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Analysis of Wake VAS Benefits Using ACES Build 3.2.1

VAMS Type 1 Assessment

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December 2005

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Summary

The FAA and NASA are currently engaged in a Wake Turbulence Research Program to revise wake turbulence separation standards, procedures, and criteria to increase airport capacity while maintaining or increasing safety.

The research program is divided into three phases: Phase I – near term procedural enhancements; Phase II – wind dependant Wake Vortex Advisory System (Wake VAS) Concepts of Operations (ConOps); and Phase III – farther term ConOps based on wake prediction and sensing.

The Phase III Wake VAS ConOps is one element of the Virtual Airspace Modelling and Simulation (VAMS) program blended concepts for enhancing the total system wide capacity of the National Airspace System (NAS).

This report contains a VAMS Program Type 1 (stand-alone) assessment of the expected capacity benefits of Wake VAS at the 35 FAA Benchmark Airports[1] and determines the consequent reduction in delay using the Airspace Concepts Evaluation System (ACES) Build 3.2.1 simulator.

The Wake VAS increased airport capacities determined by this analysis will be incorporated into the VAMS blended concept for increasing airport throughput.

Using data from a previous analysis and based on the traffic mix at each of the 35 airports selected, this analysis determined that Wake VAS has the potential to increase runway arrival rates under IFR conditions by 3% to 21% with a mean increase of 9.5%. Wake VAS also has the potential to increase departure rates under all weather conditions since wake separation rules between heavy and B757 aircraft and smaller aircraft are applied at all times. A departure rates increase of 5.0% was assumed for this study.

A series of simulation runs were performed using the Airspace Concepts Evaluation System (ACES) Build 3.21 air traffic simulator to provide an initial assessment of the reduction in delay and cost savings obtained by the use of a WakeVAS at selected U.S. airports. The flight demand set used was based on an ACES supplied ‘2020’ designated demand set which more nearly represents the increase in enplanements expected by 2010 - 2012. The airport capacities used as the basis for comparison with Wake VAS enhanced capacities was the ‘OEP 2010’ designated capacity file supplied with ACES.

The total potential benefit of using Wake VAS is not limited to the 35 airports which were equipped with Wake VAS. Network wide benefits occur, due to less delay at airports which have flights departing to, or arriving from the Wake VAS equipped airports. Wake VAS deployment reduced the mean delay per departure or arrival operation from **21.4 minutes** to **15.7 minutes** under IFR and from **11.5 minutes** to **10.3 minutes** under VFR conditions. Network wide annual total delay was reduced by **536,000** hours saving an estimated annual **$868 million** in airline direct operating costs.

The values above include a disproportionately large benefit at Las Vegas International Airport (LAS). This was found to be due to an underestimate of capacity at LAS. The FAA has substantially revised the capacity of LAS between the 2001 and 2004 airport benchmark reports. Using the revised LAS capacity, based on 2004 data reduces the network wide annual total delay to **489,000** hours saving an estimated annual **$789 million** in airline direct operating costs.

The Logistics Management Institute (LMI) published a business case analysis that contains an estimate of the costs for a Phase III Wake VAS including the wake vortex hardware and software and operating and support costs. The LMI report contains detailed cost estimates for SFO, DFW and STL only.

The cost to equip SFO or DFW is estimated to be $1.6 million for hardware and software and $280,000 per year for operation and support. For STL the costs estimates are $3.1 million for hardware and software and $690,000 per year for operation and support.

Using the average of these cost values as an approximation of the cost at each airport, the savings that could be obtained by deployment of the WakeVAS Phase III single runway ConOps would yield a substantial overall benefit within the first year of operation at 22 of the 35 airports in this analysis.

1) Except SDF (non-benchmark) is substituted for HNL

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1. Introduction

The FAA and NASA are currently engaged in a Wake Turbulence Research Program to revise wake turbulence separation standards, procedures, and criteria to increase airport capacity while maintaining or increasing safety. The Wake Vortex Advisory System (Wake VAS) Concepts of Operations (ConOps) are described in a series of reports produced by a ConOps Evaluation Team, reference 1.

The research program is divided into three phases: Phase I – near term procedural enhancements; Phase II – wind dependant Wake VAS ConOps; and Phase III – farther term ConOps based on wake prediction and sensing.

The Phase III Wake VAS ConOps is one element of the Virtual Airspace Modelling and Simulation (VAMS) program blended concepts for enhancing the total system wide capacity of the National Airspace System (NAS).

The Airspace Concepts Evaluation System (ACES) air traffic simulator is being developed as a product of the VAMS program to facilitate benefits evaluation of individual concepts and the blended concepts. Reference 2 provides an overview of ACES.

A previous analysis, reference 3, determined the expected capacity benefits due to Wake VAS at 12 of the FAA benchmark airports. A subsequent assessment, reference 4, using ACES Build 2 determined the corresponding reduction in delay that results when Wake VAS is deployed at the 12 airports.

This report contains a VAMS Program Type 1 (stand-alone) assessment of the expected capacity benefits of Wake VAS at an extended set of 35 airports and determines the reduction in delay obtained using the Airspace Concepts Evaluation System (ACES) Build 3.2.1 simulator.

The Wake VAS increased airport capacities determined by this analysis will be incorporated into the VAMS blended concept for increasing airport throughput.

2. Airports for Analysis

A total of 35 airports, are included in this current analysis; these are the FAA benchmark airports except that SDF is substituted for HNL. The airports used and characteristics of the main runways at each airport are shown in Table 1.

The current day airport capacities used in the ACES simulation are shown in Table 2. The capacity expected by 2010 including the FAA Operational Evolution Plan improvements documented in reference 5 are used as the basis for the Wake VAS evaluation in this analysis, as listed in Table 3.

Airport	Code	Runways (Number, Type)
The William B. Hartsfield Atlanta International Airport, Atlanta, Georgia	ATL	5=2PR+NEWSGL
General Edward Lawrence Logan International Airport, Boston, Massachusetts	BOS	4=CSPR+2INT+NEWSGL
Baltimore-Washington International Airport	BWI	4=PR+2INT
Hopkins International Airport, Cleveland, Ohio	CLE	5=CSPR+INT+SGL+NEWSGL
Douglas Airport, Charlotte, North Carolina	CLT	3=PR+SGL
Cincinnati-Northern Kentucky Airport, Cincinnati, Ohio	CVG	4=PR+INT+SGL+NEWSGL
Washington National Airport, Washington, D. C.	DCA	3=3INT
Denver International Airport, Denver, Colorado	DEN	5=PR+3SGL
Dallas-Fort Worth International Airport, Dallas/Fort Worth, Texas	DFW	6=2CSPR+2SGL
Detroit Metropolitan Wayne County Airport, Detroit, Michigan	DTW	6=2CSPR+2INT
Newark International Airport, Newark, Ohio	EWR	3=CSPR+INT
Fort Lauderdale/Hollywood International Airport, Florida	FLL	3=INT+2GL
Dulles International Airport, Washington, D. C.	IAD	4=3SGL+NEWSGL
Houston Intercontinental Airport, Houston, Texas	IAH	4=CSPR+SGL+NEWSGL
John F. Kennedy International Airport	JFK	4=PR+2SGL
McCarran International Airport, Las Vegas, Nevada	LAS	4=2CSPR
Los Angeles International Airport, Los Angeles, California	LAX	4=2CSPR
La Guardia Airport, New York, New York	LGA	2=2INT
Orlando International Airport, Orlando, Florida	MCO	3=CSPR+SGL
Midway Airport, Chicago, Illinois	MDW	5=2CSPR+SGL
Memphis International Airport, Memphis, Tennessee	MEM	4=CSPR+2SGL
Miami International Airport, Miami, Florida	MIA	3=CSPR+SGL
Minneapolis-Saint Paul International Airport, Minneapolis-Saint Paul, Minnesota	MSP	3=PR+INT+NEWSGL
Chicago O' Hare International Airport	ORD	5=PR+3INT
Portland International Airport, Portland, Oregon	PDX	3=CSPR+INT
Philadelphia International Airport, Philadelphia, Pennsylvania	PHL	4=CSPR+INT_SGL
Phoenix Sky Harbor International Airport, Phoenix, Arizona	PHX	2=PR
Pittsburgh International Airport, Pittsburgh, Pennsylvania	PIT	4=CSPR+INT_SGL
Lindbergh Field, San Diego, California	SAN	1=SGL
Louisville International Airport-Standiford Field, Kentucky	SDF	3=INT+2SGL
Seattle-Tacoma International Airport, Seattle, Washington	SEA	2=CSPR+NEWSGL
San Francisco International Airport, San Francisco, California	SFO	4=2CSPR
Salt Lake City International Airport, Utah	SLC	3=PR+SGL
Lambert Field, Saint Louis, Missouri	STL	3=CSPR+INT+NEWSGL
Tampa International Airport, Florida	TPA	3=PR+INT

Table 1 Airports used for Benefits Analysis

Key: CSPR – Closely Spaced Parallel Runway, PR – Parallel Runway, SGL – Single Runway, INT – Intersecting runway, NEW – New runway by 2010

Airport	Dep. VFR	Arr. VFR	Total VFR	Dep. IFR	Arr. IFR	Total IFR
ATL	104	103	200	91	90	174
BOS	69	65	126	48	46	88
BWI	69	71	120	43	44	75
CLE	59	59	105	33	33	59
CLT	80	73	140	66	60	116
CVG	76	63	125	76	63	125
DCA	44	44	80	36	36	66
DEN	123	122	218	111	109	196
DFW	132	141	270	91	97	185
DTW	80	77	146	76	73	138
EWR	63	59	108	45	43	78
FLL	71	71	126	34	34	60
IAD	76	77	121	73	74	117
IAH	65	68	123	60	63	113
JFK	60	67	98	43	48	71
LAS	47	47	85	32	32	57
LAX	84	86	150	72	73	128
LGA	43	43	81	34	34	64
MCO	79	85	145	61	66	112
MDW	78	78	138	33	33	59
MEM	86	86	152	68	68	120
MIA	76	76	134	61	61	108
MSP	67	69	120	63	65	112
ORD	110	109	202	87	87	160
PDX	63	63	111	59	59	105
PHL	61	64	110	53	56	96
PHX	59	60	110	35	36	65
PIT	107	104	160	87	85	131
SAN	33	32	57	29	28	49
SDF	63	63	111	59	59	105
SEA	56	53	91	50	47	81
SFO	55	55	99	40	40	72
SLC	72	81	132	57	64	105
STL	62	63	112	36	36	65
TPA	69	69	119	50	50	87

Table 2 Current Airport Capacities (operations per hour)
(From ACES Top250AirportCapacity.csv file)

Airport	Dep. VFR	Arr. VFR	Total VFR	Dep. IFR	Arr. IFR	Total IFR
ATL	139	138	269	120	119	231
BOS	71	67	131	49	47	91
BWI	69	71	120	43	44	75
CLE	59	59	105	33	33	59
CLT	102	93	179	80	73	142
CVG	97	80	160	96	79	158
DCA	45	45	83	38	38	71
DEN	151	149	268	126	124	223
DFW	137	146	281	110	117	224
DTW	104	100	191	93	89	170
EWR	68	63	117	47	45	83
FLL	71	71	126	34	34	60
IAD	113	114	180	106	107	170
IAH	91	95	173	84	88	159
JFK	61	68	100	44	49	73
LAS	47	47	85	35	35	63
LAX	98	100	175	74	75	133
LGA	47	47	89	35	35	66
MCO	101	109	186	82	88	151
MDW	78	78	138	33	33	59
MEM	88	88	157	70	70	124
MIA	93	93	164	75	75	134
MSP	88	91	159	82	85	147
ORD	115	114	213	97	97	179
PDX	63	63	111	59	59	105
PHL	70	73	127	58	61	106
PHX	80	81	150	54	55	101
PIT	109	106	164	87	85	132
SAN	33	32	58	29	28	50
SDF	63	63	111	59	59	105
SEA	87	82	142	74	70	121
SFO	55	55	99	41	41	74
SLC	75	84	138	59	66	109
STL	77	78	140	67	67	122
TPA	69	69	119	58	58	102

Table 3 OEP 2010 Enhanced Airport Capacities (operations per hour)
(From ACES OEP2010_250_airport_capacity.csv file)

3. Demand Sets

The demand data sets used for this analysis are based on ETMS recorded data from 17 May 2002. A demand set supplied with ACES containing approximately twice the 2002 traffic was evaluated for use in this analysis but the 2X level of demand severely overloads the airports and generates excessive delays when using the OEP 2010 airport capacities as the basis, even with Wake VAS capacity improvements. For this reason the demand set supplied with ACES, containing the projected traffic load for 2020 was used. The total number of flights contained in the demand sets is shown in Table 4. A detailed analysis of delay versus demand and capacity is contained in section 7.

All flights which departed from or arrived at any of the 35 airports for analysis were extracted and used for the ACES simulation runs. The entire demand set could not be used because ACES is a computationally intensive simulation and computing resources limited the total number of flights that could be included. The actual load on each of the 35 airports is correct, however, since all airports which are not part of the set, but have flights departing to, or arriving from one of the 35 airports analyzed are included in the simulation. Table 5 shows the 24 hour total demand for the demand data sets and traffic mix at each of the 35 airports.

Demand Set	**Total Flights**
SLIC_2002_517_250APTOpenNetwork_Intl	47,815
SLIC_2X_250OpenNetwork_Intl	96,949
SLIC_2020_250OpenNetwork_Intl	58,054

Table 4 Demand Set Flight Totals

It should be noted that the “2020” demand set represents a growth rate of only 21% from 2002 to 2020, which is 1.08% per year compound growth. This is a very low growth rate; research by NASA Langley indicates that passenger enplanements will likely double in the 2024–2025 timeframe, see reference 6. The ‘2020’ demand more closely represents the demand expected by 2010 – 2012.

Airport	Total Operations 2002	Total Operations 2020	%small	%large	%B757	%heavy	%heavy +B757
ATL	2468	3440	3.4	71.4	13.4	11.8	25.2
BOS	1141	1404	6.4	75.5	9.6	8.4	18.1
BWI	890	1233	11.0	76.5	10.6	1.9	12.5
CLE	762	914	4.9	93.8	0.3	1.0	1.3
CLT	1303	1669	8.1	85.3	4.4	2.2	6.6
CVG	1333	1909	2.4	87.5	5.6	4.6	10.1
DCA	646	905	3.9	96.0	0.2	0.0	0.2
DEN	1451	2076	3.4	81.5	9.6	5.4	15.1
DFW	2107	2517	8.0	77.1	10.6	4.3	14.9
DTW	1432	2093	3.5	86.7	6.7	3.1	9.8
EWR	1193	1592	1.9	76.7	10.6	10.7	21.4
FLL	668	992	18.4	66.3	8.4	6.9	15.3
IAD	1168	2452	13.0	74.2	5.3	7.4	12.8
IAH	1295	2131	2.8	88.8	5.1	3.3	8.4
JFK	771	1231	1.9	45.8	8.4	43.8	52.3
LAS	1198	1654	7.3	74.0	15.6	3.1	18.7
LAX	1772	2385	1.2	68.2	13.1	17.5	30.6
LGA	1107	1229	2.8	88.1	7.8	1.4	9.1
MCO	799	1297	4.0	71.0	16.5	8.5	25.0
MDW	855	989	15.7	75.8	8.3	0.2	8.5
MEM	1164	1574	11.7	65.4	1.0	21.9	22.9
MIA	1148	1276	3.7	65.0	11.8	19.5	31.3
MSP	1388	2058	8.4	81.3	7.3	3.0	10.3
ORD	2611	3342	8.3	77.7	6.8	7.2	14.1
PDX	791	927	18.8	71.9	3.8	5.4	9.2
PHL	1288	1866	7.0	83.1	5.4	4.6	9.9
PHX	1461	1919	5.4	86.7	5.6	2.3	7.9
PIT	1234	1295	3.7	90.3	3.9	2.1	6.0
SAN	560	722	5.7	85.0	5.0	4.3	9.3
SDF	483	560	8.1	58.8	9.7	23.4	33.1
SEA	1064	1344	1.6	83.4	8.7	6.3	15.0
SFO	990	1274	3.1	65.5	15.1	16.4	31.4
SLC	946	1382	14.2	74.3	4.1	7.4	11.5
STL	1297	1360	6.9	84.3	6.9	1.9	8.7
TPA	667	870	11.1	78.9	6.3	3.7	10.0

Table 5 Number of Operations and Traffic Mix for 2002 and 2020 Demand Sets
(Traffic mix is for 2002 demand but is similar for 2020)

4. Wake VAS Capacity Improvements

The expected capacity improvements from the use of a Wake Vortex Advisory System to reduce separations between aircraft using the same runway have been estimated from a previous study, reference 3. The proposed Wake VAS system uses an algorithm to predict wake behaviour based on local meteorological conditions and measurement sensors to confirm the accuracy of the predictions.

The mean runway arrival rate improvement for the 12 airports analyzed for the previous study, averaged over 6 days of differing weather data compared to the non-visual arrival rate varied between 4.5% and 19% for each airport runway, with an overall mean improvement of 10%, averaged over all of the runways for the 12 airports from the previous study.

Reduced departure time based spacing was also generated from the wake model, but analysis of the data showed a large variance in the spacing. For this reason an assumed runway departure rate improvement of 5% was used for this current analysis.

Figure 1 shows the strong correlation between the runway arrival rate improvement obtained from Wake VAS and the percentage of heavy + B757 aircraft. This confirms, as expected, that the greatest benefit from reduced wake spacing will be obtained at airports with significant percentages of heavy and/ or B757 aircraft, since these categories of aircraft generate the largest wakes. A regression analysis of the dependence of runway arrival rate improvement on percentage of heavy + B757 aircraft gave the equation shown on the chart with an $R^2 = 0.8$, indicating that approximately 80% of the systematic variance of the runway arrival rate improvement can be estimated from the percentage of heavy + B757 aircraft within the bounds of the data analyzed. Note that it is important not to extrapolate the regression line fit much beyond the bounds of the data analyzed; for the 35 airport data set, the maximum percentage of heavy + B757 aircraft is 53% at JFK. This is a reasonable extrapolation beyond the bounds of the regression analysis. All other airports are within bounds.

The regression equation of Figure 1 was used to predict the improvement that might be expected for each of the 35 airports used in this current study, based on the traffic mix at each airport in the demand set. The arrival rate improvement was only applied under non-visual conditions, since using visual approach procedures pilots are responsible for wake separation. As previously stated a 5% improvement in departure rate was assumed, and this was applied under both IMC and VMC since departure wake separation rules between heavy and B757 aircraft and smaller aircraft are applied at all times. Table 6 shows the estimated improvement factors. Table 7 shows the corresponding enhanced airport capacities, calculated by applying the improvement factors to the OEP airport capacities from Table 3.

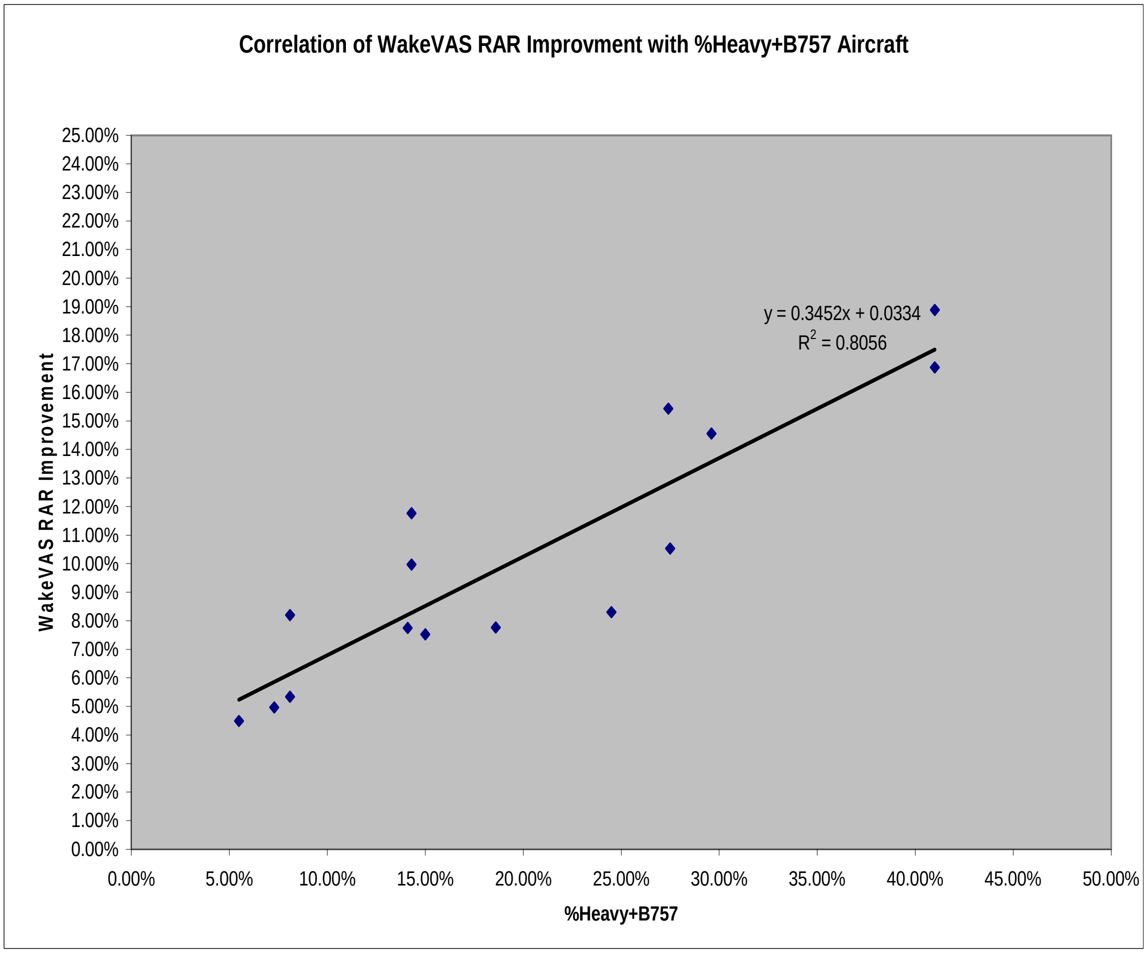

Figure 1 Wake VAS Non-Visual Arrival Rates Improvement versus Traffic Mix

Airport	Visual Departures Increase%	Visual Arrivals Increase%	Non-Visual Departures Increase%	Non-Visual Arrivals Increase%
ATL	5.0	0.0	5.0	12.1
BOS	5.0	0.0	5.0	9.6
BWI	5.0	0.0	5.0	7.6
CLE	5.0	0.0	5.0	3.8
CLT	5.0	0.0	5.0	5.6
CVG	5.0	0.0	5.0	6.8
DCA	5.0	0.0	5.0	3.4
DEN	5.0	0.0	5.0	8.6
DFW	5.0	0.0	5.0	8.5
DTW	5.0	0.0	5.0	6.7
EWR	5.0	0.0	5.0	10.7
FLL	5.0	0.0	5.0	8.6
IAD	5.0	0.0	5.0	7.7
IAH	5.0	0.0	5.0	6.2
JFK	5.0	0.0	5.0	21.4
LAS	5.0	0.0	5.0	9.8
LAX	5.0	0.0	5.0	13.9
LGA	5.0	0.0	5.0	6.5
MCO	5.0	0.0	5.0	12.0
MDW	5.0	0.0	5.0	6.3
MEM	5.0	0.0	5.0	11.3
MIA	5.0	0.0	5.0	14.1
MSP	5.0	0.0	5.0	6.9
ORD	5.0	0.0	5.0	8.2
PDX	5.0	0.0	5.0	6.5
PHL	5.0	0.0	5.0	6.8
PHX	5.0	0.0	5.0	6.1
PIT	5.0	0.0	5.0	5.4
SAN	5.0	0.0	5.0	6.5
SDF	5.0	0.0	5.0	14.8
SEA	5.0	0.0	5.0	8.5
SFO	5.0	0.0	5.0	14.2
SLC	5.0	0.0	5.0	7.3
STL	5.0	0.0	5.0	6.3
TPA	5.0	0.0	5.0	6.8
Mean	**5.0**	**0.0**	**5.0**	**9.5**

Table 6 Wake VAS Arrival and Departure Rates Improvement
(Estimated from regression analysis)

Airport	Dep. VFR	Arr. VFR	Total VFR	Dep. IFR	Arr. IFR	Total IFR
ATL	146	138	276	126	133	251
BOS	75	67	135	51	51	97
BWI	72	71	123	45	47	80
CLE	62	59	108	35	34	62
CLT	107	93	184	84	77	150
CVG	102	80	165	101	80	164
DCA	47	45	85	40	39	74
DEN	159	149	276	132	135	240
DFW	144	146	288	116	127	240
DTW	109	100	196	98	95	181
EWR	71	63	120	49	50	90
FLL	75	71	130	36	37	65
IAD	119	114	186	111	114	182
IAH	96	95	178	88	93	168
JFK	64	68	103	46	59	85
LAS	49	47	87	37	38	68
LAX	103	100	180	78	85	147
LGA	49	47	91	37	37	70
MCO	106	109	191	86	99	166
MDW	82	78	142	35	35	63
MEM	92	88	161	74	78	136
MIA	98	93	169	79	86	149
MSP	92	91	163	86	91	157
ORD	121	114	219	102	105	192
PDX	66	63	114	62	63	112
PHL	74	73	131	61	65	113
PHX	84	81	154	57	58	107
PIT	114	106	169	91	90	141
SAN	35	32	60	30	30	53
SDF	66	63	114	62	63	112
SEA	91	82	146	78	76	131
SFO	58	55	102	43	47	82
SLC	79	84	142	62	71	117
STL	81	78	144	70	71	129
TPA	72	69	122	61	62	109

Table 7 Airport Capacities with Wake VAS Improvements

5. Availability of Wake VAS ConOps

The overall benefit that will be obtained from any Wake VAS is a product of the capacity improvement and the time that the system is able to provide that capacity improvement.

The single runway Phase III ConOps is able to provide at least some improvement under nearly all meteorological conditions since several meteorological factors are used by the wake prediction model. The improvement factors used in this study were based on an analysis of 6 days of weather data at 12 different airports and represent the average improvement obtained over many hours of data collected during diverse conditions, see reference 3. For this current study, it is assumed that these improvement factors are representative of the mean improvement that would be obtained over a complete year.

The single runway Wake VAS Phase III arrival ConOps will be available to provide a potential capacity gain whenever non-visual conditions exist. The availability factors used for each airport are just the annual percentage IFR shown in Table 8. The departure ConOps will be available to provide a potential capacity gain at all times.

Airport	%IFR
ATL	23%
BOS	18%
BWI	13%
CLE	15%
CLT	18%
CVG	43%
DCA	14%
DEN	7%
DFW	17%
DTW	23%
EWR	19%
FLL	5%
IAD	20%
IAH	24%
JFK	14%
LAS	1%
LAX	18%
LGA	20%
MCO	5%
MDW	15%
MEM	21%
MIA	3%
MSP	31%
ORD	15%
PDX	18%
PHL	15%
PHX	1%
PIT	14%
SAN	30%
SDF	20%
SEA	29%
SFO	26%
SLC	15%
STL	23%
TPA	4%

Table 8 Annual Percentages of IFR Conditions at 35 Airports
(From reference 7)

6. Delay Reduction and Airline Cost Savings

Simulation Inputs

The ACES nodal airport model was used for all simulation runs using either ACES OEP 2010 airport capacity values, Table 3, or Wake VAS enhanced capacities, Table 7. Sector capacity limits were set to 200 (effectively no limits) and the Airline Operations Center federate was disabled. Each simulation run assumed either IFR or VFR conditions for all airports. The demand set used was based on the ACES '2020' demand, Table 4; the number of operations for each of the 35 airports analysed is shown in Table 5.

ACES build 3.2.1 includes a more advanced airport model as part of the enhanced terminal model. However, only ORD, EWR and DTW have configurations for the advanced airport model. Initial comparison of ORD enhanced terminal model results with nodal model results did not give good agreement. For these reasons the enhanced model is not currently being used, but will be re-considered when Build 4 of ACES becomes available.

The AOC could potentially improve throughput by cancelling flights to reduce demand, but when the AOC was enabled, not many flights actually appeared to be cancelled, so it was not used for the simulation results reported here.

Delay Reduction

Delay reductions from ACES simulation results and the corresponding estimated cost savings are presented for the airports with Wake VAS deployed. Also presented are total delay reduction and cost savings for the network wide airport set that includes all airports with flights departing to or arriving from any of the Wake VAS airports.

ACES logs data during the simulation which allows calculation of total delay (defined as the difference between actual gate arrival time and scheduled gate arrival time) and delay by flight leg, for each flight in the simulation. For this analysis delay was categorised as ground hold, ground or airborne delay. All flights delayed on departure by more than 5 hours were deemed to be cancelled and 5 hours of delay included in the ground hold delay estimate for the cancelled flight.

For brevity, only total delays are presented in this report, but the airline cost savings estimates are calculated using delay by category. Ground hold delay is least expensive, since the aircraft main engines are not operating; ground delay is incurred during taxi-in or taxi-out with engines operating; airborne delay is most expensive to the airlines.

Table 9 shows minutes of delay for 24 hours of flight operations at each of the study airports, and Table 10 shows the number of cancellations. The corresponding delay reductions obtained using Wake VAS is shown in Figure 2 and Table 11. The delay reduction figures take into account the reduced number of flights deemed to be cancelled;

for each flight cancelled 5 hours of ground hold delay is included. This is a conservative estimate of the cost of a cancellation to the airline, since it does not take into account any passenger compensation or expense due to lost connections.

Note that in a few cases the total delay values in Table 9 indicate a small increase with the use of Wake VAS, but this is predominantly due to more flights being included in the delay total since fewer flights were cancelled. A few of the delay reduction values in Table 11 are slightly negative for some airports, indicating increased total delay. This is due to network effects, increasing the traffic flow at some airports may result in increased delay at other airports because the overall traffic load is increased.

The delay reduction figures from ACES indicate a very substantial reduction of total delay at LAS of 1637 hours IFR and 297 hours VFR for 24 hours of operations. This result needs to be explained, since the IFR reduction in particular is out of line with delay savings obtained at the other airports, see Figure 2 below.

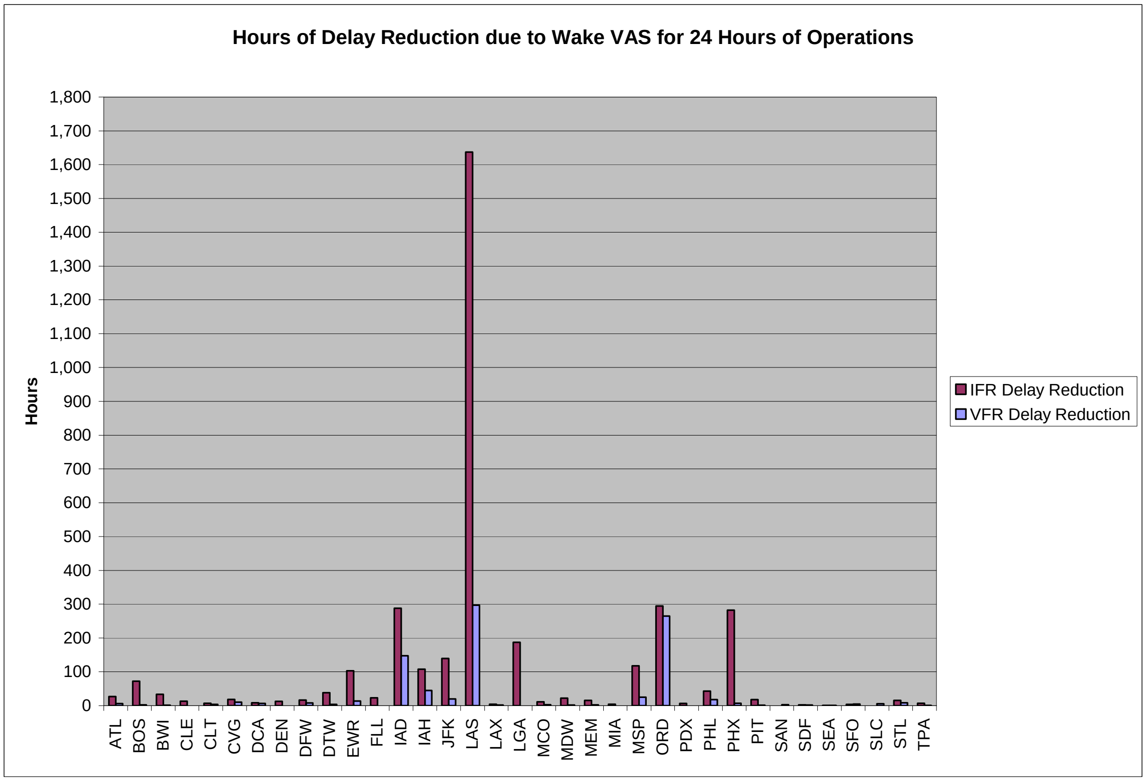

Figure 2 Delay Reductions due to Wake VAS at 35 Airports

Section 7 of this report analyzes the demand versus capacity at the benchmark airports. Table 20 shows the 24 hr demand/ capacity ratios for LAS are 1.01 IFR/ 0.79 VFR for the 2020 demand set and the Wake VAS airport capacities used for this analysis. This ratio is the largest of all the benchmark airports and leads to unrealistically high delays. The analysis described in Section 7 determined that a 24 hour demand/ capacity ratio of around 0.6 to 0.7 is required to ensure delays do not exceed about 15 minutes per operation.

The ACES 3.2.1 current capacity for LAS is 57 IFR/ 85 VFR total operations per hour, increasing to 63 IFR/ 85 VFR total operations per hour for the OEP 2010 enhanced capacity. This is in agreement with the FAA 2001 benchmark report, reference 5. However the 2004 benchmark report, reference 8 gives the current capacity as 70 IFR/ 113 VFR operations per hour with no future increase shown in the OEP version 5 for IFR or VFR conditions. The current capacity has been substantially revised, indicating that the capacity at LAS was originally underestimated in the 2001 benchmark report. This explains the excessive delay and the correspondingly large delay reduction obtained.

In actuality the annual percentage of IFR conditions at LAS is only 1% so the IFR results have very little weight in the annualized benefits. However, the VFR results are also questionable, since the VFR capacity is underestimated by 28 operations per hour. This leads to an unrealistically large estimated annual reduction in delay due to Wake VAS. A re-run of the results using OEP version 5 estimated capacities for LAS gave a reduction of total delay due to Wake VAS at LAS of 1560 hours IFR and 131 hours VFR for 24 hours of operations.

The reduction in delay obtained from ACES simulation using the improvement factors from section 4 of this report were for a single day of simulated operations. The single day results are multiplied by the number of days in a year and weighted by the annual percentage availability of the Wake VAS ConOps as shown in section 5 to obtain the annualized values for each of the airports, shown in Table 12. Note that the annualized delay reduction under VFR conditions is dominated by LAS; 107,416 hours out of 288,901 hours total reduction. This is an overestimate of the benefits for the reasons given previously. Using LAS airport capacity from OEP Version 5 reduces the annualized total delay reduction at LAS to 47,512 hours.

The total potential benefit of using Wake VAS is not limited to the airports which were equipped with Wake VAS. Network wide benefits occur, due to less delay at airports which have flights departing to, or arriving from the Wake VAS equipped airports. Table 13 show the network wide total cancellations, delays and the delays per flight for the OEP 2010 baseline airport capacities and for the Wake VAS ConOps increased capacities. Wake VAS reduces the network wide mean delay per operation from 21.4 minutes to 15.7 minutes under IFR and from 11.5 minutes to 10.3 minutes under VFR conditions. The network wide annual delay reduction due to wake VAS was 536,402 hours, see Table 16. Again, this figure is an overestimate due to LAS. Using OEP 5 LAS capacities reduces the annual network wide delay reduction to 489,703 hours.

Airport	USING OEP 2010 AIRPORT CAPACITIES		USING WAKE VAS ENHANCED CAPACITIES	
	IFR	VFR	IFR	VFR
ATL	12,019	8,472	11,294	8,107
BOS	13,345	7,318	11,428	7,490
BWI	7,393	1,451	5,394	1,387
CLE	6,386	4,675	5,581	4,409
CLT	5,276	4,055	6,036	3,824
CVG	6,886	5,900	5,779	5,293
DCA	6,814	3,639	6,307	3,233
DEN	9,414	4,311	7,472	5,294
DFW	6,382	5,769	5,396	5,319
DTW	8,840	5,997	7,736	5,798
EWR	34,906	8,926	29,012	8,091
FLL	3,438	532	2,026	516
IAD	54,066	38,113	36,775	29,274
IAH	22,214	13,451	15,724	10,751
JFK	28,942	8,956	20,873	7,757
LAS	154,135	82,815	66,722	64,979
LAX	4,621	4,556	4,358	4,440
LGA	25,317	5,518	14,691	5,264
MCO	2,808	1,738	2,113	1,542
MDW	5,567	1,452	4,228	1,346
MEM	4,899	3,926	4,274	3,779
MIA	2,228	1,457	1,974	1,556
MSP	19,021	10,884	12,269	9,378
ORD	32,248	31,616	17,268	15,704
PDX	2,095	1,510	1,698	1,493
PHL	13,112	11,501	11,120	10,411
PHX	82,282	7,460	61,747	7,341
PIT	5,297	3,274	4,227	3,197
SAN	7,307	4,296	7,164	3,807
SDF	1,618	1,240	1,475	1,143
SEA	1,245	1,237	1,199	1,219
SFO	2,771	2,732	2,553	2,458
SLC	8,379	5,135	9,173	5,398
STL	5,803	4,009	4,862	3,511
TPA	1,936	985	1,503	932
Total	**609,009**	**308,904**	**411,453**	**255,439**

Table 9 Minutes of Delay at 35 Airports – Wake VAS Comparison

Airport	USING OEP 2010 AIRPORT CAPACITIES		USING WAKE VAS ENHANCED CAPACITIES	
	IFR	**VFR**	**IFR**	**VFR**
ATL	8	0	5	0
BOS	27	17	19	16
BWI	0	0	0	0
CLE	2	0	2	1
CLT	4	0	0	0
CVG	0	0	0	0
DCA	0	0	0	0
DEN	10	9	14	6
DFW	0	0	0	0
DTW	7	0	3	0
EWR	1	0	0	0
FLL	0	0	0	0
IAD	0	0	0	0
IAH	0	0	0	0
JFK	3	0	2	0
LAS	368	0	332	0
LAX	0	0	0	0
LGA	2	0	0	1
MCO	0	0	0	0
MDW	0	0	0	0
MEM	1	0	0	0
MIA	0	0	0	0
MSP	1	0	0	0
ORD	10	0	1	0
PDX	1	1	1	2
PHL	2	0	0	0
PHX	28	11	40	10
PIT	0	0	0	0
SAN	9	4	16	5
SDF	0	0	0	0
SEA	0	0	0	0
SFO	0	0	0	0
SLC	18	6	16	4
STL	0	0	0	0
TPA	0	0	0	0
Total	**502**	**48**	**451**	**45**

Table 10 Cancellations at 35 Airports – Wake VAS Comparison
(Flight departure delayed by more than 5 hours)

Airport	Hours of Delay Reduction	
	IFR	VFR
ATL	27	6
BOS	72	2
BWI	33	1
CLE	13	-1
CLT	7	4
CVG	18	10
DCA	8	7
DEN	12	-1
DFW	16	8
DTW	38	3
EWR	103	14
FLL	24	0
IAD	288	147
IAH	108	45
JFK	139	20
LAS	1,637	297
LAX	4	2
LGA	187	-1
MCO	12	3
MDW	22	2
MEM	15	2
MIA	4	-2
MSP	118	25
ORD	295	265
PDX	7	-5
PHL	43	18
PHX	282	7
PIT	18	1
SAN	-33	3
SDF	2	2
SEA	1	0
SFO	4	5
SLC	-3	6
STL	16	8
TPA	7	1
Total	**3,548**	**906**

Table 11 Hours of Delay Reduction due to Wake VAS at 35 Airports

Airport	Hours of Delay Reduction	
	IFR	VFR
ATL	2,274	1,710
BOS	4,727	636
BWI	1,581	337
CLE	734	-174
CLT	482	1,153
CVG	2,895	2,106
DCA	432	2,123
DEN	316	-467
DFW	1,020	2,274
DTW	3,223	933
EWR	7,159	4,114
FLL	430	92
IAD	21,037	43,016
IAH	9,476	12,481
JFK	7,128	6,271
LAS	5,975	107,416
LAX	288	580
LGA	13,659	-221
MCO	211	1,135
MDW	1,222	546
MEM	1,181	706
MIA	46	-589
MSP	13,298	6,323
ORD	16,133	82,278
PDX	435	-1,413
PHL	2,365	5,637
PHX	1,030	2,524
PIT	911	402
SAN	-3,571	805
SDF	174	472
SEA	81	79
SFO	344	1,232
SLC	-177	1,743
STL	1,316	2,333
TPA	105	310
Total	**117,938**	**288,901**

Table 12 Annual Hours of Delay Reduction due to Wake VAS at 35 Airports

	USING OEP 2010 AIRPORT CAPACITIES		USING WAKE VAS ENHANCED CAPACITIES	
	IFR	VFR	IFR	VFR
Flown	44,681	45,347	44,767	45,346
Cancelled	856	190	770	191
Total Delay (minutes)	956,216	522,818	704,072	468,362
Delay per Flight (minutes)	**21.4**	**11.5**	**15.7**	**10.3**

Table 13 Total Network Wide Delays and Cancellations – Wake VAS Comparison

Airline Cost Savings

The airline cost savings calculated in this analysis are based on the fleet and operations weighted air carrier costs contained in reference 9. From this FAA sponsored source, the average air carrier variable operating cost for aircraft adjusted to 2004 $ is $2209 per hour in the air, $1702 on the ground with engines operating while taxiing or waiting for takeoff and $852 while waiting in ground hold with engines off and only auxiliary power units operating. The reduced costs on the ground reflect 66% and 95% reduction in fuel/ oil costs respectively, compared to in the air consumption. The cost data used in this analysis are summarized in Table 14. These values are used to calculate the estimated cost savings due to Wake VAS delay reduction, according to the flight segment where the delay occurred

The estimated annual airline cost savings that results from the use of Wake VAS at each airport analysed are shown in Figure 3 and Table 15. The total annual savings at the 35 airports amount to **$666 million**, but this includes **$193 million** at LAS which is an overestimate, for the reasons given previously. Using OEP Version 5 as the basis for LAS airport capacity reduces the annual savings at LAS to **$92.5 million** and the total savings at the Wake VAS airports to **$573.5 million**.

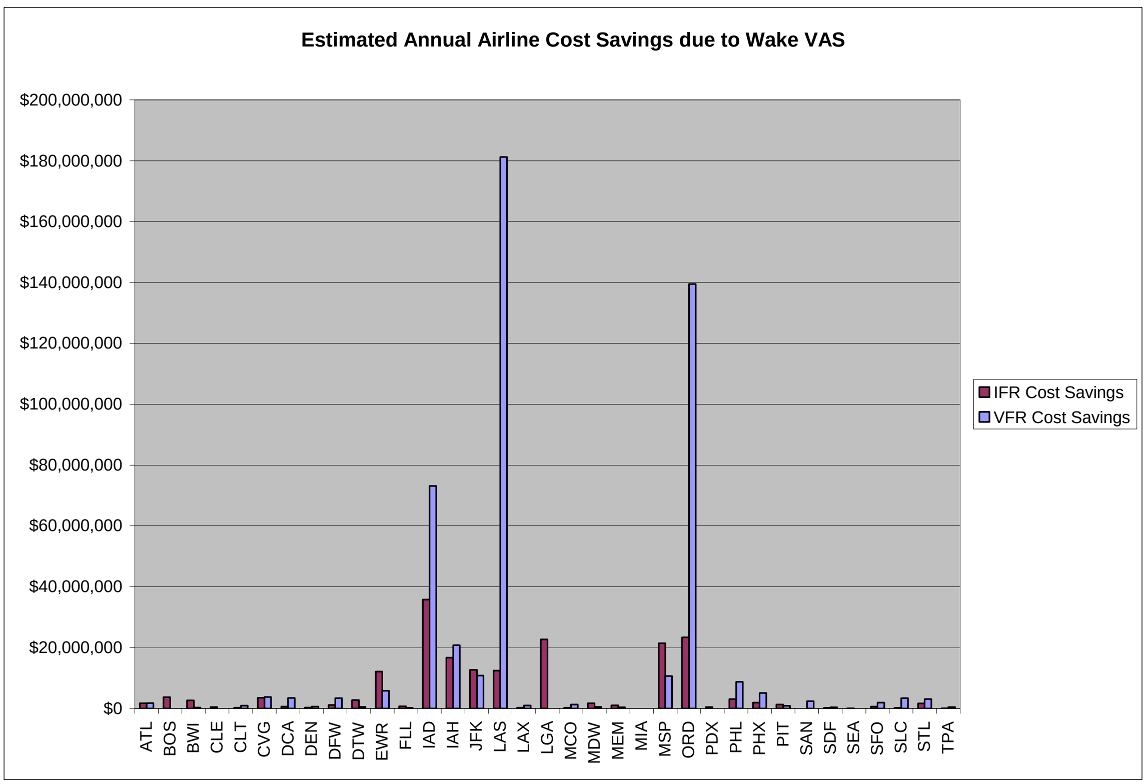

Figure 3 Annual Airline Cost Savings due to Wake VAS at 35 Airports

The total cost savings at the 35 airports and network wide total savings, which includes airports having flights departing to, or arriving from any of the Wake VAS airports is shown in Table 16. An annual network wide total saving of **$868 million** occurs with use of Wake VAS at the airports analyzed, but this value includes an overestimate of benefits at LAS, and the actual savings are sensitive to inaccuracies in the demand forecast and future airport capacity estimates. Using OEP version 5 LAS capacities reduces network wide total saving to **$789 million**.

Cost per hr	**Airborne**	**Ground**	**Ground Hold**
Aircraft Average	$2,209	$1,702	$852

Table 14 Airlines Operating Costs

Airport	Airline Cost Savings
ATL	$3,470,411
BOS	$3,554,012
BWI	$2,963,850
CLE	-$917,015
CLT	$1,242,644
CVG	$7,296,508
DCA	$4,027,710
DEN	$935,670
DFW	$4,444,841
DTW	$3,328,216
EWR	$17,977,061
FLL	$898,250
IAD	$108,972,351
IAH	$37,595,281
JFK	$23,545,703
LAS	$193,679,300
LAX	$1,306,253
LGA	$20,800,722
MCO	$1,535,632
MDW	$2,261,898
MEM	$1,440,092
MIA	-$919,392
MSP	$32,111,557
ORD	$162,875,876
PDX	-$760,181
PHL	$11,811,608
PHX	$7,021,760
PIT	$2,148,438
SAN	-$624,383
SDF	$615,471
SEA	$86,695
SFO	$2,518,277
SLC	$3,591,915
STL	$4,801,718
TPA	$589,692
Total	**$666,228,442**

Table 15 Annual Airline Cost Savings due to Wake VAS at 35 Airports

	35 AIRPORTS	NETWORK WIDE
Hours of Delay Reduction	**406,893**	**536,402**
Airline Annual Cost Savings	**$666,228,442**	**$867,927,449**

Table 16 Total Annual Delay Reduction and Cost Savings due to Wake VAS

Wake VAS Installation, Operating and Support Costs

The Logistics Management Institute published a business case analysis, reference 10 that contains an estimate of the costs for a Phase III Wake VAS including the wake vortex hardware and software and operating and support costs. The LMI report contains detailed cost estimates for SFO, DFW and STL only.

From reference 10, the cost to equip SFO or DFW is estimated to be $1.6 million for hardware and software and $280,000 per year for operation and support. For STL the costs estimates are $3.1 million for hardware and software and $690,000 per year for operation and support.

Using these cost values, the savings that could be obtained by deployment of the Wake VAS Phase III single runway ConOps would yield a substantial overall benefit within the first year of operation at many of the FAA benchmark airports, see Table 15.

7. Dependence of Delay on Demand and Airport Capacity

ACES Build 3.2.1 has a simple nodal model of airports which represents the airport capacity under VFR and IFR as a boundary for each operating state, generated from a triplet of values representing hourly capacity for arrivals only, departures only and maximum total mixed departures and arrivals. This nodal model keeps track of arrival and departure queues of aircraft and attempts to adjust the allowed departure and arrival rates within the capacity limits to optimise throughput. All queuing models exhibit rapid growth in delay when the average demand approaches some fraction of the capacity and tend to exhibit an exponential trend in delay. The use of a queuing model to represent an airport can give good analytical results so long as the airport is operated such that average demand does not exceed the queue capacity for long periods. If the average demand does exceed the queue capacity for prolonged periods the delays reach extreme levels.

ACES build 3.2.1 includes a more advanced airport model as part of the enhanced terminal model. However, only ORD, EWR and DTW have configurations for the advanced airport model. Initial comparison of ORD enhanced terminal model results with nodal model results did not give good agreement. For these reasons the enhanced model is not currently being used, but will be re-considered when Build 4 of ACES becomes available. The enhanced model will be investigated to determine if the growth in delay with demand is less steep than with the nodal model, but with any airport model, as in reality, the delays will become excessive once demand approaches some fraction of capacity.

The mean delay per flight versus demand/capacity ratio for various ACES simulation runs is shown in Figure 4.

A capacity benefits analysis should take into account the operating point on the delay curve when constructing a demand set. For a mean total delay per flight of 15 minutes the average demand/ capacity ratio should not exceed about 0.6. If the ratio exceeds 0.7 the mean delays start to become excessive, exceeding 1 hour per flight. If the analysis is performed using a demand set which operates too far up the demand curve of Figure 4, for example, using an average demand to capacity ratio of 0.8 or more, then a small increase in capacity will give an apparent very large reduction in delay, which is not likely to be realised in practice.

Table 17 shows the current day airport capacities, OEP 2010 capacities as supplied with ACES and Wake VAS enhanced capacities used for the simulation.

Tables 18, 19 and 20 below show the demand/ capacity ratio for 35 FAA benchmark airports (actually excluding HNL and including SDF which is not a benchmark airport) for various demand sets and airport capacity combinations. The demand sets analysed are from the ACES build 3 demand sets.

Table 18 shows that current day average demand/capacity ratios do not exceed 0.6 under VFR. Even under IFR the majority of airports do not exceed 0.6 with most of the remaining airports below 0.7.

Table 19 shows the demand/capacity ratios for the SLIC generated 2X demand set using OEP-2010 and Wake VAS improved airport capacities. Many of the airports have demand/capacity ratios exceeding 0.7, which is the level at which delays start to become excessive. In fact there are many cases where the average 24hr demand exceeds 1, so the demand is infeasible. Wake VAS alone does not add sufficient capacity to enable the 2X demand set to be used for a meaningful analysis. ACES simulation results gave a mean delay per flight of 3 hours under VFR and 4.2 hours under IFR with 2X demand using Wake VAS at 12 airports.

Table 20 shows the demand/capacity ratios for the SLIC generated 2020 demand set. The demand set shows reasonable demand/capacity ratios at most airports except for ORD and LAS which have too much demand for the capacity.

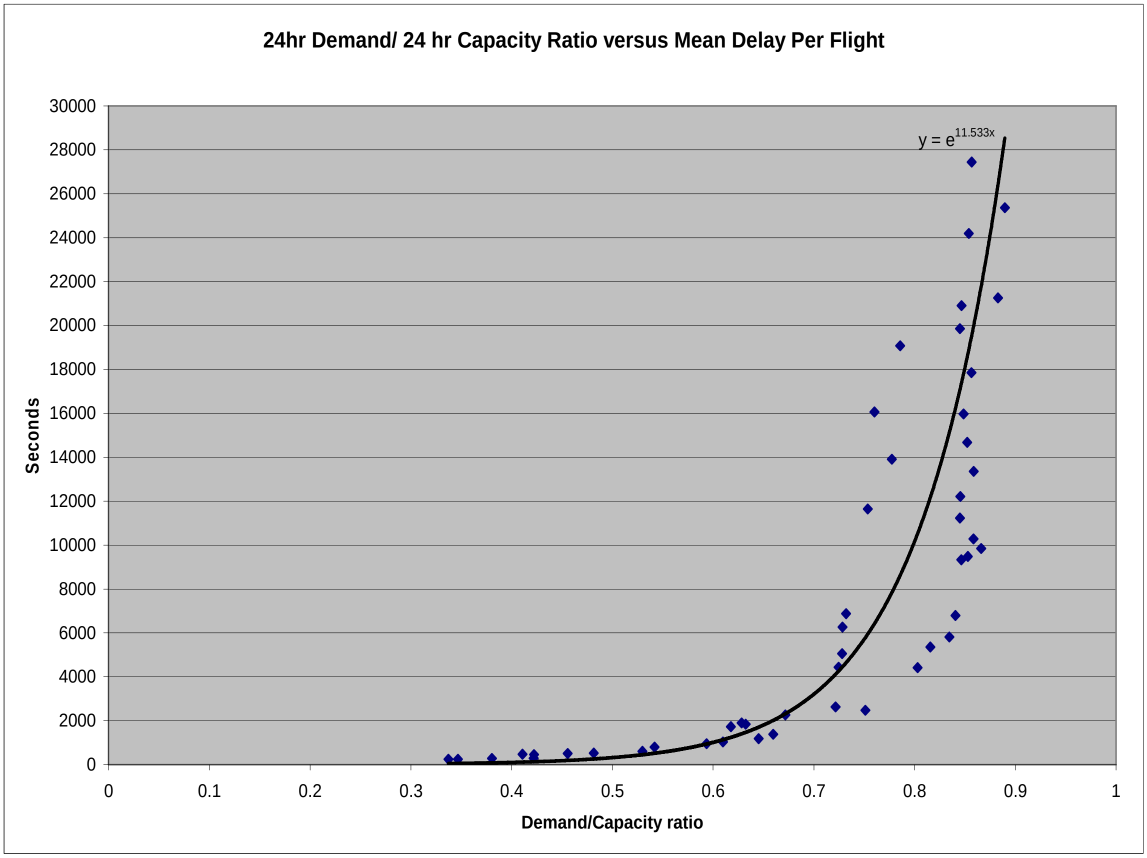

Figure 4 Demand/Capacity Ratios versus Mean Delay per Flight

Airport	Current VFR Capacity ops/hr	Current IFR Capacity ops/hr	OEP 2010 VFR Capacity ops/hr	OEP 2010 IFR Capacity ops/hr	WAKE VAS VFR Capacity ops/hr	WAKE VAS IFR Capacity ops/hr
ATL	200	174	269	231	276	251
BOS	126	88	131	91	135	97
BWI	120	75	120	75	123	80
CLE	105	59	105	59	108	62
CLT	140	116	179	142	184	150
CVG	125	125	160	158	165	164
DCA	80	66	83	71	85	74
DEN	218	196	268	223	276	240
DFW	270	185	281	224	288	240
DTW	146	138	191	170	196	181
EWR	108	78	117	83	120	90
FLL	126	60	126	60	130	65
IAD	121	117	180	170	186	182
IAH	123	113	173	159	178	168
JFK	98	71	100	73	103	85
LAS	85	57	85	63	87	68
LAX	150	128	175	133	180	147
LGA	81	64	89	66	91	70
MCO	145	112	186	151	191	166
MDW	138	59	138	59	142	63
MEM	152	120	157	124	161	136
MIA	134	108	164	134	169	149
MSP	120	112	159	147	163	157
ORD	202	160	213	179	219	192
PDX	111	105	111	105	114	112
PHL	110	96	127	106	131	113
PHX	110	65	150	101	154	107
PIT	160	131	164	132	169	141
SAN	57	49	58	50	60	53
SDF	111	105	111	105	114	112
SEA	91	81	142	121	146	131
SFO	99	72	99	74	102	82
SLC	132	105	138	109	142	117
STL	112	65	140	122	144	129
TPA	119	87	119	102	122	109

Table 17 Airport Capacities Total Operations Summary

Airport	Flight Operations ops/24hr	24hr DEMAND /CAPACITY CURRENT	
		VFR	IFR
ATL	2468	0.51	0.59
BOS	1141	0.38	0.54
BWI	890	0.31	0.49
CLE	762	0.30	0.54
CLT	1303	0.39	0.47
CVG	1333	0.44	0.44
DCA	646	0.34	0.41
DEN	1451	0.28	0.31
DFW	2107	0.33	0.47
DTW	1432	0.41	0.43
EWR	1193	0.46	0.64
FLL	668	0.22	0.46
IAD	1168	0.40	0.42
IAH	1295	0.44	0.48
JFK	771	0.33	0.45
LAS	1198	0.59	0.88
LAX	1772	0.49	0.58
LGA	1107	0.57	0.72
MCO	799	0.23	0.30
MDW	855	0.26	0.60
MEM	1164	0.32	0.40
MIA	1148	0.36	0.44
MSP	1388	0.48	0.52
ORD	2611	0.54	0.68
PDX	791	0.30	0.31
PHL	1288	0.49	0.56
PHX	1461	0.55	0.94
PIT	1234	0.32	0.39
SAN	560	0.41	0.48
SDF	483	0.18	0.19
SEA	1064	0.49	0.55
SFO	990	0.42	0.57
SLC	946	0.30	0.38
STL	1297	0.48	0.83
TPA	667	0.23	0.32

Table 18 Demand/Capacity Ratios for 2002 Demand Set
Using Current Airport Capacities
(From SLIC_2002_517_250APTOpenNetwork_Intl demand file)

Airport	Flight Operations ops/24hr	24hr DEMAND /CAPACITY OEP_2010		24hr DEMAND /CAPACITY WAKE VAS	
		VFR	IFR	VFR	IFR
ATL	6558	1.02	1.18	0.99	1.09
BOS	2309	0.73	1.06	0.71	0.99
BWI	2401	0.83	1.33	0.81	1.25
CLE	1426	0.57	1.01	0.55	0.96
CLT	2895	0.67	0.85	0.66	0.80
CVG	3719	0.97	0.98	0.94	0.94
DCA	1764	0.89	1.04	0.86	0.99
DEN	4125	0.64	0.77	0.62	0.72
DFW	3832	0.57	0.71	0.55	0.67
DTW	4238	0.92	1.04	0.90	0.98
EWR	2920	1.04	1.47	1.01	1.35
FLL	2068	0.68	1.44	0.66	1.33
IAD	6535	1.51	1.60	1.46	1.50
IAH	4891	1.18	1.28	1.14	1.21
JFK	2739	1.14	1.56	1.11	1.34
LAS	3302	1.62	2.18	1.58	2.02
LAX	4400	1.05	1.38	1.02	1.25
LGA	1566	0.73	0.99	0.72	0.93
MCO	2857	0.64	0.79	0.62	0.72
MDW	1489	0.45	1.05	0.44	0.98
MEM	2919	0.77	0.98	0.76	0.89
MIA	1637	0.42	0.51	0.40	0.46
MSP	4271	1.12	1.21	1.09	1.13
ORD	5770	1.13	1.34	1.10	1.25
PDX	1482	0.56	0.59	0.54	0.55
PHL	3715	1.22	1.46	1.18	1.37
PHX	3447	0.96	1.42	0.93	1.34
PIT	1411	0.36	0.45	0.35	0.42
SAN	1291	0.93	1.08	0.90	1.01
SDF	840	0.32	0.33	0.31	0.31
SEA	2309	0.68	0.80	0.66	0.73
SFO	2250	0.95	1.27	0.92	1.14
SLC	2812	0.85	1.07	0.83	1.00
STL	1482	0.44	0.51	0.43	0.48
TPA	1547	0.54	0.63	0.53	0.59

Table 19 Demand/Capacity Ratios for 2X Demand Set Using OEP2010 and Wake VAS Airport Capacities
(From SLIC_2X_250OpenNetwork_Intl demand file)

Airport	Flight Operations ops/24hr	24hr DEMAND /CAPACITY OEP_2010		24hr DEMAND /CAPACITY WAKE VAS	
		VFR	IFR	VFR	IFR
ATL	3440	0.53	0.62	0.52	0.57
BOS	1404	0.45	0.64	0.43	0.60
BWI	1233	0.43	0.69	0.42	0.64
CLE	914	0.36	0.65	0.35	0.61
CLT	1669	0.39	0.49	0.38	0.46
CVG	1909	0.50	0.50	0.48	0.49
DCA	905	0.45	0.53	0.44	0.51
DEN	2076	0.32	0.39	0.31	0.36
DFW	2517	0.37	0.47	0.36	0.44
DTW	2093	0.46	0.51	0.44	0.48
EWR	1592	0.57	0.80	0.55	0.74
FLL	992	0.33	0.69	0.32	0.64
IAD	2452	0.57	0.60	0.55	0.56
IAH	2131	0.51	0.56	0.50	0.53
JFK	1231	0.51	0.70	0.50	0.60
LAS	1654	0.81	1.09	0.79	1.01
LAX	2385	0.57	0.75	0.55	0.68
LGA	1229	0.58	0.78	0.56	0.73
MCO	1297	0.29	0.36	0.28	0.33
MDW	989	0.30	0.70	0.29	0.65
MEM	1574	0.42	0.53	0.41	0.48
MIA	1276	0.32	0.40	0.31	0.36
MSP	2058	0.54	0.58	0.53	0.55
ORD	3342	0.65	0.78	0.64	0.73
PDX	927	0.35	0.37	0.34	0.34
PHL	1866	0.61	0.73	0.59	0.69
PHX	1919	0.53	0.79	0.52	0.75
PIT	1295	0.33	0.41	0.32	0.38
SAN	722	0.52	0.60	0.50	0.57
SDF	560	0.21	0.22	0.20	0.21
SEA	1344	0.39	0.46	0.38	0.43
SFO	1274	0.54	0.72	0.52	0.65
SLC	1382	0.42	0.53	0.41	0.49
STL	1360	0.40	0.46	0.39	0.44
TPA	870	0.30	0.36	0.30	0.33

Table 20 Demand/Capacity Ratios for '2020' Demand Set Using OEP2010 and WAKE VAS Airport Capacities
(From SLIC_2020_250OpenNetwork_Intl demand set)

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14. ABSTRACT

The FAA and NASA are currently engaged in a Wake Turbulence Research Program to revise wake turbulence separation standards, procedures, and criteria to increase airport capacity while maintaining or increasing safety. The research program is divided into three phases: Phase I – near term procedural enhancements; Phase II – wind dependant Wake Vortex Advisory System (WakeVAS) Concepts of Operations (ConOps); and Phase III – farther term ConOps based on wake prediction and sensing. The Phase III Wake VAS ConOps is one element of the Virtual Airspace Modelling and Simulation (VAMS) program blended concepts for enhancing the total system wide capacity of the National Airspace System (NAS).
This report contains a VAMS Program Type 1 (stand-alone) assessment of the expected capacity benefits of Wake VAS at the 35 FAA Benchmark Airports and determines the consequent reduction in delay using the Airspace Concepts Evaluation System (ACES) Build 3.2.1 simulator.

15. SUBJECT TERMS
ACES; VAMS Type 1 Assessment; Wake VAS; Wake Vortex

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