Analysis of Delay Reduction due to use of a Wake Vortex Advisory System (Wake VAS)

Results from ACES Build 2.03 and LMINET

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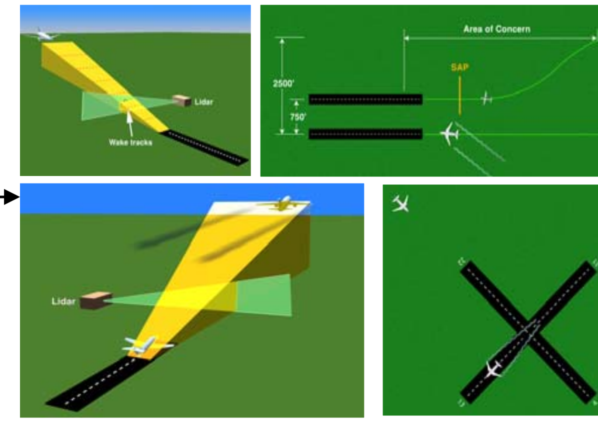
Concept Development

Real-Time Wake Hazard Knowledge

- **Weather sensing and prediction**
- **Wake hazard predictions**
- **Wake sensing**

Procedures/Rules

Interfaces



- **Controller Tools**
  - **Course – wake is/ is not a factor**
  - **Fine – integrate into approach spacing tool**
- **Flight Deck**
  - **Intuitive Displays (increase situational awareness)**
  - **NAV/Guidance Integration**

- **Ground System**
- **Airborne System**
- **Hybrid System**

Concept Architecture

- Airport weather system augmented with wake and weather sensors and prediction algorithms

  - Wake algorithm provides probabilistic wake behavior output
  - Fusing algorithm combines sensor data and closes a feedback loop between wake and weather predictions and measurements
  - Closed-Loop prediction system senses current conditions diverging from predictions and adjusts to more conservative spacing and changes prediction duration appropriately

Meteorological Data Required for Wake Behavior Prediction

- Wind, Temperature, Turbulence Vertical Profiles
- Measure of turbulence used is Eddy Dissipation Rate (EDR)
- High spatial (~10m) and temporal (~10Hz) resolution data are required for EDR

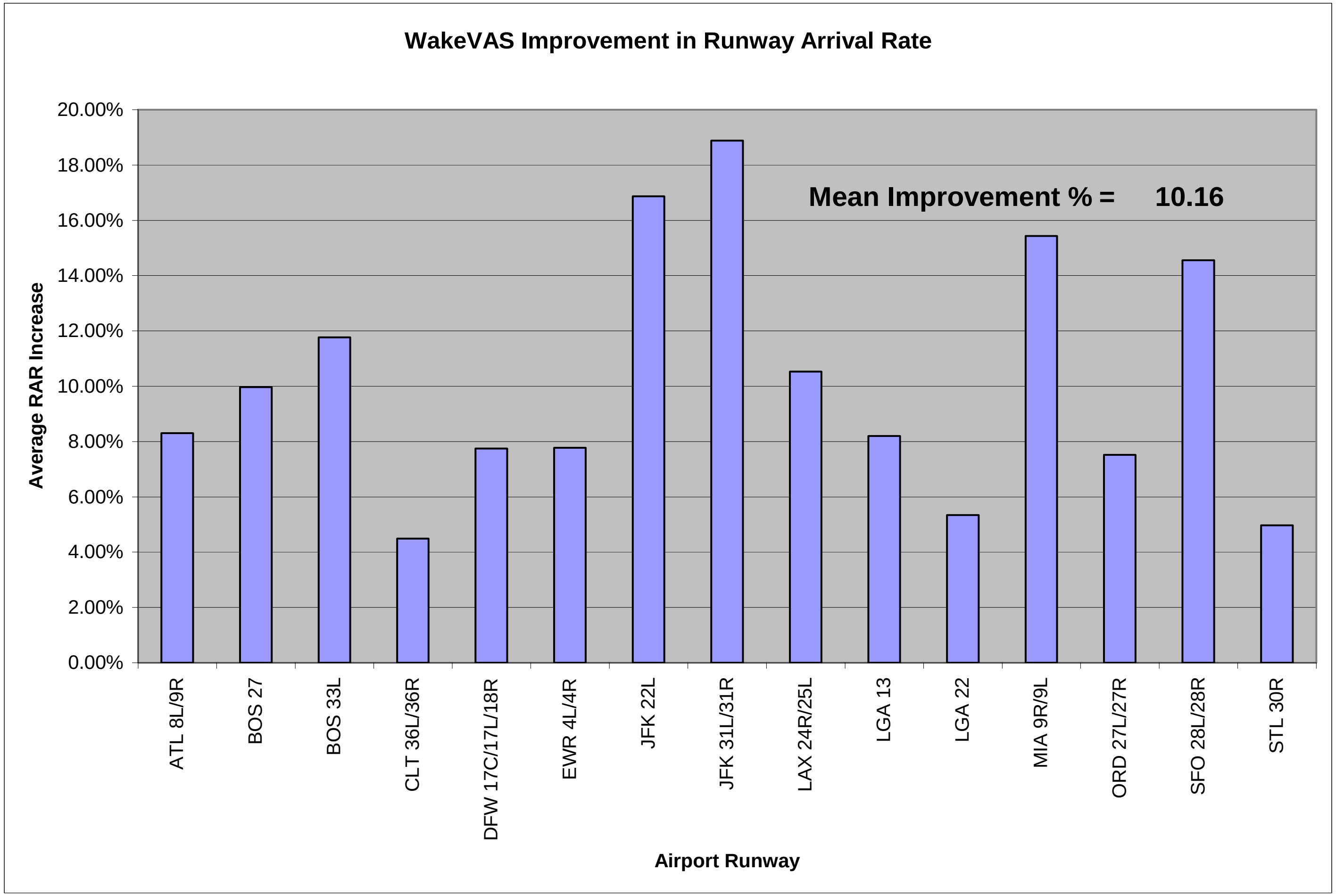
- ASOS data includes surface wind speed and direction, temperature reported at one-minute intervals
- Multi-variate statistical analysis established correlations between ASOS data and AVOSS measured EDR[1]
- ASOS data available at most major U.S. Airports

Airports for WakeVAS Capacity Gains Analysis

	ATL	BOS	CLT	DFW	EWR	JFK	LAX	LGA	MIA	ORD	SFO	STL
Config.	**2 pair CSPR**	**CSPR INT**	**INDEP INT**	**2 pair CSPR**	**CSPR INT**	**2 pair INDEP**	**2 pair CSPR**	**INT**	**1 pair INDEP**	**INT**	**2 pair CSPR**	**CSPR INT**
RCL (ft)	**4500**	**1500**		**1200**	**900**		**700/ 750**				**750**	**1300**
% B757 + Heavy	**25**	**14**	**6**	**14**	**19**	**41**	**21**	**9**	**26**	**15**	**30**	**7**
% Time IFR	**23**	**18**	**18**	**17**	**19**	**14**	**18**	**20**	**3**	**15**	**26**	**23**

CSPR - Closely spaced parallel runways
INT – Intersecting runways
INDEP – Independent runways

Initial Benefits Analysis for WakeVAS Reduced In-Trail Separation of Arrivals under IMC



Spacing data for each aircraft class from wake Parametric Model[1,2] was used along with data from simulation (RAMS Plus[10]) to determine runway arrival rates under IMC, detailed results are presented in reference 2.

ANALYSIS OF WAKE VAS DELAY REDUCTION

USING LMINET

NAS Wide Delay Reductions

- LMINET[3] Queuing network model of NAS used to investigate delay reduction for estimated 2010 demand
- Delays recorded:
  - Departure Queue
  - Arrival Queue
  - Departure Taxi Queue
  - Arrival Taxi Queue
  - Ground Hold
  - Wait for Aircraft (aircraft not available for departure)
  - Total Delay (sum of the above)
- 64 U.S. Airports modeled at runway level of detail, included FAA Operational Evolution Plan (OEP) improvements expected by 2010
- Investigated Wake VAS deployment at 12, 30, 64 airports
- Wake VAS used for arrivals only and arrivals + departures
- Assumed 5% departure rate improvement

Demand Data Set
for LMINET NAS Delay Reduction Assessment

Traffic Type	17 May 2002 Baseline Flights	2010 Flights*	% Growth
Commercial + Cargo from OAG	30853	37163	20%
GA from FAA reported data	21294	27533	29%
Total	52147	64696	24%

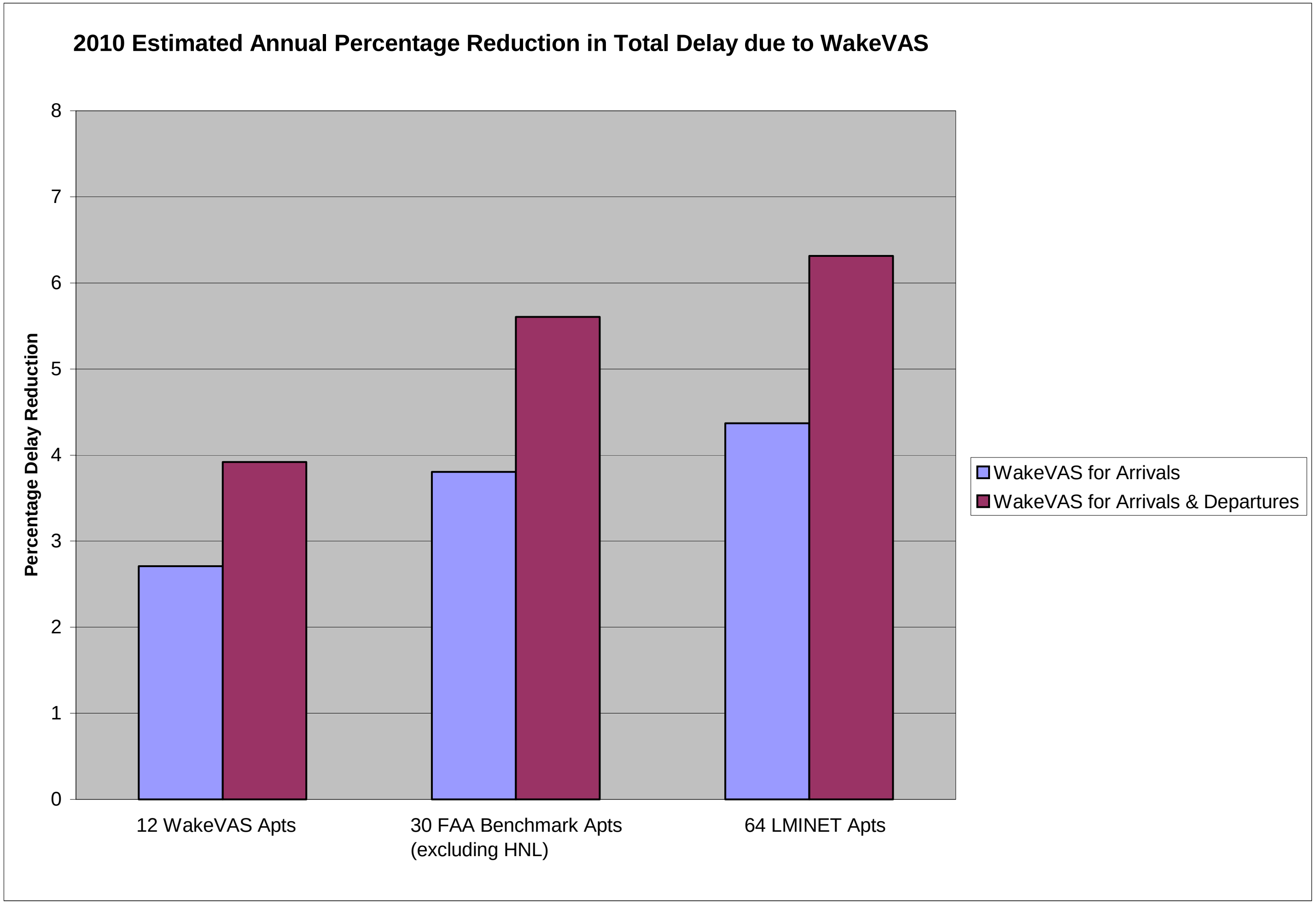
* Generated using models references 4, 5

Weather data for NAS Delay Analysis

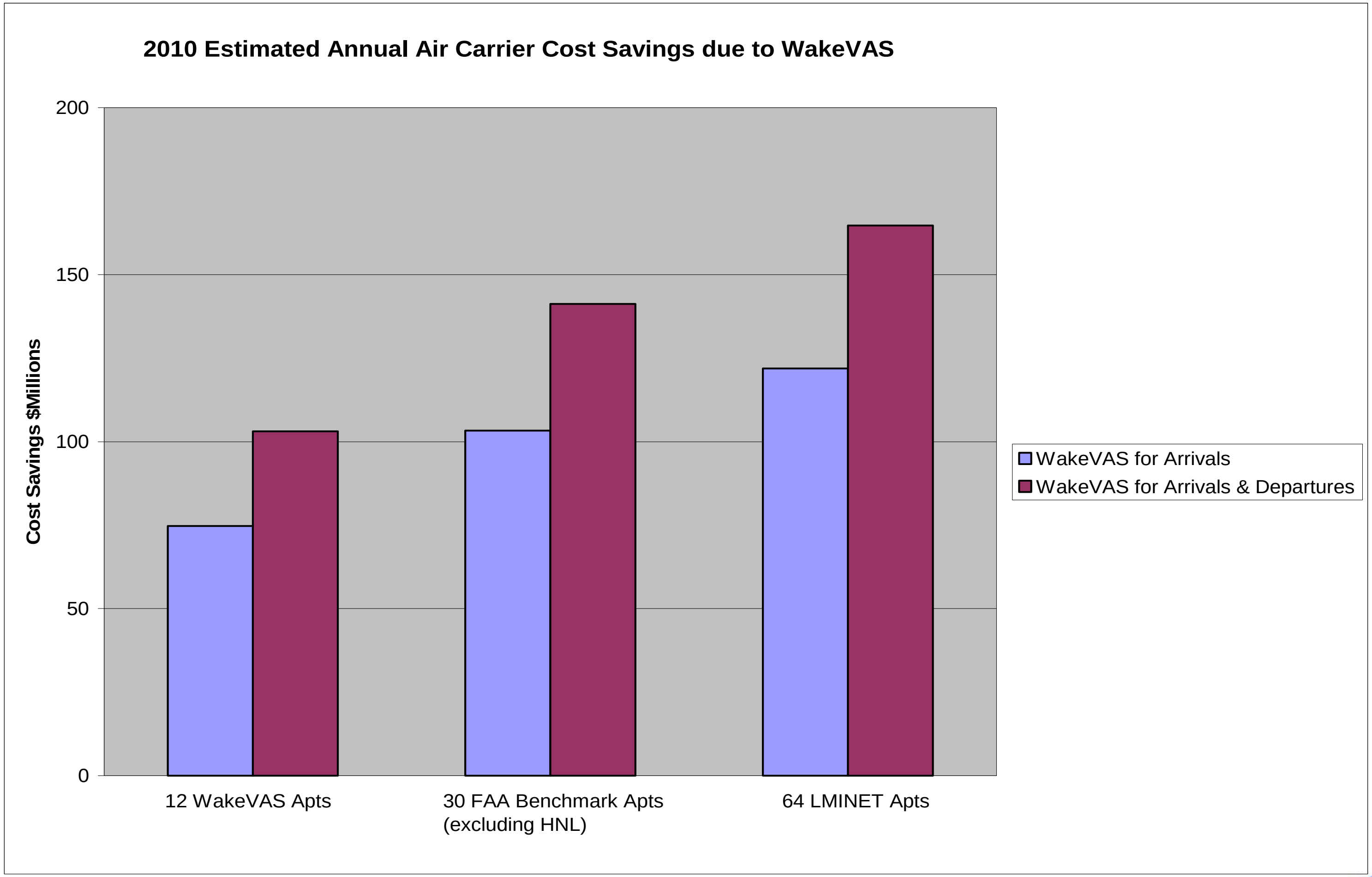
- 3 Representative days in the NAS
- Annualized delay calculated as weighted average of each weather day according to probability of occurrence APR (0.13), JUN (0.8), NOV (0.07)

Weather Set	%VMC	%MVMC	%IMC	#Airports IMC/MVMC
April	77.0	16.9	6.1	33
June	67.1	26.8	6.1	40
November	72.0	14.4	13.6	28

Estimated Annual Reduction in Delay for 2010 Demand



Estimated Annual Air Carrier Cost Savings for 2010 Demand



Annualized Delay Reduction and Cost Savings Calculation

- Weighted annual hours of delay reduction for WakeVAS deployment:

  @ 12 study airports for arrivals only
  46,563 hrs - saving approximately $75 million

  @ 12 study airports for arrivals + departures
  67,340 hrs - saving approximately $103 million

  @ 64 LMINET airports for arrivals and departures
  108,481 hrs saving approximately $165 million

Cost data from reference 6, detailed results presented in reference 7

ANALYSIS OF WAKE VAS DELAY REDUCTION

USING ACES BUILD 2.03

ACES DEMAND SETS

- Available demand sets
  - *May 17, 2002 NAS Demand (62,589 flights)*
  - *May 17, 2002 CONUS Demand (45,965 flights)*
  - *May 17, 2002 CONUS Top 250 Airports Demand (31,708 flights)*
  - *May 17, 2002 CONUS Top 250 Airports FLTGEN Demand (29,423 flights)*
  - *TAF 2015 - May 17, 2002 CONUS Top 250 Airports FLTGEN Demand (37,257 flights)*
  - *TAF 2020 - May 17, 2002 CONUS Top 250 Airports FLTGEN Demand (40,540 flights)*
  - *2X - May 17, 2002 CONUS Top 250 Airports FLTGEN Demand (59,353 flights)*

- 2020 ACES demand set is closest to 2010 demand used for LMINET study
- 2015 ACES demand set contains fewer flights than LMINET 2010 set

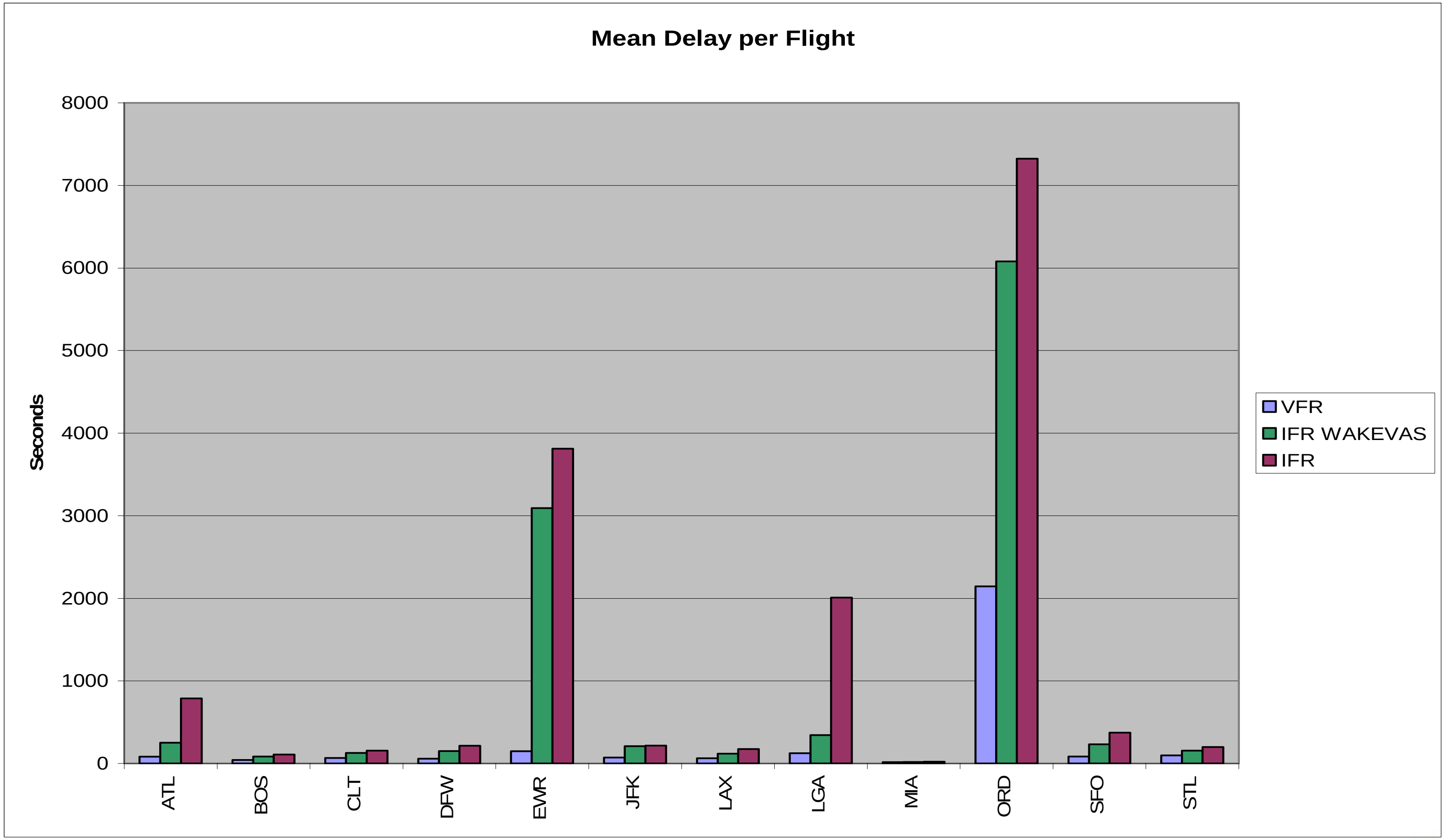
Number of Operations in Demand Data Sets at Wake VAS Airports

AIRPORT	2002 NAS	2002 FltGen	2020 FltGen	2020 ACES SIM	2010 LMINET
ATL	2468	2176	3640	3424	3006
BOS	1141	908	1132	926	1249
CLT	1303	1038	1387	1205	1452
DFW	2107	1849	3045	2714	2760
EWR	1193	974	1520	1417	1497
JFK	771	475	762	713	929
LAX	1772	1338	1990	1744	2118
LGA	1107	975	1133	841	1255
MIA	1148	527	631	598	1569
ORD	2611	2260	3544	3304	2917
SFO	990	723	1065	1011	1006
STL	1297	1134	1221	1185	1394
Total	17908	14377	21070	19082	21152

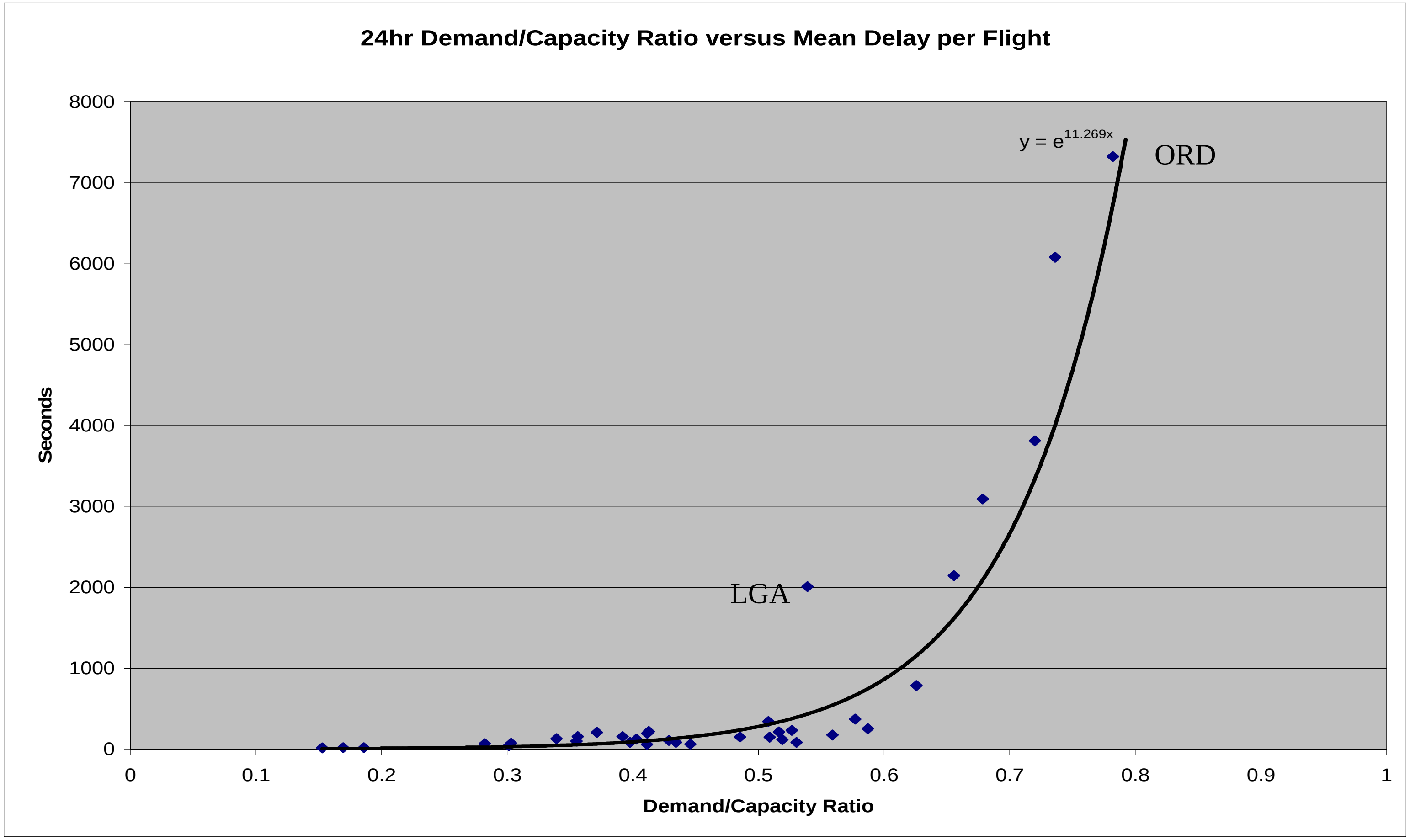
Airport Capacity Frontiers

- Increase by OEP 2010 enhancements
- Increase arrival rates under IMC by WakeVAS improvement factors
- Increase departure rates under IMC by 5%

Mean Delay Reduction per Flight at WakeVAS Airports



Demand/Capacity Ratio versus Delay



Comparison of ACES 2.03 Results with LMINET

LMINET and ACES delays under VFR

AIRPORT	LMINET		ACES	
	Total (hrs)	Per Flight (mins)	Total (hrs)	Per Flight (mins)
ATL	382	7.7	79	1.4
BOS	53	2.6	11	0.7
CLT	44	1.8	22	1.1
DFW	346	7.5	44	1.0
EWR	53	2.1	58	2.5
JFK	36	2.3	14	1.2
LAX	92	2.6	30	1.0
LGA	128	6.1	29	2.1
MIA	64	2.4	3	0.3
ORD	253	5.2	1967	35.7
SFO	33	2.0	23	1.4
STL	51	2.2	33	1.6
Total	1535		2313	

ACES Annualized Reduction in Delay due to WakeVAS under IFR

AIRPORT	Delay Reduction for 24 hrs of IFR operations (hrs)	Annual %IFR	Annualized Delay Reduction (hrs)
ATL	507.9	23	42636
BOS	6.2	18	410
CLT	9.6	18	631
DFW	47.1	17	2926
EWR	283.5	19	19663
JFK	1.6	14	82
LAX	27.0	18	1772
LGA	389.5	20	28433
MIA	0.3	3	4
ORD	1140.9	15	62464
SFO	39.6	26	3754
STL	13.8	23	1155
Total	2467.0		163929

Comparison between ACES and LMINET Delay Reduction due to WakeVAS

- ACES annualized delay reduction ~ 163,929 hrs
- LMINET annualized delay reduction ~ 67,340 hrs

- Exclude ORD (unrealistically large delays)
- Exclude LGA (anomalous)

- Average Delay Reduction per Airport LMINET ~ 5,600 hrs
- Average Delay Reduction per Airport ACES ~ 7,300 hrs

Planned use of ACES 3.2.1 in support of WakeVAS Program and VAMS Blended Concepts

Build 3.2.1 Features Relevant to WakeVAS

- Individual Runway Identification and Aircraft Spacing Matrices
- Site-specific VFR and IFR configuration models for each airport based on current airport designs
- Representative set of Terminal Areas (currently only ORD, EWR)
- International Flights
- Tail # connectivity feature keeps track of individual aircraft within ACES

Modeling WakeVAS within ACES Build 3.2.1

- Enhanced Terminal Area Model required for increased modeling fidelity of WakeVAS concept (up to 12 airports)

- Modify Runway Aircraft Spacing Tables[8]

(part of Enhanced Terminal Area Model)

  – For each airport modeled with individual runway operations, the user specifies the runway interactions and the appropriate spacing and buffer requirements

  – These common descriptors are encoded in:

    - Runway Interaction Tables

    - Minimum Separation Tables

    - Separation Buffer Tables

WakeVAS Proposed Spacing Modifications for Blended Concepts Analysis

- Arrivals
  - Single runway arrivals using WakeVAS reduced spacing (IMC)
  - CSPR (RCL < 1000FT) dependant runways treated as single runway using WakeVAS reduced spacing (IMC)
  - CSPR (RCL 1000ft – 2500ft) using 1.5 NM diagonal spacing, cross-wind dependant (IMC)

Note: 1000 ft RCL could potentially be reduced to 700ft for use with 1.5nm diagonal spacing, reference 9.

- Departures
  - Single runway departures, remove 4 /5 nm or 2 minutes behind Heavy/B757 restriction, cross-wind dependant (IMC, VMC)
  - CSPR (RCL < 2500ft) dependant runways treated as single runway

Note: Reference 9 states that Wake VAS applied to intersecting runway operations is not likely to be provide significant benefits.

Issues

- WakeVAS arrival spacing values are distance based, ACES are time based
- WakeVAS arrival spacing values are average for each of the study airports over set of weather data, not same set as ACES Wx
- Need cross-wind component values at study airports
- ACES Enhanced Terminal Model is complex, will require significant effort to set up and significant computational resources to run
- ACES simple Pareto based airport model will need to be used for WakeVAS candidate airports not-modeled in detail, need to ensure consistency with Enhanced Terminal Model

References

1) **Multivariable Regression Models for Prediction of Eddy Dissipation Rate from Available Meteorological Data**
Gerald E. Plassman1, Gerald H. Mall2, and John R. Quagliano3
1 - Raytheon Technical Services Company, Hampton, Virginia
2 - Analytical Services and Materials, Hampton, Virginia
3 - NCI Information Systems, Hampton, Virginia
NASA/CR (in publication)

2) **Systems Analysis for a Wake Vortex Advisory System (WakeVAS) at Selected U.S. Airports**
Appendix – Parametric Model for the Performance of a Wake Vortex Advisory System
Gary D. Millsaps, Jeremy C. Smith, Swales Aerospace, Hampton, VA, David Rutishauser, AST, David Hamilton, AST, LaRC Airborne Systems Competency, Hampton, VA
NASA/CR (in publication)

3) **Modeling Air Traffic Management Technologies with a Queuing Network Model of the National Airspace System**
Dou Long, David Lee Jesse Johnson, Eric Gaier, Peter Kostiuk, Logistics Management Institute, McLean, VA, NASA/CR-1999-208988. January 1999

4) **Integrated Mode Choice, Small Aircraft Demand and Airport Operations Model**
Dollyhigh, Samuel M., NASA/CR-2004-212998, *January 2004*

5) **Future Air Traffic Growth and Schedule Model**
Smith, Jeremy C., Dollyhigh, Samuel M., NASA/CR-2004-213027, January 2004

6) **Economic Values for Evaluation of FAA Investment and Regulatory Decisions**
GRA Incorporated, DTFA 01-02-C0020, May 2004

7) **Wake Vortex Advisory System (WakeVAS) Evaluation of Impacts on the National Airspace System**
Jeremy C. Smith, Swales Aerospace, Hampton, VA
NASA/CR-2005-213523

8) **CTOD 7.39 - Airspace Concept Evaluation System (ACES) Build 3 Software User Manual, 30 September 2004, Contract Number NAS2-00015**

9) **FAA/NASA Wake Turbulence Research Program WakeVAS Conops Evaluation Team Baseline Report, Arrivals and Departures; Single Runway and Closely Spaced Parallel Runways, December 31, 2004**

10) **RAMS Plus, ISA Software, Inc., http://www.ramsplus.com/Home.asp**