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SURVEY OF 101 U.S. AIRPORTS FOR NEW MULTIPLE INSTRUMENT APPROAC--ETC(U)

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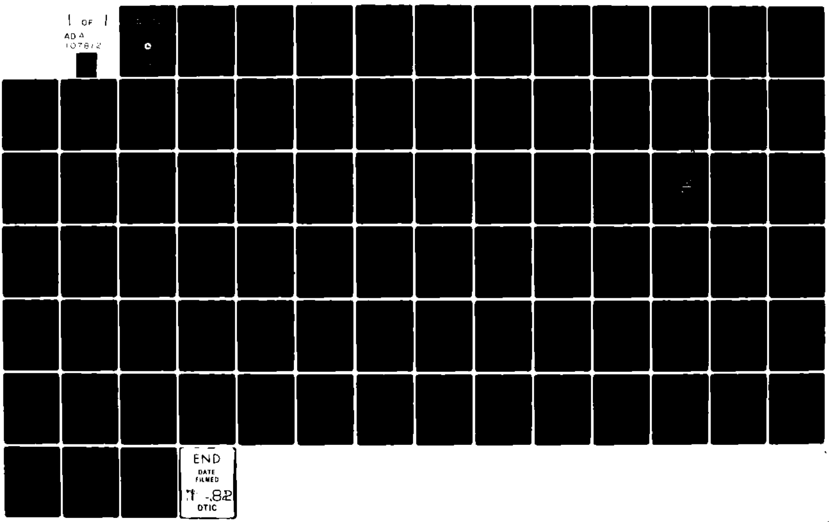

Report No. FAA-EM-82-3 MTR-81W234

LEVEL II

(12)

SURVEY OF 101 U.S. AIRPORTS FOR NEW MULTIPLE INSTRUMENT APPROACH CONCEPTS

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SEPTEMBER 1981

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
OFFICE OF SYSTEMS ENGINEERING MANAGEMENT
Washington, D.C. 20591

N O T I C E

Technical Report Documentation Page

1. Report No. FAA-EM-82-3	2. Government Accession No. AD-A107 812	3. Recipient's Catalog No.
4. Title and Subtitle Survey of 101 U.S. Airports for New Multiple Instrument Approach Concepts		5. Report Date September 1981 6. Performing Organization Code
7. Author(s) L. C. Newman, Dr. T. N. Shimi, W. J. Swedish		8. Performing Organization Report No. MTR-81W234
9. Performing Organization Name and Address The MITRE Corporation Metrek Division 1820 Dolley Madison Blvd. McLean, VA 22102		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFA01-81-C-10001
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Office of Systems Engineering Management Washington, DC 20591		13. Type of Report and Period Covered 14. Sponsoring Agency Code AEM-100
15. Supplementary Notes		

16. Abstract

Several new concepts for multiple instrument approaches have been proposed to improve capacity and reduce delays at U.S. airports. The concepts include:

- dependent parallel approaches at reduced runway spacing,
- independent parallel approaches at reduced runway spacing,
- converging approaches,
- triple approaches.

One of the runways involved may be a separate short runway for general aviation and commuter traffic.

A survey of 101 top U.S. airports was performed to determine the potential for applying the concepts to the existing runways. Specific applications of each relevant concept are provided. Calculations were performed for the top 30 U.S. air carrier airports to determine the actual delay improvement which could be expected to result from application of the multiple-approach concepts. Additionally, some general results are obtained for the remaining 71 airports.

17. Key Words Airports, Capacity, ATC Procedures, Multiple Approaches		18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, VA 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGEMENTS

The authors would like to thank Dr. John D. Garner, for his assistance in surveying the 101 airports for applicability of the new concepts; Frank A. Amodeo, for his help in modifying the MIT "DELAYS" model to run at MITRE; and to Julie M. Hargroves, for her technical editing of this report.

EXECUTIVE SUMMARY

INTRODUCTION

The Federal Aviation Administration has long recognized the problems of inadequate airport capacity and increasing delays. The report of the Air Traffic Control Advisory Committee (ATCAC) in 1969 concluded that the critical capacity problem affected arrivals during Instrument Flight Rules (IFR) conditions, and recommended reducing IFR separation standards.

Subsequent FAA efforts included the formation of specific Airport Capacity Improvement Task Forces to evaluate airport capacity and delays and the development of Metering and Spacing systems, wake vortex sensing systems, and the Microwave Landing System. However, most of the proposed capacity improvements would require large capital investments which may be difficult to fund.

An attractive alternative to new runways or new technology is the use of new procedures to conduct multiple IFR approaches to existing runways. These concepts include dependent and independent parallel approaches at reduced runway centerline spacings, converging approaches, and triple approaches. One hundred and one top U.S. airports were surveyed for the applicability of these concepts to existing runway layouts; in addition, the effect of these concepts on arrival capacity and delay has been calculated.

DESCRIPTION OF CONCEPTS

The concepts considered in this study deal with procedures for Category I approaches (Decision Height not less than 200 ft) to various runway geometries. All of the concepts utilize multiple approach streams. Requirements and procedures have been developed in several previous reports.

Dependent Parallel Approaches

At the present time, dependent alternating arrivals with a 2.0 nmi diagonal separation may be conducted to runways spaced as close as 3000 ft apart. For runways spaced from 2500 ft to 2999 ft, a 3 nmi diagonal separation is required. For spacing below 2500 ft, the need for protection from the effects of wake vortices dictates diagonal separation that varies by size of aircraft.

The new concept of dependent parallel approaches extends the use of 2.0 nmi diagonal separation to runways as close as 1000 ft apart. This is felt to be potentially feasible for the following reasons:

- An analysis of such dependent parallel approaches has shown that blunders are not a critical obstacle to reducing the runway spacing.
- Secondly, a recent study indicates that a combination of operational procedures (different glide slope angles, etc.) can be used to overcome the wake vortex problem.

Independent Parallel Approaches

At the present time, independent approaches may be made to parallel runways (less than 15° deviation from parallel is considered parallel) if the runways are at least 4300 ft apart.

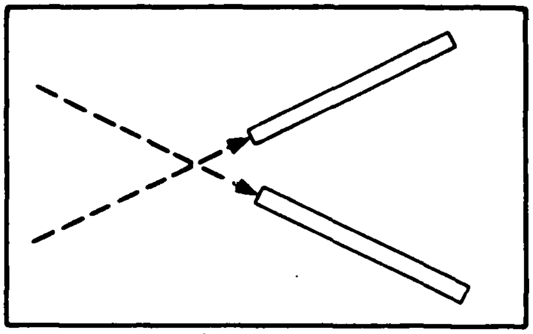
The new concept involves decreasing the required runway separation for independent arrivals to 3000 ft. This can most likely be achieved with an improved radar system (1 milliradian azimuth accuracy, 1 second update). A gain in capacity results from the treatment of arrivals as two independent streams.

Converging Approaches

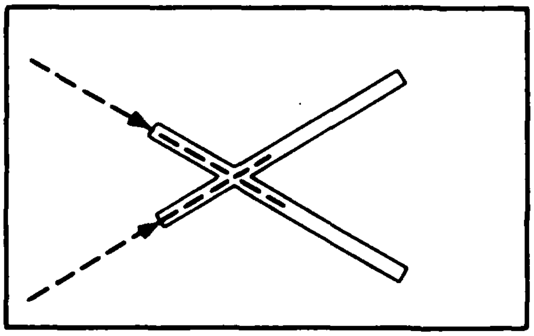
For the purposes of this study the Terminal Instrument Procedures definition of "converging" is accepted: runways with an included angle greater than 15°. Two runways that diverge by more than 100° are unlikely to be used together because of the effect of wind -- if there is a headwind on one runway, there would probably be a tailwind on the other.

Converging approaches have been considered for runways with an included angle between 15° and 100°. There are three general categories of converging approaches.

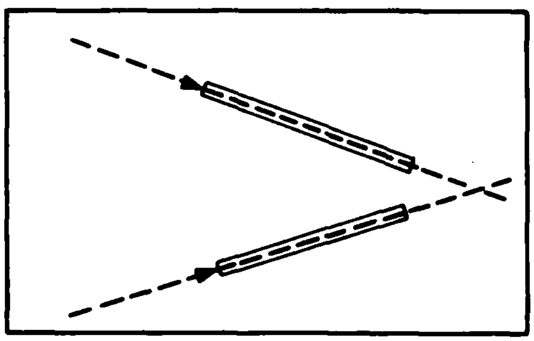
Converging approaches in which the final approaches must intersect (Figure A.a) would be most difficult to operate safely during any condition. There is no precedent for this



a. Intersecting Approaches



b. Intersecting Runways



c. Converging Runway (Extended) Centerlines

FIGURE A
TYPES OF CONVERGING APPROACHES

operation during VFR conditions. Such geometries were not considered feasible for converging operations.

Independent operation of converging runways that physically intersect (Figure A.b) pose two kinds of problems: the possibility of collision between two aircraft on the ground, and the possibility of collision during simultaneous missed approaches. Neither problem by itself would prevent the independent operation of intersecting runways; however, the presence of two problems makes intersecting runways less likely candidates for independent converging approaches.

Those runways in which the extended centerlines intersect or a variation, in which the extended centerline of one runway intersects the other runway, present only simultaneous missed approach problems (Figure A.c). Because this category is the least complex, such an application of the converging concept was preferred.

Adequate separation between missed approaches can be attained by application of criteria which account for variations in missed approach performance. These criteria have been applied to the candidate configurations to determine whether independent converging approaches are feasible.

This study considers two categories of converging approaches:

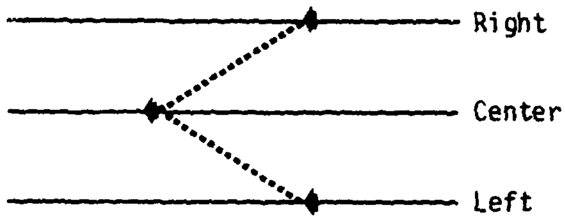
- Dependent approaches to intersecting runways, or to non-intersecting runways with unfavorable geometries

- Independent approaches to favorable non-intersecting runways, or to intersecting runways with "hold-short" procedures

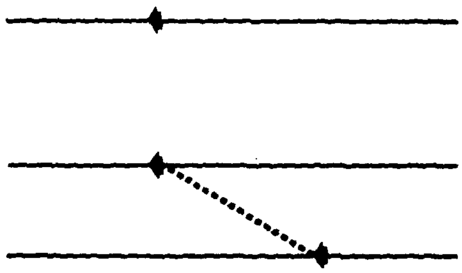
Independent and Dependent Triple Approaches

A logical combination of the first three concepts could result in the use of three runways simultaneously. Currently, no airport has three parallel runways, each 4300 ft apart; any triple configuration using existing pavement would therefore include either one closely-spaced pair or one converging pair of runways.

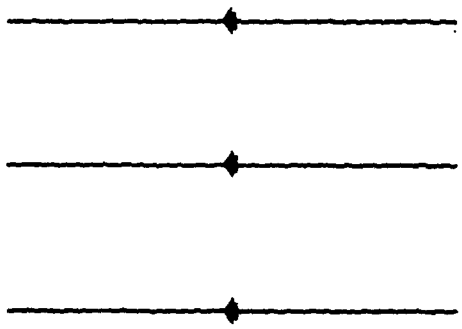
Three types of triple approaches are considered (Figure B):



a. Dependent/Dependent



b. Independent/Dependent



c. Independent/Independent

FIGURE B
TYPES OF TRIPLE APPROACHES

- Dependent/Dependent - approaches to the Center and Right runways are dependent, as are the approaches to the Center and Left approaches. Approaches to the Right and Left runways are independent of each other, however (this is true for all three types of triples).

- Independent/Dependent - approaches to the Center runway are independent of either the Right or the Left runway, but dependent on the other.

- Independent/Independent - approaches to the Center runway are independent of approaches on both the Right and the Left runways.

Separate Short Runways

Currently, it is the convention to organize aircraft on approach according to time of arrival, not type of aircraft. This results in a string of unlike aircraft, separated according to type of aircraft. The concept of a separate short runway involves separating aircraft by type, with one runway reserved exclusively for general aviation and commuter aircraft. Traffic streams are segregated in this manner in order to minimize longitudinal distances between aircraft, thereby increasing throughput.

If new runway construction is considered, it is not difficult to find an airport where a separate short runway could theoretically be constructed and utilized in conjunction with one of the above concepts. However, due to limited availability of data an accurate determination of the feasibility of new runway construction at the 101 airports could not be accomplished. Instead, only existing pavement was considered.

APPLICATION OF CONCEPTS

One of the principal objectives of this study was to determine the applicability of the new concepts for multiple IFR approaches to a large and representative sample of airports. This sample is comprised of all large and medium hubs (73 airports), as well as several others that were added to ensure a representative and inclusive set. As a result, a total of 101 airports were included in this study.

Most of the delay experienced by air carriers occurs at the top 30 airports. These airports have therefore been given special attention in this report. Table A shows the top thirty air carrier airports for 1980 and the 1980 NASCOM delays for each.

TABLE A

TOP 30 U.S. AIR CARRIER AIRPORTS

RANK	AIRPORT	CODE	1980 NASCOM DELAY[1]
1	Chicago O'Hare	ORD	8743
2	Atlanta International	ATL	3819
3	Los Angeles International	LAX	2435
4	Dallas - Ft. Worth	DFW	830
5	Denver Stapleton	DEN	6705
6	Miami International	MIA	717
7	San Francisco	SFO	1189
8	New York Kennedy	JFK	5755
9	New York LaGuardia	LGA	6578
10	Washington National	DCA	703
11	Boston Logan	BOS	2973
12	St. Louis International	STL	1804
13	Pittsburgh	PIT	626
14	Detroit Metro	DTW	487
15	Houston Intercontinental	IAH	517
16	Minneapolis St. Paul	MSP	291
17	Memphis International	MEM	169
18	Seattle Tacoma	SEA	436
19	Tampa International	TPA	207
20	Las Vegas McCarran	LAS	0
21	Cleveland Hopkins	CLE	305
22	Phoenix Sky Harbor	PHX	0
23	Philadelphia Int'l	PHL	793
24	Honolulu	HNL	0
25	Kansas City Int'l	MCI	239
26	Orlando	MCO	0
27	Newark	EWR	750
28	New Orleans	MSY	203
29	Fort Lauderdale	FLL	171
30	Milwaukee Mitchell	MKE	0

[1] Number of Aircraft Reporting Delays of More Than 30 Minutes.
Source: Federal Aviation Administration, National Aviation System Communications Staff (NASCOM) Office.

In determining whether a concept could be applied at any of the 101 airport sites, both general criteria and concept-specific criteria were employed.

General Criteria

- The runway pavement necessary to apply the concept must already exist. However, the runway need not be active; closed runways and taxiways which met the other criteria of size and location were also considered.

- The runway width must be at least 100 ft so that an instrument approach can be made.

- In every runway combination, the available runway length must be at least 6000 ft on one runway and 4000 ft on the other. This is to insure that aircraft as large as a B-727 can be accommodated. Large twin-propeller aircraft such as used by air taxi and commuter operators could land on either runway.

- An ILS need not be present on each runway.

Criteria for Dependent Parallel Approaches

- Spacing between runways must be between 1000 ft and 2999 ft.

Criteria for Independent Parallel Approaches

- Spacing between runways must be between 3000 ft and 4299 ft.

Criteria for Converging Approaches

- The angle of convergence must be greater than 15^{o} but less than 100^{o}.

- Independent - runways must be non-intersecting, or intersecting with one runway at least 8400 ft from threshold to intersection, to allow hold short operations by all aircraft.

  - must meet preliminary requirements for independent converging approaches at no higher minima than 800 ft Decision Height.

- Dependent - intersecting or non-intersecting runways that could not meet the above requirements for independence.

  - the available runway length on one runway must be at least 6000 ft, and 4000 ft on the other. Available runway length is the distance from threshold to runway end, or threshold to intersection if hold-short procedures are required.

Criteria for Triple Independent/Dependent Approaches

- Since the handling of three streams of traffic simultaneously is itself a new concept, demonstrations of triple approaches will incorporate no more than one other new concept. An airport would not be a candidate for triple approaches if, for example, a combination of converging approaches and reduced-spacing parallel approaches were required.

Criteria for Separate Short Runways

Any of the above multiple approach concepts could include segregated traffic streams. In some cases, segregated traffic could be used to improve capacity by removing large variations in aircraft speed or weight (requiring additional separation between arrivals). In other cases, segregated traffic would be required due to differences in runway length. Such cases are categorized as Separate Short Runways. Available runway length must be between 4000 and 6000 ft.

Summary

Table B shows the application of each concept to the top 30 airports first; then, all other airports are listed in alphabetical order according to state. Only two of the top 30 airports (LAX and SEA) are not candidates for at least one of the concepts.

EVALUATION OF DELAY SAVINGS -- METHODOLOGY

To calculate the delay savings possible through implementation of the new concepts, the following procedure was followed:

- The level of future demand in 1982 was calculated. This daily demand was divided into 24 hours to construct a daily demand profile.

TABLE B

CONCEPT APPLICATION TO 101 AIRPORTS

	AIRPORTS	DEPENDENT PARALLELS	INDEPENDENT PARALLELS	DEPENDENT CONVERGING	INDEPENDENT CONVERGING	TRIPLES	SEPARATE SHORT RUNWAYS
1.	Chicago (ORD)				22R,27L	9L,9R,4R	
2.	Atlanta (ATL)	9L,9R (1000')				8,9R,9L	
3.	Los Angeles (LAX)						
4.	Dallas Ft. Worth (DFW)				35R,31R	35L,35R,31R	
5.	Denver (DEN)	17R,17L (1600')		17L,26L			
6.	Miami (MIA)			12,9R	27R,30		
7.	San Francisco (SFO)			10L,1R			10L,1R
8.	New York (JFK)		4L,4R (3000')	13L,4L	13R,22L		
9.	New York (LGA)			4,31			4,31
10.	Washington (DCA)			36,33			36,33
11.	Boston (BOS)	22R,22L (1500')		22L,27	22R,27		22L,27
12.	St. Louis (STL)	30R,30L (1300')		24,30L			
13.	Pittsburgh (PIT)	10R,10C (1200')		14,10C		10L,10R,10C	
14.	Detroit (DTW)	3C,3R (2200')	3L,3R (3800')		3R,9	3R,3C,3L	
15.	Houston (IAH)				26,32		
16.	Minneapolis (MSP)		11R,11L (3500')	22,29L			
17.	Memphis (MEM)		35L,35R (3300')	21,27			21,27
18.	Seattle (SEA)						
19.	Tampa (TPA)			27,18L	27,18R		27,18R
20.	Las Vegas (LAS)				19L,25		
21.	Cleveland (CLE)			10L,5R			10L,5L
22.	Phoenix (PHX)		8R,8L (3400')				
23.	Philadelphia (PHL)	9L,9R (1400')		17,9R			17,9R
24.	Honolulu (HNL)			8,4R	22L,26L		
25.	Kansas City (MCI)				19,27		
26.	Orlando (MCO)	18L,18R (1600')					
27.	Newark (EWR)			11,4R	11,4L		
28.	New Orleans (MSY)			10,19			10,19
29.	Fort Lauderdale (FFL)		27L,27R (4000')	27R,31			27L,27R
30.	Milwaukee (MKE)	1L,1R (1000')		7R,1L	13,7R		13,7R
31.	Anchorage (ANC)			13,6R			13,6R
32.	Fairbanks (FAI)						
33.	Birmingham (BHM)			5,36			5,36

TABLE B
(Continued)

AIRPORTS	DEPENDENT PARALLELS	INDEPENDENT PARALLELS	DEPENDENT CONVERGING	INDEPENDENT CONVERGING	TRIPLES	SEPARATE SHORT RUNWAYS
34. Tucson (TUS)			3,29R			
35. Little Rock (LIT)				18,22		18,22
36. Burbank (BUR)			7,15			7,15
37. Fresno (FAT)----------						
38. Long Beach (LGB)			12,7R			12,7R
39. Oakland (OAK)	27L,27R (1000')			29,27L		29,27R
40. Ontario (ONT)			21,26L			21,26L
41. Sacramento (SMF)----------						
42. San Diego (SAN)			13,9			13,9
43. San Jose (SJC)----------						
44. Santa Ana (SNA)----------						
45. Colorado Springs (COS)				30,35		
46. Windsor Locks (BDL)			24,33			24,33
47. Daytona Beach (DAB)			16,6L			16,6L
48. Jacksonville (JAX)				31,25		
49. West Palm Beach (PBI)			13,9L			13,9L
50. Kahului, Hawaii (HOG)			5,2			5,2
51. Lihue, Hawaii (HLI)----------						
52. Boise (BOI)----------						
53. Chicago (MDW)----------						
54. Indianapolis (IND)			4L,31			4L,31
55. Des Moines (DSM)			12L,5			12L,5
56. Wichita (ICT)			1L,32	14,19L		1L,32
57. Louisville (SDF)			29,24			29,24
58. Portland, ME (PWM)			11,18			11,18
59. Baltimore (BWI)			15R,10			15R,10
60. Detroit (DET)			7,15			7,15
61. Lansing (LAN)			27L,24			27L,24
62. Jackson (JAN)		33L,33R (3800')				
63. Billings, MT (BIL)				16,22		16,22
64. Omaha (OMA)			14R,17			14R,17
65. Reno (RNO)			16,25			16,25
66. Manchester, NH (MHT)			35,6			35,6
67. Albuquerque (ABQ)			26,17	26,30		26,30

TABLE B
(Concluded)

AIRPORTS	DEPENDENT PARALLELS	INDEPENDENT PARALLELS	DEPENDENT CONVERGING	INDEPENDENT CONVERGING	TRIPLES	SEPARATE SHORT RUNWAYS
68. Albany (ALB)			28,1			28,1
69. Buffalo (BUF)			14,5			14,5
70. Rochester, NY (ROC)			22,28	22,25		22,25
71. Syracuse (SYR)			14,10			
72. Charlotte, NC (CLT)			5,36R	18R,23		
73. Greensboro, NC (GSO)			23,14			23,14
74. Raleigh (RDU)			32,5			32,5
75. Grand Forks, ND (GFK)			26,35			26,35
76. Cincinnati (CVG)	27R,27L (1700')		27L,36			27R,27L
77. Columbus (CMH)	10L,10R (2800')		10R,5	31,28R		31,28R
78. Dayton (DAY)			18,24L	6L,36		18,24L
79. Oklahoma City (OKC)			12,17R	12,17L		12,17R
80. Tulsa (TUL)			17R,26			17R,26
81. Eugene (EUG)						
82. Portland (PDX)		28L,28R (3100')	10R,2			10R,2
83. Providence, RI (PVD)	5L,5R (1700')		34,5L			34,5L
84. Charleston, SC (CHS)			33,3			3,33
85. Sioux Falls, SD (FSD)			3,33			3,33
86. Knoxville, TN (TYS)	4L,4R (1200')					4L,4R
87. Nashville, TN (BNA)	2L,2R (1800')		2L,31			2L,2R
88. Austin, TX (AUS)			35L,31L			35L,31L
89. Dallas Love (DAL)		31L,31R (3000')	36,31R			36,31R
90. El Paso (ELP)	26L,26R (1200')			22,26R		22,26R
91. Houston Hobby (HOU)			17,22			17,22
92. San Antonio (SAT)			12R,21L			
93. Salt Lake City (SLC)		16L,16R (3500')		14,16L		14,16L
94. Burlington (BTV)						
95. Norfolk (ORF)			23,14			23,14
96. Spokane (GEG)			2,25			2,25
97. Charleston, WY (CRW)			23,32			23,32
98. Madison, WI (MSN)			36,31	18,22		18,22
99. Washington, DC (IAD)				12,19L	12,19R,19L	
100. Casper, WY (CPR)				30,34		
101. San Juan, PR (SJU)				25,28		

- The capacity of each airport was then calculated for each applicable concept.

- Lastly, the demand profiles and capacity values were used to calculate the total daily delay, by applying an analytical queuing model.

Demand, capacity, and delay have been calculated only for arrival operations. Consideration of departures as well would have masked the impact of the new concepts being analyzed here, which only affect the arrival capacity of the airport.

Because of the time and expense involved in the delay calculations, only the top thirty airports were analyzed in detail. For the remaining seventy-one airports, some general conclusions were drawn from a study of three typical airports.

Demand Calculation

An unconstrained demand for 1982 was computed; that is, the likely effects of excessive demand at an airport (namely, the shift of traffic to other hours or even other airports) have been ignored.

To compute the future demand profile for scheduled traffic, an actual daily profile was first obtained from Profiles of Scheduled Air Carrier Operations by Stage Length, August 1979. The 1978 hourly profiles were then scaled up to reflect the levels of scheduled traffic in 1982 at each airport, as obtained from Terminal Area Forecasts, FY 1981-1992.

To construct an hourly demand profile for general aviation, data in Hourly Airport Activity Profiles was used to construct a standard daily profile of general aviation traffic, which was then applied to all airports. Forecasted levels of itinerant general aviation traffic were then applied to this standard profile to derive an hourly demand profile for average general aviation arrivals.

These two demand profiles (air carrier and general aviation) were then added together to form a total arrival demand, by hour, for each of the top 30 airports.

Capacity Calculation

Capacity was calculated using the Upgraded FAA Airfield Capacity Model. This model computes the maximum throughput of the given runway configuration by first calculating an average time between successive arrivals, then inverting this value.

The arrival capacity for some of the new concepts could not be obtained directly from the FAA Capacity Model. These capacities were calculated using similar but specialized techniques.

The forecasted fleet mix, a necessary input to the capacity calculations, was calculated for each of the top thirty airports, by assuming a certain mix for general aviation and air taxi operations, and by using the actual 1978 mix for air carriers (obtained from Airport Activity Statistics of Certificated Route Air Carriers).

Delay Calculation

Given the hourly demand profile and the arrival capacity, it was possible to calculate the expected delay. A version of the MIT "DELAYS" model was used to calculate the delay at the top 30 U.S. airports. This analytical model solves a number of time-dependent queueing equations to compute the average delay per aircraft during each hour. This average delay was then multiplied by the hourly demand, and summed over the 24 hours to provide a total daily delay (over all aircraft).

This resulting total delay represents 24 hours of continuous IFR operations on the given runway configuration. To reflect the occurrence of actual IFR conditions, these totals were multiplied by the recorded percentage of IFR conditions, to derive an expected daily IFR delay.

Detailed delay calculations were performed for three of the non-top 30 airports to illustrate the effect of the multiple IFR approach concepts on the delay at these less busy airports. These three airports were Wichita, Kansas (ICT), San Diego, California (SAN), and Providence, Rhode Island (PVD). These three airports were chosen to provide a range of total demand, to be representative of all 71 remaining airports.

If it is felt that these three airports are not truly representative of the remaining airports, or if more detailed results are desired for a particular airport, an alternative methodology is available for calculating delays. The FAA "Capacity Handbook" may be used. This method is less expensive and more widely available than the computer model described above, but the results tend to be more approximate.

EVALUATION OF DELAY SAVINGS -- RESULTS

Top 30 Airports

The total daily delay for each of the top 30 U.S. air carrier airports was calculated, then multiplied by the annual percentage of Category I IFR conditions (between 1500/3 and 200/0.5), to produce an expected daily IFR delay. Table C shows the reduction in this delay that would result from the ATC concepts under review.

In this table, the new concepts are compared with the existing runway configuration with the highest IFR arrival capacity under current ATC rules. At 15 of the top 30 airports, the best currently available configuration was a single arrival runway. These airports had the greatest potential for improvement. Ten airports currently have independent parallel approaches in IFR; capacity here can only be bettered by a triple approach configuration. The remaining five airports can currently use dependent parallel approaches with 2.0 nmi diagonal separation in IFR conditions. This capacity can usually be bettered, even by a dependent converging approach.

It should be noted that the assessment of "best current configuration" was based solely on the existing runway layout, and did not consider local factors such as noise sensitive areas or equipment limitations which might prevent usage of the configuration.

At two airports, LAX and SEA, this "best current configuration" was also the best future configuration, even under the new ATC procedures. No IFR delay savings are attributable to the new concepts at Las Vegas (LAS) or Phoenix (PHX), even though the new concepts provide higher IFR capacities, because no IFR weather was recorded for these airports. At other airports, such as MIA and JFK, no IFR delay savings are indicated because the new ATC concepts do not provide any additional capacity compared to the best current configuration. The new concepts can still provide a benefit, of course, during those times when the "best current configuration" cannot be operated (for example, if one runway is closed for construction). No attempt was made to estimate the probability of such occurrences.

The remaining airports show expected delay improvements ranging from 30 minutes to 280 hours per day, due to the new concepts. Several airports show improvements in the range of 200 hours per day. The top 30 airports may be ranked by the amount of delay

TABLE C

EXPECTED IMPROVEMENT IN
1982 DAILY IFR DELAY (HOURS)
AT TOP 30 AIRPORTS

AIRPORT	% IFR (1500/3 to 200/0.5)	ARRIVAL CONFIGURATION: SINGLE RUNWAY	DEPEN PAR	INDEP PAR	DEPEN CVG	INDEP CVG	TRIPLES
ORD	15			*		0	251[3]
ATL	13			*			28[2]
LAX	23			*			
DFW	8**			*		0	5[3]
DEN	6	*	87		119		
MIA	2			*		0	
SFO	15	*			230		
JFK	14			*		0	
LGA	16	*			161		
DCA	11	*			98		
BOS	15	*	212		254	265	
STL	11	*	168		281		
PIT	16			*		0	1[2]
DTW	13			*		0	0.2[1]
IAH	15	*			81	84	
MSP	13		*	5	4		
MEM	9		*	46	38	46	
SEA	12	*					
TPA	6			*		0	
LAS	0	*			0	0	
CLE	15	*			21		
PHX	0		*	0			
PHL	15	*	183		201		
HNL	1			*		0	
MCI	10	*			2	2	
MCO	6	*	0.5				
EWR	16	*			6	6	
MSY	10	*			4		
FLL	3		*	18	16		
MKE	13	*	26		28	29	

[1] Dependent/dependent triples
[2] Independent/dependent triples
[3] Independent/independent triples

*Best current configuration
**Observations taken at Dallas Love (DAL)

improvement expected, for each concept, as is done in Table D. A table such as this may be useful for deciding which airports are prime candidates for implementation of the new concepts. For instance, Boston (BOS) appears at or near the top of three lists; Philadelphia (PHL) should also be a strong candidate for concept implementation.

Remaining Airports

In Table D, the less busy airports of the top 30 tend to lie near the bottom of the lists. This is to be expected. Without as much demand as one of the top 10 airports, these airports would have less delay, and therefore the new concepts would provide less improvement in the delay.

Similarly, the new concepts would be expected to provide less delay improvement at one of the 71 less busy airports than at one of the top 30. This may be illustrated by the detailed delay results obtained for three typical smaller airports (Table E). It was not felt necessary to perform detailed delay calculations for all the 71 smaller airports.

The non-"top 30" airports are not likely to be prime candidates for implementation of the new concepts, but the concepts may still be beneficial. If the new concepts are authorized and approved, even a small delay reduction could be worthwhile, if the costs were not high.

CONCLUSIONS

Of the 101 airports studied for this report, it was found that:

- Sixteen were suitable for close-spaced dependent parallel approaches.
- Ten were suitable for close-spaced independent parallel approaches.
- Sixty-eight had converging runways which could only be operated dependently (a total of 84 airports had converging runways).
- Thirty-one had converging runways which could be operated independently below 1000 ft ceiling/3 mi visibility.
- Six airports had triple runway configurations.

TABLE D

TOP 30 AIRPORTS RANKED BY EXPECTED IMPROVEMENT IN IFR DELAY BY CONCEPT

DEPENDENT PARALLEL	INDEPENDENT PARALLEL	DEPENDENT CONVERGING	INDEPENDENT CONVERGING	TRIPLE APPROACHES
BOS (1500 ft)[1]	MEM (3400ft)[1]	STL	BOS (625 DH)[2]	ORD
PHL (1400)	FLL (4000)	BOS	IAH (475)	ATL
STL (1300)	MSP (3200)	SFO	MEM (800)	DFW
DEN (1600)		PHL	MKE (800)	PIT
MKE (1000)		LGA	EWR (775)	DTW
MCO (1600)		DEN	MCI (650)	
		DCA		
		IAH		
		MEM		
		MKE		
		CLE		
		FLL		
		EWR		
		MSP		
		MSY		
		MCI		

---

1 Spacing between parallel runways

2 Decision Height

Note: 1982 demand.
Delay improvement is weighted by probability of IFR conditions.

TABLE E

EXPECTED 1982 DELAY IMPROVEMENT FOR THREE TYPICAL SMALLER AIRPORTS

ARRIVAL CONFIGURATION	ICT	SAN	PVD
Dependent Parallels	2.1 hr	1.9 hr	1.0 hr
Independent Parallels	2.6	2.5	1.3
Dependent Converging	2.4	2.4	1.2
Independent Converging	2.6	2.5	1.3
Independent/Dependent Triples	2.7	2.7	1.4
Independent/Independent Triples	2.8	2.8	1.5

NOTE: Expected Improvement is calculated relative to single runway operations. Results shown are illustrative only; the "best current configuration" at each airport may not be a single runway, and all concepts may not be applicable.

RECOMMENDATIONS

This study has shown that the concepts under review can be applied at a large number of airports, with potentially large delay savings, without requiring new runway construction. More detailed analyses can provide additional information about the value of these concepts.

The next step should be the conduct of proof-of-concept testing, using the preliminary operational procedures developed for each new concept. This concept demonstration phase would probably involve actual test flights at the Technical Center at Atlantic City, NJ, and at one of the airports where implementation is foreseen. The ranking of delay savings in this report should be useful to the selection of a demonstration site.

Once the site (or sites) is chosen, a more accurate determination of applicability and benefit could be performed. Local factors could then be properly accounted for, such as:

- Airspace restrictions
- ILS installation problems
- Obstructions
- Departure demand patterns
- Wind and weather patterns
- Other operational restrictions

With more detailed data, it would be possible to incorporate the effects of variations in the aircraft mix by runway or by hour, or variations in demand over the year. Alternatively, data could be collected for a typical day, and the effect of the new concept on that day's operations could be analyzed.

It is recommended that these tests be conducted, leading to the demonstration and eventual implementation of one or more of the new concepts for multiple IFR approaches presented in this report.

TABLE OF CONTENTS

	Page
1. INTRODUCTION	1-1
1.1 History	1-1
1.2 Current Situation	1-1
1.3 Preview of Study	1-2
2. DESCRIPTION OF CONCEPTS	2-1
2.1 Dependent Parallel Approaches	2-1
2.2 Independent Parallel Approaches	2-2
2.3 Converging Approaches	2-3
2.3.1 Intersecting Approach Streams	2-3
2.3.2 Intersecting Runways	2-5
2.3.3 Converging Runway (Extended) Centerlines	2-5
2.4 Independent and Dependent Triple Approaches	2-6
2.5 Separate Short Runways	2-6
3. APPLICATION OF CONCEPTS	3-1
3.1 Application Criteria	3-1
3.1.1 General Criteria	3-1
3.1.2 Criteria for Dependent Parallel Approaches	3-3
3.1.3 Criteria for Independent Parallel Approaches	3-3
3.1.4 Criteria for Converging Approaches	3-3
3.1.5 Criteria for Triple Independent/Dependent Approaches	3-5
3.1.6 Criteria for Separate Short Runways	3-5
3.2 Determination of Applicability	3-5
4. EVALUATION OF DELAY SAVINGS -- METHODOLOGY	4-1
4.1 General Introduction	4-1
4.2 Demand Calculations	4-2
4.3 Capacity Calculations	4-3
4.4 Delay Calculations	4-7

TABLE OF CONTENTS
(Concluded)

	Page
4.4.1 Top 30 Airports	4-7
4.4.2 Remaining Airports	4-7
5. EVALUATION OF DELAY SAVINGS -- RESULTS	5-1
5.1 Top 30 Airports	5-1
5.2 Remaining Airports	5-3
6.0 CONCLUSIONS AND RECOMMENDATIONS	6-1
6.1 Summary	6-1
6.2 Conclusions	6-1
6.3 Recommendations	6-2
APPENDIX A DAILY ARRIVAL DEMAND PROFILES	A-1
APPENDIX B ARRIVAL CAPACITY	B-1
APPENDIX C TOTAL DAILY DELAY	C-1
APPENDIX D REFERENCES	D-1

LIST OF ILLUSTRATIONS

		Page
TABLE 2-1:	IN-TRAIL SEPARATION (nmi)	2-9
TABLE 3-1:	TOP 30 U.S. AIR CARRIER AIRPORTS	3-2
TABLE 3-2:	HOLD-SHORT CRITERIA FOR DEPENDENT CONVERGING APPROACHES TO INTERSECTING RUNWAYS	3-4
TABLE 3-3:	CONCEPT APPLICATION TO 101 AIRPORTS	3-6
TABLE 4-1:	COMPARISON OF STANDARD DEMAND PROFILE FOR GENERAL AVIATION TRAFFIC WITH ACTUAL DATA	4-4
TABLE 4-2:	CATEGORIZATION OF AIR CARRIER AIRCRAFT	4-6
TABLE 5-1:	EXPECTED IMPROVEMENT IN 1982 DAILY IFR DELAY (HOURS) AT TOP 30 AIRPORTS	5-2
TABLE 5-2:	TOP 30 AIRPORTS RANKED BY EXPECTED IMPROVEMENT IN IFR DELAY BY CONCEPT	5-4
TABLE 5-3:	DETAILED 1982 DELAY RESULTS FOR THREE TYPICAL SMALLER AIRPORTS	5-5
TABLE A-1:	1982 DAILY ARRIVAL DEMAND PROFILE	A-2
TABLE B-1:	CAPACITY CALCULATION INPUT	B-2
TABLE B-2:	1982 AIRPORT FLEET MIXES - TOP 30 AIRPORTS	B-3
TABLE B-3:	ARRIVAL CAPACITY RESULTS FOR APPLICABLE CONFIGURATIONS AT TOP 30 AIRPORTS - 1982 AIRCRAFT MIX	B-4
TABLE C-1:	EXAMPLE OF HOURLY DELAY VALUES	C-2
TABLE C-2:	TOTAL 1982 DAILY DELAY (HOURS) AT TOP 30 AIRPORTS	C-3
TABLE C-3:	EXAMPLE OF HOURLY DELAY RESULTS AT STL	C-4
FIGURE 2-1:	TYPES OF CONVERGING APPROACHES	2-4

LIST OF ILLUSTRATIONS
(Concluded)

Page

FIGURE 2-2: AIRPORT LAYOUT PLAN FOR WASHINGTON DULLES INTERNATIONAL 2-7

FIGURE 2-3: TYPES OF TRIPLE APPROACHES 2-8

FIGURE 5-1: CAPACITY VS. DELAY AT THREE TYPICAL SMALLER AIRPORTS 5-7

1. INTRODUCTION

1.1 History

The Federal Aviation Administration (FAA) has long recognized the problems of inadequate airport capacity and increasing delays. The report of the Air Traffic Control Advisory Committee (ATCAC) in 1969 (Reference 1) concluded that the critical capacity problem was typically in the arrival process during Instrument Flight Rules (IFR) conditions. ATCAC recommended that capacity be increased by finding a method to decrease the minimum separation between aircraft on final approach during IFR conditions.

Similar problems were noted in an FAA report to the Congress in 1974 (Reference 2) which concluded that:

- "Delays are down from the peak (1969-70 levels, but) they remain undesirable and substantial increases may be expected in the future if improvements to the system are not instituted."

- "Operational changes can provide additional capacity to meet adverse conditions such as severe weather and uneven traffic loads."

As a follow-up to the 1974 report, the FAA created specific Airport Capacity Improvement Task Forces to assess the effects of various technologies on airport capacity and delays. These studies were completed at Chicago, Denver, Los Angeles, Atlanta, New York Kennedy and La Guardia, Miami, and San Francisco. All of the analyses indicated a need for long term, major increases in capacity.

1.2 Current Situation

In the meantime, major airports in the U. S. continued to experience increases in traffic. Annual airline delay costs now exceed $1 billion. The rise in fuel costs will further increase this delay cost. Furthermore, moderate traffic growth may lead to disproportionately large delay costs, especially when demand approaches or exceeds current capacity.

The following items may alleviate the lack of capacity (Reference 3):

- Metering and Spacing -- automation aids for terminal controllers to increase the precision of delivery of aircraft to the runway.

- Wake Vortex Sensing Systems -- devices to detect vortex transport and decay in order to identify conditions where Instrument Flight Rules (IFR) in-trail spacings may be safely reduced.

- Microwave Landing Systems -- advanced approach navigation used to provide noise abatement and operational route separation for high capacity operations.

- Airport Surface Traffic Control -- new surveillance techniques and data processing to improve IFR ground control.

- New airports and air carrier runways.

Although each of these options could be effective in increasing capacity, there are barriers to their application. Most of the candidate solutions require a large capital investment financed by the Aviation Trust Fund, but the disposition of this Fund is still uncertain with regard to airport improvements. Major additions of new airports or air carrier runways are considered unlikely before the year 2000 (Reference 4). Some of the technologies cannot be applied universally because of the investment cost and the problems that inevitably accompany the introduction of non-standard processes. Finally, some technologies have not yet been developed and/or tested under actual conditions.

1.3 Preview of Study

Recognizing that airport capacity increases are needed but many of the candidate solutions are not likely to be implemented soon, a different approach was evaluated. New procedures and the possible upgrading of airport navigational and surveillance aids are all that is required to apply certain concepts which employ multiple arrival streams to existing runway geometry during IFR conditions.

These concepts, which will be described in Section 2, include (Reference 5):

- dependent parallel approaches at reduced centerline spacing

- independent parallel approaches at reduced centerline spacing

- dependent and independent approaches to converging runways

- triple approaches

- separate short runways

A preliminary look was taken at the major air carrier airports to determine the feasibility of applying the multiple approach concepts (Reference 5). Section 3 of this report examines 101 airports in more detail to determine the feasibility of reducing delay through application of these concepts. The top 30 airports were analyzed in greater detail than the remainder as there was a greater need for improvement at these airports.

At each airport the demand, aircraft mix, capacity, and expected delay were calculated for conditions with and without the application of one or more of the concepts. The details of this procedure are explained in Section 4, while the results are presented in Section 5.

Finally, the method and results of the present study are reviewed in Section 6.

2. DESCRIPTION OF CONCEPTS

The concepts examined in this study deal with procedures for Category I approaches (200 ft Decision Height) to various runway geometries. All of the concepts utilize multiple approach streams. Four of the five are tailored to particular runway geometries:

- Dependent parallel approaches with reduced runway spacing
- Independent parallel approaches with reduced runway spacing
- Converging approaches
- Triple approaches

These concepts will be described below. A fifth concept, separate short runways for general aviation and air taxi/commuters, can be applied with any of the first four. This concept takes advantage of the efficiency of specialization by segregating traffic streams into air carrier (requiring long runways) and other traffic which can use shorter runways.

These concepts may be applied to new or existing runways. Because of the long time period required to gain approval for the construction of a new runway, a decision was made early in this study to attempt capacity increase without the construction of new pavement. Since it is unlikely that a new runway would be constructed on the premise that an untried new concept could be utilized, implementation of the above concepts depends on their usefulness when applied to existing runways.

2.1 Dependent Parallel Approaches

At the present time, dependent alternating arrivals with a 2.0 nmi diagonal separation may be conducted to runways spaced as close as 3000 ft apart. For runways spaced from 2500 ft to 2999 ft, a 3 nmi diagonal separation is required. For spacing below 2500 ft, the need for protection from the effects of wake vortices dictates diagonal separation that varies by size of aircraft.

The new concept of dependent parallel approaches extends the use of 2.0 nmi diagonal separation to runways as close as 1000 ft apart (Reference 6). This is felt to be potentially feasible for the following reasons:

- An analysis of such dependent parallel approaches has shown that, if one arrival should blunder towards the other approach, the minimum miss distance after the controller acts is greater at smaller runway spacings. Blunders are therefore not a critical obstacle to reducing the runway spacing.

- At spacings below 2500 ft, wake vortex is currently a problem. However, a recent study (Reference 7) indicates that a combination of multiple glide slope angles, runway threshold stagger, and minimum headwind and crosswind values can be used to keep light aircraft away from the vortices produced by larger aircraft on the other approach. This presents the possibility that the wake vortex problem can also be overcome. The analysis only considered a 3.0 nmi longitudinal separation between alternating arrivals.

Two categories of dependent parallel approaches are considered.

- Category A -- dependent arrivals can be operated at runway spacings between 2500 ft and 2999 ft with 2.0 nmi diagonal separation between aircraft during final approach.

- Category B -- dependent arrivals can be operated at runway spacings between 1000 ft and 2499 ft with 2 to 3 nmi diagonal spacing between aircraft during final approach.

This report assumes that all runways spaced 1000 to 2499 ft apart can be considered in Category B. No attempt has been made to analyze each configuration to determine the actual glide slope angles, headwinds or crosswinds which would be required, or the percentage of the year such operation would be feasible.

2.2 Independent Parallel Approaches

At the present time, independent approaches may be made to parallel runways (less than 15^{o} deviation from parallel is considered parallel) under the following conditions:

- Runways are at least 4300 ft apart

- ILS, radar and two-way communications are required

- Aircraft are separated by a minimum of 1000 ft vertically or 3 miles horizontally on radar until established on their respective localizer courses

- Two monitor controllers provide lateral separation between aircraft

Separate short runways which satisfy current criteria for independent approaches have been shown to be a cost-beneficial means of increasing airport capacity (Reference 8). Traffic is divided into separate air carrier and GA (general aviation)/commuter streams, each arriving at separate runways. This concept takes advantage of the fact that long separations between air carrier and smaller aircraft because of wake vortex problems are not necessary if there are exclusive queues for each of the two types of aircraft.

Decreasing the runway separation to as little as 3000 ft for independent arrivals can most likely be achieved with an improved radar system (1 milliradian azimuth accuracy, 1 second update -- Reference 6). The gain in capacity results from the treatment of arrivals as two independent streams. All configurations with parallel runways which are between 3000 and 4300 ft apart, and at least 4000 ft long and 100 ft wide have been included under this category.

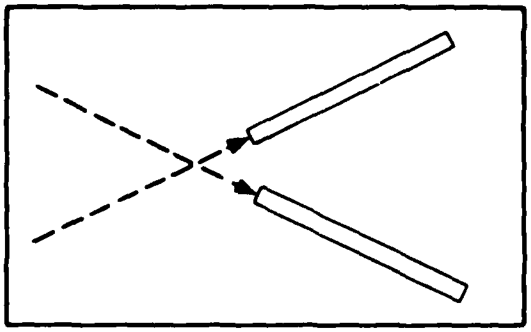
2.3 Converging Approaches

Technically, any airport with two or more separate runways that are not parallel must have converging runways. For the purposes of this study the Terminal Instrument Procedures (TERPS, Reference 9) definition of "converging" is accepted: runways with an included angle greater than 15°. Two runways that diverge by more than 100° are unlikely to be used together because of the effect of wind -- if there is a headwind on one runway, there would probably be a tailwind on the other.

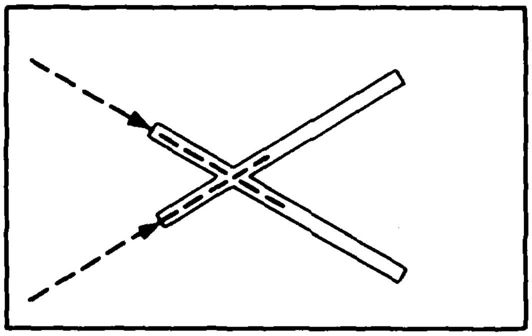
There are three general categories of converging approaches, which are described below and depicted in Figure 2-1.

2.3.1 Intersecting Approach Streams

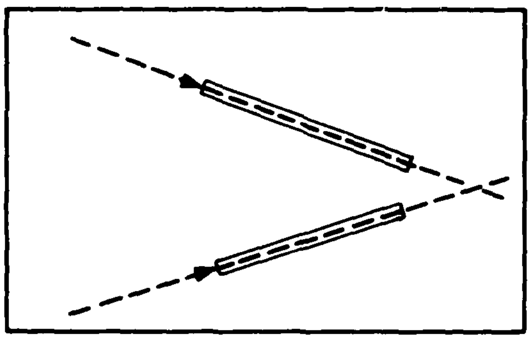
Converging approaches in which the final approaches must intersect (Figure 2-1a) would be most difficult to operate safely during any condition. There is no precedent for this



a. Intersecting Approaches



b. Intersecting Runways



c. Converging Runway (Extended) Centerlines

FIGURE 2-1
TYPES OF CONVERGING APPROACHES

operation during VFR conditions. Such geometries were not considered feasible for converging operations.

2.3.2 Intersecting Runways

Independent operation of converging runways that intersect (Figure 2-1b) pose two kinds of problems:

- The possibility of collision between two aircraft on that portion of each runway in which the pavement is shared;

- The possibility of collision during simultaneous missed approaches.

Neither problem by itself would prevent the independent operation of intersecting runways. The process of holding short before the intersection is practiced at ORD and can possibly be employed at runway geometries with at least one long runway. The criteria for hold-short operations are found in Reference 10. The missed approach problem can also be resolved (see Reference 11). However, the presence of two problems makes intersecting runways less likely candidates for independent converging approaches.

2.3.3 Converging Runway (Extended) Centerlines

Those runways in which the extended centerlines intersect, or a variation in which the extended centerline of one runway intersects the other runway, present only simultaneous missed approach problems (Figure 2-1c). Because this category is the least complex, such an application of the converging concept was preferred.

Adequate separation between missed approaches can be attained by application of the criteria in Reference 11. These criteria have been applied to the candidate configurations to determine whether independent converging approaches are feasible.

This study considers two categories of converging approaches:

- Dependent approaches to intersecting runways, or to non-intersecting runways with unfavorable geometries

- Independent approaches to favorable non-intersecting runways, or to intersecting runways with "hold-short" procedures

2.4 Independent and Dependent Triple Approaches

A logical combination of the first three concepts could result in the use of three runways simultaneously (Reference 12). Currently, no airport has three parallel runways, each 4300 ft apart; therefore, any triple configuration using existing pavement would include either one closely-spaced pair or one converging pair of runways. An example of a typical configuration is runways 19R/L and 12, Figure 2-2, at Washington Dulles. This is very similar to the airport plan at Dallas/Ft. Worth. There is no present restriction on operating runways 19R and 19L independently, but because runway 12 converges, new procedures would be required to operate the three runways simultaneously under IFR.

Three types of triple approaches are considered (Figure 2-3):

- Dependent/Dependent - approaches to the Center and Right runways are dependent, as are the approaches to the Center and Left approaches. However, approaches to the Right and Left runways are independent of each other (this is true for all three types of triple approaches).

- Independent/Dependent - approaches to the Center runway are independent of either the Right or the Left runway, but dependent on the other.

- Independent/Independent - approaches to the Center runway are independent of approaches on both the Right and the Left runways.

2.5 Separate Short Runways

Currently, it is the convention to organize aircraft on approach according to time of arrival, not type of aircraft. This results in a string of unlike aircraft, separated according to type of aircraft as shown in Table 2-1. The object of segregating traffic streams is to minimize longitudinal distances between aircraft, thereby increasing throughput.

An attempt was made to determine if it were possible to construct a 4000 ft (minimum) separate short runway (SSR) on the existing property of each airport. Maps on file at the FAA were used to examine 60 of the candidate airports, but many of the maps were rather old (dated mid-1950s to late-1970s) and probably not current. Two other sources were used to identify possible candidates for SSRs -- a previous MITRE report on the

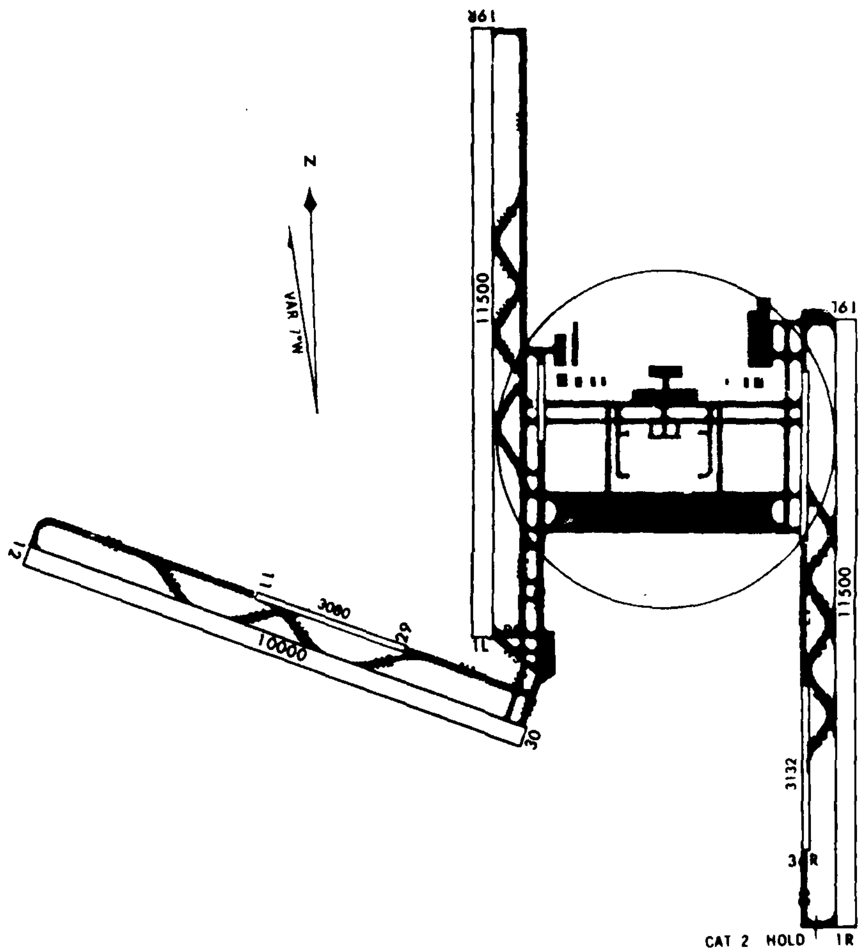


FIGURE 2-2
AIRPORT LAYOUT PLAN FOR WASHINGTON DULLES INTERNATIONAL

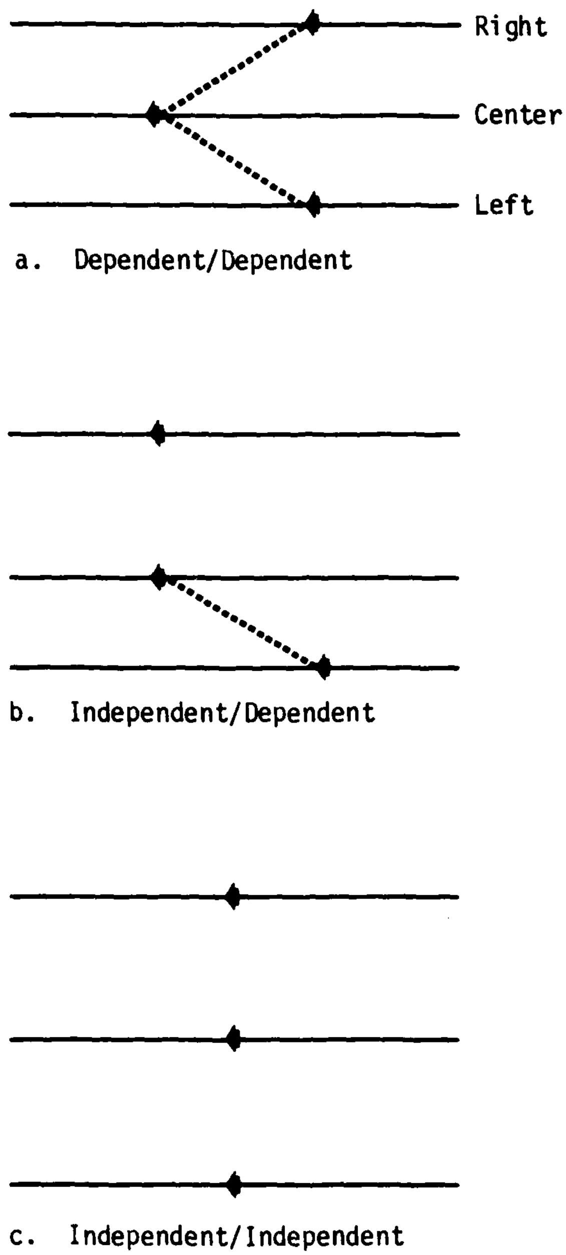


FIGURE 2-3
TYPES OF TRIPLE APPROACHES

TABLE 2-1

IN-TRAIL SEPARATION (nmi)

LEAD AIRCRAFT	TRAIL AIRCRAFT		
	Small	Large	Heavy
Small	3	3	3
Large	4	3	3
Heavy	6	5	4

Note: Small - defined as less than 12,500 pounds.
Large - between 12,500 and 300,000 pounds.
Heavy - over 300,000 pounds.

benefits of SSRs at major airports (Reference 8), and the responses of FAA Regional Directors to a request from the Administrator to comment on the use of separate short runways.

Once the possibility of new runway construction was considered, however, it was difficult to find an airport where a separate short runway could not theoretically be constructed and utilized in conjunction with one of the above concepts; but the decision to build a new runway depends as much on local political factors as on technical issues. The land for a new runway may be available, but construction may be blocked by environmental concerns or alternative land uses. On the other hand, the land may not be available, but additional land could be acquired if the perceived need for the new runway was strong enough. Consequently, an accurate determination of the feasibility of new runway construction at the 101 airports could *not* be accomplished. Instead, only existing pavement was considered, as previously mentioned.

3. APPLICATION OF CONCEPTS

One of the principal objectives of this study was to determine the applicability of the new concepts for multiple IFR approaches to a large and representative sample of airports. This sample is comprised of all large and medium hubs (73 airports), as well as several others that were added for the following reasons:

- To ensure representation from all states (except Delaware, which has no airports of appreciable size).
- To ensure inclusion of the top 100 airports ranked by order of total aircraft operations, as listed in Reference 13 (unless there were no appreciable air carrier operations).
- To include the airports considered by the Regional Directors to need capacity improvement (as indicated by their response to the Administrator's memo of 18 October 1980, which requested an evaluation of the use of separate short runways to relieve airport capacity problems).
- To include those airports with traffic volume similar to airports on the expanded list.

As a result, a total of 101 airports were included in this study.

Most of the delay experienced by air carriers occurs at the top 30 airports. These airports have therefore been given special attention in this report. Table 3-1 shows the top thirty air carrier airports for 1980 and the 1980 NASCOM delays for each.

3.1 Application Criteria

In determining whether a concept could be applied at any of the 101 airport sites, both general criteria and concept-specific criteria were employed.

3.1.1 General Criteria

- The runway pavement necessary to apply the concept must already exist. However, the runway need not be active; i.e. closed runways and taxiways which met the other criteria of size and location were also considered.
- The runway width must be at least 100 ft so that an instrument approach can be made.

TABLE 3-1

TOP 30 U.S. AIR CARRIER AIRPORTS

RANK[1]	AIRPORT	CODE	1980 NASCOM DELAY[2]
1	Chicago O'Hare	ORD	8743
2	Atlanta International	ATL	3819
3	Los Angeles International	LAX	2435
4	Dallas - Ft. Worth	DFW	830
5	Denver Stapleton	DEN	6705
6	Miami International	MIA	717
7	San Francisco	SFO	1189
8	New York Kennedy	JFK	5755
9	New York LaGuardia	LGA	6578
10	Washington National	DCA	703
11	Boston Logan	BOS	2973
12	St. Louis International	STL	1804
13	Pittsburgh	PIT	626
14	Detroit Metro	DTW	487
15	Houston Intercontinental	IAH	517
16	Minneapolis St. Paul	MSP	291
17	Memphis International	MEM	169
18	Seattle Tacoma	SEA	436
19	Tampa International	TPA	207
20	Las Vegas McCarran	LAS	0
21	Cleveland Hopkins	CLE	305
22	Phoenix Sky Harbor	PHX	0
23	Philadelphia Int'l	PHL	793
24	Honolulu	HNL	0
25	Kansas City Int'l	MCI	239
26	Orlando	MCO	0
27	Newark	EWR	750
28	New Orleans	MSY	203
29	Fort Lauderdale	FLL	171
30	Milwaukee Mitchell	MKE	0

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1 Source: Reference 13

2 Number of Aircraft Reporting Delays of More Than 30 Minutes.
Source: Federal Aviation Administration, National Aviation System Communications Staff (NASCOM) Office.

- In every runway combination, the available runway length must be at least 6000 ft on one runway and 4000 ft on the other. This is to insure that aircraft as large as a B-727 can be accommodated. Large twin-propeller aircraft such as used by air taxi and commuter operators could land on either runway.

- An ILS need not be present on each runway.

3.1.2 Criteria for Dependent Parallel Approaches

- Spacing between runways must be between 1000 ft and 2999 ft. Only one airport (CMH--Columbus, OH) was found to have runways spaced between 2500 and 2999 ft.

3.1.3 Criteria for Independent Parallel Approaches

- Spacing between runways must be between 3000 ft and 4299 ft.

3.1.4 Criteria for Converging Approaches

- The angle of convergence must be greater than 15° but less than 100°.

- Independent - runways must be non-intersecting, or intersecting with one runway at least 8400 ft from threshold to intersection, to allow hold short operations by all aircraft (Table 3-2).

  - runways must meet preliminary requirements for independent converging approaches (Reference 11) at no higher minima than 800 ft Decision Height.

- Dependent - intersecting or non-intersecting runways that could not meet the above requirements for independence.

  - the available runway length on one runway must be at least 6000 ft, and 4000 ft on the other. Available runway length is the distance from threshold to runway end, or threshold to intersection if hold-short procedures are required.

TABLE 3-2

HOLD-SHORT CRITERIA FOR DEPENDENT
CONVERGING APPROACHES TO INTERSECTING RUNWAYS

DISTANCE TO HOLD SHORT (FT)	APPLICABLE AIRCRAFT
8400	All
8000	All except B-747
6000	B-727 and smaller
4500	Large twin propeller and smaller (except CV 580)
3000	STOL and small propeller aircraft (< 12,500 lbs.)
1650	STOL only

Source: Reference 10, Paragraph 1121.

3.1.5 Criteria for Triple Independent/Dependent Approaches

- Since the handling of three streams of traffic simultaneously is a new concept, demonstrations of triple approaches will incorporate no more than one other new concept. An airport would not be a candidate for triple approaches if, for example, a combination of converging approaches and reduced-spacing parallel approaches were required.

3.1.6 Criteria for Separate Short Runways

Any of the above multiple approach concepts could include segregated traffic streams. In some cases, segregated traffic could be used to improve capacity by removing large variations in aircraft speed or weight (requiring additional separation between arrivals).

In other cases, segregated traffic would be required due to differences in runway length. Such cases are categorized as Separate Short Runways. Available runway length must be between 4000 and 6000 ft.

3.2 Determination of Applicability

Table 3-3 shows the potential application of each concept to the 101 airports, with identification of the runway involved. More than one set of runways may be suitable for the application of a concept at a particular airport, but only one set will be shown in the Table.

The top 30 airports are listed first; then, all other airports are listed in alphabetical order according to state. Only two of the top 30 airports (LAX and SEA) are not candidates for at least one of the concepts.

TABLE 3-3

CONCEPT APPLICATION TO 101 AIRPORTS

	AIRPORTS	DEPENDENT PARALLELS	INDEPENDENT PARALLELS	DEPENDENT CONVERGING	INDEPENDENT CONVERGING	TRIPLES	SEPARATE SHORT RUNWAYS
1.	Chicago (ORD)				22R,27L	9L,9R,4R	
2.	Atlanta (ATL)	9L,9R (1000')				8,9R,9L	
3.	Los Angeles (LAX)						
4.	Dallas Ft. Worth (DFW)				35R,31R	35L,35R,31R	
5.	Denver (DEN)	17R,17L (1600')		17L,26L			
6.	Miami (MIA)			12,9R	27R,30		
7.	San Francisco (SFO)			10L,1R			10L,1R
8.	New York (JFK)		4L,4R (3000')	13L,4L	13R,22L		
9.	New York (LGA)			4,31			4,31
10.	Washington (DCA)			36,33			36,33
11.	Boston (BOS)	22R,22L (1500')		22L,27	22R,27		22L,27
12.	St. Louis (STL)	30R,30L (1300')		24,30L			
13.	Pittsburgh (PIT)	10R,10C (1200')		14,10C		10L,10R,10C	
14.	Detroit (DTW)	3C,3R (2200')	3L,3R (3800')		3R,9	3R,3C,3L	
15.	Houston (IAH)				26,32		
16.	Minneapolis (MSP)		11R,11L (3500')	22,29L			
17.	Memphis (MEM)		35L,35R (3300')	21,27			21,27
18.	Seattle (SEA)						
19.	Tampa (TPA)			27,18L	27,18R		27,18R
20.	Las Vegas (LAS)				19L,25		
21.	Cleveland (CLE)			10L,5R			10L,5L
22.	Phoenix (PHX)		8R,8L (3400')				
23.	Philadelphia (PHL)	9L,9R (1400')		17,9R			17,9R
24.	Honolulu (HNL)			8,4R	22L,26L		
25.	Kansas City (MCI)				19,27		
26.	Orlando (MCO)	18L,18R (1600')					
27.	Newark (EWR)			11,4R	11,4L		
28.	New Orleans (MSY)			10,19			10,19
29.	Fort Lauderdale (FFL)		27L,27R (4000')	27R,31			27L,27R
30.	Milwaukee (MKE)	1L,1R (1000')		7R,1L	13,7R		13,7R
31.	Anchorage (ANC)			13,6R			13,6R
32.	Fairbanks (FAI)						
33.	Birmingham (BHM)			5,36			5,36

TABLE 3-3
(Continued)

	AIRPORTS	DEPENDENT PARALLELS	INDEPENDENT PARALLELS	DEPENDENT CONVERGING	INDEPENDENT CONVERGING	TRIPLES	SEPARATE SHORT RUNWAYS
34.	Tucson (TUS)			3,29R			
35.	Little Rock (LIT)				18,22		18,22
36.	Burbank (BUR)			7,15			7,15
37.	Fresno (FAT)						
38.	Long Beach (LGB)			12,7R			12,7R
39.	Oakland (OAK)	27L,27R (1000')			29,27L		29,27R
40.	Ontario (ONT)			21,26L			21,26L
41.	Sacramento (SMF)						
42.	San Diego (SAN)			13,9			13,9
43.	San Jose (SJC)						
44.	Santa Ana (SNA)						
45.	Colorado Springs (COS)				30,35		
46.	Windsor Locks (BDL)			24,33			24,33
47.	Daytona Beach (DAB)			16,6L			16,6L
48.	Jacksonville (JAX)				31,25		
49.	West Palm Beach (PBI)			13,9L			13,9L
50.	Kahului, Hawaii (HOG)			5,2			5,2
51.	Lihue, Hawaii (HLI)						
52.	Boise (BOI)						
53.	Chicago (MDW)						
54.	Indianapolis (IND)			4L,31			4L,31
55.	Des Moines (DSM)			12L,5			12L,5
56.	Wichita (ICT)			1L,32	14,19L		1L,32
57.	Louisville (SDF)			29,24			29,24
58.	Portland, ME (PWM)			11,18			11,18
59.	Baltimore (BWI)			15R,10			15R,10
60.	Detroit (DET)			7,15			7,15
61.	Lansing (LAN)			27L,24			27L,24
62.	Jackson (JAN)		33L,33R (3800')				
63.	Billings, MT (BIL)				16,22		16,22
64.	Omaha (OMA)			14R,17			14R,17
65.	Reno (RNO)			16,25			16,25
66.	Manchester, NH (MHT)			35,6			35,6
67.	Albuquerque (ABQ)			26,17	26,30		26,30

TABLE 3-3
(Concluded)

	AIRPORTS	DEPENDENT PARALLELS	INDEPENDENT PARALLELS	DEPENDENT CONVERGING	INDEPENDENT CONVERGING	TRIPLES	SEPARATE SHORT RUNWAYS
68.	Albany (ALB)			28,1			28,1
69.	Buffalo (BUF)			14,5			14,5
70.	Rochester, NY (ROC)			22,28	22,25		22,25
71.	Syracuse (SYR)			14,10			
72.	Charlotte, NC (CLT)			5,36R	18R,23		
73.	Greensboro, NC (GSO)			23,14			23,14
74.	Raleigh (RDU)			32,5			32,5
75.	Grand Forks, ND (GFK)			26,35			26,35
76.	Cincinnati (CVG)	27R,27L (1700')		27L,36			27R,27L
77.	Columbus (CMH)	10L,10R (2800')		10R,5	31,28R		31,28R
78.	Dayton (DAY)			18,24L	6L,36		18,24L
79.	Oklahoma City (OKC)			12,17R	12,17L		12,17R
80.	Tulsa (TUL)			17R,26			17R,26
81.	Eugene (EUG)						
82.	Portland (PDX)		28L,28R (3100')	10R,2			10R,2
83.	Providence, RI (PVD)	5L,5R (1700')		34,5L			34,5L
84.	Charleston, SC (CHS)			33,3			3,33
85.	Sioux Falls, SD (FSD)			3,33			3,33
86.	Knoxville, TN (TYS)	4L,4R (1200')					4L,4R
87.	Nashville, TN (BNA)	2L,2R (1800')		2L,31			2L,2R
88.	Austin, TX (AUS)			35L,31L			35L,31L
89.	Dallas Love (DAL)		31L,31R (3000')	36,31R			36,31R
90.	El Paso (ELP)	26L,26R (1200')			22,26R		22,26R
91.	Houston Hobby (HOU)			17,22			17,22
92.	San Antonio (SAT)			12R,21L			
93.	Salt Lake City (SLC)		16L,16R (3500')		14,16L		14,16L
94.	Burlington (BTV)						
95.	Norfolk (ORF)			23,14			23,14
96.	Spokane (GEG)			2,25			2,25
97.	Charleston, WY (CRW)			23,32			23,32
98.	Madison, WI (MSN)			36,31	18,22		18,22
99.	Washington, DC (IAD)				12,19L	12,19R,19L	
100.	Casper, WY (CPR)				30,34		
101.	San Juan, PR (SJU)				25,28		

4. EVALUATION OF DELAY SAVINGS -- METHODOLOGY

4.1 General Introduction

Section 3 tabulated the airports where each of the new concepts could be applied, based upon the existing runway layout. In this section, the benefits at each airport of implementing each concept will be addressed.

The actual reduction in delay which can be expected is a function of both the improvement in capacity as a result of concept implementation, and the level and pattern of demand at each airport. For example, it may be possible to double the capacity at a given airport, but if demand is much less than the original capacity, the original small delay would be virtually unaffected.

To calculate the delay savings possible through implementation of the new concepts, the following procedure was followed:

- The level of future demand in 1982 was calculated, and the daily demand was divided into 24 hours to construct a daily demand profile.
- The capacity of each airport was then calculated for each applicable concept.
- Lastly, the demand profiles and capacity values were used as input to an analytical model that calculated the total daily delay.

Each of these steps will be described in more detail in the following sections.

Demand, capacity, and delay have been calculated only for arrival operations. Consideration of departures as well would have masked the impact of the new concepts being analyzed here, which only affect the arrival capacity of the airport. If, for example, arrival and departure operations share the same runway, the arrival delay in a given hour would be affected by the departure demand during the hour, a factor affected only indirectly by the new concepts.

Because of the time and expense involved in the delay calculations, only the top thirty airports were analyzed in detail. For the remaining seventy-one airports, some general conclusions were drawn from a study of three typical airports.

4.2 Demand Calculations

Demand was forecasted for the 1982 period. This time frame was chosen to show the benefits which could be achieved if the new concepts were available today. A forecast was necessary because actual daily demand profile data was not available for any year after 1978. An unconstrained demand has been computed; that is, the likely effects of excessive demand at an airport (namely, the shift of traffic to other hours or even other airports) have been ignored.

The hourly profile of demand was derived in two parts; scheduled arrivals and general aviation traffic were treated separately. The distinction was necessary because different data were available for each category.

To compute the future demand profile for scheduled traffic, an actual daily profile was first obtained from Reference 14, Profiles of Scheduled Air Carrier Operations by Stage Length, August 1979. This report gives the number of scheduled arrivals, by hour, for the top 100 U.S. airports. Included are domestic trunk, local service, international (U.S. flag and foreign flag), air commuter, intrastate and all-cargo operations. All data is based upon the same day -- Friday, 4 August 1978 -- which is expected to be a typical busy day for scheduled operations. This was the most recent daily profile data available.

The 1978 hourly profiles were then scaled up to reflect the forecast levels of scheduled traffic in 1982 at each airport. For each hour:

$$\text{1982 arrivals} = \text{1978 arrivals} * \frac{\text{1982 total scheduled ops.}}{\text{1978 total scheduled ops}}$$

The total scheduled operations were obtained from Reference 15, Terminal Area Forecasts, Fiscal Years 1981 - 1992, which also includes actual data for the years 1976 - 1979. The total for itinerant air carriers plus air taxi/commuters was used.

Unfortunately, hourly profile data was not available for general aviation, at least not for all of the top thirty airports. Eight of the top thirty, plus twenty-two other airports, are included in Reference 16, Hourly Airport Activity Profiles, which categorizes hourly traffic by air carrier, air taxi/commuter, general aviation and military for selected days in June, July and August 1978. Arrivals and departures are not separated.

This data was used to construct a standard daily profile of general aviation traffic, which was then applied to all airports. Table 4-1 compares the standard profile with actual operations at four different airports. Forecasted levels of itinerant general aviation traffic (from Reference 15) were then applied to this standard profile to derive an hourly demand profile for average general aviation arrivals.

These two demand profiles (air carrier and general aviation) were then added together to form a total arrival demand, by hour, for each airport. The resulting demand profiles for 1982 are tabulated in Appendix A. This demand, representing a busy day for scheduled traffic and an average day for itinerant general aviation traffic, is expected to be representative of future conditions, although not exact.

4.3 Capacity Calculations

Capacity was calculated using the Upgraded FAA Airfield Capacity Model (Reference 17). This model computes the maximum throughput of the given runway configuration by first calculating an average time between successive arrivals, then inverting this value to give the number of arrivals per hour.

The arrival capacity for some of the new concepts could not be obtained directly from the FAA Capacity Model. These capacities were calculated as follows:

- Independent Converging Approaches -- equal to the capacity of independent parallel approaches.

- Dependent Converging Approaches -- calculated by the method outlined in Appendix D of Reference 11. This capacity is dependent upon the geometry of the runway layout, particularly the threshold locations.

- Independent/Independent Triple Approaches -- since all three runways are independent, this capacity is simply three times the capacity of a single runway.

TABLE 4-1

COMPARISON OF STANDARD DEMAND PROFILE FOR GENERAL AVIATION TRAFFIC WITH ACTUAL DATA

		PERCENT OF DAILY GENERAL AVIATION OPERATION[1]			
HOUR	STANDARD PROFILE	O'HARE ORD	WASHINGTON DCA	NASHVILLE BNA	PHOENIX PHX
1	0.86%	2.2%	0.9%	1.2%	0.5%
2	0.86	1.1	0.5	0.7	0.3
3	0.86	1.1	0.0	0.5	0.3
4	0.86	0.5	0.5	0.2	0.1
5	0.86	1.1	0.5	0.2	0.3
6	0.86	1.1	0.5	0.5	1.3
7	0.86	1.1	0.9	0.5	6.0
8	0.86	2.2	3.3	1.2	8.4
9	5.6	4.9	6.2	3.6	8.6
10	7.0	6.5	7.1	5.5	8.5
11	7.0	5.9	7.1	6.3	7.4
12	7.0	4.3	6.7	6.5	7.0
13	7.0	5.4	5.7	7.5	6.1
14	7.0	5.4	6.7	6.7	5.9
15	7.0	5.4	6.7	6.7	5.9
16	7.0	7.0	8.6	7.5	5.7
17	7.0	8.1	8.6	7.9	6.1
18	7.0	8.1	8.1	8.4	6.5
19	7.0	7.0	6.7	8.2	5.5
20	4.9	6.5	4.3	6.7	3.5
21	4.2	5.4	4.3	5.5	2.9
22	3.5	3.8	2.9	3.4	1.7
23	2.8	3.2	2.4	2.9	0.8
24	2.1	2.7	0.9	1.7	0.7
	99.98%	100.0%	100.1%	100.0%	100.0%

[1] Source: Reference 16

- Independent/Dependent Triple Approaches -- capacity is equal to the calculated capacity of the dependent pair, plus the capacity of the single runway.

- Dependent/Dependent Triple Approaches -- assumed to be equal to 150 percent of the capacity of one dependent pair, although it is likely to be slightly less.

Appendix B contains the input values used to compute capacity, and the capacity results. The input values reflect current-day performance of aircraft and the ATC system.

The forecasted fleet mix, a necessary input to the capacity calculations, was calculated for each of the top thirty airports as follows. Total operations for 1982 were obtained from Reference 15, divided by air carrier, air taxi/commuter, and general aviation. All general aviation operations were assumed to be Class A, small aircraft less than 12,500 pounds. Air taxi/commuter operations were assumed to be 25 percent Class A and 75 percent Class B, large propeller aircraft over 12,500 pounds.

The mix of air carrier aircraft was obtained from Reference 18, Airport Activity Statistics of Certificated Route Air Carriers, for the 12 months ending June 30, 1978. This report contains the number of operations by aircraft type for all U.S. airports. These aircraft types were categorized into Class B, Class C (large jet aircraft under 300,000 pounds) and Class D (heavy jets over 300,000 pounds) according to the groupings in Table 4-2.

The resulting fleet mix for the future years is only a rough approximation, for several reasons. First, the classification of general aviation and air taxi/commuter operations is only a crude estimate. Secondly, the classification of air carrier operations does not consider the fleets of foreign air carriers, which can be significant at airports like JFK or Miami. Lastly, the mix of aircraft serving a particular airport is quite likely to vary over time, as air carriers change the composition of their fleets and vary the type of aircraft used on particular flights.

However, the fleet mix used has less of an effect on airport capacity than the type of instrument approaches in use, as can be seen in Appendix B. Different fleet mixes were calculated for each airport in an attempt to represent the actual characteristics of each airport, but the delay savings calculated for each new concept are more directly affected by

TABLE 4-2

CATEGORIZATION OF AIR CARRIER AIRCRAFT

CLASS B	CLASS C	CLASS D
large prop >12,500 lb	large jet 12,500- 300,000 lb	heavy jet >300,000 lb
CV340	BAC 111	A300
CV580	B707-100B	B707-300
CV600	B720	B707-300B
DHC-6	B727-100	B707-300C
FH227	B727-100C/QC	B747
L-188	B727-200	B747SP
M404	B737-200	DC8-50
METRO	DC8-20	DC8-61
MO298	DC9-10	DC8-62
YS11	DC9-30	DC8-63
	DC9-50	DC10-10
		DC10-30
		DC10-40
		L-1011

the level of demand at each airport than by the particular fleet mix used.

Partially for this reason, the simplifying assumption was made that the same fleet mix applied to all runways, regardless of other factors. In actual practice, one runway might be too short for heavy aircraft to use, or another runway might be preferred by air carriers because it is closer to the terminal. Such factors would affect the aircraft mix, and therefore the capacity, of that individual runway. However, the effect on the overall airport capacity is not always as great. In addition, the difficulty of determining the aircraft mix by runway, combined with the limitations of the analytical tools used in this study, led to the decision not to attempt a more sophisticated analysis.

4.4 Delay Calculations

4.4.1 Top 30 Airports

Given the hourly demand profile and the arrival capacity, it was possible to calculate the expected delay. A version of the MIT "DELAYS" model was used (Reference 19) to calculate the delay at the top 30 U. S. airports. This analytical model solves a number of time-dependent queueing equations to compute the average delay per aircraft during each hour. This average delay was then multiplied by the hourly demand and summed over the 24 hours to provide a total daily delay (over all aircraft). The results are tabulated in Appendix C.

This resulting total delay represents 24 hours of continuous IFR operations on the given runway configuration. To reflect the occurrence of actual IFR conditions these totals were multiplied by the percentage of IFR conditions to derive an expected daily IFR delay. Reference 20 was used to obtain the annual percentage of IFR weather, between 1500 ft ceiling and 3 mi visibility (the minimums used in the report for VFR conditions) and 200 ft/0.5 mi (CAT I minima).

Table 5-1 will present the recorded percentages of IFR conditions which were used, and the resulting expected IFR delays.

4.4.2 Remaining Airports

The above procedure for calculating demand profiles, runway capacity, and expected delay was not followed for the remaining 71 airports being studied. It was felt that the major benefits of the new concepts would accrue to the top 30 airports where the air carrier demand was highest. The time and expense required to perform the delay calculations for the remaining 71 airports did not seem justifiable.

However, detailed delay calculations were performed for three of the 71 airports to illustrate the effect of the multiple IFR approach concepts on the delay at these less busy airports. These three airports were Wichita, Kansas (ICT), ranked 62nd in air carrier operations and 48th in total itinerant operations in FY 1980 (Reference 13); San Diego, California (SAN), 34th in air carrier and 69th in total itinerant operations; and Providence, Rhode Island (PVD), 80th in air carrier and 84th in total itinerant operations. These three airports were chosen to provide a range of total demand, representative of all 71 remaining airports.

Daily demand profiles for each were calculated as described above. Individual fleet mixes were also computed, but these were merged into a composite mix. This was done to provide the same capacity at all three airports for the same configuration; therefore, only the different demands would affect the delay results. These results will be discussed in Section 5, along with the results for the top 30 airports.

If it is felt that these three airports are not truly representative of the remaining airports, or if more detailed results are desired for a particular airport, an alternative methodology is available for calculating delays. The FAA "Capacity Handbook" (Reference 21) may be used. This method is less expensive and more widely available than the computer models described above, but the results tend to be more approximate.

The "Capacity Handbook" uses a series of graphs to determine the capacity and delay of a given runway configuration. First, the mix of aircraft types and the daily demand profile are derived using the methodology described above or using data from other sources. Hourly capacity is then obtained from a curve of hourly operations versus the "mix index", a surrogate variable equal to the percentage of large aircraft (over 12.500 lb) plus triple the percentage of heavy aircraft (over 300,000 lb) in the mix. Three curves are presented in each graph, representing 40%, 50%, and 60% arrivals; sixty-two such graphs are included for different runway configurations under different meteorological conditions.

A second set of graphs relates the mix index to the Delay Index, given the ratio of demand to capacity; then the Delay Index is used to determine the average delay per aircraft through another series of curves. This average delay is then multiplied by the hourly demand to obtain total delay for the hour; the process is then repeated for each hour to calculate the total daily delay.

There are many opportunities for imprecision using this Capacity Handbook technique. The use of a single number (the mix index) to represent the fleet mix, rather than the exact percentages of each aircraft type, is one source of imprecision. More severe are the successive estimates and interpolations from the many graphical readings necessary, not to mention the approximations inherent in the graphs themselves. Nonetheless, there is no reason to believe that this technique is significantly less accurate than the use of delay-calculating computer programs for computing the relative benefit of different alternative procedures.

5. EVALUATION OF DELAY SAVINGS -- RESULTS

The previous section described the methodology used to calculate the daily delay at 33 U.S. airports for 1982 conditions. In this section, the results of the calculations will be examined, and some conclusions will be derived.

5.1 Top 30 Airports

The total daily delay for each of the top 30 U.S. air carrier airports was calculated; these values were then multiplied by the annual percentage of Category I IFR conditions (between 1500/3 and 200/0.5), to produce an expected daily IFR delay. Table 5-1 shows the reduction in this delay that would result from the ATC concepts under review.

In this table, the new concepts are compared with the existing runway configuration with the highest IFR arrival capacity under current ATC rules.

The expected improvement in daily IFR delay is therefore equal to (delay for best current configuration) minus (delay for new concept), times (annual percentage of Category I IFR conditions). At 16 of the top 30 airports, the best current configuration was a single arrival runway; these airports had the greatest potential for improvement. Ten airports currently have independent parallel approaches in IFR; this capacity can only be bettered by a triple approach configuration. The remaining four airports can currently use dependent parallel approaches with 2.0 nmi diagonal separation in IFR conditions; this capacity can usually be improved, even by a dependent converging approach.

It should be noted that the assessment of "best current configuration" was based solely on the existing runway layout, and did not consider local factors such as noise sensitive areas or equipment limitations which might prevent usage of the configuration.

At two airports, LAX and SEA, this "best current configuration" was also the best future configuration, even under the new ATC procedures. The runway layout at LAX consists of four parallel runways, with 4500 ft between the two inside runways, 6R/24L and 7L/25R. Independent parallel approaches are therefore possible today. Since the 6/24 runway pair and the 7/25 runway pair are both closer than 1000 ft apart, dependent approaches with 2.0 nmi separation are not possible for these runways, ruling out triple parallel approaches as well. There are no converging runways. SEA consists of two parallel runways, less than 1000 ft apart; therefore, only a single approach is possible in IFR.

TABLE 5-1

EXPECTED IMPROVEMENT IN
1982 DAILY IFR DELAY (HOURS)
AT TOP 30 AIRPORTS

		ARRIVAL CONFIGURATION					
AIRPORT	% IFR (1500/3 to 200/0.5)	SINGLE RUNWAY	DEPEN PAR	INDEP PAR	DEPEN CVG	INDEP CVG	TRIPLES
ORD	15			*		0	251[3]
ATL	13			*			28[2]
LAX	23			*			
DFW	8**			*		0	5[3]
DEN	6	*	87		119		
MIA	2			*		0	
SFO	15	*			230		
JFK	14			*		0	
LGA	16	*			161		
DCA	11	*			98		
BOS	15	*	212		254	265	
STL	11	*	168		281		
PIT	16			*		0	1[2]
DTW	13			*		0	0.2[1]
IAH	15	*			81	84	
MSP	13		*	5	4		
MEM	9		*	46	38	46	
SEA	12	*					
TPA	6			*		0	
LAS	0	*			0	0	
CLE	15	*			21		
PHX	0		*	0			
PHL	15	*	183		201		
HNL	1			*		0	
MCI	10	*			2	2	
MCO	6	*	0.5				
EWR	16	*			6	6	
MSY	10	*			4		
FLL	3		*	18	16		
MKE	13	*	26		28	29	

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[1] Dependent/Dependent triples
[2] Independent/Dependent triples
[3] Independent/Independent triples

*Best current configuration
**Observations taken at Dallas Love (DAL)

Even though the new concepts can provide higher IFR operations at Las Vegas (LAS) and Phoenix (PHX) no IFR delay savings can be expected at these airports, because no IFR weather was recorded. At other airports, such as MIA and JFK, no IFR delay savings are indicated because the new ATC concepts do not provide any additional capacity compared to the best current configuration. The new concepts can still provide a benefit, of course, during those times when the "best current configuration" cannot be operated (for example, if one runway is closed for construction). No attempt was made to estimate the probability of such occurrences.

At JFK, the "best current configuration" may be unavailable due to local noise or airspace problems. For example, simultaneous IFR approaches are not authorized for runways 31R and 31L (6650 ft apart) because the missed approaches cannot diverge; both aircraft must turn left to 189°. It is not known if the applicable new concepts would be similarly restricted, or would provide additional capacity.

The remaining airports show expected delay improvements ranging from 30 minutes to 280 hours per day, due to the new concepts. Several airports show improvements in the range of 200 hours per day. The top 30 airports may be ranked by the amount of delay improvement expected, for each concept, as was done in Table 5-2. A table such as this may be useful for deciding which airports are prime candidates for implementation of the new concepts. For instance, Boston (BOS) appears at or near the top of three lists; Philadelphia (PHL) should also be a strong candidate for concept implementation.

5.2 Remaining Airports

In Table 5-2, the less busy airports of the top 30 tend to lie near the bottom of the lists. This is to be expected. Without as much demand as one of the top 10 airports, these airports would have less delay, and therefore the new concepts would provide less improvement in the delay.

This would also be expected for the remaining 71 airports. These airports have less air carrier demand than the top 30 airports, and generally less total demand as well. The new concepts would therefore be expected to provide less delay improvement at one of the 71 airports than at one of the top 30. This may be illustrated by the detailed delay results obtained for three typical smaller airports. Table 5-3 presents the capacity values, total daily delay, and expected IFR delay improvement which were calculated for the three typical

TABLE 5-2

TOP 30 AIRPORTS RANKED BY EXPECTED IMPROVEMENT IN IFR DELAY BY CONCEPT

DEPENDENT PARALLEL	INDEPENDENT PARALLEL	DEPENDENT CONVERGING	INDEPENDENT CONVERGING	TRIPLE APPROACHES
BOS (211 hr)	MEM (46 hr)	STL (281 hr)	BOS (265 hr)	ORD (251 hr)
PHL (183)	FLL (18)	BOS (254)	IAH (84)	ATL (28)
STL (168)	MSP (5)	SFO (230)	MEM (46)	DFW (5)
DEN (87)		PHL (201)	MKE (29)	PIT (1)
MKE (22)		LGA (160)	EWR (6)	DTW (0.5)
MCO (0.5)		DEN (119)	MCI (2)	
		DCA (98)		
		IAH (81)		
		MEM (38)		
		MKE (28)		
		CLE (21)		
		FLL (16)		
		EWR (6)		
		MSP (4)		
		MSY (4)		
		MCI (2)		

Note: 1982 demand.
Delay improvement is weighted by probability of IFR conditions.

TABLE 5-3

DETAILED 1982 DELAY RESULTS FOR
THREE TYPICAL SMALLER AIRPORTS

		ARRIVAL CONFIGURATION					
						TRIPLES	
	SINGLE RUNWAY	DEPENDENT PARALLELS	INDEPENDENT PARALLELS	DEPENDENT CONVERGING	INDEPENDENT CONVERGING	IND/DEP	IND/IND
CAPACITY[1]	24.7	34.6	49.3	43.0	49.3	59.3	74.0
TOTAL DAILY DELAY (HR)							
ICT	31.8	8.9	3.3	4.7	3.3	2.0	1.2
SAN	16.4	5.7	2.3	3.2	2.3	1.4	0.9
PVD	9.3	3.5	1.4	2.0	1.4	0.9	0.6
EXPECTED IFR DELAY IMPROVEMENT OVER SINGLE RUNWAY (HR)							
% IFR							
ICT 9%	--	2.1	2.6	2.4	2.6	2.7	2.8
SAN 18%	--	1.9	2.5	2.4	2.5	2.7	2.8
PVD 17%	--	1.0	1.3	1.2	1.3	1.4	1.5

1 Same typical fleet mix assumed for all three airports: 75% A, 10% B, 15% C, 0% D.

airports. Since these results are intended to be illustrative of other airports as well, all concepts were included, whether or not they are applicable at the three specific airports. Similarly, the expected delay improvement was calculated relative to single runway operations, although this may not be the best current configuration at each airport. This maximizes the delay improvement attributable to a concept, which nevertheless is not great.

Total daily delay at each of the three airports is less than that for most of the top 30 airports (MCO has more air carrier traffic but less total itinerant traffic than ICT or SAN, and therefore less delay). Delay improvement is also less, especially when the annual probability of IFR conditions is included. These airports are not likely to be prime candidates for the new concepts. It was not felt necessary to perform detailed delay calculations for all the 71 smaller airports.

If delay results for one of the other airports are desired, the handbook methods described in Section 4.4.2 may be used; alternatively, the results for the three typical airports can be used to provide a very rough approximation of the delay. In Figure 5-1, the total daily delay for these three airports is plotted against the arrival capacity. Three different levels of demand are shown: about 300 operations per day (ICT), 250 operations (SAN) and 200 operations (PVD). If demand is less than 300 operations per day and the approximate capacity is known, this figure can be used to derive an approximate daily delay. These curves are not valid if the arrival demand during any single hour exceeds the capacity; in this case, new arrivals would join an ever-lengthening queue, and total delay rises rapidly.

Although the non-"top 30" airports may not be prime candidates for implementation of the new concepts, these concepts are still beneficial. If the new concepts are authorized and approved, even a small delay reduction could be worthwhile, providing the costs were not high.

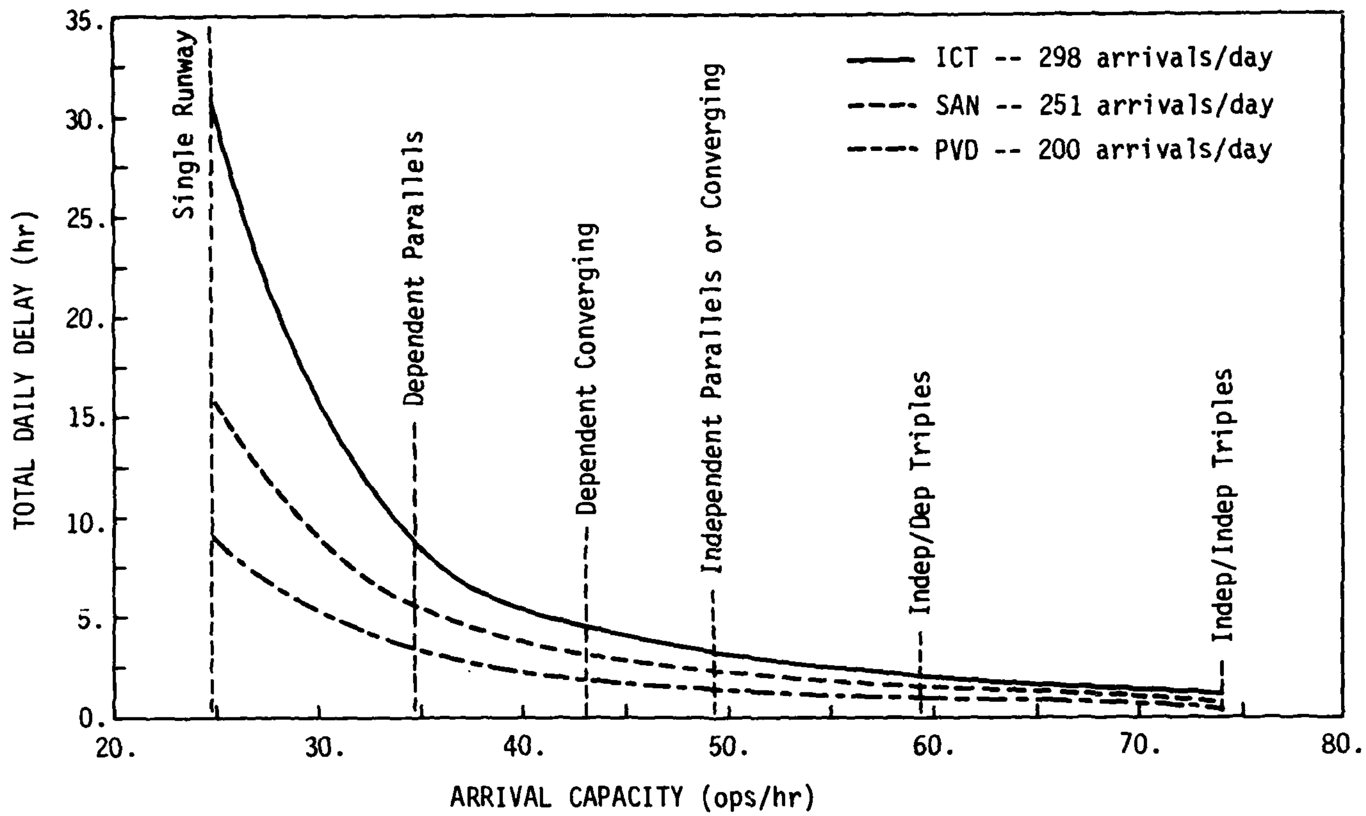

FIGURE 5-1
CAPACITY VS. DELAY AT THREE TYPICAL SMALLER AIRPORTS

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

This report has been a first attempt to define the applicability and benefits of several new concepts for multiple IFR approaches. These new concepts include:

- Dependent parallel approaches, with 2.0 nmi diagonal separation, at reduced centerline spacing (1000 to 2999 ft)
- Independent parallel approaches at reduced centerline spacing (3000 to 4299 ft)
- Independent and dependent approaches to converging runways
- Triple approaches

The runway layouts of 101 top U.S. airports were reviewed to determine whether any of these concepts would apply to the current runways. Only the physical characteristics of the runway were considered; other local conditions, such as special noise restrictions or equipment limitation, were not examined for determining concept suitability.

A detailed analysis was then performed for the top 30 U.S. air carrier airports to determine the expected benefit of the new concepts. The total daily delay for a forecasted 1982 demand was computed for the best current configuration at each airport as well as for each feasible and favorable new concept. These results were then compared to derive an expected IFR delay improvement.

6.2 Conclusions

Of the 101 airports studied for this report, it was found that:

- Sixteen were suitable for close-spaced dependent parallel approaches.
- Ten were suitable for close-spaced independent parallel approaches.
- Sixty-eight had converging runways which could only be operated dependently (a total of 84 airports had converging runways).

- Thirty-one had converging runways which could be operated independently below 1000 ft ceiling/3 mi visibility.

- Six airports had triple runway configurations.

6.3 Recommendations

This study has shown that the concepts under review can be applied at a large number of airports, with potentially large delay savings, without requiring new runway construction. More detailed analyses can provide additional information about the value of these concepts.

The next step should be the conduct of proof-of-concept testing, using the preliminary operational procedures developed for each new concept. This concept demonstration phase would probably involve actual test flights at the Technical Center at Atlantic City, NJ, and at one of the airports where implementation is foreseen. The ranking of delay savings in this report should be useful to the selection of a demonstration site.

Once the site (or sites) is chosen, a more detailed determination of applicability and benefit could be performed. Local factors could then be properly accounted for, such as:

- Airspace restrictions

- ILS installation problems

- Obstructions

- Departure demand patterns

- Wind and weather patterns

- Other operational restrictions

With more detailed data, it would be possible to incorporate the effects of variations in the aircraft mix by runway or by hour, or variations in demand over the year. Alternatively, data could be collected for a typical day, and the effect of the new concept on that day's operations could be analyzed.

It is recommended that these tests be conducted, leading to the demonstration and eventual implementation of one or more of the new concepts for multiple IFR approaches presented in this report.

APPENDIX A

DAILY ARRIVAL DEMAND PROFILES

Table A-1 shows the daily arrival demands which were used in the calculation of 1982 daily delays. Total daily demand is divided among 24 hours as described in Section 4.2.

Demand profiles are presented for the top 30 U.S. air carrier airports, as well as three typical non-"top 30" airports: Wichita, KS (ICT), San Diego, CA (SAN), and Providence, RI (PVD).

TABLE A-1

1982 DAILY ARRIVAL DEMAND PROFILE

	AIRPORT					
HOUR	ORD	ATL	LAX	DFW	DEN	MIA
1	19	5	18	10	8	20
2	16	2	15	8	6	6
3	12	2	5	1	1	7
4	6	1	4	4	3	2
5	7	2	6	10	2	1
6	32	31	4	14	3	3
7	8	2	16	13	2	10
8	53	6	27	43	15	9
9	52	50	37	20	54	19
10	65	89	33	31	56	18
11	75	29	56	58	57	16
12	53	68	63	46	59	48
13	75	35	42	53	38	61
14	84	45	40	42	48	27
15	78	48	45	51	42	40
16	66	63	40	34	52	37
17	78	56	42	49	38	50
18	73	80	51	61	68	32
19	63	33	46	32	51	26
20	72	95	65	48	53	20
21	76	15	40	55	31	24
22	34	54	41	30	31	22
23	27	13	39	17	21	23
24	21	84	28	17	14	17

TABLE A-1
(Continued)

HOUR	AIRPORT SFO	JFK	LGA	DCA	BOS	STL
1	13	9	1	2	5	1
2	11	6	1	1	3	5
3	8	8	1	1	2	1
4	1	2	1	1	2	3
5	3	1	1	1	2	1
6	6	4	1	2	1	11
7	8	10	4	6	3	7
8	27	15	16	16	20	26
9	27	14	32	33	43	67
10	30	14	28	33	33	50
11	38	13	33	35	26	22
12	48	14	36	30	41	45
13	35	9	32	32	35	49
14	27	19	31	35	38	45
15	37	24	29	32	35	37
16	26	37	35	34	51	49
17	38	49	34	34	36	58
18	36	39	37	34	46	47
19	41	28	34	35	55	49
20	44	37	30	29	35	50
21	36	29	36	32	29	36
22	18	19	27	26	24	16
23	17	13	11	19	15	28
24	17	6	9	3	15	17

TABLE A-1
(Continued)

HOUR	PIT	DTW	IAH	MSP	MEM	SEA
	AIRPORT					
1	3	7	2	4	25	5
2	8	6	5	4	19	4
3	2	6	1	2	4	1
4	4	4	1	2	3	1
5	2	4	3	1	3	2
6	2	7	1	2	3	6
7	3	6	11	5	5	12
8	30	12	19	14	13	18
9	35	22	14	24	55	10
10	38	28	28	31	26	15
11	25	27	31	30	44	24
12	32	28	27	29	38	21
13	34	26	25	17	28	29
14	34	20	28	26	39	20
15	26	27	36	30	38	19
16	31	30	30	24	43	24
17	43	37	30	49	35	22
18	31	27	36	31	35	21
19	26	25	26	27	41	25
20	41	35	40	30	45	14
21	38	22	31	18	26	34
22	31	29	17	23	15	15
23	16	14	15	19	12	13
24	7	10	16	8	23	19

TABLE A-1
(Continued)

	AIRPORT					
HOUR	TPA	LAS	CLE	PHX	PHL	HNL
1	10	3	7	8	7	2
2	7	6	1	6	2	2
3	1	3	4	3	6	2
4	1	3	3	3	1	3
5	1	3	6	3	2	2
6	3	3	2	4	5	3
7	2	3	8	6	10	4
8	20	7	9	14	29	18
9	15	29	22	35	40	25
10	17	31	28	42	33	42
11	17	42	21	41	33	32
12	34	40	31	37	28	45
13	30	40	23	36	28	42
14	25	33	16	39	34	35
15	30	33	27	37	30	40
16	20	31	26	35	30	42
17	20	42	26	36	39	37
18	27	37	26	41	42	40
19	25	28	28	45	30	42
20	17	32	23	29	38	20
21	19	24	14	22	39	17
22	21	21	21	17	29	20
23	7	11	17	19	20	8
24	11	14	8	12	11	10

TABLE A-1
(Continued)

HOUR	AIRPORT MCI	MCO	EWR	MSY	FLL	MKE
1	1	9	11	6	11	2
2	5	8	4	3	9	3
3	0	1	3	1	7	2
4	1	0	2	1	5	2
5	2	0	4	2	3	2
6	2	0	1	1	3	3
7	0	1	2	6	5	6
8	7	8	12	8	14	13
9	10	6	24	18	42	24
10	21	6	14	15	40	26
11	21	12	14	19	29	25
12	13	18	12	20	42	25
13	21	22	20	21	50	29
14	20	14	11	21	46	26
15	19	14	20	23	41	20
16	13	12	25	18	34	26
17	22	6	22	23	35	27
18	31	14	23	19	43	30
19	17	8	21	21	43	25
20	16	11	16	23	30	21
21	19	11	21	11	27	20
22	16	14	19	9	29	13
23	10	6	17	14	20	10
24	6	4	10	3	14	9

TABLE A-1
(Concluded)

HOUR	AIRPORT ICT	AIRPORT SAN	AIRPORT PVD
1	4	2	1
2	2	3	1
3	2	2	1
4	2	2	1
5	2	1	1
6	3	1	1
7	5	3	1
8	5	3	1
9	18	15	15
10	18	16	13
11	23	13	17
12	18	21	13
13	19	15	16
14	19	14	13
15	18	14	17
16	22	14	14
17	19	17	14
18	17	13	12
19	21	21	12
20	14	12	6
21	11	19	9
22	16	14	8
23	10	11	7
24	8	5	6

APPENDIX B

ARRIVAL CAPACITY

This appendix presents the inputs and results for the capacity calculations for the top 30 airports. Capacity was calculated using the Upgraded FAA Airfield Capacity model (Reference 17).

Table B-1 presents the inputs which were not airport-specific. Nominal values were used for arrival runway occupancy times; in IFR conditions, the required airborne separations result in inter-aircraft intervals which are greater than the runway occupancy times. Using actual occupancy times would therefore have had no effect on capacity.

Table B-2 presents the aircraft fleet mixes which were used in the capacity calculations. Derivations of these mixes was described in Section 4.3.

Lastly, Table B-3 gives the results of the capacity calculations. Capacities were calculated for all applicable concepts at each airport, not just for those which provided an improvement over the best current configuration.

TABLE B-1

CAPACITY CALCULATION INPUT

		AIRCRAFT TYPES			
		CLASS A SMALL PROP <12,500 lb	CLASS B LARGE PROP >12,500 lb	CLASS C LARGE JET 12,500 lb to 300,000 lb	CLASS D HEAVY JET >300,000 lb
RUNWAY OCCUPANCY TIME (s)		40	45	50	55
APPROACH SPEEDS (kn)		100	120	130	140
ARRIVAL-ARRIVAL SEPARATIONS (nmi)	LEAD \ TRAIL				
	A	3.0	3.0	3.0	3.0
	B	4.0	3.0	3.0	3.0
	C	4.0	4.0	3.0	3.0
	D	6.0	5.0	5.0	4.0

FINAL APPROACH PATH LENGTH		5 nmi
PRESENT-DAY ATC SYSTEM:	INTERARRIVAL ERROR	18s
	PROBABILITY OF VIOLATION	5%

TABLE B-2

1982 AIRPORT FLEET MIXES - TOP 30 AIRPORTS

AIRPORT	CLASS A Small Prop <12,500 lb	CLASS B Large Prop >12,500 lb	CLASS C Large Jet 12,500 lb to 300,000 lb	CLASS D Heavy Jet >300,000 lb
ORD	11%	12%	60%	17%
ATL	9	6	74	11
LAX	17	14	42	27
DFW	11	18	65	7
DEN	25	19	47	9
MIA	22	8	50	20
SFO	17	6	50	27
JFK	15	12	32	41
LGA	25	12	61	2
DCA	33	17	49	0
BOS	21	28	43	8
STL	29	14	54	3
PIT	26	20	51	2
DTW	26	13	48	13
IAH	30	14	50	6
MSP	39	10	44	6
MEM	53	11	36	1
SEA	23	19	38	19
TPA	35	10	50	6
LAS	56	11	27	6
CLE	40	9	44	6
PHX	67	5	25	3
PHL	29	31	33	7
HNL	51	18	22	10
MCI	19	28	50	2
MCO	24	7	58	12
EWR	24	18	45	13
MSY	37	9	47	7
FLL	68	3		5
MKE	63	11		2

TABLE B-3

ARRIVAL CAPACITY RESULTS FOR APPLICABLE CONFIGURATIONS AT TOP 30 AIRPORTS -- 1982 AIRCRAFT MIX

	ARRIVAL CONFIGURATION					
AIRPORT	SINGLE RUNWAY	DEPEN PAR	INDEP PAR	DEPEN CVG	INDEP CVG	TRIPLES
ORD	26.8		53.7[1]	44.2	53.7	80.4[2]
ATL	28.0	39.2	56.0[1]			67.2[3]
LAX	25.0		50.1[1]			
DFW	27.3		54.5[1]	40.0	54.5	81.8[2]
DEN	25.5[1]	35.8		39.8		
MIA	25.1		50.2[1]	41.9	50.2	
SFO	25.2[1]			45.1		
JFK	24.5	36.8	49.0[1]	43.4	49.0	
LGA	26.5[1]			45.8		
DCA	26.3[1]			46.1		
BOS	26.0[1]	36.4		44.0	52.0	
STL	25.9[1]	35.9		44.8		
PIT	26.7	37.7	53.4[1]	44.9		64.4[3]
DTW	25.1	35.7	50.3[1]	43.5	50.3	53.6[4]
IAH	25.4[1]			40.5	50.8	
MSP	25.2	36.8[1]	50.4	44.0		
MEM	24.1	33.7[1]	48.2	40.5		
SEA	25.3[1]					
TPA	24.6		49.2[1]	42.6	49.2	
LAS	24.0[1]			40.5	48.0	
CLE	25.2			43.4		
PHX	24.2	34.6[1]	48.4			
PHL	25.2[1]	35.2		41.9		
HNL	23.2		46.5[1]	39.7	46.5	
MCI	27.5[1]			44.2	55.0	
MCO	25.1[1]	35.0				
EWR	25.3[1]			43.8	50.6	
MSY	24.8[1]			43.3		
FLL	24.0	34.7[1]	48.0	42.9		
MKE	24.3[1]	33.9		42.4	48.6	

1 Best current configuration
2 Independent/Independent
3 Independent/Dependent
4 Dependent/Dependent

APPENDIX C

TOTAL DAILY DELAY

The MIT "DELAYS" model was used to calculate the expected delay per aircraft for each hour of the daily demand profile. This number was then multiplied by the number of aircraft to obtain the total hourly delay; these hourly delays were summed to obtain the total daily delay. Figure C-1 illustrates this for a typical case.

Table C-2 presents the total daily delay, for 1982 demand, which was calculated for the top 30 U.S. air carrier airports. The table shows the total delay, in hours, accumulated by all arrivals during the day.

Delay was calculated only for the best current configuration and for applicable new concepts with equal or greater capacity. Other applicable concepts with less capacity are indicated in Table C-2 by dashes. Non-applicable concepts are left blank in the Table.

To illustrate the magnitude of change as concepts are applied to a single airport, Table C-3 was prepared. Note the substantial improvement in delay from employing either of the two new concepts and especially, the dependent converging concept.

TABLE C-1

EXAMPLE OF HOURLY DELAY VALUES

Airport: DFW

Configuration: Independent Parallels

Capacity: 54.5 arrivals/hour

HOUR	DEMAND	DELAY PER AIRCRAFT	TOTAL HOURLY DELAY
0100-0159	8	.003	.03
0200	1	.000	.00
0300	4	.001	.01
0400	10	.004	.04
0500	14	.006	.09
0600	13	.006	.08
0700	43	.040	1.74
0800	20	.013	0.26
0900	31	.022	0.68
1000	58	.102	5.92
1100	46	.142	6.55
1200	53	.157	8.30
1300	42	.132	5.53
1400	51	.129	6.58
1500	34	.074	2.52
1600	49	.081	3.96
1700	61	.188	11.49
1800	32	.127	4.05
1900	48	.087	4.17
2000	55	.150	8.27
2100	30	.075	2.26
2200	17	.010	0.18
2300	17	.008	0.14
2400-0059	10	.004 hr	0.04 hr
			72.9 hr

TABLE C-2

TOTAL 1982 DAILY DELAY (Hours) AT TOP 30 AIRPORTS

	ARRIVAL CONFIGURATION					
AIRPORT	SINGLE RUNWAY	DEPEN PAR	INDEP PAR	DEPEN CVG	INDEP CVG	TRIPLES
ORD	--		1770.	--	1770.	98.1[1]
ATL	--	--	308.			94.2[2]
LAX	--		--			
DFW	--		72.9	--	72.9	11.5[1]
DEN	3350.	1910.		1370.		
MIA	--		--	--	--	
SFO	1590.			50.1		
JFK	--	--	--	--	--	
LGA	828.			25.3		
DCA	918.			24.4		
BOS	1800.	391.		107.	38.6	
STL	2900.	1380.		348.		
PIT	--	--	16.7	--	16.7	8.8[2]
DTW	--	--	10.3	--	10.3	8.4[3]
IAH	571.			31.9	12.7	
MSP	--	52.6	13.2	22.6		
MEM	--	554.	42.6	129.	42.6	
SEA	--					
TPA	--		--	--	--	
LAS	1560.			75.6	27.8	
CLE	149.			10.7		
PHX	--	414.	36.2			
PHL	1400.	176.		55.0		
HNL	--		--	--	--	
MCI	26.3			5.2	2.8	
MCO	9.9	3.6				
EWR	40.2			5.6	3.8	
MSY	41.5			5.3		
FLL	--	649.	58.7	130.		
MKE	229.	29.5		12.0	7.7	

[1] Independent/Independent
[2] Independent/Dependent
[3] Dependent/Dependent

TABLE C-3

EXAMPLE OF HOURLY DELAY RESULTS AT STL

HOUR	DEMAND	DELAY/AIRCRAFT (hrs)**		
		SINGLE RUNWAY (25.9 arr/hr)*	DEPEND. PARALLEL (35.9 arr/hr)*	DEPEND. CONVERGING (44.8 arr/hr)*
0100-0159	5	0.0	0.0	0.0
0200	1	0.0	0.0	0.0
0300	3	0.0	0.0	0.0
0400	1	0.0	0.0	0.0
0500	11	0.0	0.0	0.0
0600	7	0.0	0.0	0.0
0700	26	0.1	0.0	0.0
0800	67	0.9	0.5	0.3
0900	50	2.2	1.1	0.6
1000	22	2.6	1.1	0.4
1100	45	2.9	1.0	0.3
1200	49	3.7	1.3	0.4
1300	45	4.5	1.7	0.4
1400	37	5.0	1.8	0.4
1500	49	5.4	2.0	0.4
1600	58	5.7	2.5	0.6
1700	47	5.7	2.9	0.8
1800	49	5.8	3.2	0.9
1900	50	5.8	3.5	1.0
2000	36	5.7	3.6	0.9
2100	16	5.5	3.3	0.6
2200	28	5.4	2.9	0.3
2300	17	5.2	2.5	0.1
2400-0059	1	4.5	1.8	0.0

* Arrival capacity
** Represents average delay for all aircraft arriving during a specified hour

APPENDIX D

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