NASA Contractor Report 191549, Volume 1

PARALLEL RUNWAY REQUIREMENT ANALYSIS STUDY

Volume 1 - The Analysis

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Contract NAS1-18027
December 1993

NASA

National Aeronautics and
Space Administration

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ACKNOWLEDGEMENTS

The author is indebted to Ken Chun (BCS) for building the simulation model, and Rick Wray (BCAG) for writing subsections 9.2 and 9.3.

1.0 SUMMARY

The correlation of increased flight delays with the level of aviation activity is well recognized. A main contributor to these flight delays has been the capacity of airports. Though new airport and runway construction would significantly increase airport capacity, few programs of this type are currently underway, let alone planned, because of the high cost associated with such endeavors. Therefore, it is necessary to achieve the most efficient and cost effective use of existing fixed airport resources through better planning and control of traffic flows. In fact, during the past few years the FAA has initiated such an airport capacity program designed to provide additional capacity at existing airports. Some of the improvements that that program has generated thus far have been based on new Air Traffic Control procedures, terminal automation, additional Instrument Landing Systems, improved controller display aids, and improved utilization of multiple runways/Instrument Meteorological Conditions (IMC) approach procedures.

A useful element to understanding potential operational capacity enhancements at high demand airports has been the development and use of an analysis tool called *The PLAND_BLUNDER (PLB) Simulation Model*. The objective for building this simulation was to develop a parametric model that could be used for analysis in determining the minimum safety level of parallel runway operations for various parameters representing the airplane, navigation, surveillance, and ATC system performance. This simulation is useful as: 1) a quick and economical evaluation of existing environments that are experiencing IMC delays, 2) an efficient way to study and validate proposed procedure modifications, 3) an aid in evaluating requirements for new airports or new runways on an old airports, 4) a simple, parametric investigation of a wide range of issues and approaches, 5) an ability to trade-off air and ground technology and procedures contributions, and 6) a way of considering probable blunder mechanisms and range of blunder scenarios.

This study describes the steps of building the simulation and considers the input parameters, assumptions and limitations, and available outputs. Validation results and sensitivity analysis are addressed as well as outlining some IMC and Visual Meteorological Conditions (VMC) approaches to parallel runways. Also, present and future applicable technologies (e.g., Digital Autoland Systems, Traffic Collision and Avoidance System II, Enhanced Situational Awareness System, Global Positioning Systems for Landing, etc.) are assessed and recommendations made.

2.0 INTRODUCTION

2.1 BACKGROUND

The steady increase in the number and duration of flight delays has become a major aviation problem in recent years. One of the primary reasons for this increase has been the inability of airports to keep pace with traffic growth. Federal Aviation Administration (FAA) Airline Delay Statistics for total delay per air carrier flights from 1982 to 1989 (*Figure 1*) indicate that in 1989 alone about 1,600,000 hours worth of delay time occurred. Hence, from this data the assumption can be made that 3,000 hours (or the approximate time utilized by an airplane per year) results in 530 airplanes (or 12 percent in the United States - US Air Carrier Fleet) being required to absorb the delay.

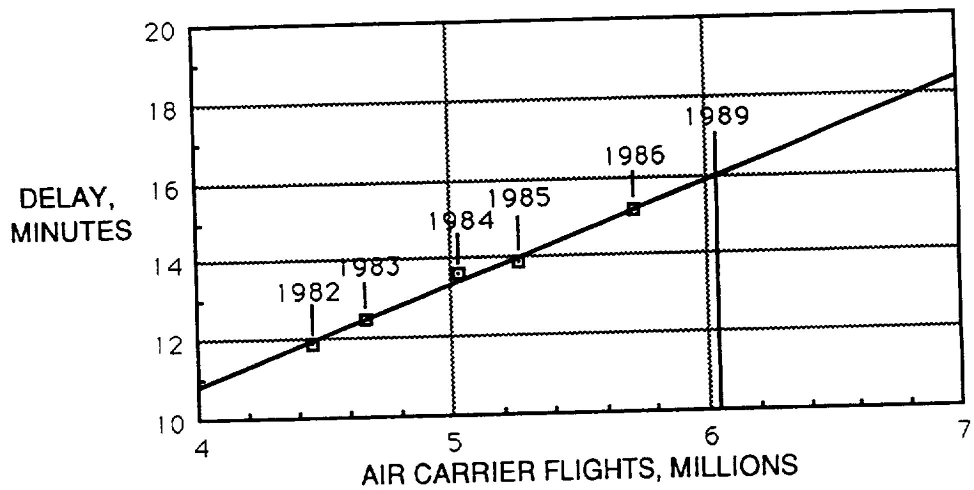


Figure 1. Total Delay Per Air Carrier Flight [1]

Forecasts suggest that, in the absence of capacity improvements, delay in the system will continue to grow (*Table 1*). In 1988, 21 airports each exceeded 20,000 hours of airline flight delays. Assuming no improvements in airport capacity are made, 41 airports are forecast to each exceed 20,000 hours of airline flight delays by 1998. With no improvements in airport and airspace capacity, four airports are forecast to each exceed 1000,000 hours of airline aircraft delays by 1998 as opposed to one airport in 1988. Likewise, with no capacity improvements, 15 airports are forecast to have 50,000 to 100,000 hours of airline aircraft delays by 1998, as opposed to just five today.

In addition, Boeing Commercial Airplane Group (BCAG) published a Current Market Outlook (February 1992) in which it was predicted that the number of US domestic air carrier flights would increase 50% between 1989 and 2010 (*Figure 2*). These factors raise the question of whether this growth can be accommodated by future capacity improvement plans of US airports?

Table 1. 1988 Actual and 1998 Forecast Air Carrier Delay Hours [2]

ANNUAL AIRCRAFT DELAY	1988	1998
GREATER THAN 100,000 HOURS	ORD	ORD, DFW, ATL, DEN
50,000 TO 99,999 HOURS	ATL, DFW, LAX, EWR DEN	15 AIRPORTS
20,000 TO 49,999 HOURS	15 AIRPORTS	22 AIRPORTS

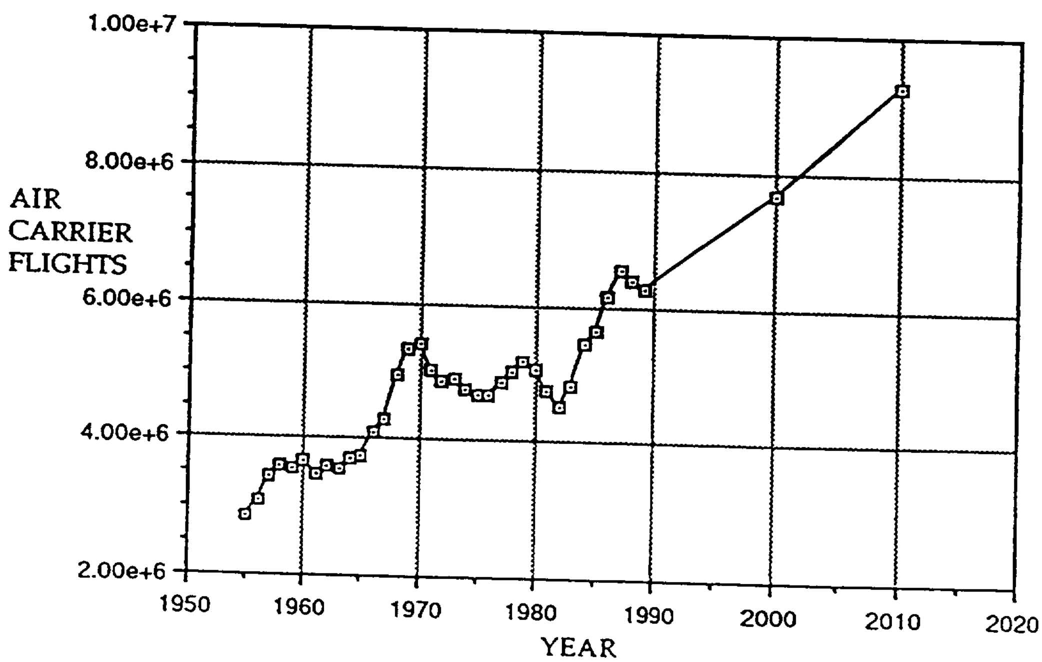


Figure 2. US Domestic Air Carrier Flight

A main contributor to these flight delays has been the capacity of airports. Though new airport and runway construction would significantly increase airport capacity, few programs of this type are currently underway, let alone planned. Improved procedures and new technology are being studied to maximize the use of existing fixed airport resources. In addition, initiating some modest changes in airport geometry would also help in better accommodating traffic. Therefore with regard to this alternate approach, the FAA has initiated during the past few years an airport capacity program designed to provide additional capacity at existing airports. Some of the improvements include new Air Traffic Control (ATC) procedures, terminal automation, additional instrument landing systems, improved controller display aids, and improved utilization of multiple runways/Instrument Meterological Conditions (IMC) approach procedures developed via:

1. Close-spaced Independent Parallel Approaches
2. Close-spaced Dependent Parallel Approaches
3. Independent Non-Parallel Approaches
4. Dependent Non-Parallel Approaches
5. Triple and Quadruple Approaches
6. Improved Longitudinal Separation
7. Flight Management Systems (FMS) Approaches

This study focuses on the latter improvement by addressing the potential for increasing capacity through the use of independent parallel approaches under IMC.

2.2 HISTORY OF SIMULTANEOUS PARALLEL APPROACHES

The concepts for independent parallel IMC approaches date to the 1950s. The basic premise is that aircraft can approach parallel runways along parallel Instrument Landing System (ILS) courses (*Figure* 3).

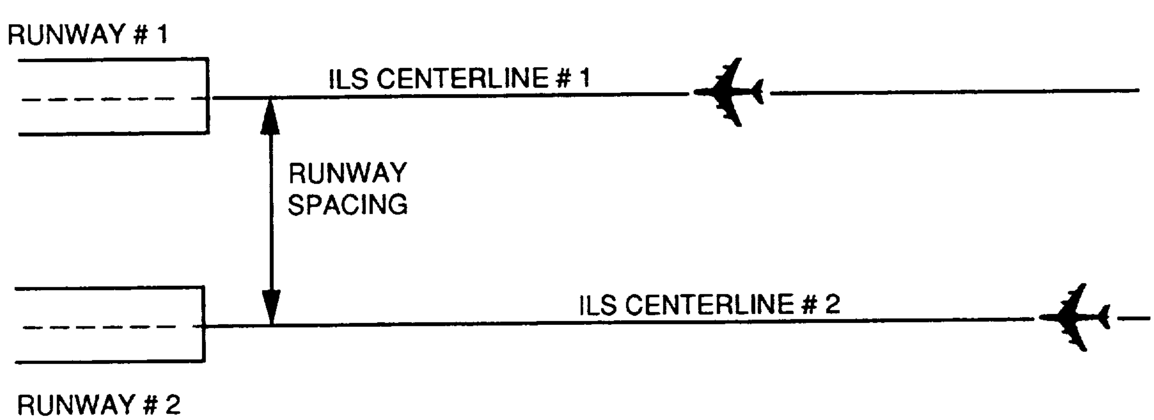


Figure 3. Parallel Runway Approaches

The procedures for parallel approaches have evolved over a long period of time (paragraphs 2.2.1 and 2.2.2). When appropriate clearance is given from the controller, pilots in Visual Meteorological Conditions (VMC) can provide their own separation visually during a visual approach. In such an environment, simultaneous independent parallel approaches can be made to runways spaced as close as 700 ft (centerline to centerline). However, under IMC the controller must provide radar monitoring to assure separation because of pilot problems with detection and avoidance during an instrument approach. In this case, simultaneous independent parallel approaches can be made to runways as close as either 4,300 or 3,400 ft, depending on the ground equipment. There are occasions when instrument approaches are performed during VMC or marginal VMC. However, for the purposes of this report, it will be assumed that visual approaches with pilot visual separation are performed during VMC (VMC parallel approaches) and that the instrument approaches with radar separation are performed during IMC (IMC parallel approaches).

2.2.1 SPACING FOR INDEPENDENT PARALLEL IMC APPROACHES

Prior to 1962, J.F. Kennedy and Washington-Dulles airports were the only two airports operating independent parallel approaches with a 6,200-foot spacing limit. In the early 1960s the FAA sponsored several studies for developing independent (simultaneous) parallel IMC approaches requirements which were predicated on the use of an ILS for lateral navigational guidance. These studies included some field data collection and theoretical analyses, as well as a field flight test program at Chicago O'Hare. This latter test was intended to verify the parameters of pilot and controller performance in the event of a blunder by one aircraft on parallel approach toward an aircraft on the adjacent approach.

At the conclusion of these studies, independent (simultaneous) parallel IMC approaches were approved for use with a 5,000-foot spacing limit. This requirement applied to a number of runway pairs at major airports (*Table* 2).

However, independent approaches could only be conducted when several requirements were satisfied: the approaches had to be straight in, turn-on to localizer had to be separated in altitude by at least 1,000 ft between approach courses, separate parallel approach controllers had to monitor the approaches once the 1,000-foot vertical separation was lost inside the point of glide slope intercept, and the parallel monitor had to have a direct communications channel for immediate access to the pilot. The separate parallel monitor controllers insured that if either aircraft exited a designated Normal Operating Zone (NOZ) and entered the No Transgression Zone (NTZ), then any threatened aircraft on the other approach course could be vectored away. The NOZ (*Figure 4*) was 1,500 ft with a 5,000-foot spacing and the NTZ was 2,000 ft.

Table 2. Simultaneous(Independent)Parallel Approaches Approved at 5,000 ft Spacing

Initial Approval		
	O'Hare	6,510 ft 5,400 ft
	Los Angles	5,280 ft
	Atlanta	5,450 ft
	Miami	5,100 ft
Later Additions		
	Washington-Dulles	6,500 ft
	Dallas	6,300 ft

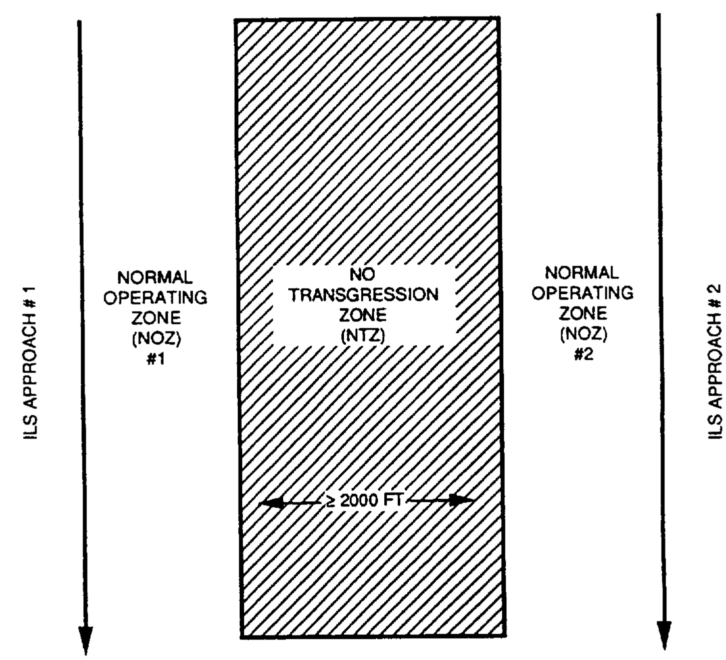


Figure 4. Parallel Runway Monitoring Zones

With the advent of wide body commercial jets in the late 1960s, hazards from the wake vortices created by these larger aircraft were identified. This identification led to the 3 nmi in-trail IFR separation requirement being increased for some aircraft pairs (i.e., aircraft in-trail to the same runway and aircraft on parallel approaches to runways spaced less than 2,500 ft apart). However, with this change came a decrease in available airport capacity for single runway approaches, as well as a reduction in the capability of efficiently utilizing runways spaced less than 2,500 ft apart. These added problems contained in the initial solution generated the impetus to find ways of regaining the airport capacity lost because of wake vortex hazards. The FAA initiated programs to develop systems which would permit reduction of the in-trail spacing requirements under some or all operating conditions.

An effort to reduce the 5,000-foot minimum runway spacing requirement was stated as a goal of the Air Traffic Control Advisory Committee in its 1969 Report. The minimum spacing requirement was reduced to 4,300 ft by the FAA in 1974 following successful data collection and analysis supported by MITRE and Reslab, Inc. The data collection showed that real-world performance on parallel arrivals was better than previously estimated. Hence, it was surmised that the same levels of safety could be achieved without a significant increase in the false-alarm rate at the reduced runway separation. The principal beneficiaries of this change were the Los Angeles and Atlanta airports, where reduced runway spacing could be applied to some special configurations or when a runway was closed. (This evolution of changes in parallel runway spacing is shown in *Figure 5*.) MITRE continued to analyze for further reductions in spacing. A BCAG parallel approach model was developed at this time which pointed to the need for improved radar surveillance to support further separation reductions [3].

Although these reductions required advanced equipment (e.g., a high quality, special purpose radar system), it was assumed that reductions in the minimum spacing were still feasible if lateral and/or longitudinal separations between aircraft on the two approaches were adequately maintained.

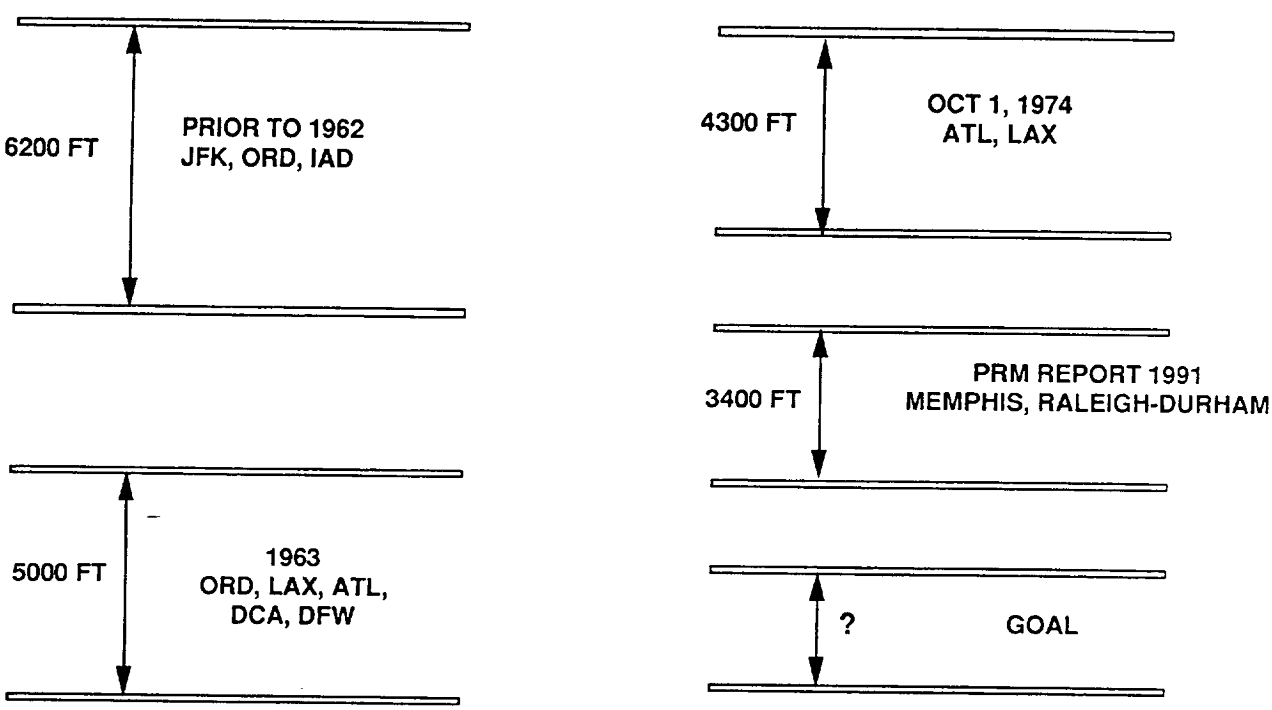


Figure 5. Evolution of Parallel Runway Spacing

2.2.2 SPACING FOR DEPENDENT PARALLEL APPROACHES

A dependent approach procedure must be employed whenever there is inadequate runway separation for independent IMC approaches. Prior to 1978, this meant that arrivals to different runways had to be separated by a minimum of 3 nmi at less than a 2,500-foot separation with the wake vortex standards (3/4/5/6 nmi) being applied as though the aircraft were approaching a single runway.

In 1978 the FAA provided for parallel dependent approaches with a 2-nmi diagonal separation between aircraft on alternating approaches wherever runways were separated by 3,000 ft or more (*Figure 6*). With this procedure, aircraft approach parallel runways on parallel courses, while consecutive aircraft alternate between the two approaches with normal in-trail separations applying between arrivals to the same runway.

This separation permits easier handling of blunder situations when compared to the requirements for independent approaches because it eases controller monitoring requirements and reduces runway spacing.

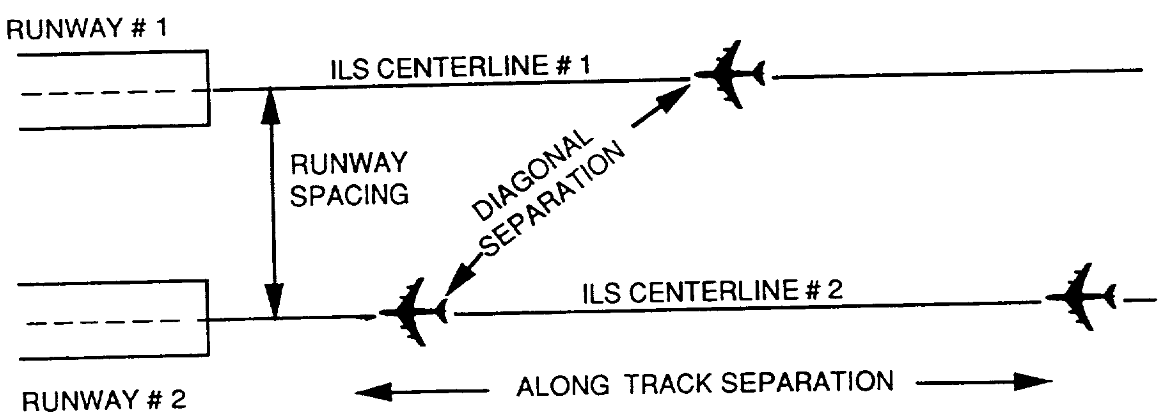


Figure 6. Dependent Parallel Geometry

2.3 CURRENT PARALLEL APPROACH SPACING

Currently, a diagonal separation of 1.5 nmi is required for runways spaced between 2,500 ft and 4,300 ft. When there are any runways spaced below 2,500 ft with a diagonal separation, then wake vortex considerations apply between the runways which limit that runway pair to the arrival spacings of a single IMC arrival runway. Current US procedures for parallel IMC approaches are briefly summarized in *Table 3.*

Table 3. Runway Spacing for IMC Approaches to Parallel Runways Without PRM Implementation

RUNWAY SPACING	TYPE OF APPROACH	SEPARATION REQUIREMENTS BETWEEN AIRCRAFT TO TWO APPROACHES
>700-2,500 ft	Single Runway	3, 4, 5, 6, nmi[1]
2,500-4,300 ft	Dependent Parallel	3 nmi (1.5 nmi diagonal distance)
>4,300 ft[2]	Independent Parallel	None

1 *Specific value determined by aircraft pair, and governed by wake vortex hazards.*
2 *Present system allows IMC approach to parallel runways at 4,300 ft or greater spacing, however Precision Runway Monitor System with new radar and displays enables IMC approach to parallel runways at 3,400 ft or greater.*

2.4 CURRENT RESEARCH ACTIVITIES FOR CAPACITY INCREASE THROUGH CLOSE-SPACED PARALLEL RUNWAYS

As previously indicated, the current criteria for IMC independent approaches to parallel runways is that the runways must be separated by 4,300 ft or more. This standard has been established based on the surveillance rate and accuracy of the Airport Surveillance Radars (ASR) in conjunction with the capabilities of the terminal Advanced Radar Tracking System (ARTS).

The FAA has currently completed developing two new radar designs that could increase the capacity of a dozen airports by about 30% under adverse weather conditions. The airports targeted for employing these radars are those with parallel runways that are less than 4,300 ft apart. These radars could also enable other airports to construct parallel runways with less than a 4,300-foot separation.

Precision Runway Monitor (PRM) Program is designed to apply an improved radar to alleviate delays created during IMC. IMC creates airport slow downs wherein pilots and controllers cannot maintain visual separation such that they must rely on radar. The PRM program is intended to provide the radar and display hardware and associated procedures for controllers and pilots to yield runway acceptance and departure rates that more closely approximate those in visual conditions. Both a status report on the PRM program and a *possible* implementation timetable are currently available from the FAA. It has been estimated that when these techniques are introduced at the 12 airports in the study that total delays of more than 255,000 hours per year could be eliminated [4].

The most critical factor affecting airports when in adverse weather conditions is the time required in which to detect a potentially dangerous aircraft deviation from the ILS localizer centerline and take corrective action. Therefore, airports with close spaced approaches require staggered approaches. This constraint is imposed by the rotation rate of current ASR antennas that provide an update of aircraft position only once every 4-5 sec. For independent operations, two or more such updates may be needed for a controller to spot a potentially hazardous situation. Two evaluated techniques that could address this problem are:

1. Installation of back-to-back antenna dishes on a conventional ASR that can cut update time in half (less than 2.5 sec). (A demonstration system that has been built by MIT's Lincoln Laboratory.)

2. New electronically scanned radar antenna that can provide aircraft position updates every .5 sec, or even faster if desired. (An experimental system that has been developed by Allied-Signal Aerospace Co.)

Both these radars use monopulse techniques to achieve a five-fold increase in the accuracy for determining aircraft azimuth positions .1 mr versus .5 mr. Additionally, each radar is outfitted with two large 20x20 in, high-resolution color displays to enable each of the two controllers to monitor positions of aircraft during final approach. The display shows a 2,000-foot wide "No Transgression Zone" in red and aircraft "blips" carry alphanumeric identity tags. Each radar has a special computer designed to automatically detect an aircraft deviating from the localizer centerline at a rate that could cause it to penetrate the NTZ and alert the controller.

2.5 STUDY OBJECTIVE AND GOALS

This requirement analysis will evaluate air and ground system requirements that would enable further reductions in lateral separations, while maintaining or improving operational safety, for close-spaced independent arrival operations in the future. Aircraft navigation and flight technical error are important factors. Hence, Communication, Navigation and Surveillance (CNS); controller; pilot; and airplane response times as well as other performance issues must be thoroughly examined. The following is a list of study subtasks that were performed in developing this report:

Subtask 1 Review earlier Boeing, MITRE, and other industry collision risk modeling work for applicability to the current effort, and incorporate findings of PRM effort.

Subtask 2 Review existing simulation models and/or develop new simulation models. (Any new models developed will be accompanied with detailed user documentation to be included in the deliverable.)

Subtask 3 Develop an operational analysis of close-spaced VMC. (Compare the IMC modeling in Subtask 1 with the VMC operations and include an estimated navigation/pilot/controller VMC operational performance as well as identify the key performance areas in which IMC and VMC operations differ.)

Subtask 4. Establish for the final approach segment guidance accuracies by a parametric model and analysis.

Subtask 5 Examine the alternate technologies available to satisfy the requirements developed in Subtask 4.

Subtask 6 Examine the benefits of close-spaced arrival operation at US air carrier airfields. (Identify improved capacity and reduced delays for the affected airport configurations.)

3.0 SYMBOLS AND ABBREVIATIONS

A/C	aircraft
ADI	Attitude Director Indicator
AFDS	Autopilot Flight Director System
AGL	Above Ground Level
A/P	autopilot
APP	approach
ARTS	Automated Radar Tracking System
ASR	Airport Surveillance Radars
ATC	Air Traffic Control
ATCT	Air Traffic Control Tower
ATIS	Automated Terminal Information Service
BCAG	Boeing Commercial Airplane Group
CDI	Course Deviation Indicator
CDTI	Cockpit Display Traffic Information
CMD	command
CNS	Communication, Navigation and Surveillance
CPA	Closest Point of Approach
CPD	Cumulative Probability Distribution
CRT	Cathode Ray Tube
CWS	Control Wheel Steering
deg	degrees
DH	Decision Height
EADI	Electronic Attitude Display Indicator
EFIS	Electronic Flight Instrument System
ESAS	Enhanced Situational Awareness System
FAA	Federal Aviation Administration
FCC	Flight Control Computer
FD	Flight Director
FMS	Flight Management System
ft	feet
FTE	Flight Technical Error
GPS	Global Positioning System
GPSL	GPS for Landing
HUD	Head Up Display
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
kn	knots
LOC	localizer
MCP	Mode Control Panel
MEAN	average
MHz	Mega Hertz
mi	miles
MIT	Massachusetts Institute of Technology

MLS	Microwave Landing System
mr	milliradians
nmi	nautical miles
NOZ	Normal Operating Zone
NTZ	No Transgression Zone
PLB	PLAND_BLUNDER
PRM	Precision Runway Monitor
RA	Resolution Advisory
RMS	Root Mean Square
RNAV	Area Navigation
SD	Standard Deviation
sec	seconds
TAE	Total Azimuth Error
TCAS	Traffic Alert and Collision Avoidance System
TRACON	Terminal Radar Approach Control
UHF	Ultra High Frequency
US	United States
VHF	Very High Frequency
VMC	Visual Meteorological Conditions

4.0 PARALLEL RUNWAYS APPROACH PROCEDURES AND REQUIREMENTS

This section outlines procedures and requirements for independent and dependent Instrument Landing System (ILS) approaches to parallel runways and visual approaches to close-spaced parallel runways.

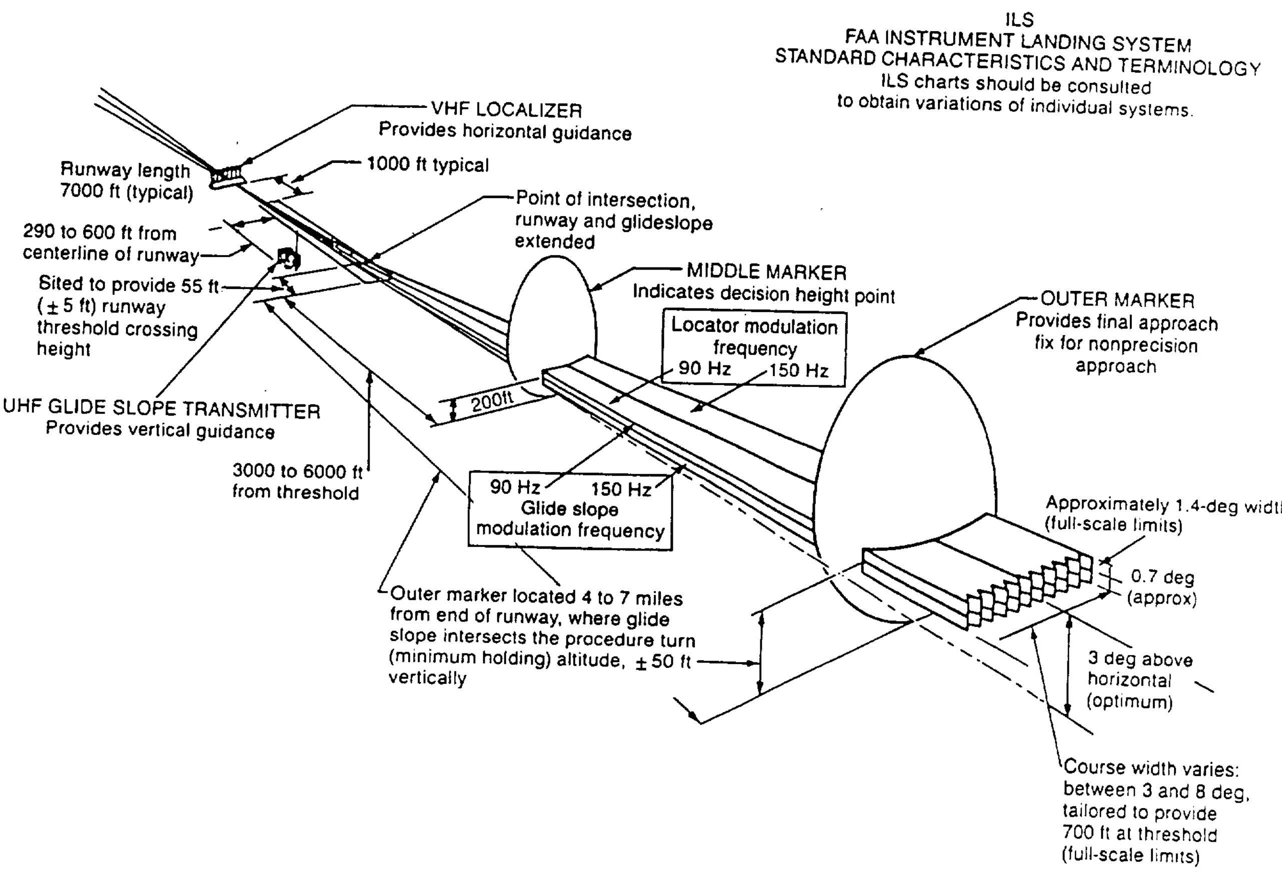
4.1 INSTRUMENT LANDING SYSTEMS FUNCTION

A variety of instrument approach procedures have been developed to guide appropriately equipped aircraft safely to the vicinity of the runway during IMC. The most precise procedure commonly employed is based on use of the ILS. The ILS is a system which provides the horizontal and vertical guidance information required to enable a pilot (or autopilot) to accurately position an airplane on a defined approach path to an airport runway. The ILS consists of two component systems: the localizer which provides the horizontal guidance that aligns the airplane with the runway, and the glideslope which provides the vertical guidance that establishes a safe descent angle for the airplane approach to the runway surface. Furthermore, the ILS equipment consists of ground and onboard airplane equipment.

4.1.1 ILS GROUND EQUIPMENT

The ILS ground equipment consists of highly directional transmitting systems for the localizer and glideslope (*Figure 7*). The localizer transmitter and antenna array are located at the upwind end of the runway (*Figure 7*). The localizer provides lateral course guidance out to a distance of 18 nmi from the approach end of the runway and to 10° on either side of the approach course. Coverage is provided to 35° on either side of the approach course at 10 nmi. Localizer information is unreliable from 35° to 90° on either side of the localizer course. If the ground facility provides a usable localizer *back course*, the coverage is the same as the front course. However, the back course signal is reversed with respect to the front course unless the airplane installation includes a back course switch that reverses the left/right indicator. The localizer signal can be disturbed by departing airplanes overflying the antenna, taxiing airplanes, airplanes parked close to the approach runway, or airport structures (e.g., blast fences or buildings that reflect some of the localizer energy).

The glideslope transmitter and antenna are located approximately 1,000 feet past the approach end of the runway and about 500 feet from the runway center line (*Figure 7*). The glideslope provides vertical guidance out to a distance of 10 nmi either side of approach course center line. The projected glide path is typically 3 deg above the horizon and 1.4 deg wide (0.7 deg above and below the center line). A number of false glideslope courses exist at multiples of the approach angle (i.e., 6 deg, 9 deg, ...), but these are identified by reversed indications and/or flags along with the steepness of the descent angle. The glideslope does not provide back course guidance. The stability of the glideslope beam can be affected by airplanes ahead on the approach course or by vehicles and/or moving equipment in front of the approach end of the runway. At any ILS equipped airport, the localizer and glideslope transmitters operate on designated pairs: VHF signals of 108.10 to 111.95 MHz for localizer and UHF signals of 329.30 to 335.00 MHz for glideslope. There are 40 ILS frequency pairs assigned to various ground facilities in a pattern that minimizes the possibility of receiving two ILS signals at one time. The ILS ground facility is identified by a three letter coded identification signal transmitted on the localizer frequency.



-Figure 7. ILS Ground Equipment - Localizer and Glideslope

A typical ILS also includes a third VHF signal that indicates passage of the outer, middle, and, in some instances, inner markers at published distances from the runway threshold. An approach plate developed by the FAA describes each instrument approach to a given runway.

4.1.2 ILS ONBOARD EQUIPMENT

An aircraft executing an instrument approach is required to have an ILS receiver that informs the pilot of how accurately the aircraft is following the prescribed approach course. Three ILS receivers and one control panel are installed on a typical modern airplane. All receiver operations are identical. Airborne ILS installations range from the very simple Course Deviation Indicator (CDI) (which indicate whether the aircraft is left, right, above, or below the prescribed course) to sophisticated avionics equipment (e.g., Electronic Flight Instrument System - EFIS - which couples with Autopilot Flight Director Systems - AFDS - and FMS to provide automatic flight control down to Decision Height - DH).

The DH is the altitude (varying from 200 feet above ground level for a Cat I ILS to ground level for a Cat IIIC ILS) from which the pilot must be able to visually sight the landing runway. This height primarily depends on both the sophistication of the installed ILS transmitters and the airborne equipment. IMC approach procedures require that if the pilot is not able to spot the runway at the DH, or if the aircraft is so misaligned that the pilot would not be able to adequately correct before touchdown, then a missed approach must be executed.

4.1.3 ILS APPROACH PROCEDURES

The ILS approach course runs along a vector extending from the runway threshold upward at approximately a 3 deg angle relative to the ground. ILS approach procedures typically require that radar controllers vector aircraft to intercept the localizer signal (typically 5 to 15 mi from the runway threshold) after which the pilot is to stabilize the aircraft on the localizer beam prior to intersecting the outer marker (which is typically located about 5 nmi from runway threshold) and to proceed with descent when the glideslope signal is detected.

4.2 INSTRUMENT APPROACH PROCEDURES TO PARALLEL RUNWAYS

The need to reduce the impact of weather on parallel approach operations led to several studies that examined radar update rate, surveillance accuracy, and aircraft performance on parallel approaches. These studies analyzed data collected from several airports to justify reductions in minimum runway spacing from 5,000 ft in 1963 to 4,300 ft in 1974.

The surveillance system is a critical element in determining required runway spacing. The current terminal area system provides an azimuthal accuracy of about 5 mr and update period of 4 sec (or 5 mr/4 sec). A MITRE Corporation study in 1981 that examined the potential benefits of improved surveillance accuracy and update rate concluded that the minimum runway spacing for independent parallel approaches could be further reduced [3]. The conclusions of that study are summarized in *Table 4*.

Table 4. Minimum Runway Separation Summary

RMS AZIMUTH Accuracy (Milliradians)	Update Rate (Seconds)			
	4	2	1	0.5
5	4,300*	4,100	3,800	3,600
4	4,000	3,800	3,500	3,400
3	3,700	3,600	3,300	3,200
2	3,500	3,400	3,100	3,000
1	3,400	3,200	3,000	2,900

* Current Airport Surveillance Radar Performance

Table 4 indicates that an accurate special purpose surveillance system (1 mr/1 s) could support spacing as low as 3,000 ft. Azimuth accuracy together with update rates were considered the key surveillance parameters.

Generally one of three types of procedures are employed for an ILS approach to parallel runways during instrument conditions (depending on the distance between the runways): independent or simultaneous IMC approaches (standard radar and high update radar) and dependent IMC approaches.

4.2.1 IMC APPROACHES - STANDARD RADAR PROCEDURES

The conditions currently required for conducting simultaneous IMC approaches in conjunction with existing standard radar are described in paragraph 5-126 of FAA Order No. 7110.65H [5] as follows:

1. Parallel runways that are at least 4,300 ft apart.

2. Straight-in landings will be made.

3. An operating ILS, radar, two-way radio communication link.

4. Aircraft must be separated by a minimum of 1,000 ft vertically or a minimum distance of 3 nmi during turn-on to parallel final approaches until established on their respective localizer courses.

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

6. Aircraft established on final approach course are considered separated from aircraft established on an adjacent parallel final approach course provided neither aircraft penetrates the NTZ (a 2,000-foot wide NTZ centered between the two extended runway centerlines).

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

8. Monitor all approaches regardless of weather.

9. When simultaneous IMC approaches are being conducted to parallel runways, consideration should be given to know factors that may in any way affect the safety of the instrument approach phase of flight, such as surface wind direction and velocity, windshear 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.

During simultaneous IMC approaches to parallel runways the following are accomplished by the final controller (who vectors the aircraft with a 1,000-foot altitude buffer to the appropriate ILS course):

1. The pilot has been given and has confirmed the local controller's radio frequency.

2. The pilot has been given and has confirmed ILS runway number, position from a fix on the localizer course, an altitude to maintain until established on the localizer course, and the localizer and glideslope frequencies.

3. The aircraft has intercepted the final approach course at an angle not greater than 30 deg.

Two monitor controllers take over the aircraft monitoring after interception of localizer beam, with one responsible for aircraft on the left runway and the other responsible for aircraft on the right runway. These controllers share the radio channel with the local controller in the event of having to communicate with the aircraft. (The local controller is normally in contact with the aircraft from the final approach fix to the runway.)

The monitor controllers use the same ARTS display since they require interaction with one another. Radar monitoring begins when separation based on the 1,000-foot altitude separation is lost as the higher aircraft begins descending on the glideslope. The monitor controllers are then responsible for keeping their aircraft within their respective NOZ.

Control responsibility routinely remains with the local controller throughout the approach operation. The monitor controllers only act to ensure separation, and normally maintain a passive function requiring no communication with the pilot except during infrequent situations necessitating warning, advisory, or vectoring action. Judicious use of the radio frequency is required since the monitor controllers share their frequency with the local controller.

The radar monitoring will be terminated when one of the following occurs:

1. Visual separation is applied.

2. The aircraft reports the approach lights or runway in sight.

3. The aircraft is 1 mi or less from the runway threshold, if procedurally required and contained in facility directives

Termination of monitoring the aircraft should not be informed to the pilot. (*Figure 8* shows paragraph 5-126 of FAA Order No. 7110.65H [5].)

4.2.2 INDEPENDENT SIMULTANEOUS ILS APPROACHES - HIGH UPDATE RADAR PROCEDURES

In February 1991 the final report of Precision Runway Monitor Demonstration recommended that further reduction in parallel runway spacing for simultaneous approaches can be made if high update radars were used. This recommendation was added to paragraph 5-127 of [5] for simultaneous IMC approaches with high update radar as:

> Authorize simultaneous IMC approaches to parallel runways with centerlines separated by 3,400 to 4,300 feet when precision runway monitors are utilized with a radar update rate of 2.4 seconds or less.

The rest of requirements are similar to the paragraph 5-126 of [5]. *Figure 9* shows paragraph 5-127 of [5].

5–126 SIMULTANEOUS ILS/MLS APPROACHES

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.

Phraseology:
I-L-S RUNWAY (runway number) (left/right).

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

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.

5–126g2 Reference.—Arrival Instructions, paragraph 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 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 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 as necessary to ensure aircraft do not enter the 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) IMMEDIATELY HEADING (degrees), CLIMB AND MAINTAIN (altitude).

2. Instruct aircraft on the adjacent final approach course to alter course to avoid the deviating aircraft when an aircraft is observed penetrating the NTZ.

Phraseology:
TURN (right/left) IMMEDIATELY HEADING (degrees), 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.

i. 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, windshear 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.

5–126 Reference.—Radar Service Termination, paragraph 5–13. Final Approach Course Intersection, paragraph 5–121.

Figure 8. Paragraph 5-126 of FAA Order No. 7110.65H

5–127 SIMULTANEOUS ILS/MLS APPROACHES - HIGH UPDATE RADAR

TERMINAL

a. Authorize simultaneous independent ILS, MLS, or ILS and MLS approaches to parallel runways with centerlines separated by 3,400 to 4,300 feet when precision runway monitors are utilized with a radar update rate of 2.4 seconds or less, and:

1. Straight-in landings will be made.

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

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

c. Inform the aircraft of the ILS/MLS runway number on the initial vector.

Phraseology:

I-L-S RUNWAY (runway number) (left/right).

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

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.

5–127d 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 onto parallel final approach. Provide the minimum applicable radar separation between aircraft on the same final approach course

5–127f 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 no transgression zone (NTZ).

g. Issue the following to an aircraft when assigning a final heading to intercept the final approach course:

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.

5–127g2 Reference.— Arrival Instructions, paragraph 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 I-L-S RUNWAY (number) (left/right) APPROACH.

or

POSITION (number) MILES FROM (fix). TURN (left/right) HEADING (degrees). MAINTAIN (altitude) UNTIL ESTABLISHED ON THE FINAL APPROACH COURSE. CLEARED 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 as necessary to ensure aircraft do not enter the NTZ.

5–127h 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 define the responsibility for providing the minimum applicable longitudinal separation between aircraft on the same final approach course.

5–127h Note 2.— An NTZ at least 2,000 feet wide is established equidistant between extended runway final approach course centerlines and shall be depicted on the monitor display. The primary responsibility for navigation on the final approach course rests with the pilot. Control instructions and information are issued only to ensure that aircraft do not penetrate the NTZ. Pilots are not expected to acknowledge those transmissions unless specifically requested to do so.

5–127h Note 3.— The aircraft is considered the center of the digitized target for that aircraft for the purposes of ensuring an aircraft does not penetrate the NTZ.

1. Instruct the aircraft to return immediately to the correct final approach course when aircraft are observed to overshoot the turn-on or continue on a track which will penetrate the NTZ.

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 THE LOCALIZER/AZIMUTH COURSE.

2. Instruct aircraft on the adjacent final approach course to alter course to avoid the deviating aircraft when an aircraft is observed penetrating the NTZ.

Phraseology:

TURN (left/right) IMMEDIATELY HEADING (degrees), 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 has landed or, in the event of a missed approach, is one-half mile beyond the departure end of the runway.

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.

i. Consideration should be given to known factors that may in any way affect the safety of the instrument approach phase of flight when simultaneous ILS, MLS, or ILS and MLS approaches are being conducted to parallel runways. Factors include but are not limited to wind direction/velocity, wind-shear alerts/reports, severe weather activity. 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 the approach in use.

Figure 9. Paragraph 5-127 of FAA Order No. 7110.65H

4.2.3 DEPENDENT ILS APPROACH PROCEDURES

The IMC procedure in use whenever the runway separation is between 2,500 to 4,300 ft[1] is termed *dependent approaches*. The requirements to be followed when conducting dependent parallel ILS, MLS, or ILS and MLS approaches are:

1. Provide a minimum of a 1,000-foot vertical or a minimum of a 3-mile radar separation between aircraft during turn on.

2. Provide a minimum of a 3-mile radar separation between aircraft on the same localizer course and/or MLS azimuth course.

3. Provide a minimum of a 2-mile radar separation between successive aircraft on adjacent localizer/azimuth courses when the following conditions are met:

    a. Runway centerlines are at least 2,500 ft apart.

    b. Apply this separation standard only after aircraft are established on the parallel final approach courses.

    c. Straight-in landings will be made.

    d. Missed approach procedures do not conflict.

    e. Aircraft are informed that approaches to both runways are in use. (This information may be provided through the Automated Terminal Information Service - ATIS.)

    f. Approach control shall have the interphone capability of communicating directly with the local controller at locations where separation responsibility has not been delegated

Figure 10 shows paragraph 5-125 of [5].

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[1] 3,400 ft for PRM system with high update radar and new displays.

5–125 PARALLEL ILS/MLS APPROACHES

TERMINAL

When conducting parallel ILS, MLS, or ILS and MLS approaches:

a. Provide a minimum of 1,000 feet vertical or a minimum of 3 miles radar separation between aircraft during turn on.

b. Provide a minimum of 2.5 miles radar separation between aircraft within 10 miles of the runway end on the same localizer course and/or MLS azimuth course and comply with paragraph 5–72f.

c. Provide a minimum of 1.5 miles radar separation diagonally between successive aircraft on adjacent localizer/azimuth courses when runway centerlines are at least 2,500 feet but no more than 4,300 feet apart.

5–125c Note.—Applying this procedure does not replace the prescribed minima in 5–125b.

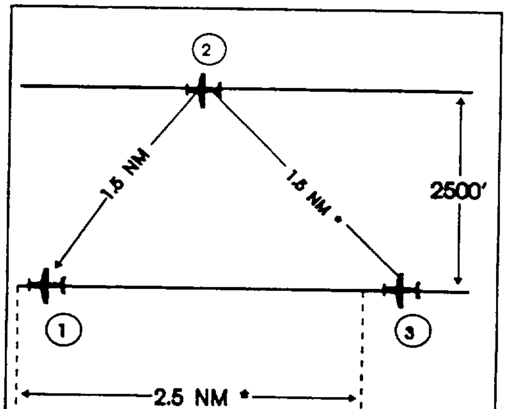

Figure 5–125[1]

In Figure 5–125[1], aircraft 2 is 1.5 miles from aircraft 1, and aircraft 3 is 1.5 miles or more from aircraft 2. •The resultant separation between aircraft 1 and 3 is at least 2.5 miles.

d. Provide a minimum of 2 miles radar separation diagonally between successive aircraft on adjacent localizer/azimuth courses where runway centerlines are more than 4,300 feet but no more than 9,000 feet apart.

5–125d Note.—Applying this procedure does not replace the prescribed minima in 5–125b.

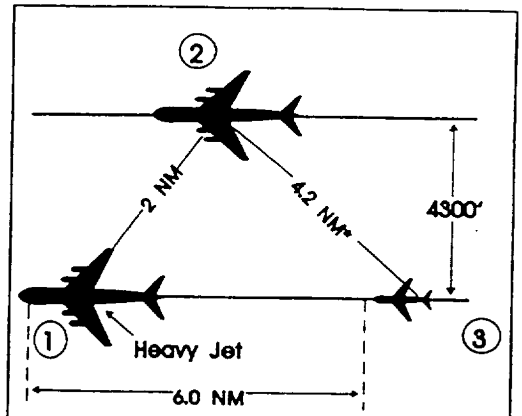

Figure 5–125[2]

In Figure 5–125[2], aircraft 2 is 2 miles from heavy aircraft 1. Aircraft 3 is a small aircraft and is 6 miles from aircraft 1. •The resultant separation between aircraft 2 and 3 is 4.2 miles.

e. The following conditions are required when applying the minimum radar separation on adjacent localizer/azimuth courses allowed in 5–125c or 5–125d:

1. Apply this separation standard only after aircraft are established on the parallel final approach course.

2. Straight-in landings will be made.

3. Missed approach procedures do not conflict.

4. Aircraft are informed that approaches to both runways are in use. This information may be provided through the ATIS.

5. Approach control shall have the interphone capability of communicating directly with the local controller at locations where separation responsibility has not been delegated to the tower.

5–125e5 Note.—The interphone capability is an integral part of this procedure when approach control has the sole separation responsibility.

5–125e5 Reference.—Approach Separation Responsibility, paragraph 5–124; Order 7210.3, Authorization for Separation Services by Towers, paragraph 2–14.

f. 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, windshear 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.

5–125 Reference.—Final Approach Course Intersection, paragraph 5–121.

Figure 10. Paragraph 5-125 of FAA Order No. 7110.65H

4.3 VMC APPROACHES TO PARALLEL RUNWAYS

Several airports with close-spaced parallel runways (Seattle-Tacoma, San Francisco, Los Angles, Chicago O'Hare and St. Louis) were visited to better understand the operation and procedures of Visual Approaches to parallel runways. Based on discussions with Tower and Terminal Radar Approach Control (TRACON) Air Traffic Control personnel at these airports, several Boeing Flight Operations test pilots and PRM project pilots, and reviewing the completed questionnaires (*Figure 11*) from these individuals the following summary of Visual Approach procedures to parallel runways were derived:

1. In VMC an aircraft can be cleared for a visual approach if it has the runway in sight or sees another aircraft (i.e., the preceding aircraft) that has the runway in sight. Additional aircraft can be added to this chain if it can see the preceding aircraft.

2. No other VMC separation conditions exist for this situation (i.e., there are no initial lateral or vertical separation criteria that apply for the initial turn on separation of parallel simultaneous Visual Approaches)

3. The controller expects the aircraft to be separated according to IFR rules prior to going visual.

4. The first aircraft must see the airport before requesting a visual approach. (This is not difficult at 10 nmi according to ATC.)

5. The Air Traffic Control Tower (ATCT) may provide separation suggestions (i.e., speed recommendations) to simultaneous parallel approaching aircraft. (Both the tower and the two pilots have a vested interest in maintaining safe separations.)

6. Generally, in a simultaneous parallel approach situation, only one controller has control over the two aircraft. Exceptions to that are, for instance, simultaneous visual approaches to Seattle-Tacoma and Boeing Field where a letter of agreement exists that covers responsibilities.

7. Approach generally gives the clearance to go visual, or answers the pilot's request to go visual. Approach will hand arrivals over to the ATCT at about 10-12 nmi.

8. Longitudinal separation is limited to wake vortex and runway occupancy considerations in VMC approach/landings.

9. Approach will provide radar vectors for visual approaches.

VISUAL APPROACHES TO PARALLEL RUNWAYS

Air Traffic Controller Questionnaire

1. Where the clearance for visual approach normally issued? How far out?

2. What is the vertical separation at turn-on?

3. Do you normally use radar vectoring to transition to final approach course?

4. What is the longitudinal separation strategy?

5. Is the either aircraft in sight(by the pilot of the other aircraft)?

6. What is standard separation provided by ATC?

7. When two aircraft turn-on to approach, are both flying visual?

8. What is the minimum longitudinal separation before the aircraft stabiliz on the extended runway centerline?

9. Is there a limit on intercept angle when two aircraft approaching simultaneously?

10. Does separation depend on type, class and speed of aircraft?

11. Is position and direction of one aircraft communicated to the pilot of the other aircraft by controller?

12. Does 1st pilot hear the radio communication with the 2nd pilot? (Two runway two different frequency)

13. Does controller see both aircraft and maintain separation? How often does controller interject during visual approach?

14. Does pilot scan the behavior of the other aircraft? In what time intervals?

15. Deleted.

16. Does controller instruct the pilot to maintain visual separation?What instructions does the controller give?

17. If the procedure require turn-on at _15 nm, is it necessary that either pilot actually see the runway?

18. What does the controller monitor on close spaced Visual approaches?

19. –At what point does he discontinue monitoring?

20. What conditions must be satisfied to clear two aircraft for simultaneous visual approaches?

Figure 11. Sample of Air Traffic and Pilot Questionnaire

10. Refer to [5]. (*Figure* 12 shows paragraph 7.33 of [5]).

It can be concluded from this summary that: 1) the responsibility for separation of aircraft transfers from the controller to the pilot after a Visual Approach clearance is issued, and 2) runway separations down to 700 ft are acceptable as opposed to 3,400 ft during instrument operations with high radar update rates.

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7–33 APPROACHES TO MULTIPLE RUNWAYS

a. All aircraft must be informed that approaches are being conducted to parallel/ intersecting/converging runways. This may be accomplished through use of the ATIS.

b. When conducting visual approaches to multiple runways, DO NOT PERMIT THE RESPECTIVE AIRCRAFTS' PRIMARY RADAR RETURNS TO MERGE UNLESS VISUAL SEPARATION IS BEING APPLIED.

c. In addition to the requirements in, paragraph 7–10, paragraph 7–30, paragraph 7–31 and, paragraph 7–32, the following conditions apply to visual approaches being conducted simultaneously to parallel, intersecting, and converging runways, as appropriate:

1. Parallel runways separated by less than 2,500 feet. Unless standard separation is provided by ATC, an aircraft must report sighting a preceding aircraft making an approach (instrument or visual) to the adjacent parallel runway. When an aircraft reports another aircraft in sight on the adjacent final approach course and visual separation is applied, controllers must advise the succeeding aircraft to maintain visual separation. DO NOT PERMIT A HEAVY AIRCRAFT TO OVERTAKE ANOTHER AIRCRAFT. DO NOT PERMIT A LARGE AIRCRAFT TO OVERTAKE A SMALL AIRCRAFT.

2. Parallel runways separated by at least 2,500 feet, but less than 4,300 feet.

(a) Standard separation is provided until the aircraft are established on a heading which will intercept the extended centerline of the runway at an angle not greater than 30 degrees, and each aircraft has been issued and the pilot has acknowledged receipt of the visual approach clearance.

7–33c2(a) Note.—The intent of the 30 degree intercept angle is to reduce the potential for overshoots of the final, and preclude side-by-side operations with one or both aircraft in a "belly-up" configuration during the turn. Aircraft performance, speed, and the number of degrees of the turn to the final are factors to be considered by the controller when vectoring aircraft to parallel runways.

(b) Visual approaches may be conducted to one runway while visual or instrument approaches are conducted simultaneously to the other runway, provided the conditions of subparagraph 7–33c2(a) are met.

(c) When the provisions of subparagraphs 7–33c2(a) and (b) are met, it is not necessary to apply any other type of separation with aircraft on the adjacent final approach course.

3. Parallel runways separated by 4,300 feet or more.

(a) Visual approaches may be conducted simultaneously, provided standard separation is maintained until aircraft has been issued and the pilot acknowledges receipt of the visual approach clearance.

(b) Visual approaches may be conducted to one runway while instrument approaches are conducted simultaneously to the other runway, provided separation is maintained until the aircraft conducting the visual approach has been issued and the pilot acknowledges the visual approach clearance.

(c) When the provisions of subparagraphs 7–33c3(a) and (b) are met it is not necessary to apply any other type of separation with aircraft on the adjacent final approach course.

4. Intersecting and converging runways. Visual approaches may be conducted simultaneously with visual or instrument approaches to another runway, provided standard separation is maintained until the aircraft conducting the visual approach have been issued and the pilot has acknowledged receipt of the visual approach clearance.

7–33c4 Note.—Although simultaneous approaches may be conducted to intersecting runways, staggered approaches may be necessary to meet the airport separation requirements specified in, paragraph 3–123.

7–33 Reference.—Charted Visual Flight Procedures (CVFP). USA/USAF/USN Not Applicable, paragraph 7–34. Separation, paragraph 7–92.

Figure 12. Paragraph 7-33 of FAA Order No. 7110.65H

4.4 AUTOMATIC FLIGHT CONTROLS FOR APPROACH AND LANDING

4.4.1 FUNCTION

The main element of automatic flight controls system is the Flight Control Computer (FCC). The FCC has evolved from a simple gyro stabilized control system to the sophisticated multifunctional system currently found in jet powered transports.

The *automatic pilot* began as a device for reducing the pilot workload (i.e., the autopilot and the system would maintain the airplane attitude while the pilot tended to other things). The next evolution of the automatic pilot was the addition of *pitch* and *roll* knobs to provide inputs of the pilot to adjust the stabilized attitude. After this development, the functions of holding an altitude at system engagement and the capability of maintaining an engaged heading were entrusted to the autopilot. Further developments of the automatic pilot included the development of air data computers which takes sensor data and calculates several essential parameters for the autopilot (e.g., altitude, Mach No., and true airspeed), and the installation of ground based navigation which spurred the development of additional directional control modes.

As the popularity of air travel increased and emphasis on schedule regularity grew, instrument landing systems were developed to provide the pilot with guidance to the runway when weather conditions did not permit a visual approach to landing. The autopilot was subsequently coupled to the ILS. The natural extension was to continue this coupled approach to automatically land the airplane at its destination regardless of the weather conditions.

Fully automatic landing (autoland) systems were demonstrated in the early 1960s, but routine use of these systems in poor weather conditions did not emerge until the mid 1970s. The main reason for this was the large initial investment in equipment (redundant, high-integrity systems are required to ensure safety) and the high cost of ownership (training and maintenance costs were high). However, the advent of micro-circuit technology provided improvements in packaging and reliability, as well as a reduction in power requirements that not only lowered producibility and maintenance costs, but allowed system designers to be more inventive.

The FCCs of the new generation digital autopilots (the older generation were analog - e.g., B727, B737-100 and -200, B747-100 and -200, and etc) consist of an integrated autopilot and Flight Director (F/D) system. The autopilot controls the aircraft through hydraulic servos connected to the primary control surfaces while the F/D provides steering commands to the pilot which are displayed on primary flight instruments.

4.4.2 CONTROL MODES

The Autopilot/Flight Director System (AFDS) has implemented a number of control modes that provide control of the aircraft, or guidance to the pilot, for the complete flight profile (i.e., takeoff, climb, cruise, descent, and landing). The control modes of the autopilot and F/D are common with the following exceptions:

1. Takeoff Mode-F/D only
2. Autoland-Autopilot (A/P) only

Control modes on the 747-400 and all 757/767s common to the autopilot and F/D consist of:

1. Vertical Speed
2. Flight Level Change
3. Altitude Capture
4. Altitude Hold
5. Heading Select
6. Heading Hold
7. Vertical Navigation
8. Lateral Navigation
9. Localizer
10. Backcourse
11. Approach

The control modes are selected through cockpit mounted Mode Control Panels (MCPs) which are typically installed under the glareshield and over the engine instruments. Three autopilot channels are provided for the 747/57/67 airplanes: L (left), C (center), and R (right). Only one of these autopilot channels is engaged during the flight, except for automatic landing. The autopilot is selected either by pushing the appropriate CMD (command) push button or by raising the appropriate engage lever.

The autopilots for 737, 757, 767, and 747-400 airplanes have a Control Wheel Steering (CWS) mode. Sensors are installed in the primary flight controls to measure the force applied by pilot(s) in the pitch and roll axes. These forces are converted to elevator and aileron commands to drive the autopilot servos. When no force is applied to the controls, the autopilot will either maintain the current pitch and roll attitudes, track or heading, depending upon the individual airline or system design preference.

There are two F/D switches on the MCP (one for the pilot flying and one for the pilot not flying) that allow the flight crew to select F/D commands for display on the Attitude Director Indicator (ADI). While the initial ADIs were electromechanical devices with a gyro stabilized attitude display used as a backdrop for the F/D commands, the latest ADIs are Electronic Attitude Director Indicators (EADI) which consist of a Cathode Ray Tube (CRT) display driven by a computer. This computer generates the attitude display and all of the other data required by the flight crew.

The F/D commands can be displayed with a cross pointer or in an integrated cue format. With the cross-pointer, one pointer provides commands in the pitch axis while the other pointer provides commands in the roll axis. Whereas with the single cue, the instrument has a single inverted V symbol to produce commands in both axes. In either case, the pilot needs to keep the command bars superimposed on the aircraft symbol in order to fly the required flight path.

The AFDS engaged status (CMD, CWS or F/D) is displayed on the EADI onboard the 757/767 and 747-400 aircraft. The AFDS modes are selected by pushing the appropriate pushbutton on the MCP and the AFDS annunciating successful mode engagement on a cockpit mode annunciator. Onboard the 757/767 and 747-400 aircraft, the AFDS mode annunciations are integrated into the EADI with the mode annunciations split into pitch axis modes (armed and operating) and roll axis modes (armed and operating). Some modes can be armed and subsequently engaged when predetermined criteria are satisfied. (Examples of modes that are armed prior to engagement are the glideslope, localizer, flare, and rollout submodes of the approach mode.)

The following are descriptions of the AFDS modes (localizer, backcourse, approach, and go-around) for autoland as used onboard 757/767 and 747-400 aircraft. (Note: Other aircraft will have similar autoflight modes but their detailed-operation may be different.)

4.4.2.1 LOCALIZER MODE

The localizer mode controls the aircraft during capture and tracking of the localizer beam, and like the other ILS modes, is an armable mode. The mode is armed by pushing the localizer (LOC) pushbutton on the MCP. The AFDS then measures the aircraft progress with respect to the localizer beam and transitions to engage the localizer mode at the appropriate point. The control law, upon engagement, turns the aircraft to acquire the runway heading and line up with the extended runway centerline. Once on the beam, the control law tracks the beam centerline down to the runway threshold. (The localizer mode only provides guidance in the lateral axis with no glideslope signal, i.e., automatic landing is not available in this mode.)

4.4.2.2 BACKCOURSE MODE

The backcourse mode is similar to the localizer mode (except that the transmitter is not available at the far end of the runway), so the backbeam of the reciprocal runway localizer transmitter is used for guidance. This mode is selected by pushing the Localizer and Backcourse pushbuttons on the MCP. Two factors that must be taken into account in the design the backcourse mode are: 1) the location of the transmitter at the front end of the runway indicates that the beam cannot be used down to and along the runway as with a front course approach, and 2) the polarity of the deviation signal is reversed as the backbeam is being used.

4.4.2.3 APPROACH MODE

The approach mode gives the pilot the capability for full automatic landing when multiple autopilot channels are selected. Multiple A/P channels are required to provide sufficient redundancy to ensure a safe landing. An automatic landing is not allowed with only one autopilot channel selected nor is the F/D approved for providing landing flare commands.

A typical approach scenario would be:

1. Select approach mode by pushing the approach (APP) button to arm the localizer and glideslope modes.

2. Localizer mode capture criteria is satisfied and the localizer mode engages.

3. Glideslope mode capture criteria is satisfied and the glideslope mode engages.

4. The aircraft tracks the localizer and glideslope beams down to approximately 1,500 ft above ground level (AGL), as measured by the radio altimeter, at which point the other autopilot channels engage and the Flare and Rollout submodes arm.

5. The aircraft continues to track the localizer and glideslope signals down to approximately 50 ft AGL at which time the flare mode engages. (The glideslope signal is unusable below 50 ft.)

6. The flare mode controls the aircraft to touchdown approximately 450 ft past the glideslope transmitter with a vertical sink rate of at approximately 2.5 ft/sec.

7. The rollout mode engages at 5 ft AGL to control the aircraft to the localizer beam using the rudder. (Prior to this point the localizer control has been through the ailerons.)

8. The aircraft nose wheel is lowered to the ground (Nose Let Down) at touchdown and is held on the ground during the ground roll by commanding nose down elevator.

The approach mode can be flown on the F/D but is not approved for use below 100 ft AGL.

The submodes in the multichannel approach which are not annunciated on the EADI but are always active are runway alignment and engine out compensation which execute control through the rudder. The rudder servos engage at multichannel autopilot engagement. Should an engine fail at any time after rudder engagement, the autopilot will apply compensatory rudder to correct for yaw moment due to asymmetric thrust.

The alignment mode becomes active at 500 ft and is used to introduce a forward slip in the aircraft in the presence of strong crosswinds. The forward slip is required to reduce the crab angle at touchdown. The alignment mode does not take into effect until the crab angle on the approach exceeds 5 deg.

The approach mode with its automatic landing capability typically requires the most design analysis and test activity. The major design concerns for the approach mode are:

1. Localizer

   a. Capture the localizer beam with minimal overshoot for various intercept angles and speeds, distances from the runway, and wind conditions.

b. Maintain localizer centerline tracking in the presence of windshears, beam noise and disturbances (e.g., over-flights, etc.), and engine failures.

2. Glideslope

a. Capture the glideslope beam smoothly with minimal overshoot for entries from above and below the beam, various speeds, and various aircraft configuration changes (e.g., flaps, speedbrakes, gear, etc.).

(*Figure 13* shows geometry of approach for localizer and glideslope during ILS approach.)

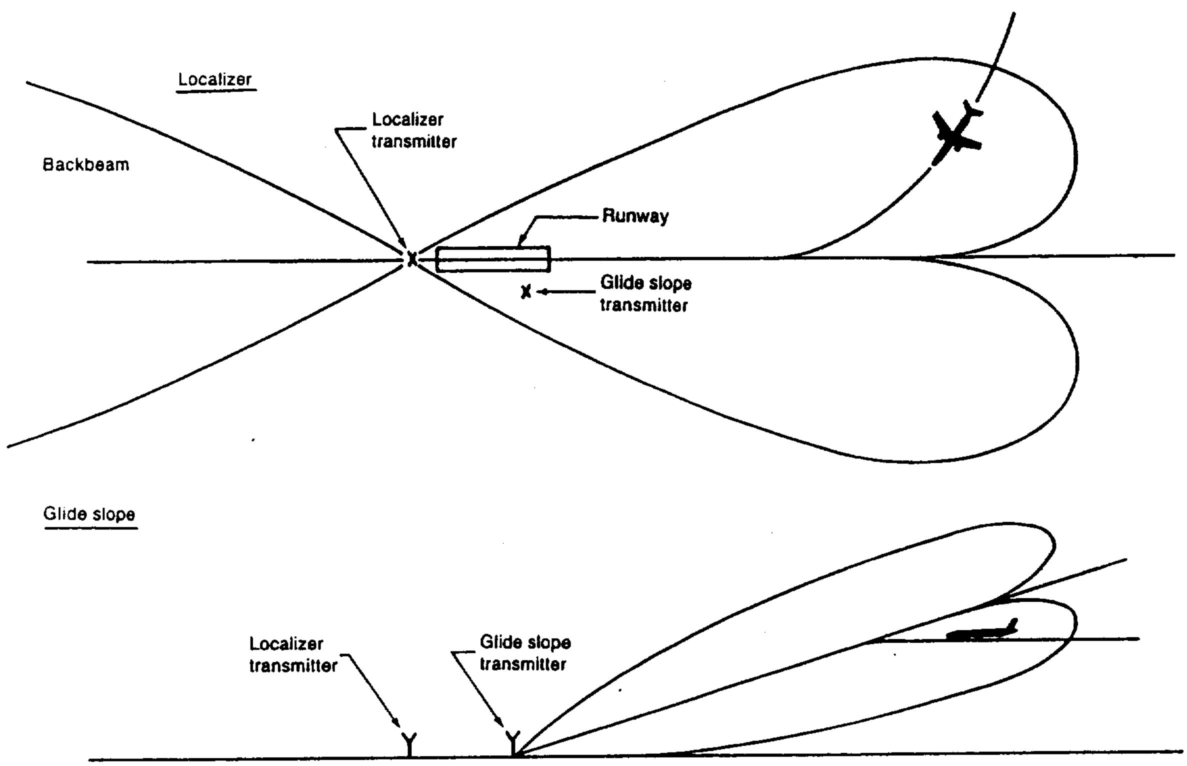

Figure 13. Localizer and Glideslope Geometry of ILS Approach

3. Alignment

a. Transition to the slip maneuver should be smooth with the bank angle limited for pilot acceptance as well as to ensure that there is no occurrence of a wing tip or an engine contacting the ground.

b. The slip response to windshears and engine failures must be analyzed.

c. The lateral touchdown performance in the presence of windshears, steady winds, beam noise, turbulence, etc. must be analyzed.

4. Flare

   a. The longitudinal touchdown performance (distance from threshold and touchdown rate) in the presence of steady winds, windshear, turbulence, throttle, mismanagement, etc. must be analyzed.

   b. The touchdown performance for various airport variables (i.e., airport altitude, runway slope, approach terrain, glideslope beam angle, transmitter location, etc.) must be analyzed.

5. Nose Let Down

   a. The nose gear should be lowered to the ground smoothly with various braking conditions and in the presence or lack of ground spoiler deployment.

6. Rollout

   a. Acquiring and maintaining the runway centerline (actually localizer beam null) must be analyzed for various runway conditions (e.g., wet, icy, etc.), asymmetric braking, and asymmetric reverse engine thrust.

A great deal of analysis and testing has to be completed to obtain regulatory approval for automatic testing.

4.4.2.4 GO-AROUND MODE

The go-around mode is selected by pushing the palm switches on the engine power levers and is annunciated on the EADI whenever a missed approach is necessary. In the longitudinal axis, the go-around mode introduces an initial rate of climb bias to generate a rotation in the aircraft, and then transitions to a speed through elevator control for climbout. In the lateral axis, the go-around mode maintains runway track.

The go-around mode may be engaged any time after flaps are in a landing configuration. The design considerations for the go-around mode include:

1. Height Loss during Rotation

2. Performance with an Engine Failure

3. Manual vs Automatic Throttle Operation

5.0 BENEFITS OF CLOSE-SPACED PARALLEL RUNWAYS

Prior to the introduction of PRM, the separation between parallel runways was at least 4,300 ft for simultaneous independent IMC approach operations. The PRM program demonstrated that by using new radar technology and new displays the parallel runway spacing for IMC operation could be decreased to 3,400 ft. Currently, the FAA goal for spacing between runways is 3,000 ft along with improving or maintaining the existing safety standards. This goal may permit an increase of 12-17 arrivals per hour under IMC at qualifying airports. This section considers which US airports will be effected and what would be the benefits if the parallel spacing were reduced to approximately 2,500 ft.

5.1 US AIRPORT CANDIDATES FOR INDEPENDENT PARALLEL IMC APPROACH OPERATIONS

Preliminary analysis indicates that 26 of the top 100 US airports have or plan to have parallel runways with spacing between 3,000 and 4,300 ft. These candidate sites could potentially operate independent parallel approaches with the use of new technology. *Figure 14* shows the existing airports with the parallel runway that may be effected by the new procedures while *Figure 15* shows the future plans for the airports with parallel runways that will be effected by the new procedures.

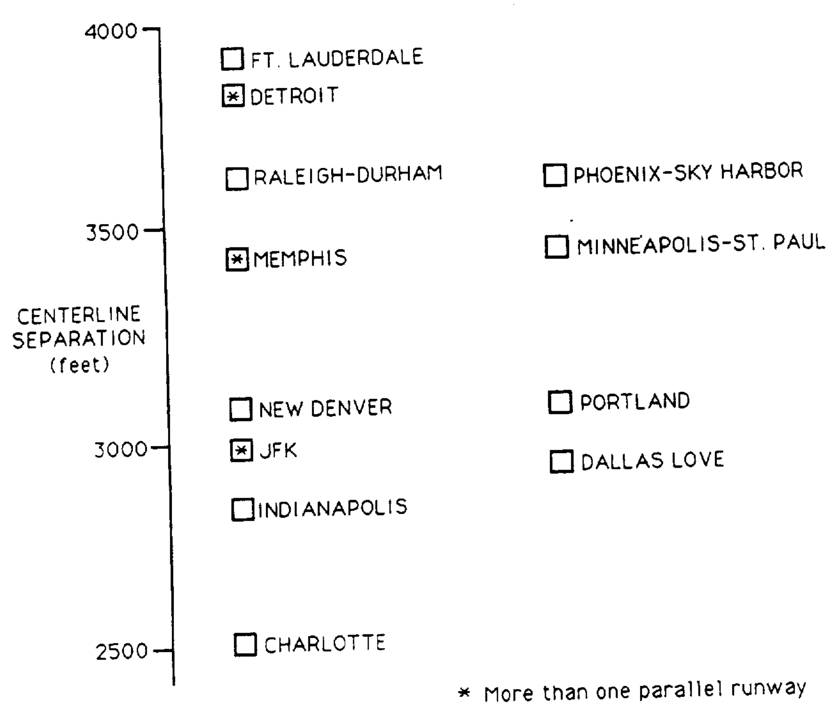

Figure 14. Airports With Existing Parallel Runways

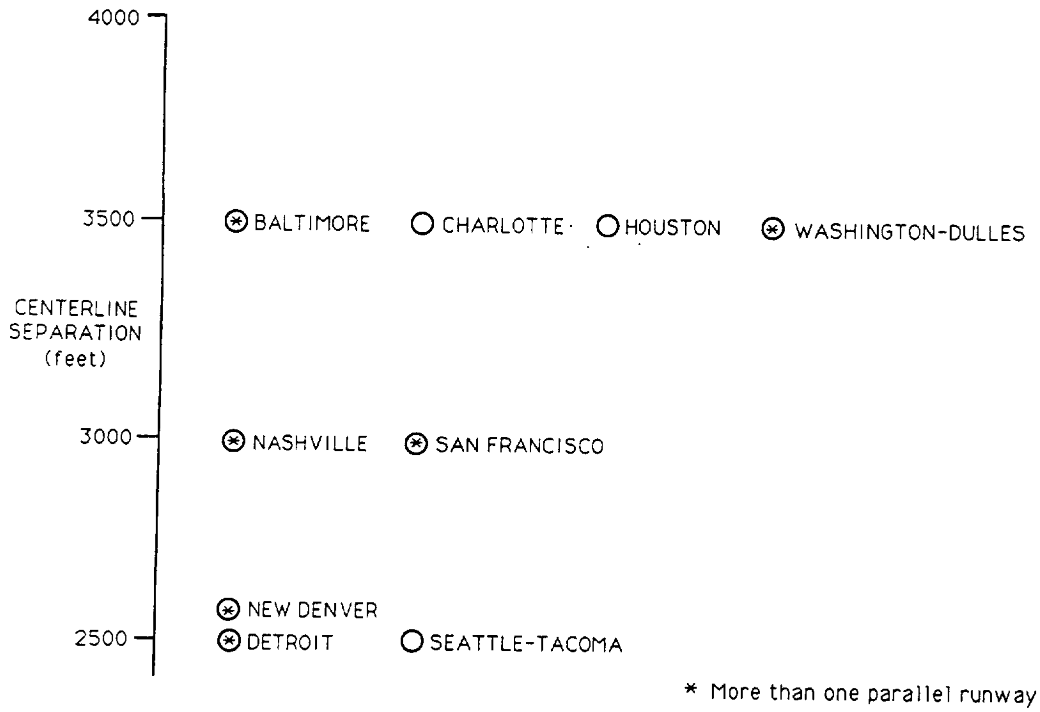

Figure 15. Airports Planning for Future Parallel Runways

In addition, combinations of independent IMC parallel operations and dependent IFR parallel operations could be used at some airports to implement a system involving triple IMC arrival streams with multiple departure streams. The primary recipients of this concept would be those airports having independent IMC arrival streams to parallel runways (using either the 4,300-foot runway separation standard or proposed new independent parallel approach standards). For such airports, a third parallel runway, or a favorably located non-parallel runway, may be used for a third arrival stream. If triple operations were to be permitted in IMC, then airports could achieve up to a 50 percent increase in capacity. Preliminary analysis indicates that, of the top 100 airports, 14 are possible candidates for triple IFR approaches (*Table 5*).

5.2 CAPACITY SIMULATION PROGRAM

In order to evaluate the benefits of close-spaced parallel runways a simulation program called Capacity-Delay that has been developed by Avionics Flight Systems/ATC Research System Analysis organization of BCAG will be used. Capacity-Delay is a fast time computer program that simulates arrival and departure operations of airport runways for estimating average delays and airfield operation capacity. The program determines airport capacity and delay as a function of:

Table 5. Candidates for Triple IMC Approaches

Potential Annual Delay Savings of Over 1,000 Hours+	
Atlanta ATL*	Pittsburgh PIT*
Chicago ORD	Raleigh-Durham RDU*
Dallas-Ft. Worth DFW*,**	Salt Lake City SLC*
Washington IAD	Orlando MCO*
Detroit DTW*	
Other Candidates	
Cincinnati CVG*	Charlotte CLT
Houston IAH*	Denver (New DVX)
Tulsa TUL*	

\+ 1989 - 1995 Demand Levels.

* The procedure is applicable upon construction of a planned new runway.

** Upon implementation of Triple Parallel Approaches.

1. Airport Configuration

2. Traffic Characteristics

3. Aircraft Performance Parameters

4. Separation Minimums

5. Runway Configurations

6. ATC Performance Parameters

An input data file must exist before the simulation can begin. The input data is grouped into six categories:

1. Program Control Parameters (e.g., number of Monte-Carlo samples, number of data sets, samples per traffic level, etc.)

2. Airport Configuration Data (e.g., number of runways, runway entrance speed, runway length, exit locations, maximum exit speed, length of primary runway, etc.)

3. Traffic Inputs (e.g., percentages of airplane classes in a mix, arrival and departure mixtures, traffic level, etc.)

4. ATC Performance Parameters (e.g., safety separation probability, outer-marker location, inter-arrival errors, etc.)

5. Airplane Performance Parameters (e.g., final approach velocities for each class, initial climb velocities, acceleration and deceleration rates, maximum exit speed for each class, rolling deceleration, rolling speed, etc.)

6. Flight Separation Rules Between Operations (e.g., interoperational spacing, longitudinal separation, wake vortex for different classes, etc.).

The capacity simulation selects an operation from the schedule (according to the operation sequencing rule specified) and then assigns the operation a runway (according to the runway assignment rule specified) while separating consecutive operations by the mean interoperational time until the operation demand is empty. When the demand is empty, statistical means and standard deviations are calculated to determine the average airplane delay and averaged rates of operation. Finally the average delay per operation along with throughput and practical capacities are summarized at the end of the file.

5.3 ESTIMATION OF BENEFITS DERIVED FROM CAPACITY-DELAY SIMULATION PROGRAM

Only airports with dual parallel runways will be considered. (*Figures 14* and *15* can be summarized in *Table 6*).

Table 6. Airports with Parallel Runways Affected by New Procedures

RUNWAY SPACING	FUTURE PLAN	EXISTING
3,400-4,300 ft	2	6
3,000-3,400 ft	3	3
2,500-2,999 ft	2	3

An initial evaluation using the Capacity program provides the following information:

1. IMC parallel runway approaches result in 27% more operations than IFR dependent parallel runway approaches.

2. VMC approaches result in 48% more operations than IFR dependent parallel runway approaches.

3. VMC approaches result in 16% more operations than IMC parallel runway approaches.

This data must be utilized together with the weather conditions to obtain the best estimate of improved capacity.

6.0 DEVELOPMENT OF A BLUNDER SIMULATION MODEL

A key element toward increasing operational capacity at high-demand airports is to develop analysis tools for determining a *safe* runway separation of independent parallel ILS approaches. A blunder simulation model is one such tool.

A critical problem of final approach and terminal area air route operations is maintaining separation between aircraft independtly flying close-proximity tracks. These operations consist of assigning tracks for the aircraft to fly and monitoring progress (i.e., determine that the assigned tracks are being maintained). The control problem is to identify when an aircraft is deviating from the track and to take corrective action in preventing a collision with another aircraft. The technical approach used for this study was to begin with analyzing all final approach factors that might influence achievable separations (i.e., turn-on, approach tracking, blunder operation, and missed approach).

6.1 FINAL APPROACH FACTORS

Factors involved in the current 4,300-foot (or proposed PRM 3,400-foot) separation criteria include: turn-on, normal approaches, blunder, and missed approach.

6.1.1 TURN-ON FACTORS

The first stage after cruise transition mode is the approach mode or turn-on to localizer capture. For final approach to parallel runway the parameters involved are:

1. Vertical Separation (current operations require minimum of 1,000 ft altitude separation between two aircraft)

2. Final Approach Path Length Requirement

3. Overshoot versus capture method
   a. Manual Flight
   b. Flight Director
   c. Analogue Autopilot
   d. Digital Autopilot

4. Minimum Localizer Capture Distance

5. Requirements for Close-in Capture

6. Technologies to Permit Close-in Captures
   a. Traffic Alert and Collision Avoidance System/Cockpit Display Traffic Information (TCAS/CDTI)
   b. Air/Air Data Link
   c. Enhanced Situational Awareness System (ESAS)
   d. Global Positioning System/Area Navigation (GPS/RNAV)
   e. State of the Art Autopilot

6.1.2 NORMAL APPROACH FACTORS

The approach factors, after aircraft turn-on to parallel runway localizer, to be analyzed are:

1. Lateral Separation (current independent ILS approaches to parallel runways requires minimum of 4,300 ft - or 3,400 ft using PRM - space between two runways)

2. Final Approach Probability of Loss of Lateral Separation (CDI, Flight Director and Analogue or Digital Autopilot tracking performance)

3. Final Approach Probability of NTZ Encounter

6.1.3 BLUNDER FACTORS

Whenever the approach is abnormal, then either a blunder or missed approach have occurred. In the case of a blunder, some of the reasons for an aircraft flying into the NTZ and crossing a parallel approach path are:

1. Airborne Equipment Failure
   a. Aircraft Control Surface Malfunction (e.g., spoiler hardover, spoiler float and rudder, aileron or flaps failure)
   b. Navigation Instrument Failure
   c. Engine Failure
   d. Aircraft Control Law Logic Failure (e.g., during localizer or glideslope capture)
   e. Power Supply Failure
   f. Fire
   g. Air Ground Communication Failure
   h. Hydraulic Failure

2. Ground Equipment Failure and Errors
   a. Ground Air Communication Failure
   b. Fly Over Antenna
   c. Power Failure

d. Distorted Signals
e. Large Amplitude of Oscillation (due to sensitivity of localizer beam)

3. Human Errors
   a. Disorientation (because of failure or warning)
   b. Lack of Attention (to hear or see a warning)
   c. Miss Identification from Controller
   d. Dialing Wrong Frequencies/Tracking Wrong Beam
   e. Power Failure
   f. Misunderstanding of Duties by Pilot Flying and Pilot Not Flying.

The blunder factors to be analyzed are:

1. Data on Frequency and Type of Blunder

2. Current FAA Sponsored Blunder Scenarios

3. Blunder Model Probability of Recovery
   a. Communication Delay
   b. Surveillance Rate and Accuracy
   c. Controller/Pilot/Aircraft Response Time

4. Simulation Data on Blunder Recovery

5. Technologies to Support Blunder Recovery
   a. TCAS/CDTI
   b. Air/Air Data Link
   c. ESAS
   d. New Color Monitors and Faster Radars
   e. GPS/RNAV

6. New ATC Procedures

7. Technologies to Support Blunder Avoidance

6.1.4 MISSED APPROACH FACTORS

If a blunder should occur, then a missed approach is required. The missed approach factors to be analyzed are:

1. Data on Frequency and Type of Blunder

2. Dual, Triple and Quadruple Missed Approach Operation

3. Missed Approach Probability of Loss of Separation (e.g., navigation performance, missed approach deviation errors due to Flight Technical Error (FTE), and other errors)

4. Technologies to support missed approach (e.g., GPS, TCAS/CDTI, ESAS, Autopilot, etc.)

6.2 PARAMETRIC SIMULATION MODEL FOR PARALLEL RUNWAY APPROACHES

Among the four factors discussed in subsection 6.1, only the blunder factor will be utilized to develop the simulation model. This area is emphasized because of its recognized criticality to the runway spacing problem. The objective of building this simulation is to develop a parametric model that can be used for analyses in determining the minimum safety level of parallel runway operations for various parameters representing the airplane, navigation, surveillance, and ATC system performance. The safety criterion is based on the conditional probability of successfully resolving a blunder given that one has occurred.

6.2.1 PARAMETRIC MODEL DEVELOPMENT RATIONALE

A study of the existing airport runway geometry and proposed ATC procedures for ensuring safety must be conducted in order for an airport to qualify for acceptable simultaneous IMC operation on parallel runways (or to determine a limit for national standard for parallel runway spacing). Though this type of qualification process involves extensive and costly flight test data, there is a growing recognition of the usefulness of a fast time simulation model to set lateral separation requirements guidelines in the terminal area. A fast time simulation model can parametrically represent airplane, navigation, and air traffic control performance and economically investigate a wide range of *what if* questions regarding parallel runway operations.

Such a theoretical model of parallel runway operations is useful as:

1. A quick and economical evaluation of existing environments that are experiencing IMC delays.

2. An efficient way to study and validate proposed procedure modifications to permit simultaneous operations.

3. A tool to develop a set of general requirements for simultaneous operations.

4. A simple, parametric investigation of a wide range of issues and approaches.

5. A measure for determining trade-off of air and ground technology and procedures contributions.

6. A tool for outlining probable blunder mechanisms and a range of blunder scenarios.

6.2.2 FLOW DIAGRAM OF BUILDING PARAMETRIC SIMULATION MODEL

To accomplish the objectives of building a parametric simulation model the following steps were followed in the order presented:

1. Environment Specification

2. Model Development

3. Model Exercise and Sensitivity Analysis for IMC and VMC Approach Operation

4. Documentation

Figure 16 shows the interrelations between these steps and outlines some of the inputs and outputs.

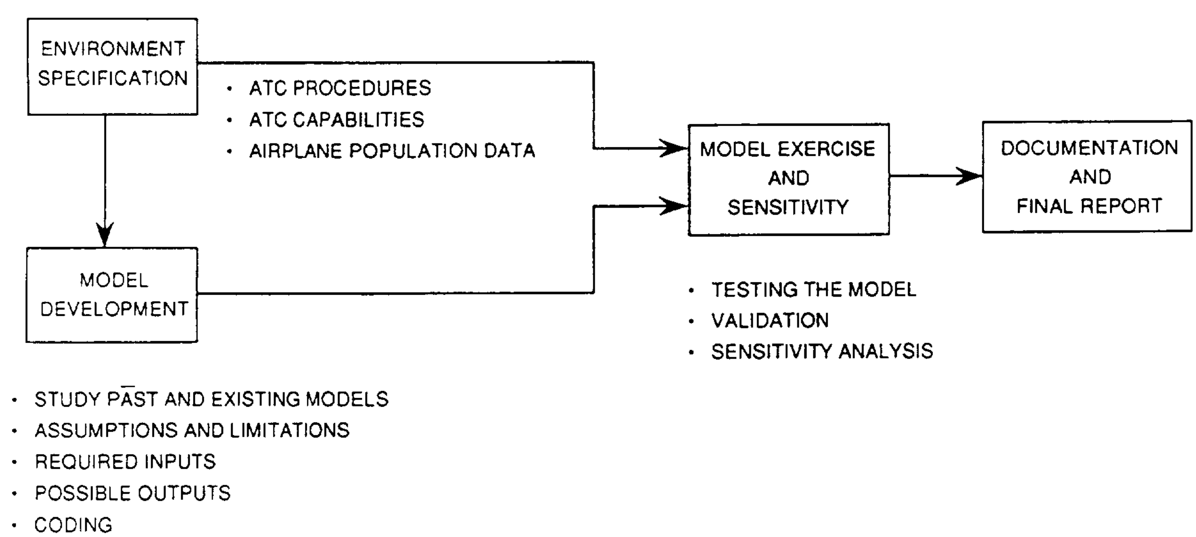

Figure 16. Study Flow Diagram

The environment specification task is a continuing effort of the study that provides inputs for developing the model and exercising the task. The types of information required for the task include ATC procedures (i.e., data to be used in the model development) and a set of airplane characteristics (i.e., data to be used in developing and exercising the model). The environment specification and aircraft parameters consist of terminal area environment, ATC procedures, and aircraft population and class data.

6.2.2.1 TERMINAL AREA APPROACH ENVIRONMENT

The terminal area modeling will consider: the terminal approach control region, runway spacing, NTZ and NOZ width, aircraft distance from runway threshold, longitudinal and lateral distance of aircraft, three dimensional approach path, etc.

6.2.2.2. ATC PROCEDURES

The basic model will use the procedures specified in [5] with variations on the regulations contained therein being exercised as a requirement in satisfying the study goals.

6.2.2.3 AIRCRAFT POPULATION DATA

Appropriate parameters of a family of aircraft to be used in the model are defined here. These parameters are: velocity distributions, maneuver performance data, response time, and approach characteristics.

1. Velocity distributions for descent and approach configurations will be obtained from the operations manual for the specific airplane. These velocity distributions will provide the nominal values and deviations to be considered. While the BCAG family of transports provide a broad coverage of the weight spectrum, it will be necessary to obtain parameters for other transports and lighter aircraft.

2. Maneuver performance data (i.e., turning radius, bank angle, and normal accelerations available) are a function of the difference between reference speed and the speed for stall warning or the onset of buffet. The required parameters are available from flight test documentation for all BCAG transports. For other than BCAG aircraft the required parameters will be estimated by BCAG performance methods whenever test data are not available.

3. Combined pilot-airplane response times for initiation and completion of required maneuvers will be obtained via the use of real time simulator data and available data which has been collected by FAA supported studies. The flight simulator is capable of determining the effects of speed, weight, and configuration changes with great accuracy. Also Autopilot and Autoland System Performance can be utilized for accurate response characterization of approach maneuvers.

4. The approach and missed approach airplane dynamic performance will be provided.

6.3 PARAMETRIC BLUNDER SIMULATION MODEL

The simulation program PLAND_BLUNDER (PLB) is designed to study blunders during landings on parallel runways. A typical scenario of PLB assumes that two streams of aircraft approaching parallel runways independently of one another during IMC parallel approaches. If one aircraft should deviate from its assigned localizer towards the opposite runway, there could be an endangered (evader) aircraft in its path. A deviation from the parallel approach towards the opposite runway constitutes a *blunder*. The scenario of concern would be one in which the blundering aircraft was unable to recover (i.e., returning to the assigned approach) and continue toward the adjacent stream of aircraft.

PLB is a Monte Carlo-type fast simulation of the events and aircraft position during a blunder situation. This model simulates two aircraft performing parallel ILS approaches using IMC or VMC procedures with one aircraft blundering and the other possibly reacting to avoid the blunderer. PLB uses a simple movement model and control law in three (X, Y, Z) dimensions to represent the aircraft responses.

6.3.1 INPUT(S) OF SIMULATION PARAMETERS

The input parameters include: runway geometry, aircraft class, approach speed of aircraft, general type of blunder, general type of reaction, near miss criteria, and number of Monte Carlo cases to run. Some of the randomly influenced parameters are: initial along-track distance between aircraft, angle of blunder, location of blunder, time to detect blunder, time to react by controller, time to react by pilot, aircraft response delay, and aircraft class. Figure 17 shows a sample input file.

```
******************** AC TYPE SEGMENT *********************
! Comment:  Define aircraft types and fleetmix.
AC_TYPE 4   SIZE 230.0 200.0  70.0 Tresponse  3.0  1.0  SPD 1,2 m+SD 170.0 10.0 140.0  5.0   kts
>>>      ESC ACEL,CLMB m+SD 30.0 10.0 40.0 10.0  TAE ANGLE(mR) m+SD  -2.0   5.0
AC_TYPE 1   SIZE  50.0  60.0  30.0 Tresponse  2.0  1.0  SPD 1,2 m+SD 110.0 10.0  80.0  5.0   kts
>>>      ESC ACEL,CLMB m+SD 30.0 10.0 30.0 10.0  TAE ANGLE(mR) m+SD  -3.0  10.0
AC_TYPE 2   SIZE 100.0 100.0  50.0 Tresponse  2.0  1.0  SPD 1,2 m+SD 140.0 10.0 110.0  5.0   kts
>>>      ESC ACEL,CLMB m+SD 30.0 10.0 40.0 10.0  TAE ANGLE(mR) m+SD  -2.0   7.0
AC_TYPE 3   SIZE 150.0 160.0  60.0 Tresponse  3.0  1.0  SPD 1,2 m+SD 160.0 10.0 130.0  5.0   kts
>>>      ESC ACEL,CLMB m+SD 30.0 10.0 40.0 10.0  TAE ANGLE(mR) m+SD  -2.0   5.0
FLEETMIX (1-6)  10.0  20.0  30.0  40.0   0.0   0.0
ALT_FMIX (1-6)  10.0  20.0  30.0  40.0   0.0   0.0

******************** PROFILE SEGMENT *********************
! Comment:  Define the blunder and escape profiles for the aircraft.
AC_CASE BLUNDER_1  AC 1  TYPE 0  RWY L  Dstart  70000.0  Tstart m+SD   0.0  0.0
>>>     dTURN  3.0 Dblund hi,lo 60761.0 60761.0  BLUND m+SD ANG  30.0  1.0 SLOPE  0.0  1.0 DV  0.0 10.0
AC_CASE NORM_ESC_1 AC 2  TYPE 9  RWY R  Dstart  70000.0  Tstart m+SD   0.0  0.0
>>>     BANK m+SD 60.0  0.0  HEAD  50.0 CLIMB/ACCEL BY TYPE

******************** RUNWAY GEOMETRY SEGMENT *********************
! Comment:  Define runway geometry.
RWY_DEF  R  THRESH    0.0    CENTERLINE,NOZ   -2150.0   1150.0
RWY_DEF  L  THRESH    0.0    CENTERLINE,NOZ   -2150.0   1150.0

******************** RESPONSE TIME SEGMENT *********************
! Comment:  Define alarm criteria and response delay times..
ALARM     Dalarm  300.0
RESPONSE SENSOR GAUSSIAN   3.0    1.0
RESPONSE ATC    DISTR_FILE study.0.ATC.dat
RESPONSE COM    GAUSSIAN   1.5    0.5
RESPONSE PILOT  GAUSSIAN   4.0    1.0
******************** RUNX SEGMENT *********************
! Comment:  Define the range of x-offset geometries and the number of runs.
STEP_T   Tmin,max,step    -3.0    3.0    2.0
RUN_X        3    SEED    7000000
QUIT
```

Figure 17. Sample Input File

6.3.2 ASSUMPTIONS AND LIMITATIONS

The movement model assumes that the bank and pitch angles are decoupled and instantaneous while the turns are modeled as constant radius and level. There is no energy modeling of altitude, speed, and turning. The aircraft is assumed to follow the nominal profile plan with no minor adjustments to course, altitude and speed. There is no flight control system to react to perturbations or changes. The runways are assumed to be exactly parallel and level. Only the part of the approach after turn-on is modelled. Each run is terminated 50 sec after the evasion maneuver starts, since it is assumed that the closest approach will have occurred before then. The aircraft position update interval is .5 second. A blunder is considered to have occured when either the alarm distance from the centerline or the edge of the NTZ is breached by the blunder aircraft. The alarm distant and the NTZ edge are set equal for IMC runs. The alarm distance defines a blunder for VMC runs.

6.3.3 OUTPUT OF SIMULATION

The standard output of PLB is the probability of successful resolution of a blunder, once it has occurred. *Figure 18* is a sample output file. (Refer to *Volume 2* of this document for a complete description of inputs and outputs.)

LO	HI	HITSper	HITSn	HITSper_cum	HITSn_cum
0.0	100.0	0.0087	105	0.0087	105
100.0	200.0	0.0104	126	0.0191	231
200.0	300.0	0.0164	198	0.0355	429
300.0	400.0	0.0226	274	0.0581	703
400.0	500.0	0.0264	320	0.0845	1023
500.0	600.0	0.0305	369	0.1150	1392
600.0	700.0	0.0413	500	0.1564	1892
700.0	800.0	0.0420	508	0.1983	2400
800.0	900.0	0.1526	1847	0.3510	4247
900.0	1000.0	0.0477	577	0.3987	4824
1000.0	1100.0	0.0349	422	0.4336	5246
1100.0	1200.0	0.0360	435	0.4695	5681
1200.0	1300.0	0.0308	373	0.5003	6054
1300.0	1400.0	0.0299	362	0.5302	6416
1400.0	1500.0	0.0336	406	0.5638	6822
1500.0	1600.0	0.0289	350	0.5927	7172
1600.0	1700.0	0.0285	345	0.6212	7517
1700.0	1800.0	0.0292	353	0.6504	7870
1800.0	1900.0	0.0265	321	0.6769	8191
1900.0	2000.0	0.0345	417	0.7114	8608
2000.0	2100.0	0.0292	353	0.7406	8961
2100.0	2200.0	0.0295	357	0.7701	9318
2200.0	2300.0	0.0279	337	0.7979	9655
2300.0	2400.0	0.0297	359	0.8276	10014
2400.0	2500.0	0.0277	335	0.8553	10349
2500.0	2600.0	0.0283	342	0.8836	10691
2600.0	2700.0	0.0248	300	0.9083	10991
2700.0	2800.0	0.0178	215	0.9261	11206
2800.0	2900.0	0.0151	183	0.9412	11389
2900.0	3000.0	0.0158	191	0.9570	11580
3000.0	3100.0	0.0123	149	0.9693	11729
3100.0	3200.0	0.0130	157	0.9823	11886
3200.0	3300.0	0.0074	90	0.9898	11976
3300.0	3400.0	0.0056	68	0.9954	12044
3400.0	3500.0	0.0027	33	0.9981	12077
3500.0	3600.0	0.0019	23	1.0000	12100
3600.0	3700.0	0.0000	0	1.0000	12100
3700.0	3800.0	0.0000	0	1.0000	12100
3800.0	3900.0	0.0000	0	1.0000	12100
3900.0	4000.0	0.0000	0	1.0000	12100
4000.0	4100.0	0.0000	0	1.0000	12100
4100.0	4200.0	0.0000	0	1.0000	12100
4200.0	4300.0	0.0000	0	1.0000	12100
4300.0	4400.0	0.0000	0	1.0000	12100
4400.0	4500.0	0.0000	0	1.0000	12100
4500.0	4600.0	0.0000	0	1.0000	12100
4600.0	4700.0	0.0000	0	1.0000	12100
4700.0	4800.0	0.0000	0	1.0000	12100
4800.0	4900.0	0.0000	0	1.0000	12100
4900.0	5000.0	0.0000	0	1.0000	12100

Figure 18. Sample Output File

7.0 ANALYSIS OF IMC APPROACH TO PARALLEL RUNWAYS

Herein a baseline case for analyzing IMC approach to parallel runways is outlined and examined. This baseline case is for determining the probability of the closest point of approach (CPA) for two aircraft (one blundering and the other evading) as a baseline case. From this baseline then, the sensitivity analysis results can be investigated and the parameter variations in the simulation model evaluated.

7.1 BASELINE CASE FOR IMC APPROACH TO PARALLEL RUNWAYS

The PLB Model was validated by comparing it to an existing model, the MITRE Blunder Resolution Model. This comparison resulted in a < 500 ft CPA for the PLB which was within the expected agreement bound (20%) of the MITRE model [4] using almost identical inputs. *Figure 19* shows this baseline case representing the IMC approaches to parallel runways. A brief summary of the parameters and their values are:

runway separation	4,300 ft
alarm distance	1,150 ft
NTZ width	2,000 ft
TAE mean/SD	-1/3 mr
response time/SD	8.9/9.8 sec
longitudinal relation	-2,500 to 3,000 ft
sim blunderer start	blunder at 60,761 to 12,152 ft (from runway threshold)
nominal speed	varies according to aircraft type (refer to input file)
blunder angle	30 deg
blunder turn rate	3 deg/sec
evader bank angle	22 deg
evader turn heading	55 deg
evader climb rate	varies according to aircraft type (refer to input file)
evader speed increase	0
evader/blunder fleetmix	percent of aircraft fleetmix (6 types of aircraft class) categorized by speed mean and standard deviation (SD) at far/close distances from runway threshold

Figure 20 is the output file of the baseline case showing only the data out to a CPA of 5,000 ft. This table indicates that the probability of an unresolved blunder (i.e., CPA <500 ft) is about 4% for the baseline conditions. *Figure 21* plots the cumulative probability distribution function of the CPA miss-distance.

```
****************** AC TYPE SEGMENT ********************
! Comment:  Define aircraft types and fleetmix.
! Comment:  MITRE_type : AC_TYPE correlation (1:1  2:2  3:3  4:-  5:-  6:-  7:4  8:5  9:6)
AC_TYPE 1  SIZE 100.0 100.0  50.0 Tresponse  0.0  0.0  SPD 1,2 m+SD 150.0 1.78 100.0 1.78   kts
>>>      ESC ACEL,CLMB m+SD  0.0  0.0 33.0  0.0  FTE ANGLE(mR) m+SD  -1.0   3.0
AC_TYPE 2  SIZE 100.0 100.0  50.0 Tresponse  0.0  0.0  SPD 1,2 m+SD 150.0 1.78 110.0 1.78   kts
>>>      ESC ACEL,CLMB m+SD  0.0  0.0 17.0  0.0  FTE ANGLE(mR) m+SD  -1.0   3.0
AC_TYPE 3  SIZE 100.0 100.0  50.0 Tresponse  0.0  0.0  SPD 1,2 m+SD 150.0 1.78 110.0 1.78   kts
>>>      ESC ACEL,CLMB m+SD  0.0  0.0 25.0  0.0  FTE ANGLE(mR) m+SD  -1.0   3.0
AC_TYPE 4  SIZE 230.0 200.0  70.0 Tresponse  0.0  0.0  SPD 1,2 m+SD 180.0 1.78 140.0 1.78   kts
>>>      ESC ACEL,CLMB m+SD  0.0  0.0 33.0  0.0  FTE ANGLE(mR) m+SD  -1.0   3.0
AC_TYPE 5  SIZE 230.0 200.0  70.0 Tresponse  0.0  0.0  SPD 1,2 m+SD 180.0 1.78 140.0 1.78   kts
>>>      ESC ACEL,CLMB m+SD  0.0  0.0 42.0  0.0  FTE ANGLE(mR) m+SD  -1.0   3.0
AC_TYPE 6  SIZE 230.0 200.0  70.0 Tresponse  0.0  0.0  SPD 1,2 m+SD 180.0 1.78 140.0 1.78   kts
>>>      ESC ACEL,CLMB m+SD  0.0  0.0 50.0  0.0  FTE ANGLE(mR) m+SD  -1.0   3.0
FLEETMIX (1-6)   9.0   5.7   5.3  21.0  43.0  16.0

****************** PROFILE SEGMENT ********************
! Comment:  Define the blunder and escape profiles for the aircraft.
AC_CASE BLUNDER_1  AC 1  TYPE 0  RWY L  Dstart  62000.0  Tstart m+SD   0.0  0.0
>>>      dTURN 3.0 Dblund hi,lo 60761.0 12152.2 BLUND m+SD ANG 30.0 0.0 SLOPE -3.0 0.0 DV 0.0 0.0
AC_CASE NORM_ESC_1 AC 2  TYPE 0  RWY R  Dstart  62000.0  Tstart m+SD   0.0  0.0
>>>      BANK m+SD 22.0  0.0  HEAD  55.0 CLIMB/ACCEL BY TYPE

****************** RUNWAY GEOMETRY SEGMENT ********************
! Comment:  Define runway geometry.
RWY_PAIR  SEP 4300.0  NTZ 2000.0

! Comment:  Define alarm criteria and response delay times.
ALARM     Dalarm 1150.0

****************** RESPONSE TIME SEGMENT ********************
RESPONSE SENSOR GAUSSIAN    8.9    9.8
RESPONSE ATC    GAUSSIAN    0.0    0.0
RESPONSE COM    GAUSSIAN    0.0    0.0
RESPONSE PILOT  GAUSSIAN    0.0    0.0

****************** RUNX SEGMENT ********************
! Comment:  Define the range of x-offset geometries and the number of runs.
! Comment:  Evader ranges from 2500 ahead to 3500 feet behind blunderer.
STEP_DX  DXmin,max,step  -2500.0   3500.0     50.0
RUN_X      100    SEED    9876543
QUIT
```

Figure 19. Baseline Case Input File for IMC Approach to Parallel Runways

LO	HI	HITSper	HITSn	HITSper_cum	HITSn_cum
0.0	100.0	0.0039	47	0.0039	47
100.0	200.0	0.0084	102	0.0123	149
200.0	300.0	0.0075	91	0.0198	240
300.0	400.0	0.0100	121	0.0298	361
400.0	500.0	0.0107	130	0.0406	491
500.0	600.0	0.0114	138	0.0520	629
600.0	700.0	0.0109	132	0.0629	761
700.0	800.0	0.0131	159	0.0760	920
800.0	900.0	0.0154	186	0.0914	1106
900.0	1000.0	0.0162	196	0.1076	1302
1000.0	1100.0	0.0164	198	0.1240	1500
1100.0	1200.0	0.0199	241	0.1439	1741
1200.0	1300.0	0.0202	244	0.1640	1985
1300.0	1400.0	0.0205	248	0.1845	2233
1400.0	1500.0	0.0215	260	0.2060	2493
1500.0	1600.0	0.0234	283	0.2294	2776
1600.0	1700.0	0.0247	299	0.2541	3075
1700.0	1800.0	0.0261	316	0.2802	3391
1800.0	1900.0	0.0296	358	0.3098	3749
1900.0	2000.0	0.0273	330	0.3371	4079
2000.0	2100.0	0.0298	360	0.3669	4439
2100.0	2200.0	0.0307	372	0.3976	4811
2200.0	2300.0	0.0350	424	0.4326	5235
2300.0	2400.0	0.0332	402	0.4659	5637
2400.0	2500.0	0.0309	374	0.4968	6011
2500.0	2600.0	0.0340	411	0.5307	6422
2600.0	2700.0	0.0320	387	0.5627	6809
2700.0	2800.0	0.0308	373	0.5936	7182
2800.0	2900.0	0.0262	317	0.6198	7499
2900.0	3000.0	0.0249	301	0.6446	7800
3000.0	3100.0	0.0193	234	0.6640	8034
3100.0	3200.0	0.0196	237	0.6836	8271
3200.0	3300.0	0.0164	198	0.6999	8469
3300.0	3400.0	0.0180	218	0.7179	8687
3400.0	3500.0	0.0140	170	0.7320	8857
3500.0	3600.0	0.0110	133	0.7430	8990
3600.0	3700.0	0.0101	122	0.7531	9112
3700.0	3800.0	0.0088	106	0.7618	9218
3800.0	3900.0	0.0074	89	0.7692	9307
3900.0	4000.0	0.0082	99	0.7774	9406
4000.0	4100.0	0.0131	158	0.7904	9564
4100.0	4200.0	0.0147	178	0.8051	9742
4200.0	4300.0	0.0190	230	0.8241	9972
4300.0	4400.0	0.0234	283	0.8475	10255
4400.0	4500.0	0.0250	302	0.8725	10557
4500.0	4600.0	0.0281	340	0.9006	10897
4600.0	4700.0	0.0202	245	0.9208	11142
4700.0	4800.0	0.0161	195	0.9369	11337
4800.0	4900.0	0.0135	163	0.9504	11500
4900.0	5000.0	0.0108	131	0.9612	11631

Figure 20. Baseline Case Output File for IMC Approach to Parallel Runways

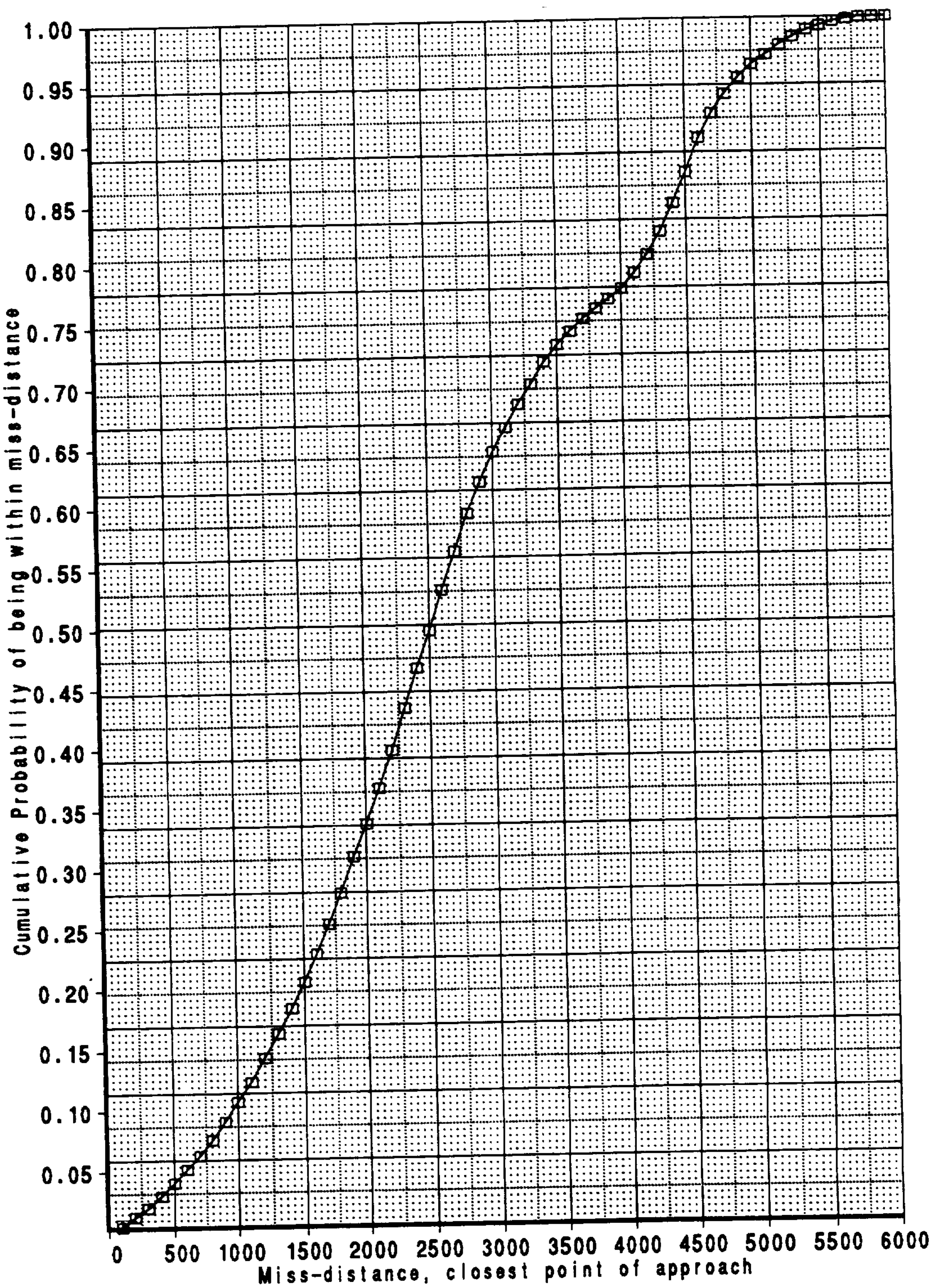

Figure 21. Cumulative Probability Distribution Function of the CPA Miss-Distance

7.2 SENSITIVITY ANALYSIS OF IFR SIMULATION

The sensitivity analysis for IMC simulation was determined by separately conducting a series of runs for each of 14 parameters. Each individual run consisted of 12,100 trials. In each series the parameters were varied through a range of values so as to measure the system sensitivity to that parameter. The histogram data for the probability of miss distance from 0 to 1,000 ft for incremental values of 14 parameters are listed in *Appendix A*. The tabular data are presented graphically in *Figures 22-36*. The nominal baseline values in the sensitivity analysis for the parameters were shown in subsection 7.1.

7.2.1 SENSITIVITY TO TOTAL RESPONSE TIME

The total response time is defined as the time that commences with the start of blunder and ends when the evading aircraft starting to turn (i.e., communications time + controller response time + pilot response time + aircraft response time = total response time). *Figure 22* shows the sensitivity of the probability of unresolved blunders to these times with zero variation, and for 4, 8, 12, 16 and 20 sec. In addition, *Figure 22* illustrates that the longer the time, then the higher the probability of closest miss distance.

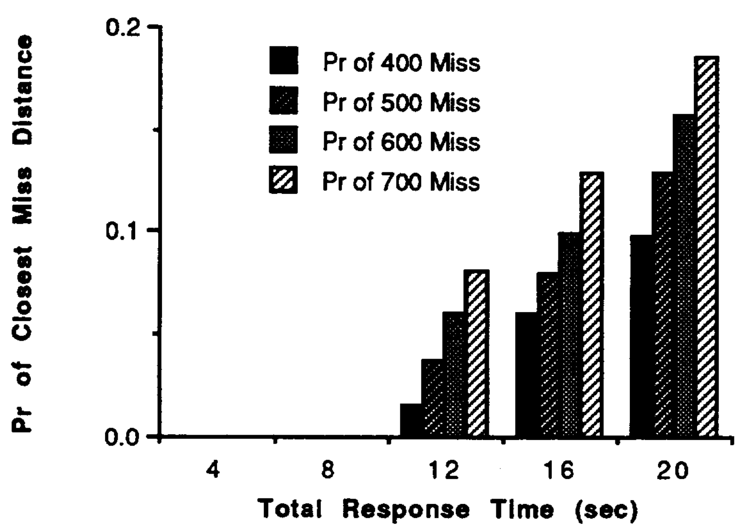

Figure 22. Sensitivity Analysis - Total Response Time

7.2.2 SENSITIVITY TO TOTAL SYSTEM RESPONSE TIME UNCERTAINTY

The sensitivity with respect to total system response time uncertainty is shown in *Figure 23*. The uncertainties are in the form of variation in standard deviation (SD). The baseline case has been varied from 0 to 4, 8, 12 and 16 sec. The bars in *Figure 23* indicate that the larger the response time uncertainties the higher the probabilities of closest miss distance.

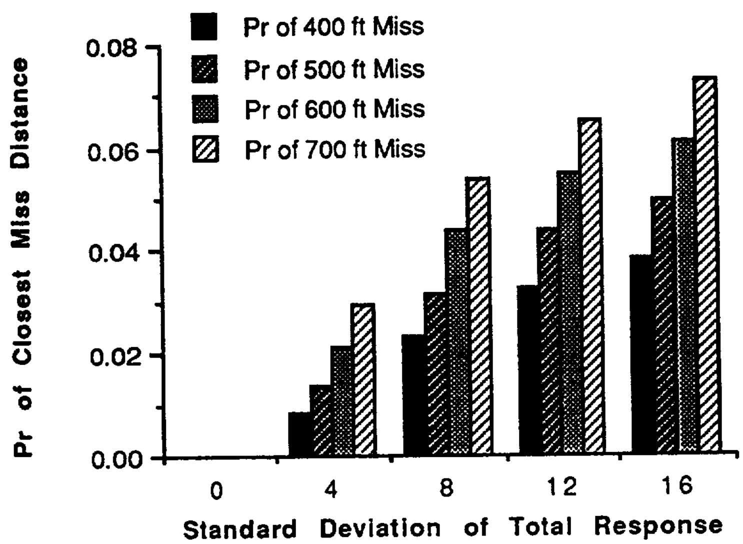

Figure 23. Sensitivity Analysis - Uncertainty of Total Response Time

7.2.3 SENSITIVITY TO RUNWAY SEPARATION WITH VARIABLE NOZ WIDTH

The sensitivity of the probability of unresolved blunder with respect to runway spacing with variable NOZ width is shown in *Figure 24*. In this case the NTZ width remains constant at 2,000 ft. The runway spacing for these runs were at 2,900; 3,600; 4,300; 5,000; and 5,700 ft, respectively. The bars illustrate that when there is smaller spacing between the parallel runways, then greater probability of closest miss distance results.

7.2.4 SENSITIVITY TO RUNWAY SEPARATION WITH VARIABLE NTZ WIDTH

Sensitivity with respect to runway separation with variable NTZ width is shown in *Figure 25*. In this case the NOZ width remains constant at 1,150 ft. The runway spacing for these runs were at 2,900; 3,600; 4,300; 5,000; and 5,700 ft, respectively. Again as seen in *Figure 24*, when there is smaller spacing between the parallel runways, then greater probability of closest miss distance results.

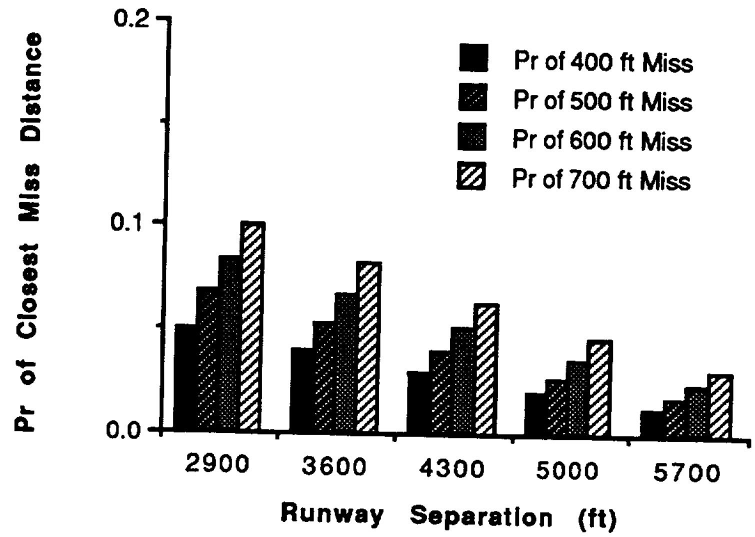

Figure 24. Sensitivity Analysis - Constant NTZ = 2,000 ft

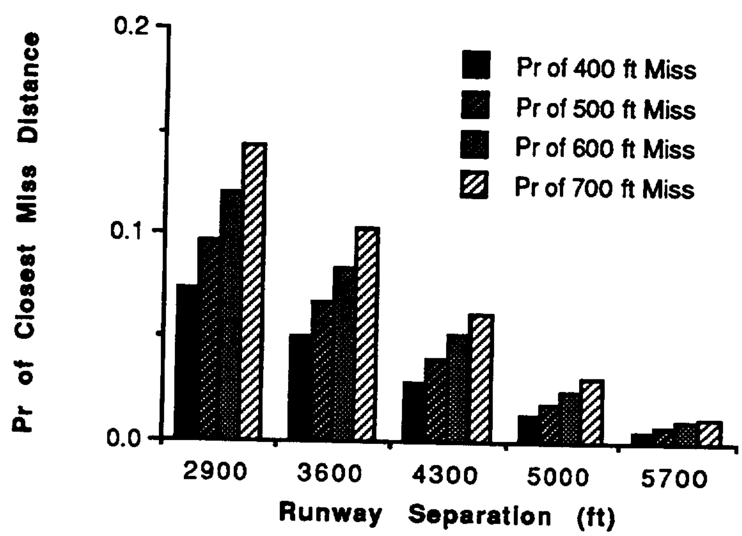

Figure 25. Sensitivity Analysis - Constant NOZ=1,150 ft

(NOTE: When comparing *Figures 24* and *25* it is observed that the NTZ width of a constant 2,000 ft has smaller probability of closest miss distance for less than 4,300 ft parallel runway spacing and a slightly greater probability of closest miss distance for more than 4,300 ft parallel runway spacing. Therefore, relative to the collision probability current 2,000-foot width for NTZ, for runway spacing below 4,300 ft, is the best choice.)

7.2.5 SENSITIVITY TO LONGITUDINAL OFFSET WHEN BLUNDER OCCURS

The sensitivity with respect to the longitudinal relation between evader and blunderer is shown in *Figure 26*. The horizontal axis shows the relation of evading aircraft with respect to the blunderer (i.e., -10,000 ft indicates that the evader is 10,000 ft behind the blundering aircraft projected at the approach centerline of the other runway). The longitudinal relation between the blunderer and evader has been set at -10,000; -20,000; -1,000; 1,000; 2,000; and 10,000 ft, respectively. As it can be seen in *Figure 26*, the case with the highest probability of closest miss distance is the one in which the blunderer is 1,000 ft ahead of the evader.

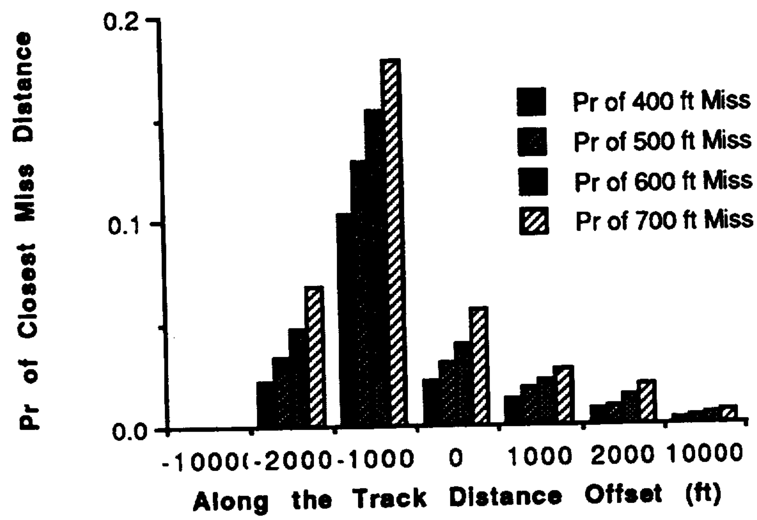

Figure 26. Sensitivity Analysis - Along the Track Offset

7.2.6 SENSITIVITY TO APPROACH SPEEDS OF THE TWO AIRCRAFT

The sensitivity with respect to variations in approach speeds of the two aircraft is shown in *Figure 27*. The horizontal axis shows that the speed of the two aircraft is at 100, 120, 140, 160 and 180 kn (true air speed), respectively. *Figure 27* indicates that an increasing speed would increase the probability of the closest miss distance.

7.2.7 SENSITIVITY TO CHANGE IN BANK ANGLE OF EVADER

The sensitivity with respect to changes in the maximum bank angle of evader is shown in *Figure 28*. The horizontal axis indicates the bank angle of the evader to be 15, 22, 30, 38 and 45 deg immediately after evading. It can be inferred from *Figure 28* that the greater the allowable bank angle, the smaller the probability of closest miss distance.

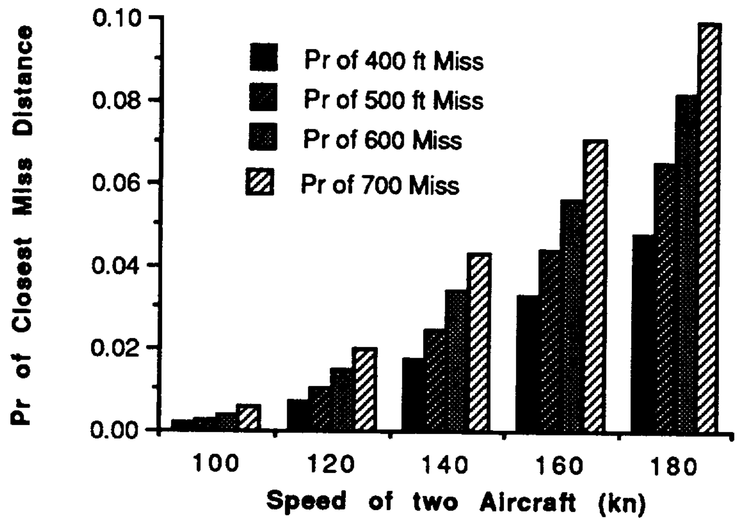

Figure 27. Sensitivity Analysis - Speed of the Two Aircraft

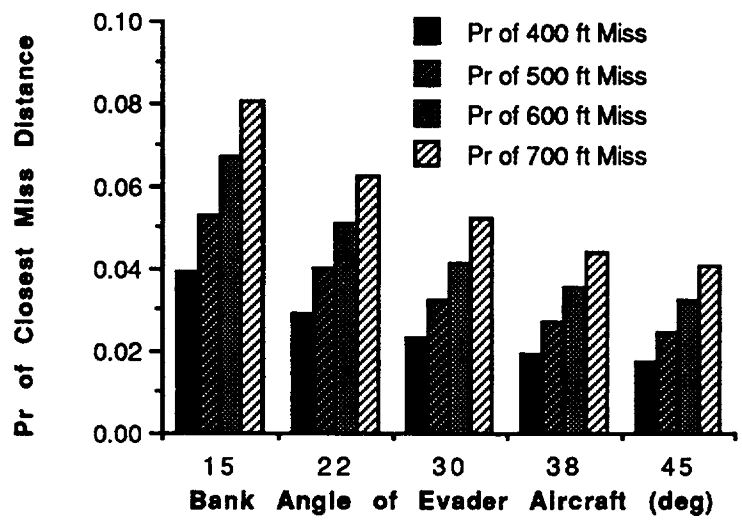

Figure 28. Sensitivity Analysis - Bank Angle of Evader

7.2.8 SENSITIVITY TO CLIMB RATE OF EVADER

The sensitivity with respect to climb rate of evader aircraft is shown in *Figure 29*. The horizontal axis scaling shows the variation at 20, 30, 40, 50 and 60 ft/sec, respectively, for the climb rate of the evader. The bars in *Figure 29* indicate that a change in the climb rate of the evader does not effect the probability of the closest miss distance because, in most cases, the turn is only partially completed at the instant of closest approach. The climb maneuver is assumed to start only after the turn is complete. If the bank angle is increased (from 22 deg) or the evasion turn heading angle is decreased (from 55 deg), then the climb rate will have a minor effect.

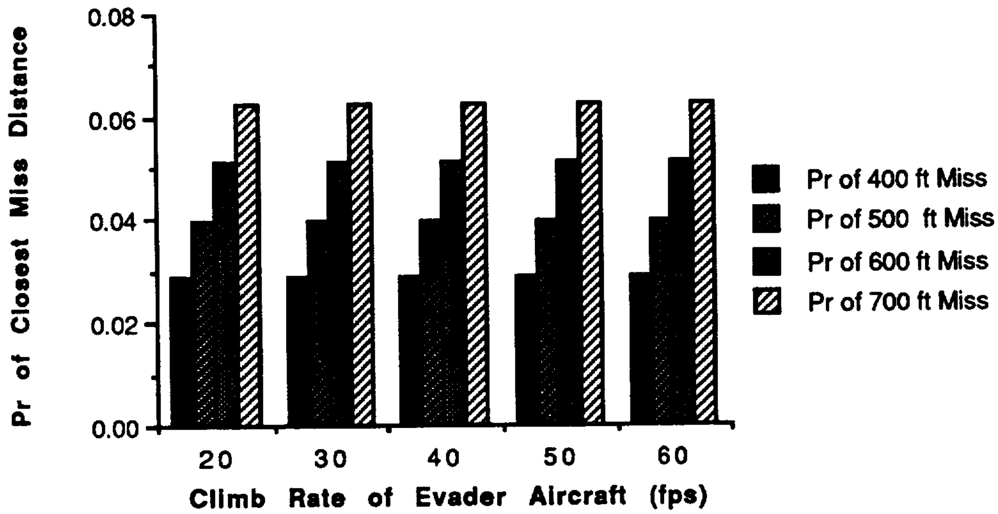

Figure 29. Sensitivity Analysis - Climb Rate of Evader

7.2.9 SENSITIVITY TO TURN RATE OF BLUNDERER

Figure 30 shows the sensitivity to the turn rate of the blundering aircraft. The horizontal axis scaling shows the changes in turn rate of the blunderer at 1, 2, 3, 4, or 5 deg/sec, respectively. The turn rate of the blunderer appears to have little effect on probability of closest miss distance.

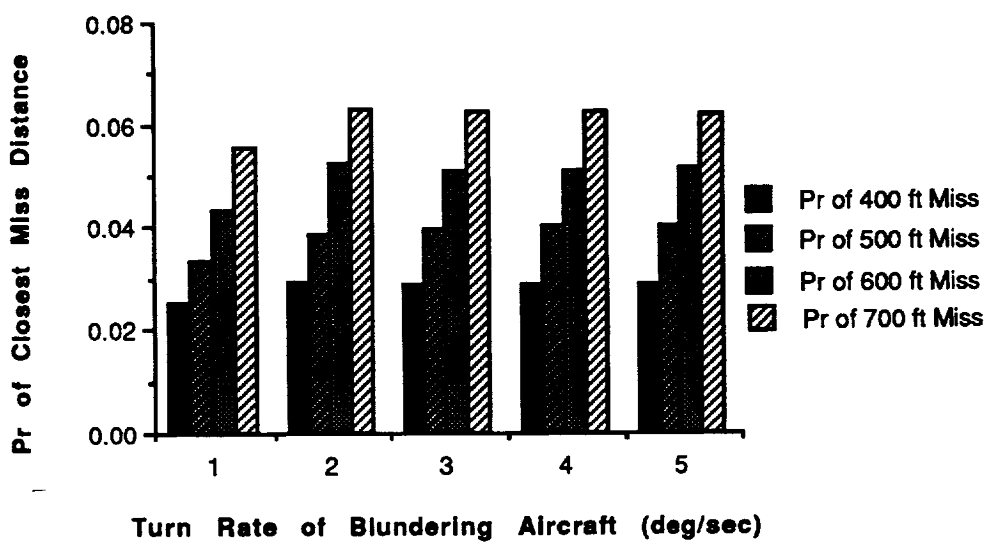

Figure 30. Sensitivity Analysis - Turn Rate of Blunderer

7.2.10 SENSITIVITY TO BLUNDER ANGLE

Sensitivity to the crossing angle of blundering aircraft is shown in *Figure 31*. The horizontal scale shows the assumed blunder angle variation at 15, 20, 25, 30, and 35 deg. It can be seen that blunder angle has a strong effect on the probability of the closest miss distance (i.e., the greater the blunder angle the greater the risk of unresolved blunder.)

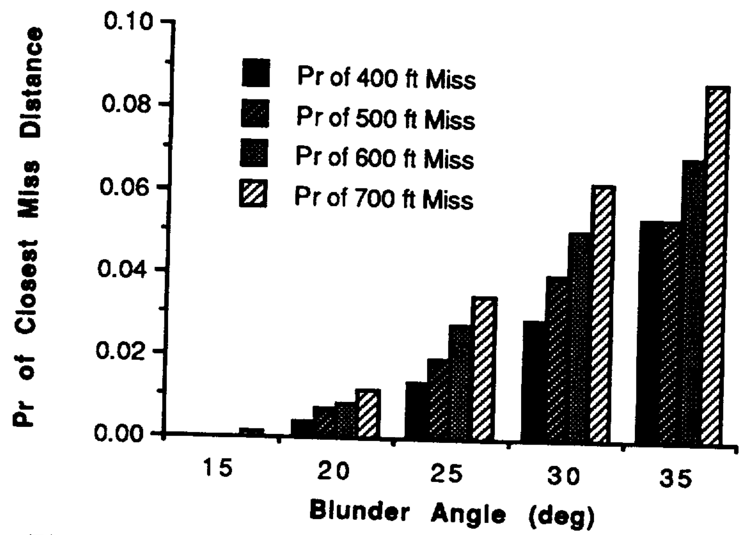

Figure 31. Sensitivity Analysis - Blunder Angle

7.2.11 SENSITIVITY TO SURVEILLANCE AZIMUTH ERROR

The sensitivity with respect to assumed surveillance error is shown in *Figure 32*. This error has been varied at 0, 3, 6, and 9 mr. Surveillance error changes do not appear to effect the probability of closest miss distance of unresolved blunder.

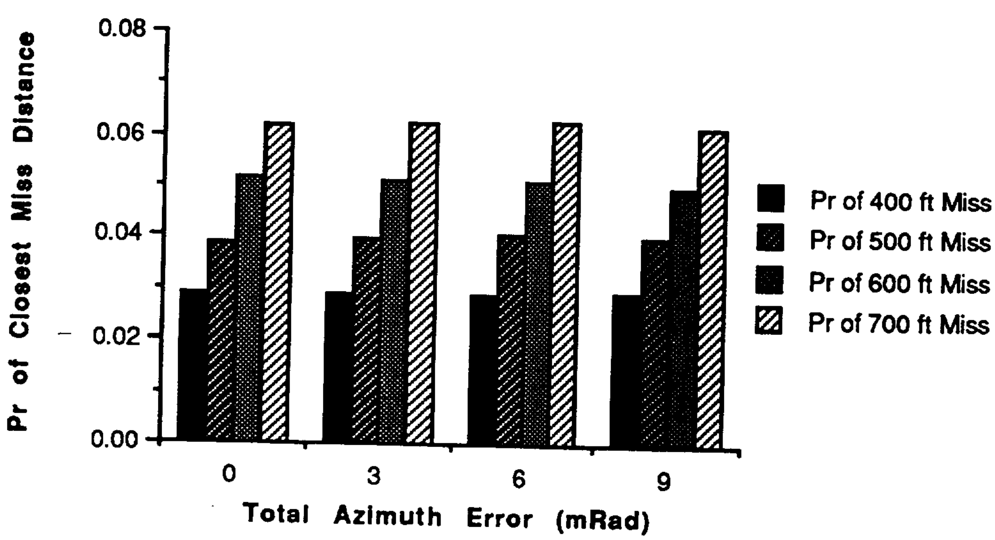

Figure 32 Sensitivity Analysis - Surveillance Error

7.2.12 SENSITIVITY TO EVASION HEADING TURN

The evasion maneuver heading turn sensitivity is shown in *Figure 33*. The evader aircraft heading turn is assumed for 30, 45, 60, 75 and 90 deg in this analysis. Evasion heading turn does not appear to have any effect on the probability of closest miss distance.

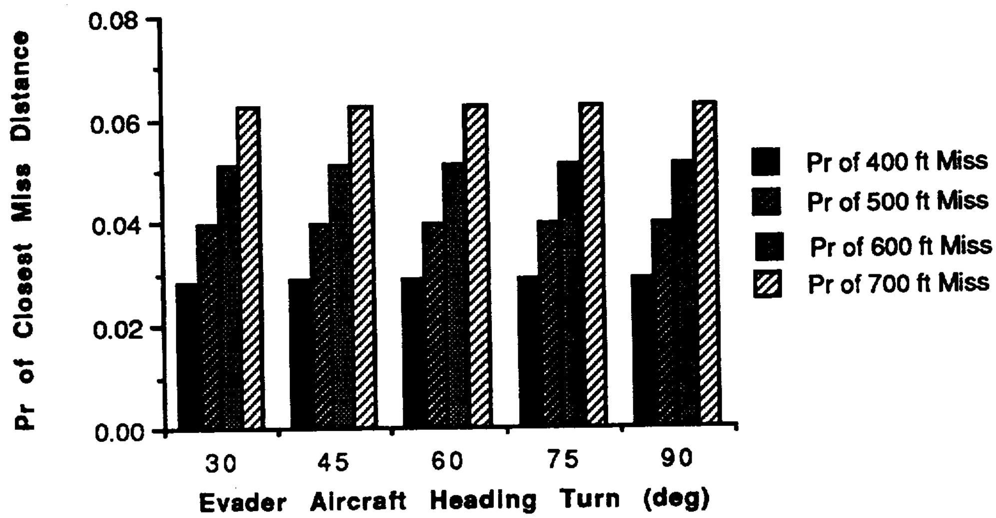

Figure 33 Sensitivity Analysis - Evasion Heading Turn

7.2.13 SENSITIVITY TO BLUNDERING AIRCRAFT DISPLACEMENT FROM THE CENTERLINE WHEN BLUNDER OCCURS

Figure 34 shows the sensitivity with respect to the displacement of the blundering aircraft from the approach centerline. The assumed displacement values are 150, 400, 650, 900 and 1,150 ft, respectively, from the approach center line of the intended runway that the blundering aircraft is assigned. It can be observed that the initial displacement from the approach centerline of the blunderer has a significant effect on the probability of closest miss distance.

7.2.14 SENSITIVITY TO EVADER SPEED INCREASE

The sensitivity with respect to evader speed increase is shown in *Figure 35*. The scaling of horizontal axis shows the effect of speed increases at 0, 15, 30, 45 and 60 ft/sec which are caused by the evader maneuvering to escape. The evader's speed increase does not appear to have any effect on the probability of closest miss distance. The model assumption is that the evader will not increase speed until the turn is completed. The analysis indicates that the point of closest approach occurs before the turn is complete, which explains the lack of sensitivity to this variable.

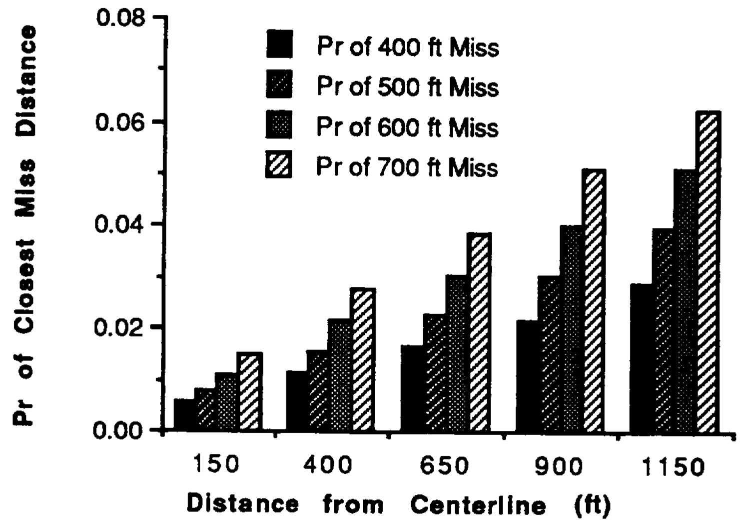

Figure 34 Sensitivity Analysis - Displacement from Approach Centerline

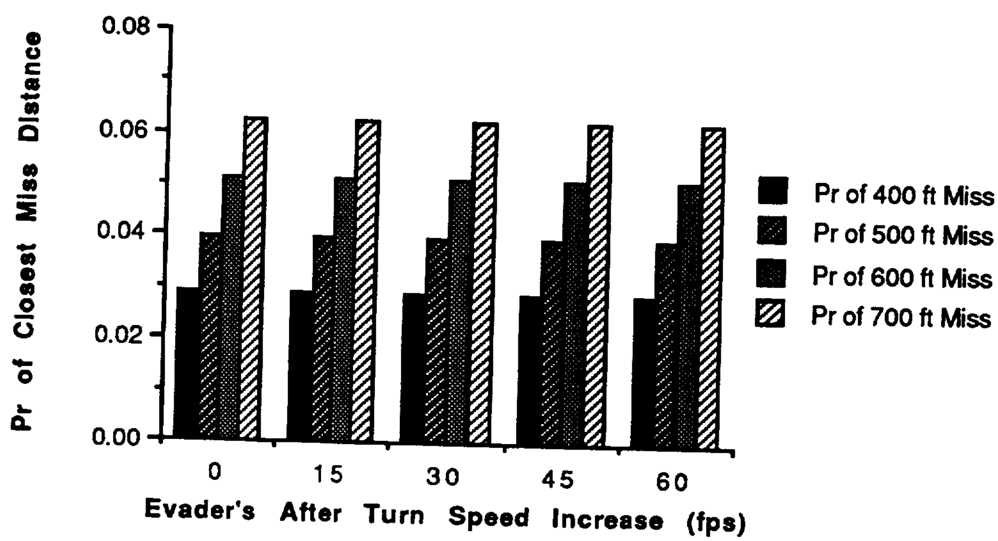

Figure 35 Sensitivity Analysis - Evader Speed Increase

7.2.15 COMPARISON WITH *NO EVASION MANUEVER*

Figure 36 shows the total response time effect compared with the scenario where the endangered aircraft does not react to a blunderer. The figure indicates that when the system response time approaches 20 sec, the evasion maneuver contributes little or nothing to the safety of the operation.

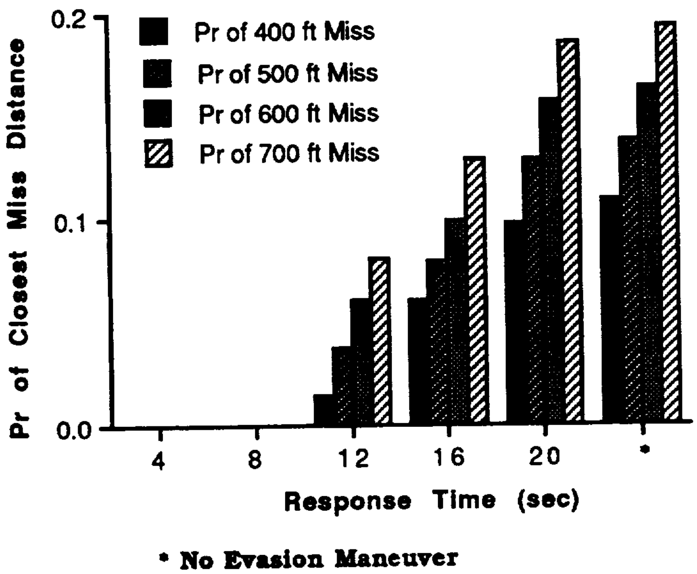

Figure 36 Sensitivity Analysis - Total Response Time

7.3 INTER-RELATIONS OF SENSITIVE PARAMETERES OF THE MODEL

The sensitivity analysis for individual parameters of the simulation model (subsection 7.2) showed that some of the parameters have a strong impact on the probability of closest miss distance, whereas other parameters had virtually no effect or minor impact on the probability of the closest miss distance. Herein the most sensitive parameters are observed more closely and their variation analyzed with respect to total response time and parallel runway separation. This is done by varying the parameters, total response time, and runway separation while maintaining the same risk as the inter-relations baseline case. The data used in this subsection is in *Appendix B*.

The inter-relations baseline case is like the previous baseline except that the nominal alarm distance criteria is 10% of the runway separation for each run (e.g., the alarm distance criteria would be 4,300 feet for a 4,300-foot runway separation). This 10% criteria was chosen to make the blunder response more realistic while preserving simplicity. The probability of an unresolved blunder (CPA < 500 ft) is about 1.5% for the inter-relations baseline case.

7.3.1 IMPACT OF CHANGE IN AIRCRAFT SPEED

Figure 37 shows the relation of change in speed for both the blunderer and evader aircraft and how these effect the total response time and runway spacing. The horizontal axis shows the response time increments in seconds while the vertical axis shows the runway separation in feet. The plots and legend show the different variations in speed.

These plots indicate that change in speed of aircraft direct correlation with the total delay time and runway separation. Also it indicates that the higher the speed, the less time that is allowed for the controller and pilot to react in resolving the blunder. Furthermore, greater runway spacing is required if the aircraft is flying at higher speeds. The plots also indicate the relation of the baseline with respect to these changes.

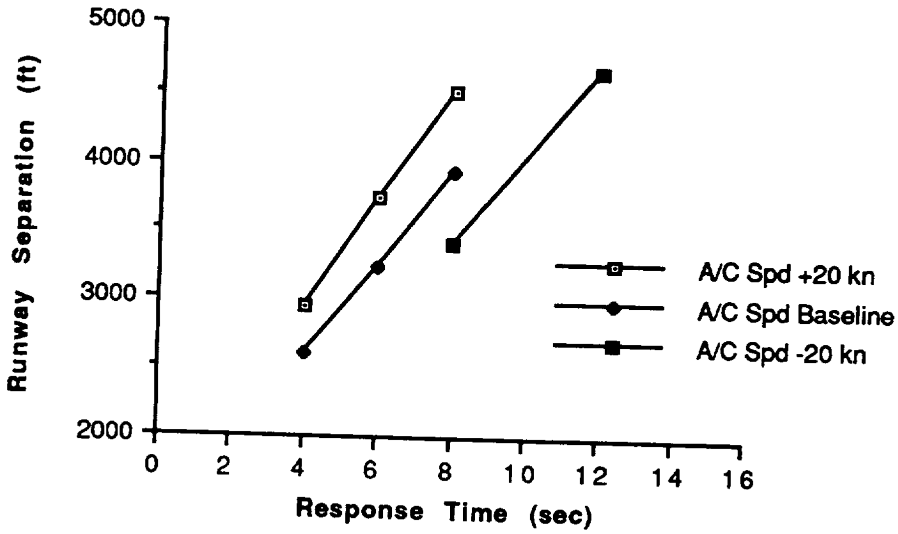

Figure 37 Change In Speed

7.3.2 IMPACT OF CHANGE IN SPEED OF BLUNDERING AIRCRAFT

Figure 38 shows the plots that represent the changes in speed of the blunderer. The scaling of the horizontal and vertical axis are the same as in *Figure 37*. The plot indicates that the relation of the blunderer speed change with respect to total response time or parallel runway spacing is nonlinear. The lower speed by the blunderer reduces the risk much faster than the higher speed by blunderer increases the risk. Also, the figure indicates that there is less time to take action if the blunderer is flying with faster speed. The plots show the relation of the baseline with respect to these changes.

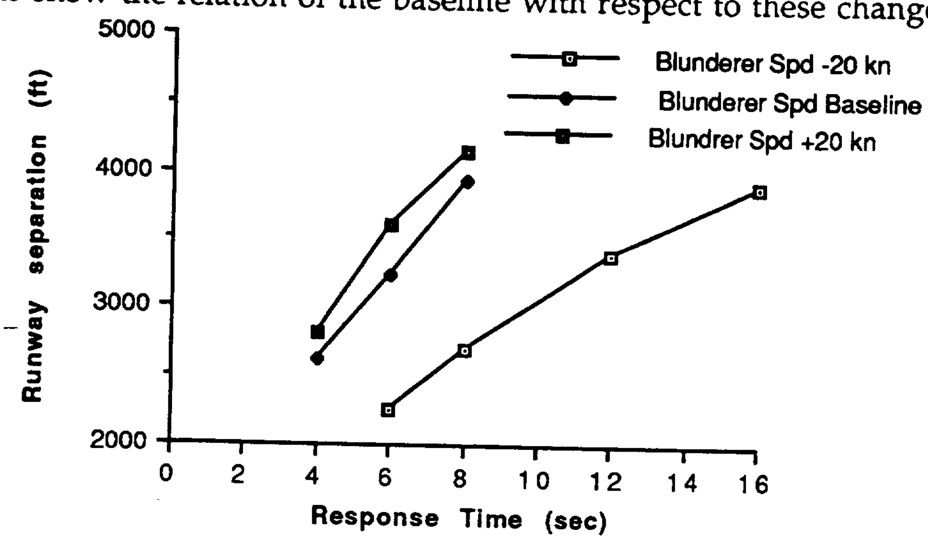

Figure 38 Blunderer Speed

7.3.3 IMPACT OF CHANGE IN BLUNDER ANGLE

Figure 39 shows the relation of change in the crossing angle of the blundering aircraft and its effects on parallel runway spacing and total response time of the evading aircraft. The plot shows a slight nonlinear correlation between blunder angle and other two parameters. Also, it shows that the larger the blunder-angle the less the response time that is available to the evader in order to satisfy the miss distance criteria. The plot shows the relation of the baseline with respect to these changes.

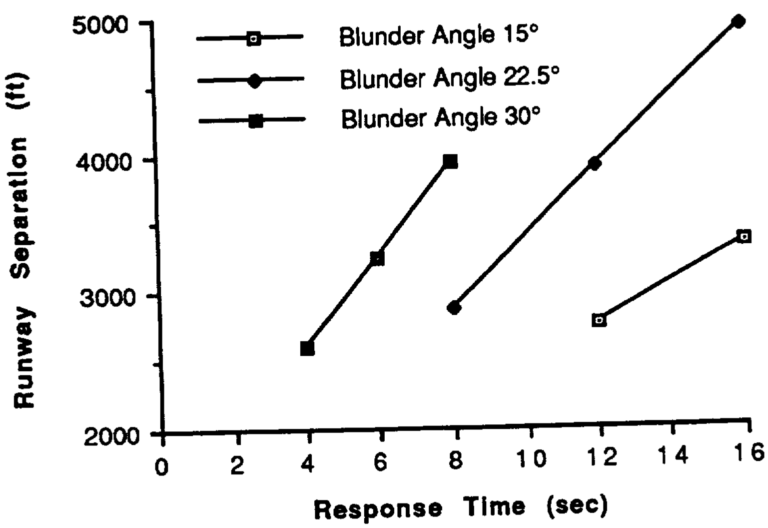

Figure 39 Blunder Angle

7.3.4 IMPACT OF ALONG THE TRACK OFFSET DISTANCE

Figure 40 shows the relation of change in the evader aircraft longitudinal offset distance from the blundering aircraft to the parallel runway spacing and total response time of the evading aircraft. The correlation is nonlinear, and the plots show the relation of the nominal baseline case with respect to the variations. As was seen in sensitivity analysis and is indicated here, the highest probability of unresolved blunders occurs when the evader is 1,000 ft behind (on the other runway) the blundering aircraft. The plot indicates that the more the two aircraft are staggered the greater allowance of the response time for the evader to react and the smaller the requirement for parallel runway spacing compared to the baseline case.

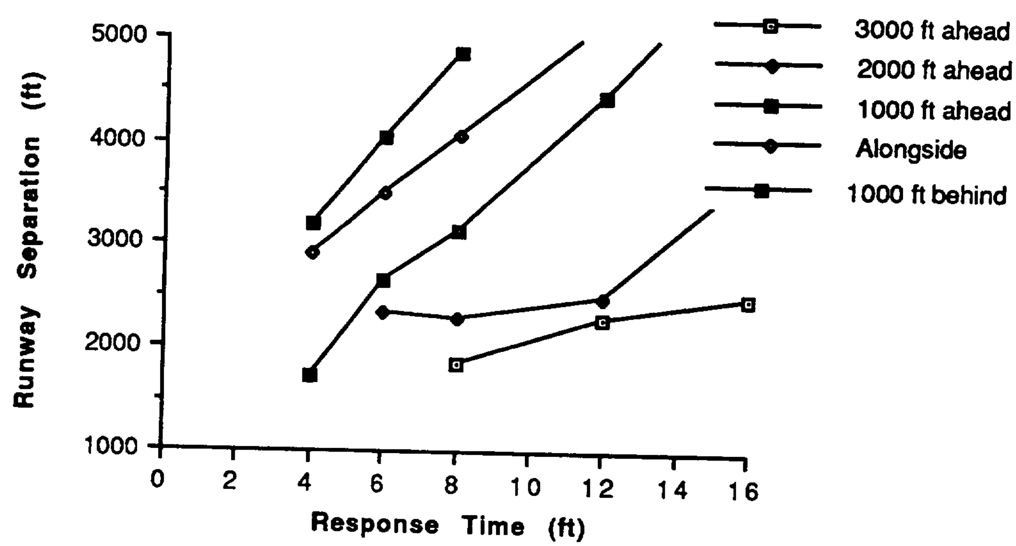

Figure 40 Longitudinal Offset Distance

7.3.5 IMPACT OF DISPLACEMENT FROM RUNWAY CENTERLINE

Figure 41 shows the effect of change in the displacement from the extended runway centerline of the blundering aircraft on parallel runway spacing and total response time of evading aircraft. The plots indicate that the greater the lateral distance of blundering aircraft from its extended centerline before the blunder maneuver, then the greater the probability of an unresolved blunder.

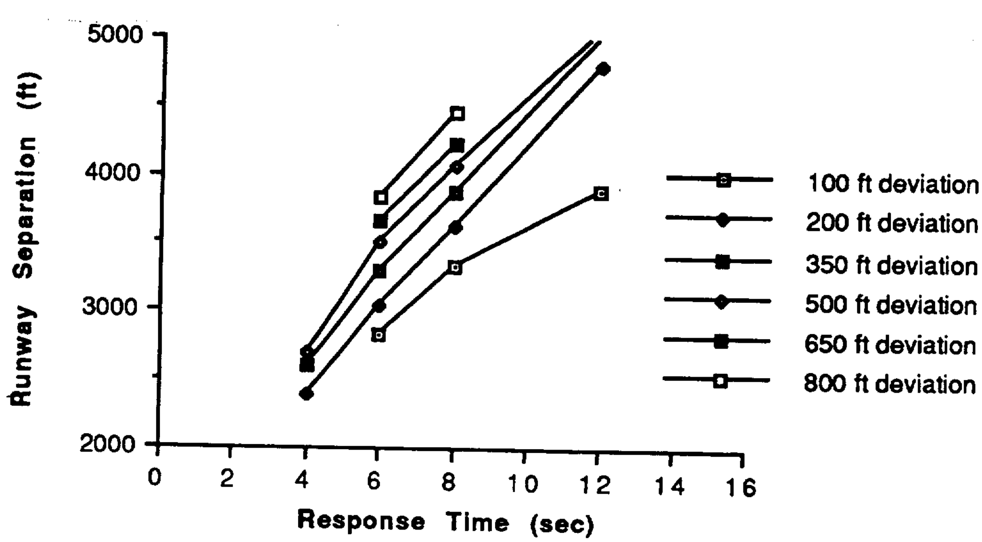

Figure 41 Lateral Offset Distance

7.3.6 IMPACT OF RESPONSE TIME UNCERTAINITY

Figure 42 shows the effect of total response time uncertainty SD on parallel runway spacing and total response time. The plots indicate that the larger the total response time uncertainty, the shorter the response time and the greater parallel runway spacing required for the evading aircraft. This response time uncertainty can be interpreted as a reflection of the various levels of controller proficiency and/or aircraft fleetmix.

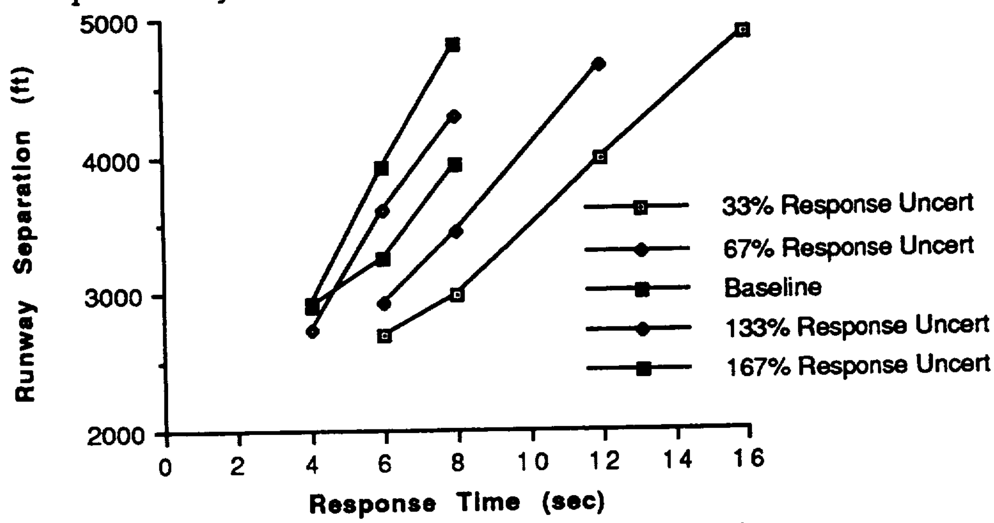

Figure 42. Response Time Uncertainty

7.3.7 IMPACT OF EVADING AIRCRAFT BANK ANGLE

Figure 43 shows the effect of maximum bank angle of the evader aircraft on parallel runway spacing and total response time of evading aircraft. The plot indicates that the greater the bank angle of the evader, the faster it moves away from the blundering aircraft. The bank angle of the baseline case is 22 deg. The plot shows the effect of the response time on runway separation.

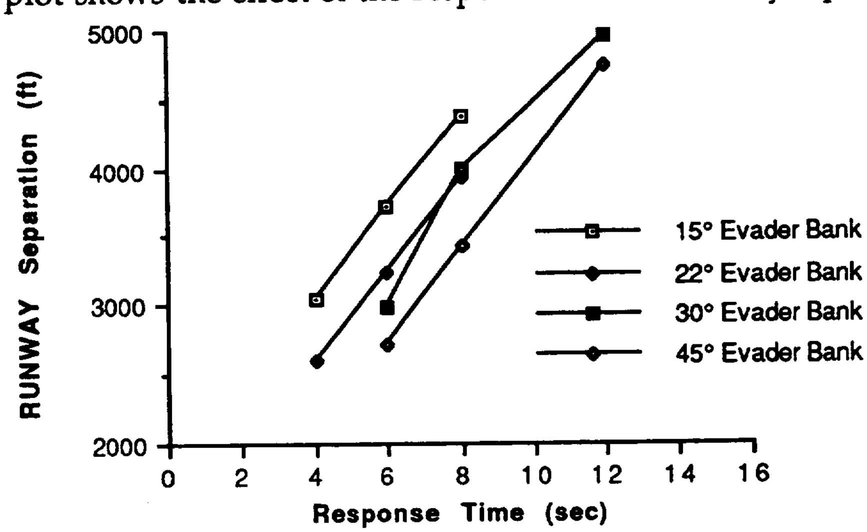

Figure 43. Evader Bank Angle

8.0 ANALYSIS OF VMC APPROACH TO PARALLEL RUNWAYS

The same method used for defining the baseline for instrument approach during IMC (Section 7) is used here to define the baseline for visual approaches to parallel runways. As with IMC analysis, the probability of CPA of two aircraft (i.e., one blundering and one evading) for visual approach was selected as the guideline for investigating the sensitivity analysis results as well as evaluating the variation and cross correlation of the simulation model parameters.

8.1 SENSITIVITY ANALYSIS OF VISUAL APPROACH TO PARALLEL RUNWAYS

Figure 44 shows the baseline case parameters selected to represent the visual approaches to parallel runways. A brief summary of the parameters and their values are:

runway separation	800 ft
alarm distance	100 ft
NTZ width	1 ft
TAE mean/SD	-1/-1 mr
response time	3 sec
response time SD	3 sec
longitudinal relation	-2,500 to 3,500 ft
sim blunderer start	28,000 ft (from runway threshold)
nominal speed	varies according to aircraft type (refer to input file)
blunder at	24,304 to 6,076 ft
blunder angle	30 deg
blunder turn rate	3 deg/sec
evader bank angle	45 deg
evader turn heading	55 deg
evader climb rate	varies according to aircraft type (refer to input file)
evader speed increase	0
evader/blunder fleetmix	percent of aircraft fleetmix (6 types of aircraft class) categorized by speed mean and SD at far/close distances from runway threshold

Figure 44 shows the inputs and *Figure 45* the output of the VMC baseline case. In the latter figure, data out to a CPA of 5,000 ft is shown. The probability of an unresolved blunder is almost 8% for the baseline case (i.e., CPA < 500 ft). Although the unresolved blunder probability for the VMC baseline is double that of the IMC case, the underlying blunder probability has not been factored into the analysis. Therefore it is difficult to draw any conclusions regarding the relative safety of instrument versus visual parallel approaches. *Figure 46* shows the cumulative probability distribution functions of the miss distance for respective CPAs.

```
******************** AC TYPE SEGMENT *********************
! Comment:  Define aircraft types and fleetmix.
! Comment:  MITRE_type : AC_TYPE correlation (1:1  2:2  3:3  4:-  5:-  6:-  7:4  8:5  9:6)
AC_TYPE 1  SIZE 100.0 100.0  50.0 Tresponse  0.0  0.0  SPD 1,2 m+SD 150.0 1.78 100.0 1.78   kts
>>>      ESC ACEL,CLMB m+SD  0.0  0.0 33.0  0.0  FTE ANGLE(mR) m+SD  -1.0   1.0
AC_TYPE 2  SIZE 100.0 100.0  50.0 Tresponse  0.0  0.0  SPD 1,2 m+SD 150.0 1.78 110.0 1.78   kts
>>>      ESC ACEL,CLMB m+SD  0.0  0.0 17.0  0.0  FTE ANGLE(mR) m+SD  -1.0   1.0
AC_TYPE 3  SIZE 100.0 100.0  50.0 Tresponse  0.0  0.0  SPD 1,2 m+SD 150.0 1.78 110.0 1.78   kts
>>>      ESC ACEL,CLMB m+SD  0.0  0.0 25.0  0.0  FTE ANGLE(mR) m+SD  -1.0   1.0
AC_TYPE 4  SIZE 230.0 200.0  70.0 Tresponse  0.0  0.0  SPD 1,2 m+SD 180.0 1.78 140.0 1.78   kts
>>>      ESC ACEL,CLMB m+SD  0.0  0.0 33.0  0.0  FTE ANGLE(mR) m+SD  -1.0   1.0
AC_TYPE 5  SIZE 230.0 200.0  70.0 Tresponse  0.0  0.0  SPD 1,2 m+SD 180.0 1.78 140.0 1.78   kts
>>>      ESC ACEL,CLMB m+SD  0.0  0.0 42.0  0.0  FTE ANGLE(mR) m+SD  -1.0   1.0
AC_TYPE 6  SIZE 230.0 200.0  70.0 Tresponse  0.0  0.0  SPD 1,2 m+SD 180.0 1.78 140.0 1.78   kts
>>>      ESC ACEL,CLMB m+SD  0.0  0.0 50.0  0.0  FTE ANGLE(mR) m+SD  -1.0   1.0
FLEETMIX (1-6)   9.0   5.7   5.3  21.0  43.0  16.0
******************** PROFILE SEGMENT *********************
! Comment:  Define the blunder and escape profiles for the aircraft.
AC_CASE BLUNDER_1  AC 1  TYPE 0  RWY L  Dstart  28000.0  Tstart m+SD   0.0  0.0
>>>      dTURN  3.0 Dblund hi,lo  6076.1 24304.4  BLUND m+SD ANG  30.0  0.0 SLOPE -3.0  0.0 DV  0.0  0.0
AC_CASE NORM_ESC_1 AC 2  TYPE 0  RWY R  Dstart  28000.0  Tstart m+SD   0.0  0.0
>>>      BANK m+SD 45.0  0.0  HEAD  55.0 CLIMB/ACCEL BY TYPE
******************** RUNWAY GEOMETRY SEGMENT *********************
! Comment:  Define runway geometry.
RWY_PAIR  SEP  800.0  NTZ    1.0
! Comment:  Define alarm criteria and response delay times.
ALARM    Dalarm  100.0
******************** RESPONSE TIME SEGMENT *********************
RESPONSE SENSOR GAUSSIAN    3.0    3.0
RESPONSE ATC    GAUSSIAN    0.0    0.0
RESPONSE COM    GAUSSIAN    0.0    0.0
RESPONSE PILOT  GAUSSIAN    0.0    0.0
******************** RUNX SEGMENT *********************
! Comment:  Define the range of x-offset geometries and the number of runs.
! Comment:  Evader ranges from 2500 ahead to 3500 feet behind blunderer.
STEP_DX  DXmin,max,step  -2500.0   3500.0     50.0
RUN_X      100     SEED     9876543
QUIT
```

Figure 44. Baseline Case Input File for Visual Approach to Parallel Runways

LO	HI	HITSper	HITSn	HITSper_cum	HITSn_cum
0.0	100.0	0.0087	105	0.0087	105
100.0	200.0	0.0104	126	0.0191	231
200.0	300.0	0.0164	198	0.0355	429
300.0	400.0	0.0226	274	0.0581	703
400.0	500.0	0.0264	320	0.0845	1023
500.0	600.0	0.0305	369	0.1150	1392
600.0	700.0	0.0413	500	0.1564	1892
700.0	800.0	0.0420	508	0.1983	2400
800.0	900.0	0.1526	1847	0.3510	4247
900.0	1000.0	0.0477	577	0.3987	4824
1000.0	1100.0	0.0349	422	0.4336	5246
1100.0	1200.0	0.0360	435	0.4695	5681
1200.0	1300.0	0.0308	373	0.5003	6054
1300.0	1400.0	0.0299	362	0.5302	6416
1400.0	1500.0	0.0336	406	0.5638	6822
1500.0	1600.0	0.0289	350	0.5927	7172
1600.0	1700.0	0.0285	345	0.6212	7517
1700.0	1800.0	0.0292	353	0.6504	7870
1800.0	1900.0	0.0265	321	0.6769	8191
1900.0	2000.0	0.0345	417	0.7114	8608
2000.0	2100.0	0.0292	353	0.7406	8961
2100.0	2200.0	0.0295	357	0.7701	9318
2200.0	2300.0	0.0279	337	0.7979	9655
2300.0	2400.0	0.0297	359	0.8276	10014
2400.0	2500.0	0.0277	335	0.8553	10349
2500.0	2600.0	0.0283	342	0.8836	10691
2600.0	2700.0	0.0248	300	0.9083	10991
2700.0	2800.0	0.0178	215	0.9261	11206
2800.0	2900.0	0.0151	183	0.9412	11389
2900.0	3000.0	0.0158	191	0.9570	11580
3000.0	3100.0	0.0123	149	0.9693	11729
3100.0	3200.0	0.0130	157	0.9823	11886
3200.0	3300.0	0.0074	90	0.9898	11976
3300.0	3400.0	0.0056	68	0.9954	12044
3400.0	3500.0	0.0027	33	0.9981	12077
3500.0	3600.0	0.0019	23	1.0000	12100
3600.0	3700.0	0.0000	0	1.0000	12100
3700.0	3800.0	0.0000	0	1.0000	12100
3800.0	3900.0	0.0000	0	1.0000	12100
3900.0	4000.0	0.0000	0	1.0000	12100
4000.0	4100.0	0.0000	0	1.0000	12100
4100.0	4200.0	0.0000	0	1.0000	12100
4200.0	4300.0	0.0000	0	1.0000	12100
4300.0	4400.0	0.0000	0	1.0000	12100
4400.0	4500.0	0.0000	0	1.0000	12100
4500.0	4600.0	0.0000	0	1.0000	12100
4600.0	4700.0	0.0000	0	1.0000	12100
4700.0	4800.0	0.0000	0	1.0000	12100
4800.0	4900.0	0.0000	0	1.0000	12100
4900.0	5000.0	0.0000	0	1.0000	12100

Figure 45. Baseline Case Output File for Visual Approach to Parallel Runways

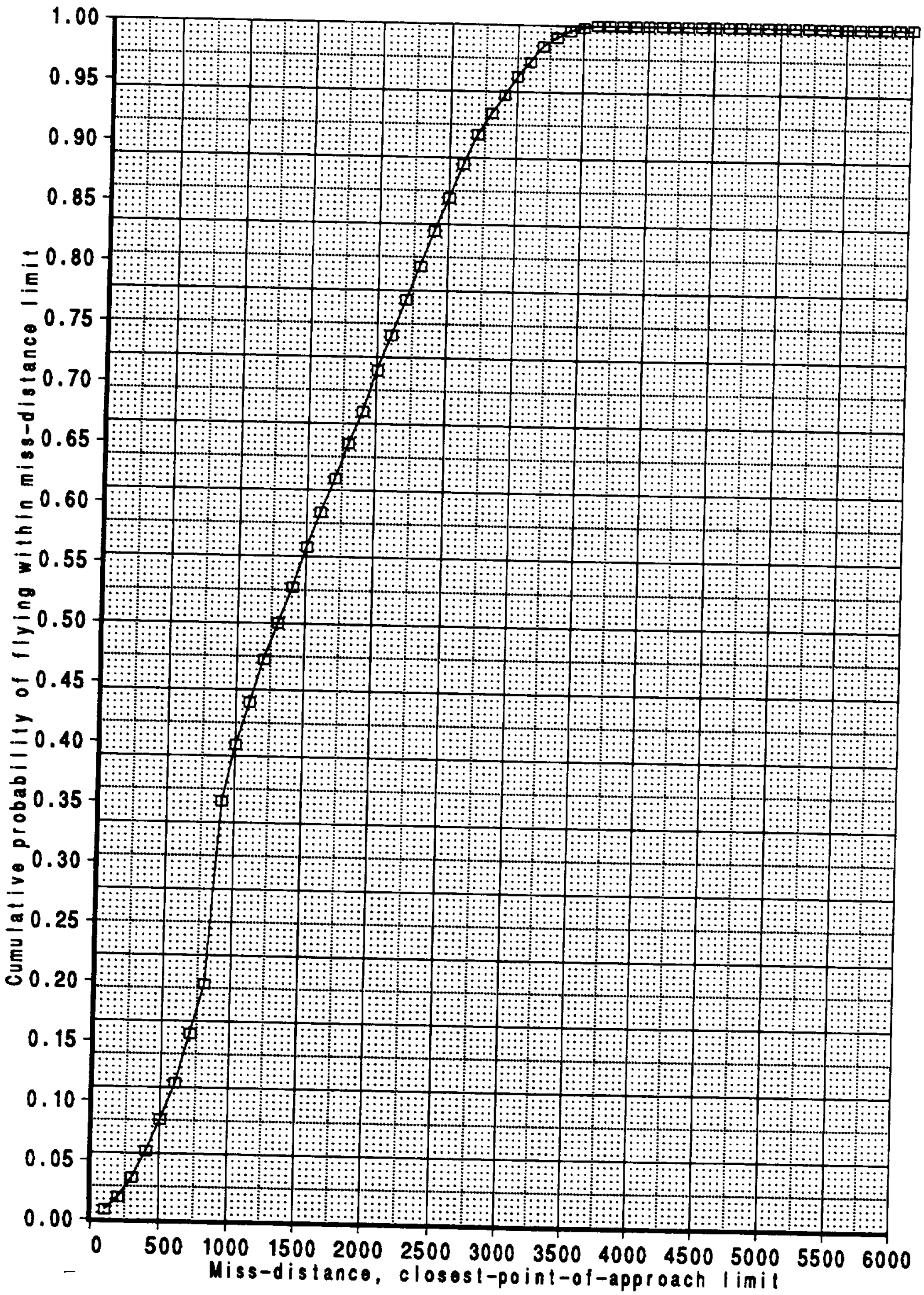

Figure 46. Cumulative Probability Distribution Function of CPA Miss Distance

8.2 SENSITIVITY ANALYSIS OF VISUAL APPROACH SIMULATION

A number of simulation runs with parameter variation was conducted to observe the sensitivity of each simulation parameter. Each run consists of 12,100 trials with each case parameter varied separately through the given values to measure their sensitivity. As previously stated, the probability of unresolved blunder for a nominal case of visual approach to parallel runways is 8%.

The numerical data for sensitivity analysis of visual approach to parallel runways is presented in *Appendix* C. The data presented is for the probability of miss distance for CPA values ranging from 0 to 700 ft. Eleven sensitivity analyses were performed. *Figures 47-58* illustrate the effects on parameter variation in the probability of miss distance, for the various miss criteria.

8.2.1 SENSITIVITY TO TOTAL RESPONSE TIME

Figure 47 displays sensitivity of the probability of closest miss distance with respect to total response time (i.e., the time from the evading aircraft pilot decision to take action to the start of turn of the aircraft). These response times are for zero variation and for 1 to 6 sec. After 2 sec, the probability of closest miss distance increases sharply and levels off to a degree thereafter.

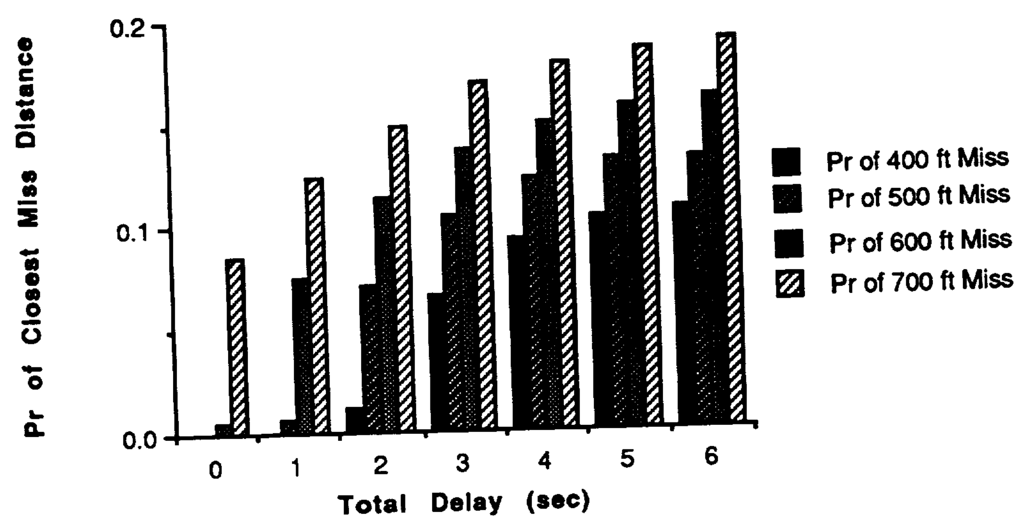

Figure 47. Sensitivity Analysis - Total Delay Time

8.2.2 SENSITIVITY TO TOTAL SYSTEM RESPONSE TIME UNCERTAINTY

Figure 48 shows the sensitivity with respect to the total response time (for the pilot and aircraft) uncertainty. The uncertainties are represented in the model in the form of assumed values of the SD (i.e., 0, 1, 2, 3, 4, 5, and 6 sec). The bars indicate that increasing SD results in some decrease in the probability for the closest miss distance.

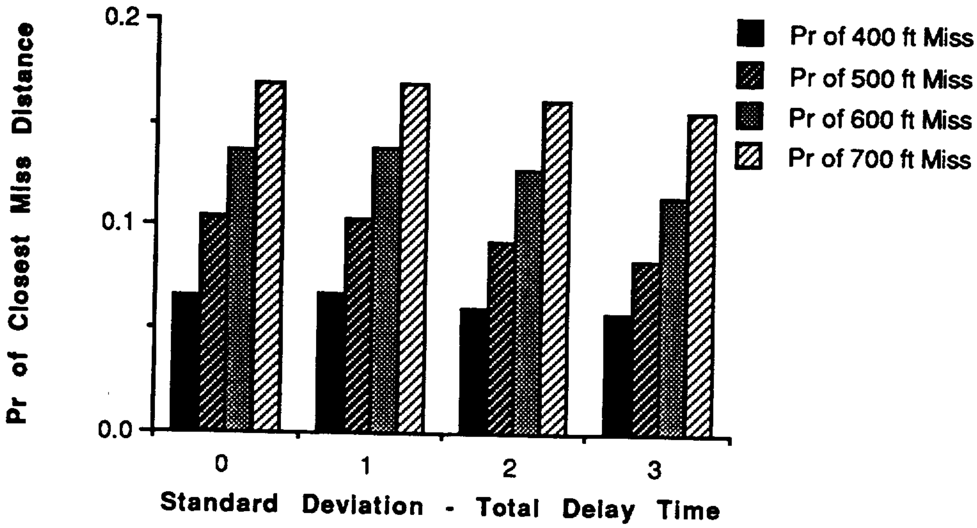

Figure 48. Sensitivity Analysis - Delay Time Uncertainty

8.2.3 SENSITIVITY TO PARALLEL RUNWAY SPACING

Figure 49 shows the sensitivity with respect to parallel runway spacing. Runway spacing is evaluated from 700 to 1,200 ft with 100 ft increments. The closer the parallel runway, the higher the indicated probability of closest miss distance for unresolved blunders. Note that the alarm distance is 100 ft (i.e., 100 ft from the extended centerline of the blundering aircraft).

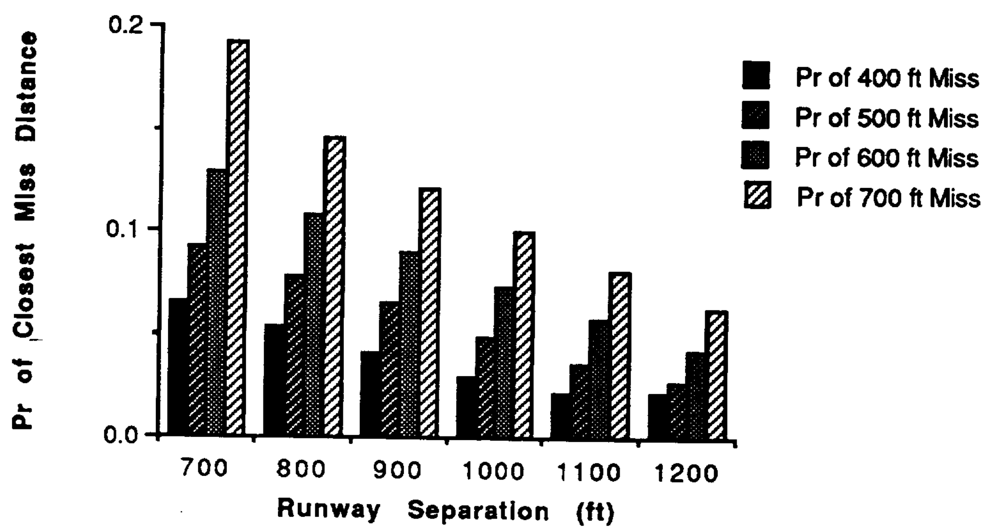

Figure 49. Sensitivity Analysis - Runway Separation

8.2.4 SENSITIVITY TO LONGITUDINAL OFFSET WHEN BLUNDER OCCURS

Figure 50 shows the sensitivity of the assumed longitudinal relation between the evader and blunderer. The horizontal axis shows the relation of evading aircraft with respect to the blunderer (i.e., 5,000 ft refers to the evader being 5,000 ft behind the blundering aircraft on the localizer beam of the other runway. The longitudinal relation between the blunderer and evader is evaluated at -5,000; -2,000; -1,000; 0; 1,000; 2,000; and 5,000 ft. *Figure 50* indicates that the highest probability of unresolved blunders occurs when the blunderer and evader are abreast of each other (i.e., equal distance from the runways). Note that the highest probability of the closest miss distance for IFR parallel approaches was at 1,000 ft along the track offset.

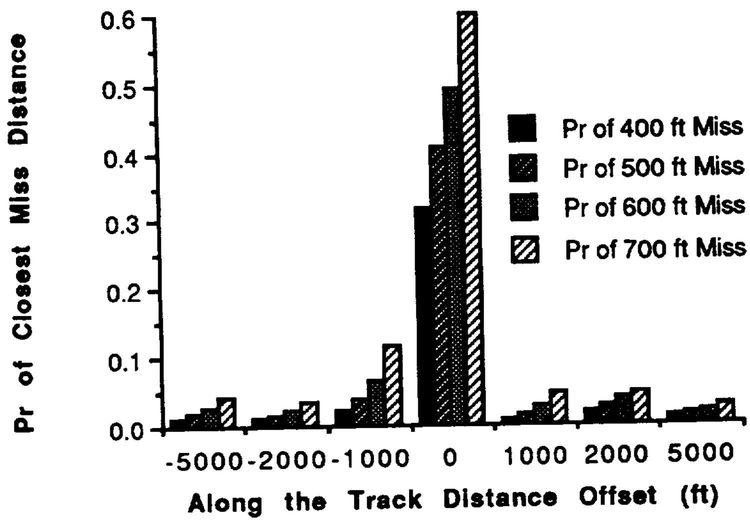

Figure 50. Sensitivity Analysis - Along the Track Offset

8.2.5 SENSITIVITY TO APPROACH SPEEDS OF TWO AIRCRAFT

Figure 51 shows the sensitivity with respect to variation in assumed approach speeds of the two aircraft. The horizontal axis shows the range of the speed of the two aircraft at 100, 120, 140, 160, and 180 kn. As indicated in *Figure 51*, increasing speed has a small effect in the increase of the probability of closest miss distance. This inference is unlike that of the IFR parallel runway case in which the effect was substantial.

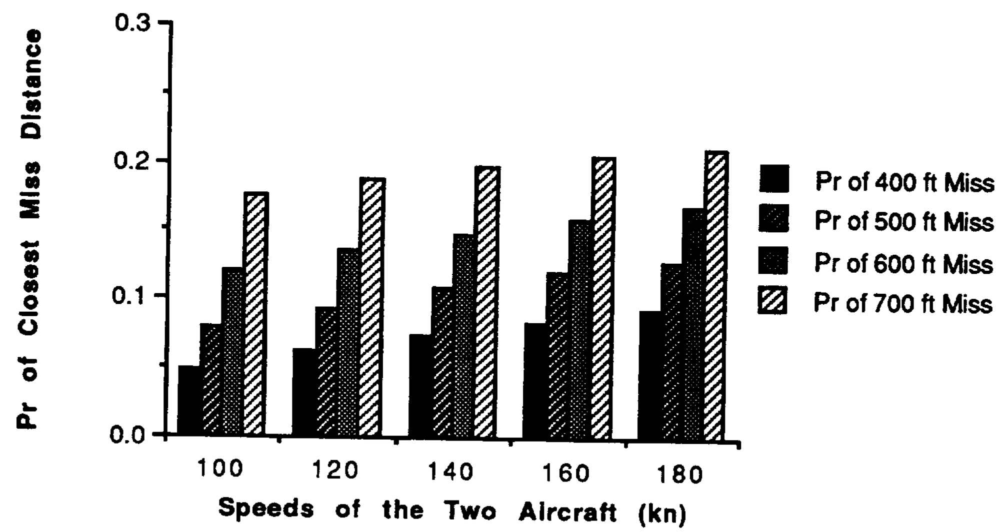

Figure 51. Sensitivity Analysis - Speed of Aircraft

8.2.6 SENSITIVITY TO CHANGE IN BANK ANGLE OF EVADER

Figure 52 shows sensitivity with respect to change in bank angle of the evading aircraft. The horizontal axis shows the assumed maximum bank angle of the evader (22, 30, 38, 45, and 52 deg). This figure indicates that the greater the bank angle, then the smaller the probability of closest miss distance. This result is similar to the corresponding IFR parallel runway approach case.

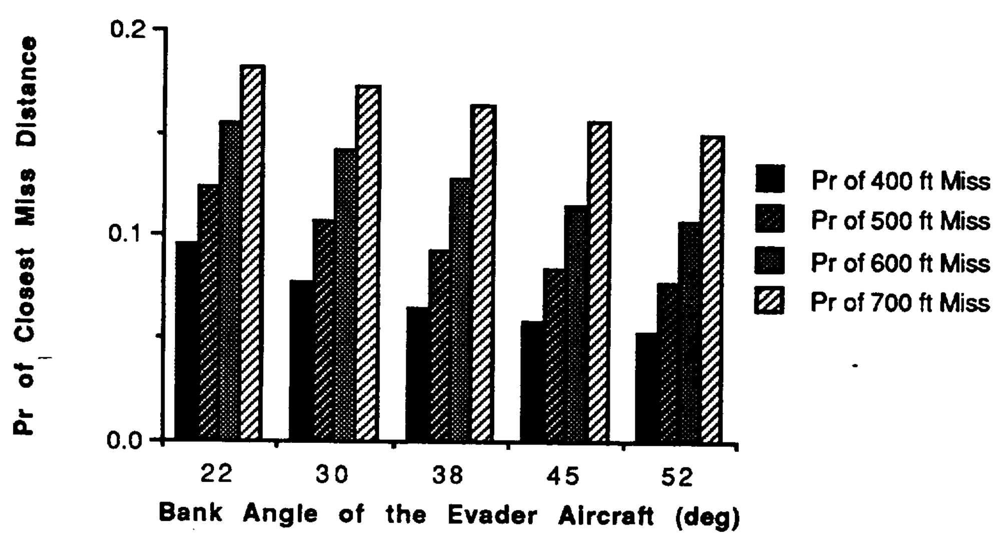

Figure 52. Sensitivity Analysis - Evader Aircraft Bank Angle

8.2.7 SENSITIVITY TO TURN RATE OF BLUNDERER

Figure 53 shows the sensitivity of closest miss probability to the turn rate of the blundering aircraft. The horizontal axis depicts the range of turn rates evaluated for the blunderer (1, 2, 3, 4, and 5 deg/sec). The figure indicates that an increase in the turn rate of the blunderer, above the baseline of 3 deg/sec, has a small effect in probability of closest miss distance.

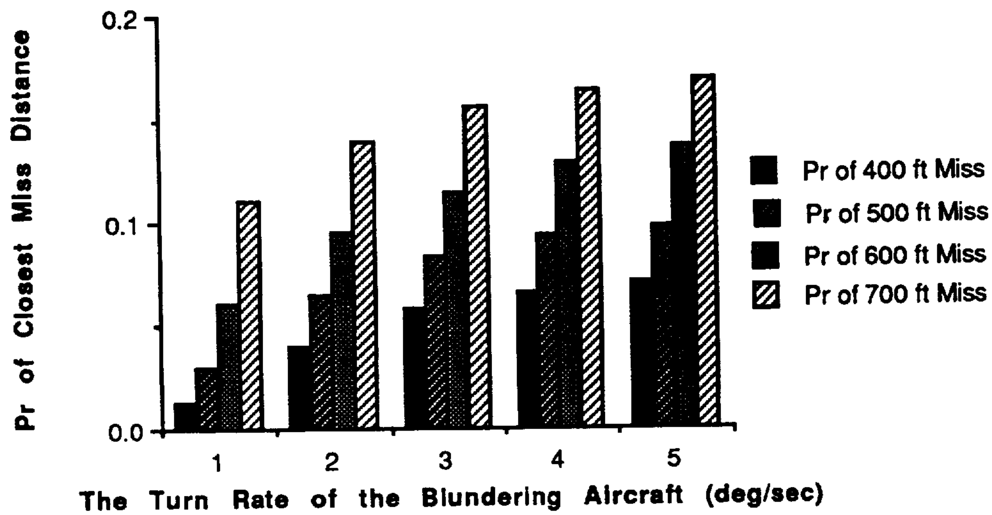

Figure 53. Sensitivity Analysis - Turn Rate of Blunderer

8.2.8 SENSITIVITY TO BLUNDER ANGLE

Figure 54 shows sensitivity of closest miss probability to the crossing angle of the blundering aircraft. The assumed blunder angle variations are for 15, 20, 25, 30, and 35 deg. *Figure 54* suggests that the blunder angle has a small effect on the probability of the closest miss distance of two aircraft. These results are unlike those of the corresponding IFR parallel runway approach case.

8.2.9 SENSITIVITY TO SURVEILLANCE AZIMUTH ERROR

Figure 55 shows the sensitivity of closest miss probability to surveillance error. Surveillance errors are assumed for 0, 2, 4, and 6 mr. *Figure 55* indicates that surveillance error changes have only a small effect on the probability of closest miss distance. This result is like the corresponding result for the IFR parallel runway case.

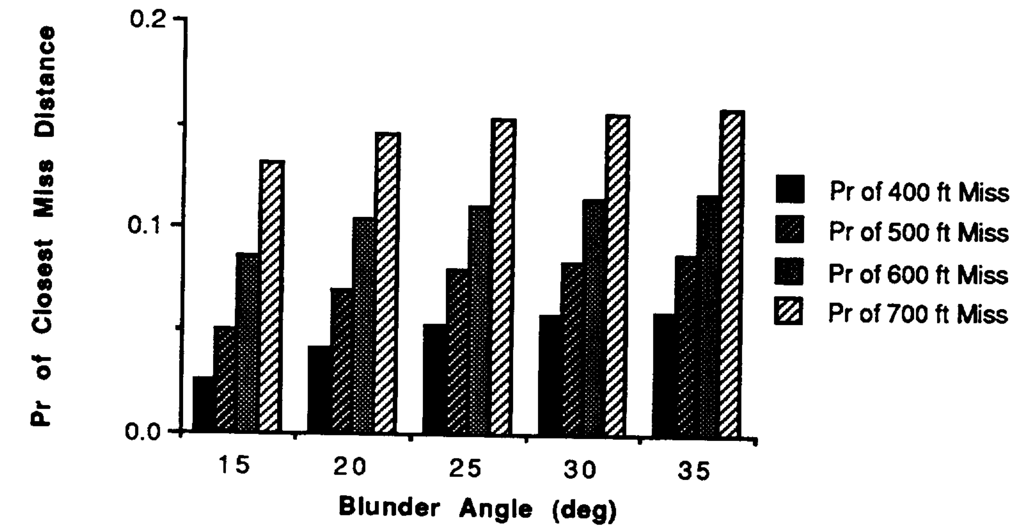

Figure 54. Sensitivity Analysis - Blunder Angle

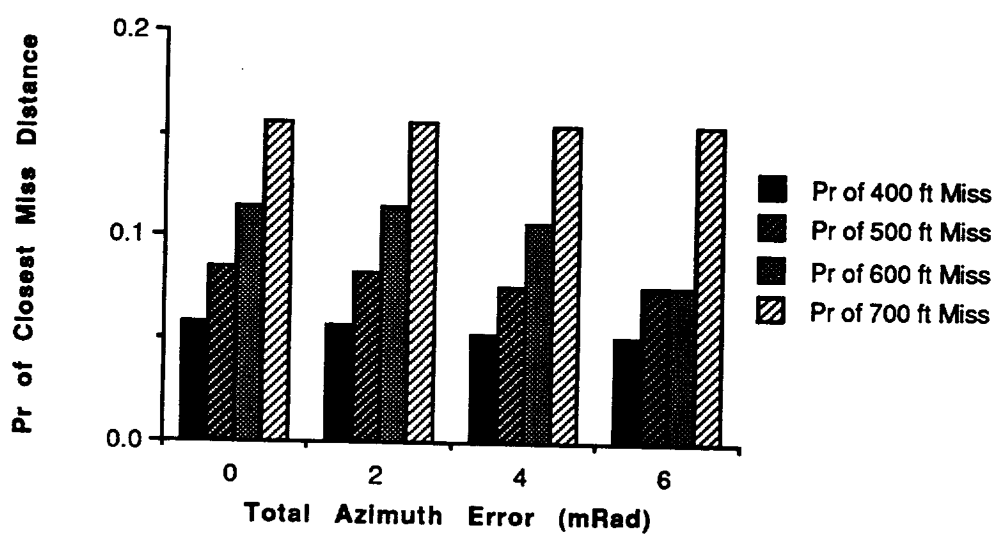

Figure 55. Sensitivity Analysis - Surveillance Error

8.2.10 SENSITIVITY TO EVADER TURN HEADING

Figure 56 shows sensitivity of closest miss probability with respect to the turn heading of the evading aircraft. The evader aircraft heading turn values assumed are for 30, 45, 60, 75, and 90 deg. Evasion heading turn does not appear to have any effect on the probability of closest miss distance, consistent with the assumed evasion maneuver mechanism.

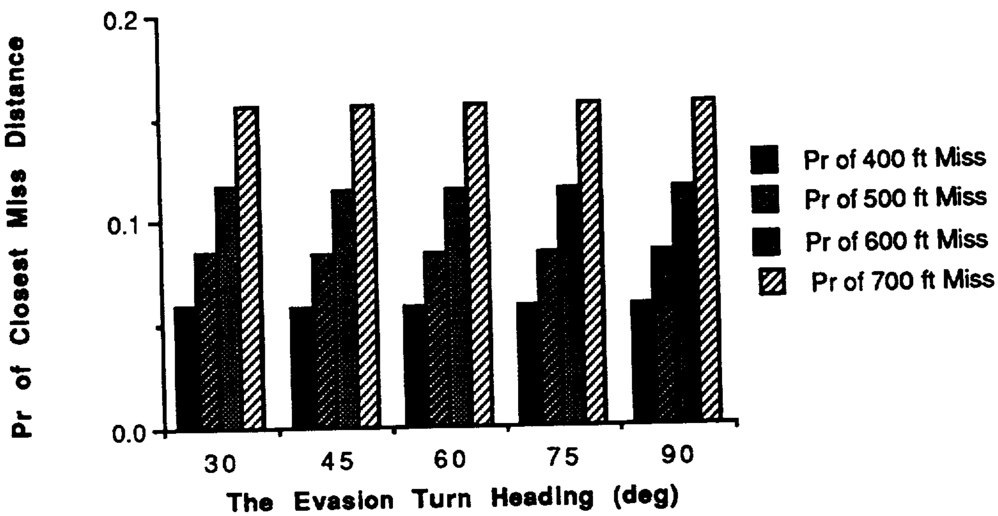

Figure 56. Sensitivity Analysis - Evader Turn Heading

8.2.11 SENSITIVITY TO BLUNDERING AIRCRAFT DISPLACEMENT FROM CENETERLINE WHEN THE BLUNDER OCCURS

Figure 57 shows the sensitivity with respect to the blundering aircraft displacement from the extended runway centerline. The assumed values due for displacements of 50, 100, and 150 ft from the extended runway centerline for the blundering aircraft. *Figure 57* indicates that at the initiation of a blunder, the displacement from the centerline has a significant effect on the probability of the closest miss distance.

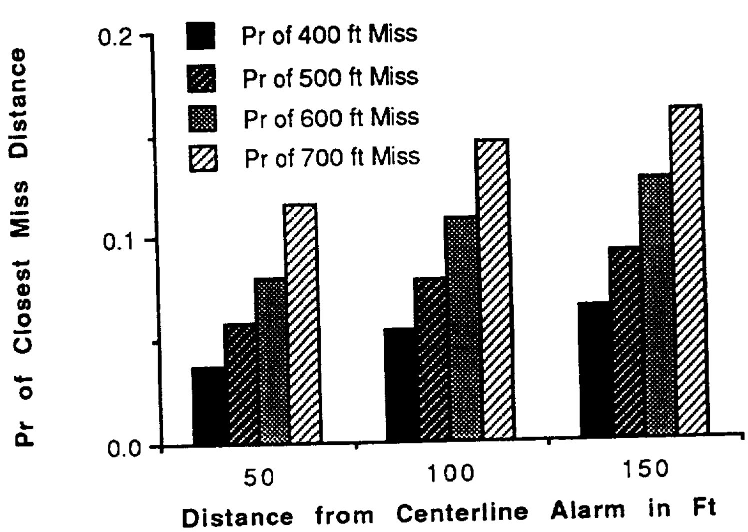

Figure 57. Sensitivity Analysis - Alarm Distance

8.2.12 SENSITIVITY TO NO EVASION MANEUVER

Figure 58 shows the sensitivity of closest miss probability to the total response time (the time interval from onset of the blunder until the endangered aircraft reacts to the blunderer). The figure indicates that approximately 6 sec (i.e., pilot and aircraft response times) is the maximum length of reaction time of the endangered aircraft in order to reduce the miss probability. If the endangered aircraft does not initiate an evasion maneuver within 6 sec then the later maneuver has no impact on probability of closest miss distance.

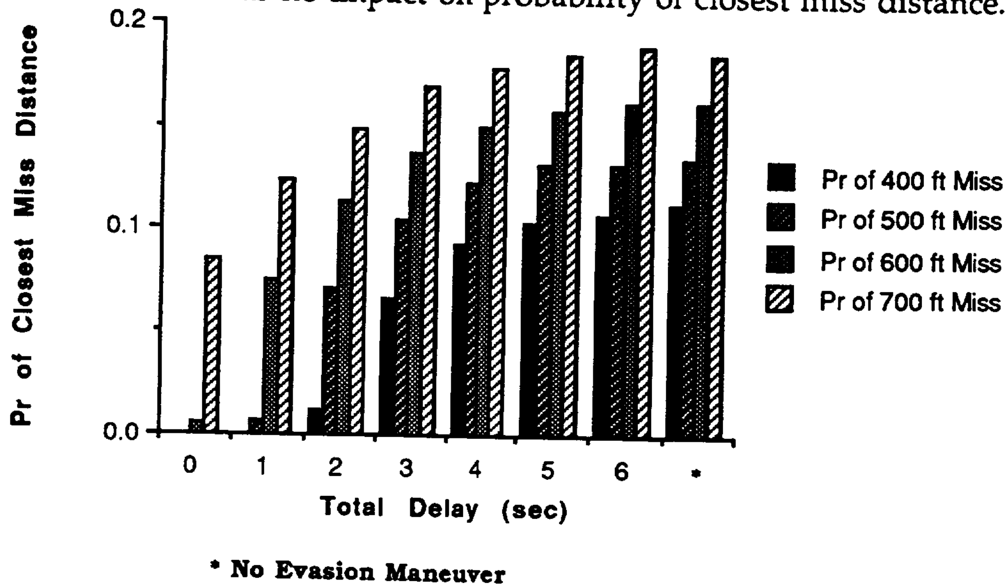

Figure 58. Sensitivity Analysis - Total Delay Time

8.3 INTER-RELATION OF SENSITIVE PARAMETERS OF THE MODEL FOR VISUAL APPROACHES TO PARALLEL RUNWAYS

It was observed in the sensitivity analysis of individual parameters of the simulation model (subsection 8.2) that some of the parameters have a strong correlation to the probability of the closest miss distance. In the following paragraphs the most sensitive of these parameters will be studied in more detail along with the variations with respect to total time response. These parameters will be evaluated for their effect on parallel runway spacing for the 500-foot miss distance and 8% baseline case probability.

8.3.1 IMPACT OF CHANGE IN AIRCRAFT SPEED

Figure 59 shows the relation of the blunderer and evader aircraft change in speed to runway spacing and total response time. The horizontal axis depicts the total response time from 0 to 5 seconds, and the vertical axis depicts the runway spacing in feet. The legend indicates the assumed variation of the fleet mix speed. *Figure 59* indicates that the change in speed has a linear effect requiring greater response time for recovery and runway spacing to resolve a blunder for a higher speed.

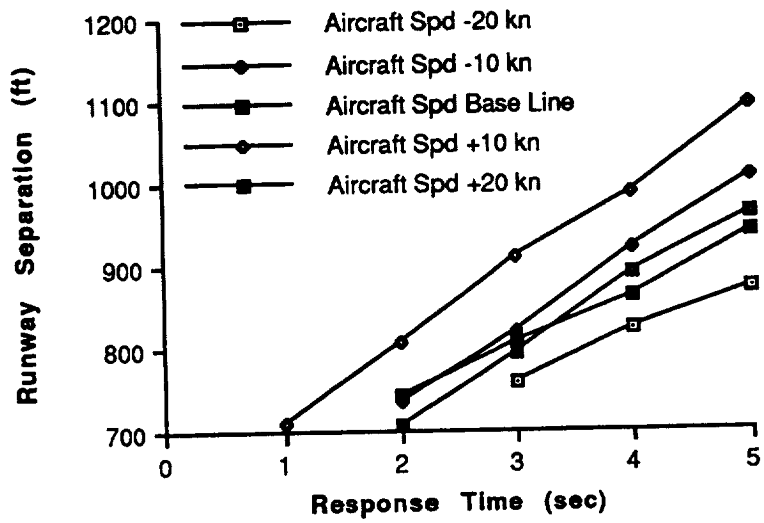

Figure 59. Aircraft Speed

8.3.2 IMPACT OF CHANGE IN BLUNDERING AIRCRAFT SPEED

Figure 60 shows the interrelationship of the blunderer change in speed to runway spacing and total response time. The horizontal axis depicts the total response time in seconds and the vertical axis depicts the runway spacing in feet. The plot shows that the greater the blunderer speed the greater the probability of unresolved blunder. This relationship is almost linear.

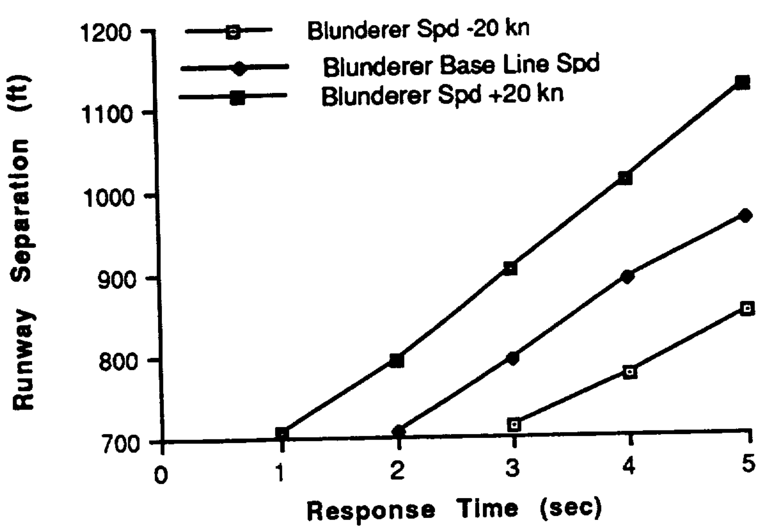

Figure 60. Blunderer Speed

8.3.3 IMPACT OF ALARM DISTANCE

Figure 61 shows the relation of the changes in the alarm distance from the extended runway centerline of the blundering aircraft to parallel runway spacing and the evading aircraft total response time. The plot shows that the greater the alarm distance the greater the probability of unresolved blunder. This relation is almost linear.

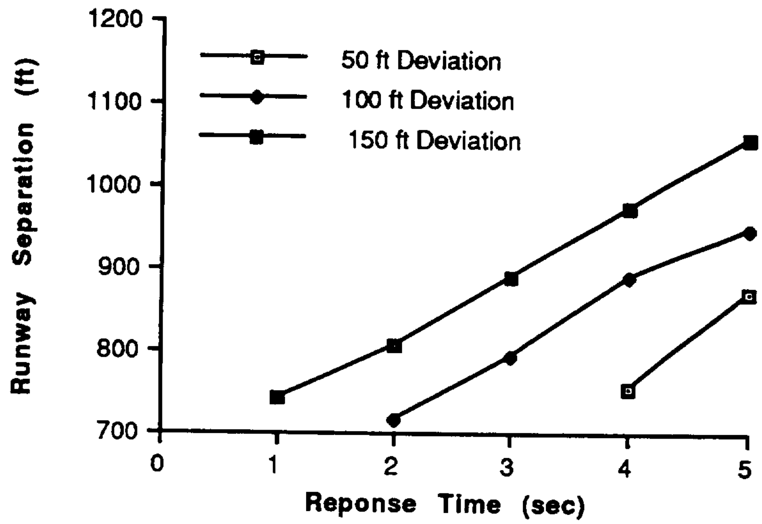

Figure 61. Alarm Distance

8.4 COMPARISON OF PBL SIMULATION RESULTS FOR IFR AND VISUAL APPROACHES TO PARALLEL RUNWAYS

Since the parametric sensitivity and analysis of instrument and visual approach operations to parallel runways were provided in Section 7 thru subsection 8.3, herein is outlined the major differences between these two operations as indicated by the PLB simulation results. Those major differences are:

1. Visual operation blunder resolution time is very short due to the short distance between the two runways with the probability of closest miss distance growing very fast and leveling off.

2. A positive correlation between probability of closest miss distance and response time uncertainty is indicated for IFR operations, whereas a negative correlation with less magnitude is indicated for visual approach operations because of initial assumptions and shorter time.

3. Simultaneous visual approach operations without any along track offset have the highest probability of closest miss distance because of the short

spacing between the runways. (For IFR approaches, a staggered operation of 1,000 ft has the highest probability of closest miss distance.)

4. Increasing the speed of the aircraft has a strong effect in the probability of closest miss distance for instrument approaches, unlike visual approaches where the short distance between the runways dilutes the effect.

5. Turn rate of the blunderer has a strong effect in the first two seconds of a visual approach operation and then levels off similar to that of an IFR operation.

6. The steepness of turn of a large blunder angle toward the other runway has an almost insignificant effect in the probability of closest miss distance due to the shortness of time required to cross the space between the two runways for visual approaches.

7. Instrument approach results are quite different than the visual approach results where no evasion maneuver is assumed because the IFR operation tolerates a time delay which is approximately three times longer than the visual approach and then levels off (i.e., no impact on probability of miss distance).

9.0 APPLICABLE TECHNOLOGIES

This section examines the input of three areas of applicable technologies: 1) performance of Digital Autoland Systems, 2) TCAS II and the possibility of its application during parallel runway approaches during IFR operations, and 3) other feasible technologies (e.g., ESAS, GPSL, etc.); as well as considers the potential impact that each technology may have on future parallel runway operations.

9.1 PERFORMANCE OF DIGITAL AUTOLAND SYSTEMS [6]

This is an analysis of localizer track performance data (simulated and actual autopilot-coupled approaches) associated with a state-of-the-art digital autoland system (refer to Section 4 regarding Automatic Flight Control Functions and Control Modes) and its relation to parallel runway approach operations. The simulation data used here was generated by a BCAG aircraft Monte Carlo simulation while the actual data was generated from BCAG flight test tapes. The certification of the autoland system requires precision tracking of the localizer beam. The FAA requirements for localizer tracking are found in FAA AC 120-29.

9.1.1 MONTE CARLO DATA ANALYSIS

A Monte Carlo simulation statistical analysis was generated for a contemporary BCAG aircraft to determine the localizer tracking accuracy. The BCAG aircraft Monte Carlo simulation model is designed to generate a realistic autoland environment composed of winds and turbulence, beam noise and biases, runway characteristics and airplane configuration variations. For this localizer performance analysis, the simulation was set up to record the maximum lateral deviation from the runway centerline during localizer track (when the aircraft is stabilized on the localizer beam). The localizer intercept angle was varied from -90 to 90 deg (Gaussian distribution). To filter out the overshoots of the localizer beam, an algorithm was used to determine when the airplane was stabilized on the localizer beam.

The Cumulative Probability Distribution (CPD) of the maximum deviation from the centerline during track is shown in *Figure 62*. The Gaussian approximation is represented in this figure by the solid line. The simulated performance can be very closely approximated by the Gaussian line.

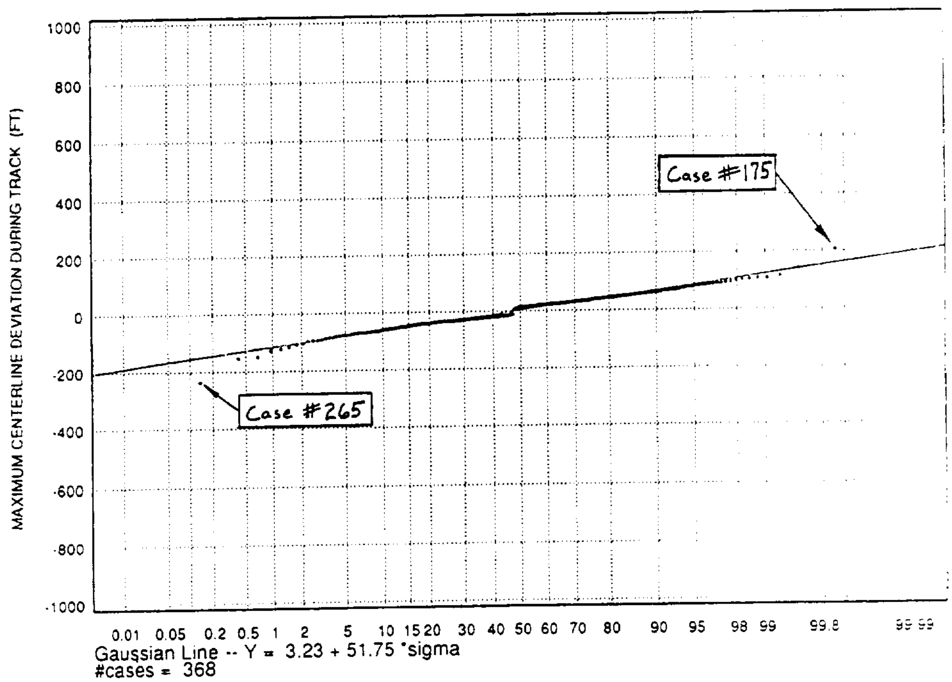

Figure 62. After 2 mi Capture Criteria

9.1.2 IMPACT OF AUTOPILOT PERFORMANCE ON PARALLEL RUNWAY OPERATIONS

The Gaussian line is used here to extrapolate the probability of penetrating the NTZ during an autopilot-coupled approach. The average (MEAN) maximum centerline deviation during track is 3.2 ft and the standard deviation (RMS) is 51.8 ft. The distance from the runway centerline to the NTZ is dependent on the centerline spacing of the parallel runways. For example, the centerline spacing between runways 36R and 36L at Memphis is 3,400 ft, which places the boundary of the NTZ at 700 ft from the runway centerline (*Figure 63*). Thus, the probability of penetrating the NTZ at Memphis for the simulated autopilot performance is:

$$P = (700. -3.2)/51.8 = 13.4\sigma$$
$$P << 10^{-10}$$

Therefore, it is extremely unlikely that the NTZ will be penetrated during the localizer track stage of an autopilot coupled approach. The probability of penetrating the NTZ for the other airports with closely spaced parallel runways is shown in *Table 7*.

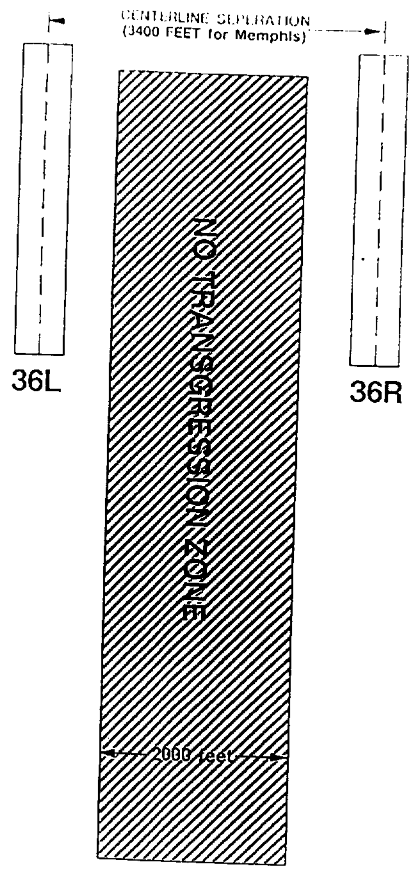

Figure 63. No Transgression Zone Definition

Table 7. Probability of Penetrating the NTZ at Selected Airports

AIRPORT	RUNWAYS	CENTERLINE SPACING	PROBABILITY OF PENETRATING NTZ
FT. Lauderdale	27/27L	4,000 feet	$P = 19.2\sigma \ll 10^{-10}$
Detroit	3L/3C	3,800 feet	$P = 17.3\sigma \ll 10^{-10}$
Raleigh	5R/5L	3,500 feet	$P = 14.4\sigma \ll 10^{-10}$
Phoenix	8R/8L	3,400 feet	$P = 13.4\sigma \ll 10^{-10}$
Dallas Love	31R/31L	2,975 feet	$P = 9.3\sigma \ll 10^{-10}$

It is important to note that the maximum lateral deviations recorded for this analysis were measured with respect to the runway centerline. The Monte Carlo simulation used to generate this data also includes a localizer offset. The localizer offset is included in the Monte Carlo simulation to represent a wide range of ILS facilities. The degree of localizer offset relative to the runway centerline is defined by the magnitude of the offset at the runway threshold. The distribution of the localizer offset is assumed Gaussian with a MEAN of 0 ft and an RMS of 7.3 ft at the runway threshold. The offset at the threshold can be as much as 16 ft. A 16-foot offset at the threshold translates to an offset of 75 ft at 8 mi out. This distribution is based on an analysis of worldwide CAT II/III runway installations [7]. The maximum lateral deviation during track was measured relative to the center of the localizer beam instead of the runway centerline. The resultant landing dispersion depends on the degree of centerline offset from the localizer as well as localizer error.

Probable failure and extreme environmental conditions are reflected, whereas human errors are not reflected. The procedure that the pilot follows for autopilot coupled approaches to parallel runways is: 1) check the data base of the FMC prior to engaging the autopilot Approach Mode for the correctness of the aircraft's assigned runway localizer and glideslope frequencies (pilot tunes frequencies manually whenever the airport information is not in the FMC database), and 2) engage the Approach Mode at approximately 150 miles from the runway, afterwhich the FMC tunes into the localizer and glideslope frequencies, the localizer capture arms and then engages, and the normal sequence of events for autoland follows.

9.1.3 FLIGHT TEST DATA ANALYSIS

Flight test data for the aircraft has been provided to demonstrate the localizer tracking performance. The lateral deviations from the localizer centerline versus the longitudinal distance from the glideslope transmitter for 18 autopilot-coupled approaches is shown in *Figure 64*. Using the capture algorithm described in paragraph 9.1.1, the maximum lateral deviation from the localizer centerline for these flight test conditions were less than 100 ft. The simulator data (Monte Carlo) correlates well with the flight test data.

Herein a BCAG aircraft Monte Carlo simulation analysis and flight test data were used in exhibiting the localizer tracking performance. For closely spaced parallel runways, there is a NTZ that is 2,000 ft in width between the approach paths where, for safety reasons, the aircraft are not allowed to enter. The Monte Carlo simulation analysis has shown that the likelihood that this BCAG aircraft (when stabilized on the localizer beam) will penetrate the NTZ during a correctly established autopilot-coupled approach is extremely improbable ($< < 10^{-10}$). The flight test data support this conclusion. These conclusions apply to all the new generation of BCAG aircraft.

9.2 TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEM (TCAS) [8]

9.2.1 CURRENT TCAS SYSTEM

TCAS is a family of ground independent collision avoidance systems which protect the host aircraft from potential and predicted aircraft collision threats. This is accomplished by datalink communication between nearby aircraft

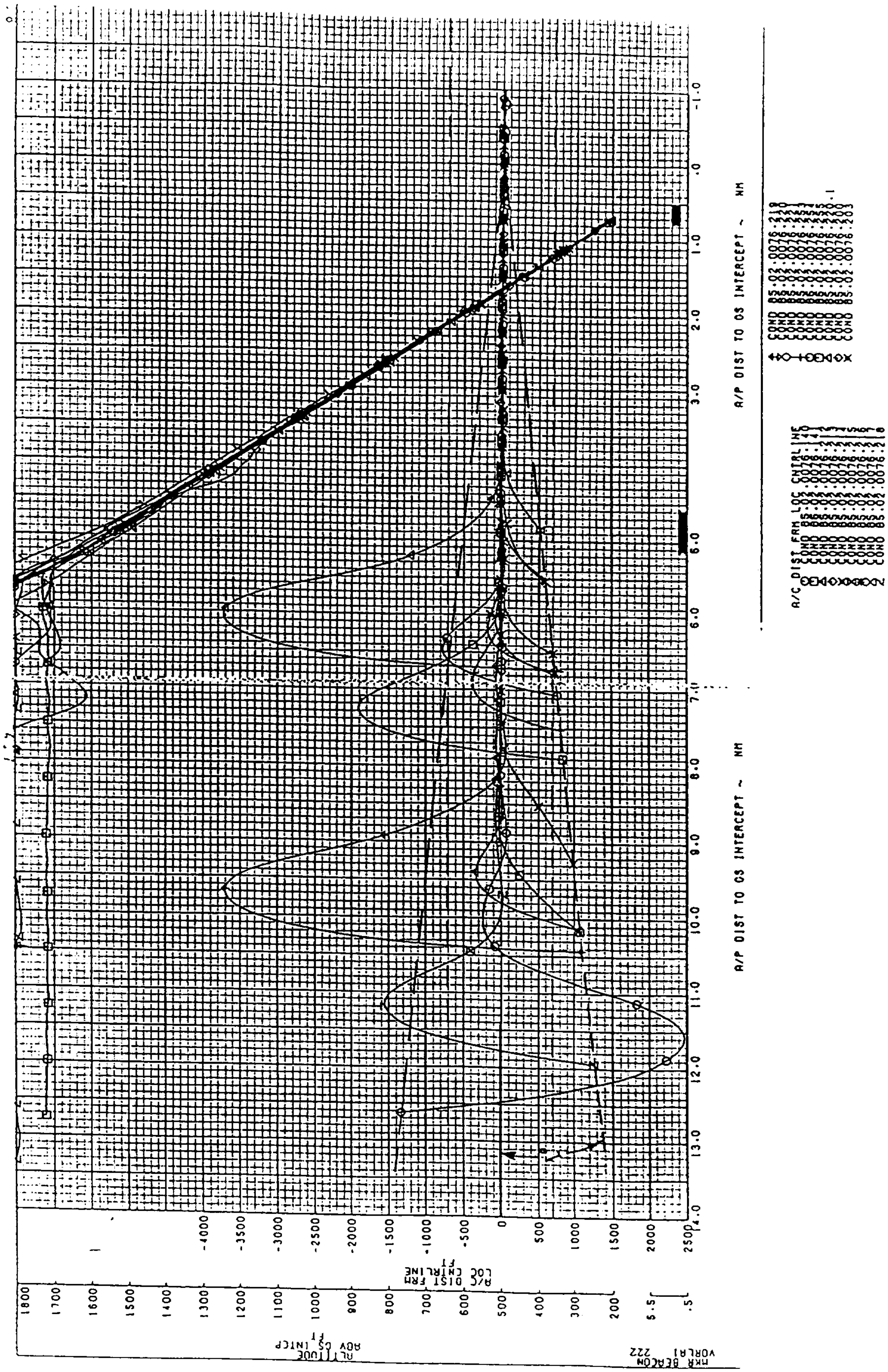

Figure 64. Localizer Tracking Flight Test Data

using Mode S transponders. Aircraft equipped with TCAS can also track nearby aircraft equipped with Mode A and Mode C transponders, but has no knowledge of aircraft without transponder equipment.

Depending on the TCAS equipment installed (TCAS I, II or III), and the selected operational mode, the system can issue a Traffic Advisory (TA), and in the more advanced systems, a Resolution Advisory (RA). The TA provides a synthetic voice alert and displays the relative position of potentially threatening aircraft. An RA provides a synthetic voice alert and displays an advised action (maneuver) or an advised inaction (maneuver restriction) to avoid a closing aircraft. TCAS II equipment provides RAs in the vertical plane only, where as TCAS III will issue RAs in both the vertical and horizontal planes (TCAS III is currently still in development).

Table 8 shows the type of advisories issued in an aircraft to aircraft encounter given the equipage of the two aircraft.

Table 8. TCAS Levels of Protection

		Own Aircraft Equipment		
		TCAS I	TCAS II	TCAS III
Target Aircraft Equipment	No Transponder	—	—	—
	Mode A Transponder	TA	TA	TA
	Mode C or S Xponder	TA	TA&VRA	TA&VHRA
	TCAS I	TA	TA&VRA	TA&VHRA
	TCAS II	TA	TA,VRA&TTC	TA,VHRA&TTC
	TCAS III	TA	TA,VRA&TTC	TA,VHRA&TTC

TA - Traffic Advisory Only
VRA - Vertical Resolution Advisory
VHRA - Vertical and Horizontal Resolution Advisory
TTC - TCAS to TCAS Coordination

The effectiveness of TCAS is dependent on the accuracy of the threat aircraft's reported altitude and the assumption that the threat will not make an abrupt maneuver which may invalidate the TCAS resolution. RAs are automatically inhibited below 500 ft AGL and aural annunciations (both TAs and RAs) are inhibited below 400 ft AGL.

TCAS operates to a range of 14 nmi with a density of .3 aircraft per square nmi including all altitudes. The Mode S system has a selective addressing feature (each airborne unit is directly addressable) and is capable of datalink communications. Modes A and C equipped targets only respond to broadcast interrogations. The TCAS target recognition sequence is therefore different depending on the targets onboard transponder equipment.

Mode S transponders generate a *squitter* (i.e., brief transmission containing self address information) at a rate of once per second. The Mode S unit uses the squitter to announce its presence to other airborne (and earthbound) Mode S equipment. The TCAS/Mode S to Mode S target recognition sequence is:

1. TCAS receives squitter transmission from nearby (Mode S) aircraft.

2. TCAS sends interrogation signal addressed to that specific aircraft.

3. Altitude of the target is encoded in the target response transmission.

4. Timing of the response will determine range and bearing of the target.

9.2.2 CLOSE SPACED PARALLEL APPROACHES WITH TCAS

Generally the current practice is to inhibit RAs (crew switches to *TA-ONLY* mode) during parallel runway approaches. This is to minimize false alarms induced, primarily, during the turn-on to the localizer. Another problem with TCAS in the terminal area, is the conflict of authority between the ground based air traffic control and the TCAS advisory generated onboard. In one of the worst case scenarios (e.g., LAX), parallel pairs of parallel runways are on separate approach frequencies making the resolution of a control discrepancy even more difficult.

A modified version of TCAS could have merit in the parallel approach scenario. The role of TCAS, however, would have to be carefully integrated into the terminal control environment.

A summation of the results from the blunder simulation could be stated as follows:

1. The closer the spacing of the parallel runways the less the total reaction time available (automation, ground controller plus pilot reaction time). With the minimum visual approach runway centerline separations currently in practice, the optimal reaction time may be as little as 3 sec. If a reaction is delayed as much as 6 sec, then an evasive maneuver may be useless.

2. A predefined evasion maneuver triggered by the violation of the NTZ is in all likelihood not the best solution. Given the wide range of possible aircraft pairs and the varied engagement geometries (at the onset of a blunder event), a pre-programmed evasion may do more harm than good.

Potential TCAS modifications could be incorporated with several levels of sophistication.

1. A selected TCAS display range that would be optimized for monitoring the relative position of a parallel approaching aircraft.

2. Modifying the altitude driven TCAS resolution advisory so as to inhibit limits for a parallel approach mode.

3. An evasion maneuver based on a TCAS type resolution advisory should yield a lower probability of collision.

4. Mode S datalink could be used to transmit the TCAS resolution advisory to the ground facility, providing nearly simultaneous display to both the controller and pilot. This would provide the possibility of a coordinated reaction to the TCAS advisory.

5. Mode S datalink could be used to transmit aircraft flight information (e.g., position, velocity, altitude, altitude rate, etc.) to the parallel aircraft for assisting in the monitoring/threat assessment process. The availability of attitude information could provide an earlier warning of a blunder than would waiting until the blundering aircraft violates the NTZ (based on position only).

6. The FMC or ground based computer could provide TCAS with expected threat trajectory and flight performance (database) information for assisting in the monitoring/threat assessment process.

9.3 ENHANCED SITUATIONAL AWARENESS SYSTEM (ESAS)

9.3.1 GENERAL CONCEPT

ESAS is a concept currently in development. The basic system requirements and objectives have been defined, with efforts continuing on system design. As currently conceived ESAS is a system which will provide the flight crew with information about their surroundings that would otherwise be unavailable due to adverse weather. The system would include sensors, computers, database information, displays and controls which present visual images of the environment.

The major sub-systems envisioned for ESAS are:

1. Remote Sensors/Radar (probably with infrared, millimeter-wave and/or laser radar)

2. Displays (head-up and/or head-down)

3. Digital Terrain (possibly available as part of an electronic library system)

4. Information Integration and Management

Ultimately, the system will allow a flight crew to safely takeoff, land and taxi autonomously in any weather, including zero visibility, at any airport capable of operations during clear weather. Approach and landing will be accomplished without the necessity for ILS/MLS equipped runways. In addition, the system will provide the ability to avoid hazards such as terrain, other aircraft, and weather.

ESAS will probably be implemented in stages with the initial design most likely including one or more of the currently defined capabilities:

1. Autonomous approach, landing and departure capability incorporating terrain awareness in the terminal area, in visibility conditions down to those normally associated with CAT IIIA.

2. Visually aided approach, landing and departure capability using Type I ILS/MLS facilities in visibility conditions down to those normally associated with CAT IIIA.

3. VFR type terminal procedures, operations and traffic densities incorporating terrain awareness in the area under IMC visibility conditions.

4. Enhanced enroute terrain awareness.

5. Autonomous taxi capability in visibility conditions down to those normally associated with CAT IIIB.

6. Takeoff and landing performance awareness.

7. Visually aided approach, landing and departure capability using Type II ILS/MLS facilities in visibility conditions down to those normally associated with CAT IIIB.

8. Enhanced wake vortex awareness.

Three of the capabilities involve approach, landing and takeoff functions. One will allow operations on runways with no ILS/MLS system in weather down to CAT IIIA (700-foot Runway Visual Range). Another will allow the use of a CAT I ILS to land in CAT IIIA weather. The third identified capability may allow the use of a CAT II ILS to land in CAT IIIB (as low as 300 ft RVR) weather.

The traffic separation capability (including lateral and longitudinal separation from other aircraft) will allow flight crews to operate in the terminal area using visual flight rules in weather associated with IMC. Functions necessary to achieve this capability will involve sensing and displaying the area around the aircraft to a distance of at least 5 nmi which will allow airport traffic flow to remain at levels close to normal even during low visibility conditions.

The enroute terrain awareness capability involves the display of terrain data and is needed for route planning and off course descents in case of emergency. Required functions involve the inclusion of strategic and tactical planning displays for the avoidance of ground obstacles and an immediate flight path display using sensed data. Strategic planning involves checking the flight path entered into the FMC for terrain conflicts. The tactical planning display functions enable emergency and off route descent terrain clearance. The immediate flight path display will be used to ensure that the actual flight path is clear of obstacles. It will also be used to verify terrain alerts and to facilitate the execution of escape maneuvers.

The taxi capability will allow air crews to taxi in visibility conditions down to 300 ft RVR. The functions include the display of the information provided by runway and taxiway markings, signs, lights, and color coding schemes. The pilot must be able to verify that the aircraft is on the assigned taxiway. In addition, a function will be necessary to detect and avoid obstacles as well as to detect other aircraft in the immediate area and display them with enough clarity so that the flight crew can identify and follow them. The benefits of this capability are tied to the takeoff and landing capabilities since taxiing will be required in the same visibility conditions.

The predictive wind shear capability deals with detecting and displaying hazardous weather conditions defined as wind shear and microburst. This capability must allow the pilot to determine the location and the severity of either of these hazardous weather conditions within a range of 5 nmi. This added safety feature will allow the pilot to avoid a potential dangerous situation.

9.3.2 CLOSE SPACED PARALLEL APPROACHES AND ESAS

ESAS is not fully defined, but could potentially provide, or assist in providing, relative position information, threat detection, and alert messages in the parallel approach scenario. With regard to wake vortices, the capability to detect and display wake vortices generated by other aircraft is included in ESAS. The location and severity of detected wake vortices must be able to be determined and displayed early enough to allow the pilot to avoid them. This will add a margin of safety presently not available. This capability might be used to reduce the current 2,500-foot lateral requirement for operations where wake vortex is involved to a lower value. The monitoring and alerting capability, using ESAS, could be similar to that provided by a modified TCAS (subsection 9.2), but with some specific differences. Currently ESAS is envisioned as an autonomous system using active sensors and an internal database to enhance the pilots *vision*, and to some extent allow VFR type of operations in IFR conditions. The detection of proximity aircraft would include all aircraft visible to the sensors, and not just those with a functioning transponder (as with TCAS). However, ESAS would not provide a resolution advisory or any aircraft-to-aircraft negotiations.

A threat detection function and alert messaging could be provided (by some onboard unit) using inputs from ESAS sensors, navigational sources, and library database information. This potential ESAS based system is currently not as well defined as the potential TCAS based system, but may be easier to incorporate in the ground based approach control authority structure.

The use of a head-up display (HUD) to represent a potential threat aircraft is unlikely to be useful given the limited field of view of a hard mounted HUD system. In the parallel approach scenario the head-down display could provide a 360 degree relative position representation.

10.0 CONCLUSIONS

Recommended follow on work:

1. Identifying accurate fleet mix, weather data, and projection of growth for airports with 2,000 to 3,400 ft. (High Priority)

2. Studying causes of blunder and effect of failures in type of blunder. (High Priority)

3. Modeling radar error (current and high update rate).

4. Identifying false alarms and their effects.

5. Analyzing turn onto localizer segment approach. (High Priority)

6. Developing an intelligent evader maneuver model.

7. Studying aging aircraft with regard to digital and analog autopilot.

8. Extending the simulation to triple and quadruple runways. (High Priority)

9. Studying different types of technology for close space multiple parallel runway approaches. (High Priority)

10. Analyzing real time simulation and actual flight data with regard to pilot, aircraft and controller response time. (High Priority)

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APPENDIX A

SENSITIVITY ANALYSIS OUTPUT DATA FOR IMC APPROACH TO PARALLEL RUNWAYS

This series was run 5/1/93 to check sensitivity to
the absolute speeds of the 2 aircraft. More detailed info is in sens2.comp..stat .

LO	HI	AC speed 100 kts HITS%_cum	AC speed 100 kts HITSn_cum	AC speed 120 kts HITS%_cum	AC speed 120 kts HITSn_cum	AC speed 140 kts HITS%_cum	AC speed 140 kts HITSn_cum	AC speed 160 kts HITS%_cum	AC speed 160 kts HITSn_cum	AC speed 180 kts HITS%_cum	AC speed 180 kts HITSn_cum
0	100	0.0000	0	0.0008	10	0.0022	27	0.0044	53	0.0080	97
100	200	0.0005	6	0.0025	30	0.0072	87	0.0135	163	0.0210	254
200	300	0.0010	12	0.0046	56	0.0114	138	0.0216	261	0.0330	399
300	400	0.0017	21	0.0069	83	0.0177	214	0.0328	397	0.0475	575
400	500	0.0026	31	0.0102	124	0.0246	298	0.0439	531	0.0650	787
500	600	0.0040	48	0.0148	179	0.0341	413	0.0564	683	0.0817	988
600	700	0.0059	71	0.0202	245	0.0435	526	0.0707	855	0.0995	1204
900	1000	0.0170	206	0.0451	546	0.0836	1011	0.1272	1539	0.1650	1996

This set of runs was run 5/4/93 to check sensitivity to
the bank angle of the evader aircraft. More detailed info is in sens2.comp.7.stat .

LO	HI	bank = 15 deg. HITS%_cum	bank = 15 deg. HITSn_cum	bank = 22 deg. HITS%_cum	bank = 22 deg. HITSn_cum	bank = 30 deg. HITS%_cum	bank = 30 deg. HITSn_cum	bank = 38 deg. HITS%_cum	bank = 38 deg. HITSn_cum	bank = 45 deg. HITS%_cum	bank = 45 deg. HITSn_cum
0	100	0.0058	70	0.0039	47	0.0032	39	0.0028	34	0.0026	31
100	200	0.0164	198	0.0117	141	0.0094	114	0.0079	95	0.0072	87
200	300	0.0258	312	0.0193	233	0.0150	182	0.0127	154	0.0110	133
300	400	0.0393	475	0.0288	348	0.0231	280	0.0195	236	0.0174	211
400	500	0.0532	644	0.0397	480	0.0320	387	0.0271	328	0.0247	299
500	600	0.0674	815	0.0512	620	0.0411	497	0.0357	432	0.0324	392
600	700	0.0807	977	0.0625	756	0.0520	629	0.0441	534	0.0406	491
900	1000	0.1357	1642	0.1052	1273	0.0879	1064	0.0788	954	0.0731	884

This set of runs was run 5/4/93 to check sensitivity to
the climb rate of the evader aircraft. More detailed info is in sens2.comp.8.stat .
The climb had no effect in this series. This is because in most cases the turn is only partially completed at the instant of closest approach. The climb maneuver is mechanized so as to start after the turn is complete. If the bank angle is increased (from 22 deg), or the evasion turn heading angle is decreased (from 55 deg), then the climb rate will have a minor effect. See evade.hilo.comp for runs with a minor climb effect.

LO	HI	climb 20 fps HITS%_cum	climb 20 fps HITSn_cum	climb 30 fps HITS%_cum	climb 30 fps HITSn_cum	climb 40 fps HITS%_cum	climb 40 fps HITSn_cum	climb 50 fps HITS%_cum	climb 50 fps HITSn_cum	climb 60 fps HITS%_cum	climb 60 fps HITSn_cum
0	100	0.0039	47	0.0039	47	0.0039	47	0.0039	47	0.0039	47
100	200	0.0117	141	0.0117	141	0.0117	141	0.0117	141	0.0117	141
200	300	0.0193	233	0.0193	233	0.0193	233	0.0193	233	0.0193	233
300	400	0.0288	348	0.0288	348	0.0288	348	0.0288	348	0.0288	348
400	500	0.0397	480	0.0397	480	0.0397	480	0.0397	480	0.0397	480
500	600	0.0512	620	0.0512	620	0.0512	620	0.0512	620	0.0512	620
600	700	0.0625	756	0.0625	756	0.0625	756	0.0625	756	0.0625	756
900	1000	0.1052	1273	0.1052	1273	0.1052	1273	0.1052	1273	0.1052	1273

This set of runs was run 5/4/93 to check sensitivity to
the turn rate of the blundering aircraft. More detailed info is in sens2.comp.9.stat .

		turn 1 deg/sec		turn 2 deg/sec		turn 3 deg/sec		turn 4 deg/sec		turn 5 deg/sec	
LO	HI	HITS%_cum	HITSn_cum	HITS%_cum	HITSn_cum	HITS%_cum	HITSn_cum	HITS%_cum	HITSn_cum	HITS%_cum	HITSn_cum
0	100	0.0046	56	0.0040	49	0.0039	47	0.0036	44	0.0036	44
100	200	0.0101	122	0.0121	146	0.0117	141	0.0116	140	0.0110	133
200	300	0.0180	218	0.0194	235	0.0193	233	0.0193	234	0.0193	233
300	400	0.0254	307	0.0292	353	0.0288	348	0.0289	350	0.0288	348
400	500	0.0337	408	0.0388	470	0.0397	480	0.0402	486	0.0402	487
500	600	0.0436	527	0.0524	634	0.0512	620	0.0513	621	0.0514	622
600	700	0.0555	671	0.0628	760	0.0625	756	0.0626	758	0.0621	752
900	1000	0.0955	1155	0.1055	1276	0.1052	1273	0.1046	1266	0.1050	1270

This set of runs was run 5/4/93 to check sensitivity to
the blunder angle of the blundering AC. More detailed info is in sens2.comp.10.stat .

		blunder angle 15deg		blunder angle 20deg		blunder angle 25deg		blunder angle 30deg		blunder angle 35deg	
LO	HI	HITS%_cum	HITSn_cum	HITS%_cum	HITSn_cum	HITS%_cum	HITSn_cum	HITS%_cum	HITSn_cum	HITS%_cum	HITSn_cum
0	100	0.0000	0	0.0002	3	0.0021	26	0.0039	47	0.0058	70
100	200	0.0000	0	0.0013	16	0.0047	57	0.0117	141	0.0184	223
200	300	0.0001	1	0.0031	37	0.0084	102	0.0193	233	0.0284	344
300	400	0.0001	1	0.0040	49	0.0135	163	0.0288	348	0.0412	499
400	500	0.0002	2	0.0068	82	0.0193	234	0.0397	480	0.0541	655
500	600	0.0003	4	0.0084	102	0.0275	333	0.0512	620	0.0692	837
600	700	0.0013	16	0.0115	139	0.0350	423	0.0625	756	0.0869	1051
900	1000	0.0046	56	0.0267	323	0.0660	798	0.1052	1273	0.1436	1737

This set of runs was run 5/4/93 to check sensitivity to
the FTE error uncertainty of both aircraft. More detailed info is in sens2.comp.11.stat .

		FTE SD = 0mRAD		FTE SD = 3mRAD		FTE SD = 6mRAD		FTE SD = 9mRAD	
LO	HI	HITS%_cum	HITSn_cum	HITS%_cum	HITSn_cum	HITS%_cum	HITSn_cum	HITS%_cum	HITSn_cum
0	100	0.0036	44	0.0039	47	0.0045	54	0.0045	54
100	200	0.0119	144	0.0117	141	0.0120	145	0.0116	140
200	300	0.0201	243	0.0193	233	0.0193	233	0.0196	237
300	400	0.0289	350	0.0288	348	0.0288	348	0.0292	353
400	500	0.0388	469	0.0397	480	0.0408	494	0.0402	487
500	600	0.0516	624	0.0512	620	0.0511	618	0.0502	607
600	700	0.0617	747	0.0625	756	0.0628	760	0.0621	752
900	1000	0.1043	1262	0.1052	1273	0.1058	1280	0.1041	1260

This set of runs was run 5/4/93 to check sensitivity to
the evasion turn heading. More detailed info is in sens2.comp.12.stat .

LO	HI	evasion head 30deg HITS%_cum	HITSn_cum	evasion head 45deg HITS%_cum	HITSn_cum	evasion head 60deg HITS%_cum	HITSn_cum	evasion head 75deg HITS%_cum	HITSn_cum	evasion head 90deg HITS%_cum	HITSn_cum
0	100	0.0037	45	0.0038	46	0.0039	47	0.0039	47	0.0039	47
100	200	0.0114	138	0.0114	138	0.0117	141	0.0117	141	0.0117	141
200	300	0.0188	228	0.0193	233	0.0193	233	0.0193	233	0.0193	233
300	400	0.0283	343	0.0288	348	0.0288	348	0.0288	348	0.0288	348
400	500	0.0395	478	0.0397	480	0.0397	480	0.0397	480	0.0397	480
500	600	0.0510	617	0.0512	620	0.0512	620	0.0512	620	0.0512	620
600	700	0.0625	756	0.0625	756	0.0625	756	0.0625	756	0.0625	756
900	1000	0.1055	1277	0.1052	1273	0.1052	1273	0.1052	1273	0.1052	1273

This set of runs was run 5/4/93 to check sensitivity to
distance-from-centerline alarm criteria. More detailed info is in sens2.comp.13.stat .

LO	HI	alarm-dist=150ft HITS%_cum	HITSn_cum	alarm-dist=400ft HITS%_cum	HITSn_cum	alarm-dist=650ft HITS%_cum	HITSn_cum	alarm-dist=900ft HITS%_cum	HITSn_cum	alarm-dist=1150ft HITS%_cum	HITSn_cum
0	100	0.0011	13	0.0016	19	0.0024	29	0.0031	38	0.0039	47
100	200	0.0028	34	0.0049	59	0.0069	83	0.0094	114	0.0117	141
200	300	0.0039	47	0.0073	88	0.0106	128	0.0146	177	0.0193	233
300	400	0.0055	67	0.0112	135	0.0167	202	0.0217	263	0.0288	348
400	500	0.0080	97	0.0157	190	0.0229	277	0.0307	371	0.0397	480
500	600	0.0108	131	0.0215	260	0.0306	370	0.0403	488	0.0512	620
600	700	0.0150	181	0.0281	340	0.0387	468	0.0511	618	0.0625	756
900	1000	0.0293	355	0.0521	630	0.0698	845	0.0875	1059	0.1052	1273

This set of runs was run 5/4/93 to check sensitivity to
the evaders speed increase. More detailed info is in sens2.comp.12.stat .
The speed increase had no effect in this series. This is because in most cases the turn is only partially completed at the instant of closest approach. The speed increase is mechanized so as to start after the turn is complete. If the bank angle is increased (from 22 deg), or the evasion turn heading angle is decreased (from 55 deg), then speed increase will have a minor effect. See evade.hilo.comp for runs with a minor effect from speed increase.

LO	HI	speed change 0fps HITS%_cum	HITSn_cum	speed change 15 fps HITS%_cum	HITSn_cum	speed change 30 fps HITS%_cum	HITSn_cum	speed change 45 fps HITS%_cum	HITSn_cum	speed change 60 fps HITS%_cum	HITSn_cum
0	100	0.0039	47	0.0039	47	0.0039	47	0.0039	47	0.0039	47
100	200	0.0117	141	0.0117	141	0.0117	141	0.0117	141	0.0117	141
200	300	0.0193	233	0.0193	233	0.0193	233	0.0193	233	0.0193	233
300	400	0.0288	348	0.0288	348	0.0288	348	0.0288	348	0.0288	348
400	500	0.0397	480	0.0397	480	0.0397	480	0.0397	480	0.0397	480
500	600	0.0512	620	0.0512	620	0.0512	620	0.0512	620	0.0512	620
600	700	0.0625	756	0.0625	756	0.0625	756	0.0625	756	0.0625	756
900	1000	0.1052	1273	0.1052	1273	0.1052	1273	0.1052	1273	0.1052	1273

This set of runs was run 5/1/93 to check sensitivity to parallel runway separation when NTZ width stays constant at 2000 ft. More detailed info is in sens2.comp.3.stat .

LO	HI	Rwy sep = 2900 ft. HITS%_cum	HITSn_cum	Rwy sep = 3600 ft. HITS%_cum	HITSn_cum	Rwy sep = 4300 ft. HITS%_cum	HITSn_cum	Rwy sep = 5000 ft. HITS%_cum	HITSn_cum	Rwy sep = 5700 ft. HITS%_cum	HITSn_cum
0	100	0.0099	120	0.0058	70	0.0039	47	0.0026	31	0.0017	21
100	200	0.0226	273	0.0164	199	0.0123	149	0.0086	104	0.0052	63
200	300	0.0352	426	0.0282	341	0.0198	240	0.0136	165	0.0088	107
300	400	0.0500	605	0.0402	486	0.0298	361	0.0212	256	0.0130	157
400	500	0.0679	822	0.0524	634	0.0406	491	0.0277	335	0.0179	216
500	600	0.0837	1013	0.0668	808	0.0520	629	0.0362	438	0.0250	302
600	700	0.1007	1219	0.0828	1002	0.0629	761	0.0460	556	0.0312	378
900	1000	0.1630	1972	0.1345	1627	0.1076	1302	0.0813	984	0.0603	730

This set of runs was run 5/1/93 to check sensitivity to parallel runway separation when NTZ width varies with runway separation. More detailed info is in sens2.comp.4.stat .

LO	HI	Rwy sep = 2900 ft. NTZ = 600 HITS%_cum	HITSn_cum	Rwy sep = 3600 ft. NTZ = 1300 HITS%_cum	HITSn_cum	Rwy sep = 4300 ft. NTZ = 2000 HITS%_cum	HITSn_cum	Rwy sep = 5000 ft. NTZ = 2700 HITS%_cum	HITSn_cum	Rwy sep = 5700 ft. NTZ = 3400 HITS%_cum	HITSn_cum
0	100	0.0156	189	0.0081	98	0.0039	47	0.0016	19	0.0007	9
100	200	0.0336	407	0.0198	240	0.0117	141	0.0054	65	0.0019	23
200	300	0.0542	656	0.0356	431	0.0193	233	0.0088	107	0.0036	44
300	400	0.0735	889	0.0504	610	0.0288	348	0.0134	162	0.0055	66
400	500	0.0970	1174	0.0666	806	0.0397	480	0.0183	222	0.0074	90
500	600	0.1196	1447	0.0840	1016	0.0512	620	0.0240	291	0.0100	121
600	700	0.1426	1726	0.1035	1252	0.0625	756	0.0307	371	0.0122	148
900	1000	0.2287	2767	0.1598	1934	0.1052	1273	0.0574	695	0.0257	311

This set of runs was run 5/1/93 to check sensitivity to the longitudinal (x) relation between the evader and the blundering aircraft. More detailed info is in sens2.comp.5.sta

LO	HI	evader ahead 10k ft HITS%_cum	evader ahead 2k ft HITS%_cum	evader ahead 1k ft HITS%_cum	evader alongside HITS%_cum	evader behind 1k ft HITS%_cum	evader behind 2k ft HITS%_cum	evader behinc 10k ft HITS%_cum
0	100	0.0000	0.0008	0.0012	0.0028	0.0186	0.0014	0.0000
100	200	0.0002	0.0032	0.0052	0.0078	0.0474	0.0066	0.0000
200	300	0.0008	0.0064	0.0082	0.0132	0.0744	0.0126	0.0000
300	400	0.0024	0.0074	0.0130	0.0216	0.1032	0.0216	0.0000
400	500	0.0042	0.0096	0.0180	0.0310	0.1284	0.0332	0.0000
500	600	0.0050	0.0136	0.0224	0.0398	0.1538	0.0478	0.0000
600	700	0.0066	0.0192	0.0268	0.0562	0.1776	0.0690	0.0002
900	1000	0.0120	0.0344	0.0464	0.1290	0.2536	0.1402	0.0018

This set of runs was run 4/30/93 to check sensitivity to
total system response delay time (with 0 variation). More detailed info is in sens2.comp.1.stat .

LO	HI	delay-time = 4 sec. HITS%_cum	HITSn_cum	delay-time = 8 sec. HITS%_cum	HITSn_cum	delay-time = 12 sec. HITS%_cum	HITSn_cum	delay-time = 16 sec. HITS%_cum	HITSn_cum	delay-time = 20 sec. HITS%_cum	HITSn_cum
0	100	0.0000	0	0.0000	0	0.0000	0	0.0104	126	0.0131	159
100	200	0.0000	0	0.0000	0	0.0003	4	0.0298	360	0.0364	440
200	300	0.0000	0	0.0000	0	0.0026	32	0.0438	530	0.0654	791
300	400	0.0000	0	0.0000	0	0.0147	178	0.0610	738	0.0984	1191
400	500	0.0000	0	0.0000	0	0.0372	450	0.0796	963	0.1287	1557
500	600	0.0000	0	0.0000	0	0.0602	729	0.0993	1201	0.1580	1912
600	700	0.0000	0	0.0002	3	0.0818	990	0.1288	1559	0.1859	2249
900	1000	0.0000	0	0.0256	310	0.1403	1698	0.2364	2860	0.2698	3265

This set of runs was run 5/1/93 to check sensitivity to
total-system-response-delay-time-uncertainty. More detailed info is in sens2.comp.2.stat .

LO	HI	delay-time-SD = 0 HITS%_cum	HITSn_cum	delay-time-SD=4.0 HITS%_cum	HITSn_cum	delay-time-SD=8.0 HITS%_cum	HITSn_cum	delay-time-SD=12 HITS%_cum	HITSn_cum	delay-time-SD=16 HITS%_cum	HITSn_cum
0	100	0.0000	0	0.0007	9	0.0031	37	0.0051	62	0.0060	73
100	200	0.0000	0	0.0025	30	0.0094	114	0.0142	172	0.0173	209
200	300	0.0000	0	0.0051	62	0.0154	186	0.0220	266	0.0260	315
300	400	0.0000	0	0.0082	99	0.0232	281	0.0327	396	0.0383	463
400	500	0.0000	0	0.0135	163	0.0317	384	0.0440	532	0.0494	598
500	600	0.0000	0	0.0211	255	0.0437	529	0.0549	664	0.0607	734
600	700	0.0002	3	0.0292	353	0.0536	648	0.0652	789	0.0726	879
900	1000	0.0269	325	0.0686	830	0.0944	1142	0.1074	1299	0.1150	1392

APPENDIX B

CROSS CORRELATION DATA ANALYSIS OF SENSITIVE PARAMETERS

blunderer mean speed relative to Evader mean speed, 500 CPA collision rate.

spd -20	response.04	response.06	response.08	response.12	response.16
way.2500	0.0060	0.0120	0.0178	0.0260	0.0302
way.3000	0.0014	0.0062	0.0105	0.0176	0.0231
way.3400	0.0002	0.0033	0.0081	0.0149	0.0188
way.3700	0.0000	0.0019	0.0064	0.0132	0.0174
way.4000	0.0000	0.0006	0.0033	0.0099	0.0138
way.4300	0.0000	0.0002	0.0014	0.0076	0.0107
way.5000	0.0000	0.0000	0.0006	0.0039	0.0060

e AC spd	response.04	response.06	response.08	response.12	response.16
way.2500	0.0174	0.0403	0.0593	0.0764	0.0835
way.3000	0.0048	0.0207	0.0382	0.0651	0.0754
way.3400	0.0023	0.0112	0.0267	0.0533	0.0688
way.3700	0.0006	0.0066	0.0202	0.0448	0.0626
way.4000	0.0000	0.0039	0.0134	0.0382	0.0576
way.4300	0.0000	0.0023	0.0095	0.0318	0.0510
way.5000	0.0000	0.0002	0.0037	0.0171	0.0357

spd +20	response.04	response.06	response.08	response.12	response.16
ay.2500	0.0229	0.0345	0.0417	0.0486	0.0512
ay.3000	0.0105	0.0236	0.0337	0.0426	0.0457
ay.3400	0.0060	0.0163	0.0273	0.0393	0.0444
ay.3700	0.0031	0.0126	0.0219	0.0366	0.0424
ay.4000	0.0010	0.0087	0.0171	0.0331	0.0409
ay.4300	0.0004	0.0074	0.0130	0.0295	0.0401
ay.5000	0.0000	0.0014	0.0079	0.0200	0.0331

pd -20	CPA lim	response.04	response.06	response.08	response.12	response.16
ay.2500	CPA 400	0.0039	0.0085	0.0120	0.0169	0.0215
	CPA 500	0.0060	0.0120	0.0178	0.0260	0.0302
	CPA 600	0.0091	0.0178	0.0248	0.0329	0.0380
ay.3000	CPA 400	0.0006	0.0045	0.0079	0.0126	0.0159
	CPA 500	0.0014	0.0062	0.0105	0.0176	0.0231
	CPA 600	0.0025	0.0085	0.0145	0.0231	0.0310
ay.3400	CPA 400	0.0000	0.0025	0.0060	0.0112	0.0134
	CPA 500	0.0002	0.0033	0.0081	0.0149	0.0188
	CPA 600	0.0004	0.0054	0.0114	0.0180	0.0240
y.3700	CPA 400	0.0000	0.0012	0.0048	0.0099	0.0134
	CPA 500	0.0000	0.0019	0.0064	0.0132	0.0174
	CPA 600	0.0000	0.0029	0.0079	0.0149	0.0196
y.4000	CPA 400	0.0000	0.0002	0.0021	0.0083	0.0114
	CPA 500	0.0000	0.0006	0.0033	0.0099	0.0138
	CPA 600	0.0000	0.0012	0.0056	0.0132	0.0182
y.4300	CPA 400	0.0000	0.0000	0.0014	0.0070	0.0091
	CPA 500	0.0000	0.0002	0.0014	0.0076	0.0107
	CPA 600	0.0000	0.0002	0.0021	0.0097	0.0138
y.5000	CPA 400	0.0000	0.0000	0.0000	0.0029	0.0048
	CPA 500	0.0000	0.0000	0.0006	0.0039	0.0060
	CPA 600	0.0000	0.0000	0.0008	0.0054	0.0079

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This series of runs examines the relation of
absolute aircraft speed vs runway separation vs total alarm response time.
This was run 5/6/93. The baseline P(collision) is about 1.5%.

AC spd +20	response.04	response.06	response.08	response.12	response.16
runway.2500	0.0337	0.0614	0.0760	0.0855	0.0903
runway.3000	0.0132	0.0364	0.0552	0.0756	0.0841
runway.3400	0.0043	0.0225	0.0405	0.0663	0.0771
runway.3700	0.0031	0.0161	0.0318	0.0581	0.0725
runway.4000	0.0017	0.0095	0.0246	0.0525	0.0690
runway.4300	0.0004	0.0058	0.0178	0.0440	0.0624
runway.5000	0.0000	0.0014	0.0085	0.0287	0.0481

Base AC spd	response.04	response.06	response.08	response.12	response.16
runway.2500	0.0174	0.0403	0.0593	0.0764	0.0835
runway.3000	0.0048	0.0207	0.0382	0.0651	0.0754
runway.3400	0.0023	0.0112	0.0267	0.0533	0.0688
runway.3700	0.0006	0.0066	0.0202	0.0448	0.0626
runway.4000	0.0000	0.0039	0.0134	0.0382	0.0576
runway.4300	0.0000	0.0023	0.0095	0.0318	0.0510
runway.5000	0.0000	0.0002	0.0037	0.0171	0.0357

AC spd -20	response.04	response.06	response.08	response.12	response.16	response.20
runway.2500	0.0066		0.0428	0.0667	0.0773	0.0839
runway.3000	0.0012		0.0238	0.0496	0.0669	0.0748
runway.3400	0.0000		0.0153	0.0376	0.0574	0.0692
runway.3700	0.0000		0.0095	0.0318	0.0523	0.0622
runway.4000	0.0000		0.0060	0.0256	0.0432	0.0576
runway.4300	0.0000		0.0041	0.0205	0.0399	0.0535
runway.5000	0.0000		0.0010	0.0103	0.0264	0.0409

```
cp runway.2500.seg.dat  runway.a.seg.dat
cp runway.3000.seg.dat  runway.b.seg.dat
cp runway.3400.seg.dat  runway.c.seg.dat
cp runway.3700.seg.dat  runway.d.seg.dat
cp runway.4000.seg.dat  runway.e.seg.dat
cp runway.4300.seg.dat  runway.f.seg.dat
cp runway.5000.seg.dat  runway.g.seg.dat
cp response.04.seg.dat response.1.seg.dat
cp response.06.seg.dat response.2.seg.dat
cp response.08.seg.dat response.3.seg.dat
cp response.12.seg.dat response.4.seg.dat
cp response.16.seg.dat response.5.seg.dat
```

This was run 5/6. Each number is based on 4840 trials.
This series of runs examines the effect of
blunder-angle, total-response-time, and runway-separation
on the probability of collision (CPA < 500 ft).

The baseline collision rate is about 0.015

probability of (CPA < 500 ft)

blunder 15d	response.04	response.06	response.08	response.12	response.16	response.20	response.24
runway.2500			0.0050	0.0219	0.0434	0.0581	0.0705
runway.3000			0.0006	0.0081	0.0240	0.0409	0.0531
runway.3400			0.0000	0.0039	0.0134	0.0293	0.0405
runway.3700			0.0000	0.0014	0.0076	0.0202	0.0347
runway.4000			0.0000	0.0006	0.0045	0.0149	0.0260
runway.4300			0.0000	0.0000	0.0014	0.0093	0.0192
runway.5000			0.0000	0.0002	0.0008	0.0033	0.0091

blunder 22.5d	response.04	response.06	response.08	response.12	response.16
runway.2500	0.0014	0.0136	0.0320	0.0581	0.0756
runway.3000	0.0000	0.0027	0.0128	0.0411	0.0614
runway.3400	0.0000	0.0008	0.0045	0.0279	0.0483
runway.3700	0.0000	0.0002	0.0029	0.0194	0.0399
runway.4000	0.0000	0.0000	0.0017	0.0130	0.0318
runway.4300	0.0000	0.0000	0.0006	0.0079	0.0267
runway.5000	0.0000	0.0000	0.0000	0.0050	0.0132

blunder 30d	response.04	response.06	response.08	response.12	response.16
runway.2500	0.0174	0.0403	0.0593	0.0764	0.0835
runway.3000	0.0048	0.0207	0.0382	0.0651	0.0754
runway.3400	0.0023	0.0112	0.0267	0.0533	0.0688
runway.3700	0.0006	0.0066	0.0202	0.0448	0.0626
runway.4000	0.0000	0.0039	0.0134	0.0382	0.0576
runway.4300	0.0000	0.0023	0.0095	0.0318	0.0510
runway.5000	0.0000	0.0002	0.0037	0.0171	0.0357

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probability of (CPA < 400-700 ft)

blunder 15d	CPA lim	response.04	response.06	response.08	response.12	response.16	response.20	response.2
runway.2500	CPA 400			0.0033	0.0147	0.0308	0.0430	0.0545
	CPA 500			0.0050	0.0219	0.0434	0.0581	0.0705
	CPA 600			0.0068	0.0329	0.0554	0.0727	0.0862
	CPA 700			0.0099	0.0417	0.0694	0.0907	0.1023
runway.3000	CPA 400			0.0004	0.0056	0.0176	0.0320	0.0430
	CPA 500			0.0006	0.0081	0.0240	0.0409	0.0531
	CPA 600			0.0010	0.0118	0.0335	0.0508	0.0674
	CPA 700			0.0029	0.0169	0.0430	0.0649	0.0835
runway.3400	CPA 400			0.0000	0.0025	0.0095	0.0221	0.0339
	CPA 500			0.0000	0.0039	0.0134	0.0293	0.0405
	CPA 600			0.0000	0.0058	0.0202	0.0376	0.0533
	CPA 700			0.0002	0.0079	0.0264	0.0479	0.0661
runway.3700	CPA 400			0.0000	0.0008	0.0062	0.0157	0.0271
	CPA 500			0.0000	0.0014	0.0076	0.0202	0.0347
	CPA 600			0.0000	0.0033	0.0126	0.0293	0.0450
	CPA 700			0.0000	0.0041	0.0167	0.0349	0.0535
runway.4000	CPA 400			0.0000	0.0002	0.0027	0.0099	0.0207
	CPA 500			0.0000	0.0006	0.0045	0.0149	0.0260
	CPA 600			0.0000	0.0010	0.0083	0.0213	0.0351
	CPA 700			0.0000	0.0017	0.0116	0.0260	0.0424
runway.4300	CPA 400			0.0000	0.0000	0.0012	0.0064	0.0126
	CPA 500			0.0000	0.0000	0.0014	0.0093	0.0192
	CPA 600			0.0000	0.0002	0.0041	0.0149	0.0271
	CPA 700			0.0000	0.0010	0.0064	0.0184	0.0329
runway.5000	CPA 400			0.0000	0.0000	0.0004	0.0027	0.0070
	CPA 500			0.0000	0.0002	0.0008	0.0033	0.0091
	CPA 600			0.0000	0.0004	0.0012	0.0056	0.0126
	CPA 700			0.0000	0.0004	0.0019	0.0087	0.0161

blunder 22d	CPA lim	response.04	response.06	response.08	response.12	response.16
runway.2500	CPA 400	0.0008	0.0060	0.0198	0.0401	0.0541
	CPA 500	0.0014	0.0136	0.0320	0.0581	0.0756
	CPA 600	0.0045	0.0217	0.0401	0.0738	0.0913
	CPA 700	0.0068	0.0298	0.0517	0.0890	0.1062
runway.3000	CPA 400	0.0000	0.0014	0.0068	0.0293	0.0469
	CPA 500	0.0000	0.0027	0.0128	0.0411	0.0614
	CPA 600	0.0000	0.0058	0.0205	0.0514	0.0754
	CPA 700	0.0000	0.0076	0.0281	0.0616	0.0872
runway.3400	CPA 400	0.0000	0.0004	0.0029	0.0205	0.0372
	CPA 500	0.0000	0.0008	0.0045	0.0279	0.0483
	CPA 600	0.0000	0.0019	0.0085	0.0380	0.0612
	CPA 700	0.0000	0.0023	0.0126	0.0494	0.0760
runway.3700	CPA 400	0.0000	0.0000	0.0017	0.0153	0.0302
	CPA 500	0.0000	0.0002	0.0029	0.0194	0.0399
	CPA 600	0.0000	0.0002	0.0043	0.0271	0.0504
	CPA 700	0.0000	0.0010	0.0064	0.0374	0.0622
runway.4000	CPA 400	0.0000	0.0000	0.0012	0.0072	0.0260
	CPA 500	0.0000	0.0000	0.0017	0.0130	0.0318
	CPA 600	0.0000	0.0000	0.0025	0.0209	0.0419
	CPA 700	0.0000	0.0000	0.0045	0.0264	0.0550
runway.4300	CPA 400	0.0000	0.0000	0.0002	0.0052	0.0182
	CPA 500	0.0000	0.0000	0.0006	0.0079	0.0267
	CPA 600	0.0000	0.0000	0.0012	0.0120	0.0341
	CPA 700	0.0000	0.0000	0.0021	0.0159	0.0432
runway.5000	CPA 400	0.0000	0.0000	0.0000	0.0041	0.0093
	CPA 500	0.0000	0.0000	0.0000	0.0050	0.0132
	CPA 600	0.0000	0.0000	0.0000	0.0066	0.0188
	CPA 700	0.0000	0.0000	0.0000	0.0076	0.0246

blunder 30d	CPA lim	response.04	response.06	response.08	response.12	response.16
runway.2500	CPA 400	0.0114	0.0298	0.0459	0.0636	0.0692
	CPA 500	0.0174	0.0403	0.0593	0.0764	0.0835
	CPA 600	0.0258	0.0529	0.0760	0.0955	0.1031
	CPA 700	0.0380	0.0709	0.0932	0.1114	0.1194
runway.3000	CPA 400	0.0035	0.0155	0.0279	0.0502	0.0610
	CPA 500	0.0048	0.0207	0.0382	0.0651	0.0754
	CPA 600	0.0068	0.0287	0.0510	0.0789	0.0915
	CPA 700	0.0110	0.0405	0.0634	0.0973	0.1087
runway.3400	CPA 400	0.0010	0.0064	0.0196	0.0399	0.0531
	CPA 500	0.0023	0.0112	0.0267	0.0533	0.0688
	CPA 600	0.0029	0.0178	0.0355	0.0676	0.0849
	CPA 700	0.0041	0.0221	0.0444	0.0810	0.1006
runway.3700	CPA 400	0.0004	0.0039	0.0151	0.0339	0.0498
	CPA 500	0.0006	0.0066	0.0202	0.0448	0.0626
	CPA 600	0.0012	0.0085	0.0269	0.0574	0.0758
	CPA 700	0.0021	0.0124	0.0312	0.0721	0.0940
runway.4000	CPA 400	0.0000	0.0029	0.0101	0.0289	0.0434
	CPA 500	0.0000	0.0039	0.0134	0.0382	0.0576
	CPA 600	0.0002	0.0050	0.0182	0.0490	0.0709
	CPA 700	0.0006	0.0068	0.0238	0.0595	0.0833
runway.4300	CPA 400	0.0000	0.0021	0.0074	0.0240	0.0382
	CPA 500	0.0000	0.0023	0.0095	0.0318	0.0510
	CPA 600	0.0000	0.0037	0.0122	0.0395	0.0645
	CPA 700	0.0000	0.0041	0.0149	0.0481	0.0764
runway.5000	CPA 400	0.0000	0.0002	0.0027	0.0143	0.0271
	CPA 500	0.0000	0.0002	0.0037	0.0171	0.0357
	CPA 600	0.0000	0.0006	0.0050	0.0229	0.0477
	CPA 700	0.0000	0.0008	0.0062	0.0310	0.0589

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series below is for
sep vs Tresp vs x-offset
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CPA < 500ft, runway separation VS evader along-track relation to blunderer VS total response delay time.
5/12/93, 3990 trials per number.

sponse.04	3000'ahead	2000'ahead	1000'ahead	alongside	1000'behind	2000'behind	3000'behind
nway.2500	0.0065	0.0055	0.0083	0.0386	0.0586	0.0048	0.0018
nway.3000	0.0033	0.0013	0.0040	0.0095	0.0216	0.0015	0.0000
nway.3400	0.0010	0.0008	0.0013	0.0035	0.0078	0.0005	0.0000
nway.3700	0.0003	0.0005	0.0003	0.0015	0.0023	0.0000	0.0000
nway.4000	0.0000	0.0003	0.0000	0.0000	0.0005	0.0000	0.0000
nway.4300	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0.0000
nway.5000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

sponse.06	3000'ahead	2000'ahead	1000'ahead	alongside	1000'behind	2000'behind	3000'behind
nway.2500	0.0093	0.0115	0.0170	0.0915	0.1228	0.0113	0.0050
nway.3000	0.0068	0.0065	0.0100	0.0381	0.0752	0.0075	0.0015
nway.3400	0.0048	0.0038	0.0065	0.0185	0.0444	0.0058	0.0003
nway.3700	0.0035	0.0023	0.0055	0.0085	0.0286	0.0045	0.0000
nway.4000	0.0023	0.0018	0.0035	0.0038	0.0163	0.0023	0.0000
nway.4300	0.0010	0.0010	0.0013	0.0028	0.0090	0.0020	0.0000
nway.5000	0.0000	0.0005	0.0000	0.0003	0.0010	0.0003	0.0000

sponse.08	3000'ahead	2000'ahead	1000'ahead	alongside	1000'behind	2000'behind	3000'behind
nway.2500	0.0113	0.0138	0.0233	0.1263	0.1732	0.0228	0.0078
nway.3000	0.0085	0.0108	0.0165	0.0684	0.1311	0.0165	0.0038
nway.3400	0.0070	0.0080	0.0125	0.0398	0.0942	0.0160	0.0015
nway.3700	0.0063	0.0055	0.0108	0.0258	0.0677	0.0133	0.0010
nway.4000	0.0050	0.0048	0.0080	0.0165	0.0489	0.0110	0.0008
nway.4300	0.0043	0.0033	0.0058	0.0103	0.0346	0.0088	0.0008
nway.5000	0.0020	0.0013	0.0025	0.0040	0.0105	0.0045	0.0000

sponse.12	3000'ahead	2000'ahead	1000'ahead	alongside	1000'behind	2000'behind	3000'behind
nway.2500	0.0140	0.0150	0.0291	0.1599	0.2203	0.0341	0.0118
nway.3000	0.0115	0.0145	0.0243	0.1085	0.2080	0.0366	0.0080
nway.3400	0.0103	0.0143	0.0218	0.0749	0.1807	0.0414	0.0055
nway.3700	0.0090	0.0123	0.0185	0.0539	0.1531	0.0406	0.0038
nway.4000	0.0080	0.0105	0.0185	0.0401	0.1278	0.0353	0.0033
nway.4300	0.0075	0.0093	0.0160	0.0291	0.1038	0.0353	0.0035
nway.5000	0.0060	0.0068	0.0118	0.0178	0.0561	0.0293	0.0028

sponse.16	3000'ahead	2000'ahead	1000'ahead	alongside	1000'behind	2000'behind	3000'behind
nway.2500	0.0153	0.0170	0.0311	0.1797	0.2461	0.0404	0.0138
nway.3000	0.0133	0.0155	0.0281	0.1278	0.2424	0.0456	0.0103
nway.3400	0.0120	0.0158	0.0273	0.0977	0.2288	0.0564	0.0103
nway.3700	0.0115	0.0150	0.0243	0.0762	0.2098	0.0599	0.0083
nway.4000	0.0105	0.0148	0.0236	0.0594	0.1875	0.0637	0.0070
nway.4300	0.0098	0.0138	0.0211	0.0471	0.1622	0.0632	0.0068
nway.5000	0.0078	0.0130	0.0185	0.0303	0.1060	0.0617	0.0060

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runway separation VS evader along-track relation to blunderer VS total response delay time.
For CPA < 400-500-600-700ft ,Run 5/12/93, 3990 trials per number.

response.04	CPA lim	3000'ahead	2000'ahead	1000'ahead	alongside	1000'behind	2000'behind	3000'behind
runway.2500	CPA 400	0.0048	0.0028	0.0045	0.0241	0.0368	0.0018	0.0003
	CPA 500	0.0065	0.0055	0.0083	0.0386	0.0586	0.0048	0.0018
	CPA 600	0.0073	0.0083	0.0133	0.0639	0.0792	0.0073	0.0025
	CPA 700	0.0098	0.0123	0.0193	0.0910	0.1058	0.0100	0.0035
runway.3000	CPA 400	0.0018	0.0008	0.0023	0.0053	0.0150	0.0010	0.0000
	CPA 500	0.0033	0.0013	0.0040	0.0095	0.0216	0.0015	0.0000
	CPA 600	0.0043	0.0028	0.0055	0.0145	0.0303	0.0020	0.0000
	CPA 700	0.0050	0.0050	0.0075	0.0241	0.0419	0.0038	0.0000
runway.3400	CPA 400	0.0008	0.0008	0.0008	0.0023	0.0050	0.0003	0.0000
	CPA 500	0.0010	0.0008	0.0013	0.0035	0.0078	0.0005	0.0000
	CPA 600	0.0010	0.0013	0.0020	0.0053	0.0123	0.0013	0.0000
	CPA 700	0.0020	0.0020	0.0033	0.0075	0.0173	0.0025	0.0000
runway.3700	CPA 400	0.0003	0.0005	0.0000	0.0008	0.0010	0.0000	0.0000
	CPA 500	0.0003	0.0005	0.0003	0.0015	0.0023	0.0000	0.0000
	CPA 600	0.0005	0.0005	0.0005	0.0025	0.0048	0.0000	0.0000
	CPA 700	0.0010	0.0008	0.0013	0.0038	0.0070	0.0003	0.0000
runway.4000	CPA 400	0.0000	0.0003	0.0000	0.0000	0.0003	0.0000	0.0000
	CPA 500	0.0000	0.0003	0.0000	0.0000	0.0005	0.0000	0.0000
	CPA 600	0.0003	0.0005	0.0000	0.0005	0.0010	0.0000	0.0000
	CPA 700	0.0003	0.0005	0.0000	0.0010	0.0020	0.0000	0.0000
runway.4300	CPA 400	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	CPA 500	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0.0000
	CPA 600	0.0000	0.0003	0.0000	0.0000	0.0003	0.0000	0.0000
	CPA 700	0.0000	0.0003	0.0000	0.0000	0.0005	0.0000	0.0000
runway.5000	CPA 400	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	CPA 500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	CPA 600	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	CPA 700	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

runway separation VS evader along-track relation to blunderer VS total response delay time.
For CPA < 400-500-600-700ft ,Run 5/12/93, 3990 trials per number.

response.06	CPA lim	3000'ahead	2000'ahead	1000'ahead	alongside	1000'behind	2000'behind	3000'behind
runway.2500	CPA 400	0.0075	0.0073	0.0110	0.0612	0.0887	0.0078	0.0028
	CPA 500	0.0093	0.0115	0.0170	0.0915	0.1228	0.0113	0.0050
	CPA 600	0.0118	0.0128	0.0243	0.1236	0.1549	0.0175	0.0073
	CPA 700	0.0140	0.0180	0.0303	0.1602	0.1935	0.0278	0.0090
runway.3000	CPA 400	0.0058	0.0040	0.0073	0.0261	0.0551	0.0058	0.0010
	CPA 500	0.0068	0.0065	0.0100	0.0381	0.0752	0.0075	0.0015
	CPA 600	0.0078	0.0088	0.0150	0.0569	0.0977	0.0143	0.0025
	CPA 700	0.0105	0.0125	0.0216	0.0774	0.1195	0.0198	0.0030
runway.3400	CPA 400	0.0033	0.0028	0.0048	0.0108	0.0328	0.0035	0.0003
	CPA 500	0.0048	0.0038	0.0065	0.0185	0.0444	0.0058	0.0003
	CPA 600	0.0060	0.0055	0.0095	0.0253	0.0574	0.0088	0.0008
	CPA 700	0.0068	0.0078	0.0130	0.0373	0.0737	0.0128	0.0015
runway.3700	CPA 400	0.0020	0.0015	0.0033	0.0048	0.0195	0.0018	0.0000
	CPA 500	0.0035	0.0023	0.0055	0.0085	0.0286	0.0045	0.0000
	CPA 600	0.0043	0.0038	0.0063	0.0145	0.0373	0.0065	0.0000
	CPA 700	0.0055	0.0055	0.0080	0.0208	0.0476	0.0090	0.0005
runway.4000	CPA 400	0.0013	0.0010	0.0020	0.0025	0.0115	0.0015	0.0000
	CPA 500	0.0023	0.0018	0.0035	0.0038	0.0163	0.0023	0.0000
	CPA 600	0.0025	0.0023	0.0043	0.0063	0.0233	0.0035	0.0000
	CPA 700	0.0038	0.0035	0.0063	0.0108	0.0288	0.0073	0.0000
runway.4300	CPA 400	0.0010	0.0005	0.0010	0.0023	0.0055	0.0018	0.0000
	CPA 500	0.0010	0.0010	0.0013	0.0028	0.0090	0.0020	0.0000
	CPA 600	0.0015	0.0013	0.0025	0.0030	0.0128	0.0028	0.0000
	CPA 700	0.0023	0.0020	0.0033	0.0045	0.0163	0.0040	0.0000
runway.5000	CPA 400	0.0000	0.0005	0.0000	0.0000	0.0005	0.0003	0.0000
	CPA 500	0.0000	0.0005	0.0000	0.0003	0.0010	0.0003	0.0000
	CPA 600	0.0003	0.0005	0.0003	0.0008	0.0020	0.0003	0.0000
	CPA 700	0.0003	0.0008	0.0005	0.0015	0.0030	0.0010	0.0000

runway separation VS evader along-track relation to blunderer VS total response delay time.
For CPA < 400-500-600-700ft ,Run 5/12/93, 3990 trials per number.

response.08	CPA lim	3000'ahead	2000'ahead	1000'ahead	alongside	1000'behind	2000'behind	3000'behind
runway.2500	CPA 400	0.0098	0.0100	0.0153	0.0917	0.1343	0.0143	0.0053
	CPA 500	0.0113	0.0138	0.0233	0.1263	0.1732	0.0228	0.0078
	CPA 600	0.0140	0.0158	0.0316	0.1639	0.2098	0.0321	0.0098
	CPA 700	0.0168	0.0190	0.0398	0.2013	0.2474	0.0459	0.0128
runway.3000	CPA 400	0.0075	0.0075	0.0125	0.0464	0.0970	0.0110	0.0028
	CPA 500	0.0085	0.0108	0.0165	0.0684	0.1311	0.0165	0.0038
	CPA 600	0.0118	0.0133	0.0221	0.0922	0.1617	0.0276	0.0053
	CPA 700	0.0135	0.0168	0.0303	0.1253	0.1907	0.0404	0.0073
runway.3400	CPA 400	0.0063	0.0058	0.0103	0.0268	0.0717	0.0088	0.0010
	CPA 500	0.0070	0.0080	0.0125	0.0398	0.0942	0.0160	0.0015
	CPA 600	0.0088	0.0110	0.0185	0.0529	0.1175	0.0243	0.0030
	CPA 700	0.0110	0.0128	0.0228	0.0757	0.1396	0.0321	0.0045
runway.3700	CPA 400	0.0050	0.0043	0.0078	0.0185	0.0531	0.0073	0.0010
	CPA 500	0.0063	0.0055	0.0108	0.0258	0.0677	0.0133	0.0010
	CPA 600	0.0068	0.0090	0.0148	0.0353	0.0842	0.0190	0.0018
	CPA 700	0.0098	0.0105	0.0190	0.0506	0.1040	0.0266	0.0028
runway.4000	CPA 400	0.0038	0.0033	0.0055	0.0113	0.0366	0.0068	0.0005
	CPA 500	0.0050	0.0048	0.0080	0.0165	0.0489	0.0110	0.0008
	CPA 600	0.0060	0.0058	0.0118	0.0246	0.0624	0.0165	0.0018
	CPA 700	0.0075	0.0088	0.0145	0.0326	0.0767	0.0228	0.0020
runway.4300	CPA 400	0.0030	0.0023	0.0045	0.0058	0.0258	0.0060	0.0000
	CPA 500	0.0043	0.0033	0.0058	0.0103	0.0346	0.0088	0.0008
	CPA 600	0.0050	0.0043	0.0080	0.0148	0.0426	0.0135	0.0013
	CPA 700	0.0058	0.0073	0.0108	0.0211	0.0544	0.0206	0.0020
runway.5000	CPA 400	0.0013	0.0005	0.0018	0.0028	0.0083	0.0038	0.0000
	CPA 500	0.0020	0.0013	0.0025	0.0040	0.0105	0.0045	0.0000
	CPA 600	0.0025	0.0025	0.0033	0.0040	0.0145	0.0070	0.0003
	CPA 700	0.0030	0.0038	0.0053	0.0048	0.0190	0.0088	0.0008

runway separation VS evader along-track relation to blunderer VS total response delay time.
For CPA < 400-500-600-700ft ,Run 5/12/93, 3990 trials per number.

response.12	CPA lim	3000'ahead	2000'ahead	1000'ahead	alongside	1000'behind	2000'behind	3000'behind
runway.2500	CPA 400	0.0113	0.0113	0.0208	0.1206	0.1739	0.0238	0.0085
	CPA 500	0.0140	0.0150	0.0291	0.1599	0.2203	0.0341	0.0118
	CPA 600	0.0160	0.0173	0.0373	0.2028	0.2622	0.0456	0.0140
	CPA 700	0.0195	0.0218	0.0461	0.2466	0.2997	0.0634	0.0173
runway.3000	CPA 400	0.0095	0.0120	0.0185	0.0774	0.1659	0.0278	0.0063
	CPA 500	0.0115	0.0145	0.0243	0.1085	0.2080	0.0366	0.0080
	CPA 600	0.0145	0.0173	0.0318	0.1426	0.2431	0.0544	0.0118
	CPA 700	0.0168	0.0203	0.0421	0.1799	0.2742	0.0722	0.0158
runway.3400	CPA 400	0.0085	0.0118	0.0158	0.0524	0.1441	0.0261	0.0033
	CPA 500	0.0103	0.0143	0.0218	0.0749	0.1807	0.0414	0.0055
	CPA 600	0.0135	0.0165	0.0278	0.0997	0.2123	0.0574	0.0083
	CPA 700	0.0153	0.0188	0.0343	0.1323	0.2429	0.0734	0.0118
runway.3700	CPA 400	0.0073	0.0100	0.0140	0.0383	0.1238	0.0256	0.0028
	CPA 500	0.0090	0.0123	0.0185	0.0539	0.1531	0.0406	0.0038
	CPA 600	0.0115	0.0148	0.0246	0.0759	0.1840	0.0526	0.0068
	CPA 700	0.0153	0.0185	0.0308	0.1005	0.2135	0.0709	0.0090
runway.4000	CPA 400	0.0070	0.0083	0.0135	0.0278	0.1025	0.0251	0.0025
	CPA 500	0.0080	0.0105	0.0185	0.0401	0.1278	0.0353	0.0033
	CPA 600	0.0100	0.0133	0.0223	0.0556	0.1521	0.0504	0.0050
	CPA 700	0.0143	0.0168	0.0261	0.0739	0.1782	0.0677	0.0070
runway.4300	CPA 400	0.0065	0.0073	0.0115	0.0213	0.0827	0.0266	0.0023
	CPA 500	0.0075	0.0093	0.0160	0.0291	0.1038	0.0353	0.0035
	CPA 600	0.0098	0.0125	0.0208	0.0416	0.1243	0.0479	0.0053
	CPA 700	0.0123	0.0158	0.0241	0.0544	0.1451	0.0639	0.0065
runway.5000	CPA 400	0.0043	0.0043	0.0088	0.0128	0.0409	0.0203	0.0018
	CPA 500	0.0060	0.0068	0.0118	0.0178	0.0561	0.0293	0.0028
	CPA 600	0.0078	0.0090	0.0148	0.0216	0.0699	0.0391	0.0045
	CPA 700	0.0105	0.0118	0.0195	0.0306	0.0815	0.0494	0.0060

runway separation VS evader along-track relation to blunderer VS total response delay time.
For CPA < 400-500-600-700ft ,Run 5/12/93, 3990 trials per number.

response.16	CPA lim	3000'ahead	2000'ahead	1000'ahead	alongside	1000'behind	2000'behind	3000'behind
runway.2500	CPA 400	0.0118	0.0125	0.0216	0.1348	0.1947	0.0278	0.0095
	CPA 500	0.0153	0.0170	0.0311	0.1797	0.2461	0.0404	0.0138
	CPA 600	0.0173	0.0195	0.0396	0.2206	0.2870	0.0534	0.0163
	CPA 700	0.0203	0.0243	0.0489	0.2634	0.3246	0.0739	0.0213
runway.3000	CPA 400	0.0110	0.0128	0.0218	0.0957	0.1975	0.0341	0.0088
	CPA 500	0.0133	0.0155	0.0281	0.1278	0.2424	0.0456	0.0103
	CPA 600	0.0165	0.0183	0.0346	0.1639	0.2779	0.0654	0.0150
	CPA 700	0.0190	0.0213	0.0436	0.2048	0.3155	0.0867	0.0190
runway.3400	CPA 400	0.0098	0.0135	0.0201	0.0727	0.1892	0.0363	0.0060
	CPA 500	0.0120	0.0158	0.0273	0.0977	0.2288	0.0564	0.0103
	CPA 600	0.0160	0.0185	0.0326	0.1276	0.2642	0.0754	0.0125
	CPA 700	0.0185	0.0216	0.0393	0.1642	0.2930	0.0962	0.0173
runway.3700	CPA 400	0.0090	0.0135	0.0185	0.0554	0.1717	0.0426	0.0055
	CPA 500	0.0115	0.0150	0.0243	0.0762	0.2098	0.0599	0.0083
	CPA 600	0.0145	0.0178	0.0303	0.1038	0.2456	0.0797	0.0123
	CPA 700	0.0183	0.0216	0.0383	0.1306	0.2782	0.1018	0.0173
runway.4000	CPA 400	0.0090	0.0128	0.0178	0.0409	0.1516	0.0476	0.0045
	CPA 500	0.0105	0.0148	0.0236	0.0594	0.1875	0.0637	0.0070
	CPA 600	0.0135	0.0178	0.0288	0.0837	0.2216	0.0830	0.0115
	CPA 700	0.0175	0.0218	0.0348	0.1053	0.2514	0.1060	0.0158
runway.4300	CPA 400	0.0080	0.0105	0.0163	0.0306	0.1333	0.0494	0.0045
	CPA 500	0.0098	0.0138	0.0211	0.0471	0.1622	0.0632	0.0068
	CPA 600	0.0130	0.0170	0.0266	0.0637	0.1930	0.0847	0.0108
	CPA 700	0.0163	0.0213	0.0311	0.0840	0.2193	0.1095	0.0143
runway.5000	CPA 400	0.0065	0.0080	0.0150	0.0203	0.0810	0.0439	0.0043
	CPA 500	0.0078	0.0130	0.0185	0.0303	0.1060	0.0617	0.0060
	CPA 600	0.0100	0.0153	0.0221	0.0371	0.1271	0.0792	0.0090
	CPA 700	0.0143	0.0175	0.0281	0.0501	0.1451	0.0960	0.0118

is was run 5/17/93.
arm-dist VS rwy separation VS total alarm response time.

larmDist 100	response.04	response.06	response.08	response.12	response.16
unway.2500	0.0072	0.0246	0.0390	0.0605	0.0663
unway.3000	0.0017	0.0099	0.0211	0.0459	0.0595
unway.3400	0.0004	0.0039	0.0140	0.0322	0.0486
unway.3700					
unway.4000					
unway.4300					
unway.5000					

larmDist 200	response.04	response.06	response.08	response.12	response.16
nway.2500	0.0128	0.0351	0.0543	0.0736	0.0802
nway.3000	0.0033	0.0161	0.0306	0.0579	0.0707
nway.3400	0.0006	0.0064	0.0198	0.0430	0.0589
nway.3700	0.0000	0.0035	0.0134	0.0343	0.0525
nway.4000	0.0000	0.0021	0.0085	0.0285	0.0467
nway.4300	0.0000	0.0010	0.0050	0.0233	0.0393
nway.5000	0.0000	0.0000	0.0017	0.0118	0.0256

armDist 350	response.04	response.06	response.08	response.12	response.16
nway.2500 *	0.0174	0.0403	0.0593	0.0764	0.0835
nway.3000	0.0056	0.0240	0.0440	0.0680	0.0793
nway.3400	0.0023	0.0116	0.0275	0.0539	0.0690
nway.3700	0.0006	0.0064	0.0194	0.0438	0.0605
nway.4000	0.0000	0.0035	0.0120	0.0368	0.0552
nway.4300	0.0000	0.0021	0.0076	0.0291	0.0473
nway.5000	0.0000	0.0002	0.0025	0.0153	0.0318

armDist 500	response.04	response.06	response.08	response.12	response.16
nway.2500 *	0.0174	0.0403	0.0593	0.0764	0.0835
nway.3000	0.0110	0.0331	0.0527	0.0744	0.0845
nway.3400	0.0033	0.0180	0.0341	0.0599	0.0744
nway.3700	0.0017	0.0093	0.0246	0.0510	0.0678
nway.4000	0.0004	0.0052	0.0165	0.0403	0.0595
nway.4300	0.0000	0.0029	0.0105	0.0341	0.0535
nway.5000	0.0000	0.0002	0.0037	0.0171	0.0357

rmDist 650	response.04	response.06	response.08	response.12	response.16
way.2500 *					
way.3000 *	0.0110	0.0331	0.0527	0.0744	0.0845
way.3400	0.0050	0.0227	0.0415	0.0655	0.0779
way.3700	0.0029	0.0138	0.0304	0.0556	0.0711
way.4000	0.0010	0.0074	0.0219	0.0461	0.0632
way.4300	0.0000	0.0039	0.0130	0.0399	0.0574
way.5000	0.0000	0.0006	0.0045	0.0211	0.0388

rmDist 800	response.04	response.06	response.08	response.12	response.16
way.2500 *					
way.3000 *					
way.3400 *					
way.3700	0.0037	0.0190	0.0341	0.0601	0.0758
way.4000	0.0017	0.0101	0.0260	0.0521	0.0671
way.4300	0.0002	0.0060	0.0176	0.0428	0.0612
way.5000	0.0000	0.0012	0.0064	0.0244	0.0417

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The series below is for
total response time uncertainty VS rwy separation VS total response time.
This was run 5/14/93.

Time SD 33%	response.04	response.06	response.08	response.12	response.16
runway.2500	0.0019	0.0227	0.0519	0.0919	0.1118
runway.3000	0.0000	0.0039	0.0143	0.0622	0.0946
runway.3400	0.0000	0.0000	0.0033	0.0411	0.0754
runway.3700	0.0000	0.0000	0.0000	0.0256	0.0585
runway.4000	0.0000	0.0000	0.0000	0.0143	0.0473
runway.4300	0.0000	0.0000	0.0000	0.0062	0.0347
runway.5000	0.0000	0.0000	0.0000	0.0008	0.0107

Time SD 67%	response.04	response.06	response.08	response.12	response.16
runway.2500	0.0068	0.0329	0.0548	0.0806	0.0946
runway.3000	0.0004	0.0120	0.0283	0.0649	0.0810
runway.3400	0.0000	0.0039	0.0163	0.0481	0.0698
runway.3700	0.0000	0.0027	0.0081	0.0370	0.0607
runway.4000	0.0000	0.0010	0.0048	0.0302	0.0529
runway.4300	0.0000	0.0000	0.0023	0.0217	0.0452
runway.5000	0.0000	0.0000	0.0002	0.0087	0.0252

TimeSD Normal	response.04	response.06	response.08	response.12	response.16
runway.2500	0.0174	0.0403	0.0593	0.0764	0.0835
runway.3000	0.0048	0.0207	0.0382	0.0651	0.0754
runway.3400	0.0023	0.0112	0.0267	0.0533	0.0688
runway.3700	0.0006	0.0066	0.0202	0.0448	0.0626
runway.4000	0.0000	0.0039	0.0134	0.0382	0.0576
runway.4300	0.0000	0.0023	0.0095	0.0318	0.0510
runway.5000	0.0000	0.0002	0.0037	0.0171	0.0357

Time SD 133%	response.04	response.06	response.08	response.12	response.16
runway.2500	0.0223	0.0450	0.0601	0.0742	0.0793
runway.3000	0.0068	0.0279	0.0432	0.0651	0.0748
runway.3400	0.0033	0.0186	0.0322	0.0562	0.0696
runway.3700	0.0023	0.0134	0.0252	0.0508	0.0638
runway.4000	0.0012	0.0089	0.0202	0.0426	0.0597
runway.4300	0.0002	0.0056	0.0145	0.0384	0.0548
runway.5000	0.0000	0.0023	0.0074	0.0273	0.0407

Time SD 167%	response.04	response.06	response.08	response.12	response.16
runway.2500	0.0264	0.0496	0.0610	0.0729	0.0781
runway.3000	0.0130	0.0331	0.0486	0.0655	0.0729
runway.3400	0.0054	0.0248	0.0370	0.0583	0.0694
runway.3700	0.0037	0.0198	0.0324	0.0537	0.0649
runway.4000	0.0023	0.0134	0.0264	0.0473	0.0607
runway.4300	0.0012	0.0105	0.0225	0.0415	0.0574
runway.5000	0.0000	0.0050	0.0122	0.0320	0.0442

e series below is for
ader bank angle VS rwy separation VS total alarm response time.
is was run 5/14/93.

vade bank 15	response.04	response.06	response.08	response.12	response.16
ınway.2500	0.0413	0.0628	0.0736	0.0835	0.0901
ınway.3000	0.0161	0.0384	0.0552	0.0744	0.0831
ınway.3400	0.0056	0.0242	0.0424	0.0638	0.0748
ınway.3700	0.0039	0.0157	0.0310	0.0554	0.0702
ınway.4000	0.0017	0.0085	0.0244	0.0490	0.0638
ınway.4300	0.0002	0.0050	0.0159	0.0419	0.0589
ınway.5000	0.0000	0.0014	0.0072	0.0248	0.0430

vade bank 22	response.04	response.06	response.08	response.12	response.16
ınway.2500	0.0174	0.0403	0.0593	0.0764	0.0835
ınway.3000	0.0048	0.0207	0.0382	0.0651	0.0754
ınway.3400	0.0023	0.0112	0.0267	0.0533	0.0688
ınway.3700	0.0006	0.0066	0.0202	0.0448	0.0626
nway.4000	0.0000	0.0039	0.0134	0.0382	0.0576
nway.4300	0.0000	0.0023	0.0095	0.0318	0.0510
nway.5000	0.0000	0.0002	0.0037	0.0171	0.0357

ade bank 30	response.04	response.06	response.08	response.12	response.16
nway.2500	0.0072	0.0281	0.0481	0.0721	0.0789
nway.3000	0.0021	0.0147	0.0300	0.0576	0.0719
nway.3400	0.0006	0.0060	0.0202	0.0455	0.0626
nway.3700	0.0002	0.0037	0.0153	0.0372	0.0581
nway.4000	0.0000	0.0025	0.0093	0.0333	0.0519
nway.4300	0.0000	0.0014	0.0062	0.0267	0.0444
nway.5000	0.0000	0.0000	0.0025	0.0143	0.0320

ade bank 45	response.04	response.06	response.08	response.12	response.16
nway.2500	0.0033	0.0200	0.0374	0.0651	0.0767
nway.3000	0.0008	0.0076	0.0219	0.0519	0.0676
nway.3400	0.0002	0.0037	0.0157	0.0386	0.0585
nway.3700	0.0000	0.0027	0.0097	0.0324	0.0541
nway.4000	0.0000	0.0012	0.0072	0.0267	0.0461
nway.4300	0.0000	0.0004	0.0043	0.0221	0.0401
nway.5000	0.0000	0.0000	0.0014	0.0112	0.0285

APPENDIX C

SENSITIVITY ANALYSIS OUTPUT DATA FOR VMC APPROACH TO PARALLEL RUNWAYS

This is a series of runs to determine the sensitivity of the simulation
to each parameter (taken 1 at a time). Each run has 12100 trials.

The BASELINE is:

runway separation	800 ft
alarm distance	100 ft
NTZ width	1 ft
TAE mean/SD	-1/-1 mR
response time	3 sec
response time SD	3 sec
longit (x) relation	-2500 to 3500 ft
evader bank angle	45 deg
evader turn heading	55 deg
blunder angle	30 deg
blunder turn rate	3 deg/sec

evader=blunder fleetmix

mix %	AC speed mean & SD at far/close dist from rwy threshold
9.0 %	150.0 & 1.78 / 100.0 & 1.78 kts
5.7 %	150.0 & 1.78 / 110.0 & 1.78 kts
5.3 %	150.0 & 1.78 / 110.0 & 1.78 kts
21.0 %	180.0 & 1.78 / 140.0 & 1.78 kts
43.0 %	180.0 & 1.78 / 140.0 & 1.78 kts
16.0 %	180.0 & 1.78 / 140.0 & 1.78 kts

This set of runs was run 5/28/93 to check sensitivity to
total system response delay time (with 0 time variation).
More detailed info is in sens3.comp.1.stat

	Tresponse 0	Tresponse 1	Tresponse 2	Tresponse 3	Tresponse 4	Tresponse 5	Tresponse 6
CPA 400	0.0000	0.0000	0.0116	0.0653	0.0926	0.1036	0.1067
CPA 500	0.0000	0.0062	0.0705	0.1046	0.1228	0.1312	0.1332
CPA 600	0.0053	0.0746	0.1140	0.1364	0.1499	0.1578	0.1612
CPA 700	0.0851	0.1240	0.1487	0.1686	0.1783	0.1849	0.1882

This set of runs was run 5/28/93 to check sensitivity to
total-system-response-delay-time-uncertainty.
More detailed info is in sens3.comp.2.stat .

	Tresp.SD 0	Tresp.SD 1	Tresp.SD 2	Tresp.SD 3	Tresp.SD 4	Tresp.SD 5	Tresp.SD 6
CPA 400	0.0653	0.0671	0.0602	0.0581	0.0570	0.0562	0.0557
CPA 500	0.1046	0.1035	0.0923	0.0845	0.0789	0.0761	0.0745
CPA 600	0.1364	0.1378	0.1272	0.1150	0.1082	0.1037	0.0998
CPA 700	0.1686	0.1693	0.1617	0.1564	0.1531	0.1508	0.1488

This set of runs was run 5/20/93 to check sensitivity to
parallel runway separation when the dist-from-nominal-track alarm criteria stays constant at 100 ft.
The data was extracted from ../yse.dir/study.10.comp.stat

	rwy sep 700	rwy sep 800	rwy sep 900	rwy sep 1000	rwy sep 1100	rwy sep 1200
CPA 400	0.0661	0.0537	0.0417	0.0302	0.0213	0.0126
CPA 500	0.0924	0.0783	0.0657	0.0496	0.0364	0.0269
CPA 600	0.1293	0.1081	0.0907	0.0738	0.0581	0.0424
CPA 700	0.1928	0.1463	0.1213	0.1002	0.0814	0.0634

This set of runs was run 5/28/93 to check sensitivity to the
evaders' longitudinal (x) relation to the blundering aircraft at the start of the run.
More detailed info is in sens3.comp.5.stat .

	5k ft ahead	2k ft ahead	1k ft ahead	alongside	1k ft behind	2k ft behind	5k ft behin
CPA 400	0.0104	0.0176	0.0096	0.3170	0.0218	0.0098	0.0134
CPA 500	0.0146	0.0270	0.0172	0.4054	0.0380	0.0152	0.0194
CPA 600	0.0208	0.0372	0.0270	0.4930	0.0660	0.0242	0.0286
CPA 700	0.0282	0.0482	0.0456	0.5990	0.1166	0.0338	0.0418

This series was run 5/28/93 to check sensitivity to
the absolute speeds of the 2 aircraft.
More detailed info is in sens3.comp.6.stat .

	Both 100 kts	Both 120 kts	Both 140 kts	Both 160 kts	Both 180 kts
CPA 400	0.0483	0.0624	0.0740	0.0839	0.0921
CPA 500	0.0800	0.0936	0.1084	0.1202	0.1278
CPA 600	0.1209	0.1356	0.1472	0.1580	0.1690
CPA 700	0.1770	0.1883	0.1982	0.2052	0.2109

This set of runs was run 5/28/93 to check sensitivity to
the bank angle of the evader aircraft.
More detailed info is in sens3.comp.7.stat .

	Ev bank 22deg	Ev bank 30deg	Ev bank 38deg	Ev bank 45deg	Ev bank 52deg
CPA 400	0.0960	0.0771	0.0650	0.0581	0.0524
CPA 500	0.1243	0.1077	0.0928	0.0845	0.0769
CPA 600	0.1545	0.1418	0.1276	0.1150	0.1073
CPA 700	0.1822	0.1732	0.1635	0.1564	0.1496

This set of runs was run 5/28/93 to check sensitivity to
the turn rate of the blundering aircraft.
More detailed info is in sens3.comp.9.stat .

	Blund 1 deg/s	Blund 2 deg/s	Blund 3 deg/s	Blund 4 deg/s	Blund 5 deg/s
CPA 400	0.0128	0.0396	0.0581	0.0664	0.0713
CPA 500	0.0297	0.0644	0.0845	0.0936	0.0980
CPA 600	0.0612	0.0953	0.1150	0.1294	0.1365
CPA 700	0.1113	0.1400	0.1564	0.1644	0.1693

This set of runs was run 5/28/93 to check sensitivity to
the blunder angle of the blundering AC.
More detailed info is in sens3.comp.10.stat .

	Blunder 15deg	Blunder 20deg	Blunder 25deg	Blunder 30deg	Blunder 35deg
CPA 400	0.0255	0.0417	0.0534	0.0581	0.0591
CPA 500	0.0504	0.0698	0.0802	0.0845	0.0871
CPA 600	0.0864	0.1045	0.1115	0.1150	0.1176
CPA 700	0.1316	0.1461	0.1530	0.1564	0.1589

This set of runs was run 5/4/93 to check sensitivity to
the TAE error uncertainty of both aircraft.
More detailed info is in sens3.comp.11.stat .

	TAE.SD 0 mRad	TAE.SD 2 mRad	TAE.SD 4 mRad	TAE.SD 6 mRad
CPA 400	0.0579	0.0571	0.0531	0.0519
CPA 500	0.0848	0.0831	0.0760	0.0762
CPA 600	0.1150	0.1142	0.1076	0.1106
CPA 700	0.1556	0.1555	0.1549	0.1550

This set of runs was run 5/28/93 to check sensitivity to
the evasion turn heading.
More detailed info is in sens3.comp.12.stat .

	Ev turn 30deg	Ev turn 45deg	Ev turn 60deg	Ev turn 75deg	Ev turn 90deg
CPA 400	0.1050	0.1060	0.1060	0.1060	0.1060
CPA 500	0.1355	0.1362	0.1364	0.1364	0.1364
CPA 600	0.1645	0.1661	0.1663	0.1663	0.1663
CPA 700	0.1947	0.1963	0.1964	0.1964	0.1964

This set of runs was run 5/20/93 to check sensitivity to
the distance-from-centerline alarm criteria.
The data was extracted from ../yse.dir/study.10.comp.stat

	Dalarm 50	Dalarm 100	Dalarm 150
CPA 400	0.0374	0.0537	0.0649
CPA 500	0.0581	0.0783	0.0921
CPA 600	0.0806	0.1081	0.1264
CPA 700	0.1159	0.1463	0.1603

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 1993	Contractor Report

4. TITLE AND SUBTITLE
Parallel Runway Requirement Analysis Study
Volume 1 - The Analysis

5. FUNDING NUMBERS
CNAS1-18027
WU505-66-41-04

6. AUTHOR(S)
Yaghoob S. Ebrahimi

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Boeing Commercial Airplane Group
P.O. Box 3707 M/S 7X-MR
Seattle, WA 98124-2207

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23665-5225

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA CR191549
Volume 1 - Volume 1

11. SUPPLEMENTARY NOTES
Langley Technical Monitor: Leonard Credeur
Langley Contracting Officer's Technical Representative: Cary P. Spitzer
Final Report - Task 25

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 04

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A key element to understand potential operational capacity enhancements at high demand airports is the development of an analysis tool *The Parametric Simulation Model*. The objective for building such a simulation is to develop a parametric model that could be used for analysis in determining the minimum safety level of parallel runway operations for various parameters representing the airplane, navigation, surveillance, and ATC system performance. This simulation is useful as: 1) a quick and economical evaluation of existing environments that are experiencing IMC delays, 2) an efficient way to study and validate proposed procedure modifications, 3) an aid in evaluating requirements for new airports or new runways on old airports, 4) a simple, parametric investigation of a wide range of issues and approaches, 5) an ability to trade-off air and ground technology and procedures contributions, and 6) a way of considering probable blunder mechanisms and range of blunder scenarios.
This document describes the steps of building the simulation and considers the input parameters, assumptions and limitations, and available outputs. Validation results, sensitivity analysis and cross correlations are addressed as well as outlining some available technology applications during IMC approaches to parallel runways.

14. SUBJECT TERMS
Parallel Runway Approaches, Parallel Runway ILS Approaches, Parametric Simulation Model for Parallel Runways

15. NUMBER OF PAGES
119

16. PRICE CODE
A04

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified		

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102