Airport Capacity and Delay Analyses

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16. Abstract

This report addresses the benefits achievable in terms of reduced delay and capacity gained at several major airports if products of the Wake Vortex Program were implemented resulting in reduced intrail separation standards. These theoretical separation standards were developed from products of the Wake Vortex Program and were used in a simulation of runway operations at John F. Kennedy (JFK), Boston (BOS), and St. Louis (STL) airports. These products include Vortex Advisory System (VAS), Wake Vortex Avoidance System, (WVAS), Wake Vortex Detection/Monitoring System, and Advanced Wake Vortex Detection/Monitoring System. In addition to site specific airports, generic runway configurations were explored as a means of grouping many airports with similar configurations. The estimates derived from this study include delay time saved in dollars per day and capacity gained in operations per hour for each airport evaluated. It was shown that considerable benefits to the airlines and the economy could be achieved if these wake vortex products were implemented resulting in reduced separation standards.

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1. INTRODUCTION.

1.1 BACKGROUND.

The Federal Aviation Administration (FAA) Research and Development Service requested that a capacity and delay study be performed that would involve new wake vortex separation standards which could be realized by the implementation of wake vortex products. These products include a Vortex Advisory System (VAS), a Wake Vortex Avoidance System (WVAS), a Wake Vortex Detection/ Monitoring System, and an Advanced Wake Vortex Detection/Monitoring System. Theoretical wake vortex separation standards which could be achieved from each of these products are described in appendix A.

Theoretical instrument flight rules (IFR) separation standards for several wake vortex products were provided by Dr. James Hallock, Transportation Systems Center (TSC). Additional separation standards that were evolved from theory and used in the analysis are defined in FAA Report Number FAA-EM-78-8A, "Parameters of Future ATC Systems Relating to Airport Capacity/Delay," dated June 1978.

1.2 PURPOSE.

The purpose of this study was to report the benefits achieved, in terms of reduced delay and increased capacity of specific and generic airports, as a result of reducing wake vortex separation standards. These separation standards would be a result of the specific wake vortex products that are mentioned above. This report provides both guidance and support to the Wake Vortex Program.

1.3 METHOD.

The impact of the proposed wake vortex separation standards which could be achieved from several wake vortex products was evaluated by four methods:

- Arrival capacity analysis of generic runway configurations.
- Capacity and delay analyses of John F. Kennedy (JFK) International airport.
- Recent wake vortex delay analyses of Boston-Logan International (BOS) and Lambert-St. Louis (STL) International Airports.
- Summary of prior wake vortex delay studies.

Appendix A defines the minimum intrail arrival aircraft separations referenced in this report. Appendix B describes the runway delay simulation model, RDSIM, which was used in the analyses.

2. ARRIVAL CAPACITY ANALYSIS OF GENERIC RUNWAY CONFIGURATIONS.

2.1 METHOD.

An IFR arrival capacity study was performed using the runway delay simulation model, the standard separations, and two theoretical separation standards. These new separation standards included a reduced heavy-to-heavy scenario and the reduced separations resulting from the implementation of a detection/monitoring system.

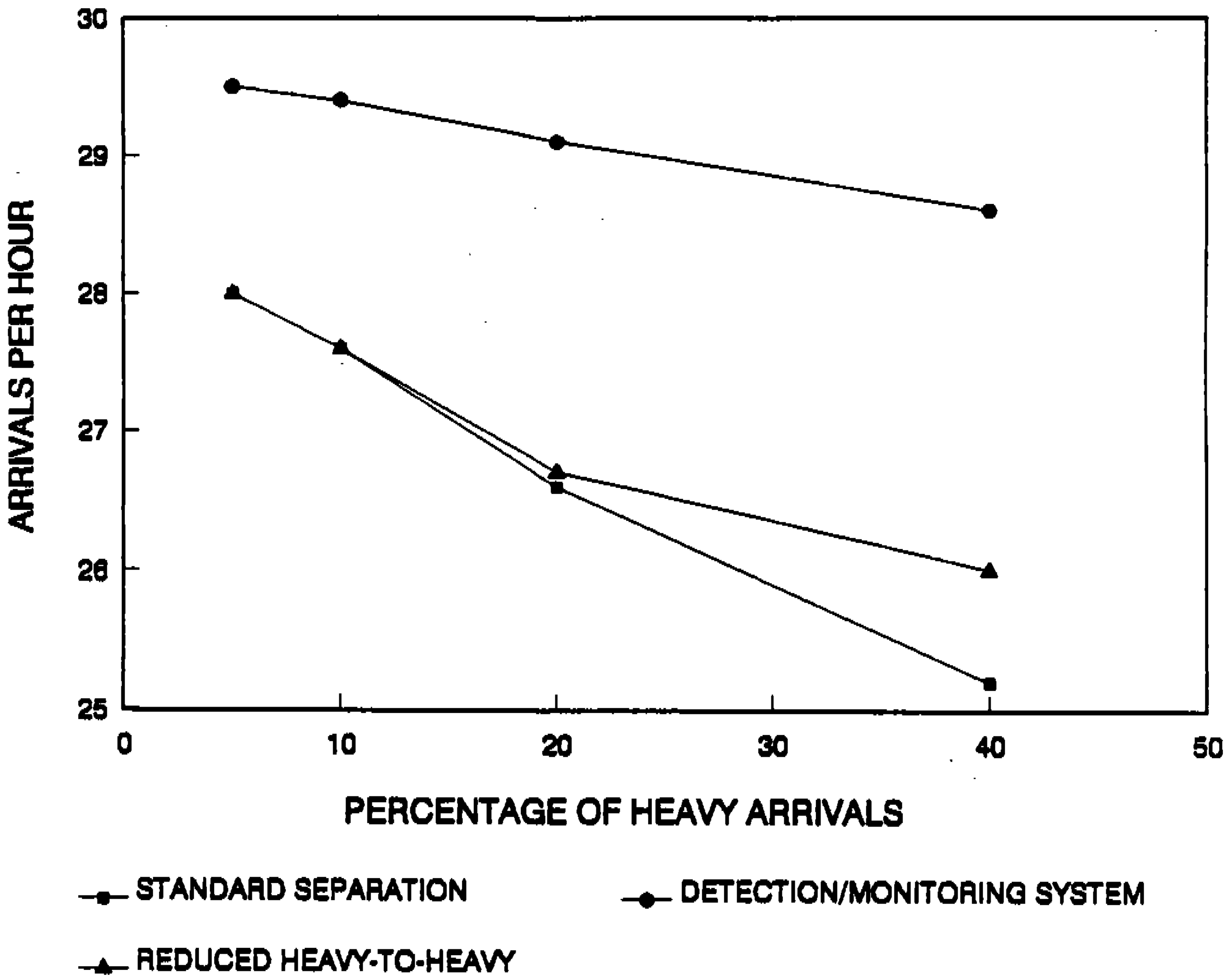
Four categories of generic runway configurations were examined for the purpose of determining improvements in capacity. The configurations were single runway, independent parallel runways, closely spaced dependent parallel runways, and intersecting runways.

The runway configurations were analyzed for the following: (1) 100 percent arrivals, (2) IFR weather, and (3) different percentages of heavy aircraft in the fleet mix (5, 10, 20, and 40 percent). The percentages of heavy and large aircraft varied so that their combined total represented 80 percent of the fleet mix. The remainder of the fleet mix, 20 percent, was small aircraft.

2.2 MODEL RESULTS.

Figure 1 represents the arrival capacity change for a single runway under IFR weather as a function of heavy arrivals for the reduced separation standards of wake vortex products. The chart indicates that the capacity, as determined from each scenario, will decrease with the increase of heavy arrivals. However, when comparing a detection/monitoring system scenario and a reduced heavy-to-heavy scenario to the current standard separation, an increase in capacity results. With as little as 5 percent heavies, the magnitude of this increase is substantial when reduced wake vortex separation standards are implemented as a result of a detection/monitoring system. Figure 1 also shows the contents of the chart in tabular form.

Since independent parallel runways are independent of one another, the gain in capacity realized by the reduced separation standards are double that which is observed in the single runway case. In addition, when operating under IFR, arrivals to closely spaced parallel runways and intersecting runways are treated as if they are landing on a single runway. Thus, the arrival capacity of closely spaced parallel and intersecting runways is that of a single arrival runway.



	STANDARD SEPARATION	DETECTION/ MONITORING SYSTEM		REDUCED HEAVY-TO-HEAVY	
% HEAVY	ARRIVALS/ HOUR	ARRIVALS/ HOUR	% INCREASE	ARRIVALS/ HOUR	% INCREASE
5	28	29.5	5.4 %	28	0 %
10	27.6	29.4	6.5 %	27.6	0 %
20	26.6	29.1	9.4 %	26.7	.3 %
40	25.2	28.6	13.5 %	26	3.2 %

FIGURE 1. ARRIVAL CAPACITY--SINGLE RUNWAY--IFR

3. CAPACITY ANALYSES AT JFK.

In addition to using generic airports, the impact of three products of the Wake Vortex Program on capacity and delay at JFK was studied. This airport was selected because of its large percentage of heavy aircraft operations.

The three products which reduce minimum intrail arrival separations are (1) reduced heavy-to-heavy separations, (2) Wake Vortex Detection/Monitoring System, and (3) Advanced Wake Vortex Detection/Monitoring System. These separation rules are described in appendix A.

3.1 METHOD.

The JFK capacity study employed an analytical technique to determine the saturation capacity of a single arrival runway. The intent of this exercise was to determine the increase in capacity that could be realized if wake vortex separation standards were reduced by the reduced heavy-to-heavy separations, the detection/monitoring system, and the advanced detection/monitoring system. The resulting separation standards for each of these products are described in appendix A.

The analysis was based on arrival priority in which a single runway was used to serve aircraft with a constant demand of traffic while operating at runway saturation. Runway saturation describes the event in which one aircraft lands immediately after another exits the runway. Instrument flight rules were used in the analysis since they provided the greatest gain in capacity when reducing separation standards. The percentage of heavy operations was altered to examine its effect on capacity.

Interarrival spacing was determined by the same fleet mix (47 percent heavy, 42 percent large, and 11 percent small) that was observed at JFK. In addition, an error term was introduced into the analysis to reflect the added time-buffer generally used by the controller to account for the uncertainty of the precision delivery.

3.2 MODEL RESULTS.

Figure 2 summarizes the model's results on a single runway at JFK under IFR weather for several wake vortex products. Each scenario reflects the changes in the number of operations a single runway at JFK could handle for changing percentages of heavy arrivals. The capacity produced by the current standard separation rules tends to steadily decrease with the increase of heavy arrivals. The reduced heavy-to-heavy scenario shows a slight initial decrease in capacity (up to 30 percent heavy arrivals), then a constant increase in capacity from 30 to 100 percent heavy operations. A capacity increase over the current set of separation rules was noted for all percentages of heavy operations for the detection/monitoring system. The capacity of the advanced detection/monitoring system increased substantially, although it was not affected by the percentage of heavies.

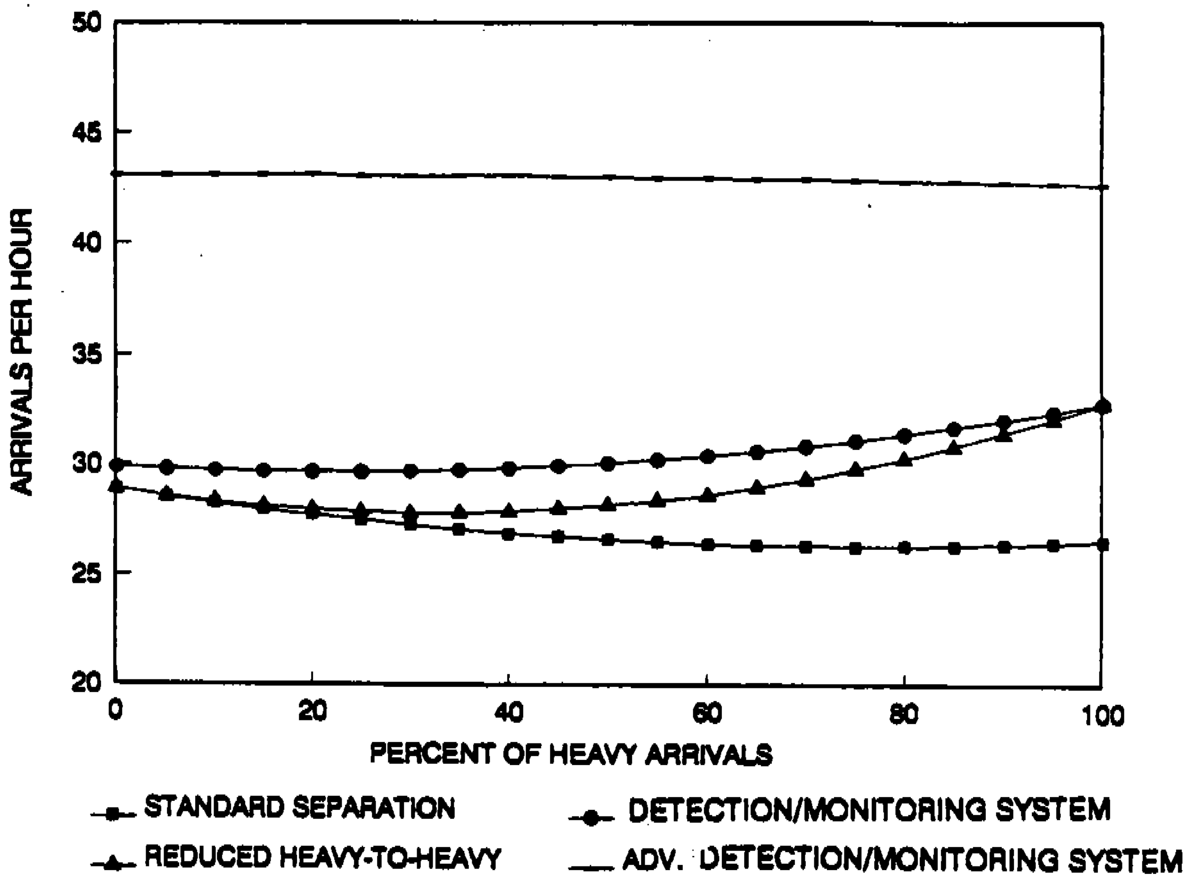


FIGURE 2. JFK ARRIVAL CAPACITY--SINGLE RUNWAY--IFR

4. DELAY ANALYSIS AT JFK.

4.1 METHOD.

Four IFR runway configurations used during IFR weather at JFK were analyzed in the delay study. Each configuration consisted of an "arrival only" runway and a "departure only" runway. The analysis used RDSIM inputs and a 1990 demand forecast from the 1985 JFK Task Force Study. Dollar savings were based on the direct operating costs of the JFK fleet mix for the 1990 demand schedule, $2,088 per hour. Costs were obtained from Avmark, December 31, 1989.

4.2 MODEL RESULTS.

The delay savings for runway configurations which are typically used at JFK under IFR weather conditions are illustrated in table 1. These savings are a result of reducing wake vortex separation standards. Estimates of daily delay savings for the four IFR configurations with the 1990 JFK demand are listed below:

$155 to $173 thousand with reduced heavy-to-heavy separations.
$530 to $572 thousand with detection/monitoring system.
$1.2 million with advanced detection/monitoring system.

TABLE 1. WAKE VORTEX DAILY DELAY SAVINGS AT JFK--IFR
(in hours and thousands of 1989 dollars)

CONFIGURATIONS		REDUCED HEAVY-TO-HEAVY		DETECTION/ MONITORING SYSTEM		ADV. DETECTION/ MONITORING SYSTEM	
ARR	DEP	HOURS	DOLLARS	HOURS	DOLLARS	HOURS	DOLLARS
4R	4L	74	$ 155	265	$ 553	562	$ 1,173
22L	22R	83	$ 173	274	$ 572	574	$ 1,199
31R	31L	77	$ 161	269	$ 562	556	$ 1,161
4R	31L	74	$ 155	254	$ 530	570	$ 1,190
ALL CONFIGURATIONS		$ 155 to $ 173 8 to 9 % SAVINGS		$ 530 to $ 572 29 to 30 % SAVINGS		$ 1,161 to $ 1,199 61 to 64 % SAVINGS	

NOTES: IFR daily delay savings are presented in both hours and thousands of dollars for the JFK 1990 demand.

The dollar savings were based on the direct operating costs of the JFK fleet mix for the 1990 demand schedule--$2,088 per hour. Costs were obtained from Avmark, December 31, 1989.

5. RECENT WAKE VORTEX DELAY ANALYSES AT BOS AND STL.

5.1 METHOD.

A recent task force studied the benefits of reduced wake vortex separations at BOS and STL. They used the simulation model RDSIM and separation standards as described in appendix A for the Vortex Advisory System (VAS) and Wake Vortex Avoidance System (WVAS).

5.2 MODEL RESULTS.

Figure 3 shows the annual delay savings (in thousands of hours) which could be obtained with a VAS at BOS, for both VFR and IFR weather. This system can save approximately $16 million (12,800 hours) each year at the lowest demand and $30 million (24,200 hours) at the highest demand. Similarly, figure 4 shows the annual delay savings of a WVAS at BOS. Savings of $22 million (17,700 hours) each year at the lowest demand and $51 million (41,100 hours) at the highest demand were projected.

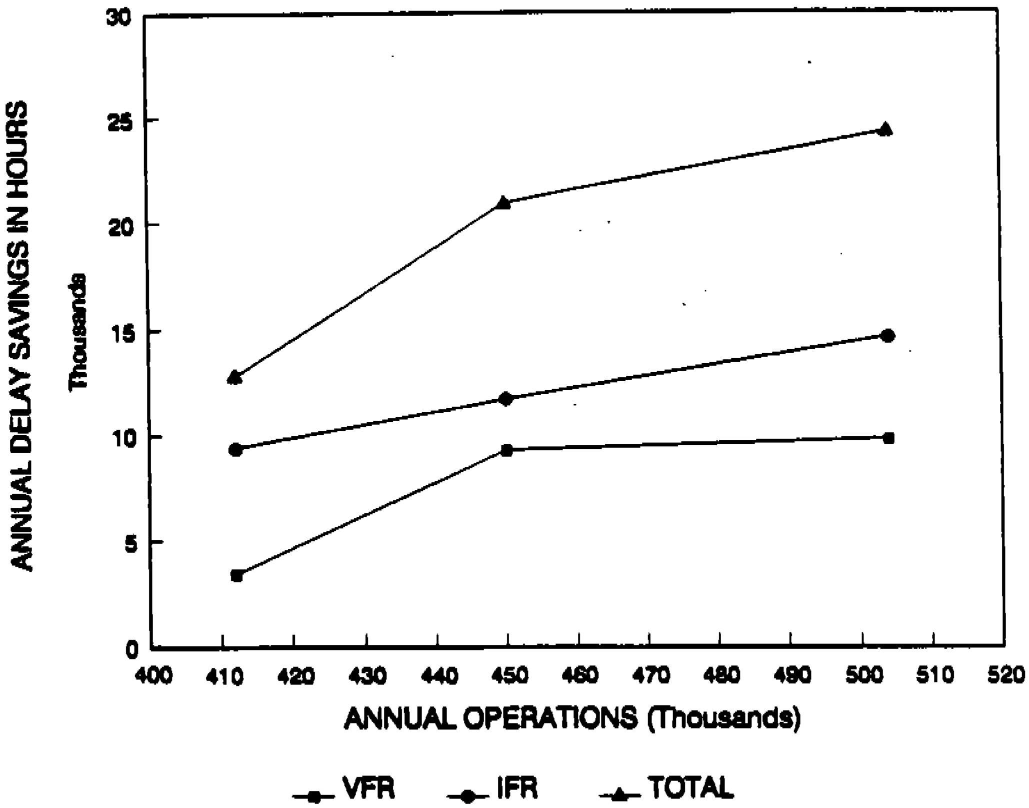


FIGURE 3. VAS ANNUAL DELAY SAVINGS AT BOS

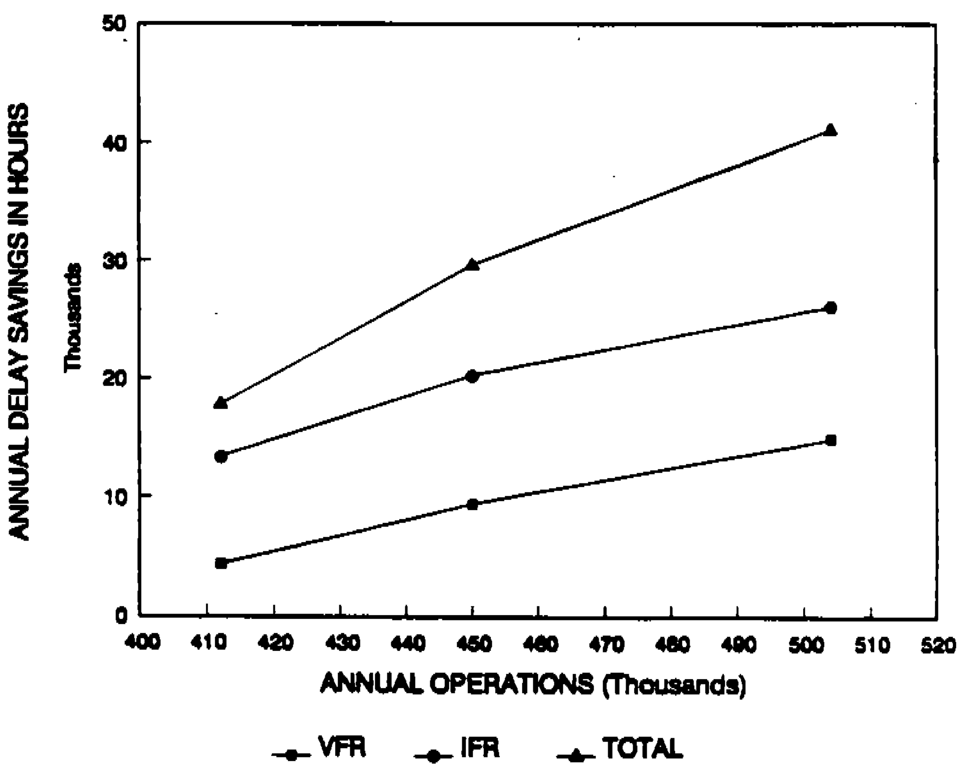


FIGURE 4. WVAS ANNUAL DELAY SAVINGS AT BOS

The curves show the relationship between annual delay savings and projected demand levels. The data may be generalized to determine the delay savings from any new separation standard that falls in the neighborhood of the original VAS and WVAS separations. These savings are based on the direct operating costs of the BOS fleet mix--$1,248 per hour in 1987 dollars.

Figure 5 shows the STL annual delay savings (in thousands of hours) that can be achieved by eliminating the wake vortex runway dependency between closely spaced parallels in VFR weather conditions. This accounts for a savings of approximately $12 million (8,000 hours) each year at the lowest demand and $127 million (86,000 hours) at the highest demand. The dollar savings are based on the direct operating costs of the STL fleet mix--$1,479 per hour in 1987 dollars.

In all cases, the potential delay savings are substantial.

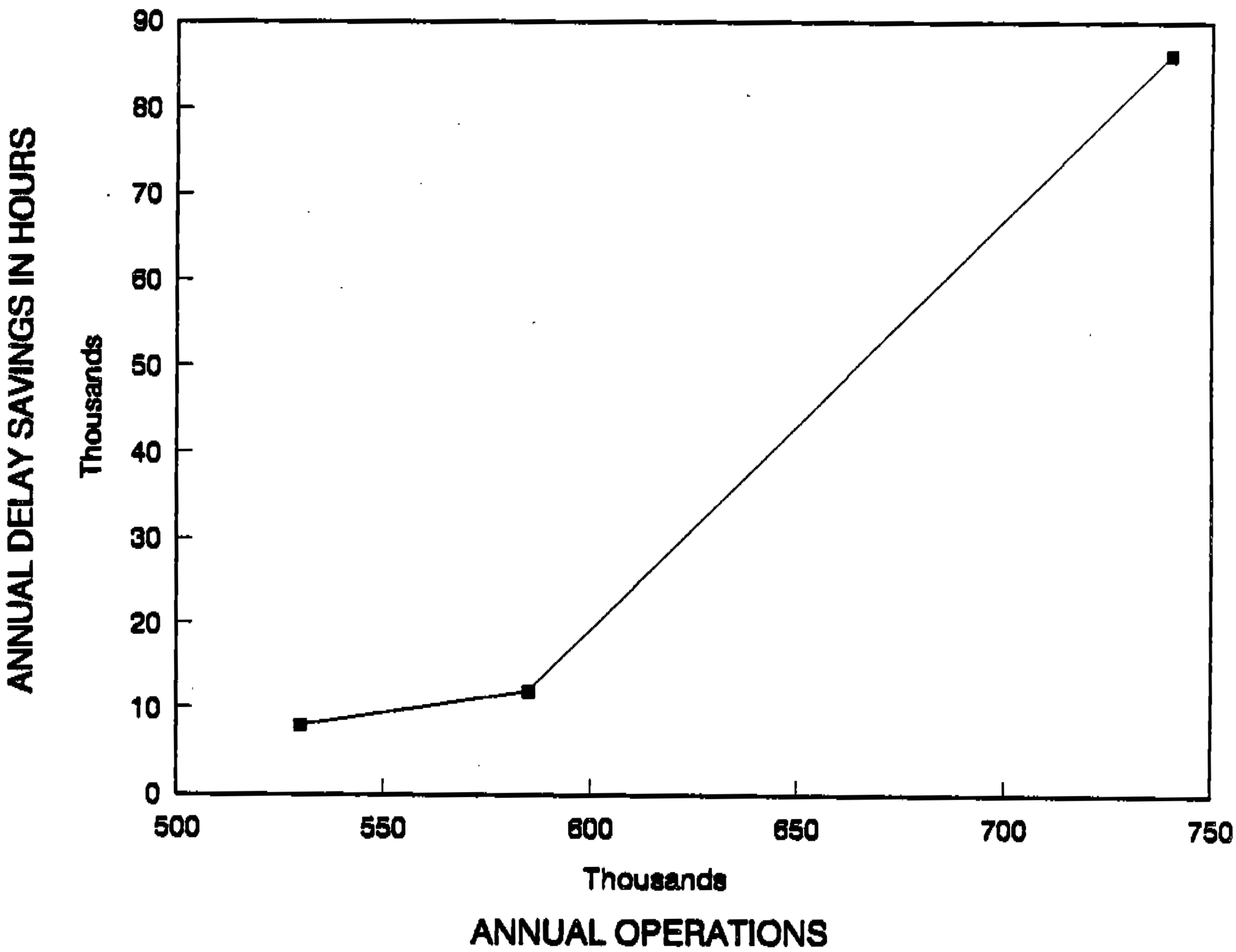


FIGURE 5. WAKE VORTEX ANNUAL DELAY SAVINGS AT STL--VFR

6. SUMMARY OF PRIOR WAKE VORTEX DELAY STUDIES.

Figure 6 summarizes the impact of reduced wake vortex separations for six airports: Atlanta (ATL), Los Angeles (LAX), John F. Kennedy (JFK), Laguardia (LGA), Miami (MIA), and Houston (IAH) using past task force studies and prior descriptions of products of the Wake Vortex Program, VAS and WVAS. These studies were completed between 1980 and 1985 using the simulation model RDSIM.

The curve, derived from the tabular data, shows the relationship between annual delay savings (in thousands of hours) and projected demand levels. The data may be generalized to determine the savings from any new separation standard that falls in the neighborhood of the original VAS and WVAS separations.

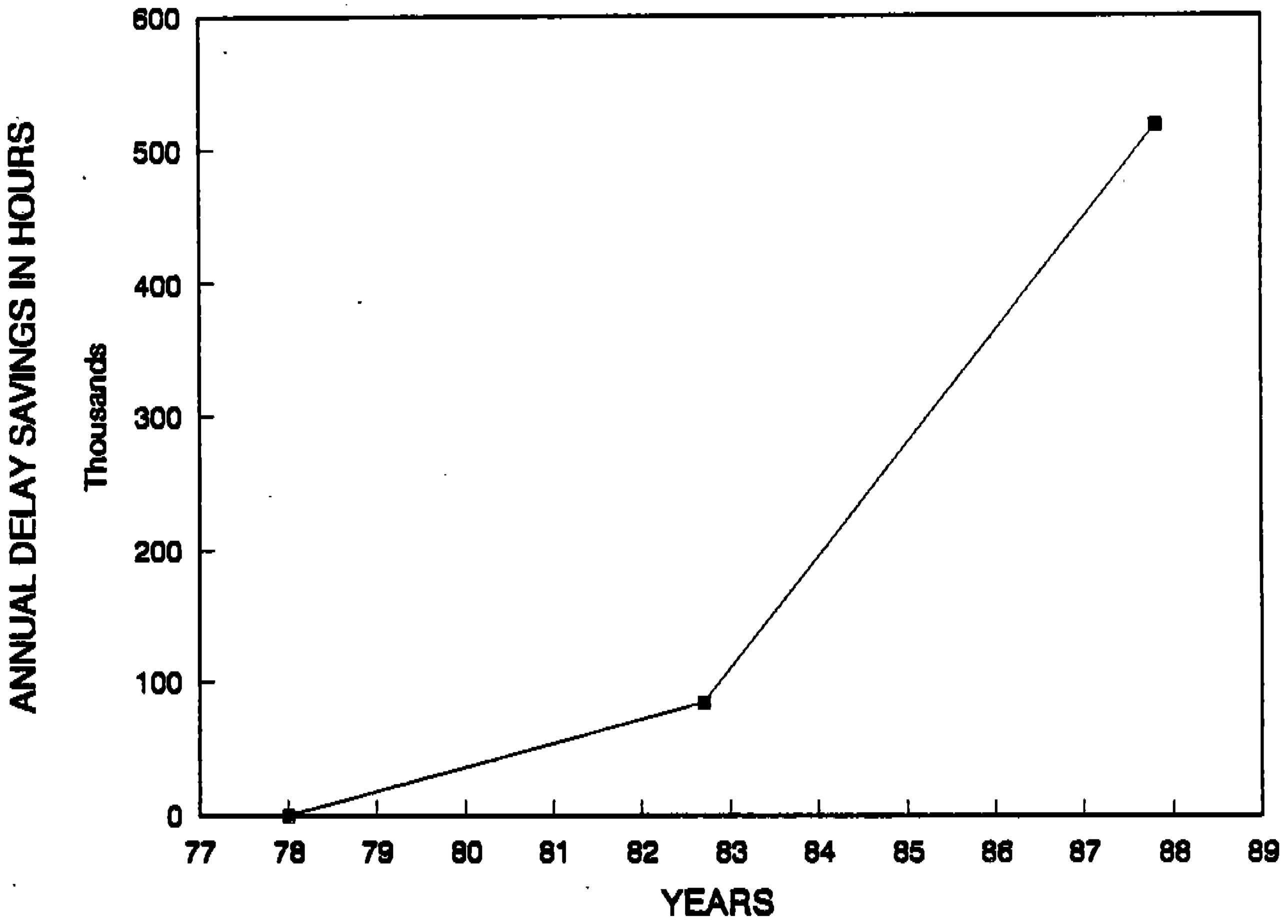
One can estimate the annual delay savings for the reduced separations for a given timeframe in the following way: multiply the number of hours of annual delay savings by the average fleet mix cost for these airports during that timeframe. Using this method, the dollar savings can be adjusted to reflect the impact of inflation on the actual dollar savings.

6.1 VAS ANNUAL SAVINGS (1982-1985).

The 1982-1985 annual savings of 84,100 hours are based on the use of a Vortex Advisory System. With an average fleet mix cost of $2,000 per hour, the VAS could have saved the airlines $168 million per year.

6.2 WVAS ANNUAL SAVINGS (1987-1990).

The 1987-1990 annual savings of 517,000 hours are based on the use of a Wake Vortex Avoidance System. With an average fleet mix cost of $2,000 per hour, the WVAS could have saved the airlines over $1 billion per year.



		VAS ANNUAL SAVINGS (1982-1985)			WVAS ANNUAL SAVINGS (1987-1990)		
AIRPORT	STUDY YEAR	FORECAST YEAR	ANNUAL OPERATIONS	SAVINGS IN HOURS	FORECAST YEAR	ANNUAL OPERATIONS	SAVINGS IN HOURS
ATL	'80	'82	633,000	14,800	'87	753,000	152,000
LAX	'81	'82	518,000	3,100		NOT STUDIED	
JFK	'81	'82	326,000	36,200	'87	331,000	145,000
LGA	'81	'82	327,000	5,900	'87	338,000	49,000
MIA	'81	'83	380,000	7,100	'88	422,000	36,000
IAH	'83	'85	373,000	17,000	'90	481,000	135,000
ALL AIRPORTS		TOTAL		84,100	TOTAL		517,000

FIGURE 6. SUMMARY OF VAS & WVAS ANNUAL DELAY SAVINGS

7. CONCLUSIONS.

1. The analyses show that the products of the Wake Vortex Program can substantially increase airport capacity while significantly reducing delay.

2. The site specific and generic airports analyzed in this report had significant reductions in delay time as a result of reducing wake vortex separation standards (saving millions of dollars).

3. Increases in revenue, which can be attributable to the increase in capacity at these airports, can also show a marketable cause for justifing wake vortex products.

4. As airports serve a higher volume of traffic, the wake vortex products provide even greater annual delay savings.

5. This study concludes that the products developed by the Wake Vortex Program, which will result in reduced intrail arrival separations, can produce considerable benefits to the aviation industry and the economy. However, these benefits can only be realized by safely coordinating operational changes with air traffic procedures.

APPENDIX A

THEORETICAL MINIMUM INTRAIL ARRIVAL SEPARATIONS

Separation values which vary from the standard are shown in **bold** type.

CURRENT SEPARATION STANDARDS (NM):

IFR

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

VFR

TRAIL	LEAD		
	Heavy	Large	Small
Heavy	2.7	1.9	1.9
Large	3.6	1.9	1.9
Small	4.5	2.7	1.9

The remaining separation standards noted in this paper are purely theoretical in nature and would be a direct result of the products of the Wake Vortex Program.

PROPOSED SEPARATION STANDARDS - VORTEX ADVISORY SYSTEM (VAS) (NM):

The VAS was one of the earlier products of the Wake Vortex Program. These separations were defined in the FAA's Report Number FAA-EM-78-8A, *Parameters of Future ATC Systems Relating to Airport Capacity/Delay, dated June 1978.*

IFR

TRAIL	LEAD		
	Heavy	Large	Small
Heavy	3	3	3
Large	3	3	3
Small	4	3	3

VFR

TRAIL	LEAD		
	Heavy	Large	Small
Heavy	2.7	1.9	1.9
Large	3	1.9	1.9
Small	4	2.7	1.9

PROPOSED SEPARATION STANDARDS - WAKE VORTEX AVOIDANCE SYSTEM (WVAS) (NM):

The WVAS was one of the earlier products of the Wake Vortex Program. These separations were defined in the FAA's Report Number FAA-EM-78-8A.

IFR

TRAIL	LEAD		
	Heavy	Large	Small
Heavy	2.5	2.5	2.5
Large	3	2.5	2.5
Small	3.5	3	2.5

VFR

TRAIL	LEAD		
	Heavy	Large	Small
Heavy	2.5	1.9	1.9
Large	3	1.9	1.9
Small	3.5	2.7	1.9

PROPOSED SEPARATION STANDARDS - REDUCED HEAVY-TO-HEAVY SCENARIO (NM):

The following are the intrail separations possible today without Wake Vortex Monitoring/Detection Systems:

IFR

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

PROPOSED SEPARATION STANDARDS - WAKE VORTEX DETECTION/MONITORING SYSTEM (NM):

The intrail separations possible with Wake Vortex Detection/Monitoring equipment and without any changes in operating procedures by controllers or airports are listed below:

IFR

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

PROPOSED SEPARATION STANDARDS - ADVANCED WAKE VORTEX DETECTION/MONITORING SYSTEM (NM):

The separation rules possible under Advanced Wake Vortex Detection/Monitoring Systems are as follows:

IFR

TRAIL	LEAD		
	Heavy	Large	Small
Heavy	2	1	1
Large	3	2	1
Small	5	3	1

APPENDIX B

COMPUTER MODEL AND METHODOLOGY

RDSIM is the short form of ADSIM, the Airfield Delay Simulation Model. ADSIM is a fast-time, discrete event model that employs stochastic processes and Monte Carlo sampling techniques. It describes significant movements by aircraft on the airport and the effect of delay in the immediate airspace. ADSIM was validated in 1978 at Chicago's O'Hare International Airport against actual flow rates and delay data.

RDSIM simulates demand only for the runways and does not consider the taxiway network or the terminal complexes. It provides both capacity and delay information.

Delay Analysis

The experiments were repeated 40 times using Monte Carlo sampling techniques to introduce system variability into each run. The results were then averaged to produce the capacity/delay outputs for a given demand level. Using the same aircraft mix, computer specialists simulated different demand levels for each improvement to generate demand versus delay relationships.

Capacity Analysis

The arrival capacity for the generic runway was calculated using RDSIM. The maximum throughput capacities were based on unlimited arrival and departure queues.