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VORTEX ADVISORY SYSTEM SIMULATION OF CHICAGO O'HARE INTERNATIONAL AIRPORT

Barry E. Keeffe

JULY 1978

FINAL REPORT

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16. Abstract

This report evaluates, in simulation, the procedural implications of the Vortex Advisory System (VAS) on the Chicago O'Hare terminal air traffic control environment. It also attempts to demonstrate any cost benefits/capacity gains which may accrue using reduced VAS aircraft separation criteria on the final approach course based upon meteorological assurance of vortex dissipation. Utilizing the National Aviation Facilities Experimental Center (NAFEC) Digital Simulation Facility (DSF), a real-time simulation of the Chicago O'Hare International Airport airside operations was conducted between March 28 and June 24, 1977. There were 105 data runs of 1 hour and 20 minutes duration completed during this period. Two favored runway configurations were identified (based on O'Hare usage data during 1977) and exercised in the VAS green, standard red, and transition conditions; that is, the green condition reducing separation between all aircraft classes to 3 nmi, the red condition maintaining 3-, 4-, 5-, and 6-nmi standard heavy-jet separation; and the transition between the two conditions under instantaneous and 5-minute warning transitions were evaluated. Three vortex clear zones were exercised: middle marker to touchdown, outer marker to touchdown and 20-nmi fix to touchdown. Test results indicate that (1) no procedural implications emerged which would deter the implementation of VAS at Chicago O'Hare Airport, and (2) arrival rate increases are sufficient to support previous cost/benefit analysis studies conducted by Landrum and Brown Aviation Consultants and Mitre Corporation.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

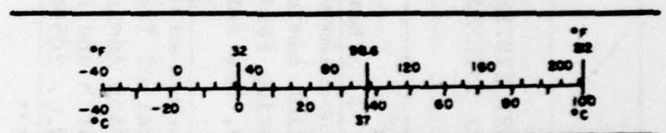


TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

PURPOSE.

The purpose of this report is to summarize the results of a National Aviation Facilities Experimental Center (NAFEC) simulation of the Vortex Advisory System (VAS). The simulation was designed to determine the procedural implications of the VAS on the air traffic control (ATC) system within the Chicago O'Hare International Airport terminal environment.

BACKGROUND.

The introduction of wide-bodied jet aircraft, coupled with an increase in airport total operations, has given added significance to the aircraft wake vortex problem. The trailing wake vortices from a large aircraft can pose a serious hazard to smaller aircraft. The smaller aircraft encountering one of these wake vortices may be subjected to extreme rolling movements which can result in a loss of control, a loss of altitude, and possibly structural damage. At present, to reduce the possibility of this occurring, and thus maintain safety standards, separation between selected aircraft pairs has been increased from previous standards. This, of course, has resulted in a reduction of operations below theoretical airport capacity.

Until recently, limited knowledge concerning the characteristics and behavior of wake vortices mandated these larger separation standards. Studies and tests sponsored by the Federal Aviation Administration (FAA) have shown that vortex characteristics are established initially by the aircraft's gross weight, airspeed, flight configuration, and wingspan. Subsequently, it has been found that vortex characteristics are altered, and eventually dominated, by interactions between the vortices and the ambient atmosphere. This was determined from analysis of over 50,000 vortex tracks entered into the data base at Transportation Systems Center (TSC), and it has led directly to the development of the VAS, a system designed to expedite ATC operations while exercising vortex avoidance.

It has been established that the concept of wake vortex avoidance is based on three considerations supported by available wake turbulence data. These are:

1. For a large percentage of the time, prevalent meteorological conditions exist which cause vortices to move quickly off the flightpath, or decay rapidly in the approach corridor, thus posing no hazard to aircraft following on the same flightpath.

2. The duration, intensity, and movement of vortices can be reliably predicted if adequate knowledge of existing meteorological conditions is obtained.

3. Vortices can be detected and tracked at selected points along the approach or departure paths through the use of existing sensing techniques.

From these considerations, it became evident that airport operations are needlessly limited by using larger separation standards for wake vortex avoidance when no real hazard exists, since vortex behavior can be predicted with sufficient accuracy to permit selection of appropriate smaller separation standards.

From analysis of the extensive data collected on vortex behavior as a function of meteorological conditions, a wind criterion has been developed and tested to determine when aircraft separations can be uniformly reduced to 3 nautical miles (nmi) between all aircraft types, rather than the 3-, 4-, 5-, and 6-nmi separations currently required between approach aircraft pairs of various weight differentials. The VAS was designed to take advantage of this wind criterion. The VAS measures wind magnitude and direction (with respect to each runway heading) for comparison with the wind criterion. The comparison indicates, via a simple red/green light display in the ATC room, when aircraft separations can be safely reduced to 3 nmi for all traffic.

SYSTEM FEASIBILITY.

Chicago's O'Hare International Airport was selected for prior system feasibility tests based on the following criteria: adequate available real estate for the VAS equipment, operations near saturation during visual flight rules (VFR) and/or instrument flight rules (IFR) conditions, and a significant percentage of large aircraft in the traffic mix. The VAS was feasibility tested at O'Hare by using an instrumentation system to measure vortex positions and ambient meteorological conditions as a function of time, and correlate these with the VAS separation criteria. The amount of time that the VAS indicated that reduced separations could be used was evaluated to determine how many additional operations could be accommodated if reduced separations were used and the dollar saving which would accrue from reduced delays. This evaluation was performed considering all the usable combinations of approach and landing runway scenarios under both VFR and IFR weather conditions. Results from this previous study statistically validated that the system could accurately determine when 3-nmi separation could be used for all aircraft types, and that the criterion algorithm contained adequate safety margins for all meteorological and vortex conditions.

SYSTEM DESCRIPTION.

METEOROLOGICAL TOWERS. The VAS incorporates a network of instrumented meteorological towers positioned to measure the wind in each operating airport corridor. A network of towers is required since variations in atmospheric conditions preclude the use of a single, centrally located sensor for measuring wind in individual approach corridors. Each tower is instrumented with three sensors for wind magnitude and direction, one at the 50-foot level and the other two at the 47-foot level. The 47-foot-level sensors are mounted on opposite sides of the tower to provide a measurement undisturbed by tower shadowing. All sensor and communication electronics at each tower are housed in an environmental enclosure. The towers are free-standing on a concrete base and are marked and lighted.

TOWER DATA COMMUNICATION SUBSYSTEM. Transmission of the data from the towers to the centrally located processors is accomplished with standard hardware. A multiplexer successively samples the sensor outputs and converts them to digital words which are serialized and transmitted over standard existing FAA control lines to a central facility. Receivers reconvert the data to a parallel format for input to a microprocessor. The sampling rate is 160 words per second, each word being 16 bits in length.

METEOROLOGICAL DATA PREPROCESSING. Individual microprocessors are used to process the data from each meteorological tower. The microprocessors contain 8k bits of read-only memory and 2k bits of random-access memory. Each microprocessor is packaged on a single plug-in board. The microprocessors sample the meteorological data output from each receiver at a sample interval rate of two samples per second. The sampled wind magnitude (R) and wind direction (Θ) are computed as a 64-second (128-sample) running average ($\bar{R}$ and $\bar{\Theta}$).

The wind magnitude and direction readings from the three sensors on each tower are compared after each sampling interval. A sensor-failure bit is generated if the magnitude of any sensor differs by more than 3 knots or if the direction of any sensor differs by more than 10°. Normally, the 50-foot-level sensor data are used for the VAS algorithm. If the 50-foot-level sensor fails, the microprocessor switches to a 47-foot-level sensor and selects the sensor which is not in the wind shadow of the tower. Failure of two sensors to agree terminates all data output from that tower. Upon detection of a failure, a failure word is generated identifying the sensor or tower which has been shut down.

The microprocessors also calculate the recommended aircraft landing separations for each runway based on the windspeed and wind direction measured by the instrumented tower. As shown in figure 1, an elliptical VAS algorithm is used which includes a buffer or "transition zone." The major and minor axes are 12.5 and 5.5 knots for the inner ellipse, and 14.5 and 7.5 knots for the outer ellipse. The transition zone is designed to preclude rapid oscillations between standard (red) and reduced separation (green) conditions, thus avoiding an unmanageable controller workload while still insuring the required level of safety from vortex effects.

The criteria for separation and for changing separation from one condition to another are:

(a) If the wind vector ($\bar{R}$, $\bar{\Theta}$) is inside the inner ellipse, the condition is red, and standard 3-4-5-6-nmi separation applies.

(b) If the wind vector ($\bar{R}$, $\bar{\Theta}$) is outside the outer ellipse, the green condition exists, and all aircraft can be separated by 3 nmi.

(c) If the condition is red and the wind is increasing, the requirement exists for the wind vector to be outside the outer ellipse for 64 seconds before the green condition is indicated.

(d) If the condition is green and the wind vector enters the inner ellipse region, a change to the red condition takes place immediately.

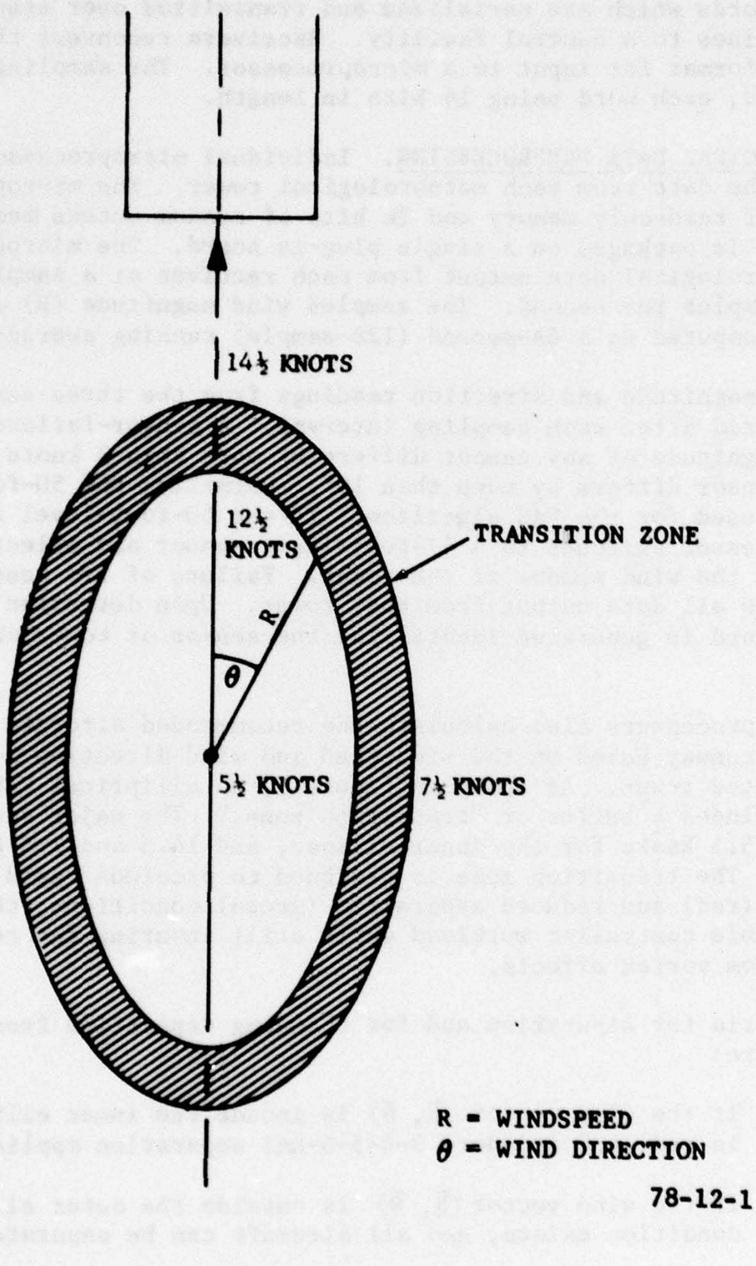


FIGURE 1. VAS ALGORITHM WIND CRITERION

SYSTEM EVALUATION

DETAILS OF APPROACH.

LABORATORY REQUIREMENTS.

General. The Digital Simulation Facility (DSF) ATC laboratory at NAFEC was configured to simulate an Automated Radar Terminal System (ARTS III) terminal ATC system. Two-way radio communication between controllers and pilots as well as coordination lines between control positions were simulated using the Bell 300 communication system.

Controller Positions. Two arrival, one departure, one tower/monitor, and two enroute feeder positions were established. The arrival positions displayed video for a radius of 35 nmi, the tower and departure positions displayed video for a 20-nmi radius, and the two enroute positions displayed a 50-nmi radius. Keyboard functions were available at all positions.

Simulator Pilot Positions. Eighteen simulator pilot positions were required. Controlled aircraft were assigned to all 18 positions. Keyboard functions were available at all pilot consoles.

Geography. The area simulated was the Chicago O'Hare International Airport Approach Control Area, with parallel approaches to the southeast on runways 14L and 14R, dual approaches to the west and northwest on runways 27R and 32L, and parallel approaches to the east on runways 9L and 9R. All runways had ILS capability.

Departure configurations were to the east off runways 9L and 9R, to the west and northwest off runways 27L and 32R, and to the northeast off runway 4L and 4R.

Traffic flows were in accordance with procedures presently employed at Chicago O'Hare International Airport as described in the Chicago ARTCC/O'Hare Tower Letter of Agreement, dated July 28, 1976, and O'Hare Tower Order 7110.6D, entitled "Chicago Approach Control - Radar."

The field elevation for the airport was 700 feet mean sea level. The video map depicted airport runways, boundaries, fixes, navigation aids (NAVAID's), and descent areas.

Sigma V Computer. The Sigma V was used in conjunction with the graphic digitizer to develop video maps and flight plans. It was utilized on a daily basis for conduct of the simulation and data reduction and analysis.

PROCEDURES.

Controller Procedures. Standard ATC procedures as provided for in FAA Handbook 7110.65 were applied. Detailed controller instructions on Chicago O'Hare arrival and departure procedures were defined in a handout prior to start of simulation. Those special controller procedures required when VAS was present in the system (i.e., reduced aircraft separation standards) were described for all controller personnel in briefings prior to simulation.

Simulator Pilot Procedure. Prior to the start of dynamic simulation, all simulator pilots received a detailed briefing on the purpose and objectives of the simulation. They were briefed on detailed pilot procedures and their expected inputs.

TRAFFIC SAMPLES. The traffic samples, representative of O'Hare traffic, were all controlled IFR aircraft. Traffic density was 150 aircraft per hour (90 arrival, 60 departure). The arrival aircraft were a mix of large (70 percent), heavy (20 percent), and small (10 percent).

TEST MEASURES.

A complete history of each simulated flight was recorded on magnetic tape. During each update cycle, elements of track position, track movement, flight status, pilot keyboard messages, display tables, and communication line usage were recorded. These data were analyzed utilizing offline data reduction programs to provide quantitative measurements of system performance, capacity, separation, and workload.

ATC SYSTEM PERFORMANCE MEASURES. Hourly operation rates were obtained for (1) arrivals, (2) departures, and (3) combined arrivals/departures. Average time in system for a completed arrival flight (in minutes) was obtained for each 1-hour data period.

Total path-stretch delay (in minutes) was ascertained. This measure is the difference between the nominal and actual flight times of completed arrivals in the 1-hour data period.

Terminal approach path separation was measured every 20 seconds between aircraft on the final approach for the following vortex clear zones: (1) threshold to middle marker (MM), (2) threshold to outer marker (OM), and (3) threshold to 20-nmi point on localizer.

The number of missed approaches under green and red conditions were determined. The number of separation criteria violations were analyzed to determine (1) total number of criteria violations, (2) aircraft in violation by controller position, (3) time of violation, and (4) degree of separation criteria violation.

CONTROLLER WORKLOAD MEASURES. The following measures were taken:

1. Number of aircraft controlled per control position during 1-hour data period.

2. Average number of radar vectors issued per control position per aircraft.

3. Average number of altitude changes issued per control position per aircraft controlled during the data hour.

4. Average number of speed changes issued per control position per aircraft controlled during the data hour.

5. Average number of control messages per control position per aircraft controlled during the data hour.

6. Total aircraft time per control position of aircraft controlled during the data hour.

7. Average duration of radio communications (controller to pilot) made per aircraft controlled per control position.

VAS IMPACT MEASURES. Additional data reduction and analysis were required to characterize quantitatively VAS activities in terms of the following:

a. Arrival rates
b. Operational procedures
c. Configuration changes
d. Separation standards
e. Flight deviations caused by VAS system changes and the effect on traffic flow.

RESULTS

SERIES I.

Series I testing consisted of heavy-density (90 arrivals, 60 departures) IFR traffic. These tests provided the baseline data on airport operations using present-day (red condition) separation minima and control techniques (speed and spacing criteria) as employed at the Chicago O'Hare Airport during the final approach phase of a flight. Baseline data were obtained after 18 simulation runs.

To insure validity, the baseline data were measured against a statistical analysis of O'Hare's Performance Measurement System (PMS) Summary Sheets for the year 1977. The results are given in table 1. The baseline data show that the simulation operations compared favorably with the PMS of present-day O'Hare operations.

Additionally, the baseline data were broken down by aircraft class, numbers of pairs (heavy-small, heavy-large, etc.), and the median separations employed.

Aircraft were categorized into three classes based on weight criteria:

Heavy - over 300,000 pounds gross weight at takeoff

Large - between 12,500 pounds and 300,000 pounds gross weight at takeoff

Small - up to 12,500 pounds gross weight at takeoff

TABLE 1. AVERAGE ARRIVAL OPERATIONS PER HOUR IN RED CONDITION

Arrival Runway Configuration	Simulation Baseline	PMS Analysis
Runways 14L and 14R	71	70.1 (peak periods of density, all configurations)
Runways 27R and 32L	69.5	
Combined average, runways 14L-14R and 32L-27R	70.3	

The mix of aircraft pairs studied was identified by separation minima required between various classes:

Lead Aircraft - Trail Aircraft	Separation Required
Heavy - small	6 nmi
Heavy - large	5 nmi
Heavy - heavy	4 nmi
Large - small	4 nmi
All others*	3 nmi

*(Large-large, small-large, small-small, small-heavy, and large-heavy)

The median separation distances were measured both inside and outside the outer marker on the final approach defined as follows:

Inside outer marker: the distance between lead aircraft and trailing aircraft based on lead aircraft last reported data position inside the outer marker prior to touchdown.

Outside outer marker: the distance between lead aircraft and trailing aircraft based on lead aircraft last reported data position prior to passing outer marker inbound.

The baseline data descriptive statistics are given in table 2.

SERIES II.

Series II testing consisted of heavy-density (90 arrivals, 60 departures) IFR traffic. These tests provided data on the procedural implications or impact of VAS reduced separation on the ATC system and comparison data on arrival operations gains or losses when weighed against baseline capacity data. The tests were conducted using the VAS in the green mode with reduced separation criteria employed within three distinct vortex clear zones on the final approach (threshold to MM, threshold to OM, and threshold to 20-nmi fix on localizer. The vortex clear zone is the portion of final approach corridor over which the VAS predicts vortex dispersion within time parameters consonant with a 3-nmi minimum aircraft separaton criterion. A total of 45 runs was accomplished. Table 3 indicates the arrival rates that were achieved.

TABLE 2. BASELINE (RED-CONDITION) PERCENTAGE OF AIRCRAFT PAIRS AND MEDIAN SEPARATION

Inside OM Lead a/c - Trail a/c	Percent of Total Pairs	Median Separation (nmi)
Heavy-small	2	5.6
Heavy-large	16	5.0
Heavy-heavy	4	4.1
Large-small	7	4.2
All others	71	3.7
Outside OM **Lead a/c - Trail a/c**		
Heavy-small	2	6.3
Heavy-large	16	5.6
Heavy-heavy	3	4.5
Large-small	4	4.8
All others	75	4.3

TABLE 3. AVERAGE NUMBER OF ARRIVALS PER HOUR IN GREEN CONDITION

Arrival Runway Configuration	(Red) Baseline	Threshold-MM	Threshold-OM	Threshold-20 nmi
Runways 14L-14R	71	72.6	71.7	72.7
Runways 27R-32L	69.5	73.0	74.6	80.0
Combined average, runways 14L-14R and 27R-32L	70.3	72.8	73.2	76.4

From table 3 it can be seen that increases in hourly operations were effected in every case for green verses red (baseline) conditions. This is supportive of MITRE and TSC predictions in this area. An analysis of types and numbers of pairs and the median separation employed inside and outside the OM under the green condition are presented in table 4.

No procedural changes were required which would impact the ATC system or deter the implementation of VAS reduced separation at Chicago O'Hare Airport during this test series.

TABLE 4. COMPARISON OF PERCENTAGE OF AIRCRAFT PAIRS AND MEDIAN PAIR SEPARATION FOR VAS GREEN AND BASELINE RED CONDITIONS

	Percent of Total Pairs Threshold to				Median Separation (nmi) Threshold to			
Lead-Trail Aircraft	Base-line	MM	OM	20 nmi	Base-line	MM	OM	20 nmi
Inside OM								
Heavy-small	2	1	2	3	5.6	4.4	3.9	3.3
Heavy-large	16	14	15	15	5.0	4.5	4.0	3.7
Heavy-heavy	4	4	5	5	4.1	3.6	3.7	3.3
Large-small	7	6	8	2	4.2	3.9	3.9	3.6
All others	71	75	70	75	3.7	3.4	3.7	3.6
Outside OM								
Heavy-small	2	1	2	2	6.3	5.4	4.8	4.0
Heavy-large	16	15	16	14	5.6	5.1	4.7	4.3
Heavy-heavy	3	6	5	4	4.5	4.4	4.3	4.1
Large-small	4	7	7	7	4.8	4.7	4.5	4.3
All others	75	71	70	73	4.3	4.1	4.5	4.3

Results show that the percentage of total pairs remained fairly constant under all categories, indicating a consistency of traffic mix for comparison purposes (appendix A). Median separations show that sufficient separation reductions were obtained under green conditions to support predicted operational gains, and that the VAS reduced separation operation does not affect separation closure rates between OM and touchdown (appendix B).

SERIES III.

Series III testing consisted of heavy-density (90 arrivals, 60 departures) IFR traffic. This series of tests was designed to investigate operational gains or losses and procedural implications on the ATC system when transitioning from one VAS condition to another under IFR conditions (table 5). (A total of 29 runs was accomplished). Tests were conducted with two vortex clear zones on the final approach path (threshold to OM and threshold to 20-nmi fix) under two specific operational parameters.

1. VAS transition from green to red instantaneously.
2. VAS transition from green to red in 5 minutes

As can be seen from table 5 for both the instantaneous and 5-minute transitions, the traffic mix at O'Hare, which is predominently of the large aircraft class (70 percent) with a relatively small mix of heavy-small pairs, precluded any major difficulties in transition from a 3-nmi separation standard a 3-, 4-, 5-, 6-nmi separation standard.

TABLE 5. AVERAGE NUMBERS OF ARRIVALS PER HOUR IN GREEN/RED CONDITION

Arrival Rate - Threshold to OM

Arrival Runway Configuration	Zero Transition	5-Minute Transition
Runways 14L and 14R	71.0	70.5
Runways 27R and 32L	72.7	73.3
Combined average, runway 14L-14R and 32L-27R	71.8	71.9

Arrival Rate - Threshold to 20-nmi Fix

Arrival Runway Configuration	Zero Transition	5-Minute Transition
Runways 14L and 14R	75.5	72.0
Runways 27R and 32L	75.5	73.6
Combined average, runway 14L-14R and 32L-27R	75.5	72.8

During the 5-minute transition phase, no difficulty was experienced in transitioning from one mode of operation to another. The trend during this phase was to employ the expanded separation early in the 5-minute transition period, effecting a general decrease in operations rate.

During the zero or instantaneous transition phase in most cases, no difficulties were experienced or special action required, due to the traffic mix at time of transition (i.e., large-large, large-heavy, etc.) These pairs of traffic mix require the same separation (3-nmi) under both red and green conditions. Where a traffic mix of heavy-small or heavy-large aircraft (which requires 6- or 5-nmi separation under a red condition) existed during the transition phase, the determining factor for controller action was the aircraft position on final approach. Beyond the outer marker, separation usually could be achieved prior to touchdown. Where it could not, a maximum of one missed approach per transition was required. Inside outer marker, depending upon separation being employed, the trailing aircraft might be required to make a missed approach, a condition considered operationally unsatisfactory. The simulation highlighted the fact that the design of VAS should be such that when an instantaneous transition occurs, aircraft within the OM should be permitted to land safely.

During this series of tests, no major procedural changes were required which would impact the ATC system as a result of transitioning from green to red operation (i.e., transition from reduced separation to increased separation).

SERIES IV.

Series IV consisted of heavy-density (90 arrivals, 60 departures) IFR traffic. This series of tests was designed to evaluate VAS as a factor in the runway selection process. Assuming availability of a similar or higher density runway configuration in a green condition, it investigated benefits or impacts of rerouting arrivals from a runway in a red condition to a runway in a green condition under heavy traffic densities. A total of 13 runs was accomplished.

Results indicate that, while there is a slight decrease in overall operations rate (table 6) below the baseline figure (table 1) as a result of a runway change during the hour of changeover operations, it can be assumed an overall increase in operation's rate would occur over the baseline operation's rate during the succeeding hours that the new runway configuration would be in a green condition.

TABLE 6. AVERAGE NUMBER OF ARRIVALS PER HOUR FOR RUNWAY CHANGEOVER HOUR

Arrival Configurations	Baseline	Threshold to OM	Threshold to 20-nmi Fix
Combined average, runways 14L-14R and 32L-27R	70.3	67.2	69.6

Runway changes from the basic configuration to a configuration of parallel approaches to runways 9R and 9L were implemented in this series under the same zones and operational parameters established in series III.

While VAS, if adopted, is expected to be a factor in the runway selection process, it should be realized that many other factors would also contribute to the process of changeover to alternative runways, such as a noise abatement procedures and ground environment conditions. However, using VAS, there were no procedural implications found in simulation which would impact the ATC system to any greater degree than a runway change now impacts ATC operations.

Due to the limitation of the DSF, this simulation dealt solely with the air operations of the O'Hare terminal environment, and many factors in the ground control operation from the runway exits to terminal aircraft gates could affect predicted VAS reduced separation gains, such as the scheduling interrelationship between arrivals and departures.

While a departure position was employed and departure aircraft were incorporated into the simulation environment, no data were taken in relation to departure operations. Departures were employed only to insure that arrival aircraft followed prescribed inbound routing and altitude restriction similar to those used at O'Hare and to provide validity of simulation results of airside operations.

SUMMARY OF RESULTS

Based on comparison of the baseline red condition and the VAS reduced separation green condition data, it is clear that increased hourly operational arrival gains of from 2.5 (MM to threshold), 2.9 (OM to threshold), and 5.1 (20 nmi to threshold) for combined runway configuration can be achieved utilizing the VAS reduced separation or no-vortex condition. (These increases are compatible with Landrum and Brown and Mitre Corporation capacity gain studies.) (references 1 and 2) (appendix C). Similarly, the presence of VAS reduced separation within the terminal environment does not create any procedural implications or major impacts on the ATC system.

From all test series data, any increases prevalent in the controller communication workload (table 7) are a direct result of increased arrival rates gains and not as a result of any VAS operating characteristic. Control instructions (table 8) for all test series showed no significant increases with VAS reduced separation in the areas of vectors, altitude changes, speed adjustments, and flightpath patterns. Separation criteria violations (table 9) showed no increasing trends with VAS reduced separation.

TABLE 7. CONTROLLER COMMUNICATIONS

Configuration	Avg. Talk Time Per Push-to-talk (Sec)	Avg. Contacts Per A/C	Avg. Talk Time Per A/C (Sec)
Baseline (red)	3.3	6.6	19.9
Threshold to MM (green)	2.9	6.3	19.2
Threshold to OM (green)	2.9	4.9	15.5
Threshold to 20 nmi (green)	3.0	5.9	18.3
Green-Red, OM, 0 min	3.0	5.9	17.7
Green-Red, 20 nmi, 0 min	3.1	5.7	18.0
Green-Red, OM, 5 min	2.6	5.6	17.5
Green-Red, 20 nmi, 5 min	2.8	5.5	17.5
Rwy Change, OM	3.0	6.4	17.5
Rwy Change, 20 nmi	3.0	6.2	19.6

VAS indicated a potential application in the runway selection processes through its ability to identify other high-capacity runway configurations in the green condition which might exist when an in-use configuration goes red.

Transition from one separation condition to another on the final approach (green to red) did not present any problems to controller personnel and, in the worst case, resulted in a single aircraft missed-approach action.

In summary, it may be stated that, although the ultimate answers to procedural questions can only be obtained through on-site operational test and evaluation due to ground operations and other factors not considered in a controlled simulation environment, no procedural implications emerged from the ATC simulation of VAS reduced separation that would deter the operational implementation of the system at Chicago's O'Hare International Airport.

TABLE 8. CONTROLLER ATC ACTIVITIES

Configuration	No. A/C Controlled	Avg. No. Vectors	Avg. No. Alt. Chg.	Avg. No. Speed Chg.	Avg. Distance Flown (nmi)
Baseline (red)	53.6	140.2	45.4	73.8	67.8
Threshold to MM (green)	54.4	146.0	44.4	73.8	69.5
Threshold to OM (green)	54.5	144.2	44.9	68.2	66.0
Threshold to 20 nmi (green)	54.4	135.6	36.9	83.1	66.3
Green-Red, OM, 0 min	55.5	135.2	40.7	83.5	69.6
Green-Red, 20 nmi, 0 min	56.3	149.3	36.9	83.4	67.4
Green-Red, OM, 5 min	54.5	120.4	48.9	70.5	69.3
Green-Red, 20 nmi, 5 min	52.8	127.8	41.0	87.5	68.5
Rwy Change, OM	52.3	131.7	38.1	89.0	66.2
Rwy Change, 20 nmi	55.8	129.8	43.4	62.0	67.4

TABLE 9. SEPARATION CRITERIA VIOLATIONS FOR TOTAL AIRCRAFT PAIRS

Approach Zones	Test Configurations			
Inside OM	Baseline	Green MM	Green OM	Green 20 nmi
Total Pairs	541	603	510	430
Median Separation (nmi)	4.5	4.0	3.8	3.5
Percent Criteria Violations	* 9	1	3	3
Outside OM				
Total Pairs	481	444	451	390
Median Separation (nmi)	5.1	4.7	4.5	4.2
Percent Criteria Violations	2	3	**7	1

*Expanded separation (6.3- and 5.7-nmi median separation) (table 2) achieved by controllers for heavy-small and heavy-large pairs was not sufficient outside the OM to offset accordion effect at touchdown.

**Reduced separation (4.8- and 4.7-nmi median separation) (table 4) achieved for heavy-small and heavy-large pairs outside OM to obtain 3-nmi separation at touchdown is under separation criteria of 5.0 nmi.

CONCLUSIONS

From the results, it is concluded that:

1. No procedural implications emerged to deter implementation of VAS reduced separation for aircraft arrivals.

2. Sufficient arrival rate increases were obtained to support cost/benefit analysis.

3. An orderly transition of separation conditions was obtained in 5 minutes.

4. An instantaneous transition of separation conditions required, at worst, one missed approach.

5. Arrival rates and ease of operation became more pronounced as the vortex clear zone increased in size, i.e., was further expanded from the runway threshold.

6. VAS could have application in the runway selection process.

REFERENCES

1. Landrum and Brown Aviation Consultants, Cost/Benefit Analysis of the Proposed Vortex Avoidance System and O'Hare International Airport, February 14, 1977.

2. Avant, A. L., Procedural Feasibility of Reduced Spacings under VAS Operation at O'Hare, May 1977.

APPENDIX A

COMPARISON TABLE OF ARRIVAL AIRCRAFT CLASSES AND PAIRING MIX

Chi-O'Hare Arrivals

Actual IFR (Sample size - 628 aircraft)

Class Breakdown		Percent of Total
Small	63	10
Heavy	87	14
Large	478	76

Pairing Mix 566 Pairs		Percent of Total
Heavy - small	7	1.5
Heavy - large	56	10
Heavy - heavy	13	2.5
Large - small	33	6
All others	451	80.

Actual VFR (Sample size - 852 aircraft)

Class Breakdown		Percent of Total
Small	89	10.5
Heavy	132	15.5
Large	631	74

Pairing Mix 758 Pairs		Percent of Total
Heavy - small	12	1.5
Heavy - large	85	11
Heavy - heavy	22	3
Large - small	50	6.5
All others	589	78

NAFEC Simulation Arrivals

Simulation (Sample size 90 aircraft per hour)

Class Breakdown		Percent of Total
Small	9	10
Heavy	18	20
Large	63	70

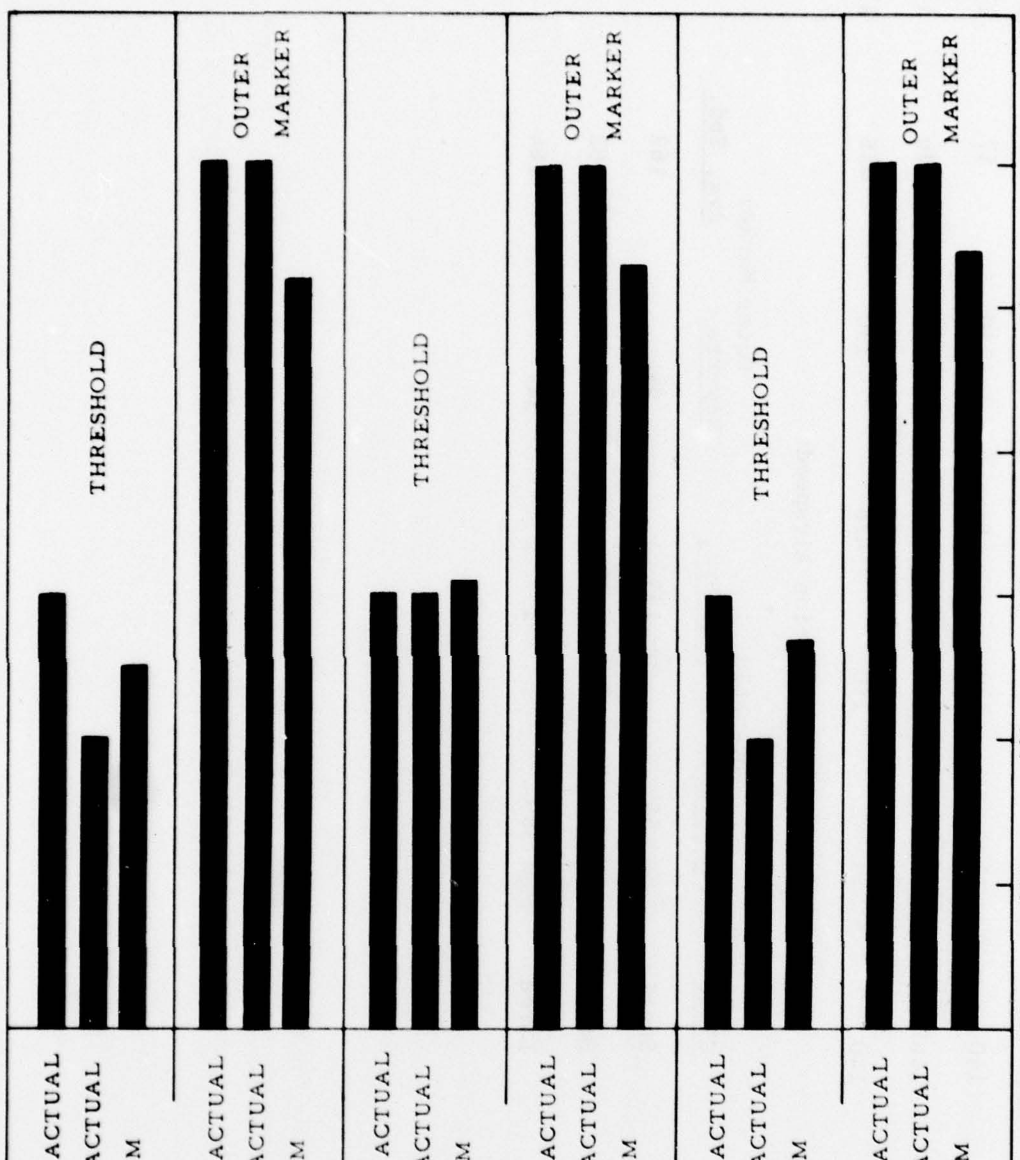
Pairing Mix 4146 Pairs		Percent of Total
Heavy - small	88	2
Heavy - large	653	16
Heavy - heavy	180	4
Large - small	267	7
All others	2958	71

Note:

All others = Small - small pairs
Small - large
Small - heavy
Large - large
Large - heavy

APPENDIX B

SPEED PROFILES (KNOTS) AT THRESHOLD AND OUTER MARKER FOR SMALL, HEAVY, AND LARGE WEIGHT CLASSES


SMALL
HEAVY
LARGE
CHI-VFR ACTUAL
CHI-IFR ACTUAL
NAFEC SIM
THRESHOLD
OUTER MARKER
110
120
130
140
150
160
170
180
SPEED - KNOTS

78-12-C-1

	CHI-VFR Actual Airspeeds				CHI-IFR Actual Airspeeds			
	Threshold		Outer Marker		Threshold		Outer Marker	
Class	Reports	Avg. Spd.	Reports	Avg. Spd.	Reports	Avg. Spd.	Reports	Avg. Spd.
Small	85	140	73	170	63	130	57	170
Heavy	133	140	117	170	87	140	86	170
Large	626	140	550	170	426	130	456	170

NAFEC Simulation Airspeeds

	Threshold		Outer Marker	
Class	Reports	Avg. Spd.	Reports	Avg. Spd.
Small	55	135	54	162
Heavy	119	141	153	163
Large	389	137	347	164

APPENDIX C

PREDICTED GAINS (IN ARRIVALS PER HOUR)

	Threshold to MM	OM	20 nmi
Mitre Corp. Study -	1.7	3.1	4.1
Landrum-Brown Study -	2.4	3.8	-
NAFEC Simulation -	2.5	2.9	5.1
Avg. Predicted Gain	2.2	3.2	4.6