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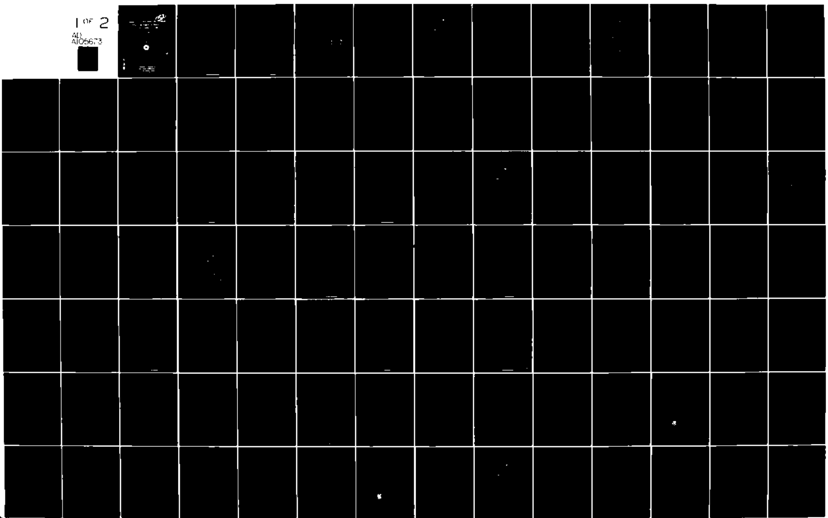

Report No. FAA-EM-81-8

LEVEL II

MTR-81W15

REQUIREMENTS FOR INDEPENDENT AND DEPENDENT PARALLEL INSTRUMENT APPROACHES AT REDUCED RUNWAY SPACING

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DR. A. L. HAINES

W. J. SWEDISH

The MITRE Corporation
McLean, Virginia 22102

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16. Abstract

Independent parallel instrument approaches are conducted today only if the runway centerlines are 4300 ft apart or more. The rationale behind this criterion is reviewed, and the requirements for reducing the criterion to 3000 ft are evaluated. Although some benefit is derived from improvements in navigational accuracy, the performance of the surveillance system has the greatest impact on the required runway spacing.

Dependent alternating instrument approaches to parallel runways are also evaluated. Currently such approaches require a runway spacing of 3000 ft or more. The effects of reducing this runway spacing are discussed, especially with regard to blunder recovery.

Reducing the runway spacing required for these approaches could increase the arrival capacity and reduce delays at certain airports and would provide increased flexibility for planning new runways.

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EXECUTIVE SUMMARY

BACKGROUND

Preamble

Current congestion levels at major airports require an increasingly efficient utilization of existing airspace and airport real estate. Several techniques and ATC procedures are being considered to increase the arrival capacity of existing runways and to provide increased flexibility in locating new runways.

Procedures exist for parallel independent and dependent approaches in instrument conditions. Extension of these procedures to reduced runway spacings can permit their broader application. This paper presents the requirements for such reductions in runway spacing for parallel approaches.

Independent Parallel Instrument Approaches

The concepts for independent parallel approaches under Instrument Flight Rules (IFR) date to the 1950s. The Federal Aviation Administration (FAA) sponsored several studies and analyses in the early 1960s of the requirements for independent (simultaneous) parallel IFR approaches (Figure A). These were presumed to be flown with the use of an Instrument Landing System (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.

Independent (simultaneous) parallel ILS approaches were then approved for use at 5000 foot spacing. Separate parallel approach controllers had to monitor the approaches. These controllers insured that if either aircraft exited a designated Normal Operating Zone (NOZ) into the No Transgression Zone (NTZ) then any threatened aircraft on the other approach course would be vectored away. For 5000 foot spacing the NOZ, as shown in Figure B, was 1500 ft, and the NTZ was 2000 ft.

The parallel monitors had to have a direct communications channel for immediate access to the pilot. Other requirements included fully operating ILS, airport surveillance radar, and air/ground communications.

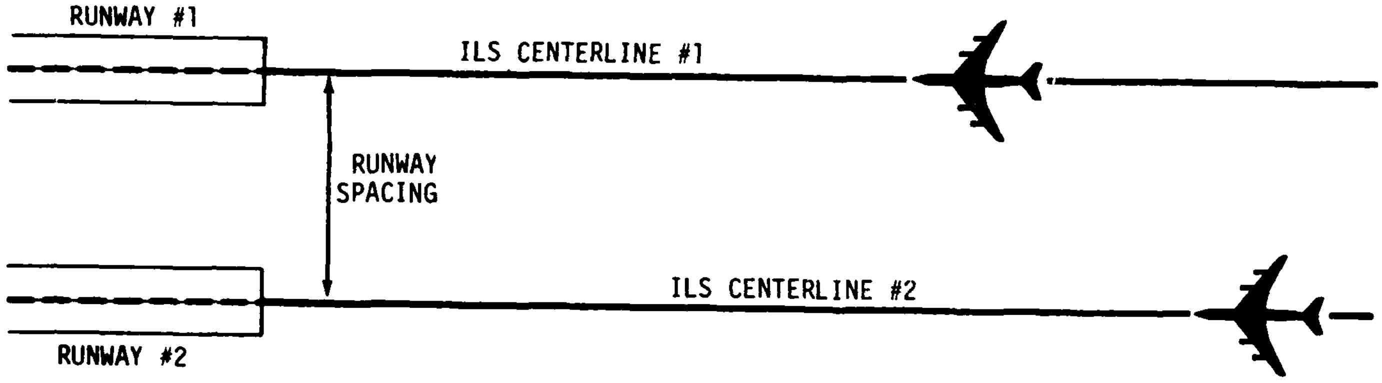

FIGURE A
PARALLEL RUNWAY APPROACHES

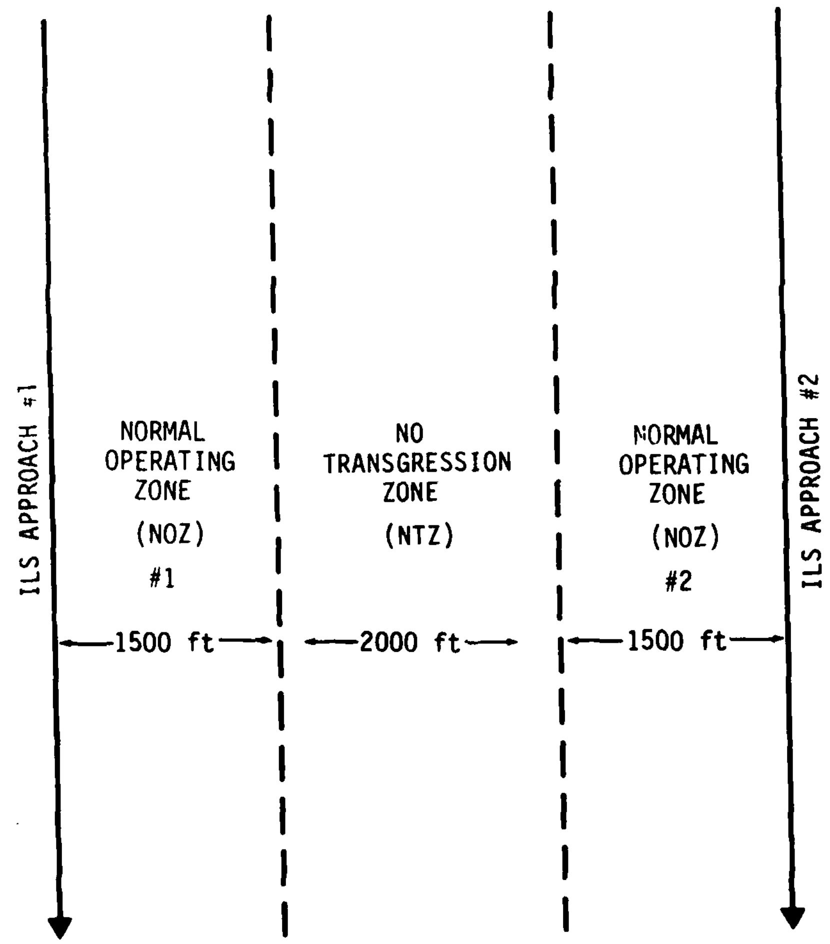

FIGURE B
PARALLEL RUNWAY MONITORING ZONES

As a result of successful data collection and analysis efforts supported by MITRE and Resalab, Inc., the minimum spacing requirement was reduced by the FAA in 1974 to 4300 ft. The data collection showed that the same levels of safety could be achieved (without a significant increase in the false-alarm rate) at the reduced runway separation. Principal beneficiaries of the change were Los Angeles and Atlanta.

Dependent Parallel IFR Approaches

If the runway separation is not adequate for independent approaches, a dependent approach procedure must be used. Prior to 1978, this meant that arrivals to different runways had to be separated by a minimum of 3.0 nmi; at less than 2500 ft separation, the wake vortex standards (3/4/5/6 nmi) were applied, as though the aircraft were approaching a single runway.

In 1978 the FAA provided for parallel (dependent) approaches with a 2.0 nmi diagonal separation between aircraft on alternating approaches, if the runways were separated by 3000 ft or more. Consecutive aircraft alternate between the two runways (Figure C). The diagonal separation is enforced between aircraft on the two approaches, while the normal in-trail separations apply between arrivals to the same runway. This separation permits easier handling of blunder situations. Controller monitoring requirements can be eased, and runway spacing reduced, compared to the requirements for independent approaches.

Currently, for runways spaced between 3000 ft and 2500 ft, a separation of 3 nmi is required. Below 2500 ft lateral separation, wake vortex considerations apply between the runways, and limit such a runway pair to the arrival spacings of a single IFR arrival runway.

The separation requirements for parallel runways are summarized in Table A.

ANALYSIS OF INDEPENDENT PARALLEL IFR APPROACHES

The spacing between parallel runway approaches may be divided into two normal operating zones (NOZs) and a No Transgression zone (NTZ). Two parallel approach controllers monitor the approaches. In the event an aircraft is observed to cross the NOZ boundary, they are required to take positive control action: they must vector away any aircraft on the adjacent approach course that might be threatened.

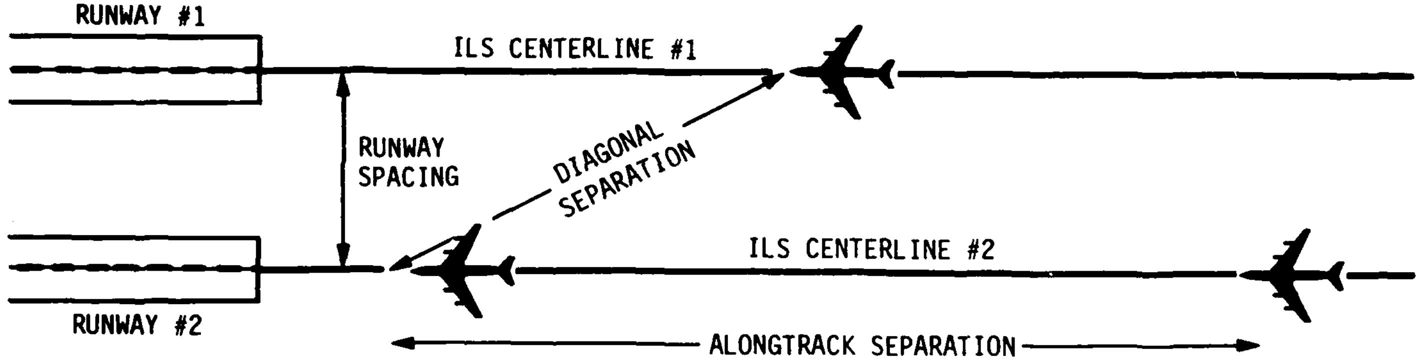

FIGURE C
DEPENDENT PARALLEL GEOMETRY

TABLE A

PARALLEL IFR APPROACH SPACING

RUNWAY SPACING	TYPE OF APPROACH	SEPARATION REQUIREMENTS BETWEEN AIRCRAFT TO TWO APPROACHES
LESS THAN 700 ft	SINGLE RUNWAY	3, 4, 5, 6 nmi*
700 - 2500 ft	ESSENTIALLY SINGLE RUNWAY	3, 4, 5, 6 nmi*
2500 - 3000 ft	DEPENDENT PARALLELS	3 nmi
3000 - 4300 ft	DEPENDENT PARALLELS	2 nmi
GREATER THAN 4300 ft	INDEPENDENT PARALLELS	NONE

*SPECIFIC VALUE DETERMINED BY AIRCRAFT PAIR, AND GOVERNED BY WAKE VORTEX HAZARDS.

The NOZ is sized so that the likelihood of any normally operating aircraft being observed outside of the NOZ is very small. This maintains a low controller workload, as well as high pilot confidence that action from the controller is not a routine "nuisance alarm." The remainder of the spacing then must suffice for the safe resolution of the potential conflict. This spacing may be divided into the following components:

(1) Detection Zone -- the allowance for inaccuracies of the surveillance system and controller observation in being able to detect the aircraft exactly as it passes the NOZ boundary.

(2) Delay Time -- the allowance for the time for the parallel approach monitor controller to react, coordinate with the other parallel monitor, and communicate the appropriate command; for the pilot to understand and react; and for the beginning of aircraft response.

(3) Correction Zone -- the allowance for the completion of the turn-away maneuver by the threatened aircraft.

(4) Miss Distance -- the allowance for an adequate miss distance in the lateral dimension, including a physical miss distance and allowance for the fact that even normally operating (threatened) aircraft may not be exactly on the ILS localizer centerline.

These four allowances, plus the NOZ, add up to the requirement for runway spacing.

Reduced Spacing With Improved Surveillance

The surveillance system is a critical element in determining required runway spacing. The current terminal area system represents an azimuthal accuracy of about 5 mr (milliradians) and an update period of 4 seconds (abbreviated 5 mr/4 s).

A summary of runway spacing requirements is presented in Table B. For convenience, these have been rounded to the nearest 100 ft. They illustrate, for example, that an accurate special purpose surveillance system (1 mr/1 s) could support spacings as low as 3000 ft.

Reduced Spacing With Improved Navigation

The primary ingredient in reduced spacing for independent parallel IFR approaches is an improved surveillance system. Navigational and ATC improvements can, however, assist in this

TABLE B

RUNWAY SEPARATION SUMMARY: BASELINE

		UPDATE (s)			
		4	2	1	.5
SURVEILLANCE SYSTEM (mr)	5	4300*	4000	3800	3600
	4	4000	3700	3500	3400
	3	3700	3500	3300	3200
	2	3500	3200	3100	3000
	1	3400	3100	3000	2900

-- RUNWAY CENTERLINE SPACING (IN FEET) REQUIRED FOR INDEPENDENT PARALLEL IFR APPROACHES

-- BASELINE DEFINED AS TODAY'S ILS SYSTEM AND APPROACHES

*TODAY'S SURVEILLANCE SYSTEM

process. Six cases of improvements have been defined, to reflect possible improvements in the system. These improvements relate to the use of three products:

- Microwave Landing System (MLS), for steeper glide path angles and possibly curved approaches, with resultant reduced common path lengths or additional altitude separation between arrivals.

- Offset runway thresholds, to permit greater traffic separation on final approach.

- Separate short runways, to provide independent streams of traffic for general aviation and commuter aircraft.

These factors are closely related in developing applications at specific airports.

The six cases defined to cover these possibilities are summarized in Table C. Case #1 is the baseline case, describing today's ATC system. Case #2 reflects an improvement in navigational accuracy, due to MLS accuracies and/or reduced common path length. Case #3 reflects both improved navigation and improved surveillance (due to reduced common path length). Cases #4 to #6 repeat these three cases, but with the added assumption of one aircraft at a significantly lower approach speed.

Table C also summarizes the results of the analysis. For each case, the required runway spacing has been calculated for several different surveillance systems. The reduction in the runway spacing requirement due to the changes in navigation error, surveillance error, and aircraft velocities were determined by comparison with Case 1 for the same surveillance system. The resulting range of reductions is given in Table C, as well as the required runway spacing with a 1 mr/1 s surveillance system.

The improved navigation (Case #2) could at best provide 300-500 ft savings, depending on the surveillance system. Navigational and surveillance improvements (Case #3) yield 500-1000 ft improvement. In either case, the lowest feasible runway spacing with a 1 mr/1 s system is 2500 ft. The addition of slower aircraft on one approach, probably in conjunction with the navigational and surveillance improvements, yields an <u>increase</u> in spacing of 200-300 ft, due to encounter geometries. At best, then, a spacing of 2700 ft with a 1 mr/1 s system would be feasible.

TABLE C

RUNWAY SEPARATION SUMMARY: SIX CASES

CASE	NAVIGATION ERROR	SURVEILLANCE ERROR	VELOCITIES (kn)	RUNWAY SPACING SAVINGS* (ft)	RUNWAY SPACING WITH 1 mr/1 s (ft)
1	BL	BL	150, 150	----	3000
2	1/2 BL	BL	150, 150	300-500	2500
3	1/2 BL	1/2 BL	150, 150	500-1000**	2500
4	BL	BL	150, 100	(200-300)***	3200
5	1/2 BL	BL	150, 100	100-300	2700
6	1/2 BL	1/2 BL	150, 100	300-700**	2700

BL = BASELINE (TODAY'S ILS SYSTEM AND APPROACHES)

*VERSUS CASE 1, FOR VARIOUS SURVEILLANCE SYSTEMS. THE SAME SURVEILLANCE SYSTEM IS ASSUMED FOR BOTH CASES.

**LARGER SAVINGS ACCRUE AT THE LOWER QUALITY SURVEILLANCE ACCURACIES

***INCREASE

ANALYSIS OF DEPENDENT PARALLEL IFR APPROACHES

Current procedures for dependent parallel IFR approaches include the following major requirements:

- o A minimum diagonal separation of 2.0 nmi is applied between aircraft on adjacent approaches.
- o A minimum separation of 3.0 nmi is applied between aircraft on the same approach course (that is, usual longitudinal separation requirements).
- o Runway centerlines must be at least 3000 ft apart.

No separate monitor controller is required. Instead, the approach controller must monitor the approaches for separation violations.

For dependent approaches, the diagonal separation between the two aircraft gives a measure of protection which is provided only by the runway spacing for independent approaches; consequently, dependent approaches can be conducted at closer runway spacings than independent approaches.

The minimum miss distance between aircraft in the event of a blunder was calculated using techniques similar to those used for independent approaches. Current procedures allow dependent approaches to runways as close as 3000 ft apart. We assumed that independent approaches would be performed if the runways were more than 4300 ft apart. Over this range of runway spacings, 3000 to 4300 ft, the minimum miss distance in the event of a blunder ranged from 7000 to 7550 ft (Table D). These values represent large safety margins for a rare event such as a blunder.

The minimum miss distance at 3000 ft runway spacing was greater than that for 4300 ft. As Table C demonstrates, this trend continued even for separations less than 3000 ft: as the runway spacing decreased, the miss distance improved. It therefore appears that, at least for blunder safety, reducing the runway spacing is not just possible but desirable.

This somewhat surprising result is actually quite reasonable. Two factors apply:

- o Since the separation is applied diagonally, less distance between runways means a greater in-trail distance between the aircraft.

TABLE D

MINIMUM MISS DISTANCES

RUNWAY SPACING (ft)	MISS DISTANCE (ft)
4300	7000
3000	7550
2500	7750
1000	8450

-- TODAY'S SURVEILLANCE AND NAVIGATION SYSTEMS

-- VELOCITIES 150 kn

- Less distance between runways also means that the blundering aircraft crosses the adjacent approach more quickly.

These results would indicate that recovery from a blunder need not be an obstacle to dependent parallel approaches. Before the required runway spacing for dependent approaches can be reduced, however, other potential problems must be addressed.

Under current procedures, parallel runways less than 2500 ft are considered for wake vortex to be a single runway. Alternating arrivals would therefore have to be separated by the single runway standards of 3/4/5/6 nmi.

MITRE is currently investigating various operational solutions to the wake vortex problem for closely spaced parallel runways. These operational solutions focus on the magnitude of the cross-wind, headwind, or tailwind required to move wake vortices away from the path of the smaller aircraft, and reducing the required winds by employing different glide slopes or staggered thresholds on the two runways. The smaller aircraft would use a higher glide slope or land on the upwind runway. Results to date indicate that alternating arrivals with a uniform 3.0 nmi separation should be feasible under a wide range of wind conditions.

Dependent Parallel Approaches With Improved Surveillance

Another potential problem at closer runway spacings is the possibility that an aircraft will line up for the wrong runway. There are two possible ways this might occur:

- the pilot may misinterpret his approach clearance or misread his approach chart and line up on the wrong localizer,

- or the pilot on an instrument approach may, after breaking out into visual conditions, then visually acquire and line up for the wrong runway.

The first situation would be less likely to arise if procedural changes are instituted which require confirmation of the runway assignment, such as verification of the localizer frequency. Such procedures would reduce, but not eliminate, the chance of an aircraft approaching the wrong runway.

As the spacing between parallel approaches decreases, it becomes more difficult for the approach controller to determine from his radar display whether an aircraft is correctly aligned. Surveillance errors and navigation errors both contribute to the uncertainty about the aircraft's intentions. Improvements in both surveillance and navigation may therefore be required to ensure that the number of centerline deviation "false alarms" is kept low.

Such deviations would not necessarily be blunders, unless the separation also decreased below 2.0 nmi. However, they might be significant if the deviating aircraft was thereby exposed to wake vortices generated on the outer approach. This factor will need to be considered in the study of operational wake vortex solutions.

The second category of runway misidentification mentioned above involved a proper approach, but visual acquisition of the wrong runway. If this is determined to be a problem, some means of improving visual runway identification may be required; color-coded Runway End Identifier Lights (REILs) are one possibility. Such events would occur too quickly and too close to the threshold to be reliably detected or resolved by the controller.

In addition to perhaps helping the runway misidentification problem, an improved surveillance sytem would also have an effect on the resulting miss distance in the event of a blunder. Any violation of the required separation would be detected sooner, allowing more time for the controller to act.

Impact of Other E&D Projects

The Microwave Landing System (MLS) currently under development would reduce the risks associated with inadvertent blunders. MLS allows more accurate navigation and provides an expanded capability for automated approaches, reducing the (already small) likelihood of a blunder. Additionally, the missed approach guidance available with MLS may make it easier to establish the "missed approach procedures (which) do not conflict" as required for dependent approaches, when these would otherwise present a problem.

The availability of dependent approaches could affect the FAA's proposed separate short runway studies. These studies concern the feasibility and benefits of a separate runway for commuter and general aviation operations at major airports. The maximum benefit from such a runway would come if the arrival stream could be completely independent of the air carrier arrivals, but few airports have the land available to locate the new runway 4300 ft from existing runways. At closer runway spacings, the feasibility of dependent alternating arrivals is important.

A blunder analysis was conducted for the separate short runway case, with the results in Table E. The velocity differential between the two aircraft leads to smaller miss distances than in the previous analyses where the speeds were initially equal. However, the miss distances are still adequate to allow dependent parallel operations. Even in the worst of cases, the aircraft still miss each other by 4100 ft.

Other studies which are currently underway involve triple parallel approaches. These may all be independent approaches, or combinations of independent and dependent approaches. Here the question of blunders acquires new significance: a blunder on one of the outer runways towards the middle may cause as many as three other aircraft to be diverted. Strategies for dealing with blunders on triple parallels are currently being investigated.

DIFFERENCES BETWEEN INDEPENDENT AND DEPENDENT APPROACH ANALYSES

The differences in the concepts and geometries of independent and dependent approaches have led to differences in the assumptions, and occasionally the methodologies, of the two analyses. These differences are summarized in Table F.

Blunder "Trigger"

For example, different criteria are used for deciding that a blunder has occurred. An independent approach is termed a blunder if it crosses into the No Transgression Zone (NTZ) between the two runways. The azimuth accuracy of current surveillance systems is not sufficient to allow the use of such "No Transgression Zones" with dependent approaches; instead, the violation of the diagonal separation between adjacent aircraft is used as a trigger for detecting a blunder and starting the avoidance maneuver.

Inputs to Analysis

Several of the inputs to the blunder analyses differ between the two cases because of the use of the different triggers. Since the lateral deviation from the centerline is the indication of a blunder in the independent approach case, the lateral (azimuth) error of the radar and display is an input. For dependent approaches, the diagonal separation between the aircraft is

TABLE E

SEPARATE SHORT RUNWAY -- MINIMUM MISS DISTANCE

RUNWAY SPACING	MISS DISTANCE
4300 ft	4150 ft
3000 ft	4100 ft
2500 ft	4100 ft
1000 ft	4300 ft

-- 2.0 nmi (12150 ft) INITIAL SEPARATION

-- AIRCRAFT AT 150 kn, 110 kn

TABLE F

SUMMARY OF DIFFERENCES BETWEEN INDEPENDENT AND DEPENDENT APPROACH ANALYSES

	INDEPENDENT PARALLELS	DEPENDENT PARALLELS
BLUNDER "TRIGGER"	VIOLATION OF NTZ (LATERAL BOUNDARY)	VIOLATION OF SEPARATION (MAINLY LONGITUDINAL)
INPUTS TO ANALYSIS	AZIMUTH ERROR (RADAR AND DISPLAY)	COMBINED RANGE & AZIMUTH ERROR (MOSTLY DISPLAY)
	LATERAL NAVIGATION ERROR	NOT IMPORTANT
	FALSE ALARM RATE	NOT EXPLICITLY CONSIDERED
	PGDP* = 1.0 (IMPLICIT) - 2 MONITOR CONTROLLERS	PGDP* = 0.5 (INPUT) - NO SEPARATE MONITORS
	8 s CONTROL DELAY	12 s CONTROL DELAY
MISS DISTANCE	ONE-DIMENSIONAL (LATERAL)	TWO-DIMENSIONAL (COMBINED LATERAL AND LONGITUDINAL)

*PROBABILITY OF GOOD DATA POINT (PROBABILITY GOOD RADAR RETURN WILL BE DISPLAYED AND RECOGNIZED BY THE CONTROLLER) significant; although there is a lateral component to this separation, it is principally a longitudinal measure. A combination of the radar range error and longitudinal display errors is, therefore, input to the dependent approach analysis.

For independent approaches, the size of the Normal Operating Zone (NOZ) is calculated. The lateral navigation error and the acceptable rate of false alarms (for excursions beyond the NOZ) are required. The dependent approach calculations do not need to consider a lateral NOZ since a longitudinal trigger is used.

Other differences in the inputs reflect the fact that two monitor controllers are required for independent (but not dependent) approaches. With this level of attention to the radar displays, we assumed that any displayed penetration of the NTZ would be detected immediately. For dependent approaches without a separate monitor, we had to recognize explicitly that the approach controller's attention would at times be directed elsewhere. For this reason, we assigned a value of 0.5 to the parameter PGDP (Probability of a Good Data Point), the probability that a good radar return is displayed and recognized by the controller.

The lack of a separate monitoring position also leads to a difference in the delay times used in the calculations. We have assumed 8 s for the monitor controller to contact the non-blundering aircraft and issue the avoidance instructions, and for the pilot and aircraft to respond. For dependent approaches we assumed that the controller would wait for the next update, 4 s later, to verify that a blunder has actually occurred.

Miss Distance

Only the lateral component of the miss distance is considered in the case of independent approaches -- a longitudinal component exists as well but is not relevant to the calculation. The initial longitudinal position of the aircraft is not fixed; an expected value of the longitudinal miss distance could be calculated, but it would require data on the probable relative position at the start of the blunder.

The dependent approach analysis explicitly considers the two-dimensional (lateral and longitudinal) miss distances involved because the initial lateral and longitudinal positions of the aircraft are known.

SUMMARY

Independent Parallel IFR Operations

Independent (simultaneous) parallel IFR approaches may currently be conducted to runways as close as 4300 ft apart. Certain procedural and equipment requirements must be met, including:

- functioning ILS, radar (ASR), and communications
- separate monitor controllers
- diverging missed approaches.

A Normal Operating Zone is defined for each approach. An aircraft which deviates towards the NOZ boundary is instructed by the controller to return to the localizer course; if the NOZ boundary is penetrated, any endangered aircraft on the adjacent approach must be vectored away.

The required 4300 ft runway spacing is based upon maintaining separation between the two aircraft in the event of such a blunder, with certain assumptions about aircraft and ATC performance. This runway spacing requirement can be reduced if improvements are made to surveillance and navigation performance. These improvements have two effects:

- The size of the NOZ can be reduced without increasing the "false alarm" rate for penetrating the NOZ boundary.
- The size of the No Transgression Zone between the runways can be reduced without decreasing the miss distance in the event of a blunder because any penetration of the NOZ would be detected sooner.

If the current surveillance system, with 5 mr accuracy and a 4 s update rate, were replaced with a 1 mr/1 s system, independent parallel IFR operations could be conducted to runways as close as 3000 ft apart. No other improvements, or changes to current ATC procecures, would be required. Such radar performance has been achieved in Precision Approach Radar (PAR) systems.

The presence of slower aircraft on one approach (for example, general aviation or commuter aircraft approaching a separate short runway) tends to increase the required spacing between the runways by 200-300 ft. If, however, the slower aircraft can be turned onto the localizer closer to the runway, this could reduce the need for such an increase.

Dependent Parallel IFR Operations

If the spacing between parallel runways is too close to allow independent operations, it may still be possible to conduct dependent IFR approaches using a 2.0 nmi diagonal separation between adjacent aircraft. Current procedures allow such operations if the runways are at least 3000 ft apart.

Some other requirements for dependent approaches are also less restrictive than for independent operations. A separate monitor controller is not required, for example, and missed approach paths are only required to "not conflict."

No NOZ or NTZ is established for dependent approaches. Instead, the diagonal separation provides the buffer between aircraft on adjacent approaches. Violating the diagonal separation therefore constitutes a blunder, recovery from which must be assured. Turning the threatened aircraft results in a minimum miss distance, over the wide range of deviations in speed and angle, of 7000 ft.

This minimum miss distance varies with the runway spacing; in general, the miss distance increases as the runways move closer together. At 3000 ft runway spacing, the minimum miss distance is 7550 ft; at 2500 ft it is 7750 ft; and at 1000 ft it is 8450 ft. This is primarily because at closer spacings, the blunderer would cross the other approach (and no longer present a hazard) more quickly.

It therefore appears that the runway spacing requirement for dependent IFR operations can be reduced. No changes to the other requirements and procedures would be necessary with a minimum runway spacing of 2500 ft.

At runway spacings below 2500 ft, wake vortex must be considered. Other studies are currently underway on the feasibility of operational solutions to this problem. Combinations of crosswinds, runway spacing, staggered thresholds and higher glide slopes will be identified which allow alternating approaches to close-spaced parallels with less than the full vortex separation. A uniform 3.0 nmi in-trail separation between adjacent aircraft is the current focus of these studies; in the future, it may be extended to allow 2.0 nmi diagonal separations at less than 2500 ft.

As parallel runways get closer together, it becomes more difficult to ensure that each aircraft is actually lined up for the proper runway. Procedural changes and improved runway lighting may reduce the possibility of such an event, but improved surveillance and navigation systems would be needed to ensure that the controller could detect such a runway misalignment if it occurred.

Next Steps

Independent and dependent parallel approaches at reduced spacing offer potential for alleviation of congestion at major airports. Application can be made with existing or future runway pavement.

The FAA is actively pursuing a program of increased airport capacity. Dual parallel instrument approaches at reduced runway spacings represent one aspect of this program. Other concepts include:

- triple instrument approaches
- non-parallel instrument approaches
- separate short runways.

Application of parallel approaches requires several steps beyond the requirements analyzed in this report. Site studies will be needed in most cases to evaluate the specific application. Procedural and operational tests may be necessary to establish the feasibility of implementation. These activities are being pursued by the FAA.

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1. INTRODUCTION

Current congestion levels at major airports require an increasingly efficient utilization of existing airspace and airport real estate. Several techniques and ATC procedures can be considered to increase capacity, particularly in Instrument Meteorological Conditions (IMC).

Better planning and control of traffic flows will permit more efficient use of existing fixed airport resources. Some modest changes in airport geometry may be made, to better accommodate traffic. For example, short special purpose runways can be constructed for use by general aviation and commuter aircraft.

Changes in ATC procedures, possibly along with new equipment, can permit more operations on existing runways. The reduction in the requirements for independent (simultaneous) parallel approaches (from 5000 ft to 4300 ft runway spacing) originated for this purpose. Further reductions in this value can be considered. Further, alternating use of close parallels in a dependent fashion can increase capacity. For non-parallel runways, converging approaches may be feasible. Combinations of three runways can be considered, either all parallel, or two parallel and a third converging. Current FAA and MITRE research addresses all these possibilities.

This paper addresses the potential for increasing capacity through the use of independent or dependent parallel approaches, under Instrument Flight Rules (IFR). Section 2 traces the history of parallel approaches from first implementation to current research.

Section 3 presents a summary of the requirements for independent parallel approaches. Starting from today's rules and procedures, it identifies the requirements for reduction in the runway spacing for independent parallel approaches. Section 4 presents a similar summary of requirements for dependent parallel operations.

2. HISTORY OF PARALLEL IFR APPROACHES

2.1 Initial Implementation

The concepts for independent parallel IFR approaches date to the 1950s. The basic premise is that aircraft can approach parallel runways along parallel courses (Figure 2-1).

The procedures for IFR parallel approaches developed from experience in Visual Meteorological Conditions (VMC). When issued an appropriate clearance, pilots in VMC can provide their own separation visually. Parallel approaches can be made to runways spaced as close as 700 ft (Reference 1). Under Instrument Meteorological Conditions (IMC), the problems of detection and avoidance are more difficult, and the controller must provide radar monitoring to assure separation.

The Federal Aviation Administration (FAA) sponsored several studies and analyses in the early 1960s of the requirements for independent (simultaneous) parallel IFR approaches. These were presumed to be flown with the use of an Instrument Landing System (ILS) for lateral navigational guidance. These studies included some field data collection, and theoretical analyses (Reference 2), as well as a field flight test program at Chicago O'Hare (Reference 3). 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.

Independent (simultaneous) parallel ILS approaches were then approved for use at 5000 foot spacing. This applied to a number of major airports, as shown in Table 2-1. New York's John F. Kennedy International (JFK), while possessing appropriately spaced runways, could not then (and cannot now) operate independent parallel approaches because of local airspace and noise constraints.

Independent approaches could be conducted only when several requirements were satisfied. The approaches had to be straight in, with turn-on to localizer separated in altitude by at least 1000 ft between approach courses. Separate parallel approach controllers had to monitor the approaches once the 1000 foot separation was lost inside the point of glide slope intercept. These controllers insured that if either aircraft exited a designated Normal Operating Zone (NOZ) into the No Transgression Zone (NTZ) then any threatened aircraft on the other approach course would be vectored away. For 5000 foot spacing the NOZ, as shown in Figure 2-2, was 1500 ft, and the NTZ was 2000 ft.

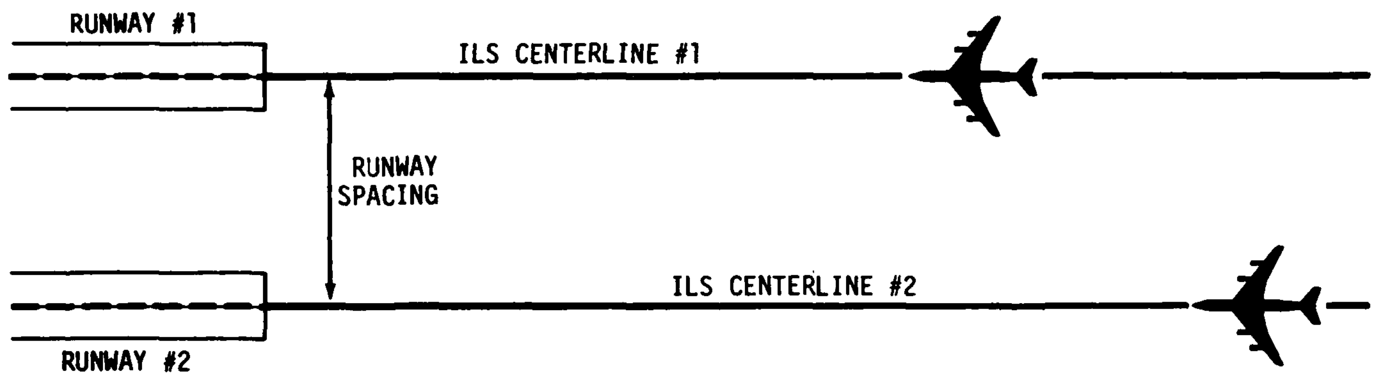


FIGURE 2-1
PARALLEL RUNWAY APPROACHES

TABLE 2-1

U. S. PARALLEL RUNWAY CHRONOLOGY

1963 SIMULTANEOUS (INDEPENDENT) PARALLEL APPROACHES APPROVED AT 5000 FOOT SPACING. APPLIED PRIMARILY TO:

O'HARE	6510 ft	(1985 m)
	5400 ft	(1646 m)
LOS ANGELES	5280 ft	(1610 m)
ATLANTA	5450 ft	(1662 m)
MIAMI	5100 ft	(1555 m)
AND LATER TO:		
DULLES	6500 ft	(1982 m)
DALLAS	6300 ft	(1921 m)

1974 SIMULTANEOUS (INDEPENDENT) PARALLEL APPROACH SPACING REDUCED TO 4300 ft

LOS ANGELES	4300 ft	(1311 m)
ATLANTA	4400 ft	(1341 m)

1978 PARALLEL (DEPENDENT) APPROACHES APPROVED AT 3000 ft WITH 2 nmi STAGGER BETWEEN RUNWAYS

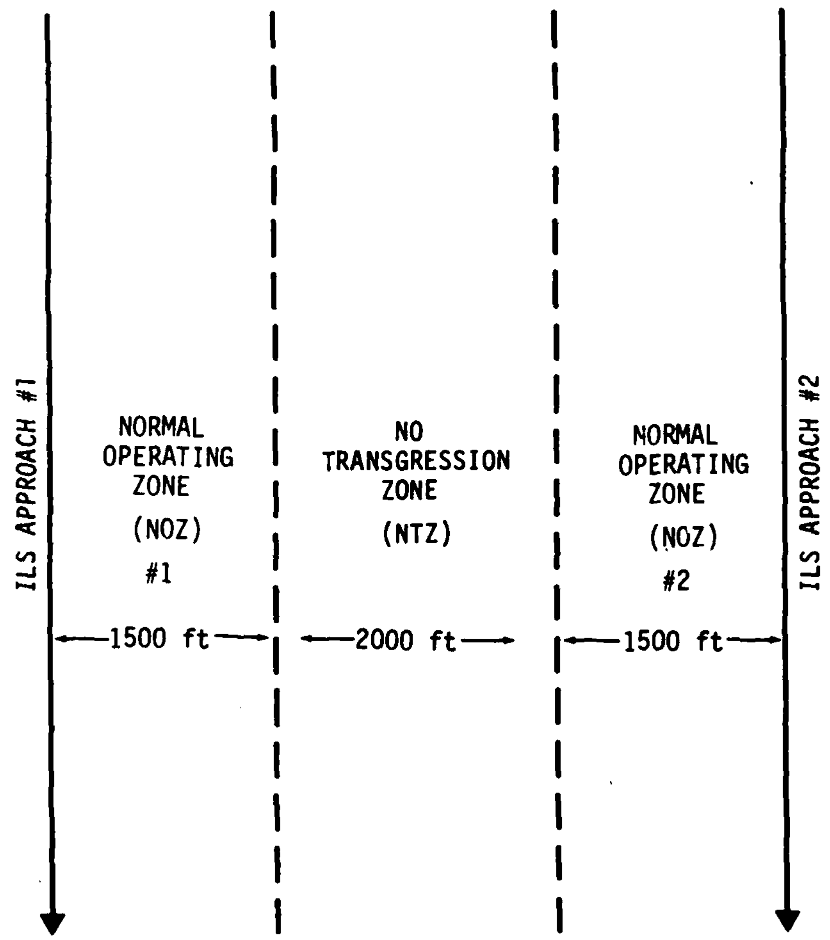


FIGURE 2-2
PARALLEL RUNWAY MONITORING ZONES

This parallel monitor had to have a direct communications channel for immediate access to the pilot. Other requirements included fully operating ILS, airport surveillance radar, and air/ground communications will be discussed in Section 3.

2.2 Wake Vortex Requirements

The late 1960s saw the introduction of the wide body jets. Users and the FAA quickly identified hazards of the wake vortices from these larger aircraft. The 3 nmi in-trail IFR separation requirement was increased for some aircraft pairs. This increased separation applied to aircraft in-trail to the same runway, and also to aircraft on parallel approaches to runways spaced less than 2500 ft.

This change decreased the available airport capacity for single runway approaches, and reduced the capability to make efficient use of runways spaced less than 2500 ft. This generated the impetus to find ways of regaining the airport capacity lost because of wake vortex hazards. Programs were initiated by the FAA to develop systems which would permit reduction of the in-trail spacing requirements under some or all operating conditions.

2.3 Reduced Spacing for Independent Parallels

Separately from the wake vortex problem, there was a drive to reduce the 5000 ft minimum runway spacing requirement. This was clearly a goal in the Air Traffic Control Advisory Committee Report in 1969 (Reference 4). Following on successful data collection and analysis supported by MITRE and Resalab, Inc. (References 5 and 6), the minimum spacing requirement was reduced by the FAA in 1974 to 4300 ft. The data collection showed that real-world performance on parallel arrivals was better than had been originally esimated, and therefore the same levels of safety could be achieved (without a significant increase in the false-alarm rate) at the reduced runway separation. Principal beneficiaries of the change were Los Angeles and Atlanta, where reduced runway spacing would have application to some special configurations, or when a runway was closed.

MITRE continued analysis of further reductions in spacing (Reference 7 and 8). While these required advanced equipment (a high quality, special purpose radar system), there was the realization that reductions in the minimum spacing were still feasible, if lateral and/or longitudinal separations between aircraft on the two approaches were adequately maintained.

2.4 Spacing for Dependent Parallels

If the runway separation is not adequate for independent approaches, a dependent approach procedure must be used. Prior to 1978, this meant that arrivals to different runways had to be separated by a minimum of 3.0 nmi; at less than 2500 ft separation, the wake vortex standards (3/4/5/6 nmi) were applied, as though the aircraft were approaching a single runway.

In 1978 the FAA provided for parallel (dependent) approaches with a 2.0 nmi diagonal separation between aircraft on alternating approaches, if the runways were separated by 3000 ft or more. This concept of alternating arrivals can be illustated with the aid of Figure 2-3. Aircraft approach parallel runways on parallel courses. Consecutive aircraft alternate between the two runways. The diagonal separation is enforced between aircraft on the two approaches, while the normal in-trail separations apply between arrivals to the same runway.

This separation permits easier handling of blunder situations. Controller monitoring requirements can be eased, and runway spacing reduced, compared to the requirements for independent approaches.

Currently, for runways spaced between 3000 ft and 2500 ft, a diagonal separation of 3 nmi is required. Below 2500 ft lateral separation, wake vortex considerations apply between the runways, and limit such a runway pair to the arrival spacings of a single IFR arrival runway.

2.5 Overview of Current Parallel Approach Procedures

Current U. S. procedures for parallel IFR approaches are briefly summarized in Table 2-2. The specific requirements given to the Controller in Reference 1 are presented in Tables 2-3 and 2-4.

Figure 2-4 presents a summary of the capacity values that result from the several types of operations summarized in Table 2-2. The input data is for a typical operation at Atlanta. Details are found in Appendix A.

2.6 Current Research Activities

Current research activities on airport efficiency are being conducted in several areas. Better planning for use of existing airport geometries is included under the concepts of Terminal Configuration Management. The primary emphasis is at Chicago

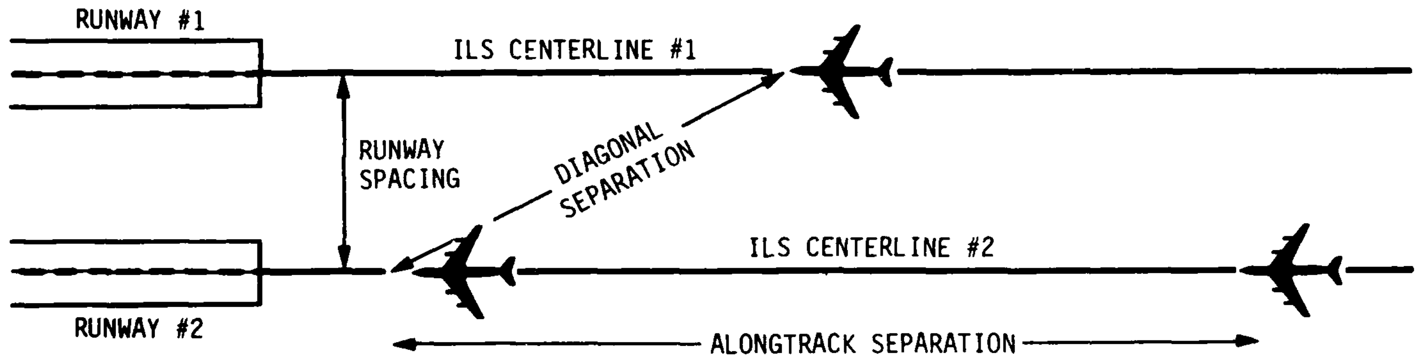


FIGURE 2-3
DEPENDENT PARALLEL GEOMETRY

TABLE 2-2

PARALLEL IFR APPROACH SPACING

RUNWAY SPACING	TYPE OF APPROACH	SEPARATION REQUIREMENTS BETWEEN AIRCRAFT TO TWO APPROACHES
LESS THAN 700 ft	SINGLE RUNWAY	3, 4, 5, 6 nmi*
700 - 2500 ft	ESSENTIALLY SINGLE RUNWAY	3, 4, 5, 6 nmi*
2500 - 3000 ft	DEPENDENT PARALLELS	3 nmi
3000 - 4300 ft	DEPENDENT PARALLELS	2 nmi
GREATER THAN 4300 ft	INDEPENDENT PARALLELS	NONE

*SPECIFIC VALUE DETERMINED BY AIRCRAFT PAIR, AND GOVERNED BY WAKE VORTEX HAZARDS.

TABLE 2-3

PROCEDURES FOR INDEPENDENT IFR PARALLELS

→ 798. SIMULTANEOUS ILS APPROACHES

TERMINAL

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

(1) Straight-in landings will be made.

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

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

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

Phraseology:
ILS RUNWAY (runway number) (left/right). LOCALIZER FREQUENCY IS (frequency).

d. Clear the aircraft to descend to the appropriate glide slope 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 localizer course intercept.

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 localizer courses. Provide a minimum of *3 miles* radar separation between aircraft on the same localizer course.

798.f. Note.—Aircraft established on a localizer course are separated from aircraft established on an adjacent parallel localizer course provided neither aircraft penetrates the depicted NTZ.

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

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

(2) An altitude to maintain until established on the localizer course.

798.g.(2) Reference.—Arrival Instructions, 794.

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

Phraseology:
POSITION (number) MILES FROM (fix). TURN (left/right) HEADING (degrees). MAINTAIN (altitude) UNTIL ESTABLISHED ON THE LOCALIZER. CLEARED FOR ILS RUNWAY (number) (left/right) APPROACH.

TABLE 2-3
(Concluded)

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

798.h. Note 1.—Separate monitor controllers, each with transmit/receive and override capability on local control frequency, shall ensure aircraft do not penetrate the depicted NTZ. Facility Directives shall delineate responsibility for providing a minimum of *3 miles* longitudinal separation between aircraft on the same localizer course.

798.h. 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 localizer 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.

798.h. 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 721. 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 localizer immediately.

Phraseology:

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

or

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

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

Phraseology:

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

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

(a) Visual separation is applied.

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

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

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

(5) Do not apply the provisions of **1220.** for simultaneous ILS approaches.

TABLE 2-4

PROCEDURES FOR DEPENDENT IFR PARALLELS

797. PARALLEL ILS APPROACHES

TERMINAL

When conducting parallel ILS 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 *3 miles* radar separation between aircraft on the same localizer course.

c. Provide a minimum of *2 miles* radar separation between successive aircraft on adjacent localizer courses when the following conditions are met:

(1) Runway centerlines are at least 3,000 feet apart.

(2) Apply this separation standard only after aircraft are established on the localizers.

(3) Straight-in landings will be made.

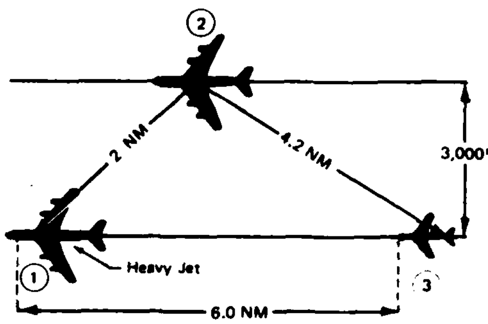
(4) Missed approach procedures do not conflict.

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

(6) Approach control shall have an override capability to local control at those locations where separation responsibility has not been delegated to the tower.

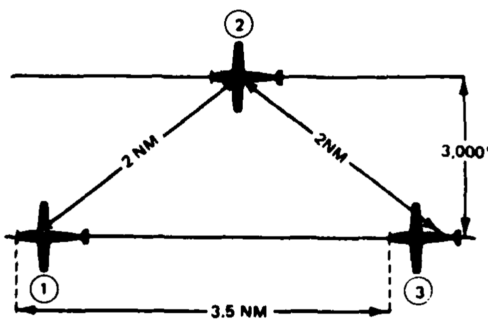
797.c.(6) Note.—The override capability is an integral part of this procedure when approach control has the sole separation responsibility.

797.c.(6) Reference.—Approach Separation Responsibility, 796. 7210.3-212, Delegation of Radar Approach Control Authority to a Nonapproach Control Tower.



797.c. Illustration 1

In this illustration, aircraft 2 is two miles from heavy aircraft 1. Aircraft 3 is a small aircraft and is six miles from aircraft 1. The resultant separation between aircraft 2 and 3 is 4.2 miles.



797.c. Illustration 2

In this illustration, aircraft 2 is two miles from aircraft 1 and aircraft 3 is two miles from aircraft 2. Resultant separation between aircraft 1 and 3 is 3.5 miles.

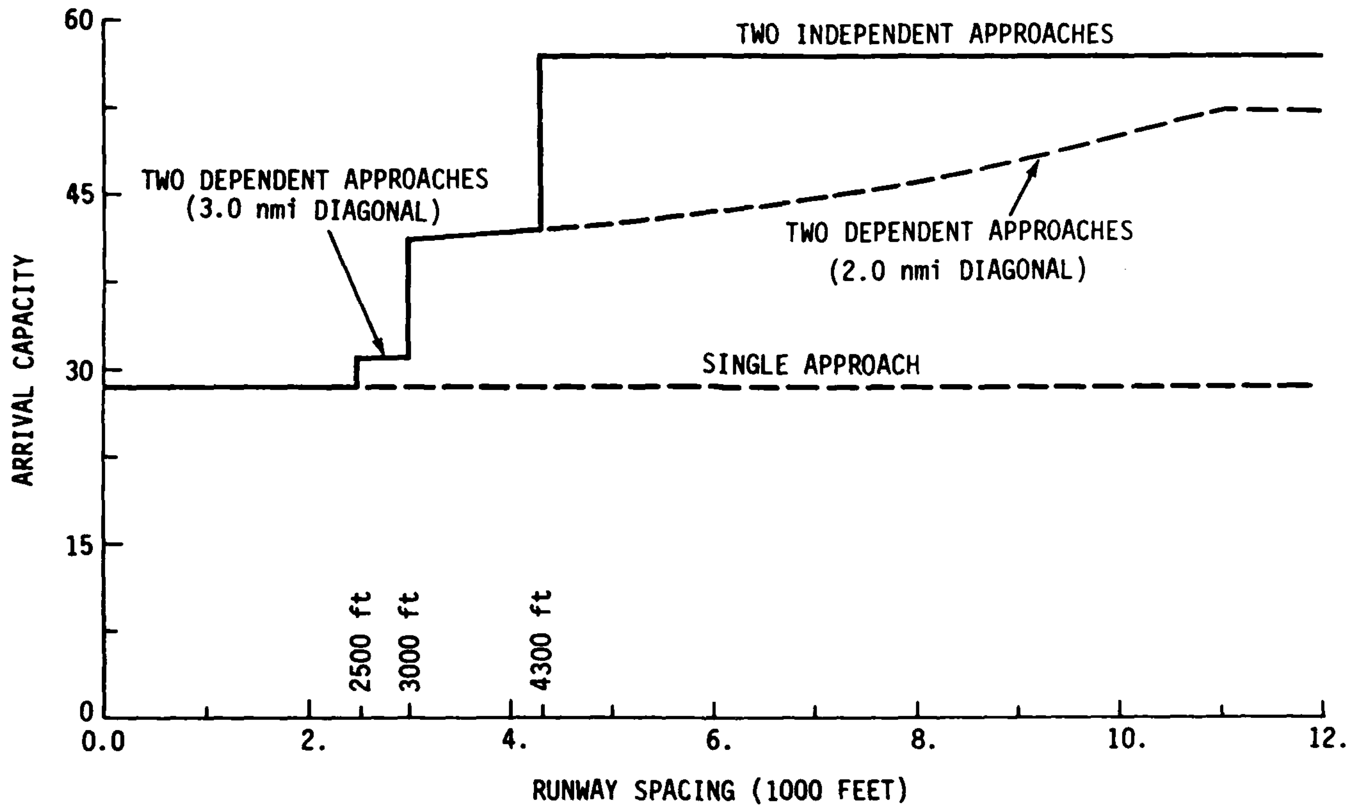


FIGURE 2-4
ARRIVAL CAPACITY AS FUNCTION OF CENTERLINE SPACING—
CURRENT PROCEDURES

O'Hare Airport (References 9 and 10). The consideration of separate short runways for general aviation and commuter aircraft has led to additional uses of parallel approaches (References 11 through 14). Concepts for dependent parallels have been developed (References 15 and 16). These will be used as the basis for selection of criteria in Section 4 of this report. The Aeroport de Paris is currently investigating the use of triple parallel approaches (References 17 and 18) and converging approaches (References 19 and 20). A summary of factors in triple parallel approaches is given in Reference 21.

Other on-going work by MITRE for the FAA will address all of the following concepts:

- o triple parallel approaches
- o converging approaches
- o separate short runways
- o terminal configuration management
- o operational solutions to wake vortices.

A brief summary of these topics is contained in References 22 and 23.

3. INDEPENDENT PARALLEL IFR APPROACHES

This section reviews current principles for independent parallel IFR approaches. It summarizes the analysis methods of Reference 5, and then presents an analysis of the potential for reduction in spacings below 4300 ft.

3.1 Basic Procedures for Independent Parallel IFR Operations

This section presents the explicit and implicit procedures and requirements for independent parallel approaches. The assumption is made throughout that separation must be provided by the air traffic controller through radar or procedural means. A more detailed presentation is contained in Appendix B.

3.1.1 Principles of Independent Parallel IFR Operations

The spacing between parallel runway approaches may be divided into two Normal Operating Zones and a No Transgression Zone. The controller takes positive action to separate aircraft when any aircraft is observed to penetrate the NTZ. The operational requirements for independent approaches will be further developed in Section 3.1.3. This section reviews the basic safety elements of runway spacing, which are related to events where the controller must take action. The details are presented in Appendix B, along with mathematical derivations.

Two parallel approach controllers monitor the approaches. They observe the lateral position of all aircraft on final approach, and may issue navigation advisories if they judge an aircraft to be wandering off course. However, in the event an aircraft is observed to cross the NOZ boundary, the controllers are required to take positive control action. This action may include attempting to contact the aircraft crossing the NOZ, but it must first involve vectoring away any aircraft on the adjacent approach course that might be threatened (see Figure 3-1).

The NOZ is sized so that the likelihood of any normally operating aircraft being observed outside of the NOZ is very small. This maintains a low controller workload, as well as high pilot confidence that action from the controller is not a routine "nuisance alarm." The remainder of the spacing then must suffice for the safe resolution of the potential conflict. This spacing may be divided into the following components:

(1) Detection Zone -- the allowance for inaccuracies of the surveillance system and controller observation in being able to detect the aircraft exactly as it passes the NOZ boundary.

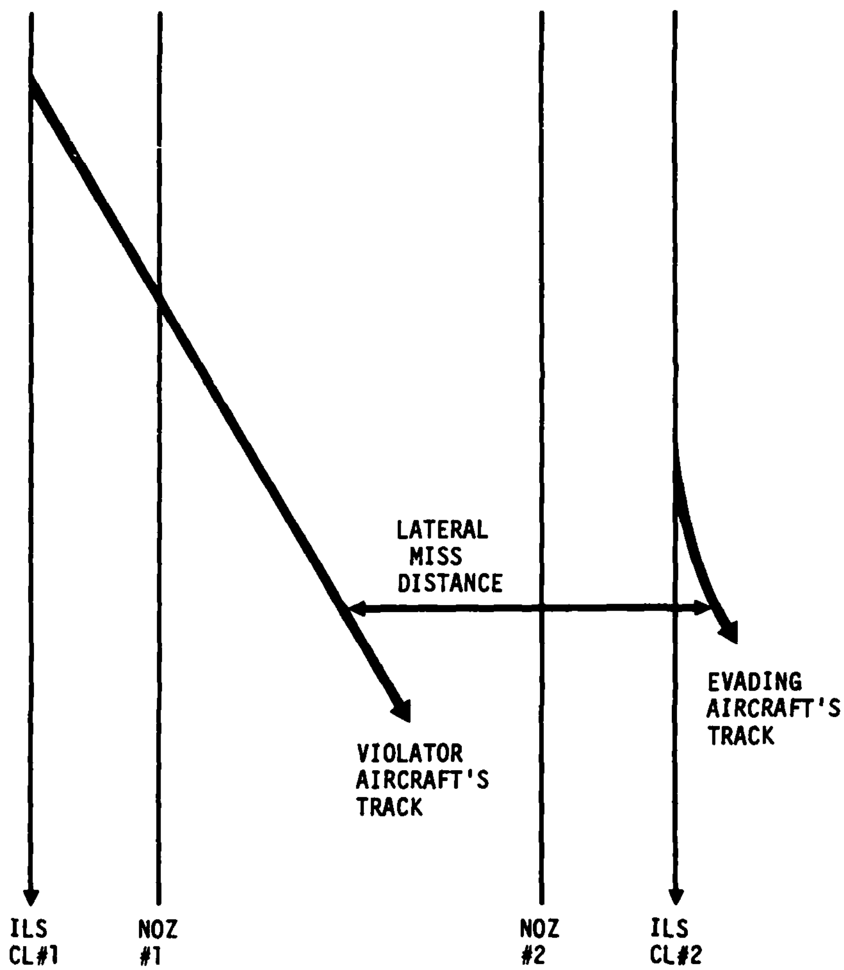


FIGURE 3-1
CORRECTIVE MANEUVER

(2) Delay Time -- the allowance for the time for the parallel approach monitor controller to react, coordinate with the other parallel monitor, and communicate the appropriate command; for the pilot to understand and react; and for the beginning of aircraft response.

(3) Correction Zone -- the allowance for the completion of the turn-away maneuver by the threatened aircraft.

(4) Miss Distance -- the allowance for an adequate miss distance in the lateral dimension, including a minimum lateral miss distance plus an allowance for the fact that even normally operating (threatened) aircraft may not be exactly on the ILS localizer centerline.

These four allowances, plus the NOZ, add up to the runway spacing. In this context only one NOZ is relevant to the process of handling a particular blunder situation. Dividing the runway spacing into two NOZs plus an NTZ is done for the convenience of the controllers in the operational procedure (see Figure 2-2).

3.1.2 Airspace Organization and Constraints

Simultaneous (independent) parallel approaches in the U.S. require several constraints on the approach geometry:

- A 1 nmi straight and level flight segment is required prior to the localizer intercept.
- Localizer intercept must be at 30 degrees or less.
- Localizer intercept is protected by 1000 foot altitude separation between the two approach courses until both aircraft are stable on the localizer. In the U.S., this process is assumed to require a 3 nmi distance (prior to glide slope capture), which may be lowered to 2 nmi if the intercept angle is less than 20 degrees.
- Only straight-in landings are made.
- Go-arounds and missed approaches must have diverging courses (by at least 45 degrees), once any necessary climb to 400 ft altitude is made.

3.1.3 Monitoring and Procedures

Within the U.S. system for simultaneous (independent) parallel approaches there is a requirement for two dedicated parallel approach controllers. There controllers monitor lateral separation once the aircraft start their descent and the 1000 foot vertical separation between approach paths is lost. Typically this is the point at which routine handoff is made to the local controller from the final radar controller. Often the monitor controllers are assigned the responsibility for monitoring longitudinal (i.e., in-trail) separation as well.

These monitors must have immediate communication access to the pilot. This is usually accomplished with an override on the local controller frequency. They monitor a radar display with a plan view presentation of the traffic (Plan View Display -- PVD) on which the ILS centerlines and NOZ boundaries are superimposed. They maintain monitoring requirements in all weather conditions, unless visual separation can be accomplished. They may issue advisories as they judge useful. They must take action when an aircraft is observed to exit the NOZ. The details of directives and phraseology, as used in the U.S. system today, were presented in Table 2-3.

In order to be able to perform simultaneous (independent) approaches, all ILS, radar, and communication systems must be operational. At the airports where such approaches are run, good position-keeping navigation is expected. The aircraft flying such approaches are generally well equipped, and have historically been mostly air carrier aircraft.

The monitoring procedure as stated above does not depend on secondary radar or tracker information. Where present, however, information such as speed and aircraft type will help the controller to anticipate problem situations and enhance his monitoring performance. The presence of displayed speed also minimizes congestion on the local control channel caused by requests for speed information.

A summary of the requirements for simultaneous parallels is given as Table 3-1.

Table 3-2 presents a list of equipment and manning items included for simultaneous parallel approaches. For dependent parallel or triple approaches the list, of course, would vary.

TABLE 3-1

REQUIREMENTS FOR SIMULTANEOUS (INDEPENDENT) PARALLELS

-- AIRCRAFT ARE INFORMED OF USE OF SIMULTANEOUS PARALLELS

-- MAXIMUM INTERCEPT ANGLE WITH LOCALIZER IS 30 DEGREES

-- 1 nmi STRAIGHT FLIGHT REQUIRED PRIOR TO LOCALIZER TURN-ON (USUALLY 3 nmi FROM GLIDE SLOPE INTERCEPT)

-- LOCALIZER TURN-ON IS PROTECTED BY 1000 ft ALTITUDE UNTIL AIRCRAFT ARE STABLE

-- STRAIGHT-IN LANDINGS ARE MADE

-- INDEPENDENT PARALLEL APPROACH MONITORS ARE REQUIRED, WITH DEDICATED OR AT LEAST VIRTUALLY CLEAR COMMUNICATIONS CHANNEL ACCESS TO ALL AIRCRAFT ON PARALLEL APPROACHES

-- GO-AROUNDS AND MISSED APPROACHES MUST HAVE DIVERGING COURSES

-- ALL AIR AND GROUND SYSTEMS MUST BE OPERATIONAL (INCLUDING COMMUNICATION, SURVEILLANCE, ILS NAVIGATION)

-- COUPLED APPROACHES ARE DESIRABLE, BUT NOT NECESSARY: GOOD AIRCRAFT LATERAL POSITION KEEPING IS NECESSARY

-- LINE TO INDICATE LIMIT OF NORMAL OPERATING ZONE IS SUPER-IMPOSED ON RADAR DISPLAY, AND CALIBRATED TO PRIMARY RADAR RETURNS. SECONDARY RADAR USED TO IDENTIFY AIRCRAFT, AND TO DISPLAY GROUND SPEEDS OF AIRCRAFT

TABLE 3-2

SIMULTANEOUS APPROACH EQUIPMENT AND MANNING

2 PARALLEL APPROACH MONITOR CONTROLLERS

1 RADAR TRAFFIC DISPLAY

2 RADIO CONTROL UNITS, WITH OVERRIDE ON LOCAL CONTROLLER FREQUENCIES

2 DIRECT INTERNAL COMMUNICATIONS HOOKUPS TO LOCAL CONTROLLERS

-- REVISED DISPLAY MAP TO INCLUDE NOZ LINES, CALIBRATED TO REST OF MAP, AND TO PRIMARY RADAR RETURNS

-- FLIGHT CHECKED PRIMARY RADAR COVERAGE

-- PUBLISHED APPROACH PLATES FOR SIMULTANEOUS APPROACHES

3.1.4 Equipment Requirements

The requirements as presented above include both explicit and implicit equipment requirements.

Radar, ILS, and communication systems need to be fully operational. They must perform to whatever levels are assumed in the derivation of runway spacing requirements. It may also be necessary to do some field testing of achievable performance to verify several parameters in the runway spacing calculation. For radar systems, the analysis generally assumes no blind spots.

3.2 Reduced Spacing With Improved Surveillance

The surveillance system is a critical element in determining required runway spacing. The current terminal area system represents an azimuthal accuracy of about 5 mr (milliradians) and an update period of 4 seconds. These and other parameter values are presented in Appendix B.3.

A summary of runway spacing requirements, derived from Appendix C, is presented in Table 3-3. For convenience, these have been rounded to the nearest 100 ft. They illustrate, for example, that an accurate special purpose surveillance system (1 mr, 1 s) could support spacings as low as 3000 ft.

The values in parentheses in Table 3-3 represent the approximate runway spacings achievable with the addition of a special purpose position/velocity tracking/detection system. These values are estimates based upon the study of Reference 5. Such a tracker, even when optimized for application to parallel approaches, offers little improvement in runway spacing to the "position only" system used today. In fact, today's system already includes visual tracking by the controller, to detect the worst of blunders early. Since trackers have relatively little impact, we will not further discuss the possibilities for position/velocity trackers in this paper.

3.3 Reduced Spacing With Improved Navigation

The primary ingredient in reduced spacing for independent parallel IFR approaches is an improved surveillance system. Navigational and ATC improvements can, however, assist in this process. Six cases of improvements have been defined, to reflect

TABLE 3-3

RUNWAY SEPARATION SUMMARY: BASELINE

		UPDATE (s)			
		4	2	1	.5
SURVEILLANCE SYSTEM (mr)	5	4300*	4000	3800	3600
	4	4000	3700	3500	3400
	3	3700	3500	3300	3200
	2	3500	3200	3100	3000
	2**				(2900)
	1	3400	3100	3000	2900
	1**		(2800)	(2600)	(2500)

-- RUNWAY CENTERLINE SPACING (IN FEET) REQUIRED FOR INDEPENDENT PARALLEL IFR APPROACHES

-- BASELINE DEFINED AS TODAY'S ILS SYSTEM AND APPROACHES

* TODAY'S SYSTEM

** VALUES IN PARENTHESES REPRESENT ESTIMATES OF RUNWAY SPACING REQUIREMENTS USING OPTIMIZED POSITION/VELOCITY TRACKER (REFERENCE 5), WHERE SUCH A TRACKER IMPROVES ON POSITION MONITORING STRATEGY.

possible improvements in the system. These improvements relate to the use of three products:

- o Microwave Landing System (MLS), for steeper glide path angles, and possibly curved approaches, with resultant reduced common path lengths or additional altitude separation between arrivals.

- o Offset runway thresholds, to permit greater traffic separation on final approach.

- o Separate short runways to provide independent streams of traffic for general aviation and commuter aircraft.

These factors are closely related in developing applications at specific airports.

The six cases defined to cover these possibilities are summarized in Table 3-4. Case #1 is the baseline case, describing today's ATC system. Case #2 reflects an improvement in navigational accuracy, due to MLS accuracies and/or reduced common path length. Case #3 reflects both improved navigation and improved surveillance (due to reduced common path length). Cases #4 to #6 repeat these three cases, but with the added assumption of one aircraft at a significantly lower approach speed.

Table 3-4 also summarizes the results of the analysis. For each case, the required runway spacing has been calculated for several different surveillance systems. The reduction in the runway spacing requirement due to the changes in navigation error, surveillance error, and aircraft velocities were determined by comparison with Case 1 for the same surveillance system. The resulting range of reductions is given in Table 3-4, as well as the required runway spacing with a 1 mr/1 s surveillance system.

The improved navigation (Case #2) could at best provide 300-500 ft savings, depending on the surveillance system. Navigational and surveillance improvements (Case #3) yield 500-1000 ft improvement. In either case, the lowest feasible runway spacing with a 1 mr/1 s system is 2500 ft. The addition of slower aircraft on one approach, probably in conjunction with the navigational and surveillance improvements, yields an <u>increase</u> in spacing of 200-300 ft, due to encounter geometries. At best, then, a spacing of 2700 ft with a 1 mr/1 s system would be feasible. Table 3-5 summarizes these conclusions.

TABLE 3-4

RUNWAY SEPARATION SUMMARY: SIX CASES

CASE	NAVIGATION ERROR	SURVEILLANCE ERROR	VELOCITIES (kn)	RUNWAY SPACING SAVINGS* (ft)	RUNWAY SPACING WITH 1 mr/1 s (ft)
1	BL	BL	150, 150	----	3000
2	1/2 BL	BL	150, 150	300-500	2500
3	1/2 BL	1/2 BL	150, 150	500-1000**	2500
4	BL	BL	150, 100	(200-300)***	3200
5	1/2 BL	BL	150, 100	100-300	2700
6	1/2 BL	1/2 BL	150, 100	300-700**	2700

BL = BASELINE (TODAY'S ILS SYSTEM AND APPROACHES)

*VERSUS CASE 1, FOR VARIOUS SURVEILLANCE SYSTEMS. THE SAME SURVEILLANCE SYSTEM IS ASSUMED FOR BOTH CASES.

**LARGER SAVINGS ACCRUE AT THE LOWER QUALITY SURVEILLANCE ACCURACIES

***INCREASE

TABLE 3-5

RUNWAY SEPARATION IMPROVEMENTS: NAVIGATION

ITEM	RUNWAY SPACING SAVINGS* (ft)	RUNWAY SPACING WITH 1 mr/1 s (ft)
IMPROVED NAVIGATION (1)	300-500	2500
IMPROVED NAVIGATION AND SURVEILLANCE (2)	500-1000 (3)	2500
SLOWER SPEED AIRCRAFT	ABOVE BENEFITS LOWER BY 200-300	2700

*VERSUS CASE 1, FOR VARIOUS SURVEILLANCE SYSTEMS. THE SAME SURVEILLANCE SYSTEM IS ASSUMED FOR BOTH CASES.

(1) BETTER LATERAL POSITION KEEPING

(2) DECREASED COMMON PATH LENGTH

(3) LARGER RELATIVE SAVINGS ACCRUE AT THE LOWER QUALITY SURVEILLANCE ACCURACIES

The navigational and surveillance improvements noted here depend largely on MLS and reduced common path lengths. The resultant possible improvements in navigation and surveillance error values (Cases 2, 3, 5, 6) are optimistic. Thus, when coupled with the presence of slower aircraft these improvements are unlikely to significantly change the results of the baseline, Case #1. The key to reduced spacing is improvements to the surveillance system itself.

Figure 3-2 presents the comparison of runway spacing versus surveillance system. Figures 3-3 and 3-4 illustrate the tradeoffs between Cases 1, 2, and 3 as a function also of the surveillance system. Finally, the individual results for all six cases (rounded to the nearest 100 ft of runway spacing) are given in Tables 3-6 to 3-11. Further detail is contained in Appendix C.

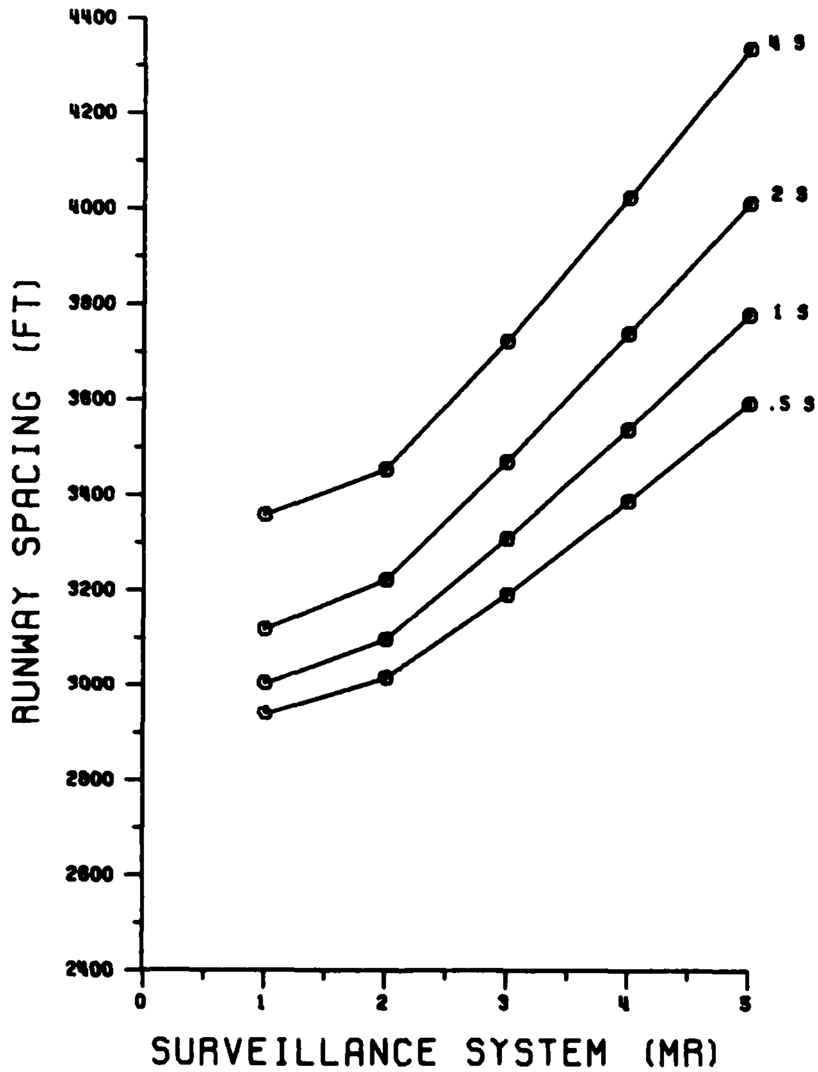


FIGURE 3-2
RUNWAY SPACING—BASELINE

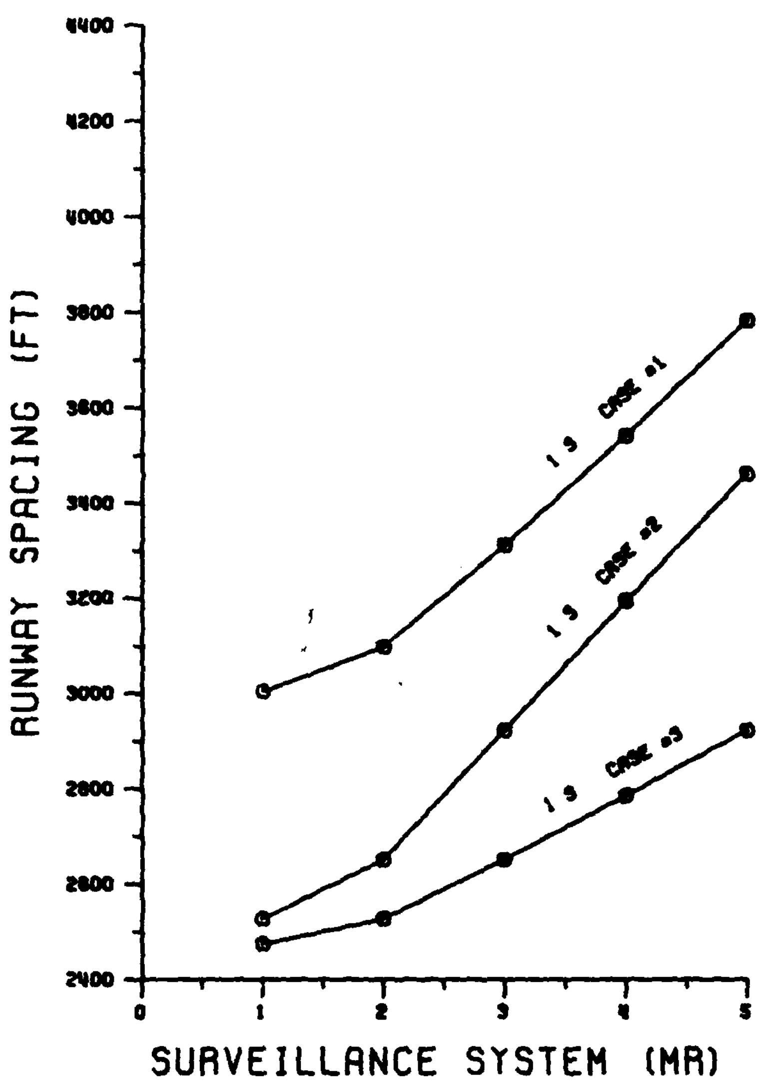


FIGURE 3-3
RUNWAY SPACING—1 s UPDATE

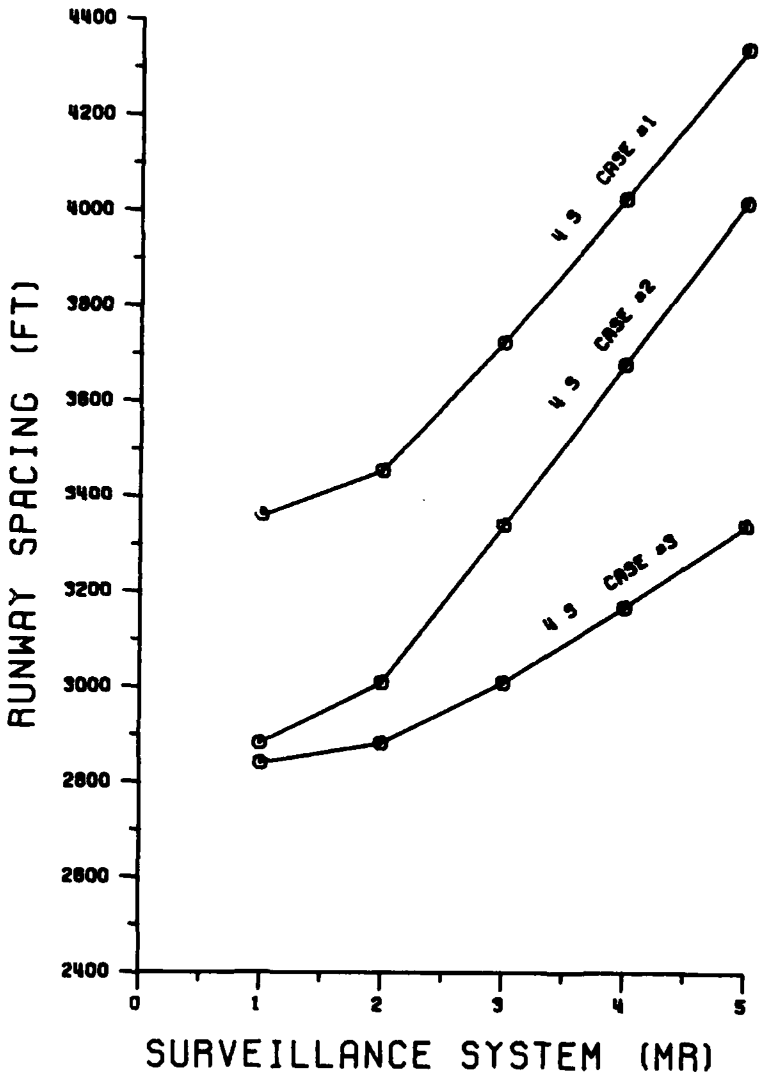


FIGURE 3-4
RUNWAY SPACING—4 s UPDATE

TABLE 3-6

RUNWAY SEPARATION SUMMARY: CASE #1

NAVIGATION ERROR: BASELINE

SURVEILLANCE ERROR: BASELINE

VELOCITIES (kn): 150, 150

		UPDATE(s)			
		4	2	1	.5
SURVEILLANCE SYSTEM (mr)	5	4300*	4000	3800	3600
	4	4000	3700	3500	3400
	3	3700	3500	3300	3200
	2	3500	3200	3100	3000
	1	3400	3100	3000	2900

*CURRENT SYSTEM

TABLE 3-7

RUNWAY SEPARATION SUMMARY: CASE #2

NAVIGATION ERROR: 50% BASELINE

SURVEILLANCE ERROR: BASELINE

VELOCITIES (kn): 150, 150

		UPDATE (s)			
		4	2	1	.5
SURVEILLANCE SYSTEM (mr)	5	4000*	3700	3500	3300
	4	3700	3400	3200	3000
	3	3300	3100	2900	2800
	2	3000	2800	2700	2600
	1	2900	2600	2500	2500

*CURRENT SYSTEM

TABLE 3-8

RUNWAY SEPARATION SUMMARY: CASE #3

NAVIGATION ERROR: 50% BASELINE

SURVEILLANCE ERROR: 50% BASELINE

VELOCITIES (kn): 150, 150

		UPDATE (s)			
		4	2	1	.5
SURVEILLANCE SYSTEM (mr)	5	3300*	3100	2900	2800
	4	3200	2900	2800	2700
	3	3000	2800	2700	2600
	2	2900	2600	2500	2500
	1	2800	2600	2500	2400

*CURRENT SYSTEM

TABLE 3-9

RUNWAY SEPARATION SUMMARY: CASE #4

NAVIGATION ERROR: BASELINE

SURVEILLANCE ERROR: BASELINE

VELOCITIES (kn): 150, 100

		UPDATE (s)			
		4	2	1	.5
SURVEILLANCE SYSTEM (mr)	5	4600*	4200	4000	3800
	4	4200	4000	3800	3600
	3	3900	3700	3500	3400
	2	3700	3400	3300	3200
	1	3600	3300	3200	3200

*CURRENT SYSTEM, WITH FURTHER CONSIDERATION FOR SIGNIFICANTLY SLOWER AIRCRAFT ON ONE APPROACH. AS PRACTICAL MATTER, SUCH APPROACHES WOULD BE ACCEPTABLE AT 4300 ft SPACINGS.

TABLE 3-10

RUNWAY SEPARATION SUMMARY: CASE #5

NAVIGATION ERROR: 50% BASELINE

SURVEILLANCE ERROR: BASELINE

VELOCITIES (kn): 150, 100

		UPDATE (s)			
		4	2	1	.5
SURVEILLANCE SYSTEM (mr)	5	4200*	3900	3700	3500
	4	3900	3600	3400	3300
	3	3600	3300	3100	3000
	2	3200	3000	2900	2800
	1	3100	2900	2700	2700

*CURRENT SYSTEM

TABLE 3-11

RUNWAY SEPARATION SUMMARY: CASE #6

NAVIGATION ERROR: 50% BASELINE

SURVEILLANCE ERROR: 50% BASELINE

VELOCITIES (kn): 150, 100

		UPDATE (s)			
		4	2	1	.5
SURVEILLANCE SYSTEM (mr)	5	3600*	3300	3100	3000
	4	3400	3100	3000	2900
	3	3200	3000	2900	2800
	2	3100	2900	2700	2700
	1	3100	2800	2700	2600

*CURRENT SYSTEM

4. DEPENDENT PARALLEL IFR APPROACHES

This section reviews current procedures for dependent parallel IFR approaches, discusses the analysis of dependent parallel operations presented in Reference 15, and extends that analysis to reduced runway centerline spacings and new navigation and surveillance equipment.

4.1 Basic Procedures for Dependent Parallel IFR Operations

4.1.1 Principles of Dependent Parallel IFR Operations

The paragraph in the Controller's Handbook referring to dependent parallel approaches (alternating arrivals with diagonal separation) was reproduced in Chapter 2 as Table 2-4. This paragraph states the following major requirements:

- A minimum diagonal separation of 2.0 nmi is applied between aircraft on adjacent approaches.
- A minimum separation of 3.0 nmi is applied between aircraft on the same approach course (that is, usual longitudinal separation requirements).
- Runway centerlines must be at least 3000 ft apart.

No separate monitor controller is required. However, since this is a radar procedure, the approach controller must monitor the approaches for separation violations. Unless the tower has been delegated responsibility for assuring separation, the approach controller monitors the approaches even after control has been handed off.

In addition to monitoring the diagonal separation, the controller must also verify that aircraft do not deviate from the localizer course. Such a deviation could endanger the aircraft on the adjacent approach. Unlike the case of independent approaches, the published procedures for dependent approaches do not establish a "No Transgression Zone" between the approaches; there is no limit on the lateral deviation at which the controller must act to protect any endangered aircraft on the other approach. Instead, the emphasis is on maintaining the minimum separation of 2.0 nmi. The impact of this procedure on the blunder analysis is discussed in Appendix D.

4.1.2 Airspace and Equipment Requirements

In this area, there are few differences between independent and dependent parallel IFR approaches. As presented in Section 3.1.2 for independent approaches:

- Interception of the localizer should be at a maximum angle of 30°.
- Aircraft on adjacent approaches should be separated by 1000 ft in altitude until they are both established on the localizer.
- Only straight-in landings are made.
- Missed approach procedures do not conflict.

Dependent approaches do not explicitly require a 1 nmi straight and level segment before localizer intercept, but this is likely to occur in any event.

Equipment requirements are also similar. The dependent approach procedures call for ILS approaches and radar separations, implying that the ILS and radar systems must be fully functional. Monitoring is performed using the primary radar return, so secondary radar need not be available. The monitoring function also requires a communications capability. Adequate levels of performance are assumed for all systems.

4.2 Dependent Parallel Approaches at Reduced Spacings

The principal criterion for determining the spacing required between parallel runways, for independent or dependent approaches, is the ability to safely handle an unplanned deviation (or blunder) by one aircraft which endangers the aircraft on the adjacent approach. For dependent approaches, the diagonal separation between the two aircraft provides a measure of protection which is provided only by the runway spacing for independent approaches; consequently, dependent approaches can be conducted at closer runway spacings than independent approaches.

The minimum miss distance between aircraft in the event of a blunder was calculated using techniques similar to those used for independent approaches. Details are presented in Appendix D.

Current procedures allow dependent approaches to runways as close as 3000 ft apart. We assumed that independent approaches would be run if the runways were more than 4300 ft apart. Over this range of runway spacings, 3000 to 4300 ft, the minimum miss distance in the event of a blunder ranged from 7000 to 7550 ft (Table 4-1). These values represent extremely large safety margins for a rare event such as a blunder.

The minimum miss distance at 3000 ft runway spacing was greater than that for 4300 ft. As Table 4-1 demonstrates, this trend continued even for separations less than 3000 ft: as the runway spacing decreased, the miss distance improved. It therefore appears that, at least for blunder safety, reducing the runway spacing is not just possible but desirable.

This somewhat surprising result is actually quite reasonable. Two factors apply:

- Since the separation is applied diagonally, less distance between runways means a greater in-trail distance between the aircraft.

- Less distance between runways also means that the blundering aircraft crosses the adjacent approach more quickly.

These results would indicate that recovery from a blunder need not be an obstacle to dependent parallel approaches. Before the required runway spacing for dependent approaches can be reduced, however, other potential problems must be addressed. These include wake vortex and the possibility of runway misidentification.

Under current procedures, parallel runways less than 2500 ft are considered, for separation, to be a single runway. Alternating arrivals would therefore have to be separated by the single runway standards of 3/4/5/6 nmi. The separations greater than 3 nmi are required when the lead aircraft produces wake vortices which are strong enough to affect the trail aircraft.

Various solutions to the wake vortex problem have been investigated in the past or are currently under investigation. These include vortex alleviation (modifying the aircraft itself to reduce vortex strength) and vortex avoidance (detection of crosswinds and headwinds which would move the vortex away from the landing area for a single runway). MITRE is currently investigating various operational solutions to the wake vortex problem

TABLE 4-1

MINIMUM MISS DISTANCES

RUNWAY SPACING (ft)	MISS DISTANCE (ft)
4300	7000
3000	7550
2500	7750
1000	8450

-- TODAY'S SURVEILLANCE AND NAVIGATION SYSTEMS

-- VELOCITIES 150 kn

for closely spaced parallel runways. These operational solutions focus on the magnitude of the crosswind, headwind, or tailwind required to move wake vortices away from the path of the smaller aircraft, and reducing the required winds by employing different glide slopes or staggered thresholds on the two runways. The smaller aircraft would use a higher glide slope or land on the upwind runway.

Results to date indicate that alternating arrivals with a uniform 3.0 nmi separation should be feasible under a wide range of wind conditions. Such operations will need to be thoroughly tested in the real world environment. They should present no problems as far as blunder recovery: the additional separation at the start of the blunder would only improve the ultimate miss distance.

4.3 Dependent Parallel Approaches With Improved Surveillance

Another potential problem at closer runway spacings is the possibility that an aircraft will line up for the wrong runway. There are two possible ways this might occur:

- the pilot may misinterpret his approach clearance or misread his approach chart and line up on the wrong localizer,

- or the pilot on an instrument approach may, after breaking out into visual conditions, then visually acquire and line up for the wrong runway.

The first situation would be less likely to arise if procedural changes are instituted which require confirmation of the runway assignment. The pilot might read back the approach clearance to the controller, or the controller might include the correct localizer frequency in the clearance itself. These steps would reduce, but not eliminate, the chance of an aircraft approaching the wrong runway.

As the spacing between parallel approaches decreases, it becomes more difficult for the approach controller to determine from his radar display whether an aircraft is correctly aligned.

Surveillance errors and navigation errors both contribute to the uncertainty about the aircraft's intentions. Improvements in both surveillance and navigation may therefore be required to ensure that the number of centerline deviation "false alarms" is kept low.

Such deviations would not necessarily be blunders, unless the separation also decreased below 2.0 nmi. However, they might be significant if the deviating aircraft was thereby exposed to wake vortices generated on the other approach. This factor will need to be considered in the study of operational wake vortex solutions.

The second category of runway misidentification mentioned above involved a proper approach, but visual acquisition of the wrong runway. If this is determined to be a problem, some means of improving visual runway identification may be required; color-coded Runway End Identifier Lights (REILs) are one possibility. Such events would occur too quickly and too close to the threshold to be reliably detected or resolved by the controller.

In addition to helping the runway misidentification problem, an improved surveillance system would also have an effect on the resulting miss distance in the event of a blunder. Any violation of the required separation would be detected sooner, allowing more time for the controller to act.

To illustrate the impact of improved surveillance, we will consider a pair of runways with 3000 ft spacing. The minimum miss distance for this situation was previously computed to be 7550 ft. A surveillance system with a 1 s update rate and half the error would increase this miss distance to 9300 ft.

Another example would be the case of dependent approaches with a reduced diagonal separation. With a 1.5 nmi separation and current surveillance, a 3000 ft runway spacing would result in a 4500 ft minimum miss distance; with improved surveillance, this value would increase to 6150 ft. These results are summarized in Table 4-2.

4.4 Impact of Other E&D Projects

So far, dependent parallel operations have only been considered in the current ATC system. Certain programs or studies now underway could affect, and be affected by, dependent parallel operations.

For example, the Microwave Landing System currently under development would further reduce the risks associated with inadvertent blunders. MLS allows more accurate navigation and provides an expanded capability for automated approaches, reducing the likelihood of a blunder. Additionally, the missed approach guidance available with MLS may make it easier to

TABLE 4-2

EFFECT OF IMPROVED SURVEILLANCE, REDUCED SEPARATIONS
ON MINIMUM MISS DISTANCE

SEPARATION	SURVEILLANCE	
	CURRENT*	IMPROVED**
2.0 nmi	7550 ft	9300 ft
1.5 nmi	4500 ft	6150 ft

*4s UPDATE

**1s UPDATE, 1/2 SURVEILLANCE ERROR

establish the "missed approach procedures (which) do not conflict" as required for dependent approaches, when these would otherwise present a problem.

The availability of dependent approaches could affect the FAA's proposed separate short runways studies. These studies concern the feasibility and benefits of a separate runway for commuter and general aviation operations at major airports (References 11-14). The maximum benefit from such a runway would come if the arrival stream could be completely independent of the air carrier arrivals, but few if any airports may have the land available to locate the new runway 4300 ft from existing runways. At closer runway spacings, the feasibility of dependent alternating arrivals is important.

A blunder analysis was conducted for the separate short runway case, with the results in Table 4-3. One approach stream was assumed to be composed solely of general aviation aircraft with a normal approach speed of 110 kn; all air carrier-type aircraft (speed 150 kn) used the other runway. This velocity differential between the two aircraft leads to smaller miss distances than in the previous analyses where the speeds were initially equal. However, the miss distances are still adequate to allow dependent parallel operations. Even in the worst of all possible cases, the aircraft still miss each other by 4100 ft. Tables of miss distances may be found in Appendix E.

Other studies which are currently underway involve triple parallel approaches. These may all be independent approaches, or combinations of independent and dependent approaches. Here the question of blunders acquires new significance: a blunder on one of the outer runways towards the middle may cause as many as three other aircraft to be diverted. Strategies for dealing with blunders or triple parallels are currently being investigated.

4.5 Conclusions

The analysis of dependent approaches has shown no obstacle to conducting dependent approaches to parallel runways 2500 ft apart. At runway spacings below 2500 ft, the effects of wake vortex must be specifically accounted for. In addition, the possibility of runway misidentification becomes more significant as runway spacings decrease.

TABLE 4-3

SEPARATE SHORT RUNWAY -- MINIMUM MISS DISTANCE

RUNWAY SPACING	MISS DISTANCE
4300 ft	4150 ft
3000 ft	4100 ft
2500 ft	4100 ft
1000 ft	4300 ft

-- 2.0 nmi (12150 ft) INITIAL SEPARATION

-- AIRCRAFT ARE INITIALLY AT 150 kn, 110 kn

5. SUMMARY AND CONCLUSIONS

5.1 Independent Parallel IFR Operations

Independent (simultaneous) parallel IFR approaches may currently be conducted to runways as close as 4300 ft apart. Certain procedural and equipment requirements must be met, including:

- functioning ILS, radar, and communications
- separate monitor controllers
- diverging missed approaches.

A Normal Operating Zone is defined for each approach. An aircraft which deviates towards the NOZ boundary is instructed by the controller to return to the localizer course; if the NOZ boundary is penetrated, any endangered aircraft on the adjacent approach must be vectored away.

The required 4300 ft runway spacing is based upon maintaining separation between the two aircraft in the event of such a blunder, with certain assumptions about aircraft and ATC performance. This runway spacing requirement can be reduced if improvements are made to surveillance and navigation performance. These improvements have two effects:

- The size of the NOZ can be reduced without increasing the "false alarm" rate for penetrating the NOZ boundary.
- The size of the No Transgression Zone between the runways can be reduced without decreasing the miss distance in the event of a blunder because any penetration of the NOZ would be detected sooner.

If the current surveillance system, with a 5 mr accuracy and 4 s update rate, were replaced with a 1 mr/1 s system, independent parallel IFR operations could be conducted to runways as close as 3000 ft apart. No other improvements, or changes to current ATC procedures, would be required. Such radar performance has been achieved in Precision Approach Radar (PAR) systems.

The presence of slower aircraft on one approach (for example, general aviation or commuter aircraft approaching a separate short runway) tends to increase the required spacing between the runways by 200-300 ft. If, however, the slower aircraft can be turned onto the localizer closer to the runway, this could reduce the need for such an increase.

5.2 Dependent Parallel IFR Operations

If the spacing between parallel runways is too close to allow independent operations, it may still be possible to conduct dependent IFR approaches using a 2.0 nmi diagonal separation between adjacent aircraft. Current procedures allow such operations if the runways are at least 3000 ft apart.

Some other requirements for dependent approaches are also less restrictive than for independent operations. A separate monitor controller is not required, for example, and missed approach paths are only required to "not conflict."

No NOZ or NTZ is established for dependent approaches. Instead, the diagonal separation provides the buffer between aircraft on adjacent approaches. Violating the diagonal separation therefore constitutes a blunder, recovery from which must be assured. Turning the threatened aircraft results in a minimum miss distance, over the wide range of deviations in speed and angle, of 7000 ft.

This minimum miss distance varies with the runway spacing; in general, the miss distance increases as the runways move closer together. At 3000 ft runway spacing, the minimum miss distance is 7550 ft; at 2500 ft it is 7750 ft; and at 1000 ft it is 8450 ft. This is primarily because, at closer spacings, the blunderer would cross the other approach (and no longer present a hazard) more quickly.

It therefore appears that the runway spacing requirement for dependent IFR operations can be reduced. No changes to the other requirements and procedures would be necessary with a minimum runway spacing of 2500 ft.

At runway spacings below 2500 ft, wake vortex must be considered. Other studies are currently underway on the feasibility of operational solutions to this problem. Combinations of crosswinds, runway spacing, staggered thresholds and higher glide slopes will be identified which allow alternating approaches to close-spaced parallels with less than the full vortex separation. A uniform 3.0 nmi in-trail separation between adjacent aircraft is the current focus of these studies; in the future, it may be extended to allow 2.0 nmi diagonal separations at less than 2500 ft.

As parallel runways get closer together, it becomes more difficult to ensure that each aircraft is actually lined up for the proper runway. Procedural changes may reduce the possibility of such an event, but improved surveillance and navigation sytems may be needed to ensure that the controller could detect such a runway misalignment if it occurred.

5.3 Capacity With Reduced Spacing Requirements

Figure 2-4 depicted the relationship of arrival capacity to the spacing between parallel runways under current ATC procedures. This diagram is modified in Figure 5-1 to show the capacity benefits possible if the runway spacing requirements are reduced.

The biggest benefit comes from operating independent approaches to runways spaced 3000 ft apart. Arrival capacity in this case increased from 41 to 57 per hour.

Reducing the required spacing for dependent approaches (with a 2.0 nmi diagonal separation) from 3000 ft to 2500 ft can increase capacity from 31 to 41 arrivals per hour. This is not as large a benefit, but it can be achieved more easily; no new surveillance system is required.

Below 2500 ft, an operational solution which allowed a uniform 3.0 nmi in-trail separation would improve capacity from 28 to 31 arrivals per hour. Larger increases would be expected if the proportion of heavies in the mix were greater (because single runway capacity would be lower).

Lastly, operational solutions allowing 2.0 nmi diagonal separation down to 1000 ft runway spacing would provide a significant capacity benefit, compared to present operations.

5.4 Next Steps

Independent and dependent parallel approaches at reduced spacing offer potential for alleviation of congestion at major airports. Application can be made with existing or future runway pavement.

The FAA is actively pursuing a program of increased airport capacity. Dual parallel instrument approaches at reduced runway spacings represent one aspect of this program. Other concepts include:

- triple instrument approaches
- non-parallel instrument approaches
- separate short runways.

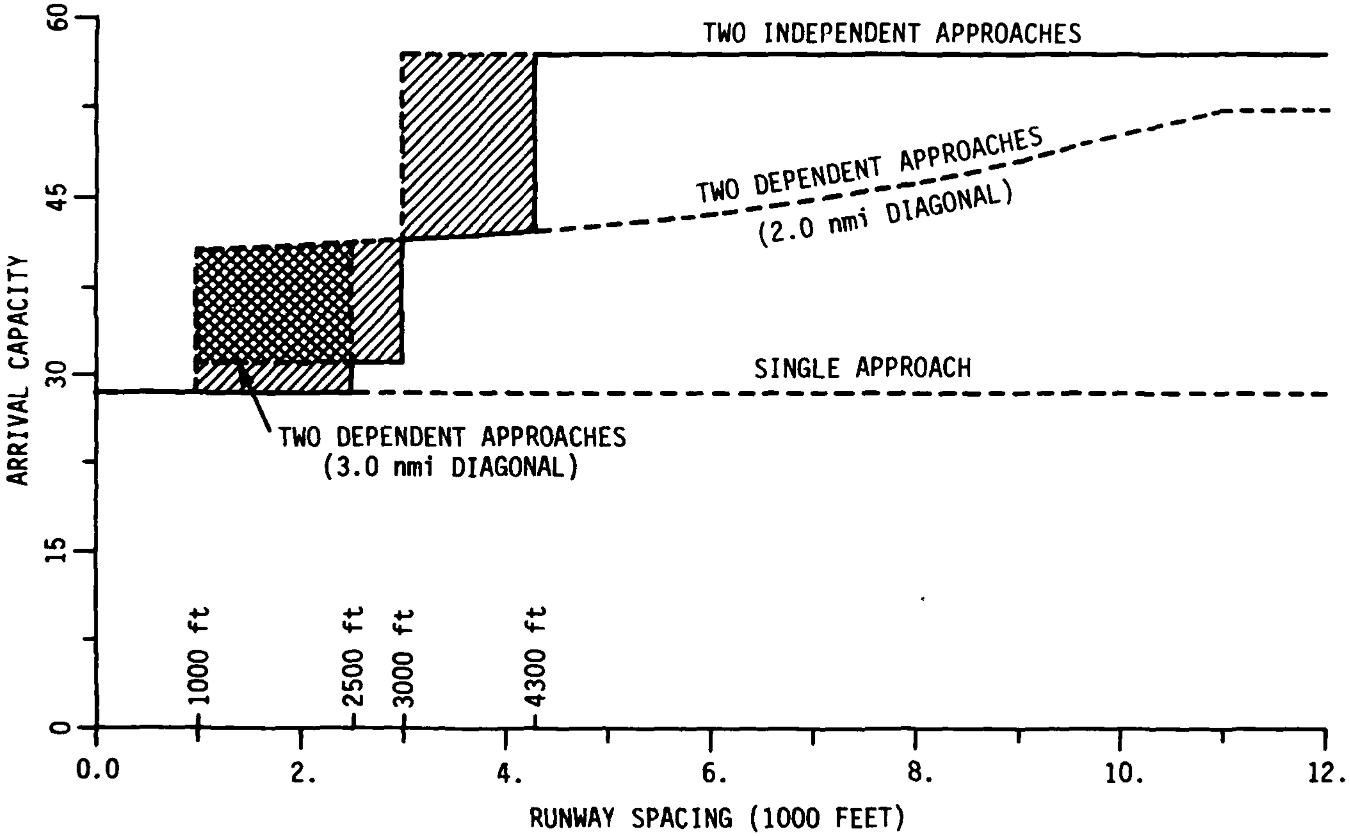


FIGURE 5-1
ARRIVAL CAPACITY AS FUNCTION OF CENTERLINE SPACING—NEW PROCEDURES

Application of parallel approaches requires several steps beyond the requirements analyzed in this report. Site studies will be needed in most cases to evaluate the specific application. Procedural and operational tests may be necessary to establish the feasibility of implementation. These activities are being pursued by the FAA.

APPENDIX A

DETAILS OF CAPACITY CALCULATION

A.1 General Background

In Section 2, a chart illustrating the effect of runway centerline separation on arrival capacity was presented. This chart is reproduced here as Figure A-1.

Two items were varied: the runway separation, and the type of approach being conducted. Otherwise, the same inputs were used to generate each curve: IFR procedures, IMC weather, and airport-specific data representative of Atlanta International Airport (Reference 24). All data used in the calculations is presented in Table A-1. The resulting capacities are listed in Table A-2.

All capacities were calculated using the Upgraded FAA Airfield Capacity Model (Reference 25).

A.2 Capacity Logic

A.2.1 Independent Runways

For a single runway, the calculation of arrival capacity is straightforward. Capacity is defined as the maximum throughput over an extended period. The average time between arrivals at the runway threshold is calculated, based upon either

- the interarrival separation between the aircraft, or
- the runway occupancy time of the lead aircraft,

whichever is limiting.

The minimum interarrival separation is converted to an average value, based upon the characteristics of the ATC system. Any speed differential between the two aircraft is also accounted for: if a slow aircraft is following a faster aircraft, separation will have increased by the time the lead aircraft reaches the threshold. The actual separation may also be increased in order to avoid simultaneous runway occupancy, as determined by the runway occupancy time of the lead aircraft.

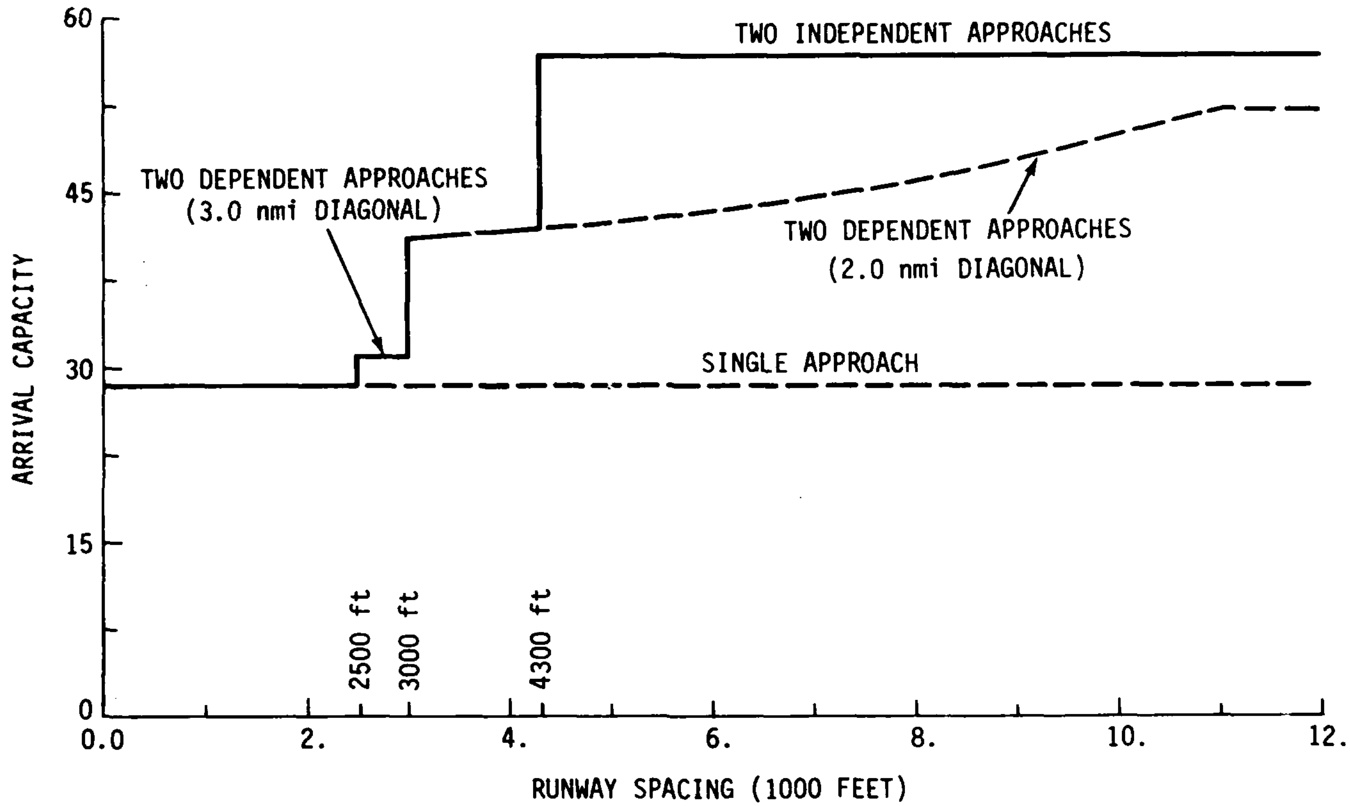


FIGURE A-1
ARRIVAL CAPACITY AS FUNCTION OF CENTERLINE SPACING—CURRENT PROCEDURES

TABLE A-1

CAPACITY CALCULATION INPUT

AIRCRAFT TYPES	A SINGLE PROP <12,500 lb	B TWIN PROP <12,500 lb	C 12,500 lb -300,000 lb	D HEAVY >300,000 lb
AIRCRAFT MIX	1%	13%	73%	13%
RUNWAY OCCUPANCY TIME (s)				
-- RUNWAY 1	38	46	50	56
-- RUNWAY 2	40	41	48	56
APPROACH SPEEDS (kn)	95	120	130	140

ARRIVAL-ARRIVAL SEPARATIONS (nmi)

LEAD \ TRAIL	A	B	C	D
A	3.0	3.0	3.0	3.0
B	3.0	3.0	3.0	3.0
C	4.0	4.0	3.0	3.0
D	6.0	6.0	5.0	4.0

FINAL APPROACH PATH LENGTH 5 nmi

PRESENT-DAY ATC SYSTEM: INTERARRIVAL ERROR 18s
PROBABILITY OF VIOLATION 5%

TABLE A-2

CAPACITY CALCULATION RESULTS

SINGLE RUNWAY		28.5
DEPENDENT APPROACHES		
-- 3.0 nmi DIAGONAL (2500-3000 ft)		31.3
-- 2.0 nmi DIAGONAL:	1000* ft SPACING	40.6
	2000*	40.8
	3000	41.2
	4000	41.8
	5000	42.5
	6000	43.4
	7000	44.7
	8000	46.1
	9000	47.8
	10000	50.1
	11000	52.2
	12000	52.2
INDEPENDENT APPROACHES		56.9

*NEW ATC PROCEDURE ONLY

Once the average interarrival time for each possible aircraft pair has been calculated, the results are weighted by the probability of occurrence for each pair, and summed together. The resulting overall average time is then inverted to determine the number of operations per hour, the runway capacity.

For two independent runways, the total capacity is simply the sum of the individual runway capacities.

A.2.2 Dependent Runways

The calculation of capacity of two dependent runways is more complex, since more factors are involved. Alternating arrivals are assumed, i.e., an arrival to runway 1 is followed by an arrival to runway 2, and vice versa. Airborne separation must be maintained relative to aircraft on the adjacent approach as well as on the same approach, and usually the separation standards are different.

For example, consider the diagram in Figure A-2. Aircraft C, a large (type C), must be at least 5.0 nmi behind Aircraft A, a heavy (type D), and more than 5.0 nmi if required by runway occupancy time. Aircraft C must also be 2.0 nmi diagonally behind Aircraft B on the adjacent approach. Since B is only 2.0 nmi diagonally behind Aircraft A, this requirement is satisfied. Aircraft D, in turn, is 2.0 nmi diagonally behind Aircraft C; the resulting separation between B and D, 5.0 nmi, is greater than would be required if independent approaches were conducted. We refer to this phenomenon as "shadow spacing."

The capacity program considers the full impact of the aircraft on the adjacent approach. It also considers the effect of any velocity differential between the aircraft and any restrictions imposed by runway occupancy times.

Two types of dependent approaches are shown in Figure A-1:

- a 3.0 nmi diagonal separation between arrivals on adjacent approaches, and

- a 2.0 nmi diagonal separation.

The same logic was used for both cases.

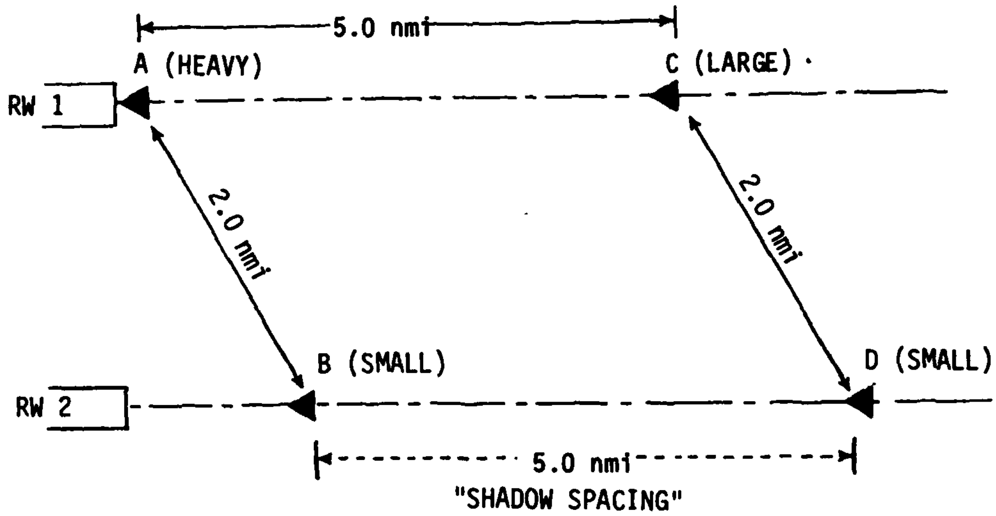


FIGURE A-2
ILLUSTRATION OF "SHADOW SPACING"

A.3 Interpretation of the Capacity Curves

A.3.1 Current Procedures

Referring again to Figure A-1, we will examine the impact which centerline spacing has on runway capacity. This discussion will only consider current ATC systems and procedures.

If the runways are spaced less than 2500 ft apart, they are treated as a single runway. Alternating approaches, even on separate runways, are subject to the same 3/4/5/6 nmi spacings for vortex safety as arrivals to a single runway. There is some capacity benefit from applying the separations diagonally rather than in-trail, but the net effect is negligible. Runway occupancy times are not as critical, but they are rarely constraining at present day IFR separations.

At centerline separations greater than 2500 ft, extra separation for vortex safety is no longer required. Use of a 3.0 nmi diagonal separation produces an increase in capacity, from 28.5 to 31.3 operations per hour. If there were more heavy aircraft in the mix, the capacity increase would be greater.

At 3000 ft separation, 2.0 nmi diagonal separation between adjacent arrivals can be applied. Since this is measured diagonally, the effective in-trail separation decreases as the distance between centerlines increases. Capacity, therefore, increases as well. Capacity with alternating arrivals will never match that of two independent runways, however, for two reasons: "shadow spacing" still occurs, and fast aircraft are not allowed to pass slower aircraft on the adjacent approach.

Of course, two independent approaches are feasible with a 4300 ft runway separation, at which point they provide a vast capacity benefit over dependent parallel approaches.

A.3.2 Revised Procedures

The capacity curves in Figure A-3 reflect the following changes in ATC procedures, as discussed in this report:

- independent approaches to runways 3000 ft apart,
- dependent alternating approaches with 2.0 nmi diagonal separation to runways as close as 1000 ft apart (wake vortex assumed to be controlled by means other than separation).

The region in which these revised procedures provide a capacity benefit is shown by cross hatching.

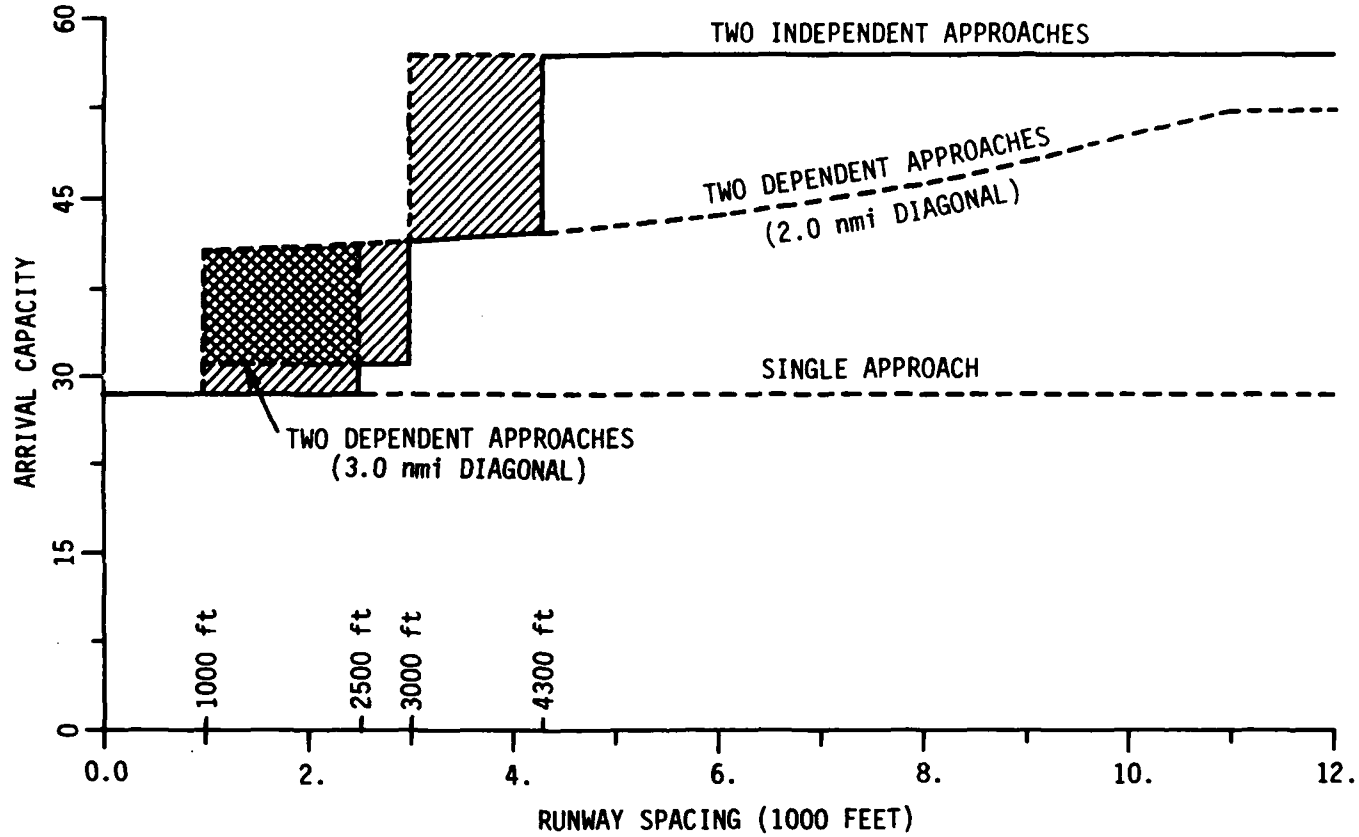


FIGURE A-3
ARRIVAL CAPACITY AS FUNCTION OF CENTERLINE SPACING—
NEW PROCEDURES

APPENDIX B

CONCEPTS FOR INDEPENDENT PARALLEL IFR APPROACHES

This Appendix gives the methodology of analyzing parallel runway operations. Further developments are found in References 1-3. Section B.1 reviews the basic concepts. Section B.2 then derives the necessary equations. A computer program for analyzing parallel runways has been developed; the computer terminal output from a sample run is given in Section B.3.

B.1 Basic Concepts

The current method of air traffic control in the final approach phase may be summarized with the aid of Figures B-1 through B-3. Figure B-1 illustrates the parallel approach situation. Figure B-2 illustrates the control process. Aircraft fly the ILS centerlines to their respective runways. There is an error in their ability to maintain that centerline, due to the effects of navigation, aircraft, pilot and weather. Through some data acquisition (surveillance) system depending upon some form of radar, the controller has available each update some measurement of each aircraft's lateral position with respect to the ILS centerline. If this lateral excursion is so large as to exceed a safety limit (called the NOZ boundary) the controller takes action to avoid a potential conflict with an aircraft on approach to the other runway. As illustrated in Figure B-3, this action is to direct a turning maneuver by the other aircraft to a parallel course. The command is given to this aircraft since it is assumed that the conditions leading to the first aircraft violating the NOZ boundary may also prevent an adequate correction (turn back) maneuver.

In order to determine the minimum runway spacing which may be achieved, the parameters of the avoidance maneuver scenario must be specified. A qualitative description of the analysis is given below. The avoidance scenario may be more finely divided as illustrated in Figure B-4. The total runway spacing is divided into four segments:

1. The Normal Operating Zone (NOZ) for the first runway

2. A Detection Zone (DZ) which allows for the inaccuracy and delay in the process of actually determining that the NOZ has been violated

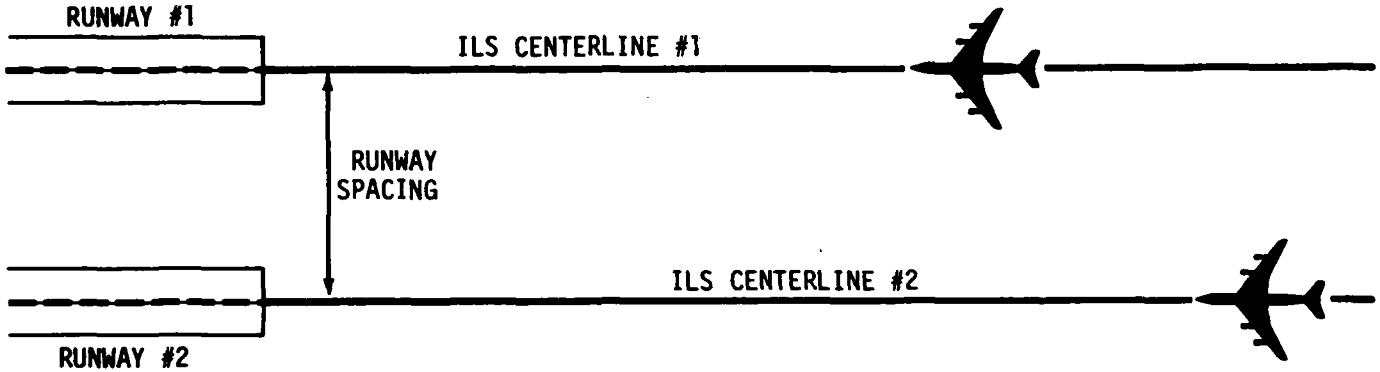


FIGURE B-1
PARALLEL RUNWAY APPROACHES

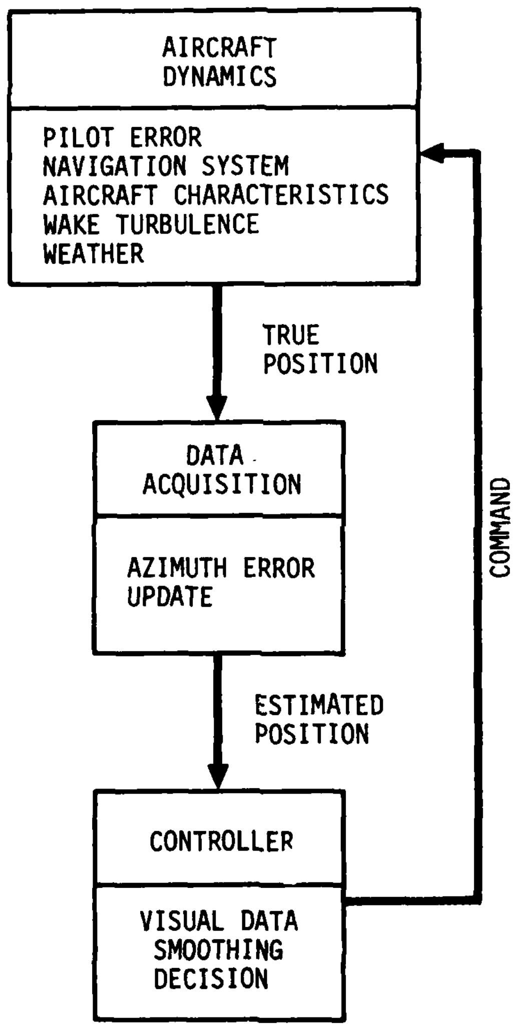


FIGURE B-2
CONTROL SYSTEM SCHEMATIC

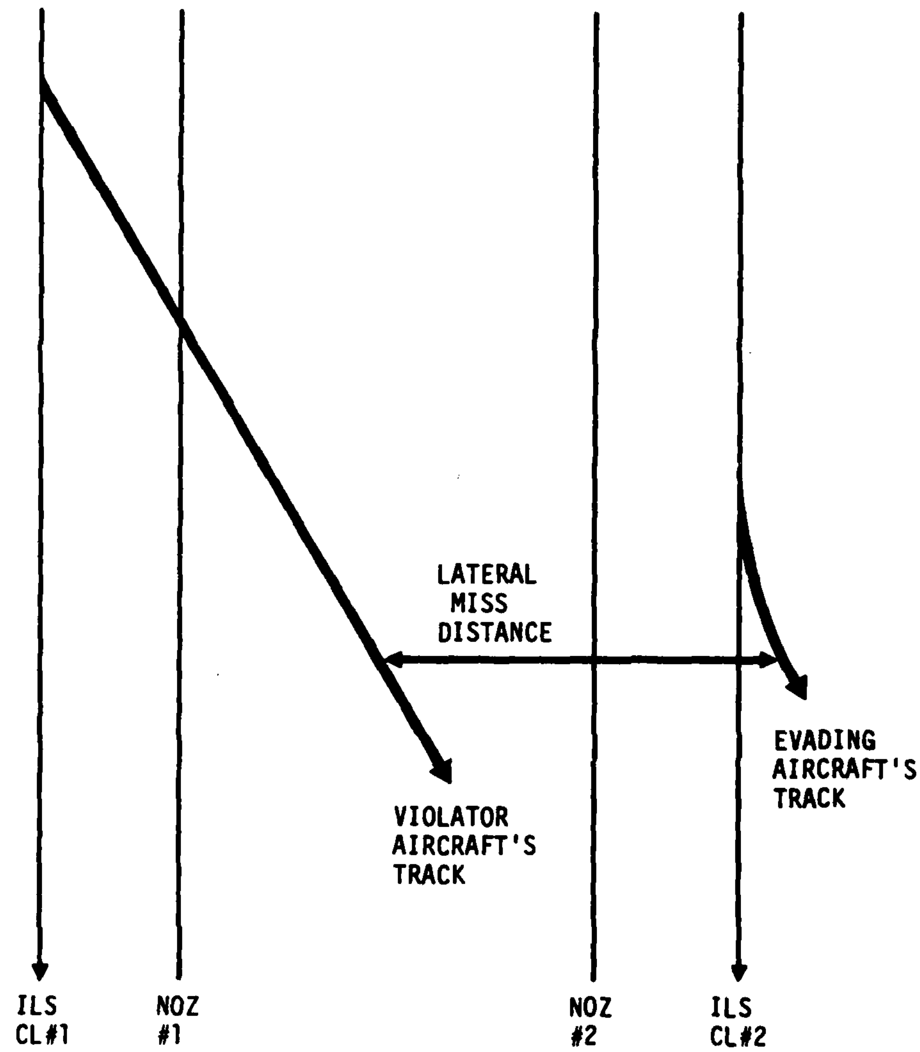


FIGURE B-3
CORRECTIVE MANEUVER

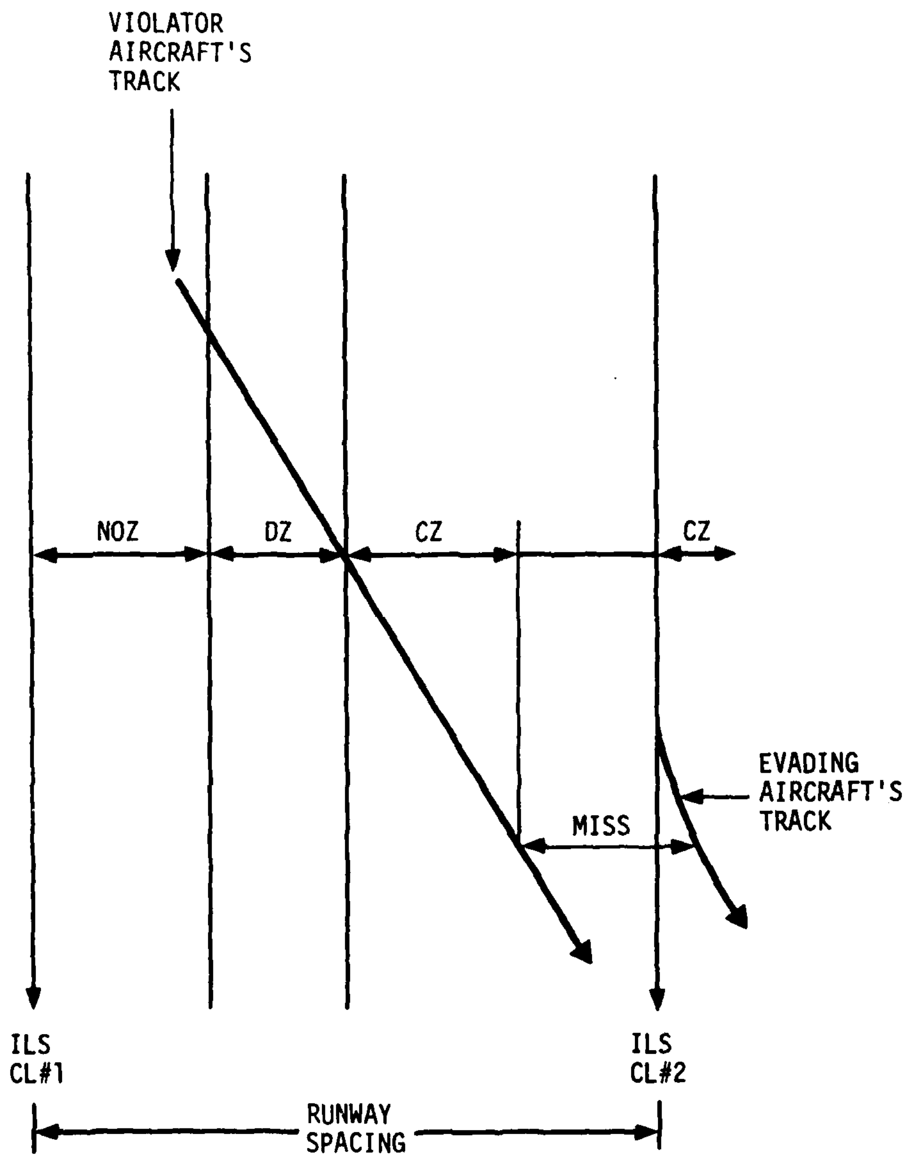


FIGURE B-4
SPACING BETWEEN AIRCRAFT

3. A Correction Zone (CZ) which allows for the time for the evading aircraft to react to the turn away command and achieve the desired course parallel to the violator

4. A Miss Distance (MISS) which accounts for an adequate lateral separation between the two aircraft at their point of closest approa

The detailed parameters necessary for the evaluation of the size of these zones are described below. A summary is given in Table B-1.

Normal Operating Zone: For safety purposes, it would be possible to establish nearly any value for the NOZ. However, if this value is too low, even normally operating aircraft would be identified as violators. Not only would this result in unnecessary avoidance maneuvers (and loss of capacity), but pilot confidence in the entire control process would be lost, with associated safety consequences. Thus, the NOZ must be large enough to insure that the alarm rate (i.e., rate of identified violations) is sufficiently small. Parameter inputs to this process are:

-- Acceptable rate of alarms (i.e., controller intervention rate).

-- Distribution of errors of aircraft lateral position with respect to the ILS centerline. This depends both on aircraft/pilot characteristics and the navigation system.

-- Distribution of errors in lateral position estimate of data acquisition (surveillance) system, to include controller error in reading data presented on this scope.

Detection Zone: The detection zone is sized so that a specified worst case violator is identified as having crossed the NOZ by the time it is in fact no further from the ILS centerline than NOZ + DZ. This identification must occur by this point except for some (very small) percent of time. Parameter inputs to this calculation are:

-- Specification of worst case violator (velocity and assumed constant angle of deviation from ILS centerline)

TABLE B-1

INPUT PARAMETERS BY ZONE

NORMAL OPERATING ZONE:
- ALARM (CONTROLLER INTERVENTION) RATE
- AIRCRAFT POSITION ERROR DISTRIBUTION
  - PILOT
  - AIRCRAFT
  - NAVIGATION
- DATA ACQUISITION SYSTEM ERROR DISTRIBUTION
  - SYSTEM
  - CONTROLLER

DETECTION ZONE:
- WORST CASE VIOLATOR SPECIFICATION
  - VELOCITY
  - DEVIATION ANGLE
- DATA ACQUISITION SYSTEM UPDATE INTERVAL
- DATA ACQUISITION SYSTEM ERROR DISTRIBUTION
  - SYSTEM
  - CONTROLLER
- NON-DETECTION RATE

CORRECTION ZONE:
- WORST CASE VIOLATOR SPECIFICATION
  - VELOCITY
  - DEVIATION ANGLE
- TOTAL DELAY TIME
  - CONTROLLER
  - COMMUNICATION
  - PILOT
  - AIRCRAFT
- EVADER AIRCRAFT TURNING PERFORMANCE

MISS DISTANCE:
- REQUIRED MISS DISTANCE
- AIRCRAFT POSITION ERROR DISTRIBUTION
  - PILOT
  - AIRCRAFT
  - NAVIGATION

AD-A105 673 MITRE CORP MCLEAN VA METREK DIV F/G 1/2
REQUIREMENTS FOR INDEPENDENT AND DEPENDENT PARALLEL INSTRUMENT --ETC(U)
MAY 81 A L HAINES, W J SWEDISH DTFA01-81-C-10001
UNCLASSIFIED MTR-81W15 FAA-EM-81-8 NL

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-- Data acquisition system update interval

-- Error in measurement of lateral position (including those due to both the data acquisition system and to the controller's reading of his display)

-- Rate (e.g., 1 in 100) at which non-detection within the bounds of the DZ may be permitted. Detection still occurs in the "1 to 100" case but at a later point.

Correction Zone: The correction zone is sized to account for the delay time between the detection of the violator by the controller, through message transmission to the pilot, to the initiation of aircraft response; as well as the distance needed during the maneuver by the evading aircraft. This latter accounts for the spacing required by the violator's continued track, less the lateral spacing increase experienced by the evading aircraft as it completes the turn to a course parallel to the violating aircraft. Parameter inputs to this calculation are:

-- Specification of worst case violator (as above)

-- Total delay time (communication channel access, transmission, pilot reaction)

-- Aircraft turning performance.

Miss Distance: At the completion of the evasive maneuver under the worst case conditions there must be an adequate lateral separation between aircraft. This must also account for the possibility the evading aircraft may not have been exactly on the ILS centerline. No altitude separation is assumed. The non-blundering aircraft is assumed to be flying at zero angle deviation. Parameter inputs to this calculation are:

-- Required lateral miss distance (longitudinal separation may be present, but is not assumed)

-- Distribution of errors of aircraft lateral position with respect to the ILS centerline. This depends upon both aircraft/pilot characteristics and navigation system.

A listing of input parameters grouped by general type is given in Table B-2.

TABLE B-2

INPUT PARAMETERS BY TYPE

PILOT/AIRCRAFT/NAVIGATION PERFORMANCE:
- LATERAL ERROR DISTRIBUTION
- *WORST CASE VIOLATOR SPECIFICATION
  - VELOCITY
  - DEVIATION ANGLE
- *DELAY TIME
- EVADER AIRCRAFT TURNING PERFORMANCE

CONTROLLER/DATA ACQUISITION SYSTEM
- ERROR DISTRIBUTION
- UPDATE INTERVAL
- *DELAY TIME

WORKLOAD/SAFETY
- ALARM (CONTROLLER INTERVENTION) RATE
- *WORST CASE VIOLATOR SPECIFICATION
  - VELOCITY
  - DEVIATION ANGLE
- NON-DETECTION RATE
- REQUIRED MISS DISTANCE

*DUAL ENTRY IN TABLE

B.2 Derivations

This section presents the basic derivations of the values of the various zones comprising the runway spacing. The various zones are illustrated in Figure B-5. The input/output parameters are defined in Table B-3. The details of the derivations are as follows:

NOZ

The position-keeping accuracy of a normally operating aircraft on the blunderer's approach course is assumed to be normally distributed with zero mean and standard deviation of SNB, or

$$\text{Normal } (0, SNB^2).$$

Also the surveillance error is assumed to be

$$\text{Normal } (0, SSV^2).$$

The distribution of the sum of these errors is thus

$$\text{Normal } (0, SNB^2 + SSV^2). \tag{1}$$

On a random update (at the maximum range represented by SNB, SSV), the probability that a displayed target has penetrated the NOZ boundary is determined from the one sided normal table (unit normal) for a value of

$$\frac{NOZ - 0}{\sqrt{SNB^2 + SSV^2}} . \tag{2}$$

Let this value be PRNOZ. In the computer program, a slight modification is used with the ERF or ERFC built-in function.

For a 4 second interval the rate of such events is:

$$\frac{4}{UP} * PRNOZ. \tag{3}$$

Iteratively, we test values of NOZ to find that value such that the above expression is equal to CIR. In the computer program, this iteration is done by Newton's method. Other techniques are also possible.

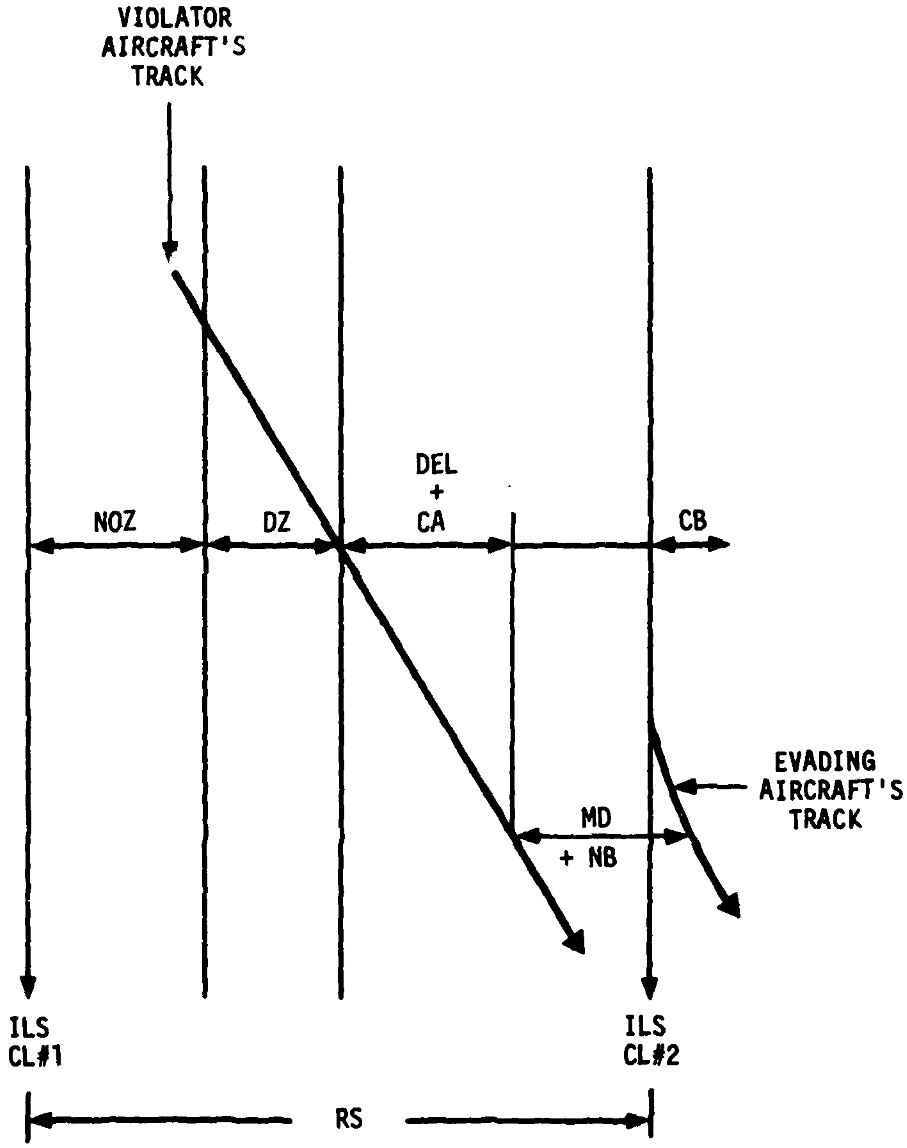


FIGURE B-5
SPACING BETWEEN AIRCRAFT
(NOMENCLATURE)

TABLE B-3

INPUT/OUTPUT PARAMETER DEFINITIONS

INPUT		
ANGLE	-	ANGLE OF BLUNDER
VELONE	-	VELOCITY OF BLUNDERER
VELTWO	-	VELOCITY OF NON-BLUNDERER
COR	-	RATE OF TURN FOR THE NON-BLUNDERER
SNB	-	NAVIGATIONAL (POSITION KEEPING) ONE SIGMA ACCURACY FOR BLUNDERER
SNN	-	NAVIGATIONAL (POSITION KEEPING) ONE SIGMA ACCURACY FOR NON-BLUNDERER
SSV	-	SURVEILLANCE (DATA ACQUISITION) ONE SIGMA ACCURACY
UP	-	SURVEILLANCE (DATA ACQUISITION) UPDATE INTERVAL
CIR	-	RATE OF CONTROLLER INTERVENTIONS PER WORST 4 SECONDS
PND	-	PROBABILITY OF NON-DETECTION OF BLUNDER BY DETECTION ZONE BOUNDARY
DELAY	-	TOTAL CONTROLLER, COMMUNICATION, PILOT DELAY TIMES FROM FIRST DISPLAY OF BLUNDER BEYOND NOZ UNTIL AIRCRAFT CONTROLS ACTIVATED
MD	-	SPECIFIED MISS DISTANCE
VSNB	-	NUMBER OF NAVIGATION SIGMAS ALLOWED FOR NON-BLUNDERER
OUTPUT		
NOZ	-	NORMAL OPERATION ZONE
DZ	-	DETECTION ZONE
DEL	-	DELAY ZONE
CA	-	LOSS IN SEPARATION BY BLUNDERER DURING CORRECTION
CB	-	GAIN IN SEPARATION BY NON-BLUNDERER DURING CORRECTION
CZ	-	NET SEPARATION LOSS OR CORRECTION ZONE (= CA - CB)
MD	-	MISS DISTANCE
NB	-	NAVIGATION BUFFER
MISS	-	TOTAL MISS ALLOWANCE (= MD + NB)
RS	-	RUNWAY SPACING

DZ

For a blundering aircraft, the controller has several opportunities to get a radar return outside of the NOZ boundary. Between these updates the blunderer travels a distance

$$D = UP * VELONE * SIN (ANGLE). \qquad (4)$$

For computational purposes, we assume the first such opportunity occurs when the aircraft is 3 * SSV - X still within the NOZ. The value X here is between 0 and D. For this first update, the probability of non-detection is:

$$1 - \Phi(-3 * SSV + X; 0, SSV^2), \qquad (5)$$

the value of the complementary cumulative normal distribution function with mean 0, variance SSV^2, at a point -3 * SSV + X. Denote this value by

$$P[-3 * SSV + X]. \qquad (6)$$

The next update occurs at (-3 * SSV + X + D) with associated non-detection probability

$$P[-3 * SSV + X + D].$$

The probability of non-detection in both updates is

$$\prod_{n=0}^{1} P[-3 * SSV + X + n * D], \qquad (7)$$

assuming radar updates are uncorrelated. We then define a sequence of such updates $K_X + 1$, with associated non-detection probability

$$\prod_{n=0}^{K_X} P[-3 * SSV + X + n * D]. \qquad (8)$$

We shall choose DZ such that

$$PND = \int_0^D \prod_{n=0}^{J_x} P(-3 * SSV + * + n * d)\,\frac{dX}{D} \qquad (9)$$

where J_x = minimum integer such that

$$-3 * SSV + X + J_x * D \le DZ.$$

Further, we require in limiting cases that DZ ≥ D.

In the computer calculation, we hypothesize a value of DZ and calculate the PND as above. If PND exceeds desired value, a new higher DZ is tried; if PND is too low, a lower DZ is tried. The iteration is ended when the successive results are sufficiently close.

DEL

The delay zone is the loss in spacing due to continued movement of blundering aircraft,

$$DEL = DELAY * VELONE * SIN(ANGLE). \qquad (10)$$

CZ

The correction zone is made up of two quantities. The first is the additional space the blunderer travels during the process of correction (or avoidance) by the non-blundering aircraft. The time for non-blundering aircraft to turn to parallel course is:

ANGLE/COR

and this value is

$$CA = ANGLE * VELONE * SIN(ANGLE)/COR. \qquad (11)$$

This is partially offset by the increase in spacing as the non-blundering aircraft begins to turn to a parallel course. This is illustrated in Figure B-6. The radius of turn R is

$$\frac{VELTWO}{COR}$$

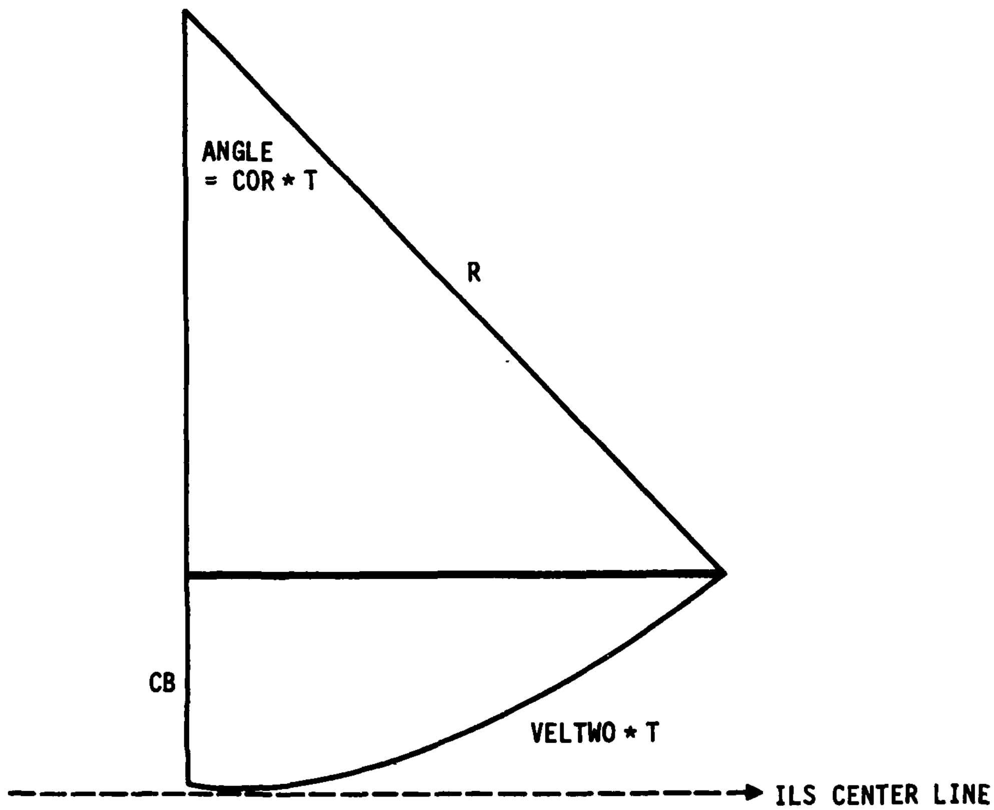


FIGURE B-6
GEOMETRY OF CORRECTIVE TURN

and the relationship

$$COS(ANGLE) + \frac{R - CB}{R}$$

yields

$$CB = R * (1 - COS(ANGLE)). \quad (12)$$

Thence,

$$CZ = CA - CB. \quad (13)$$

MISS

The miss distance is the lateral miss distance resulting after the non-blunderer completes the turn to a parallel course. It is composed of the fixed offset input value MD and a navigation buffer NB to account for the fact that non-blundering aircraft may not have been on the ILS centerline at the time of the blunder.

$$NB = VSNB * SNN \quad (14)$$

and

$$MISS = MD + NB. \quad (15)$$

Note here no safety accounting is made for (likely) longitudinal separation or the possibility of altitude separation.

RS

The required spacing between runways is therefore

$$RS = NOZ + DZ + DEL + CZ + MISS. \quad (16)$$

B.3 Recalibration of 4300 Foot Spacing

In 1974 the U.S. approved simultaneous approaches to runways spaced as low as 4300 ft. Reference 7 documented a way of evaluating this spacing, based upon logic of Reference 5. The parameters input to this calculation are given in Table B-4.

The derivation of the 4300 foot rule was then as shown in Table B-5. Here all values have been rounded to the nearest 50 ft for convenience. The various elements of the 4300 foot spacing are as described earlier in this appendix.

TABLE B-4

INITIAL NUMERICAL ASSUMPTIONS

(REFERENCE 7)

-- AIRCRAFT VELOCITIES AT 150 kn

-- RECOVERY TURN RATE OF 3 DEGREES/s

-- MAXIMUM BLUNDER ANGLE OF 30 DEGREES

-- NON-DETECTION PROBABILITY OF .01

-- CONTROLLER INTERVENTION RATE PER WORST 4s INTERVAL OF .0000001

-- RADAR UPDATE OF 4s

-- COMMUNICATIONS DELAY TIME OF 8s

-- MISS DISTANCE (LATERAL) IS 300 ft (91 m)

-- MAXIMUM RANGE 8 nmi

-- RADAR ACCURACY (1 SIGMA) OF 192 ft

-- NAVIGATION (POSITION KEEPING) ACCURACY (1 SIGMA) OF 100 ft

-- CONSIDERATION FOR NAVIGATION OF NON-BLUNDERING AIRCRAFT IS 3 SIGMA OF NET POSITION KEEPING ACCURACY

TABLE B-5

ELEMENTS OF U.S. 4300 FOOT RUNWAY SPACING

	ORIGINAL*	RECALIBRATED
NORMAL OPERATING ZONE	1,150 ft	1,150 ft
DETECTION ZONE	950	900
DELAY	1,000	1,000
CORRECTION	600	600
MISS DISTANCE	300	200
NAVIGATION BUFFER	300	450
REQUIRED RUNWAY SPACING	4,300	4,300

*REFERENCE 7

In the process of reviewing current procedures, it was clear that some of these values needed revision. These changes are shown in Table B-6. In this process, we tried to express the 4300 ft rule as it was originally intended for use at Atlanta and Los Angeles at the time of the rule change. The main change from the general case stated in Reference 7 is to account more explicitly for location of the radar and localizer antennas. This adds 1 nmi to the range of the radar and 2 nmi to the range of the localizer. Errors increase accordingly. We also noted a change from our original assumption of secondary radar surveillance to the use of primary radar. This impacts accuracies as well. We assume an ASR-7 radar with ARTS display techniques. The remainder of the changes reflected in Table B-6 are consequences of the above, as results are calibrated to the safety inherent in 4300 foot spacings. The rate of controller interventions per worst radar update appears to be higher than originally thought, although still at a low value. We modified the logic of the detection zone somewhat. Instead of measuring the non-detection probability based upon the worst case phasing of radar returns, we now measure it as the expected value probability over all possible radar return phasings. Finally, the lateral miss distance has been resized from 300 ft to 200 ft. It should be noted that distances of this size are never realized as most blunders are detected earlier, have more favorable non-blundering lateral position, or benefit from longitudinal spacings.

We believe this represents a recalibration of the 4300 foot rule as it was originally intended for use in operations at Atlanta and Los Angeles. The field data on actual operational use of the 4300 foot rule is relatively sparse. Of major U.S. airports with parallel approaches, only Atlanta (ATL) and Los Angeles (LAX) have runways spaced less than 5000 ft. Thus, the current normal mode in the U.S. system is 5000 foot (or greater) parallels, with greater provisions for NOZ and other parameters. Further, neither ATL nor LAX currently make much use of the 4400 (4500) foot parallels they have. In both cases, the normal arrival runways are the outboard parallels, spaced 5450 (ATL) and 5980 (LAX) ft. Generally, only in the case of closure of one of the outboard runways are the closer parallels used. In Atlanta, one estimate was that the 4400 foot parallels are used only 2-5% of the time in the eastbound configuration. (In the westbound configuration, there is no possibility of instrument use of the 4400 foot parallels, since one of the runways lacks an ILS.) ATL did, however, use the 4400 ft spacing parallels extensively during runway reconstruction. Operational experience was satisfactory.

TABLE B-6

RECALIBRATION OF U.S. 4300 FOOT SPACING

PARAMETER	ORIGINAL VALUE	RECALIBRATED VALUE BASED ON ATLANTA
MAXIMUM RANGE		
- SURVEILLANCE	8 nmi	9 nmi
- NAVIGATION	8 nmi	10 nmi
SURVEILLANCE TYPE AT MAXIMUM RANGE	SECONDARY	PRIMARY
SIGMA - SURVEILLANCE	192 ft	288 ft (32 ft/nmi OR .30 DEGREES)
- NAVIGATION	100 ft	150 ft (15 ft/nmi OR .14 DEGREES)
CONTROLLER INTERVENTION RATE (PER UPDATE)	10^{-7}	$2 * 10^{-4}$
DETECTION LOGIC - PHASING OF FIRST UPDATE	WORST CASE	EXPECTED VALUE
MISS DISTANCE (FIXED OFFSET)	300 ft	200 ft

When Atlanta does operate at 4400 foot spacings, they now do so with glide slope intercept ranges of 9 and 12 nmi from threshold. These glide slope intercept ranges represent the point at which parallel monitoring becomes necessary. These ranges are greater than the 5 and 8 nmi glide slope intercepts which generated the 10 nmi range from localizer shown in Table B-6, and are apparently greater than the intercepts in use at the time of the 1974 rule change. Such ranges used at Atlanta would result in higher controller intervention rates. As noted earlier in this Appendix, too great an increase in intervention rates might lead to lack of confidence and response time in the parallel monitor system. We have recalibrated on the basis of the originally intended 4300 foot rule. Since Atlanta operates 4400 foot parallels so infrequently, we are not sure whether the higher workload rates implied by the newer, higher intercept altitudes represent a feasible, stable system. We note that on the usually employed Atlanta 5450 foot parallels, even with the longer ranges to glide slope intercept, the controller intervention rate is about that shown in Table B-6 (i.e., $2 * 10^{-4}$).

B.4 Sample Problem

A sample problem illustrates the use of the MITRE computer program for computing runway spacing. The input and output are given in Table B-7. The numbers represent the recalibration of independent parallel approaches at Atlanta.

TABLE B-7

ATLANTA RECALIBRATION SAMPLE PROBLEM

```
.CALPAR
GLOBAL TXTLIB FORTMOD1
SET BLIP $
FI 12 PRINTER ( RECFM FA BLOCK 132
LOAD CALPAR
START
DMSLIO740I EXECUTION BEGINS...
BASIC UNIT IS FEET(=1) OR METERS(=2)
?
.1

INPUT BASIC VALUES:
1 -- MISS DISTANCE (FT)
2 -- BUFFER SIGMAS
3 -- DELAY TIME (SEC)
4 -- BLUNDER ANGLE (DEGREES)
5 -- BLUNDER VELOCITY (KNOTS)
6 -- NON BLUNDER VELOCITY (KNOTS)
7 -- CORRECT RATE (DEG/SEC)
?
.200,3,8,30,150,150,3

MISS DISTANCE (FT) =                   200.
NAVIGATION BUFFER (SIGMAS) =             3.00
DELAY TIME (SEC) =                       8.
BLUNDER ANGLE (DEGREES) =               30.
BLUNDER VELOCITY (KNOTS) =             150.
NON BLUNDER VELOCITY (KNOTS) =         150.
CORRECT RATE (DEG/SEC) =                 3.00

INPUT THE MAIN PARAMETERS:
1 -- CONTROLLER INTERVENTION RATE
2 -- NON-DETECTION PROBABILITY
3 -- NAVIGATION ERROR - BLUNDERER (FT)
4 -- NAVIGATION ERROR - NON BLUNDERER (FT)
5 -- SURVEILLANCE ERROR (FT)
6 -- SURVEILLANCE UPDATE (SEC)
?
..0802,.01,150,150,288,4

CONTROL INTERVENTION RATE =                          0.000200
NON-DETECTION PROBABILITY =                          0.010000
NAVIGATION ERROR - BLUNDERER (FT) =                150.
NAVIGATION ERROR - NONBLUNDERER (FT) =             150.
SURVEILLANCE ERROR (FT) =                          288.
SURVEILLANCE UPDATE (SEC) =                          4.0

  ANOZ      DZ      DEL       CA       CB       CZ       MD       NR     MISS
    RS
                            1266.     648.              200.     450.
  1150.    908.    1013.                       618.                       650.
  4338.
```

TABLE B-7
(Concluded)

```
INPUT THE MAIN PARAMETERS:
1 -- CONTROLLER INTERVENTION RATE
2 -- NON-DETECTION PROBABILITY
3 -- NAVIGATION ERROR - BLUNDERER (FT)
4 -- NAVIGATION ERROR - NON BLUNDERER (FT)
5 -- SURVEILLANCE ERROR (FT)
6 -- SURVEILLANCE UPDATE (SEC)
?
.0,0,0,0,0,0

INPUT BASIC VALUES:
1 -- MISS DISTANCE (FT)
2 -- BUFFER SIGMAS
3 -- DELAY TIME (SEC)
4 -- BLUNDER ANGLE (DEGREES)
5 -- BLUNDER VELOCITY (KNOTS)
6 -- NON BLUNDER VELOCITY (KNOTS)
7 -- CORRECT RATE (DEG/SEC)
?
.0,0,0,0,0,0,0
 R; T=3.13/5.12 16:51:13


BASIC UNIT IS  FT

MISS DISTANCE (FT) =                      200.
NAVIGATION BUFFER (SIGMAS) =                3.00
DELAY TIME (SEC) =                          8.
BLUNDER ANGLE (DEGREES) =                  30.
BLUNDER VELOCITY (KNOTS) =                150.
NON BLUNDER VELOCITY (KNOTS) =            150.
CORRECT RATE (DEG/SEC) =                    3.00

CONTROL INTERVENTION RATE =                                 0.000200
NON-DETECTION PROBABILITY =                                 0.010000
NAVIGATION ERROR - BLUNDERER (FT) =                       150.
NAVIGATION ERROR - NONBLUNDERER (FT) =                    150.
SURVEILLANCE ERROR (FT) =                                 289.
SURVEILLANCE UPDATE (SEC) =                                 4.0

  ANGZ        DZ        DEL        CA        CB        CZ
                                  1266.     648.
  1150.      908.      1013.                           618.

   MD        NB        MISS        RS
  200.      450.
                       650.      4338.
```

APPENDIX C

REDUCED SPACING WITH INDEPENDENT PARALLEL IFR APPROACHES

This Appendix presents the analysis of required runway spacing for independent IFR parallel approaches. It is based upon the discussions of basic concepts in Appendix B.

The baseline parameter values are presented in Table C-1, based upon the Atlanta recalibration of Appendix B.3. Six cases were defined for the purposes of this paper. They are summarized in Table C-2. Case #1 is the baseline (Atlanta) case. Case #2 considers a reduction in navigation error by a factor of 1/2. This could conceivably occur by improvement in navigational (position keeping) accuracy per se. Alternatively, it could occur because advanced navigation and ATC procedures permit a reduced common path. Such reductions could be facilitated by a Microwave Landing System. ATC procedures could include use of higher glide slopes and offset runway thresholds. The factor of 1/2 improvement represents an optimistic estimate of the potential for such improvement. Case #3 considers both improved navigation and a factor of 1/2 improvement in surveillance error. As with navigation, this could occur with reduction of the length of the common path.

Cases #4 through #6 are the same as #1 through #3, except one of the aircraft is assumed to fly at a significantly lower speed. In this situation, the analysis needs to consider the differences between blunders by faster or slower aircraft. The blunder by faster aircraft turn out, not surprisingly, to be the constraining case. Additional separation is required (over equal speed case) because the slower aircraft responds to ATC commands more slowly.

For each of the six cases, 20 surveillance options are generated. These reflect surveillance systems of 5 (baseline), 4, 3, 2, 1 milliradian accuracy and 4 (baseline), 2, 1, .5 second update.

The results for the six cases are graphed in Figures C-1 through C-6. The results are tabulated in Tables C-3 through C-8. Finally, Tables C-9 through C-14 present the details of the calculations. This includes delineation of the values for detection and normal operating zones.

TABLE C-1

BASELINE PARAMETER ASSUMPTIONS

PARAMETER	VALUE
CONTROLLER INTERVENTION RATE (PER WORST 4s INTERVAL)	$2 * 10^{-4}$
MAXIMUM BLUNDER ANGLE	30 DEGREES
AIRCRAFT VELOCITIES	150 kn
NAVIGATION ERROR RATE	15 ft/nmi (.14 DEGREES)
MAXIMUM RANGE (NAVIGATION)	10 nmi
SURVEILLANCE TYPE	PRIMARY
SURVEILLANCE ERROR RATE	32 ft/nmi (.30 DEGREES, 5 MILLIRADIANS)
MAXIMUM RANGE (SURVEILLANCE)	9 nmi
DETECTION LOGIC	EXPECTED VALUE
UPDATE RATE	4s
NON-DETECTION PROBABILITY	.01
COMMUNICATIONS DELAY TIME	8s
RECOVERY TURN RATE	3 DEGREES/s
NAVIGATION BUFFER (FOR NON-BLUNDERING AIRCRAFT)	3 SIGMA
MINIMUM LATERAL MISS DISTANCE	200 ft

TABLE C-2

RUNWAY SEPARATION: SIX CASES

CASE	NAVIGATION ERROR	SURVEILLANCE ERROR	VELOCITIES (kn)
1	BL	BL	150, 150
2	1/2 BL	BL	150, 150
3	1/2 BL	1/2 BL	150, 150
4	BL	BL	150, 100
5	1/2 BL	BL	150, 100
6	1/2 BL	1/2 BL	150, 100

BL = BASELINE

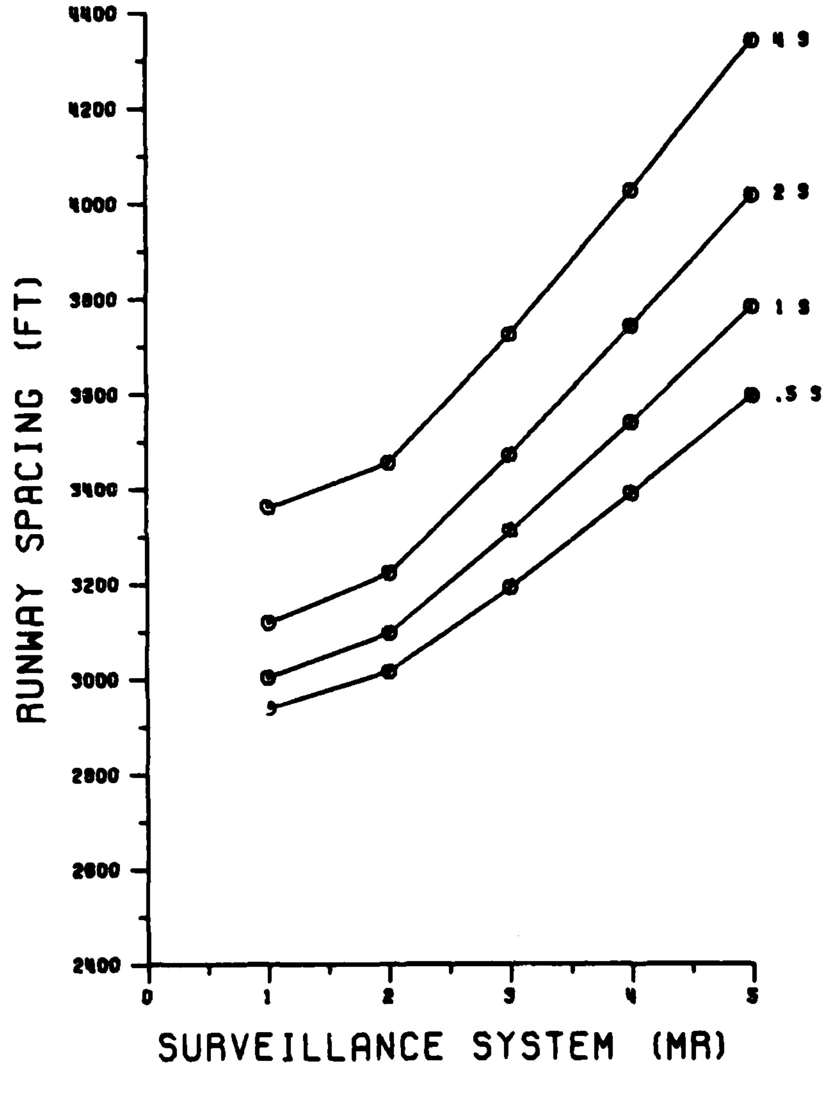


FIGURE C-1
RUNWAY SPACING—CASE #1

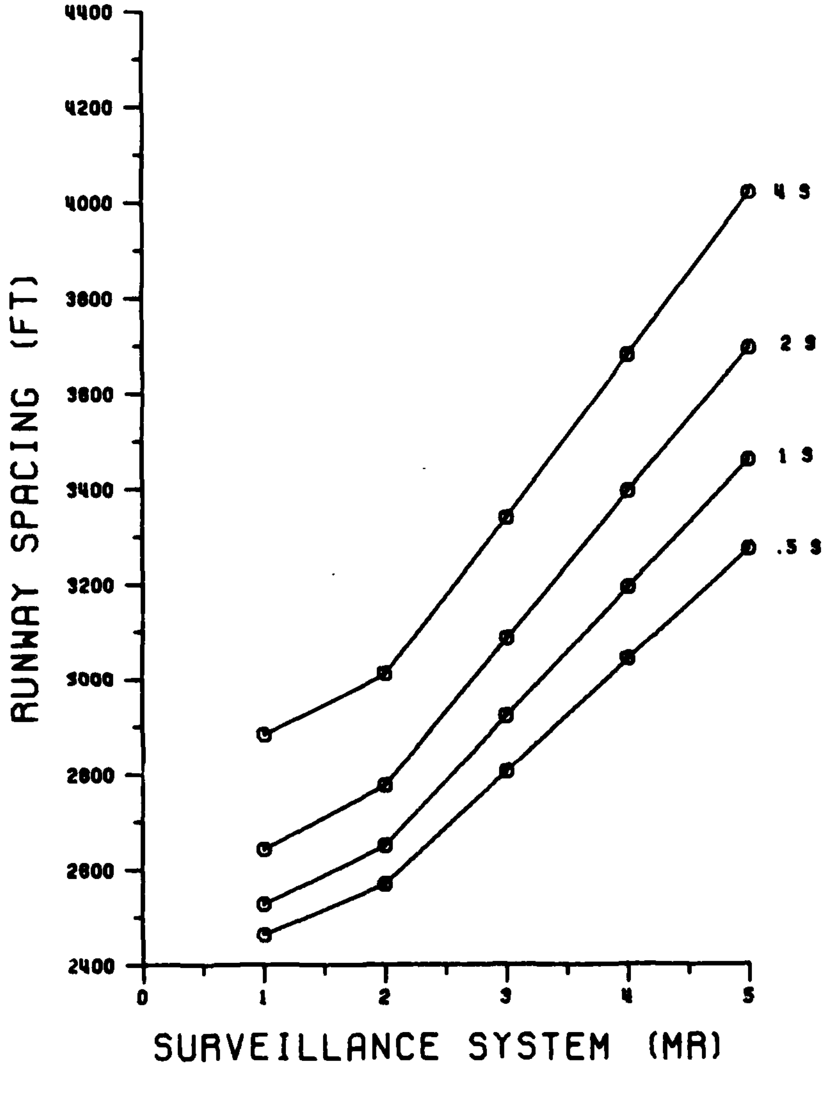


FIGURE C-2
RUNWAY SPACING—CASE #2

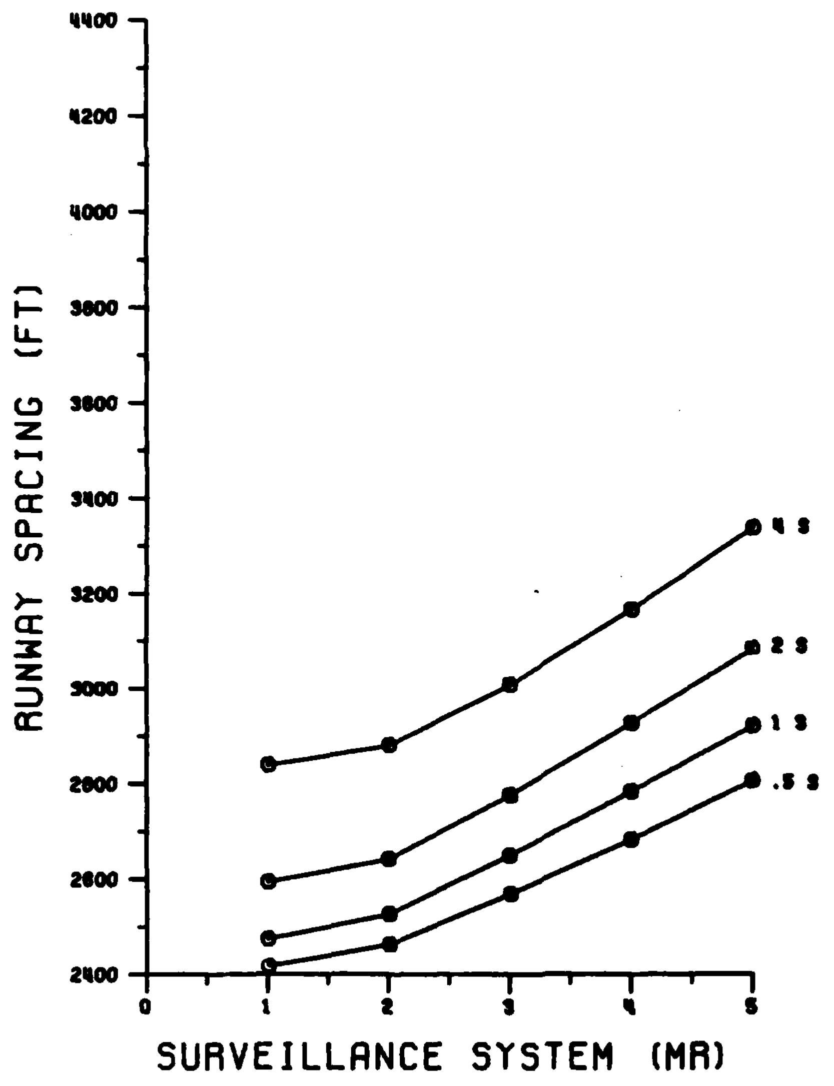


FIGURE C-3
RUNWAY SPACING—CASE #3

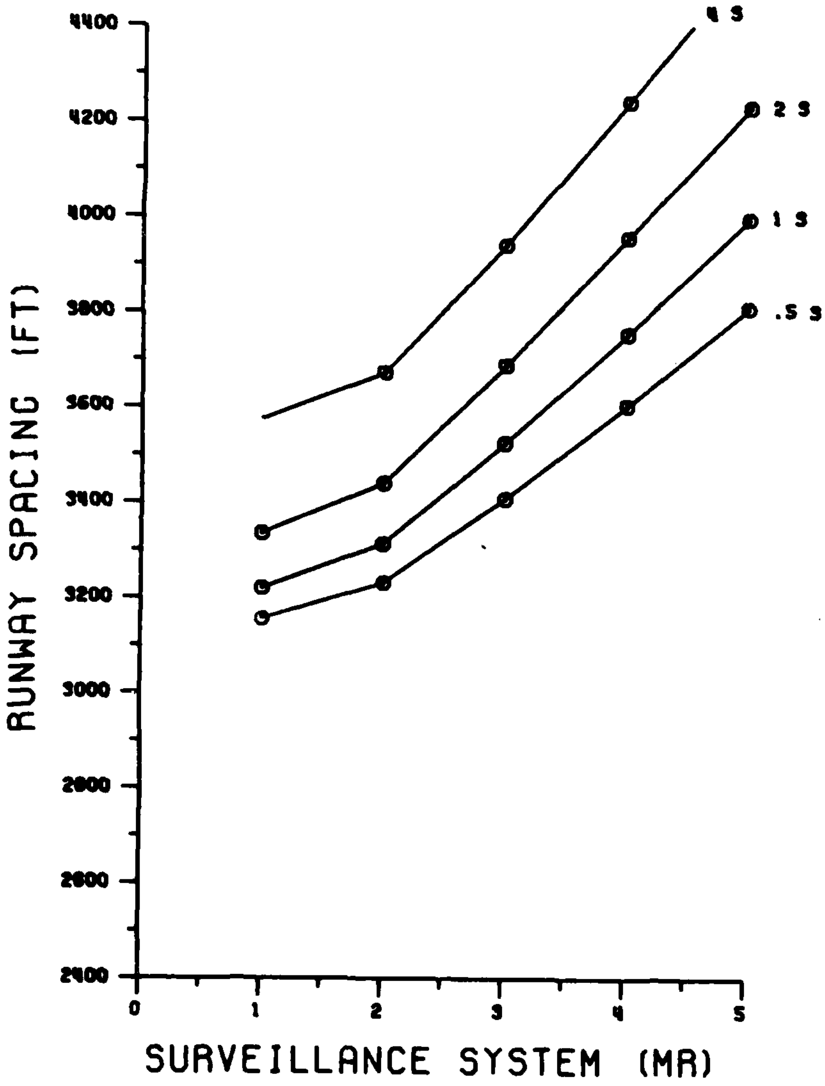


FIGURE C-4
RUNWAY SPACING—CASE #4

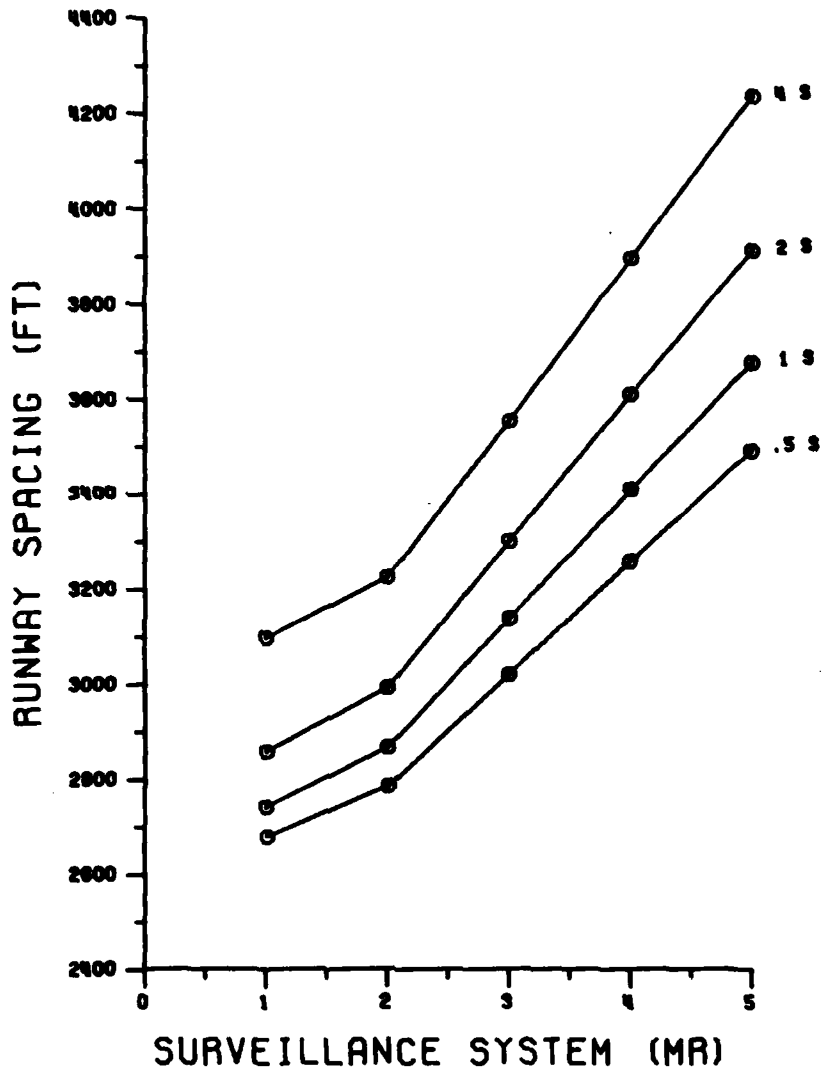


FIGURE C-5
RUNWAY SPACING—CASE #5

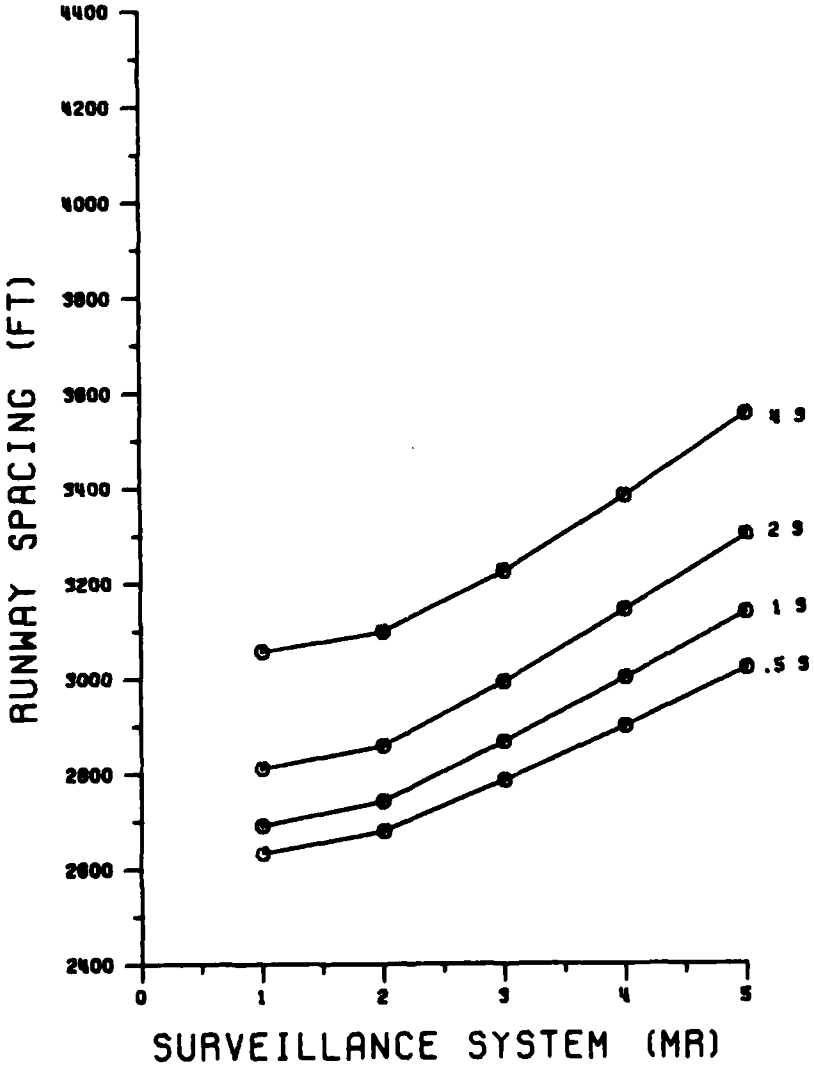


FIGURE C-6
RUNWAY SPACING—CASE #6

TABLE C-3

RUNWAY SEPARATION SUMMARY: CASE #1

NAVIGATION ERROR: BASELINE
SURVEILLANCE ERROR: BASELINE
VELOCITIES (kn): 150, 150

		UPDATE (s)			
		4	2	1	.5
SURVEILLANCE SYSTEM (mr)	5	4338	4014	3780	3594
	4	4025	3740	3538	3388
	3	3724	3471	3309	3192
	2	3455	3223	3097	3016
	1	3359	3119	3004	2940

TABLE C-4

RUNWAY SEPARATION SUMMARY: CASE #2

NAVIGATION ERROR: 50% BASELINE
SURVEILLANCE ERROR: BASELINE
VELOCITIES (kn): 150, 150

SURVEILLANCE SYSTEM (mr)	UPDATE (s) 4	2	1	.5
5	4017	3693	3459	3273
4	3678	3393	3192	3041
3	3338	3084	2922	2806
2	3009	2777	2651	2570
1	2882	2643	2527	2464

TABLE C-5

RUNWAY SEPARATION SUMMARY: CASE #3

NAVIGATION ERROR: 50% BASELINE
SURVEILLANCE ERROR: 50% BASELINE
VELOCITIES (kn): 150, 150

SURVEILLANCE SYSTEM (mr)	UPDATE (s) 4	2	1	.5
5	3338	3084	2922	2806
4	3167	2928	2785	2684
3	3009	2777	2651	2570
2	2882	2643	2527	2464
1	2840	2595	2475	2417

TABLE C-6

RUNWAY SEPARATION SUMMARY: CASE #4

NAVIGATION ERROR: BASELINE
SURVEILLANCE ERROR: BASELINE
VELOCITIES (kn): 150, 100

		UPDATE (s)			
		4	2	1	.5
SURVEILLANCE SYSTEM (mr)	5	4554	4230	3996	3810
	4	4241	3656	3754	3604
	3	3940	3687	3525	3408
	2	3671	3439	3313	3232
	1	3575	3335	3220	3156

TABLE C-7

RUNWAY SEPARATION SUMMARY: CASE #5

NAVIGATION ERROR: 50% BASELINE
SURVEILLANCE ERROR: BASELINE
VELOCITIES (kn): 150, 100

		UPDATE (s)			
		4	2	1	.5
SURVEILLANCE SYSTEM (mr)	5	4233	3909	3675	3489
	4	3894	3609	3407	3257
	3	3554	3300	3138	3021
	2	3225	2993	2867	2786
	1	3098	2859	2743	2680

TABLE C-8

RUNWAY SEPARATION SUMMARY: CASE #6

NAVIGATION ERROR: 50% BASELINE
SURVEILLANCE ERROR: 50% BASELINE
VELOCITIES (kn): 150, 100

		UPDATE (s)			
		4	2	1	.5
SURVEILLANCE SYSTEM (mr)	5	3554	3300	3138	3021
	4	3383	3144	3001	2900
	3	3225	2993	2867	2786
	2	3098	2859	2743	2680
	1	3056	2811	2691	2633

TABLE C-9

RUNWAY SEPARATIONS: CASE #1

NAVIGATION ERROR: BASELINE

SURVEILLANCE ERROR: BASELINE

VELOCITY (kn)--BLUNDERER: 150
--NON-BLUNDERER: 150

A) UPDATE INTERVAL: 4 s

SUR. (mr)	5	4	3	2	1
NOZ	1150	931	736	589	546
DZ	907	813	707	585	532
OTHER	2281	2281	2281	2281	2281
RS	4338	4025	3724	3455	3359

B) UPDATE INTERVAL: 2 s

SUR. (mr)	5	4	3	2	1
NOZ	1150	931	736	589	546
DZ	583	528	454	353	292
OTHER	2281	2281	2281	2281	2281
RS	4014	3740	3471	3223	3119

TABLE C-9
(Concluded)

C) UPDATE INTERVAL: 1 s

SUR. (mr)	5	4	3	2	1
NOZ	1150	931	736	589	546
DZ	349	326	292	227	177
OTHER	2281	2281	2281	2281	2281
RS	3780	3538	3309	3097	3004

D) UPDATE INTERVAL: .5 s

SUR. (mr)	5	4	3	2	1
NOZ	1150	931	736	589	546
DZ	163	176	175	146	113
OTHER	2281	2281	2281	2281	2281
RS	3594	3388	3192	3016	2940

TABLE C-10

RUNWAY SEPARATIONS: CASE #2

NAVIGATION ERROR: 50% BASELINE

SURVEILLANCE ERROR: BASELINE

VELOCITY (kn)--BLUNDERER: 150
--NON-BLUNDERER: 150

A) UPDATE INTERVAL: 4 s

SUR. (mr)	5	4	3	2	1
NOZ	1054	809	575	368	295
DZ	907	813	707	585	531
OTHER	2056	2056	2056	2056	2056
RS	4017	3678	3338	3009	2882

B) UPDATE INTERVAL: 2 s

SUR. (mr)	5	4	3	2	1
NOZ	1054	809	575	368	295
DZ	583	528	453	353	292
OTHER	2056	2056	2056	2056	2056
RS	3693	3393	3084	2777	2643

TABLE C-10
(Concluded)

C) UPDATE INTERVAL: 1 s

SUR. (mr)	5	4	3	2	1
NOZ	1054	809	575	368	295
DZ	349	327	291	227	176
OTHER	2056	2056	2056	2056	2056
RS	3459	3192	2922	2651	2527

D) UPDATE INTERVAL: .5 s

SUR. (mr)	5	4	3	2	1
NOZ	1054	809	575	368	295
DZ	163	176	175	146	113
OTHER	2056	2056	2056	2056	2056
RS	3273	3041	2806	2570	2464

TABLE C-11

RUNWAY SEPARATIONS: CASE #3

NAVIGATION ERROR: 50% BASELINE

SURVEILLANCE ERROR: 50% BASELINE

VELOCITY (kn)--BLUNDERER: 150
--NON-BLUNDERER: 150

A) UPDATE INTERVAL: 4 s

SUR. (mr)	5	4	3	2	1
NOZ	575	465	368	295	273
DZ	707	646	585	531	511
OTHER	2056	2056	2056	2056	2056
RS	3338	3167	3009	2882	2840

B) UPDATE INTERVAL: 2 s

SUR. (mr)	5	4	3	2	1
NOZ	575	465	368	295	273
DZ	453	407	353	292	266
OTHER	2056	2056	2056	2056	2056
RS	3084	2928	2777	2643	2595

TABLE C-11
(Concluded)

C) UPDATE INTERVAL: 1 s

SUR. (mr)	5	4	3	2	1
NOZ	575	465	368	295	273
DZ	291	264	227	176	146
OTHER	2056	2056	2056	2056	2056
RS	2922	2785	2651	2527	2475

D) UPDATE INTERVAL: .5 s

SUR. (mr)	5	4	3	2	1
NOZ	575	465	368	295	273
DZ	175	163	146	113	88
OTHER	2056	2056	2056	2056	2056
RS	2806	2684	2570	2464	2417

TABLE C-12

RUNWAY SEPARATIONS: CASES #4

NAVIGATION ERROR: 50% BASELINE

SURVEILLANCE ERROR: 50% BASELINE

VELOCITY (kn)--BLUNDERER: 100 (150)
--NON-BLUNDERER: 150 (100)

A) UPDATE INTERVAL: 4 s

SUR. (mr)	5	(5)	4	(4)	3	(3)	2	(2)	1	(1)
NOZ	1150	1150	931	931	736	736	589	589	546	546
DZ	704	907	632	813	542	707	431	585	371	532
OTHER	1521	2497	1521	2497	1521	2497	1521	2497	1521	2497
RS	3375	4554	3084	4241	2799	3940	2541	3671	2438	3575

B) UPDATE INTERVAL: 2 s

SUR. (mr)	5	(5)	4	(4)	3	(3)	2	(2)	1	(1)
NOZ	1150	1150	931	931	736	736	589	589	546	546
DZ	435	583	405	528	352	454	271	353	216	292
OTHER	1521	2497	1521	2497	1521	2497	1521	2497	1521	2497
RS	3106	4236	2857	3956	2609	3687	2381	3439	2283	3335

TABLE C-12
(Concluded)

C) UPDATE INTERVAL: 1 s

SUR. (mr)	5	(5)	4	(4)	3	(3)	2	(2)	1	(1)
NOZ	1150	1150	931	931	736	736	589	589	546	546
DZ	234	349	236	326	218	292	176	227	136	177
OTHER	1521	2497	1521	2497	1521	2497	1521	2497	1521	2497
RS	2905	3996	2688	3754	2475	3525	2286	3313	2203	3220

D) UPDATE INTERVAL: .5 s

SUR. (mr)	5	(5)	4	(4)	3	(3)	2	(2)	1	(1)
NOZ	1150	1150	931	931	736	736	589	589	546	546
DZ	71	163	102	176	118	175	109	146	88	113
OTHER	1521	2497	1521	2497	1521	2497	1521	2497	1521	2497
RS	2742	3810	2554	3604	2375	3408	2219	3232	2155	3156

TABLE C-13

RUNWAY SEPARATIONS: CASE #5

NAVIGATION ERROR: 50% BASELINE

SURVEILLANCE ERROR: BASELINE

VELOCITY (kn)--BLUNDERER: 100 (150)
--NON-BLUNDERER: 150 (100)

A) UPDATE INTERVAL: 4 s

SUR. (mr)	5	(5)	4	(4)	3	(3)	2	(2)	1	(1)
NOZ	1054	1054	809	809	575	575	368	368	295	292
DZ	704	907	632	813	542	707	431	585	371	531
OTHER	1296	2272	1296	2272	1296	2272	1296	2272	1296	2272
RS	2054	4233	2737	3894	2413	3554	2095	3225	1962	3098

B) UPDATE INTERVAL: 2 s

SUR. (mr)	5	(5)	4	(4)	3	(3)	2	(2)	1	(1)
NOZ	1054	1054	809	809	575	575	368	368	295	292
DZ	435	583	405	528	352	453	271	353	215	292
OTHER	1296	2272	1296	2272	1296	2272	1296	2272	1296	2272
RS	2785	3909	2510	3609	2223	3300	1935	2993	1806	2859

TABLE C-13
(Concluded)

C) UPDATE INTERVAL: 1 s

SUR. (mr)	5	(5)	4	(4)	3	(3)	2	(2)	1	(1)
NOZ	1054	1054	809	809	575	575	368	368	295	292
DZ	236	349	237	326	218	291	176	227	135	176
OTHER	1296	2272	1296	2272	1296	2272	1296	2272	1296	2272
RS	2584	3675	2342	3407	2089	3138	1840	2867	1726	2743

D) UPDATE INTERVAL: .5 s

SUR. (mr)	5	(5)	4	(4)	3	(3)	2	(2)	1	(1)
NOZ	1054	1054	809	809	575	575	368	368	295	292
DZ	71	163	102	176	117	174	109	146	88	113
OTHER	1296	2272	1296	2272	1296	2272	1296	2272	1296	2272
RS	2421	3489	2207	3257	1988	3021	1773	2786	1679	2680

TABLE C-14

RUNWAY SEPARATIONS: CASE #6

NAVIGATION ERROR: 50% BASELINE

SURVEILLANCE ERROR: 50% BASELINE

VELOCITY (kn)--BLUNDERER: 100 (150)
--NON-BLUNDERER: 150 (100)

A) UPDATE INTERVAL: 4 s

SUR. (mr)	5	(5)	4	(4)	3	(3)	2	(2)	1	(1)
NOZ	575	575	465	465	368	368	295	295	273	273
DZ	542	707	492	646	431	585	371	531	347	511
OTHER	1296	2272	1296	2272	1296	2272	1296	2272	1296	2272
RS	2413	3554	2253	3383	2095	3335	1962	3098	1916	3056

B) UPDATE INTERVAL: 2 s

SUR. (mr)	5	(5)	4	(4)	3	(3)	2	(2)	1	(1)
NOZ	575	575	465	465	368	368	295	295	273	273
DZ	352	453	317	407	271	353	215	292	186	266
OTHER	1296	2272	1296	2272	1296	2272	1296	2272	1296	2272
RS	2223	3300	2078	3144	1935	2993	1806	2859	1755	2811

TABLE C-14
(Concluded)

C) UPDATE INTERVAL: 1 s

SUR. (mr)	5	(5)	4	(4)	3	(3)	2	(2)	1	(1)
NOZ	575	575	465	465	368	368	295	295	273	273
DZ	218	291	203	264	176	227	135	176	108	146
OTHER	1296	2272	1296	2272	1296	2272	1296	2272	1296	2272
RS	2089	3138	1964	3001	1840	2867	1726	2743	1677	2691

D) UPDATE INTERVAL: .5 s

SUR. (mr)	5	(5)	4	(4)	3	(3)	2	(2)	1	(1)
NOZ	575	575	465	465	368	368	295	295	273	273
DZ	117	174	119	163	109	146	88	113	68	88
OTHER	1296	2272	1296	2272	1296	2272	1296	2272	1296	2272
RS	1918	3021	1880	2900	1773	2786	1679	2680	1637	2633

APPENDIX D

CONCEPTS FOR DEPENDENT PARALLEL APPROACHES

This Appendix will present a general description of dependent parallel approaches and a description of the methodology used to analyze blunders. The rationale and implications of the assumptions will also be presented.

D.1 Basic Concepts

D.1.1 Basic Concepts of Dependent Approaches

As used in this paper, the term "Dependent IFR Approaches" refers to alternating arrivals to runways closer than 4300 ft apart, using a diagonal separation between aircraft on adjacent approaches which is less than the required separation between aircraft on the same approach. This latter separation is still applied, however, in-trail. The general concept is illustrated in Figure D-1.

Current ATC procedures allow dependent approaches if the runways are at least 3000 ft apart. A 2.0 nmi separation is applied diagonally between adjacent aircraft, and 3.0 nmi is applied in-trail (with additional in-trail separation as required for vortex safety).

The 2.0 nmi separation can be applied only after the aircraft are established on the localizer. Prior to that point, there must be 3.0 nmi horizontally or 1000 ft vertically between them. This leads to the turn-on geometry shown in Figure D-2, similar to that for independent approaches.

The approach controller, who handles the turn-ons to the localizer, is also responsible for monitoring and maintaining separation between dependent arrivals. This is unlike the independent arrival case, where two monitor controllers handle the monitoring and separation tasks. Given the difficulty of properly spacing the initial turn-ons to the localizer, it might be worthwhile to consider a separate single monitor controller for dependent approaches.

The intial spacing is difficult for the following reasons. With a single arrival stream, the controller must gauge not only the separation between aircraft at the point of turn-on, but also the separation which will exist at the runway threshold. If a fast

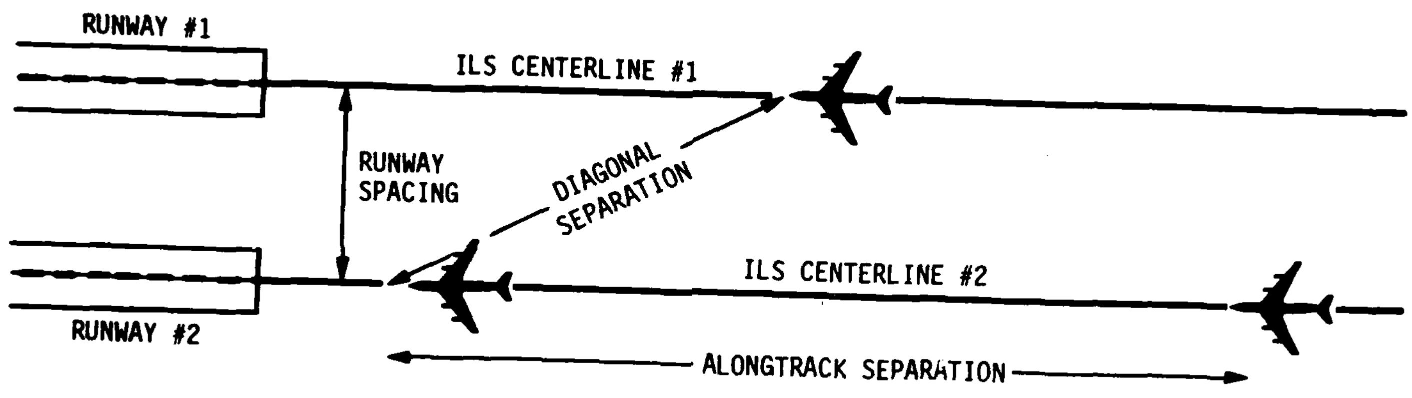


FIGURE D-1
DEPENDENT PARALLEL GEOMETRY

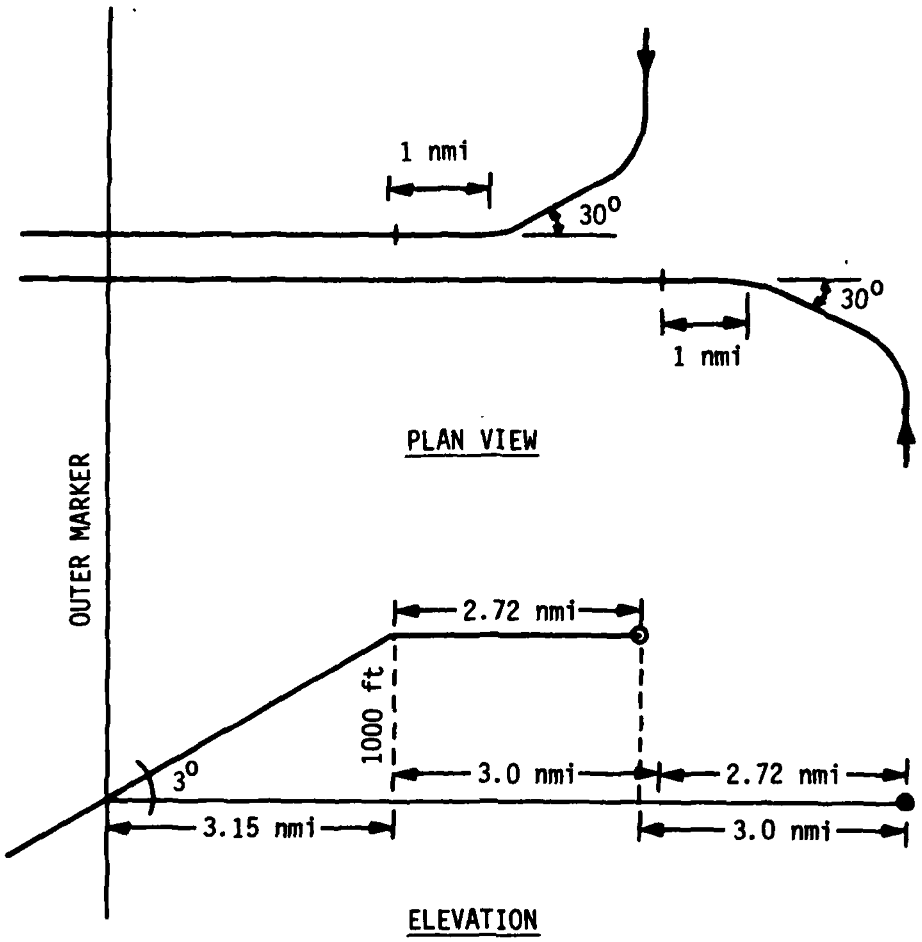


FIGURE D-2
TURN-ON GEOMETRY

aircraft is following a slow aircraft, the initial separation must be larger than the minimum to allow for the faster trail aircraft to close up the separation behind the lead aircraft. With dependent approaches, the controller must consider the speed differentials of more aircraft. Separation must be maintained between consecutive aircraft on the same approach and also between aircraft on adjacent approaches.

These factors, and others, will result in average separations between consecutive aircraft being greater than the 2.0 nmi diagonal minimum. We have assumed that this 2.0 nmi is an absolute minimum separation: if separation goes below this level, the controller must assume that a blunder has occurred.

D.1.2 Basic Concepts for Blunder Analysis

The purpose of the blunder analysis is to calculate the separation at closest approach between the blundering and non-blundering aircraft. A worst case analysis is performed; the full range of blunder errors in direction and speed is considered, and conservative assumptions are made about controller performance in order to determine the minimum expected miss distance.

The following events are assumed for each blunder:

- A blunder occurs instantaneously, with no prior warning to the controller. The blundering aircraft may deviate at any angle up to 30°, with an accompanying speed change of up to 30 knots faster or slower.

- At the start of the blunder, the two aircraft are at the minimum separation.

- The controller is not assumed to detect the blunder until such time that there is only a 1% chance that the blunder was not detected. The calculation of this probability includes considerations of radar and display errors and controller performance.

- The blunderer cannot or will not respond to control instructions, so the non-blunderer must be given an avoidance maneuver.

- The avoidance maneuver occurs at the end of the detection period plus a fixed delay time, or earlier if that leads to a smaller miss distance.

- Vertical separation may exist between the two aircraft, but only the horizontal miss distance is considered.

Given the alternating approach geometry, the blundering aircraft can endanger either the aircraft ahead of it or the one behind it on the adjacent approach, but not both. Consequently, we define two types of blunders:

- the "fast blunder," in which the lead aircraft is endangered (the blunderer accelerates and catches up to the aircraft ahead), and

- the "slow blunder," in which the trail aircraft is endangered (the blunderer slows down and cuts in front of the aircraft behind).

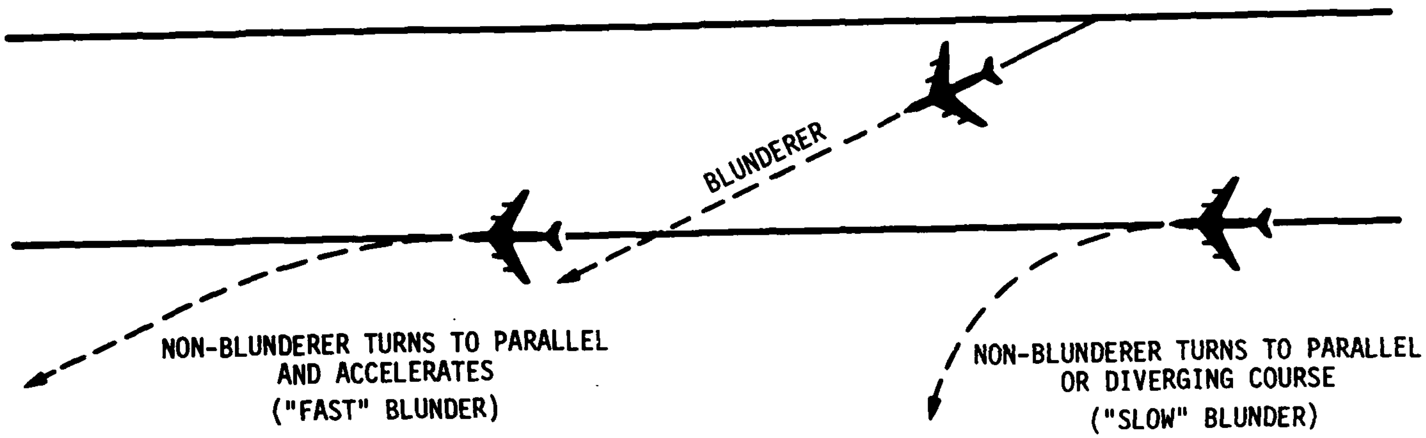
Different evasive maneuvers are postulated for the two types of blunders. For a fast blunder, the endangered aircraft turns to a course parallel to the blunderer, and then accelerates to the same speed. If it is a slow blunder, the endangered aircraft turns to a parallel or diverging course. See Figure D-3.

Other evasive maneuvers are possible and might be preferable in certain cases, but the specified maneuver has the advantage of rapidly establishing a safe situation while placing the aircraft in a favorable circumstance for being directed back into the arrival stream.

In some cases, however, a more favorable evasive maneuver is available, and this is to do nothing. For many combinations of blunder angle and speed, a turn by the non-blunderer could result in less separation than if the aircraft had not been turned. In other words, the blunderer would "shoot the gap" between aircraft on the other approach course, an outcome made more likely by the inherent geometry of alternating dependent arrivals.

D.2 Derivations

This section presents the derivation of the logic used to detect blunders with dependent approaches. It will also discuss the calculations and assumptions used to compute the miss distance between aircraft.



NOTE: BOTH NON-BLUNDERERS ARE SHOWN FOR COMPLETENESS, BUT ONLY ONE WOULD BE TURNED IN THE EVENT OF A BLUNDER.

FIGURE D-3
AVOIDANCE MANEUVERS FOR "FAST" AND "SLOW" BLUNDERS

D.2.1 Detection Logic

The scenario used for the blunder analysis assumes that the aircraft are initially at the minimum separation (2.0 nmi), and that the blunderer at that point has the assumed anglular and velocity deviations. The implications of these worst-case assumptions will be discussed below.

The detection logic calculates the time until it is virtually certain that the controller will have detected the violation of the required minimum separation, given the errors of the radar and display systems. This logic is derived from that for independent approaches (Appendix B).

The combined surveillance and display error is assumed to be

$$\text{Normal}\ (0, SE^2), \tag{17}$$

that is, normally distributed with a mean of zero and a standard deviation of SE. The value of SE used here, 1500 ft, is significantly larger than the similar measure used for independent approaches, 288 ft (32 ft/nmi * 9 nmi). The reasons for this difference are:

- we are concerned here with the relative separation between two moving aircraft, not whether an aircraft has passed a fixed boundary line, and
- we are measuring a difference in range from the radar, more so than a difference in azimuth between two objects at the same range.

Information on the range and azimuth errors of various radars may be found in Reference 17.

At any time SEC after the blunder has begun, a total loss of separation (TLS) between the blunderer and non-blunderer will have occurred, where

$$TLS = f(SEC,\ \text{blunder angle},\ \text{speed differential},\ \text{runway spacing}). \tag{18}$$

The display system will show that TLS >0 with probability

$$P = \Phi[TLS/SE], \tag{19}$$

where Φ is the cumulative distribution function operation for a normally distributed variable.

The probability that the controller detects the loss of separation is PGDP * P, where PGDP, the probability of a good data point, accounts for the controller's judgement and perception.

Since the controller will initiate the evasive action by the non-blunderer as soon as he detects that TLS > 0, we are interested in the length of time during which non-detection occurs. On the first radar scan, the probability of non-detection is

$$1 - PGDP * P_1;$$

on the second scan, UP seconds later, the probability is

$$(1 - PGDP * P_1) * (1 - PGDP * P_2),$$

and so on. The computation is continued until

$$PND \geq \prod_{i-1}^{x} (1 - PGDP * P_i) \qquad (20)$$

when PND, the final probability of non-detection, is a predefined parameter.

The computer program which performs these calculations also considers the possibility of the first radar scan occuring any time between time zero and UP seconds later. The program outputs the time after the blunder occurs at which the probability of non-detection has decreased to PND. Of course, detection has probably occurred long before this time. Additional details on the detection logic may be found in Reference 15.

D.2.2 Calculation of Miss Distances

Once the loss of separation is detected, there is an additional time lapse before the evasive maneuver actually begins. This delay is due to controller reaction time, communications time, and pilot and aircraft reaction times. The calculated detection time, plus the delay time, is considered to be the latest time at which the maneuver will begin.

A maneuver initiated at this latest time will usually result in the minimum miss distance for the given blunder. However, in certain cases, the minimum miss distance will result from an earlier maneuver. Since we are interested in the worst case miss distance, and since the maneuver will usually be initiated sooner than the latest time, these cases were of particular importance.

Given the time at which the evasive maneuver begins, calculating the position of the aircraft and the relative distance between them at any time is a simple application of the equations of motion and elementary geometry. Calculating the maneuver time which produces the minimum miss distance is more complicated. The exact equations will not be repeated here; the equations, and their derivations, may be found in Appendices C and D of Reference 15.

We can, however, describe several situations which may produce a smaller miss distance with the earlier maneuver. One of these, which arises in the "fast blunder" case, comes about when the non-blunderer turns directly into the line of flight of the faster blundering aircraft. The separation continually decreases until the non-blunderer can accelerate to the blunderer's speed.

A similar case may result if the faster aircraft passes the non-blunderer before it can accelerate to the blunderer's speed. Fortunately, no cases were seen where the non-blunderer turned onto the blunderer's line of flight and then was "passed" (i.e., collided with) by the blunderer.

Tables of miss distances for a number of blunder situations will be presented in Appendix E. The cases in which the minimum miss distance resulted from a turn at other than the latest time are noted.

D.3 Sample Problem

The computer program which performs the blunder analysis calculates the miss distance for all blunder angles (deviation from the localizer course) from 0^{o} to 30^{o}, in 3^{o} increments, and for all velocity errors from 0 to 30 kns, in 10 kn increments, both as fast and slow blunders. It then prints out a detailed report on each case. One such case will be examined here.

The case chosen involves a blunder angle of 9^{o} and a speed increase of 30 kn. These deviations produced the smallest miss distance for any fast blunder, given the same runway spacing and initial speeds. Runway spacing is 3000 ft. Both aircraft start at the same speed, 150 kn. A complete list of input values is shown in Table D-1. Detailed program output for this case is shown in Figure D-4. A plan view of the blunder, to help in understanding the program output, is shown in Figure D-5.

TABLE D-1

INPUT FOR DEPENDENT PARALLEL ANALYSIS
-- EXAMPLE CASE

VARIABLE NAME IN PROGRAM	EXPLANATION	VALUE
RS	RUNWAY SPACING	3000 ft
AS	INITIAL AIRCRAFT SEPARATION	2.0 nmi
VT	INITIAL SPEED, TRAIL AIRCRAFT	150 kn
VL	INITIAL SPEED, LEAD AIRCRAFT	150 kn
PND	PROBABILITY OF NON-DETECTION	0.01
DELAY	DELAY TIME	12s
UP	RADAR UPDATE RATE	4s
N	NUMBER OF RADAR PHASINGS PER UPDATE	8
SE	SURVEILLANCE ERROR (1 SIGMA)	1500 ft
ACCEL	ACCELERATION RATE	4 ft/s^2
PGDP	PROBABILITY OF GOOD DATA POINT	0.5
W	TURN RATE	$3^o/s$

```
BLUNDER ANGLE=   9    VELOCITY ERROR=  30    MAX CLOSING RATE=  -57.25    MISS DISTANCE=   8933.0
  TIME OF CLOSEST APPROACH (LINEAR FLIGHT)=    155.68
  TIME BLUNDERER CROSSES OPPOSING APPROACH PATH=     63.05
  DETECTION TIME=     38.95

0 LATEST TIME FOR AVOIDANCE MANEUVER=     50.95
  CLOSEST APPROACH IN LINEAR FLIGHT=   6274.1 FEET
  FINAL SEPARATION FOR AVOIDANCE MANEUVER TAKEN AT TIME=     50.95 IS    8933.0 FEET
5 NON-BLUNDERER TURNS AT TIME=     26.78 ONTO BLUNDERERS PATH WITH FINAL SEPARATION=  10182.5 FEET
```

NOTE: ALL TIMES ARE MEASURED IN SECONDS FROM THE START OF THE BLUNDER. ANGLE IS MEASURED IN DEGREES, VELOCITY ERROR IN KNOTS, CLOSING RATE IN FEET PER SECOND.

FIGURE D-4
DETAILED OUTPUT FOR EXAMPLE CASE

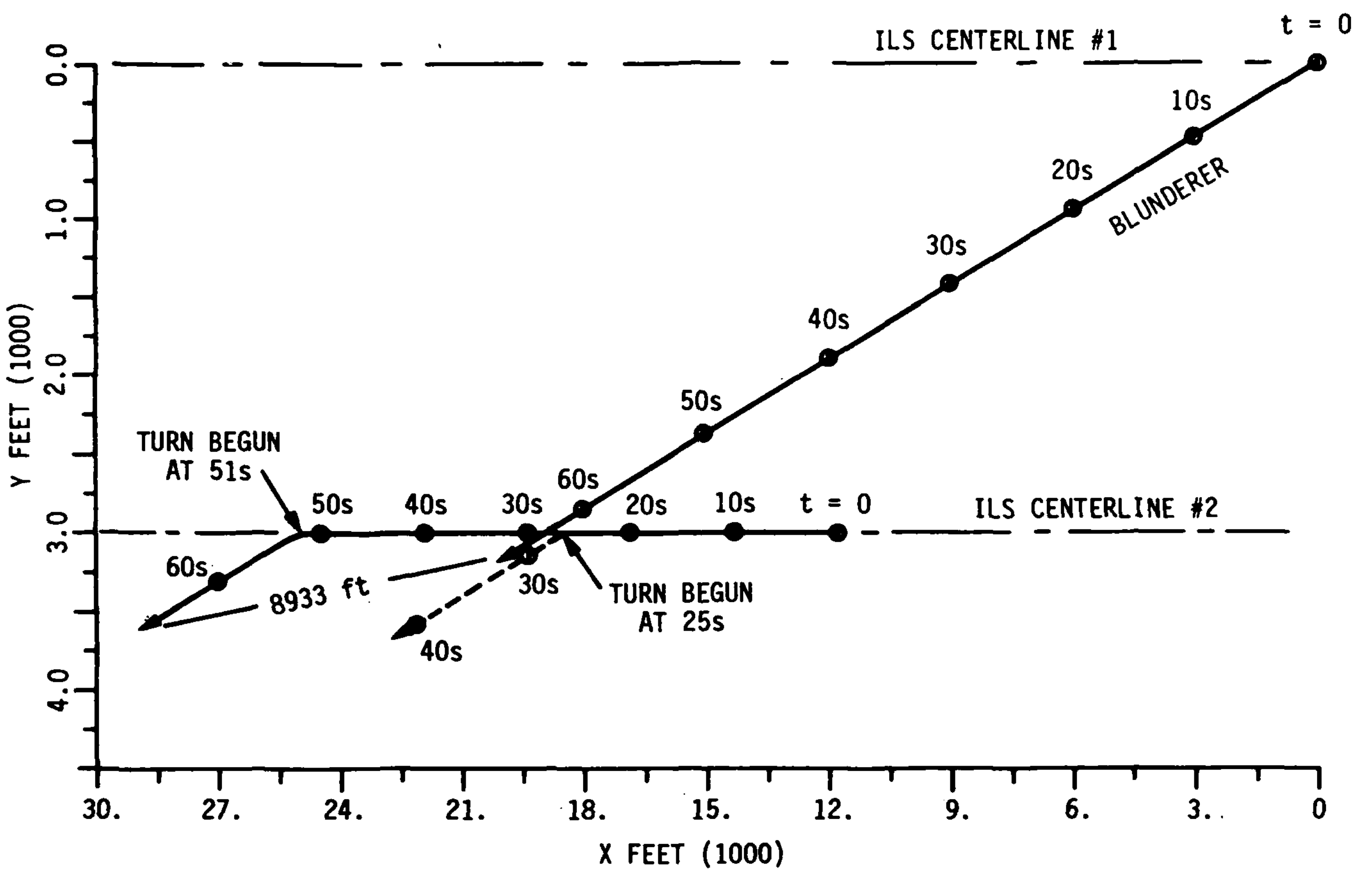


FIGURE D-5
PLAN VIEW OF EXAMPLE BLUNDER

In this fast blunder, the trail aircraft has accelerated by 30 kn, to 180 kn (line 1 in Figure D-4). It therefore endangers the aircraft ahead of it on the adjacent approach. If no evasive action is taken by the non-blunderer, the closest the two aircraft would pass would be 6274 ft, 156 s after the blunder began (lines 2 and 6).

The calculated time for the controller to detect the blunder (loss of separation) with 99% probability is 39 s (line 4). Adding the 12 s delay time, the latest time at which an avoidance maneuver would begin would be at 51 s (line 5). This gives a miss distance of 8933 ft (lines 1 and 7). This would be the worst time for the turn, since any earlier turn would result in a larger miss distance. Figure D-6 shows this with a plot of the separation between the aircraft versus time. In the plot, each curve ends at the point where the avoidance maneuver has been completed, the aircraft are on parallel courses at the same speed, and the inter-aircraft separation is constant.

An interesting case arises if the non-blunderer turns at t = 27 s. This puts the two aircraft onto the same path but with a 10,200 ft final separation (line 8).

D.4 Conservative Assumptions

In calculating the miss distance, several "worst-case" assumptions are made.

These include:

- The non-blunderer is always given a turn, even though continued linear flight might result in a greater miss distance.
- The non-blunderer may be given a turn even though the blunderer has crossed the other localizer course and the paths are diverging.

The program also assumes that the blunder occurs far enough from the runway threshold that both aircraft are airborne during the entire blunder. No consideration was made of allowing the non-blunderer to continue its approach in those cases where it would land before the point of closest approach and therefore not be endangered.

Several assumptions were embodied in the detection logic as well. For example, the "trigger" for an evasive maneuver in the dependent approach case is a violation of the minimum separation

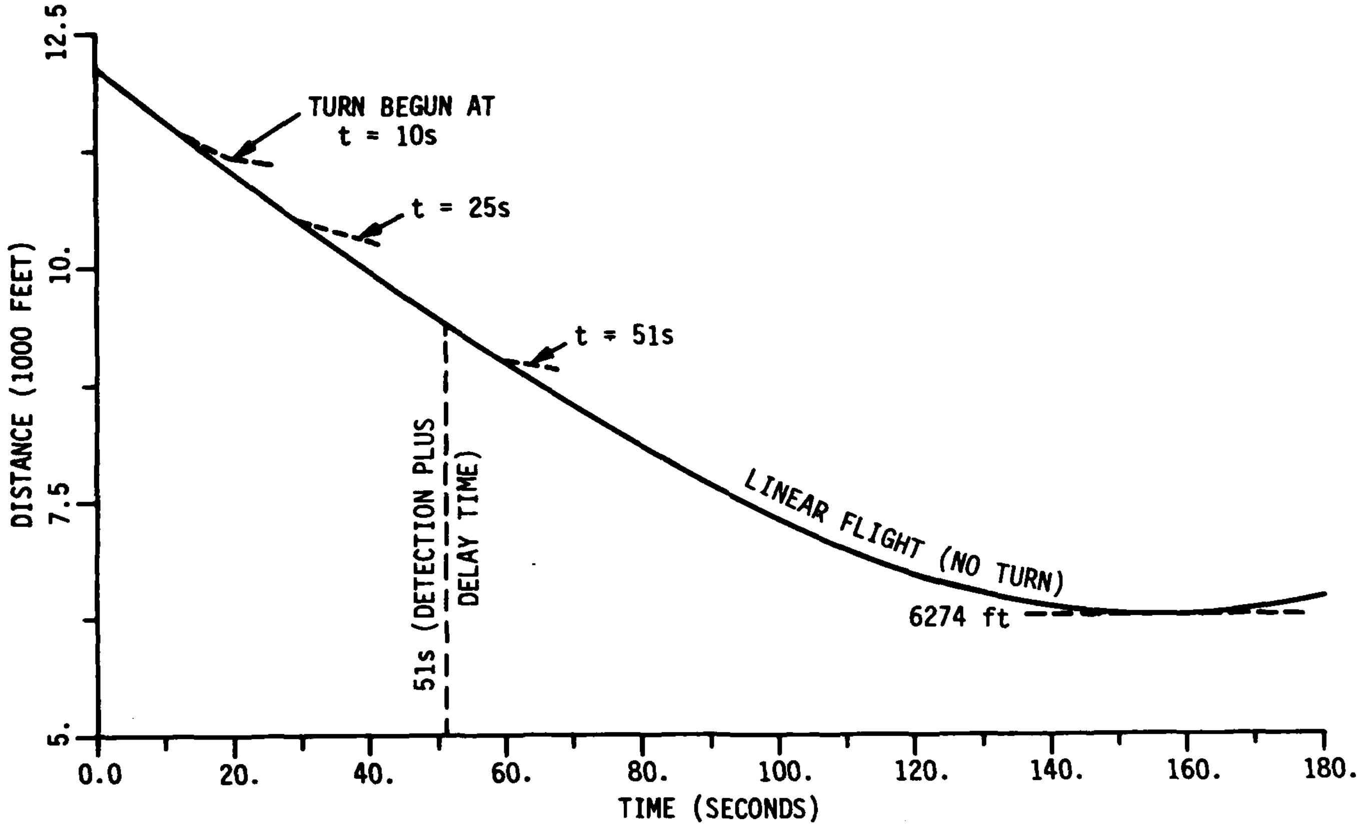


FIGURE D-6
SEPARATION DURING THE COURSE OF THE BLUNDER

between the aircraft. In the independent case, the trigger is the penetration by the blunderer of the No Transgression Zone. It was found that the separation violation criterion provided more satisfactory results for dependent approaches than would have been possible with any "No Transgression Zone." Given the accuracy of current surveillance systems, any lateral zone would have produced either an unacceptable number of false alarms or unacceptably small miss distances. This is consistent with the need for an improved surveillance system to support independent approaches at the runway spacings (on the order of 3000 ft) associated with dependent approaches.

Two assumptions of the detection logic may be questioned:

- The blunder starts with an instantaneous change of direction and speed when the aircraft are the minimum separation apart.
- The controller immediately initiates evasive maneuvers rather than other procedures to control the blunder.

These assumptions are not oversimplifications intended solely to aid the analysis; instead, they are justifiably conservative parameters.

As previously described in Section D.1.1, two aircraft are not likely to be separated exactly by the minimum required distance: extra separation results from the speed differential between aircraft or might result from the inherent inaccuracies of the ATC process. Also, the controller might add a small buffer spacing between aircraft to avoid violating the minimum. The aircraft are therefore likely to be more than 2.0 nmi apart at the start of any deviation.

A two-stage process for detecting a blunder is therefore likely in actual practice: the controller's first action upon noticing a deviation in heading or speed would be to instruct the deviating aircraft to return to its nominal path. This will focus his attention on the potentially hazardous situation, and the probability of a good data point will increase. If the deviating aircraft does not respond, and the minimum separation is violated, the controller must then issue avoidance commands to the non-blunderer.

Unfortunately, there is a real probability that the controller will not notice that the nominal separation has decreased before the minimum separation has been violated. This makes the two-stage detection process extremely difficult to model. Since two-stage detection (with a higher PGDP in the second stage) would reduce the detection time, single stage detection (that is, initiating the avoidance maneuver as soon as the violation of 2.0 nmi is detected) is a more conservative assumption.

Similarly, starting the blunder when the aircraft are the minimum separation apart is conservative. Both assumptions lead to smaller miss distances than would otherwise be the case.

One factor which has not been considered in the blunder analysis is the possibility of a wake vortex encounter during the blunder. Once the blunderer is within 2500 ft of the adjacent approach, current ATC procedures would indicate that a vortex encounter is possible. The danger of such an encounter is affected by the angle of encounter: a shallow blunder angle would lead to prolonged exposure to the vortex, and a greater chance of upset, than a larger angle which cut across the vortex quickly.

An assumption of the blunder analysis is that the blundering aircraft cannot be controlled by ATC. If the blunderer is endangered by the vortex of the lead aircraft on the other approach, there is little that ATC can do to avoid a possible vortex encounter. If a non-blundering aircraft is endangered by the vortex of the blunderer, it may be necessary to maneuver that aircraft, even if there is no danger of physical collision with the blunderer.

Fortunately, the chance of a vortex encounter is small, and the probability of a blunder is smaller still.

APPENDIX E

RESULTS OF DEPENDENT APPROACH ANALYSIS

This Appendix will present, in tabular form, the results of the blunder analysis for dependent approaches.

E.1 Miss Distance With Avoidance Turn

E.1.1 Presentation of Results

Blunder analyses were performed for angular deviations from 3° to 30° in 3° increments, and for velocity errors from 0 to 30 kn in 10 kn increments, for runway spacings of 4300 ft, 3000 ft, 2500 ft, and 1000 ft. Case 1 through 4 involved aircraft initially at the same speed (150 kn); the aircraft were at different initial speeds (110 kn and 150 kn) in cases 5 through 8. All other inputs were as listed in Table D-1.

The worst-case miss distances for these cases, as discussed in Appendix D, are presented in Tables E-1 through E-8. The results for fast and slow blunders are presented separately.

In the tables the top item in each entry is the miss distance, and the bottom item describes the type of blunder. The letter codes (A, B, and C) represent the chronological sequence of three events:

- o the time for detection and delay (called TDETECT)
- o the time at which a turn would result in the smallest miss distance (TWORST)
- o the time of closest approach in linear (non-turning) flight (TMINLF).

The three possible sequences are defined as follows:

- o A - TDETECT < TWORST ≤ TMINLF
  - the blunder is detected prior to the worst time for the turn
  - the turn is assumed to occur at TDETECT

TABLE E-1

MINIMUM MISS DISTANCE -- CASE #1

CENTERLINE SPACING: 4300 ft
VELOCITIES: 150, 150 kn

FAST BLUNDER						SLOW BLUNDER				
ANGLE	BLUNDER VELOCITY (kn)					ANGLE	BLUNDER VELOCITY (kn)			
	0	10	20	30			0	10	20	30
3	11872 A	10866 A	9968 A	9089 A		3	11826 A	10873 A	10060 A	9315 A
6	11722 A	10703 A	9774 A	8852 A		6	11546 A	10622 A	9811 A	9061 A
9	11688 A	10639 A	9681 A	8723 A		9	11294 A	10385 A	9572 A	8808 A
12	11753 C	10679 A	9693 A	8709 A		12	11061 A	10154 A	9335 A	8559 A
15	11830 C	10830 A	9817 A	8820 A		15	10839 A	9929 A	9094 A	8311 A
18	11898 C	11097 C	10061 A	9060 A		18	10627 A	9713 A	8857 A	8062 A
21	11959 C6	11342 C	10433 B	9436 A		21	10418 A	9492 A	8624 A	7801 A
24	12011 C6	11531 C	10787 C	9917 C		24	10213 A	9274 A	8392 A	7541 A
27	12056 C6	11682 C6	11062 C	10318 C		27	10010 A	9060 A	8152 A	7281 A
30	12091 C6	11805 C6	11281 C	10637 C		30	9809 B	8846 A	7913 A	7021 A

TABLE E-2

MINIMUM MISS DISTANCE -- CASE #2

CENTERLINE SPACING: 3000 ft
VELOCITIES: 150, 150 kn

FAST BLUNDER

ANGLE	BLUNDER VELOCITY (kn) 0	10	20	30
3	11978 A	10920 A	9991 A	9076 A
6	11926 A	10851 A	9893 A	8947 A
9	11975 C	10887 A	9902 A	8933 A
12	12025 C	11037 A	10023 A	9041 A
15	12067 C6	11312 C	10267 A	9278 A
18	12100 C6	11564 C	10645 B	9650 A
21	12125 C6	11738 C	11023 C	10149 B
24	12142 C6	11864 C6	11295 C	10571 C
27	12151 C6	11958 C6	11497 C6	10889 C
30	12152 [illegible]	12027 C6	11648 C6	11131 C6

SLOW BLUNDER

ANGLE	BLUNDER VELOCITY (kn) 0	10	20	30
3	11925 A	10906 A	10036 A	9229 A
6	11734 A	10731 A	9853 A	9035 A
9	11567 A	10565 A	9679 A	8845 A
12	11418 A	10412 A	9511 A	8657 A
15	11280 A	10263 A	9345 A	8473 A
18	11149 B	10119 A	9179 A	8291 A
21	11012 C	9981 A	9017 A	8112 A
24	10866 C	9844 A	8859 A	7925 A
27	10709 C	9708 A	8704 A	7739 A
30	10541 C	9574 A	8548 A	7557 A

TABLE E-3

MINIMUM MISS DISTANCE -- CASE #3

CENTERLINE SPACING: 2500 ft
VELOCITIES: 150, 150 kn

FAST BLUNDER

ANGLE	BLUNDER VELOCITY (kn) 0	10	20	30
3	12014 A	10944 A	10006 A	9083 A
6	12007 C	10911 A	9946 A	8996 A
9	12052 C	10986 A	9995 A	9026 A
12	12088 C6	11181 A	10159 A	9179 A
15	12117 C6	11482 C	10450 A	9464 A
18	12137 C6	11702 C	10867 C	9887 A
21	12149 C6	11849 C6	11209 C	10396 C
24	12152 B	11951 C6	11450 C	10782 C
27	12152 B	12022 C6	11623 C6	11067 C
30	12152 B	12072 C6	11748 C6	11280 C6

SLOW BLUNDER

ANGLE	BLUNDER VELOCITY (kn) 0	10	20	30
3	11964 A	10922 A	10031 A	9202 A
6	11809 A	10776 A	9874 A	9032 A
9	11678 A	10639 A	9725 A	8866 A
12	11563 A	10513 A	9583 A	8703 A
15	11457 C	10397 A	9448 A	8544 A
18	11342 C	10283 A	9309 A	8389 A
21	11218 C	10175 A	9175 A	8235 A
24	11083 C	10070 A	9046 A	8081 A
27	10938 C	9966 A	8920 A	7925 A
30	10783 C	9863 B	8796 A	7772 A

TABLE E-4

MINIMUM MISS DISTANCE -- CASE #4

CENTERLINE SPACING: 1000 ft
VELOCITIES: 150, 150 kn

FAST BLUNDER

ANGLE	BLUNDER VELOCITY (kn) 0	10	20	30
3	12133 C	11030 A	10077 A	9141 A
6	12147 C6	11107 A	10130 A	9180 A
9	12152 C6	11306 A	10297 A	9339 A
12	12152 M	11633 C	10591 A	9625 A
15	12152 M	11863 C	11033 B	10055 A
18	12152 M	11987 C6	11406 C	10603 C
21	12152 M	12052 C6	11638 C6	11011 C
24	12152 M	12083 C6	11782 C6	11287 C6
27	12152 M	12152 M	11870 C6	11473 C6
30	12152 M	12152 M	11921 C6	11596 C6

SLOW BLUNDER

ANGLE	BLUNDER VELOCITY (kn) 0	10	20	30
3	12085 A	10972 A	10025 A	9136 A
6	12041 C	10913 A	9946 A	9040 A
9	11994 C 99	10869 A	9875 A	8947 A
12	11936 C 99	10835 A	9813 A	8861 A
15	11870 C 99	10811 A	9759 A	8779 A
18	11793 C 99	10802 A 99	9712 A	8702 A
21	11706 C 99	10791 A 99	9670 A	8631 A
24	11609 C 99	10769 C 99	9631 A	8564 A
27	11501 C 99	10715 C 99	9596 A 99	8500 A
30	11382 C 99	10636 C 99	9567 B 99	8439 A

TABLE E-5

MINIMUM MISS DISTANCE -- CASE #5

CENTERLINE SPACING: 4300 ft
VELOCITIES: 150, 110 kn

FAST BLUNDER

ANGLE	BLUNDER VELOCITY (kn)			
	0	10	20	30
3	8248 A	7330 A	6381 A	5438 A
6	7990 A	7004 A	5978 A	4931 A
9	7810 A	6770 A	5683 A	4549 A
12	7716 A	6643 A	5519 A	4336 A
15	7717 A	6634 A	5506 A	4328 A
18	7820 A	6752 A	5656 A	4539 A
21	8028 A	7000 A	5966 A	4954 A
24	8344 A	7372 A	6423 A	5538 A
27	8769 A	7864 A	7012 A	6252 B
30	9274 B	8440 B	7656 B	6928 B

SLOW BLUNDER

ANGLE	BLUNDER VELOCITY (kn)			
	0	10	20	30
3	8605 A	7936 A	7292 A	6698 A
6	8351 A	7674 A	7033 A	6446 A
9	8097 A	7407 A	6768 A	6188 A
12	7633 A	7136 A	6496 A	5921 A
15	7564 A	6860 A	6217 A	5647 A
18	7292 A	6579 A	5933 A	5366 A
21	7017 A	6294 A	5642 A	5078 A
24	6741 A	6004 A	5344 A	4777 A
27	6462 A	5709 A	5040 A	4466 A
30	6181 A	5410 A	4725 A	4147 A

TABLE E-6

MINIMUM MISS DISTANCE -- CASE #6

CENTERLINE SPACING: 3000 ft
VELOCITIES: 150, 110 kn

FAST BLUNDER

ANGLE	BLUNDER VELOCITY (kn) 0	10	20	30
3	8169 A	7190 A	6160 A	5099 A
6	8007 A	6983 A	5901 A	4769 A
9	7930 A	6880 A	5770 A	4605 A
12	7946 A	6891 A	5785 A	4635 A
15	8061 A	7024 A	5953 A	4868 A
18	8280 A	7282 A	6273 A	5289 A
21	8605 A	7660 A	6734 A	5870 A
24	9038 A	8155 A	7322 A	6583 B
27	9559 B	8743 B	7982 B	7283 B
30	10004 C	9264 C	8553 C	7884 B

SLOW BLUNDER

ANGLE	BLUNDER VELOCITY (kn) 0	10	20	30
3	8450 A	7699 A	6966 A	6272 A
6	8251 A	7488 A	6750 A	6056 A
9	8053 A	7273 A	6530 A	5834 A
12	7850 A	7055 A	6305 A	5605 A
15	7643 A	6835 A	6075 A	5371 A
18	7434 A	6613 A	5841 A	5131 A
21	7227 A	6388 A	5603 A	4885 A
24	7019 A	6162 A	5361 A	4630 A
27	6813 A	5934 A	5115 A	4366 A
30	6607 A	5705 A	4866 A	4096 A

TABLE E-7

MINIMUM MISS DISTANCE -- CASE #7

CENTERLINE SPACING: 2500 ft
VELOCITIES: 150, 110 kn

FAST BLUNDER

ANGLE	BLUNDER VELOCITY (kn) 0	10	20	30
3	8156 A	7163 A	6112 A	5019 A
6	8032 A	7002 A	5911 A	4765 A
9	7994 A	6949 A	5844 A	4687 A
12	8052 A	7012 A	5925 A	4805 A
15	8209 A	7197 A	6157 A	5117 A
18	8471 A	7503 A	6533 A	5604 A
21	8839 A	7928 A	7045 A	6236 A
24	9317 A	8465 A	7677 A	6975 B
27	9832 C	9054 B	8322 B	7645 B
30	10244 C	9541 C	8860 C	8215 C

SLOW BLUNDER

ANGLE	BLUNDER VELOCITY (kn) 0	10	20	30
3	8399 A	7620 A	6856 A	6126 A
6	8222 A	7429 A	6658 A	5925 A
9	8045 A	7235 A	6456 A	5718 A
12	7868 A	7039 A	6250 A	5507 A
15	7685 A	6842 A	6041 A	5290 A
18	7502 A	6643 A	5829 A	5068 A
21	7321 A	6443 A	5613 A	4842 A
24	7141 A	6243 A	5394 A	4610 A
27	6962 A	6042 A	5174 A	4367 A
30	6785 A	5841 A	4951 A	4120 A

TABLE E-8

MINIMUM MISS DISTANCE -- CASE #8

CENTERLINE SPACING: 1000 ft
VELOCITIES: 150, 110 kn

FAST BLUNDER

ANGLE	BLUNDER VELOCITY (kn) 0	10	20	30
3	8173 A	7161 A	6084 A	4952 A
6	8161 A	7143 A	6064 A	4938 A
9	8242 A	7237 A	6183 A	5107 A
12	8421 A	7448 A	6446 A	5455 A
15	8702 A	7775 A	6846 A	5963 A
18	9089 A	8212 A	7373 A	6607 A
21	9586 A	8766 A	8017 A	7359 B
24	10120 C	9376 B	8681 B	8045 B
27	10531 C	9867 C	9224 C	8618 C
30	10841 C	10252 C	9662 C	9091 C

SLOW BLUNDER

ANGLE	BLUNDER VELOCITY (kn) 0	10	20	30
3	8268 A	7414 A	6564 A	5735 A
6	8157 A	7287 A	6425 A	5587 A
9	8049 A	7160 A	6285 A	5435 A
12	7944 A	7033 A	6143 A	5281 A
15	7842 A	6908 A	6000 A	5124 A
18	7740 A	6783 A	5857 A	4965 A
21	7638 A	6660 A	5713 A	4803 A
24	7540 A	6538 A	5570 A	4641 A
27	7445 A	6419 A	5427 A	4476 A
30	7353 A	6302 A	5285 A	4309 A

- o B - TWORST < TDETECT ≤ TMINLF
  - the worst time for the turn comes before the blunder is detected with high probability
  - the turn is assumed to occur at TWORST
- o C - TWORST ≤ TMINLF < TDETECT
  - the closest approach in linear flight comes before the blunder is detected with high probability
  - the turn is assumed to occur at TWORST.

There is also a letter code of N which indicates that the aircraft are not closing during the blunder.

In addition, two numeric codes are used. These are:

- o 6 - the aircraft close briefly, but the separation between them is greater than the minimum by the time the blunder is detected with high probability
- o 99 - before the blunder is detected, the blunderer has passed the non-blunderer. This is taken to be the latest time for the turn.

For the slow blunder, the minimum miss distance tends to decrease as either the angular error or the speed error increases. These changes decrease the time to closest approach in linear flight, and therefore leave less time for the avoidance maneuver to be effective (although the time for the controller to detect the blunder also decreases).

For the fast blunder, miss distance again decreases as the speed error increases, but the effect of angular deviation cannot be characterized so simply. Minimum miss distance results from a fairly shallow deviation angle ($3-9^{o}$), and increases as the angle differs above or below this value.

Even with all the worst-case assumptions which were made, the miss distances in Tables E-1 through E-8 are all quite large — greater than 7000 ft for the equal speed case, and greater than 4000 ft when the initial speeds are 150 and 110 kn. Although less than the normal separations of 2 to 6 nmi, such miss distances offer extremely large levels of safety for a rare event like a blunder. Blunders do not, therefore, seem to pose any restrictions on dependent parallel operations.

E.1.2 Acceptable Values of Miss Distance

A blunder analysis could easily be performed for dependent parallels with a reduced diagonal separation -- 1.5, or even 1.0 nmi. These would reduce the miss distances but perhaps not to unacceptable levels. Before such analyses, however, it is first necessary to determine what is an acceptable level of miss distance.

In the analysis of independent parallels, a minimum miss distance of 200 ft was assumed. Would this be adequate for dependent parallels as well?

Probably not. The independent parallel analysis was concerned solely with lateral miss distance, perpendicular to the final approach course. This was necessary because with independent approaches, the non-blundering aircraft may be at any longitudinal position relative to the blunderer. A longitudinal miss distance, therefore, cannot be computed, although it will exist for the blunder. A lateral miss distance of 200 ft is therefore acceptable because the actual miss distance will include a longitudinal separation as well.

For dependent approaches, the initial position of both aircraft is defined by the diagonal separation requirement. The total miss distance, including both lateral and longitudinal components, can thus be calculated.

Establishing comparable miss distances for the two analyses would be difficult, and may not be worthwhile. Limiting the analysis of dependent parallels to consider only the lateral miss distance would unnecessarily penalize those cases where the lateral miss distance was small, but the total miss distance was significant (if such cases exist). Calculating an expected value of the longitudinal miss distance, for the independent parallels analysis, would require consideration of the probabilistic relative location of the two aircraft. Since little data is available, any results would be tentative at best.

E.2 Detection Times

In this report the term "detection time" means the time after a blunder has begun at which there is a high probability (99%) that the controller has detected a violation of the diagonal separation standard. The logic for calculating this time, which includes consideration of surveillance system error and display error, is discussed in Appendix D.

Tables E-9 through E-16 present detection time data in seconds for several cases of dependent approaches. The numerical explanatory codes (6 and 99) were explained in Section E.1.1. In addition, a numerical code of "1" indicates that the aircraft do not close during the blunder; detection time is therefore zero.

TABLE E-9

DETECTION TIMES -- CASE #1

CENTERLINE SPACING: 4300 ft
VELOCITIES: 150, 150 kn

FAST BLUNDER

ANGLE	BLUNDER VELOCITY (kn) 0	10	20	30
3	59.53	48.74	43.07	39.47
6	56.93	47.28	42.11	38.79
9	55.51	46.47	41.48	38.34
12	55.16	46.13	41.18	38.10
15	55.71	46.26	41.19	38.07
18	57.69	46.92	41.55	38.26
21	46.70 6	48.21	42.28	38.69
24	34.98 6	50.85	43.48	39.40
27	25.83 6	50.58 6	45.67	40.63
30	18.48 6	38.80 6	49.56	42.74

SLOW BLUNDER

ANGLE	BLUNDER VELOCITY (kn) 0	10	20	30
3	58.95	48.71	43.22	39.68
6	54.87	46.70	42.02	38.94
9	51.46	44.81	40.81	38.19
12	48.62	43.17	39.69	37.44
15	46.24	41.69	38.77	36.68
18	43.95	40.21	37.85	35.95
21	42.20	39.06	36.93	35.41
24	40.44	37.96	36.04	34.86
27	39.03	36.88	35.38	34.33
30	37.74	35.88	34.74	33.81

TABLE E-10

DETECTION TIMES -- CASE #2

CENTERLINE SPACING: 3000 ft
VELOCITIES: 150, 150 kn

FAST BLUNDER

ANGLE	BLUNDER VELOCITY (kn)			
	0	10	20	30
3	61.05	49.25	43.21	39.47
6	59.56	48.37	42.69	39.10
9	59.45	48.14	42.51	38.95
12	60.69	48.58	42.68	39.03
15	43.45 6	49.74	43.21	39.35
18	28.28 6	51.74	44.20	39.92
21	17.41 6	55.65	46.13	41.10
24	9.23 6	41.82 6	49.22	42.86
27	2.85 6	28.94 6	49.45 6	45.84
30	0.00 1	19.10 6	36.40 6	49.39 6

SLOW BLUNDER

ANGLE	BLUNDER VELOCITY (kn)			
	0	10	20	30
3	60.26	49.11	43.25	39.57
6	57.10	47.50	42.37	39.03
9	54.29	46.10	41.45	38.47
12	51.64	44.61	40.49	37.87
15	49.39	43.30	39.63	37.26
18	47.23	42.07	38.86	36.63
21	45.30	40.81	38.06	35.99
24	43.46	39.64	37.25	35.51
27	41.88	38.65	36.44	35.02
30	40.26	37.64	35.73	38.53

TABLE E-11

DETECTION TIMES -- CASE #3

CENTERLINE SPACING: 2500 ft
VELOCITIES: 150, 150 kn

FAST BLUNDER

ANGLE	BLUNDER VELOCITY (kn) 0	10	20	30
3	61.68	49.48	43.29	39.50
6	60.73	48.91	42.94	39.25
9	61.29	49.01	42.95	39.23
12	46.94 6	49.80	43.30	39.43
15	28.01 6	51.36	44.06	39.89
18	15.37 6	54.39	45.65	40.85
21	6.31 6	48.93 6	47.98	42.35
24	0.00 1	32.63 6	52.54	44.62
27	0.00 1	20.69 6	41.82 6	48.92
30	0.80 1	11.61 6	29.39 6	42.94 6

SLOW BLUNDER

ANGLE	BLUNDER VELOCITY (kn) 0	10	20	30
3	60.90	49.29	43.29	39.56
6	58.10	47.84	42.54	39.10
9	55.44	46.63	41.74	38.61
12	53.09	45.32	40.88	38.08
15	50.88	43.95	39.99	37.52
18	48.75	42.85	39.29	36.94
21	46.84	41.69	38.55	36.34
24	44.98	40.47	37.79	35.80
27	43.27	39.42	37.01	35.33
30	41.73	38.46	36.23	34.86

TABLE E-12

DETECTION TIMES -- CASE #4

CENTERLINE SPACING: 1000 ft
VELOCITIES: 150, 150 kn

FAST BLUNDER

ANGLE	BLUNDER VELOCITY (kn)			
	0	10	20	30
3	63.54	50.25	43.64	39.70
6	27.51 6	50.64	43.82	39.81
9	2.36 6	51.74	44.49	40.21
12	0.00 1	54.12	45.78	41.05
15	0.00 1	58.29	47.68	42.32
18	0.00 1	36.61 6	51.14	44.13
21	0.00 1	17.92 6	52.02 6	47.44
24	0.00 1	5.21 6	32.84 6	52.75 6
27	0.00 1	0.00 1	18.89 6	36.20 6
30	0.00 1	0.00 1	8.42 6	23.48 6

SLOW BLUNDER

ANGLE	BLUNDER VELOCITY (kn)			
	0	10	20	30
3	62.77	49.94	43.51	39.64
6	61.36	49.24	43.15	39.41
9	59.81	48.42	42.71	39.13
12	58.41	47.61	42.21	38.81
15	56.76	46.80	41.64	38.44
18	55.13	45.88	41.00	38.03
21	53.42	44.84	40.31	37.58
24	51.56	43.77	39.66	37.10
27	49.82	42.82	39.04	36.58
30	47.87	41.78	38.37	36.04

TABLE E-13

DETECTION TIMES -- CASE #5

CENTERLINE SPACING: 4300 ft
VELOCITIES: 150, 110 kn

FAST BLUNDER				
ANGLE	BLUNDER VELOCITY (kn)			
	0	10	20	30
3	37.24	35.43	34.18	33.14
6	36.72	35.08	33.86	32.86
9	36.36	34.83	33.63	32.65
12	36.13	34.67	33.48	32.52
15	36.03	34.59	33.41	32.45
18	36.07	34.61	33.41	32.45
21	36.25	34.71	33.49	32.50
24	36.57	34.91	33.66	32.64
27	37.08	35.22	33.91	32.85
30	37.79	35.66	34.29	33.16

SLOW BLUNDER				
ANGLE	BLUNDER VELOCITY (kn)			
	0	10	20	30
3	37.35	35.56	34.34	33.32
6	36.76	35.22	34.07	33.12
9	36.17	34.86	33.80	32.91
12	35.68	34.50	33.52	32.70
15	35.23	34.15	33.24	32.48
18	34.78	33.79	32.96	32.27
21	34.33	33.43	32.68	32.05
24	33.89	33.08	32.41	31.88
27	33.46	32.74	32.13	31.72
30	33.04	32.40	31.90	31.56

TABLE E-14

DETECTION TIMES -- CASE #6

CENTERLINE SPACING: 3000 ft
VELOCITIES: 150, 110 kn

FAST BLUNDER

ANGLE	BLUNDER VELOCITY (kn) 0	10	20	30
3	37.11	35.30	34.03	32.98
6	36.81	35.10	33.85	32.82
9	36.66	34.99	33.75	32.73
12	36.65	34.98	33.73	32.71
15	36.79	35.06	33.79	32.76
18	37.07	35.23	33.93	32.87
21	37.53	35.52	34.18	33.07
24	38.19	35.93	34.53	33.37
27	39.08	36.66	35.01	33.78
30	40.34	37.69	35.68	34.35

SLOW BLUNDER

ANGLE	BLUNDER VELOCITY (kn) 0	10	20	30
3	37.15	35.37	34.12	33.09
6	36.72	35.12	33.93	32.95
9	36.27	34.86	33.73	32.79
12	35.85	34.58	33.51	32.63
15	35.49	34.29	33.29	32.46
18	35.11	33.98	33.05	32.28
21	34.73	33.68	32.82	32.10
24	34.34	33.37	32.57	31.94
27	33.94	33.06	32.33	31.80
30	33.55	32.75	32.09	31.65

TABLE E-15

DETECTION TIMES -- CASE #7

CENTERLINE SPACING: 2500 ft
VELOCITIES: 150, 110 kn

FAST BLUNDER

ANGLE	BLUNDER VELOCITY (kn) 0	10	20	30
3	37.16	35.30	34.00	32.94
6	37.21	35.33	34.02	32.96
9	37.41	35.45	34.13	33.05
12	37.77	35.69	34.33	33.21
15	38.31	36.04	34.63	33.47
18	39.06	36.69	35.05	33.83
21	40.06	37.56	35.62	34.33
24	41.79	38.72	36.50	35.00
27	44.06	40.32	37.86	35.88
30	48.02	43.01	39.67	37.45

SLOW BLUNDER

ANGLE	BLUNDER VELOCITY (kn) 0	10	20	30
3	37.11	35.28	34.00	32.94
6	36.92	35.17	33.91	32.88
9	36.70	35.04	33.81	32.81
12	36.44	34.88	33.69	32.71
15	36.14	34.71	33.55	32.61
18	35.86	34.50	33.39	32.49
21	35.59	34.29	33.22	32.36
24	35.30	34.05	33.04	32.22
27	34.98	33.80	32.85	32.07
30	34.65	33.54	32.64	31.94

TABLE E-16

DETECTION TIMES -- CASE #8

CENTERLINE SPACING: 1000 ft
VELOCITIES: 150, 110 kn

FAST BLUNDER

ANGLE	BLUNDER VELOCITY (kn)			
	0	10	20	30
3	37.09	35.28	34.00	32.95
6	36.88	35.13	33.87	32.84
9	36.82	35.08	33.82	32.79
12	36.90	35.13	33.85	32.81
15	37.12	35.27	33.97	32.90
18	37.51	35.51	34.18	33.08
21	38.10	35.88	34.49	33.34
24	38.89	36.51	34.93	33.71
27	39.95	37.44	35.52	34.22
30	41.81	38.68	36.42	34.92

SLOW BLUNDER

ANGLE	BLUNDER VELOCITY (kn)			
	0	10	20	30
3	37.11	35.33	34.07	33.03
6	36.75	35.11	33.90	32.91
9	36.35	34.88	33.73	32.78
12	35.95	34.63	33.53	32.63
15	35.62	34.37	33.33	32.47
18	35.27	34.09	33.12	32.31
21	34.91	33.81	32.89	32.14
24	34.54	33.51	32.67	31.98
27	34.17	33.21	32.43	31.84
30	33.79	32.91	32.20	31.71

APPENDIX F

DIFFERENCES BETWEEN INDEPENDENT AND DEPENDENT

APPROACH ANALYSES

In this report, the methods used to analyze independent and dependent parallel IFR approaches have been described and the results discussed. The differences in the concepts and geometries of independent and dependent approaches have led to differences in the assumptions, and occasionally the methodologies, of the two analyses.

Some of these differences have been discussed in previous sections. For ease of reference, however, the principal differences have been summarized in Table F-1; the following sections will briefly discuss the reasons why the differences exist.

F.1 Method of Analysis

Both analyses involve the resulting miss distance after a blunder has been detected and an avoidance maneuver has been executed. For independent approaches the resulting miss distance is an input item, and required runway spacing is an output of the analysis; the reverse is true for the dependent approach analysis.

The reason for this is not significant to the analysis. The initial formulation of the blunder analysis problem is simpler if the runway spacing is specified, and miss distance is to be calculated. The independent approach analysis was also done this way initially. The analysis was then reformulated when the emphasis shifted from implications of existing procedures to requirements for revised procedures.

F.2 Blunder "Trigger"

As discussed in Section D.4, different criteria are used for deciding that a blunder has occurred. An independent approach is termed a blunder if it crosses into the No Transgression Zone (NTZ) between the two runways. The azimuth accuracy of current surveillance systems does not allow the use of such "No Transgression Zones" with dependent approaches; instead, the violation of the diagonal separation between adjacent aircraft is used as a trigger for detecting a blunder and starting the avoidance maneuver.

TABLE F-1

SUMMARY OF DIFFERENCES BETWEEN INDEPENDENT AND DEPENDENT APPROACH ANALYSES

	INDEPENDENT PARALLELS	DEPENDENT PARALLELS
METHOD OF ANALYSIS	SPECIFIY MISS DISTANCE, CALCULATE RUNWAY SPACING	SPECIFY RUNWAY SPACING, CALCULATE MISS DISTANCE
BLUNDER "TRIGGER"	VIOLATION OF NTZ (LATERAL BOUNDARY)	VIOLATION OF SEPARATION (MAINLY LONGITUDINAL)
INPUTS TO ANALYSIS	AZIMUTH ERROR (RADAR AND DISPLAY)	COMBINED RANGE & AZIMUTH ERROR (MOSTLY DISPLAY)
	LATERAL NAVIGATION ERROR	NOT IMPORTANT
	FALSE ALARM RATE	NOT EXPLICITLY CONSIDERED
	PGDP* = 1.0 (IMPLICIT) - 2 MONITOR CONTROLLERS	PGDP* = 0.5 (INPUT) - NO SEPARATE MONITORS
	8 s CONTROL DELAY	12 s CONTROL DELAY
MISS DISTANCE	ONE-DIMENSIONAL (LATERAL)	TWO-DIMENSIONAL (COMBINED LATERAL AND LONGITUDINAL)

*PROBABILITY OF GOOD DATA POINT (PROBABILITY GOOD RADAR RETURN WILL BE DISPLAYED AND RECOGNIZED BY THE CONTROLLER)

F.3 Inputs to Analysis

Several of the inputs to the blunder analyses differ between the two cases because of the use of the different triggers. Since the lateral deviation from the centerline is the indication of a blunder in the independent approach case, the lateral (azimuth) error of the radar and display is an input. For dependent approaches, the diagonal separation between the aircraft is significant; although there is a lateral component to this separation, it is principally a longitudinal measure. A combination of the radar range error and longitudinal display error is, therefore, input to the dependent approach analysis.

One factor in the calculation of runway spacing for independent approaches is the size of the Normal Operating Zone (NOZ). For this calculation, the lateral navigation error and the acceptable rate of false alarms (for excursions beyond the NOZ) are required. The dependent approach calculations do not need to consider a lateral NOZ since a longitudinal trigger is used, and any longitudinal NOZ would not affect the runway spacings.

Other differences in the inputs reflect the different procedures for independent and dependent approaches. For example, two monitor controllers are required for independent (but not dependent) approaches. With this level of attention to the radar displays, we assumed that any displayed penetration of the NTZ would be detected immediately. For dependent approaches without a separate monitor, we had to recognize explicitly that the approach controller's attention would at times be directed elsewhere; for this reason, we assigned a value of 0.5 to the parameter PGDP (Probability of a Good Data Point). Further discussion of this parameter may be found in Section D.2.

The lack of a separate monitoring position also leads to a difference in the delay times used in the calculations. We have assumed 8s for the monitor controller to contact the non-blundering aircraft and issue the avoidance instructions, and for the pilot and aircraft to respond. For dependent approaches we assumed that the controller would wait for the next update, 4s later, to verify that a blunder has actually occurred.

F.4 Miss Distance

The difference between the miss distances used in the two cases has been extensively discussed in Section E.1.2. To summarize, only the lateral component of the miss distance is considered in the case of independent approaches -- a longitudinal component exists as well but is not relevant to the calculation. The dependent approach analysis explicitly considers the two-dimensional (lateral and longitudinal) miss distances involved because the initial lateral and longitudinal positions of the aircraft are known.

APPENDIX G

ACRONYMS AND ABBREVIATIONS

ATC	--	Air Traffic Control
ASR	--	Airport Surveillance Radar
ATL	--	Atlanta International Airport (Hartsfield)
BL	--	baseline
CZ	--	control zone
CL	--	centerline
DZ	--	detection zone
E&D	--	Engineering and Development
FAA	--	Federal Aviation Administration
ft	--	foot
IFR	--	Instrument Flight Rules
ILS	--	Instrument Landing System
IMC	--	Instrument Meteorological Conditions
JFK	--	John F. Kennedy International Airport, New York
kn	--	knot
LAX	--	Los Angeles International Airport
M&S	--	Metering and Spacing
MISS	--	miss distance zone
MLS	--	Microwave Landing System
mr	--	milliradian
nmi	--	nautical mile
NOZ	--	Normal Operating Zone
NTZ	--	No Transgression Zone
PAR	--	Precision Approach Radar
PGDP	--	Probability of a Good Data Point
PVD	--	Plan View Display
s	--	second
VFR	--	Visual Flight Rules
VMC	--	Visual Meteorological Conditions

APPENDIX H

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