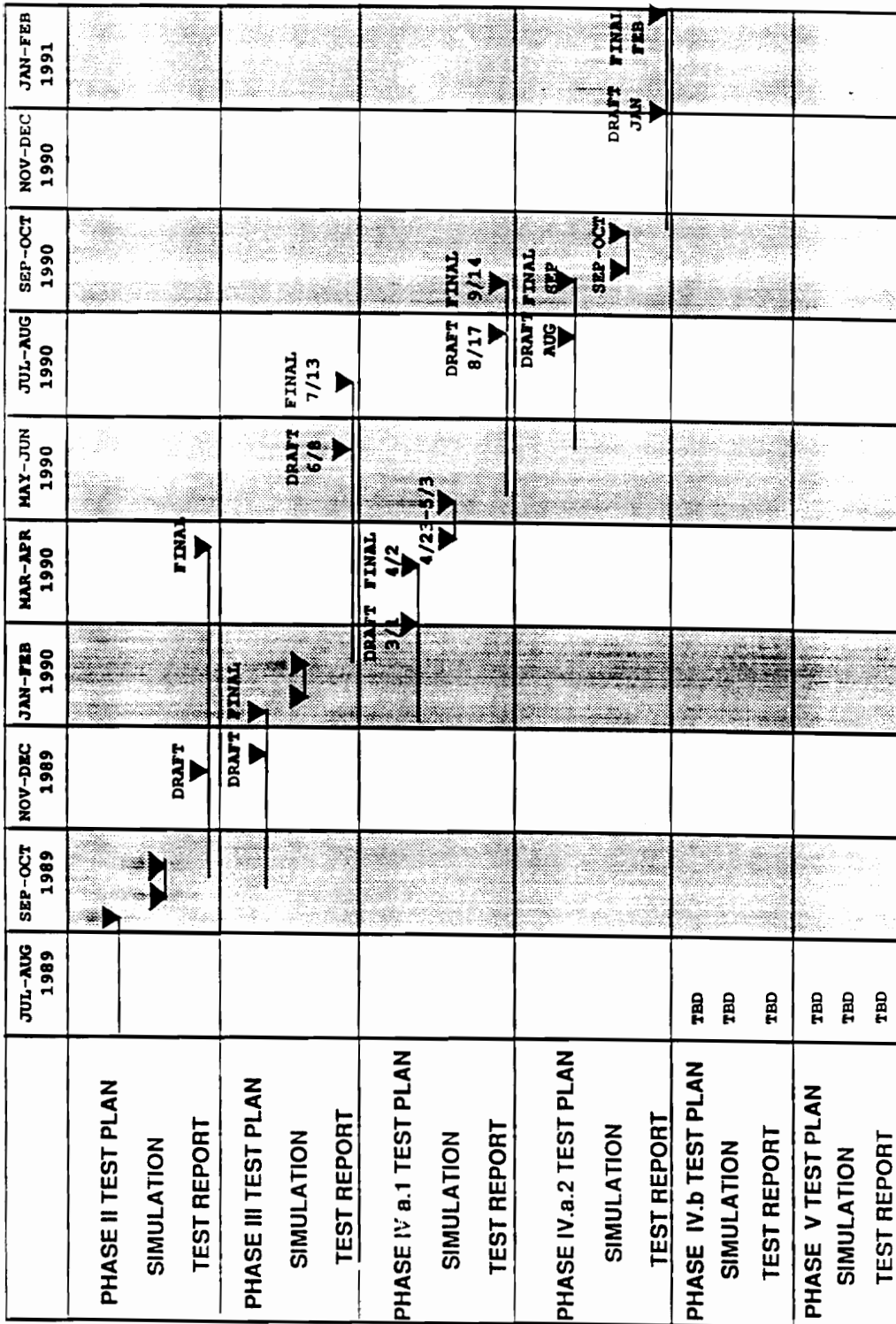


FIGURE 1. AIRPORT CAPACITY IMPROVEMENT PROGRAM SIMULATION SCHEDULE.

parallel ILS approaches can be handled through established ATC procedures.

2.5.3 Phase III.

This simulation considered D/FW quadruple simultaneous parallel ILS approaches. The runway configuration was similar to the configuration used in Phase I, except the length of 16L was 8500 ft., and the length of 16R was 9900 ft. Traffic consisted of a mixture of turbojets, props and turboprops on the outer runways; inner runway traffic consisted exclusively of turbojets. The ability of controllers to maintain adequate distances between missed approach aircraft and departing aircraft was also assessed in this simulation.

2.5.4 Phase IV.

The purpose of Phase IV is the development of national criteria and standards for application to other airport configurations, based on existing equipment. Phase IV will be assessed in 3 simulations as described below:

a. The first simulation of Phase IV will assess triple simultaneous parallel approaches with runway centerlines spaced not less than 4300 ft. apart. The simulation (Phase IV.a.1) will be conducted in April, 1990. The NASA-Ames (NA) B727 simulator and the FAA General Aviation Trainer (GAT) will be integrated into the simulation to obtain accurate measures of pilot response characteristics during blunder events. The NA B727 simulator is an FAA certified Phase II simulator with full motion capabilities.

b. The second simulation, Phase IV.a.2, assess triple simultaneous parallel approaches spaced 4300 ft. apart and will have at least 2 CAT-121 aircraft simulators. The 2 aircraft simulators will assess the interaction between aircraft flown by actual pilots in the blunder event. Phase IV.a.2 will be conducted in October, 1990.

c. The Phase IV.b simulation will be conducted to assess quadruple simultaneous parallel ILS approaches with runway centerlines not less than 4300 ft. apart. This simulation will be developed based upon the results of the Phase IV.a simulations.

2.5.5 Phase V.

The purpose of Phase V is to develop national standards for triple/quadruple simultaneous parallel ILS approaches using new technology ATC equipment. Final criteria elements will be determined at a future date based largely on the results of

Phases I through IV, plus the Raleigh-Durham and Memphis findings.

2.6 METHODOLOGICAL ISSUES.

Seven issues of particular relevance in the current series of simulations are navigational accuracy, radar error, blunders, missed approaches, safety criteria, system response time, and data ambiguity.

2.6.1 Navigational Accuracy.

The D/FW Phase I study used a navigational model that produced a standard deviation of approximately 200 ft. around the localizer beyond 10 NM of the threshold. The navigational model used in the D/FW Phase II and III simulations incorporated the Chicago data, in an effort to achieve a more accurate representation of navigational error. The model to be used in this simulation is described in Section 3.4.2.5.

2.6.2 Radar Error.

D/FW Phase I, II, and III simulations did not include a radar error model for the generation of display targets. The Phase IV.a.1 simulation will model radar error based upon the performance characteristics of the ASR-9 radar system. [17]

2.6.3 Blunders.

All three simulations used scripts that the test director and his assistant used in issuing turns to aircraft established on the localizer to create blunders. Turns were 10, 20, or 30 degrees, always toward at least one other localizer, and blundering aircraft were individually instructed (according to the script) as to whether they could acknowledge and respond to any further controller communications.

2.6.4 Missed Approaches.

Phase III included the assessment of missed approach procedures. In this portion of the simulation, the controllers monitored departing aircraft and issued vector changes as required to maintain adequate distances between the departing aircraft and the missed approach aircraft. The missed approach aircraft were subjected to drift angles of 5, 10, and 15 degrees.

2.6.5 Safety Criteria.

The Aircraft Proximity Index (API) and the Closest Point of Approach (CPA) are used to evaluate conflicts. The API ranges from 0 to 100 and is computed from the smallest horizontal and

vertical separation distances reached in each conflict. The API is a refinement of a set of weights computed from lateral separation distances and applied to conflicts in the 1984 simulation. Additionally CPA is the smallest slant range distance between two aircraft that are involved in a blunder. Detailed analyses of Initial Predicted Closest Point of Approach (PCPA) and Predicted Aircraft Proximity Index (PAPI) are also employed.

2.6.6 Response Time.

Pilot messages (i.e., any aircraft control action) and their entry times are recorded so that, in some cases, controller response times can be estimated. In the D/FW Phase II and III studies, video and audio tape recordings of the simulation were used to derive a more accurate estimate of system response time. The addition of the AMECOM audio interface equipment in the Phase IV.a.1 simulation will facilitate the collection of controller response times. The integration of the GAT and NA simulators will aid in the assessment of aircraft/pilot response times to response times.

2.6.7 Data Ambiguity.

The plan for the analysis of the previous simulation data involved a consideration of controller interventions in the traffic samples as responses to blunders or losses of longitudinal and lateral spacing. Some of the controller actions could not be directly traced to an experimentally induced antecedent. Such events included failure of NSSF simulator pilots to respond correctly to a clearance and delays in NSSF simulator pilot responses. Some errors in simulator pilot performance persisted in Phases II and III, possibly because a newly trained group of simulator pilots was employed. Average delays in NSSF simulator pilot response times have been found to be consistent and vary only slightly from actual pilot performances.

3. PHASE IV.a.1 ATC SIMULATION OF TRIPLE SIMULTANEOUS PARALLEL ILS APPROACHES FOR THE DEVELOPMENT OF NATIONAL STANDARDS.

This section describes the simulation to be performed April 24, 1990 through May 3, 1990. The objectives, methodology, and procedures of the simulation are presented in Sections 3.1 through 3.3. Section 3.4 describes the details of the simulation design.

3.1 OBJECTIVES.

The Phase IV.a.1 simulation evaluates triple simultaneous parallel ILS approaches using a minimum distance of 4300 ft.

between runway centerlines. A worst case airport will be modeled. The airport, depicted in Figure 2, will have three runways separated 4300 ft. between centerlines and even thresholds (not staggered). Traffic consists of turbojets, props, and turboprops on all runways. The ILS has a 3 degree glide slope.

The simulation addresses three questions:

a. Can controllers provide miss distances, in response to blunders, for the proposed triple approach configuration, which are statistically equivalent to those occurring in dual parallel ILS approaches?

b. Can the controllers maintain the test criterion miss distance of greater than 500 ft. between aircraft in response to blunders, for the proposed triple approach configuration?

c. Do the controllers, controller observers, and ATC management observers agree that the operation of the proposed triple simultaneous parallel ILS approaches are acceptable, achievable, and safe?

3.2 ASSESSMENT METHODOLOGY.

This simulation follows the general plan used in the Phase II and III simulations. Three assessment methodologies are used to evaluate multiple approach operations. One is based on the direct and indirect comparison of the three-runway operation with the two-runway operations. This is called the "Experimental Approach." The second consists of an assessment of system performance against a set of predetermined criteria. This is called the "Operational Approach." The final methodology is the "Administrative Approach" which consists of an analysis of controller, industry observer, and EX-COM evaluations. Requirements and recommendations are made by the EX-COM based upon this analysis.

3.2.1 Experimental Approach.

The Experimental Approach assesses system performance when only two runways are involved and compares the results with the outcome of comparable events involving three runways. This approach focuses on statistical analysis of the computer data from the simulation, and an interpretation of the results in light of the safety related questions posed in the study.

3.2.2 Operational Approach.

The Operational Approach evaluates each incident that meets criteria in Figure 3, Operational Assessment Decision Tree, as if it had occurred in an operational environment. A

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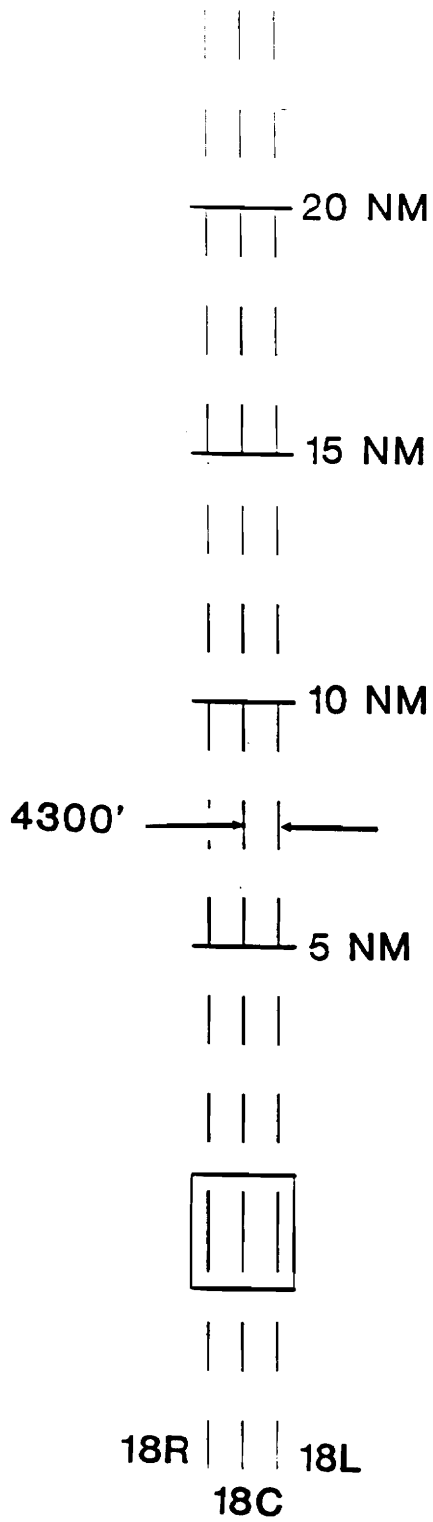


FIGURE 2. AIRPORT DIAGRAM

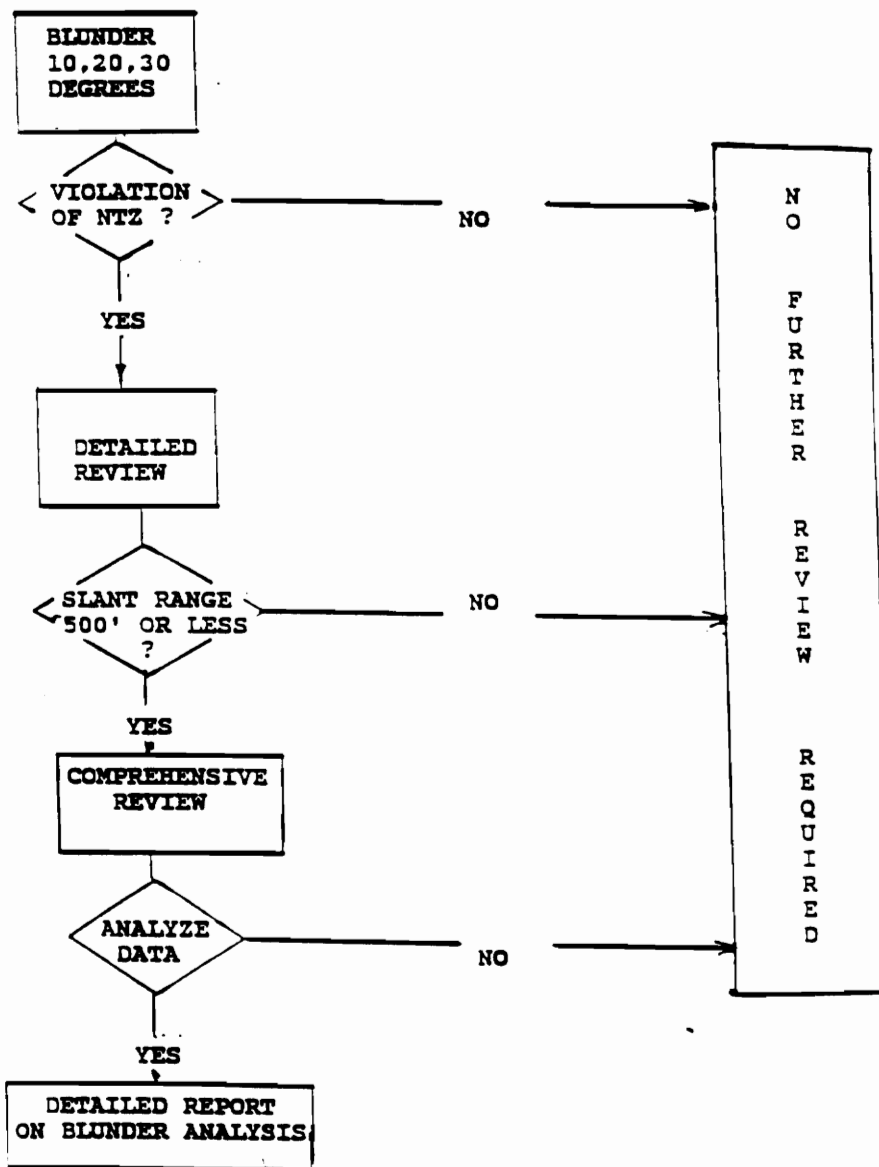


FIGURE 3. OPERATIONAL ASSESSMENT DECISION TREE.

determination is made of its seriousness and cause. The operational assessment approach differs from the experimental approach in two ways. First, only a small subset of data is 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 is considered individually, and is subjected to a detailed analysis by the EX-COM. The analysis of each event considers data from many sources, including controller and technical observer reports, computer data, and video and audio tape materials.

3.2.3 Administrative Approach.

The Administrative Approach takes a global view of the simulation. The analysis will include an assessment of the results of the Experimental and Operational Approaches. Additionally, the controller evaluation, the industry observer comments, and technical observer reports are examined. Based upon the findings of these sources, the Multiparallel Approach National Standards Team shall prepare a final report which includes evaluations, comments, and recommendations.

3.3 SIMULATION PROCEDURE.

The controllers will be manning the approach monitor or departure monitor positions. Approximately 3 aircraft will enter the simulation, 1 per ILS, every 1 1/2 minutes. Controllers will monitor aircraft position and intervene if aircraft deviate significantly from the ILS. Aircraft blunders will be initiated by the Test Director to enable the assessment of the controller's traffic handling abilities. Aircraft that successfully fly the ILS, intercept the glide slope, and are not involved in a blunder, eventually land. Aircraft that blunder, or are vectored off their ILS, as a result of a blunder, are eventually cancelled.

To attain reliable data the following procedures have been developed for running the Phase IV.a.1 simulation.

3.3.1. Schedules.

3.3.1.1 Subject Scheduling.

Nine controllers will participate as subjects. Controller assignments to runs and runway positions are shown in Table 1, which also shows the schedule for the simulation. The randomization is carried out with the following restrictions:

a. Controllers will not participate in more than two consecutive runs per day, and a total of no more than three runs in one day.

TABLE 1. CONTROLLER/RUNWAY ASSIGNMENTS

DATE	RUN	ARRIVAL			DEPARTURE			TYPE
		18R	18C	18L	18R	18C	18L	
4/24	1		B	C				DUAL
	2	D	F	G				TRIPLE
	3	H	E	A				TRIPLE
	4		C	I				DUAL
4/25	5				E	B	A	DEPART
	6		E	I				DUAL
	7	G	H	B				TRIPLE
	8		I	F				DUAL
	9	A	C	D				TRIPLE
4/26	10				C	E	G	DEPART
	11	I	C	H				TRIPLE
	12		D	F				DUAL
	13	B	D	H				TRIPLE
	14		F	G				DUAL
4/27	15	A	C	F	B	G	D	ARR/DEP
	16		E	H				DUAL
	17		I	D				DUAL
	18	C	F	B				TRIPLE
	19	G	H	A				TRIPLE
4/30	20				I	D	H	DEPART
	21	E	I	F				TRIPLE
	22		B	F				DUAL
	23	A	G	C				TRIPLE
	24		E	D				DUAL
5/1	25	A	C	F	B	G	D	ARR/DEP
	26	H	I	E				TRIPLE
	27		G	A				DUAL
	28		I	H				DUAL
	29	C	E	B				TRIPLE
5/2 DEPART	30				F	I	G	
	31		H	G				DUAL
	32		C	A				DUAL
	33	B	F	E				TRIPLE
	34	D	A	H				TRIPLE
5/3	35				H	C	E	DEPART
AD HOC RUNS								
	36		B	A				DUAL
	37	G	I	D				TRIPLE

b. Controller assignments are balanced among dual approach, triple approach, and departure control runs.

c. Each controller's assignments are equally divided with respect to runways in the dual approach, triple approach, and departure control conditions.

3.3.1.2 Run Scheduling.

A portion of the first morning of the simulation, Tuesday April 24, 1990, will be used to refamiliarize controllers with the ARTS IIIA facility and the equipment. Additionally, practice runs using dual and triple approaches will be conducted to reacquaint the controllers with the strategies involved in the control of aircraft for the runway configurations in this study. The practice runs are abbreviated in length, and the data from the practice runs are not subjected to formal analysis. Two dual approach and two triple approach runs are conducted following the practice sessions. These runs are not abbreviated in length, and data from these runs are subjected to formal analysis.

Five runs per day are scheduled for the next six days (excluding weekends), and three runs on the eighth day of the simulation (May 3rd). Two triple and two dual approach runs will occur each day. One departure control or combined arrival/departure control run will be scheduled as the first run each day. The order of occurrence of the dual and triple approach runs are randomized. The last day of testing, Thursday, May 3rd is allocated for 2 "ad hoc" runs, one departure run, make-up runs, and final documentation work of the controllers and observers.

3.3.1.3 Departure Control Runs.

Five departure control runs are conducted with an automatic simulation of arriving traffic. Standard procedures require that missed approach aircraft on the outboard approaches turn outward 45 degrees from the ILS heading. Missed approach aircraft on the inboard approach will maintain the ILS heading. The departure aircraft will be given clearance by the local controller (a controller supervisor from the Dallas/Fort Worth TRACON). Departures will be cleared for takeoff only from the outboard runways (18R & 18L). Aircraft departing from 18R and 18L will fly takeoff courses that diverge by 15 degrees immediately after departure (195 degrees and 165 degrees, respectively).

Controllers are assigned to monitor the departure runways and will attempt to keep missed approach aircraft from entering the NTZ. Approximately 16 of the arriving aircraft will execute missed approaches at the missed approach point (200

ft. AGL). Missed approach aircraft will climb to 400 ft. AGL before initiating any changes in heading. In addition to standard heading changes, missed approach aircraft may drift up to 15 degrees left or right as instructed by the Test Director.

Two additional runs will have 3 controllers monitoring arrival aircraft and 3 controllers monitoring departure aircraft. These runs will have the arrival aircraft executing both missed approaches and blunders. The first combined arrival/departure control run will be conducted on Friday, April 27. This will be used as a practice trial and will not be formally assessed. The second combined trial will be conducted on Tuesday, May 1, to allow the Industry Observers to assess the system workability. The data collected from this trial will be reported, but it will not be included in the arrival and departure analyses.

3.3.2 Blunder Scripting.

Random blunders will be scripted for aircraft on each runway and include 10, 20, and 30 degree turns. For the three-runway airport, blunders on the center runway (18C) are distributed such that 50% occur to the left and 50% to the right of the localizer centerline. Blundering aircraft on the outside approaches (18R and 18L) will move toward the inside localizer. In the two-runway system, blunders are always initiated toward the other localizer. Blunders will commence 10 NM or less from threshold, after aircraft on all 3 approaches have intercepted the glide slope. Appendix A includes an example blunder script.

The blunder script will randomly direct blundering aircraft to either maintain altitude or descend following a blunder. Blunder scenarios will be scripted such that 50% of the blunders occur before the outer marker. Deviations in the blunder scripts may be initiated by the test director to attain the involvement of the NA and GAT simulators in the blunder events. Additionally, a blunder script will be created for each run in the Phase IV.a.1 simulation.

3.3.3 Questionnaire Administration.

Following each run, a short questionnaire and workload rating scale (Appendix B) is administered to the controllers to assess their opinions concerning run realism, difficulty, controllability, and their recommendations for operational use.

The NA and the GAT simulator pilots will complete a questionnaire after each session (Appendix C). Pilots will rate their performance, activity level, stress level, and the

passenger comfort. Additionally, pilots will record any unusual occurrences and any policies which would have affected their performance.

Finally, information from technical and industry observers regarding system is acquired using the technical observer questionnaire (see Appendix D).

3.4 SIMULATION DESIGN.

The thrust of the simulation is to determine whether air traffic controllers can provide miss distances between blundering and nonblundering aircraft in the triple simultaneous parallel ILS approach operation that are comparable to those achieved in the dual simultaneous parallel ILS approach operations with runway centerlines spaced 4300 ft. apart.

3.4.1 Controllers.

There will be 9 air traffic control specialists and/or supervisors from separate control towers (Atlanta, Dallas/Fort Worth, Denver, Miami, Minneapolis, Orlando, Pittsburgh, Sacramento, and St. Louis). All controllers are volunteers and are selected in agreement with National Air Traffic Controllers Association (NATCA) offices.

3.4.2 Apparatus.

This section describes the simulation facility, simulation displays, simulation pilots, computer software, and data collection equipment.

3.4.2.1 ARTS IIIA Laboratory.

The ARTS IIIA Laboratory is located at the FAA Technical Center, Atlantic City, New Jersey. The ARTS IIIA Laboratory houses 10 Data Entry and Display Subsystems (DEDS) which are the standard Automated Radar Terminal System displays (ARTS) as shown in Figure 4. The DEDS have digital random write displays to present aircraft ID tags, and associated key board entry and communication equipment. The DEDS provides aircraft track history through phosphor persistence. The laboratory is realistically configured permitting controllers to function with little or no acclimation. A communication system provides controller-to-controller, controller-to-pilot, and pilot-to-controller communication.

3.4.2.2 Pilot Simulation Facility.

The National Airspace System Simulation Support Facility (NSSF) Pilot Complex houses individuals, who "pilot" the

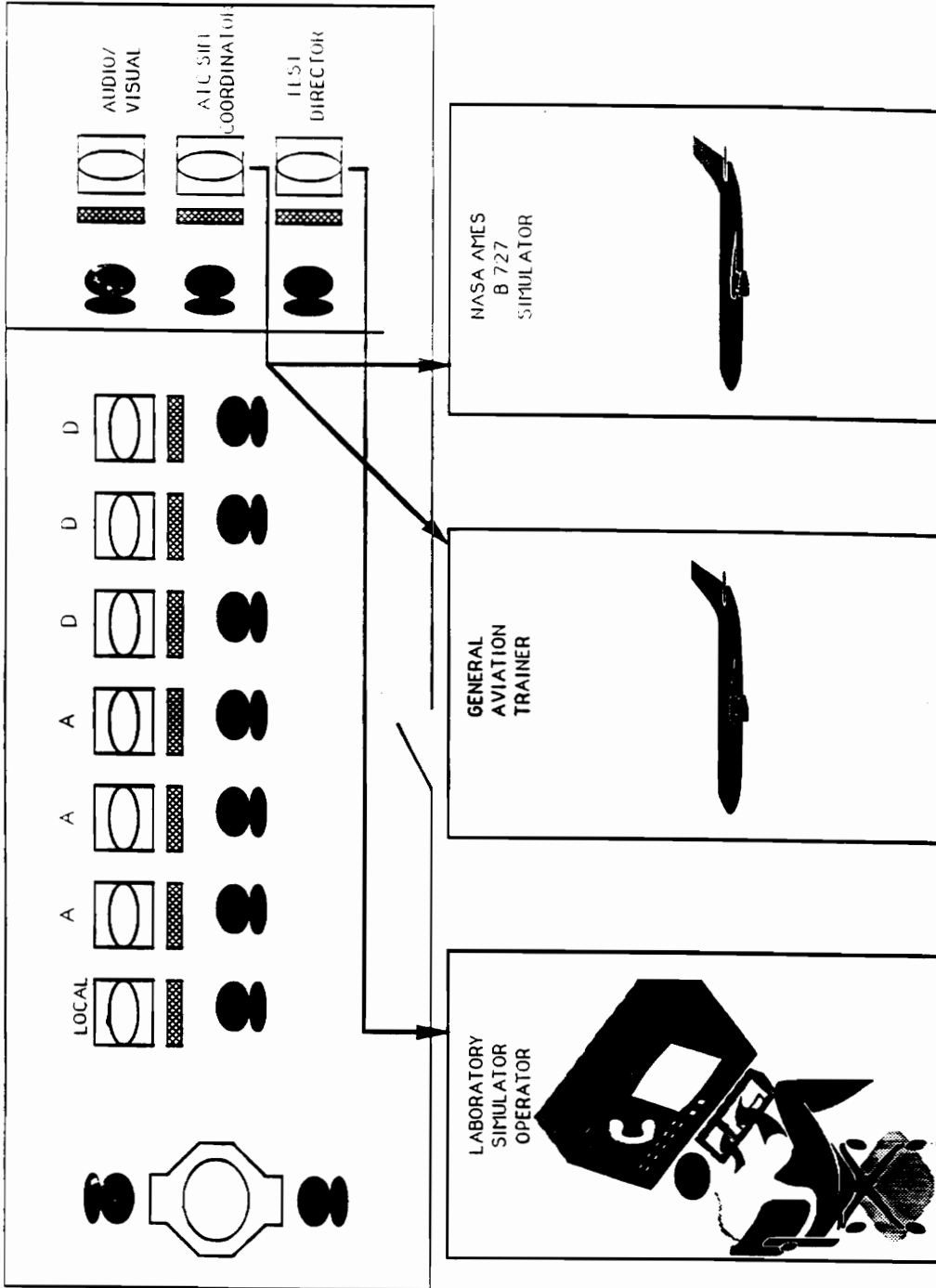


FIGURE 4. ARTS IIIA LABORATORY LAYOUT

simulation aircraft, and the equipment used to accomplish this task. NSSF Simulator Pilots are in voice contact with the 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 simulator pilot can control as many as 10 aircraft. Aircraft responses are programmed to be consistent with the type of aircraft being simulated.

Additionally, the NA simulator and the GAT will be integrated into the Phase IV.a.1 simulation to provide an assessment of the airport configuration. These simulators will be flown by pilots resident to their respective facilities. The cockpit simulators assume the configuration of aircraft flying the localizer, for arrival analyses, or departing aircraft, for missed approach analyses, and will replace other aircraft that are scheduled to enter the simulation. The NA and GAT simulator pilots will be in voice communication with the controllers. A female crew member will be present in each of the simulators and will respond to controller commands. This will prevent controllers from determining whether the pilot is a NSSF, NA, or GAT Simulator pilot. Additionally, the NA and GAT simulator pilots will be in voice communication with the ATC Simulation Coordinator, who will assist them prior to and following each flight. The NA and GAT simulators will perform approximately 5 to 6 flights per simulation run.

3.4.2.3 Airport Configurations and Flight Patterns.

The airport layout, runways, and arrival frequencies emulate a generic airport with even thresholds and glide slopes of 3 degrees. The runway lengths will be 10,000 ft. to accommodate all aircraft types.

The airport configuration in the simulation will have three parallel runways with arrival heading of 180 (18R, 18C, and 18L). The distance between the runway centerlines will be 4300 ft. The dual approach simulation runs will use the same airport display as used in the triple approach simulation runs with aircraft arriving on 18L and 18C only.

Four additional airport configurations are available for the simulation if the original airport configuration is assessed as not achievable:

1. 4300 ft. between 18R and 18C and 5000 ft. between 18C and 18L.
2. 4300 ft. between 18R and 18C and 6000 ft. between 18C and 18L.

3. 4300 ft. between 18R and 18C and 7000 ft. between 18C and 18L.

4. 5000 ft. between 18R and 18C and 5000 ft. between 18C and 18L.

Aircraft will start on the localizers and maintain the altitude at which they were cleared to the localizer until intercepting the glide slope, as shown in Table 2.

TABLE 2. ILS RUNWAY TURN ON ALTITUDES

<u>Runway</u>	<u>Turn On Altitude</u>	<u>Glide Slope Intercept</u>
R	3000 ft.	9.64 NM
C	5000 ft.	15.7 NM
L	4000 ft.	12.7 NM

3.4.2.4 Traffic Samples.

Traffic samples are based on actual traffic from a combination of several large hub airports around the country (e.g., Chicago, Atlanta, Dallas/Ft. Worth, Los Angeles, Denver, and other Terminal Radar Controls (TRACON)) and consist of representative aircraft types and identifiers. Five traffic samples will be developed for the triple runs in Phase IV.a.1. Only two traffic samples developed for the dual runs. Only two traffic samples are required for the departure control runs.

The traffic samples are developed to result in a large proportion of the aircraft flying side by side. This pattern is accomplished by calculating aircraft turn on times based upon aircraft speed and the speed of aircraft on adjacent runways. The scheduling of aircraft start times using this method results in aircraft being in close proximity at the outer marker. This is done to produce worst case situations more frequently. Additionally, the Phase IV.a.1 simulation will include two to three speed overtakes during each run.

3.4.2.5 Navigational Error Model.

The navigational error model generates flight technical error on the ILS localizer and creates the occasional "wandering" aircraft. It considers each aircraft currently on the localizer at regular intervals and determines whether to give it a deviation off the localizer. This decision is made on a random basis, with a fixed probability at each "look." If there is to be a deviation, tables of random values are used

to determine the angle and length of time the aircraft will stay on the deviated course before returning to the localizer. The combination of frequency of deviation, size of deviation, and duration of deviation determine the accuracy of the sample.

The selection of parameters for these variables, mean and standard deviation, or range, is based on two criteria:

a. The flight paths of individual aircraft should look reasonable to the controllers (i.e., deviations from the localizer centerline should be typical of "wandering" aircraft).

b. The aggregate errors should reflect the accuracy typical of aircraft in the traffic sample (i.e., the ORD data).

Controller intervention is permitted to correct flight technical error or "wandering".

A review of the ORD data by ACD-340 showed that many aircraft gradually home in on the localizer (i.e., follow paths that are asymptotic to the localizer), rather than oscillate around the localizer with reductions in oscillation amplitude as they proceed to the threshold. To more accurately model the actual motion of aircraft, a concept of pseudoroutes will be employed, as an adjunct to the navigational model. A pseudoroute is defined as a route starting at one of several fixes offset from the extended ILS centerline and joining the ILS at threshold, as shown in Figure 5.

Each aircraft will be assigned to fly the localizer or one of four pseudoroutes. These pseudoroutes are offset from the localizer by 0.2 and 0.35 degrees. Only aircraft travelling on the center pseudoroute, are subject to "wandering". Forty percent of the aircraft will be assigned to fly the localizer; 20% will fly each inside pseudoroute, and 10% will fly each outside pseudoroute.

This navigational error model produces aircraft motion distributions that correspond closely with those found in the Chicago data and provide visually realistic targets to the controllers.

3.4.2.6 Data Collection Equipment.

Data collection and reduction will be accomplished on the NSSF computers. The same types of standard NSSF data collected in Phases I, II, and III are collected during the Phase IV.a.1 simulation. Run summaries are transferred to PC compatible floppy disks based on SIMBLNDR, BLUNDERS, SNAPSHOT, SUMFILE,

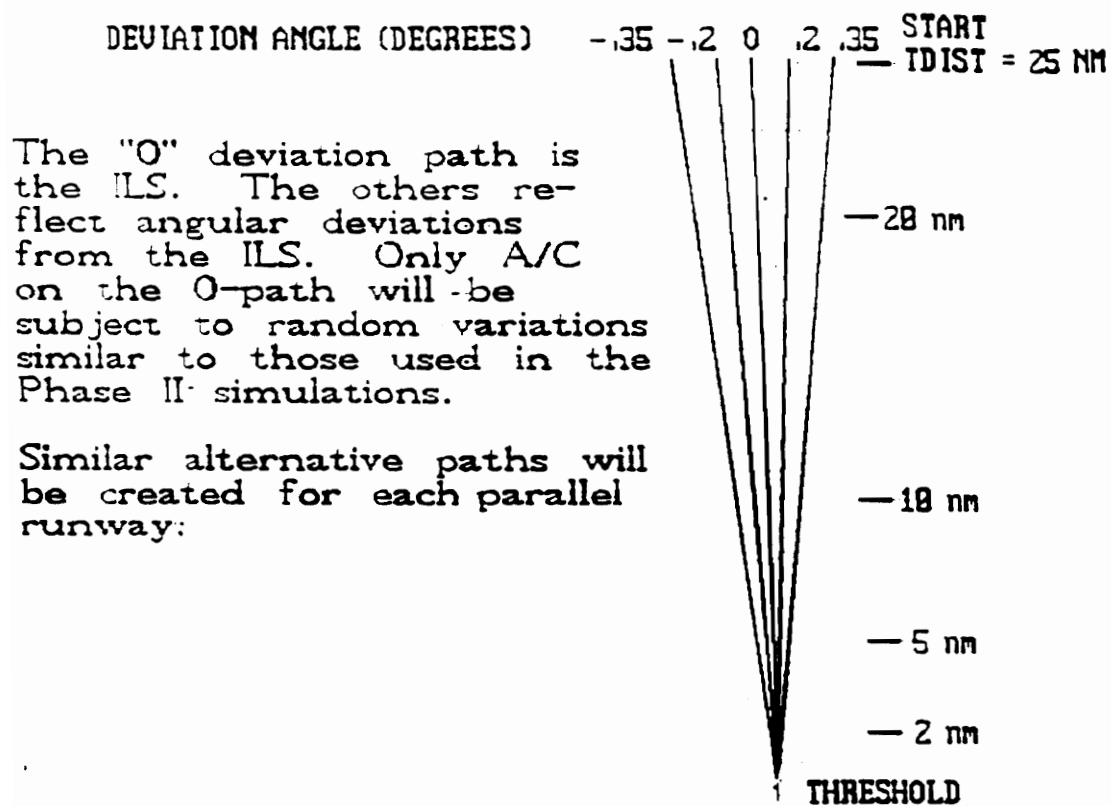


FIGURE 5. GRAPHICAL REPRESENTATION OF PSEUDOROUTES

VECTFILE, and TRANFILE data files (Appendix E). Data available for analysis from the computer summary files include, but are not limited to, the following:

- a. number of NTZ transgressions;
- b. number of parallel conflicts;
- c. API and CPA for parallel conflicts;
- d. number of longitudinal conflicts;
- e. API and CPA for longitudinal conflicts;
- f. response time to blunders (estimated from pilot message time);
- g. number of blunder responses to nonblunderers (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.

3.4.2.7 Voice Communications.

Controller, NSSF, GAT, and NASA-AMES simulator pilot voice communications are recorded using a 20-channel audio recorder available at the FAA Technical Center. Controller and simulator pilot verbal response times to blunders are extracted and statistically analyzed. Synchronization of the audio, video, and computer data will be accomplished through the insertion of a "time hack", corresponding to simulator run time, onto the video and audio recordings.

3.4.2.8 Video Recording.

Continuous video recordings, with sound and time synchronization, are made to assist in the interpretation of events and the analysis of computer recorded data. One radar display is dedicated to video recording using an S-VHS format video recorder. Two or three microphones will be used to record controllers' voices during each run. This will permit the analysis of interaction between controllers where it is deemed necessary.

3.5 ACCEPTANCE CRITERIA.

3.5.1 Experimental Approach.

Data analysis and interpretation are accomplished using the Complete Statistical System (CSS) software package for PC compatible computers. Emphasis is on overall data comparisons between the three-runway and two-runway operations. In addition, events which are unique to three-runway operations (e.g., blunders which threaten two runways) are compared with events occurring for the standard two-runway configuration. The CPA and API are dependent measures used to evaluate the observed distances between aircraft, as an estimate of the relative safety of the conditions employed in this study.

Among the questions to be answered using the experimental approach are the following:

a. Is there a difference in dependent measures as a function of the number of runways threatened by a blunder?

b. Is there a quantitative difference, in dependent measures, between blunders in the triple runway condition and blunders observed in the dual-runway condition?

c. What is the impact of the degree of blunder and communication/no communication conditions on the dependent measures?

d. Do the number of NTZ warnings and the number of false alarms vary as a function of runway separation? If so, how?

e. Does controller response time to a blunder vary as a function of degree of blunder, runway separation, and the number of runways (e.g., two versus three runway conditions)?

3.5.2 Operational Approach.

This approach provides a systematic review of the results of each blunder. It includes:

a. a review of the operational response to each blunder;

b. a determination of whether or not all "wanderers" were prevented from entering the NTZ;

c. a determination of the system's ability to manage triple parallel approaches; and

d. a comprehensive review of all blunders that result in a slant range distance of less than or equal to 500 ft.

Two questions must be answered with respect to each blunder. Did the blundering aircraft violate the NTZ? If the answer is no, further analysis is not required. If the answer is "yes", a determination is made as to whether or not the blunder recovery action resulted in a greater than 500 ft. slant range distance between the centers of the targets involved. If this determination is yes, further analysis is not required. Should a comprehensive review be necessary (i.e., a blunder has resulted in a slant range distance of 500 ft. or less), the review will be conducted by the EX-COM. No data shall be excluded from consideration, except as approved by the EX-COM. The EX-COM will make a detailed report of any events that produce unacceptable outcomes. In the event that a comprehensive review is indicated, the following data shall be reviewed:

- a. plots of aircraft positions;
- b. controller-pilot communication recordings;
- c. NSSF simulator pilot input records;
- d. computer data;
- e. video tape recordings of the radar display;
- f. audio tape recordings of controller and simulator
pilot messages;
- g. controller interviews and debriefings; and
- h. observer records and logs.

3.5.3 Administrative Approach.

This approach provides the overview analysis and documentation of the triple parallel approach simulation. The material to be used for the overview analysis includes:

- a. controller evaluation and comment reports completed by each controller immediately after selected runs of the simulation;
- b. industry observer written evaluations and comments, which are encouraged for submission after viewing the runs;
- c. reports of participating controllers, which include comments, evaluations, and recommendations; and
- d. the report of the EX-COM, which includes comments, evaluations, and recommendations.

The Multiparallel Approach National Standards Team shall compile and review all data connected with the Phase IV.a.1 simulation. These data include:

- a. the Experimental Analysis Report and associated data;
- b. the Operational Approach data;
- c. the EX-COM final Operational Assessment Report;
- d. the Controller Operational Assessment Report, and
- e. the industry observer comments.

The team shall prepare a final report, including evaluations, comments, and recommendations.

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Appendix E Phase V.a.1 and V.c Controller Briefing

CONTROLLER BRIEFING
FOR THE
MULTIPLE SIMULTANEOUS PARALLEL
ILS APPROACH PROGRAM
PHASES V.c. and V.a.1

OVERVIEW

- Program Goals
- Purpose
- Test Conditions
- Schedule
- Controller Participation
- Controller Responsibility
- Controller Instructions

OVERVIEW (continued)

- **Radar**
- **Controller Displays**
- **Traffic Scenario Description**

PROGRAM GOALS

- To increase airport capacity through the use of multiple simultaneous parallel ILS approaches during IMC. This includes:
 - closely spaced dual parallel runways
 - triple and quadruple parallel runways
- To establish criteria for multiple simultaneous parallel ILS approaches and establish National Standards.
- To evaluate the feasibility of utilizing new controller displays and high update rate radar to further reduce acceptable runway spacings.

MULTIPLE PARALLEL SIMULTANEOUS ILS APPROACH PHASES

- PHASE I QUADRUPLES AT DFW - Using mixed aircraft types
- PHASE II TRIPLES AT DFW - Using all turbojet aircraft
- PHASE III QUADRUPLES AT DFW - Using mixed aircraft types
- PHASE IV National Standards (Triples) Based on Existing Equipment (ARTS IIIA displays and ASR-9 radar)
 - IV.a Triples spaced 4300 ft with a 4.8 s radar update rate
 - IV.b Triples spaced 5000 ft with a 4.8 s radar update rate

Note: The above Phases have been completed.

MULTIPLE SIMULTANEOUS PARALLEL ILS APPROACH PHASES (continued)

- PHASE V National Standards Based on New Technologies
(Sony Displays with Alert Algorithms and
variable update rate radar)
 - V.b.1 Duals spaced 3000 ft with a 1.0 s
radar update rate (3/18 - 3/27)
 - V.b.2 Triples spaced 3000 ft with a 1.0 s
radar update rate (3/28 - 4/5)
 - V.c Triples spaced 3400 ft with a 2.4 s
radar update rate (5/6 - 5/14)
 - V.a.1 Triples and duals spaced 4300 ft with
a 4.8 s radar update rate
(5/15 - 5/24)
 - V.a.2 Triples spaced 4000 ft with a 4.8 s
radar update rate (9/23 - 10/11)
- PHASE VI National Standards (Quadruples) Based on
Existing Equipment and/or New Technologies

PURPOSE

PHASE V.c and PHASE V.a.1

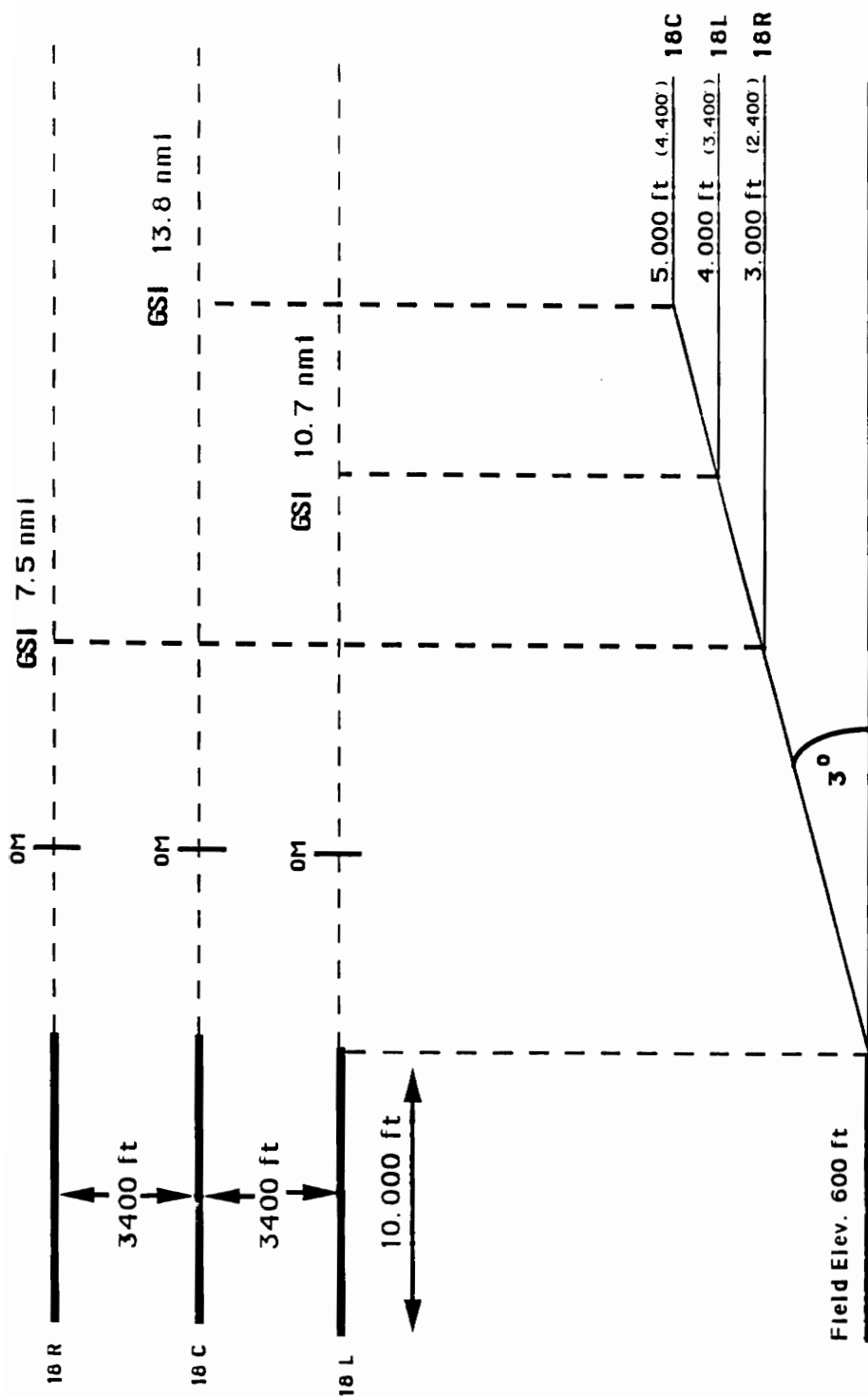
The purpose of this simulation is to measure the controllers ability to recognize potential conflicts resulting from aircraft blunders, and the ability of pilots to respond to controller instructions in sufficient time to resolve these conflicts.

- Basic Objective is to understand the effect of key variables on Controller performance:
 - Number of runways threatened by blunder
 - Improved Radar Update Rate
 - Approach Blunder Angle
 - Communication vs. No Communication
- Measurement of behavior under Controlled, Repeatable Conditions to isolate the effect of each variable.

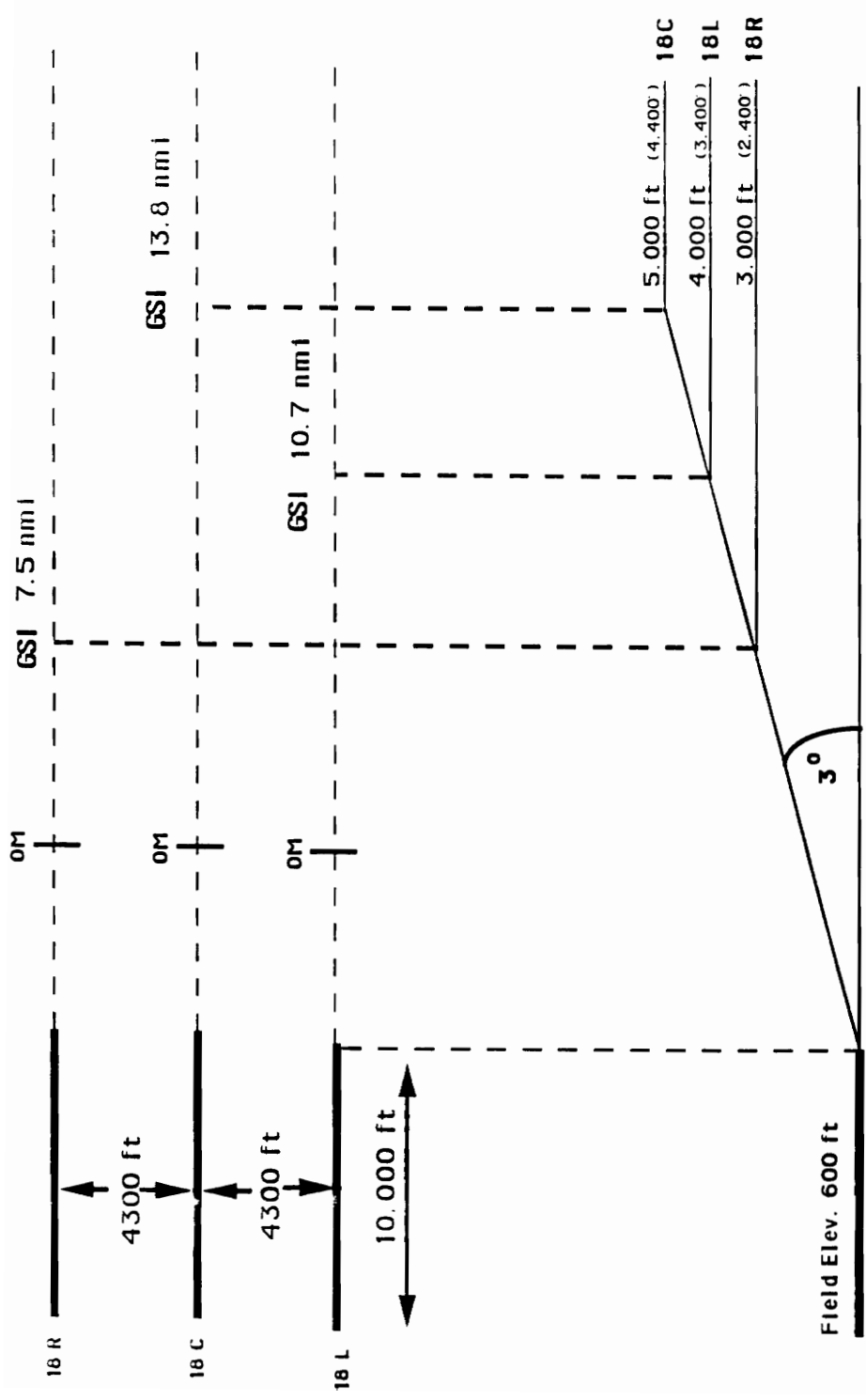
TEST CONDITIONS

PHASE V.c and PHASE V.a.1

- Aircraft commence approach on final course, with mixed aircraft types including, props, turboprops and turbojets
- Glideslopes set at 3 degrees
- Blunder turns at 20 and 30 degrees
- Communication vs. Lost Communication
- Runway Thresholds even
- Runways 10,000 ft in length
- Runway centerlines separated by 3400 ft (Phase V.c) and 4300 ft (Phase V.a.1)
- Standard 2000 ft NTZ



OM = outermarker at 5 nmi
 GSI = glide slope intercept



OM = outmarker at 5 nmi
 GSI = glide slope intercept

TEST CONDITIONS

PHASE V.c and PHASE V.a.1 (continued)

- The NTZ has been extended thru the missed approach to a point 1/2 mile beyond the departure end of the runway
- "Aircraft" will comprise both targets generated by National Simulation Support Facility (NSSF) which are flown by pseudo pilots and targets originating from aircraft simulators "flown" by Airline Pilots located at Nasa-Ames, Delta Airlines, AVIA Inc., FAA Aeronautical Center, and the FAA Technical Center.
- High resolution color display with video and audio alerts
- High update radar rate with increased target location accuracy

SCHEDULE

May 6-14	Phase V.c	3400 ft triple approaches with a 2.4 s update rate
May 15-21	Phase V.a.1	4300 ft triple approaches with a 4.8 s update rate
May 22-24	Phase V.a.1	4300 ft dual approaches with a 4.8 s update rate

CONTROLLER PARTICIPATION

- Six controllers will participate as Monitor Controllers.
 - Three, two-hour runs will be conducted each day.
 - Controllers will monitor only one hour of each run.
 - Controllers will rotate positions midway of each run.
- Participant scheduling is carried out with the following restrictions:
 - Controllers will not participate in more than two consecutive hours per day, and will participate a total of not more than three hours.
 - Controller's assignments will be equally divided with respect to runways and controller pairing.

CONTROLLER PARTICIPATION (continued)

- Controllers will be requested to complete a short questionnaire and a workload rating scale following each run.
- If necessary, a Controller Blunder Conflict Statement (CPA < 500ft) will be administered.
- It is requested that each controller complete each questionnaire in it's entirety.

CONTROLLER RESPONSIBILITY

Issue control instructions and information necessary to ensure separation between aircraft and to ensure aircraft do not enter the "No Transgression Zone" (NTZ). (7110.65F, para 5-126h.)

When, in the controller's best judgement, penetration of the NTZ is imminent, aircraft on the adjacent final course shall be instructed to change heading, altitude, or speed to avoid the flight path of the deviating aircraft.

CONTROLLER INSTRUCTIONS

- You are the Monitor Controller and are responsible for monitoring the flight path of aircraft on your assigned runway. When, in your best judgement, you determine that penetration of the NTZ is imminent, break-out the endangered aircraft.
- You do not have to wait for the alert to change color from yellow to red before issuing your instructions. You do not have to wait for the voice alert to stop talking before giving your instruction.
- The phraseology "Break left to..." or "Break right to..." will replace "Turn left immediately" or "Turn right immediately".
- Speed changes - Give instructions for speed changes whenever you determine that the separation is not in accordance with current ATC procedures.
- Lost beacon signal (track turns red and goes into coast)
 - controller will automatically break out aircraft.

CONTROLLER INSTRUCTIONS

(continued)

- Remember that this study measures your ability to maintain distance between aircraft in response to the approach blunders shown. When you react, the pilot will break-out the aircraft.
- All of our data forms will include a letter code. Your name will not appear on any of the data collected. Your responses will be totally anonymous.
- If you have any questions about the display or the procedures to follow in this study, please feel free to ask the test conductor.

Thank you. We appreciate your cooperation.

RADAR

- Accuracy: 5 - 10 milliradians in current FAA beacon radars is replaced by 3 milliradian ASR-9 radar.
- Update Interval: 2.4 seconds in current system with ASR-9 radar will be used in the 3400 ft simulation, and 4-5 seconds with ASR-9 radar will be used in the 4300 ft simulations.

CONTROLLER DISPLAYS

- Sony 20x20-inch high resolution color display
- Utilizes 2000 lines resolution television raster scan technology
- Display scale is be expanded in the area between the runways to provide the controller with an improved capability to detect aircraft movement away from the runway centerline extended.
- The NTZ is outlined with a red border.
- Extended runway centerlines are displayed as dashed white lines.
- The dash and the space between the dash are scaled to represent 1 nautical mile.

CONTROLLER DISPLAYS

(continued)

- The Controller Alert Zone is outlined with a yellow border.
- Lines to delineate 200 foot deviations from the ILS localizer course are displayed as solid light blue lines.
- Aircraft targets and data blocks are presented in green.
- When a potential NTZ entry is detected, the aircraft target and data block will change to yellow and an aural warning will sound.
- When an aircraft has entered the NTZ, the aircraft target and data block will change to red.

TRAFFIC SCENARIO DESCRIPTION

- Simulated traffic will arrive at a rate to provide a maximum throughput rate.
- The NSSF simulation targets closely model actual aircraft and pilot performance.
- At the NSSF, the pseudopilot enters the controller's instruction to the appropriate aircraft, causing the simulated aircraft to alter course.
- The flight simulators assume the configuration of aircraft flying the localizer.
- The flight simulators and NSSF pilots are in voice communications with the controllers.
- A local controller is incorporated.
- Monitor controllers have override capability.

POST RUN CONTROLLER QUESTIONNAIRE

PHASE: V.c or V.a.1

PARTICIPANT CODE _____

DATE _____

PARTNER'S CODE _____

TIME _____

RUN NUMBER _____

RUNWAY _____

PLEASE FILL OUT THIS BRIEF QUESTIONNAIRE ON THE RUN YOU HAVE JUST COMPLETED.

1. Rate your level of activity required during the past hour.

1	2	3	4	5	6	7
Minimal			Moderate			Intense

2. How well were you able to control the traffic using the high resolution displays?

1	2	3	4	5	6	7
Minimal			Moderate			Intense

3. Rate the level of stress experienced during the past hour.

1	2	3	4	5	6	7
Minimal			Moderate			Intense

4. In each of the approach blunders presented, do you think that you had adequate time to break-out an endangered aircraft?

Yes ___ No ___

If "NO", please explain:

5. Please describe any unusual occurrences from the last hour. Please note any unusually long delays or incorrect pilot responses.

6. Please rate the session you have just completed. Choose the one response that best describes your workload level based upon the mental effort and the slant range miss distances (SRMD) between blundering and nonblundering aircraft.

Large slant range miss distances (SRMD) are greater than 1 nm, adequate SRMD are greater than 500 ft but less than 1 nm, close conflicts are less than 500 ft.

1. Minimal mental effort is required and large SRMD are easily attainable.
2. Low mental effort is required and adequate SRMD are attainable.
3. Acceptable mental effort is required to maintain adequate SRMD.
4. Moderately high mental effort is required to maintain adequate SRMD.
5. High mental effort is required to maintain adequate SRMD.
6. Maximum mental effort is required to maintain adequate SRMD.
7. Maximum mental effort is required to keep the number of close conflicts to a minimum.
8. Maximum mental effort is required to keep the number of close conflicts to a moderate level.
9. Intense mental effort is required and numerous close conflicts occur.
10. Close conflicts cannot be prevented.

**Appendix F Controller Biographical Questionnaire
and Informed 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 completion of the project.

Date: _____

1. How many years of experience do you have as an air traffic controller? _____
2. How many years of experience have 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."

VITA

TERENCE J. FISCHER

Personal

Birthdate: November 9, 1959

Education

B.S.E., Systems Engineering (Human Factors Option), Wright State University, 1985

M.S., Industrial and Systems Engineering (Human Factors Option), Virginia Polytechnic Institute and State University, 1991

Thesis Title: Evaluation of Blunder Detection by Air Traffic Controllers Using Two Different Display Types.

E.I.T., New Jersey Board of Professional Engineers

Professional Experience Summary

More than 9 years experience analyzing human performance and man/machine interaction for the DOD, DOT, FAA, and commercial systems with responsibilities that have included task management, contract monitoring, experimental supervision, proposal and report writing, and data analysis.

Group Engineer, CTA INCORPORATED, 7/89 to Present

Currently Deputy Group Manager of the Simulation Group on the Communications, Navigation, Surveillance, and Landing Aids (CNSLA) contract to the FAA ACD-340 branch. Responsibilities include task management on the Air Traffic Control Simulation, Data Link Simulation, and the Terminal Concepts and Studies tasks. Duties have included program planning, staff selection, staff supervision, experimental supervision, coordination of hardware and software integration, report development and data analysis.

Human Factors Engineer, KETRON INCORPORATED, 7/88 to 4/89

Responsible for the design of studies analyzing minimum visibility requirements of traffic control devices sponsored by the Federal Highway Administration (FHWA). Responsibilities included stimulus development and experimental supervision. Additional efforts included the writing of various technical proposals for the FHWA and the Pennsylvania Department of Transportation.

Forensic Engineer, George Widas and Associates, 4/88 to 7/88

Performed engineering analyses of vehicular accidents, construction zone safety measures, product safety and personal injury accidents. Developed reports based upon the cited analyses for presentation as evidence in civil litigation cases.

Human Factors Engineer, ESSEX CORPORATION, 1/88 to 4/88

Monitored the development of the AERP prototype chemical warfare protection apparel for pilots) for the NADC 6025 branch. Responsible for the review and analysis of CDRLs and ECPs which directly and indirectly impacted US Navy helicopter crew performance and egress.

Human Factors Research Assistant, Virginia Polytechnic Institute and State University, 9/86 to 12/87

Assisted in experimentation examining driving strategies on roadways of various geometries and traffic densities to determine the attentional requirements of in-vehicle computer generated moving map display systems. Additional work was performed to determine the subjective and objective attentional demands of different roadway geometries. Performed real-time data collection and analysis of driver eye fixations and driver performance measures.

Human Factors Engineer, SRL INCORPORATED, 3/85 to 9/86

Conducted research on pilot training in an Air Force F-16 simulator analyzing the effects of simulator fidelity on pilot skill acquisition. Performed real-time data collection and data analysis on pilot control as well as secondary measures of task workload.

Quality Assurance Assistant, USAFLC MAQ, 1/83 to 1/85

Responsible for the development of a computerized system for tracking foreign object damage to military aircraft and assisted in the development of quality assurance directives for the Air Force Logistics Centers.

Professional Associations

Human Factors Society, member;

President, Wright State U. Student Chapter, 83-84.

Member, Virginia Tech Student Chapter, 86-87.

Transportation Research Board, member.

Society of Automotive Engineers, member.

American Society of Safety Engineers, member.

Alpha Pi Mu, Industrial Engineering Honor Society.

Publications

Fischer, T., Yastrop, G., Startzel-Dehel, B., Luongo, R., Evaluation of Triple Simultaneous Parallel ILS Approaches Spaced 4300 Feet Apart-Phase IV.a, FAA Technical Center, Atlantic City, New Jersey, DOT/FAA/CT-91/6, September, 1991.

Berkowitz, J., Roske-Hofstrand, R., Lee, A, and Fischer, T. Measurement of the Effects of Data Link Technology in Air Traffic Control Simulations, Technical Report prepared for FAA Technical Center Airborne Collision Avoidance and Data Systems Branch ACD-320, May, 1991.

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Fischer, T., Yastrop, G., Startzel-Dehel, B., Simulation of Quadruple Simultaneous Parallel ILS Approaches at D/FW - Phase III, FAA Technical Center, Atlantic City, New Jersey, DOT/FAA/CT-90/15, August, 1990.

Shochet, E. Dority, R., Fischer, T., Yastrop, G., Results of Real-Time Simulations of Triple and Quadruple Approaches at Dallas/Fort Worth, Proceedings of the 35th Annual Air Traffic Control Association Meeting, Boston, MA., September, 1990.

Fischer, T., Simulation of Triple Simultaneous ILS Approaches, Proceedings of the Sixth Annual Aviation Psychology Symposium, Columbus, Ohio, May 1991.

Visual Adaptation of the Driver to High Demand Driving Situations While Navigating with an In-Car Navigation System., Wierwille, W., Hulse, M., Fischer, T., Dingus, T., 3rd International Conference on Vision in Vehicles, Auschen, Germany, September 1989.

Staplin, L., Knoebel, K., Fischer, T., Gilfillan, D., Grimm, C., Effectiveness of Current Sanctions Against Habitual Offenders, PADOT Project No. 86-16, March, 1989.

Wierwille, W., Hulse, M., Fischer, T., Dingus, T., Effects of Variations in Driving Task Attentional Demand on In-Car Navigation System Usage, VA Tech IEOR Dept. Report No. 87-02, September 1987.

The Effects of Simulator Delays on the Acquisition of Flight Control Skills, Fischer, T., Riccio, G., McMillan, G., Proceedings of the 10th Psychology in the DoD Symposium, Colorado Springs, CO, April 1986.