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The Effects of Very Light Jet Air Taxi Operations on Commercial Air Traffic

Jeremy C. Smith and Samuel M. Dollyhigh
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October 2006

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Summary

This study investigates the potential effects of Very Light Jet (VLJ) air taxi operations adding to delays experienced by commercial passenger air transportation in the year 2025.

The year 2025 is the FAA and NASA Joint Program Development Office (JPDO) goal year for implementation of the Next Generation Air Transportation System (NGATS).

VLJs are a class of aircraft that are smaller, have somewhat lower performance and are lower in cost than the typical business jets of today.

Examples of VLJ designs are the Eclipse 500, Cessna Citation Mustang, Embraer Phenom, Adam Aircraft A700, Diamond D-Jet, and Honda-Jet. The Eclipse 500 and Cessna Citation Mustang have achieved production certification. Eclipse claims pre-production VLJ orders for 2600 aircraft, Adam Aircraft for 350 aircraft and Cessna for 250 aircraft as of November 2006.

The Small Aircraft Transportation System Program (SATS) led by NASA demonstrated new operating capabilities that allow higher volume operations at non-towered /non-radar airports and lower landing minimum in poor weather at minimally equipped landing facilities. These key capabilities make it possible for VLJs to operate at many more airports than those used by commercial and business jets today.

The affordable cost relative to existing business jets and ability to use many of the existing small, minimally equipped, but conveniently located airports is projected to stimulate a large demand for the aircraft.

The resulting increase in air traffic operations will mainly be at smaller airports, but this study indicates that VLJs have the potential to increase further the pressure of demand at some medium and large airports, some of which are already operating at or near capacity at peak times. Currently, some General Aviation (GA) traffic uses many of the major airports as identified in the FAA's Operational Evolution Plan (OEP). In the future VLJ air taxi service operators may choose not to use OEP airports due to cost or because of congestion. For this reason two main scenarios are examined; allowing VLJ operations at OEP airports (OEP case) which currently have significant GA operations and completely excluding VLJ operations from all OEP airports (non-OEP case). **The non-OEP case is considered to be the more likely scenario.**

VLJs will also cause an increase in traffic density, and this study shows increased potential for conflicts due to VLJ operations.

The projected air traffic demand for 2025 is generated using passenger trip forecast data from the Transportation Systems Analysis Model (TSAM) based on socio-economic and demographic modeling. *(TSAM is under development by Virginia Tech's Air*

Transportation Systems Laboratory and NASA Langley.) The projected demand for VLJ air taxi operations in 2025 is about 20,000 flights per day. This demand is then used as input to the Airspace Concepts Evaluation System (ACES) simulator. *(ACES is being developed as part of the NASA Virtual Airspace Modeling and Simulation Project led by NASA Ames Research Center.)* The figure at the end of this section shows a screen shot of the simulated VLJ air traffic, near a peak time for the traffic density.

All results presented in this study assume perfect weather, with all airports operating under Visual Meteorological Conditions and all airspace sectors operating at maximum capacity.

The OEP airport capacities are increased by 40% over and above the FAA's OEP Version 5 capacities, non-OEP airport capacities are also increased by 40% and sector capacities are increased by 300% from current values for the year 2025 analysis. These values are the JPDO Evaluation and Analysis Directorate expectations for the capabilities of the NGATS.

The key question that this study seeks to answer is –

> *Will the future use of NAS resources by VLJ traffic be significant enough to impact commercial air traffic and increase passenger delays?*

The main conclusion is that VLJ air taxi operations have the *potential* to increase delays to commercial traffic, but the effects are likely to be small for the most likely scenario where VLJ Air taxi operators avoid using OEP airports.

Simulation results from ACES show that the projected VLJ Air taxi operations for the year 2025 could increase total delay for commercial passenger flights by an estimated **1.3%** if VLJ Air Taxis do not use any OEP airports. Simulation results indicate that the increase in total delay for commercial passenger flights could be as much as **9.8%** if VLJs are not excluded from OEP airports that have significant GA traffic today and no changes are made to mitigate the effects of VLJs, **however this is considered an unlikely scenario**.

An intermediate scenario is possible where some OEP airports remain attractive to VLJ operators and through airspace re-design where necessary, the effects of VLJs are reduced. This was not included in this study.

These results should be interpreted with caution – ACES does not have a trajectory based model of flights within the terminal area. A high fidelity, trajectory based model might reveal more interactions between VLJs and commercial air traffic. A high fidelity model might then be used to investigate airspace re-design in the terminal area to mitigate the effect of VLJs where necessary.

The main results from this analysis are:

- The estimated annual delay to commercial air passenger operations in 2025 **without VLJ operations** is **3,323,700 hours**. The annual increase in air carrier direct operating costs due to this delay, compared to no delay, is estimated to be **$4.04 billion**.

  *For comparison the estimated annual delay to commercial air passenger operations in 2004 is **1,664,100 hours,** from ACES simulation results and the air carrier direct operating costs due to this delay is estimated to be **$2.08 billion.** The 2025 total delay is approximately twice the 2004 total delay; however the number of commercial flights has increased by a factor of 1.85 so the average delay per flight is not much larger in 2025 than it was in 2004.*

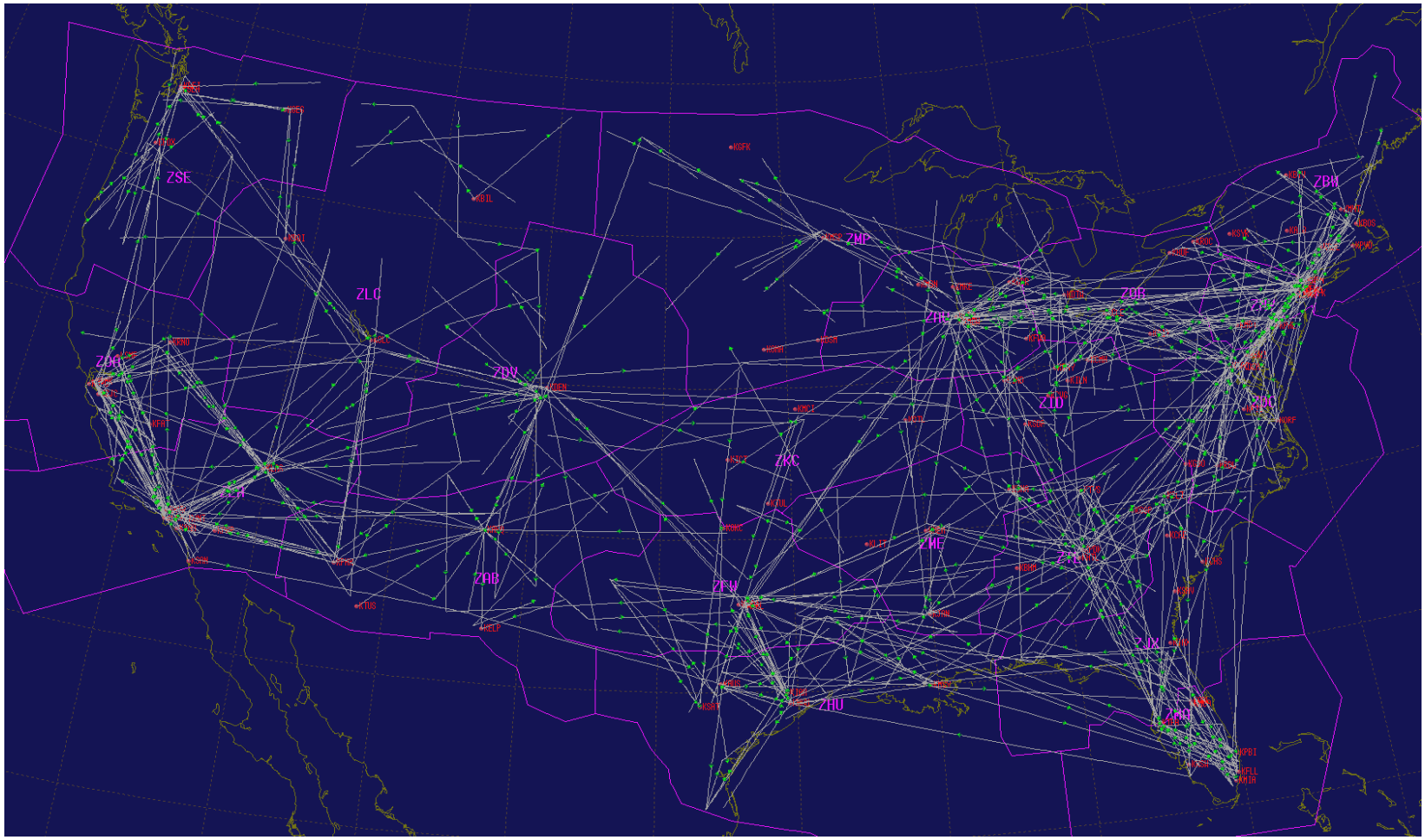
- VLJ air taxi operations have the potential to add an estimated **42,000 hours** of delay annually to commercial air passenger operations if VLJs do not use OEP airports. If some VLJ traffic uses OEP airports and no changes are made to mitigate the effects of VLJs, the increase in delay could be as much as **326,000 hours;** however this is considered an unlikely scenario.

- The additional delay due to VLJ air taxi operations potentially results in an estimated annual additional cost to commercial air carriers of **$42.6 million** (1.1%) for the non-OEP case, or as much as **$425.6 million** (10.5%) for the less likely OEP case (year 2005$).

- The total increase in cost is quite large for the less likely OEP case, however the 2025 projected daily flights in the NAS for commercial air passenger operations is **64,000 per day** so the mean increase in **cost per flight** is about **$18** for the OEP case and is less than **$2** for the non-OEP case.

- The delay in 2025 is mainly due to insufficient airport capacities, the assumed 300% increase in sector capacities is adequate to meet the demand.

- Although a 300% increase in sector capacity is adequate for the 2025 demand even with VLJs, the increase in traffic density due to VLJ operations results in a **6.6%** increase in en-route potential conflicts for the non-OEP case and a **6.9%** increase for the OEP case, assuming today's separation standards. However, VLJs generally fly at lower altitudes than most commercial air carrier flights, due to shorter trip distances and so most of the increase in potential conflicts is between VLJs and with other GA traffic. The increase in commercial air carrier potential conflicts is **2.1%** for the non-OEP case and **1.9%** for the OEP case. NGATS improvements in technology are expected to allow reduced separation standards which would reduce the number of potential conflicts reported by ACES for this study.



Snapshot of Very Light Jet Air Taxi Operations in the Year 2025

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Introduction

This study investigates the potential effects of Very Light Jet (VLJ) air taxi operations adding to delays experienced by scheduled commercial passenger air transport. This study specifically focuses on VLJs used as air taxis and does not include possible additional operations from VLJs used by private individuals, by companies for sole company use, or fractional ownership schemes.

Terminology: This report uses the term "commercial" to refer to Air Carrier, Scheduled Commuter and Air Taxi operations i.e. excluding GA and Cargo. VLJ Air Taxi operations are referred to separately from GA and existing Air Taxi operations.

VLJs are a class of aircraft that are smaller and have somewhat lower performance than the typical business jet of today. The typical VLJ has a maximum take off weight of around 6000 lbs to 10,000 lbs, seats 3 to 5 passengers and has a cruise speed of around 350 kts with a maximum useable range of around 1000 nm. VLJs are capable of reaching much the same altitudes as commercial jets. In comparison, typical business jets seat 6 to 20 passengers and have similar or better performance than today's commercial jets in terms of cruise speeds and cruise altitudes.

Examples of VLJ designs are the Eclipse 500, Cessna Citation Mustang, Embraer Phenom, Adam Aircraft A700, Diamond D-Jet, and Honda-Jet. The Eclipse 500 and Cessna Citation Mustang have achieved production certification. Eclipse claims pre-production VLJ orders for 2600 aircraft, Adam Aircraft for 350 aircraft and Cessna for 250 aircraft as of November 2006.

VLJs will cost in the region of $1.5 to $3 million compared to the cost of a conventional business jet, typically $6 to $12 million. The relatively low cost makes VLJs attractive to a wider income range of private owners and "on-demand" air taxi operators.

The Small Aircraft Transportation System Program (SATS) http://sats.nasa.gov/ led by NASA, demonstrated new operating capabilities that allow higher volume operations at non-towered /non-radar airports and lower landing minimum in poor weather at minimally equipped landing facilities. These key capabilities make it possible for VLJs to operate at many more airports than those used by commercial, air taxi and business jets today.

The affordable cost and ability to use many of the existing small, minimally equipped, but conveniently located airports will stimulate a large demand for the aircraft.

The resulting increase in air traffic operations will mainly be at smaller airports, but has the *potential* to increase further the pressure of demand at *some* medium and large airports, some of which are already operating at or near capacity at peak times. VLJs will also cause an increase in traffic density, which may cause an increase in potential

conflicts and increased airspace congestion in busy National Airspace System (NAS) sectors.

The key question that this study seeks to answer is –

> *Will the future use of NAS resources by VLJ traffic be significant enough to impact commercial air traffic and increase passenger delays?*

The impact will depend on a number of factors, the most important of which are:

- level of demand;
- distance of trips, which determines the optimum altitude of the flight;
- origin and destination airports of trips.

The number of VLJ aircraft in service is projected to reach about 5000 by 2017 according to FAA forecasts; however this study will focus on the farther term, in-line with the FAA and NASA Joint Program Development Office (JPDO) www.jpdo.aero goal for NGATS implementation, so the year 2025 is chosen. A detailed forecast of demand for 2025 is generated.

The distance distribution of trips is important, since longer trips lead to higher altitudes for efficient operations. VLJ air taxis will fly shorter trips on average than commercial air transports and current business jets and *may* not reach the altitudes where most commercial jet traffic flies today. However, the trip distance is dependent on the assumptions made when modeling demand for trips, so an alternative business model is also examined that generates somewhat longer VLJ flights, reaching slightly higher altitudes than the primary model.

The origin and destination airport distribution is also important. VLJs can land on runways as short as 3,000 ft and therefore can access as many as 3,400 of the 5,000 or so smaller airports available in the U.S. However, much of the demand is between large centers of population and often the most convenient airport is either the same major airport already heavily used by commercial air transports or an airport in close proximity.

Many of the major airports are used by General Aviation (GA) traffic; the number of business jets operations at some airports can be significant. Table 1 identifies the 35 OEP airports and lists the number of commercial and GA operations recorded in the 19 February 2004 Enhanced Traffic Management System (ETMS) data. *(This is the day chosen for the JPDO Evaluation and Analysis Directorate (EAD) baseline traffic day.)* In the future it is likely that VLJ air taxi service operators may choose not to use OEP airports, due to cost or because of congestion. For this study two VLJ air taxi scenarios are examined, one allowing the use of OEP airports where GA traffic is present today and the other with VLJs completely excluded from all OEP airports.

ID	Name	Number of Commercial Operations (excluding cargo)	Number of GA Operations	Percentage of GA Operations
ATL	Atlanta Hartsfield-Jackson International	2551	30	1.2
BOS	Boston Logan International	923	40	4.2
BWI	Baltimore-Washington International	705	52	6.9
CLE	Cleveland Hopkins	737	31	4.0
CLT	Charlotte/Douglas International	1090	79	6.8
CVG	Cincinnati/Northern Kentucky International	1283	13	1.0
DCA	Ronald Reagan Washington National	766	3	0.4
DEN	Denver International	1431	10	0.7
DFW	Dallas/Fort Worth International	2167	21	1.0
DTW	Detroit Metro Wayne County	1301	44	3.3
EWR	Newark Liberty International	1085	18	1.6
FLL	Fort Lauderdale-Hollywood International	560	90	13.8
HNL	Honolulu International	Excluded	from study	
IAD	Washington Dulles International	802	181	18.4
IAH	Houston George Bush Intercontinental	1342	45	3.2
JFK	New York John F. Kennedy International	701	6	0.8
LAS	Las Vegas McCarran International	1132	127	10.1
LAX	Los Angeles International	1369	25	1.8
LGA	New York LaGuardia	1101	17	1.5
MCO	Orlando International	783	64	7.6
MDW	Chicago Midway	766	104	12.0
MEM	Memphis International	628	118	15.8
MIA	Miami International	854	52	5.7
MSP	Minneapolis-St Paul International	1400	38	2.6
ORD	Chicago O'Hare International	2660	31	1.2
PDX	Portland International	589	50	7.8
PHL	Philadelphia International	1055	42	3.8
PHX	Phoenix Sky Harbor International	1330	79	5.6
PIT	Greater Pittsburgh International	887	43	4.6
SAN	San Diego International - Lindbergh Field	474	34	6.7
SEA	Seattle-Tacoma International	800	4	0.5
SFO	San Francisco International	748	47	5.9
SLC	Salt Lake City International	897	81	8.3
STL	Lambert-St. Louis International	709	29	3.9
TPA	Tampa International	582	92	13.6

Table 1 OEP Airports List with Number of Commercial and General Aviation Operations on 19 February 2004

Simulation Programs

The simulation program used for this study is the **Airspace Concepts Evaluation System (ACES) Simulator** (build 4.2) which was developed as part of the NASA Virtual Airspace Modeling and Simulation Project led by Ames Research Center.
http://vams.arc.nasa.gov

ACES is a comprehensive air transportation systems simulator and includes aircraft models, airport models, airspace boundaries, traffic flow management, airline operations center, conflict detection and resolution and a trajectory propagator.

Demand Data Sets

An analysis of future concepts for air transportation systems depends on being able to predict future demand and transportation patterns. Two approaches to demand generation are discussed, using the FAA Terminal Area Forecast (TAF) and using the Virginia Tech/ NASA Langley Transportation Systems Analysis Model (TSAM). Different categories of air traffic do not have the same patterns of growth and are treated separately.

The baseline schedule for current traffic levels used was ETMS recorded data for 19 Feb 2004 (includes international flights). This is the day chosen for the JPDO Evaluation and Analysis Division (EAD) baseline traffic day.

The year chosen for the demand projection used in this study is 2025 which is the NGATS goal year for implementation.

The demand data sets generated are in ACES format and include the following data items:

- Aircraft ID
- Aircraft Type
- Departure Airport
- Arrival Airport
- Cruise Altitude (based on ETMS recorded altitude)
- Cruise Speed (based on ETMS recorded track positions)
- Waypoint List(based on ETMS recorded routes)
- Scheduled Gate Departure Time

Note that ACES input data does not include a scheduled gate arrival time. Instead, the simulator computes the scheduled gate arrival time based on an unimpeded flight through the NAS. The typical performance characteristics for the aircraft type specified in the input data, along with the specified cruise altitude and speed are used. Real airline schedules typically contain time padding to allow for delays. ACES simulation results give a realistic estimate of likely delay, but this should not be directly compared to reported delays, which are understated due to schedule padding.

Terminal Area Forecast Based Demand Generation

The FAA produces the Terminal Area Forecast (TAF) that is the official forecast of aviation activity at FAA facilities. www.faa.gov/data_statistics/aviation/taf_reports/
The TAF includes forecasts for active airports in the National Plan of Integrated Airport Systems (NPIAS). The TAF bases projections mainly on analysis of historical trends using data provided by the facilities using FAA guidelines. The FAA Aerospace Forecast for fiscal years 2006 – 2017 www.faa.gov/data_statistics/aviation/aerospace_forecasts/ predicts that 5000 VLJs will be in operation by 2017, but TAF projections currently do not include VLJ operations.

The demand generation sets used in many studies of air transportation systems are generated by scaling up baseline current day flight operations, using the differential growth factors for different airports extrapolated from the TAF to provide the overall demand level required.

Seagull Technology Center / Sensis Corporation has used this approach to generate demand data sets for the JPDO. www.sensis.com

Demographics Based Demand Generation using the Transportation Systems Analysis Model

An alternative methodology for generating future demand sets is available using the Transportation Systems Analysis Model (TSAM). TSAM is under development by Virginia Tech's Air Transportation Systems Lab and NASA Langley, for details see reference 1.

TSAM improves on traditional transportation analysis models by first modeling all long distance travel (one way distance greater that 100 miles) and then projecting the mode choice of travelers based on trip characteristics and traveler demographics. Since the demand modeling is based on passenger trips and not on flight numbers, alternate future scenarios can be investigated based on transporting the same number of passengers using a different aircraft fleet mix, new demand driven routes or even entirely new means of transportation.

This approach taken for this study is to use TSAM to generate the demand and schedule for VLJs, since the TAF does not include VLJ projections, and the 19 Feb 2004 baseline does not, of course include any VLJ flights so this precludes scaling from the baseline.

TSAM is also used to generate the demand for future commercial and scheduled commuter/ air taxi traffic, but in this case, the schedule is generated by scaling and modifying the 19 Feb 2004 baseline as described in the corresponding section below.

Demand Generation for Different Categories of Air Traffic

Commercial Air Carrier, Scheduled Commuter and Air Taxi

TSAM passenger trip data is used to generate the growth factors for 443 commercial airports. The TSAM generated growth factors are for *passenger* trips to and from origin/ destination pairs, not aircraft operations.

The FAA Aerospace Forecast for fiscal years 2006-2017 projects an increase in load factor following current trends. The load factor for the 19 Feb 2004 baseline demand set is about 75.5%. However there is no load factor data for 2025 and extrapolating from 2017 to 2025 would lead to unreasonably large load factors. For this reason the load factor for 2025 is conservatively assumed to be 80%. Current (2006) reported load factors are around this value already or slightly higher, but it is not reasonable to expect load factors to continue to increase much beyond this. At 80% average load factors, flights at peak times will tend to be overbooked and airlines will start to add capacity to avoid losing customers.

The TSAM growth factors are modified to account for the increase in load factor then used as input to the Future Air Traffic Growth and Schedule Model developed by NASA Langley, see reference 2. This code grows the baseline demand set using the Fratar Algorithm to generate a schedule.

The schedule is then refined by introducing new direct routes between city pairs, when demand warrants (removing connecting flights), based on TSAM passenger trip demand between origin and destination airport pairs.

New direct routes are introduced between airport pairs (where none exist in the 2004 baseline) when passenger demand exceeds 25,000 trips (one-way) annually. This is sufficient to justify 2 flights per day each way in a ~50 seat sized aircraft.

The schedule is further refined by substituting larger aircraft for two or more smaller aircraft once schedule frequency between an airport pair is sufficient to meet passenger needs.

Larger aircraft (along with extra flights) start to be substituted when flight frequency reaches 12 flights per day between a city pair, reducing the number of extra flights needed to meet the passenger demand. The flight frequency is capped at 40 flights per day, or the 2004 frequency if 40 flights per day are exceeded in the 19 Feb 2004 data, see Table 2 below. When this limit is reached only larger aircraft are substituted to meet passenger demand (no additional flights). This is based on research by Airbus; see the Global Market Forecast reference 3.

Departure Airport	Arrival Airport	Total Departures 19 Feb 2004	Total Departures 2025	Total Departures 2025 New Routes and Larger Aircraft
BOS	LGA	44	67	44
LGA	DCA	41	53	41
SAN	LAX	40	67	40
PDX	SEA	38	39	39
ORD	MSP	37	50	39
ATL	DFW	34	73	37
LAX	LAS	34	56	37
LGA	ORD	34	44	35

Table 2 Commercial and Scheduled Commuter/ Air Taxi Daily Flight Frequency for Top City Pairs

The reduced schedule still maintains a high frequency of passenger service, for example the year 2025 frequency of service between ATL and DFW would have been 73 departures per day, but is reduced to 37 by using direct routes and substituting larger aircraft. For ORD to MSP the frequency would have been 50 departures per day but is reduced to 39 departures.

The maximum frequency of commercial passenger service between a city pair recorded in the 19 Feb 2004 ETMS data only exceeds 40 in a few cases, see Table 2. A frequency of 40 corresponds to a departure every 36 minutes if distributed evenly throughout the day; in reality more flights would be offered at peak times, so 40 departures per day can easily provide a departure every 15 minutes during the peak periods.

The growth in passenger demand from TSAM is projected to be about 2X (100%) system wide by the year 2025. (Individual airports may have lower or higher growth than this average.) This would require a corresponding 2X system wide increase in operations to meet this demand based on the same load factors, routes and aircraft fleet mix as the 19 Feb 2004 baseline demand set.

The combined effects of increased passenger load factors, new direct routes and use of larger aircraft reduces the growth in commercial operations required to meet the same passenger demand to about 1.68X (68%) system wide. This reduction is very significant; furthermore, the largest reductions in operations naturally occur at the busiest airports.

Table 3 below compares the numbers of commercial operations for 19 Feb 2004 compared with 2025 based on direct scaling of current traffic to meet the required growth in demand and with 2025 introducing new routes and substituting larger aircraft. The growth in operations required to meet the same passenger demand is reduced from 118% to 62% at ATL and from 88% to 54% at ORD.

	19 Feb 2004			2025				2025 New Routes/ Large Aircraft			
	Dep	**Arr**	**Tot**	**Dep**	**Arr**	**Tot**	**Growth Ratio**	**Dep**	**Arr**	**Tot**	**Growth Ratio**
ATL	1321	1278	2599	2836	2824	5660	2.18	2116	2085	4201	1.62
ORD	1387	1382	2769	2598	2596	5194	1.88	2144	2109	4253	1.54

Table 3 Number of Daily Operations at ORD and ATL

Figure 1 and Figure 2 show the reduced future departure demand for commercial passenger aircraft at ATL and ORD compared to not using larger aircraft and new routes (arrival demand is similarly reduced). For comparison, the 19 Feb 2004 scheduled demand is shown also. Note that the airport capacity shown is the NGATS increased future capacity (1.4X OEP Version 5) as described in the Airport and Airspace Capacity section of this report.

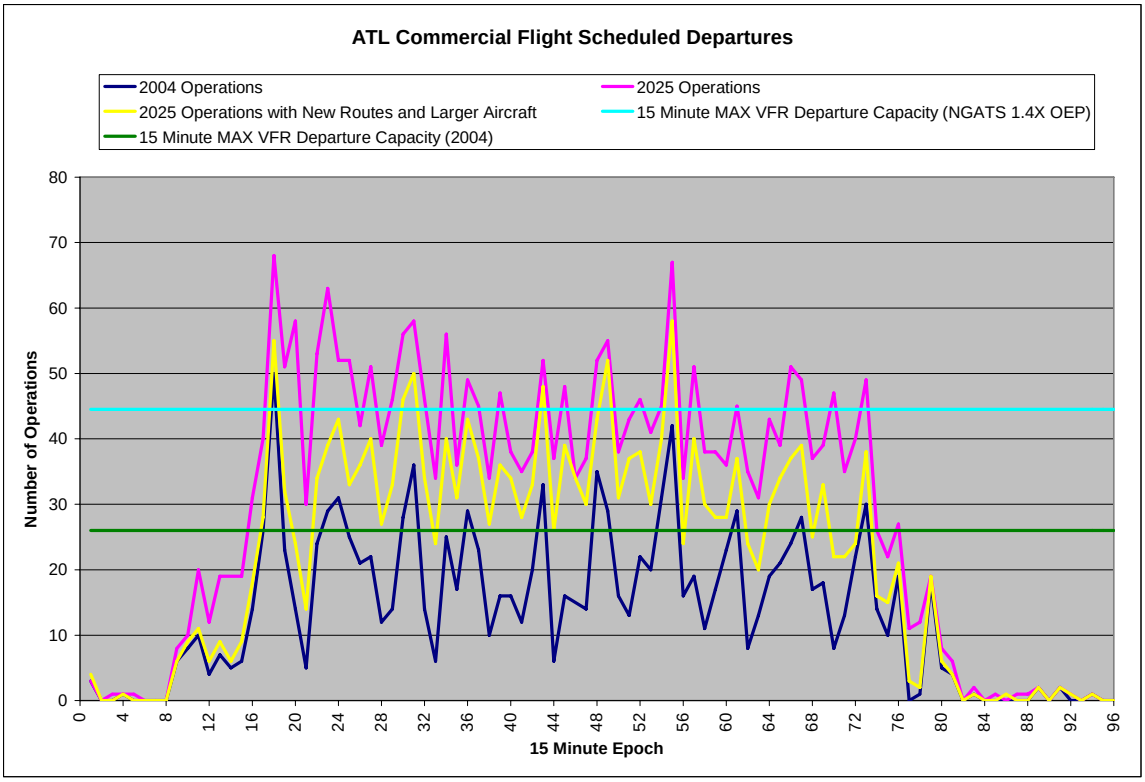

Figure 1 ATL Commercial Flight Scheduled Departures

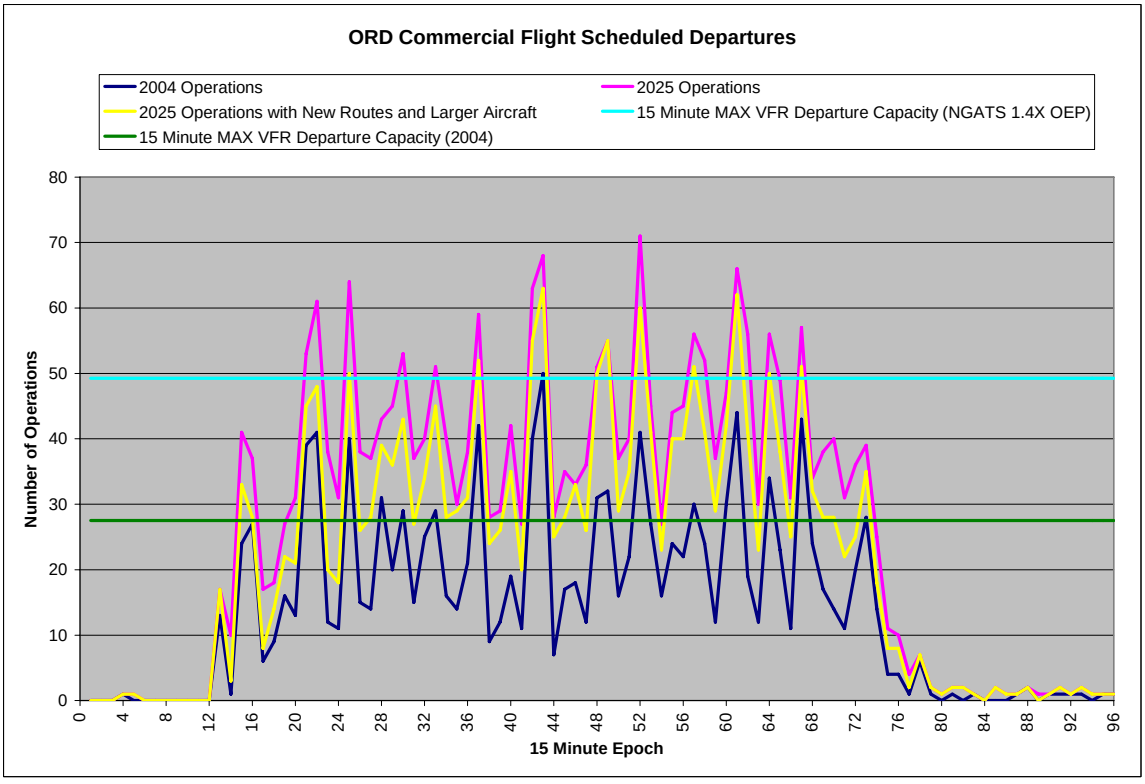

Figure 2 ORD Commercial Flight Scheduled Departures

Cargo

The cargo air traffic was simply scaled by a fixed factor, not by individual airport, to approximately represent the cargo demand expected in 2025. The cargo traffic is not a significant factor in this study. The number of cargo flights in the 19 Feb 2004 demand set is only 4.7% of the total and many cargo flights take place at night, when NAS capacity is not an issue.

General Aviation IFR Flights

The GA IFR traffic is not modeled in TSAM and was generated using the GA Operations Model, see reference 4. VFR traffic was not included.

Note: VFR flights can be generated by the GA Operations Model but were not included because the focus of this study is the impact of VLJ air taxi operations on commercial traffic, these are all IFR flights. Also, a current limitation of ACES is that no distinction between IFR and VFR flights can be made, so any VFR flights added to the simulation would add to the IFR traffic load, giving incorrect results.

Very Light Jet Air Taxi Operations

The VLJ air taxi schedule was generated directly from TSAM. Two variations of the data sets were generated, one which allows VLJs to use those OEP airports which today allow GA traffic and the second where VLJs do not use any OEP airports. (This may occur through regulation or by choice of the operator as discussed in the introduction to this report.) All VLJ schedules used the TSAM parameters listed in the Table 4 below.

The majority of the analysis runs used a fixed cost rate of $1.85 per passenger mile in year 2000 $ (this is $2.10 in 2005 $). This rate is based on a cost analysis performed as part of the SATS program, updated to reflect increases in fuel costs.

As an alternative, a variable cost business model was used to generate a different VLJ demand set using the cost schedule in Table 5. The shorter distances trips cost more per mile due to fixed operating costs and lower average fuel efficiency for short distance trips. The variable cost model results in a moderately increased average trip distance for VLJs.

Model Version	Version 3.8 - Release - Date : 04/25/2006
AveragePartySizeBusiness	2.13 persons
AveragePartySizeNonBusiness	3.40 persons
SATSPlane	VLJ.PTF generic vehicle
SATSPlaneMaximumAltitude	400 FL
SATSPlaneRange	1100 NM
SATSPlaneAcceptanceRate	.76 acceptance rates of potential clients
SATSPlaneMaxOccupancy	4 passengers
SATSPlaneLoadFactor	.7 fraction of maximum occupancy
AnnualUtilization (hours)	1200 hours
AnnualOperatingDays	300 days
RepositioningFlights	25 percent
StopOverTimeMinutes	45 minutes

Table 4 TSAM Parameters used for VLJs

Distance Statute Miles	Cost per Mile 2000 $
75	3.4
100	2.5
150	2.25
200	2.04
300	1.83
400	1.69
500	1.63
600	1.60
700	1.58
800	1.56
900	1.55
1000	1.55

Table 5 VLJ variable Cost Model

NGATS Improvements in Airport Processing Time and Gate to Gate Time

The current airport passenger processing time has been significantly impacted by enhanced security procedures. A goal of the JPDO NGATS is to reduce curb-to-curb travel time by 30%. Much of this reduction will be achieved by decreasing airport processing times, with some improvement also gained by reduced taxi times and shorter block times due to more direct routing.

The NGATS improvements are not expected to reduce VLJ air taxi curb-to-curb times further since these are already assumed to be shorter than for commercial airline transportation.

The reduction in commercial airline trip times has an impact on passenger transportation mode choice. Passengers will be more likely to choose commercial flights if the processing time is reduced and less likely to use cars or VLJs. These effects are captured by TSAM using the values in Table 6. For this reason a second demand set was generated using the assumed reduced processing times. In addition a small reduction in gate-to-gate time for commercial flights of 5% was assumed to be provided by NGATS improvements.

	Current Processing Time (hrs)		NGATS Reduced Processing Time (hrs)	
	Departure	Arrival	Departure	Arrival
Large Hub	2.0	0.75	1.0	0.5
Medium Hub	1.5	0.75	1.0	0.5
Small Hub	1.25	0.5	0.75	0.33
Non Hub	1.0	0.5	0.75	0.33

Table 6 NGATS Reduced Airport Processing Times

Definition of Demand Sets for Analysis

Table 7 below lists the various categories of flights and flight numbers used to construct the demands sets. Table 8 identifies the actual demand sets used for individual ACES runs. Each set has a unique Case ID; this is later used when discussing results for ease of reference.

Note that all future demand sets include the assumed increased passenger load factors compared to 19 Feb 2004.

	19 Feb 2004[1]	**2025 Base (without airport processing improvements)**	**2025 NGATS (reduced commercial airport processing times - 5% gate to gate)**
Commercial/ Scheduled Commuter Air Taxi	34,471	57,964 (64,395 without New Routes/ Larger Ac)	64,059
Cargo	2,323	4,607	4,607
GA	12,367	30,397	30,397
VLJ $1.85	N/A	24,872	20,904
VLJ $1.85 (excluded from OEP airports)	N/A	23,892	19,918
VLJ Variable Cost Model	N/A	23,348	20,990

Table 7 Number of Flights in Demand Sets by Category

1. The 19 Feb 2004 ETMS includes about 8000 flights which do not enter or cross the contiguous U.S. These are either international or internal Alaska or Pacific Islands and were removed. Also military flights have been removed. The figures in the table above are after removal of these flights.

Case ID	Data Set	Total Flights	Multiple of 19 Feb 2004
	Baseline Day		
1	19 Feb 2004 Baseline Day	49,961	N/A
	Without NGATS Reduced Times		
2	2025	99,399	1.99
3	2025 with new routes and larger aircraft	92,968	1.86
4	2025 with new routes and larger aircraft + VLJ (excluded from OEP airports)	116,860	2.34
5	2025 with new routes and large aircraft + VLJ at OEP	117,840	2.36
6	2025 with new routes and large aircraft + VLJ at OEP (variable cost model 1)	116,316	2.33
	With NGATS Reduced Times		
7	2025 with new routes and large aircraft	99,063	1.98
8	2025 with new routes and large aircraft + VLJ (excluded from OEP airports)	118,981	2.38
9	2025 with new routes and large aircraft + VLJ at OEP	119,967	2.40
10	2025 with new routes and large aircraft + VLJ AT OEP (variable cost model 1)	120,053	2.40

Table 8 Demand Sets used for Analysis

ACES Rejected Flights

ACES rejects flights for various reasons at start of simulation time and the fraction rejected can be quite large. The reasons for rejection are listed in Table 9 below for the 19 Feb. 2004 baseline demand set. The largest single category that is rejected is flights less than 80 nm due to Terminal Radar Approach Control (TRACON) overlap. This is a design feature of ACES.

Table 10 below shows the number of flights flown in the simulation for each demand set after ACES flight rejections.

ACES Error Message	**Number of flights**	**Reason**
Bad departure ARTCC index	100	Unknown
Bad trajectory	136	ETMS error
All waypoints are inside all meter fixes	851	Local flights
Departure and arrival airports are the same	292	Local flights
Not supported aircraft type	236	Few obscure types
International flight	1137	This is an ACES bug – these are flights that depart or arrive at U.S. airport, but only travel a short distance within the U.S.
TRACONS overlap	2398	ACES can not handle flights which do fly outside a TRACON – effectively flight distance must be > 80 nm
Trajectory contains anomalies.	25	ETMS error
Unknown aircraft type	37	Few obscure types
Unknown airport	629	Number of small airports missing from ACES data set
Other	24	Unknown
Total	**5865**	

Table 9 Flights Rejected by ACES

Case ID	Data Set	Total Flights
	Baseline Day	
1	19 Feb 2004	43,296
	Without NGATS Reduced Times	
2	2025 Base	89,433
3	2025 Base with new routes and larger aircraft	83,594
4	2025 Base with new routes and larger aircraft + VLJ (excluded from OEP airports)	106,752
5	2025 Base with new routes and large aircraft + VLJ	107,739
6	2025 with new routes and large aircraft + VLJ (variable cost model 1)	106,531
	With NGATS Reduced Times	
7	2025 NGATS with new routes and large aircraft	89,373
8	2025 NGATS with new routes and large aircraft + VLJ (excluded from OEP airports)	108,678
9	2025 NGATS with new routes and large aircraft + VLJ	109,642
10	2025 with new routes and large aircraft + VLJ (variable cost model 1)	109,893

Table 10 Number of Flights in ACES Analysis Runs After Flight Rejections

Distance Distribution of Air Traffic

The distance distribution of passenger trips is important because for shorter trips it is not efficient to climb to high altitudes, due to the time taken to climb and descend. The trip length of VLJ air taxi operations will determine the maximum altitude and this effects how much interaction the VLJs have with commercial aircraft during the en-route stage of the flight. All distances in this section are the great circle distance, which is the shortest distance between the origin and destination airports and not actual distance flown.

Commercial, Scheduled Commuter and Air Taxi

The distance distribution of commercial and scheduled commuter/ air taxi flights taken directly from the ACES demand set generated from ETMS recorded data for 19 Feb 2004 is shown in Figure 3 below. The average distance of all aircraft is 608 nm and the average cruise altitude is 26,400 ft. The average distance of jet only traffic is longer at 736 nm and the average cruise altitude is higher at 30,500 ft, see Figure 4. The 2025 base demand set has a nearly identical distribution (not shown in figure).

The 2025 demand set with new routes and larger aircraft has a somewhat longer flight average distance of 646 nm due to the introduction of longer direct routes replacing shorter connecting legs. This change in distance is not sufficient to significantly effect the altitude distribution, the average cruise altitude is 26,200 ft (not shown in figure).

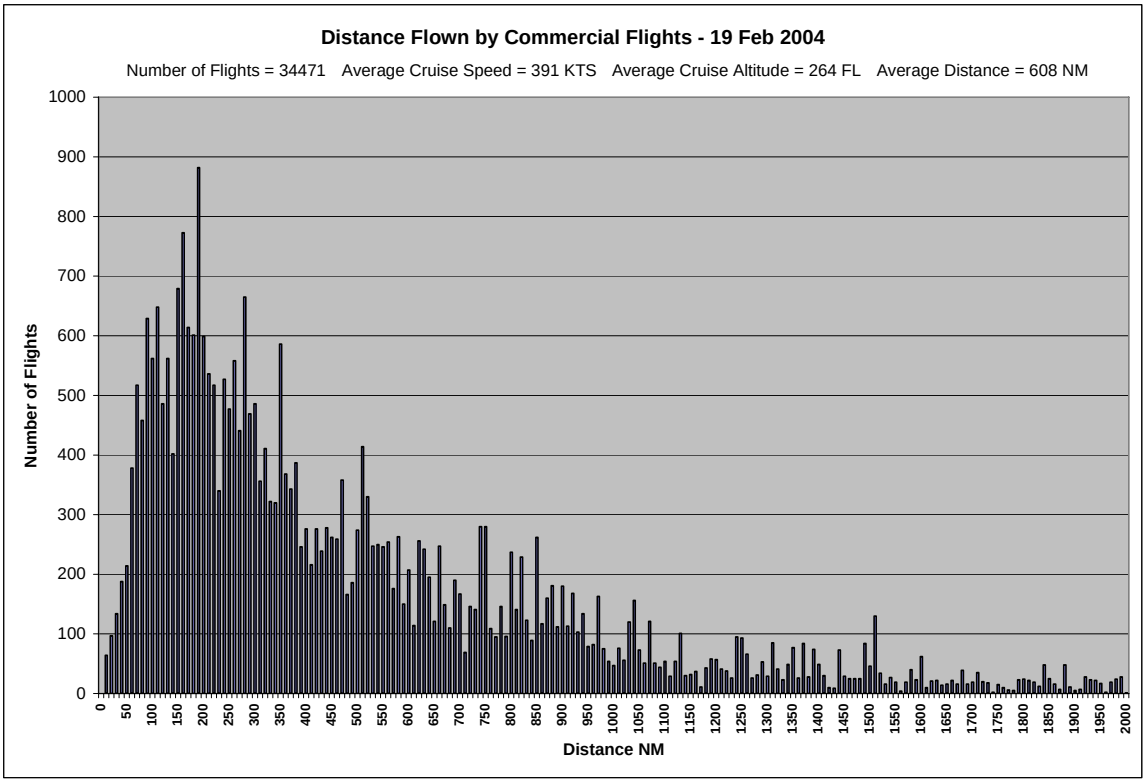

Figure 3 Distances Flown by All Commercial Flights in 19 Feb 2004 Demand Set

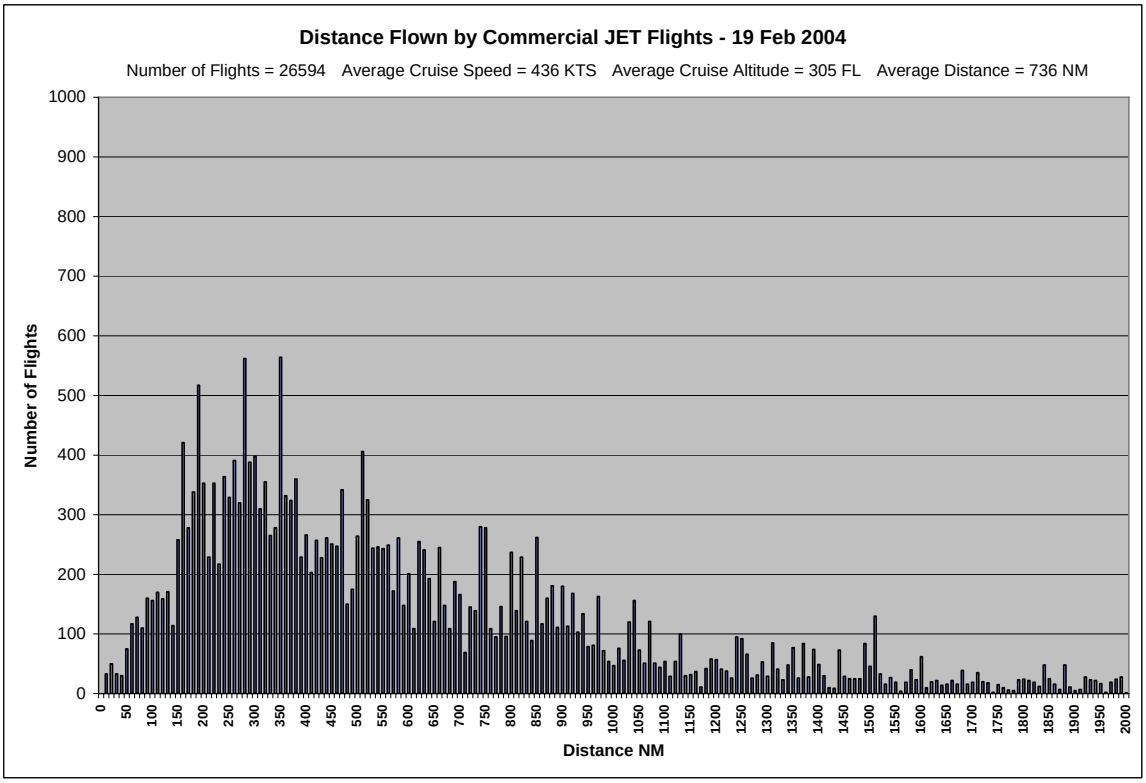

Figure 4 Distances Flown by Jet Commercial Flights in 19 Feb 2004 Demand Set

General Aviation IFR Flights

The distance distribution of general aviation flights taken directly from the ACES demand set generated from ETMS recorded data for 19 Feb 2004 is shown in Figure 5 below. The average distance is 331 nm and the average cruise altitude is 18,100 ft. The average distance of jet only GA traffic is longer at 500 nm and the average cruise altitude is higher at 29,400 ft, see Figure 6.

The 2025 GA demand data has an average distance for all flights of 443 nm and an increased average cruise altitude of 24, 000 ft (not shown in figure). The average distance of 2025 jet only GA traffic is 531 nm and the average cruise altitude is 32,400 ft, see Figure 7.

The 2025 GA average distance including all flights is significantly longer than the 19 Feb 2004 average distance. This is explained by the differential growth rates of GA jet traffic compared to non-jet traffic. In the 19 Feb 2004 data there are 4942 jet flights out of a total of 12,367 flights; jets are 40% of the total. For the 2025 demand GA jet traffic is forecast to grow much faster than the non-jet traffic. In the 2025 demand there are 17,669 jet flights out of a total of 30,397 flights; jets are now 58% of the total. Since jets fly longer distances and higher altitudes than non-jets on average, this explains the increases noted.

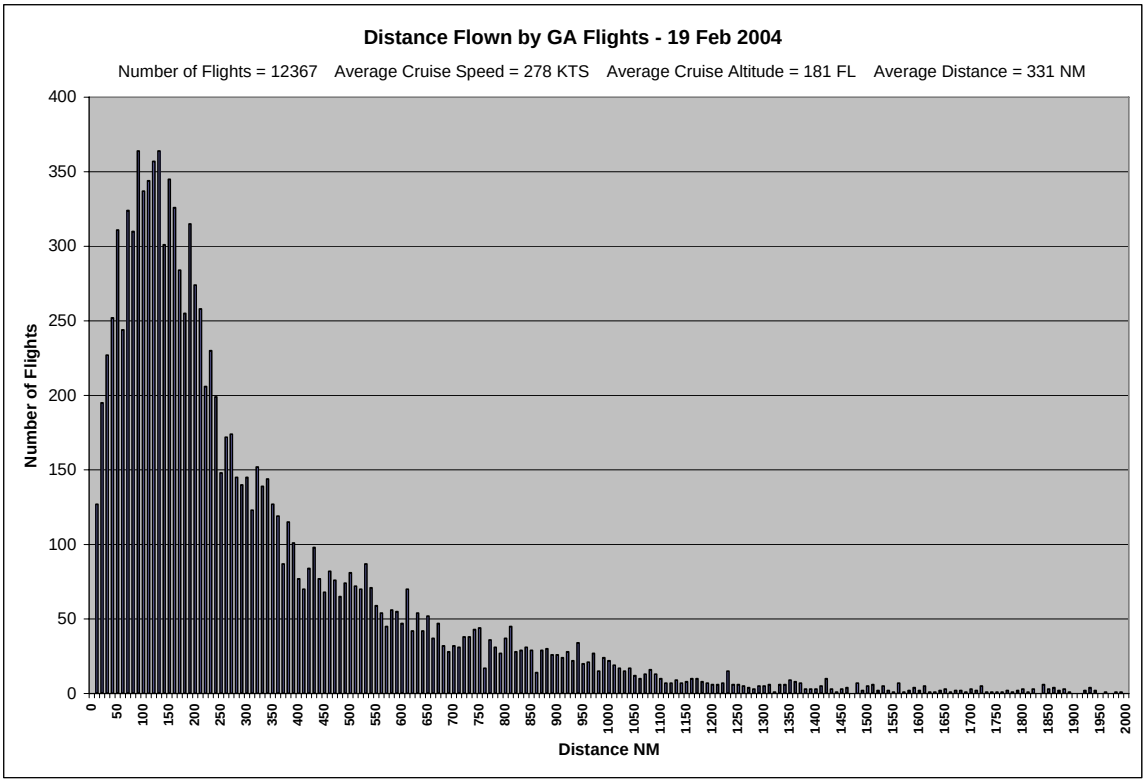

Figure 5 Distances Flown by GA Flights in 19 Feb 2004 Demand Set

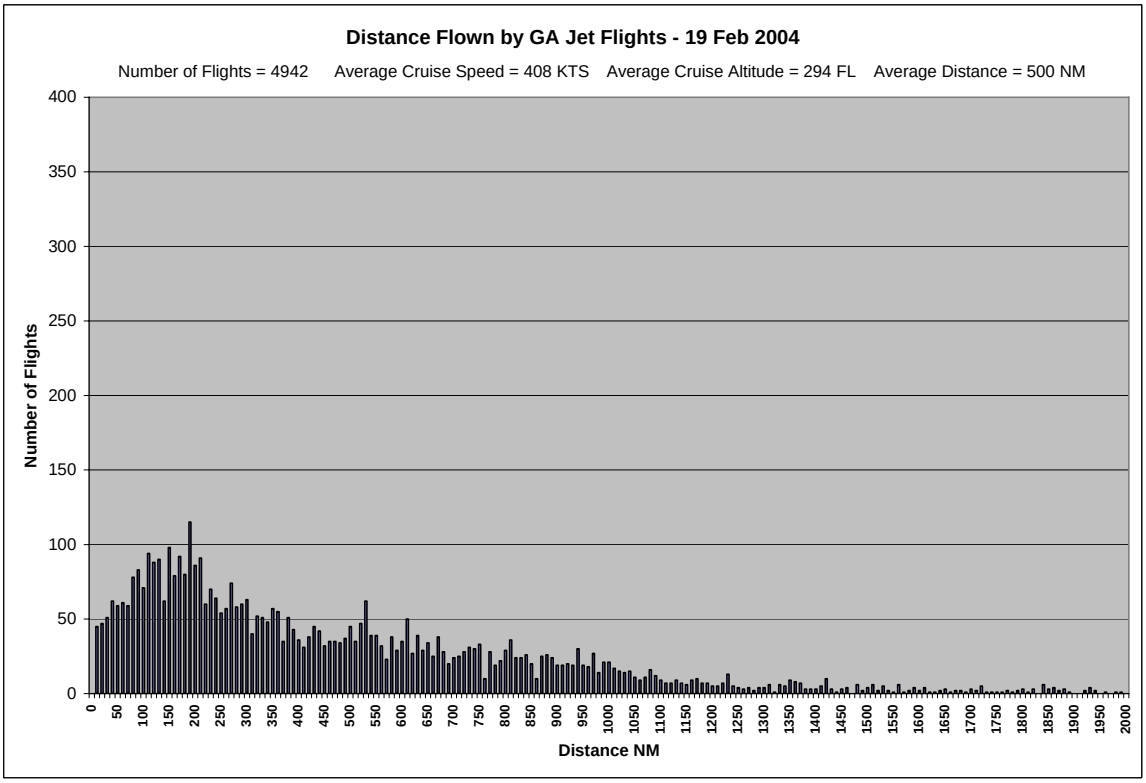

Figure 6 Distances Flown by Jet GA Flights in 19 Feb 2004 Demand Set

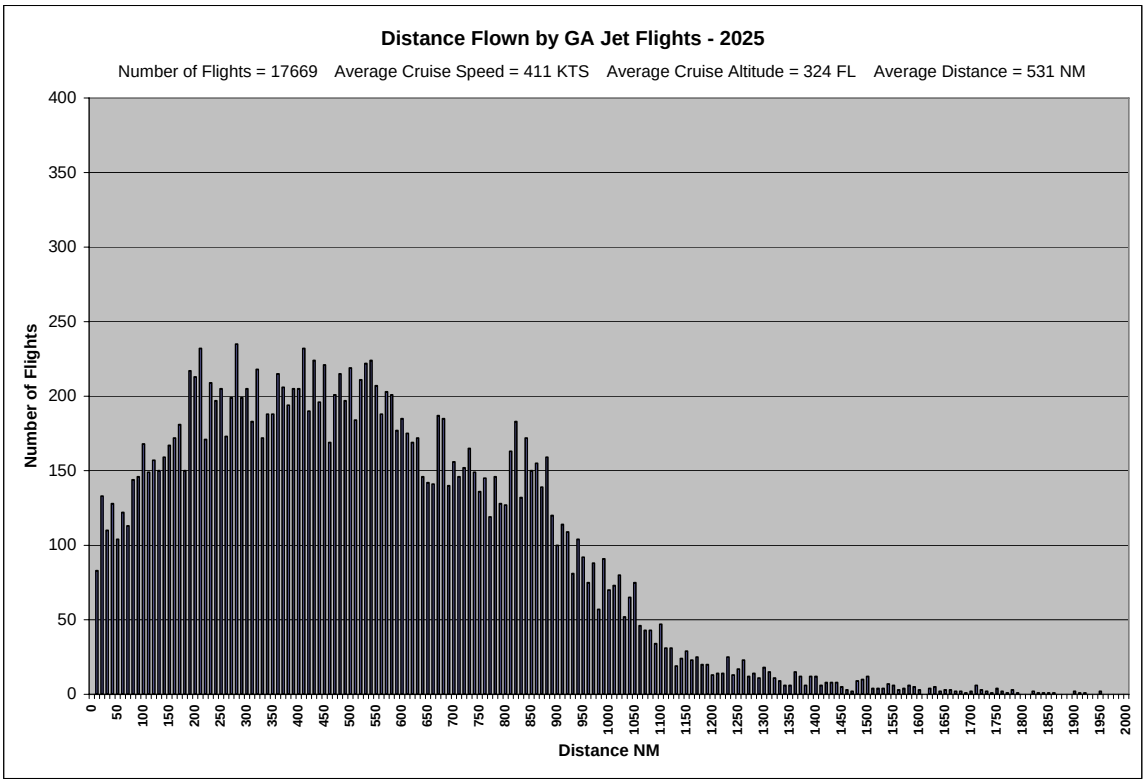

Figure 7 Distances Flown by Jet GA Flights in 2025 Demand Set

Very Light Jets Air Taxi Operations

The distance distribution for VLJ flights in the 2025 demand set is shown in Figure 8 below. The average distance is quite short at 222 nm with an average altitude of 24,200 ft. This chart is for the demand set with VLJs not excluded from OEP airports and not using the NGATS decreased processing and gate-to-gate times. Excluding VLJs from OEP airports does not change the distance distribution; using NGATS improvements decreases the average distance slightly to 213 nm. The relatively short average distance of VLJ flights indicates that the primary market for VLJ air taxi operators is the passenger trips currently being taken mainly by automobile.

The VLJ distance distribution is very different to the flight pattern of the GA business jets in the 19 Feb 2004 data; compare Figure 8 to Figure 6. The GA business jets fly much further and higher on average. Some GA business jets fly distances of 2000 nm or more whereas VLJ traffic does not extend beyond 1000 nm due to the range limits of VLJ aircraft before a re-fuelling stop is required. When a refueling stop is included the time advantage of VLJs is lost compared to commercial air transportation, so there is very little demand for air-taxi flights which require a fuel stop. This may not be true of personal flights.

The shorter distances flown by VLJs mean that many flights will be below the altitudes used by commercial airlines, in less congested airspace.

This usage pattern by VLJs for relatively short trips is driven by two factors:

- For trips of less than about 120 miles driving distance, it does not save much time and it costs significantly more to use a VLJ compared to using a car;

- For trips longer than about 600 nm to 700 nm VLJs start to get expensive compared to commercial airline fares and the proportional time savings are not as great as for medium distance trips. VLJs are slower than commercial jets so the time advantage is less for longer range trips and for trips over 1000 nm a fuelling stop is required which reduces or eliminates any time advantage over commercial flights.

Note that the flight distances are in Nautical Miles and are Great Circle (direct) distances. Driving distances will be significantly longer than the Great Circle distance, so for example a 150 nm flight distance would generally take at least 200 statute miles to drive.

This pattern is influenced by the business cost model used. For the majority of this analysis the cost model used is a straight cost per passenger mile of $1.85, see section on demand sets. This was the cost model developed by the SATS program for air-taxi operations, updated to reflect increased fuel costs.

Airline fares are typically not structured this way. Short distance fares tend to cost relatively more per mile than longer distance flights. This is because there are certain fixed costs (airport fees, initial crew costs waiting for passengers, etc) which must be met for any trip and then there are variable costs which depend on the Distances Flown (fuel, maintenance on engines etc).

For this reason an alternative fare structure was developed which better reflects operating costs of the VLJ service, based on trip distance. This was described in the section on demand generation, see Table 5. The cost per mile is more than $1.85 for trips less than about 300 nm and then becomes less than $1.85, leveling off at about $1.60 to $1.55 for the longer trips.

The variable fare cost model increases the average flight distance to 251 nm and the average cruise altitude to 25,900 ft, see Figure 9. The increase is not large, but the alternative business model was used for an ACES simulation run to compare with the fixed cost model.

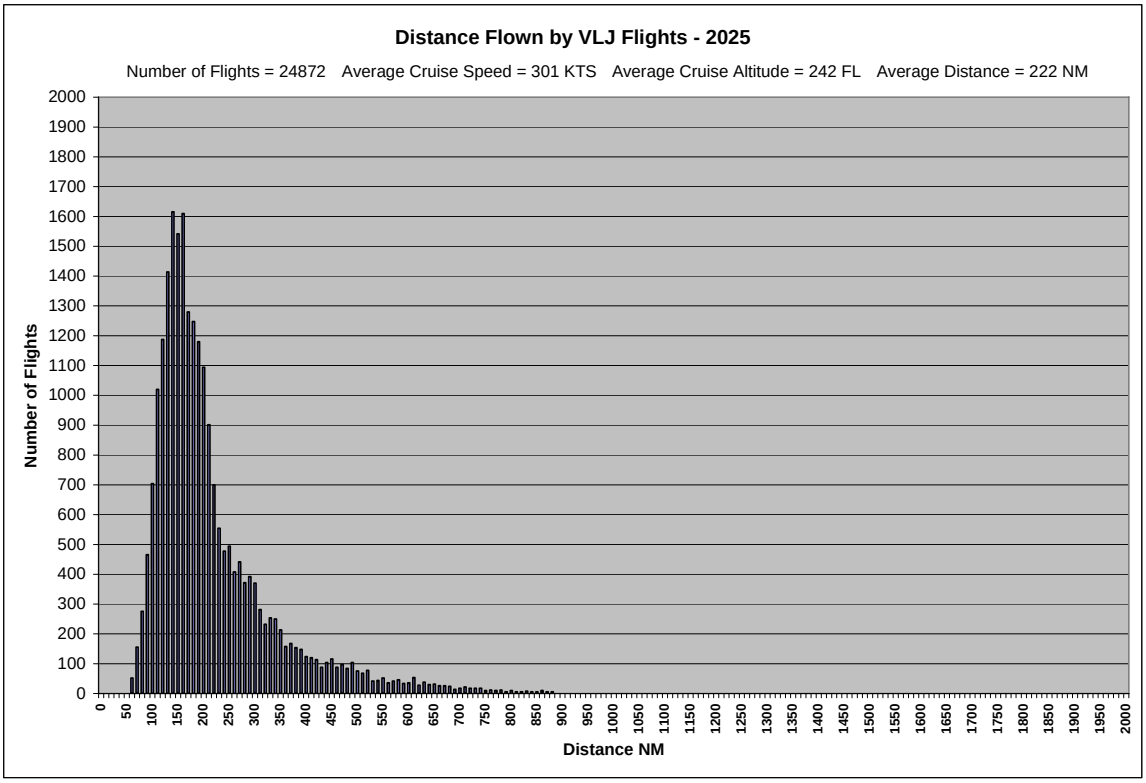

Figure 8 Distances Flown by VLJ Flights in 2025 Demand Set with Fixed Cost Business Model

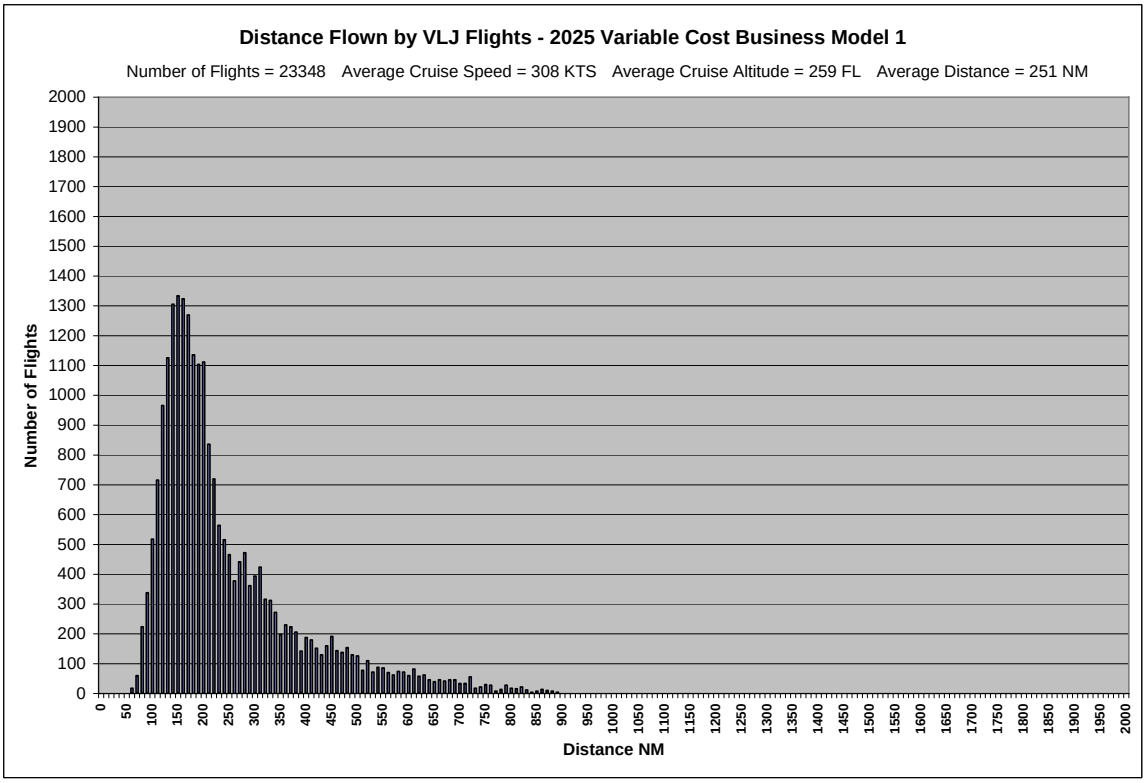

Figure 9 Distances Flown by VLJ Flights in 2025 Demand Set with Variable Cost Business Model

Airport and Airspace Capacity Increases due to NGATS

Airport and airspace capacities were increased in-line with the JPDO Evaluation and Analysis Division assumptions used in assessment of NGATS, these being NGATS goals for capacity improvements.

The sector capacities (MAP values in ACES) were increased to a factor of 3 times today's values.

The airport capacity values (VFR and IFR nodal airport model arrival and departure rates in ACES) were increased to a factor of 1.4 times over and above the FAA's OEP version 5 planned improvements. This was done for all airports, not just OEP airports.

These increased capacities were used for all assessment simulation runs except for the 19 Feb 2004 baseline assessment where today's values of airspace and airport capacity were used.

Analysis of Results from ACES

This section contains a summary of the results from ACES simulation runs followed by a detailed analysis of selected runs. The detailed analysis is separated for airports, airspace sectors and potential conflicts. The detailed analysis is only applied to the demand sets with NGATS reduced gate to gate times since this is the scenario which incorporates the JPDO goal. Each test case is given a Case ID number which relates back to the corresponding demand set, see Table 8.

All simulation runs are for a perfect VFR day and therefore use VFR Airport capacities and maximum sector capacities throughout the day.

The ACES simple nodal model was used for all airports, with generic 40 nm circular TRACON boundary and 4 equal-spaced departure and arrival fixes except for some additional test cases for the Chicago TRACON see section on ACES enhanced TRACON modeling in this report.

The bulk of the test cases used the following ACES user input options, see user guide, reference 5 for description.

- AOC Operation=Off
- Perform Delay Maneuvers=true
- Perform CD&R=false
- Enable Surface Traffic Limitations=true
- Perform Arrival Fix Spacing=false
- Disable Arrival Fix TRACON Delay=true
- Disable Departure Fix TRACON Delay=true

Additional test cases were performed with Perform CD&R=true, to evaluate the number of potential conflicts.

The additional test cases for the Chicago TRACON using the enhanced model used:

- Perform Arrival Fix Spacing=true
- Disable Arrival Fix TRACON Delay=false
- Disable Departure Fix TRACON Delay=false

The results obtained from ACES should be interpreted carefully – ACES does not have a trajectory based model of flights within TRACONS. A high fidelity, trajectory based model might reveal more interactions between VLJs and commercial air traffic. A high fidelity model might then be used to investigate re-design of the TRACON to mitigate the effect of VLJs where necessary. The results from this study are subject to the limitations of the ACES modeling.

Definition of ACES Delays

ACES computed delays are based on an unimpeded flight through the NAS and do not include schedule padding. Airlines typically add a certain amount of time to their flight schedule, because they value predictability above advertising the minimum possible flight time.

ACES simulation results give a realistic estimate of likely delay, but this should not be directly compared to reported delays, which are understated due to schedule padding. In addition airlines do not count flights as delayed, for reporting purposes, until the delay is greater than 15 minutes in accordance to the FAA definition of a delayed flight. (Actual flights delays less than 15 minutes are recorded in the FAA databases and can be obtained, but still include schedule padding.)

ACES defines the following delays, not of all of which are used in this analysis:

Ground Hold
depDelay = actualGateDepartureTime – scheduledGateDepartureTime

Taxi Out
takeOffDelay = actualTakeoffTime – scheduledTakeoffTime – depDelay

Enroute + TRACON Delay
landingDelay = actualLandingTime – scheduledLandingTime – depDelay - takeOffDelay

Taxi In
arrDelay = actualGateArrivalTime – scheduledGateArrivalTime – depDelay – takeOffDelay -landingDelay

Total Delay
totalDelay = depDelay + takeOffDelay + landingDelay + arrDelay

Airborne Delay
airDelay = landingDelay

Ground Delay
grndDelay = takeOffDelay + arrDelay

Hold Delay
holdDelay = depDelay

Notes

Departure Airport gets credited with depDelay + takeOffDelay
Arrival Airport gets credited with landingDelay + arrDelay

Definition of ACES Conflict Counts

Conflict counts reported by ACES should be interpreted as follows. Conflicts are recorded per aircraft by ACES, so each conflict situation between a pair of aircraft results in 2 conflicts and a 3 way conflict would result in a count of 3 conflicts. Only en-route conflicts are reported, since ACES does not have the capability to detect conflicts within the TRACON. These conflict counts are for potential conflicts and are based on today's separation standards. The en-route conflict detection algorithm in ACES reports a conflict when aircraft are separated by less than 2000 ft in altitude and less than 7 nm in distance (default can be changed). The current FAA separation minimum is 5 nm so ACES is actually reporting potential conflicts; a 2 nm buffer is used to allow for conflict resolution. In addition ACES only allows specification of a single parameter for altitude separation so does not take into account reduced Vertical Separation Minimum which requires 1000 ft minimum between FL290–410. NGATS also expects future technology to enable en-route minimum lateral separations to be reduced; this was not evaluated in this study. For these reasons the actual conflict counts reported by ACES are only potential conflicts and also overstate the number of potential conflicts that would require resolutions in the 2025 demand scenario, since reduced separations were not used. The values reported by ACES are useful for comparison purposes between simulation runs, but are not to be interpreted as a realistic measure of actual conflicts.

Summary

Summary results from all simulation runs are presented in Table 11.

19 Feb 2004 Baseline Day Delays

The mean delay per commercial flight in the 19 Feb 2004 demand set (Case ID 1) is 514 seconds which gives a baseline number to compare with the delays resulting from the 2025 demand sets. The mean delay for all flights in the 19 Feb 2004 demand set is lower at 428 seconds, since this includes GA flights many of which fly to small airports and experience very little delay. The mean delay per commercial flight is the more useful metric for this study. The average peak sector load for the top 50 sectors of 19.1 aircraft is closely matched to the average capacity of 18.3, based on today's MAP values. Clearly today's sectors are designed to be able to cope with the current expected traffic load and do so with little (or no) spare capacity for the top loaded sectors at peak times. The total number of potential conflicts ACES reports for this demand set was 19,851 or 45.9% as a proportion of the total flights.

2025 Delays without VLJs

The 2025 demand without new routes and without larger aircraft (Case ID 2) results in a 78% increase in mean delay per commercial flight of 916 seconds. This indicates that even with the assumed 1.4X increase in airport capacity and 3X increase in sector capacity the NAS will not have sufficient capacity to handle 2025 traffic, if based only on adding more frequent flights to meet demand, without a substantial increase in delay.

The constraint is not sector capacity; 3X sector capacities are more than sufficient. Average peak sector load for the top 50 sectors is 34.4 aircraft and the average peak sector capacity is 53.5 aircraft. The reason for the increased delay is insufficient airport capacity. This is as expected since the total number of flights in this demand set increased by a factor of 2X and the airspace sector capacities were increased by 3X, whereas the airport capacities were only increased by 1.4X.

The number of potential conflicts increases to 71,193 or 79.6% as a proportion of the total flights. This is an increase by a factor of 3.6, whereas the number of flights increases by a factor of 2.1 compared to the 19 Feb 2004 data. This is as expected since simplified theory predicts that the number of potential conflicts increases in proportion to the square of the traffic density (assuming uniform traffic density, which is not actually the case).

The 2025 passenger demand will not be met by a straight scaling of existing flights and routes. In reality airlines will introduce new direct routes and larger aircraft to better meet the demand. The 2025 demand met by inclusion of new routes and larger aircraft (Case ID 3) therefore represents a more likely scenario. The simulation results now show a 41% decrease in mean delay per commercial flight compared to 19 Feb. 2004; delay is reduced to 302 seconds. This indicates that the assumed airport capacity increase of 1.4X is

sufficient to meet 2025 passenger demand for most airports when a realistic future scenario is used. The 3X sector capacity increase is more than sufficient - in fact a sector capacity increase of 2X would be adequate for most sectors for this demand set.

Using reduced airport processing times and slightly shorter block times due to NGATS improvements results in more flights with a corresponding increase in mean delay per commercial flight to 549 seconds (Case ID 7). This is a 7% increase in delay compared to the 19 Feb 2004 baseline day. Potential conflicts also increase to 77,499 due to increased traffic density.

2025 Delays with VLJs

The addition of VLJ flights does have some effect on commercial air traffic. The most likely scenarios are those with NGATS improvements applied to the commercial traffic only, non-NGATS cases are also included in Table 11 below for completeness but are not discussed in detail.

The addition of VLJ flights with no restrictions on use of OEP airports (Case ID 9) adds 54 seconds mean delay per commercial flight (compared with Case ID 7). This is an increase of 9.8% which is significant. (The cost to commercial air carriers is analyzed in a later section of this document.) The peak sector loading for the top 50 sectors increases only slightly by about 1 additional aircraft on average. The number of potential conflicts increases by 6.9% to 82,848, due to VLJs.

If the VLJ flights are excluded from OEP airports (Case ID 8) then the increase in mean delay per commercial flight is much less at 7 seconds, which is 1.3%. This may be the most likely scenario since VLJ operators may choose to mainly avoid the largest airports in favor of less congested and more conveniently located smaller airports. The total number of potential conflicts increases by 6.6% to 82,645 compared to the case without VLJs.

The variable cost per mile business model (Case ID 10) for VLJ operations results in somewhat longer average flight distances and higher altitudes (compare Figure 8 and Figure 9) but the delay to commercial flights is virtually unchanged. The sector loading and number of potential conflicts are also very similar to the fixed cost case (Case ID 9). These results indicate that the modest changes to flight distance and altitude profiles that result from the variable cost business model do not significantly change the impact to commercial flights.

*Note that the addition of VLJ flights **reduces** the mean delay per flight when all flights (not just commercial flights) are included in the calculation of the average value. This is because the VLJ flights mainly operate to and from smaller less congested airports (even for the cases where VLJs are not excluded from OEP airports) and have smaller delays than the average commercial flight. The addition of more flights with less delay per flight will of course lower the overall average. It is misleading to compare overall average values for dissimilar data sets, which is why for this analysis only the average values for commercial flights are compared.*

Case ID	Demand Set	Mean Delay per Flight (secs)	Mean Delay per Commer-cial Flight (secs)	Mean of Peak Sector Load Top 50 Sectors (Aircraft)	Mean of Sector MAP Top 50 Sectors (Aircraft)	Total Potential conflicts
	Baseline Day					
1	19 Feb 2004	428	514	19.1	18.3	19,851
	Without NGATS reduced times					
2	2025	632	916	34.4	53.5	71,193
3	2025 N/L	208	302	33.0	52.6	65,860
4	2025 N/L VLJ	176	310	34.5	52.2	72,750
5	2025 N/L OVLJ	193	331	34.8	51.9	72,727
6	2025 N/L OVLJ VC	196	332	35.4	52.6	74,028
	With NGATS reduced times					
7	2025 N/L NG	382	549	35.5	52.9	77,499
8	2025 N/L NG VLJ	329	556* (562)	36.6	52.9	82,645
9	2025 N/L NG OVLJ	360	603	36.5	53.2	82,848
10	2025 N/L NG OVLJ VC	358	604	36.8	53.0	82,818

Table 11 Summary of Results from ACES Simulation Runs

* This value is adjusted to remove an anomalous result for ORD for this test case, see airports analysis section for explanation. Value in parenthesis is unadjusted value.

Key

N/L – Used new direct routes and substituted larger aircraft.
NG – Used NGATS improved airport processing and gate-to-gate times.
VLJ – Added VLJs, excluded from OEP airports.
OVLJ – Added VLJs, allowed into OEP airports.
VC – Used variable cost model for VLJs.

Notes

1) Mean Delay per commercial flights excludes GA, Cargo, VLJ from calculation of delay.
2) Top 50 sectors are the sectors with highest peak 5 minute load values and may differ from run to run.
3) Monitor Alert Parameter values are today's values for 2004, and 3X today's values for 2025. Mean is the average value for top 50 loaded sectors.
4) Potential conflicts are from ACES en-route conflict detection and resolution model and may not accurately represent actual conflicts, but can be used for comparison between runs. Each conflict is per aircraft so a conflict situation involving 2 aircraft counts as 2 potential conflicts.

Airports Analysis

The demand sets used for the simulation runs are identified by Case ID number and the details of each are listed in Table 8.

Analysis of 19 February 2004 Baseline Day

The 19 Feb 2004 numbers of operations and delays are analyzed for comparison with 2025 results.

Number of Operations in 19 February 2004 Baseline Day

Figure 10 shows the number of daily flight operations (departures plus arrivals, excluding cargo) at the busiest 50 airports in the 2004 demand set (Case ID 1). Included on the same figure for comparison are the commercial and GA operations. The busiest commercial airports are ORD, ATL and DFW. These airports all have a very small number of GA flights. Several of the other top 50 commercial airports do have significant GA traffic, the percentage of GA flights at LAS is 10%, IAD is 18%, DAL is 32% and HOU is 25% for example.

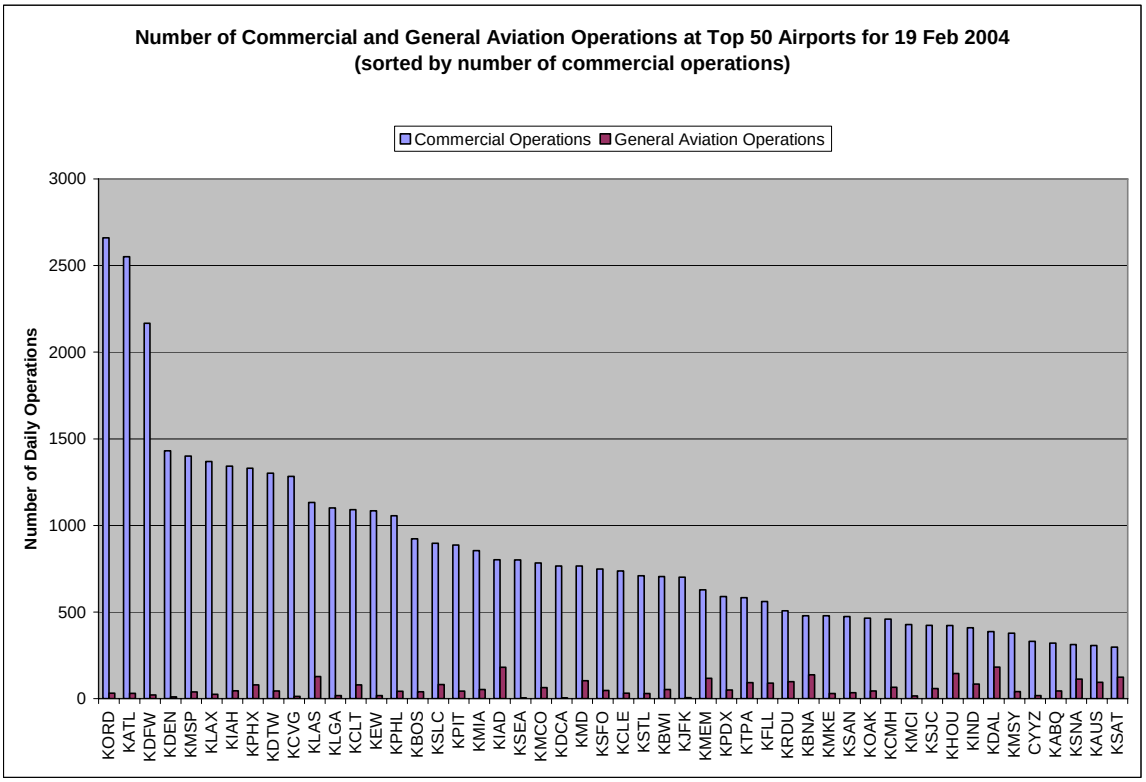

Figure 10 Number of Commercial and GA Operations at Top 50 Busiest Airports for 19 Feb 2004

19 Feb 2004 Baseline Day Delays

Figure 11 and Figure 12 show commercial flights total delay and mean delay per operation for the top 50 airports with most total delay (Case ID 1). The delays reported include both departure and arrival operations.

ORD (Chicago O'Hare International, IL) has the most total delay at 437 hours which corresponds to a mean delay of 592 seconds per operation. MSP (Minneapolis-St Paul International Airport, MN) has the next highest total delay at 285 hours, and has a higher mean delay per operation of 733 seconds. ATL (Atlanta Hartsfield International, GA) has 195 hours total delay and 275 seconds of delay per operation. ALB (Albany International Airport, New York) has the highest mean delay per operation at 798 seconds.

Figure 13 is a representation of the distribution of delays. Only flights with delay are included in this chart, flights with zero delay are excluded from the statistics. The intersection of the solid bars represents the Median (mid-point of the data, half the delays are larger and half smaller). The limits of the solid bars represent the 25th percentile and 75th percentile of the data and the end point lines represent the 10th percentile and 90th percentile of the data.

For example, the Median delay at ORD is 210 seconds, 75% of flights with delay have delays of less than 525 seconds and 90% of flights with delay have delays of less than 1437 seconds.

A few flights at ORD had quite long delays, 7 flights were delayed by more than 3 hours, and the maximum delay was 3 hours 59 minutes (not shown on chart). These few flights should probably not have been delayed for such long periods; ACES Traffic Flow Management tends to hold a few flights for an unreasonably long time on the ground. In reality a more equitable distribution of delay would be likely with a few more flights being held for shorter periods, allowing flights which had been waiting for a significant time to be released. (Weather is not a factor here; this is a good weather day with VFR capacities assumed for all sectors and airports.) However, holding a few flights for an unreasonable length of time has a minimal effect on the overall total and average delays.

The airports with fewer operations naturally show a broader distribution of delays, since the percentiles include more of the flights with large delays. For example BDL has 241 operations, 99 of which are delayed. 90% of flights with delay have delays of less than 4827 seconds (1 hour 20 minutes). 11 flights have delays of more than 1 hour and the maximum delay was 5 hours 24 minutes. The 90^{th} percentile in this case includes one of the flights with more than 1 hour of delay.

The delay distribution chart only includes flights with delays, for some airports a significant number of flights do not have any delay. Figure 14 shows the percentage of flights with delays. The numbers on the bars show the actual number of operations.

For example ORD has a total of 2660 commercial operations, 303 with zero delay, 1962 with delays of 15 minutes or less and 395 with delays of more than 15 minutes.

A more detailed view of delays at ORD and ATL are presented in Figure 15 and Figure 16. At ORD, 85% of departure plus arrival operations have delays of less than 15 minutes. At ATL, 94% of operations have delays of less than 15 minutes. (Commercial airlines flights are counted as on-time by the FAA if less than 15 minutes late.)

These delays are with respect to an unimpeded flight and do not include any schedule padding, as per the ACES definition of delay. Delays with respect to the airline schedule would therefore be lower and would likely show few flights with delay greater than 15 minutes. This is as expected, the 19 Feb 2004 data is an actual schedule derived from ETMS for a day with good weather and the simulation assumed perfect VFR conditions. The delays should be low.

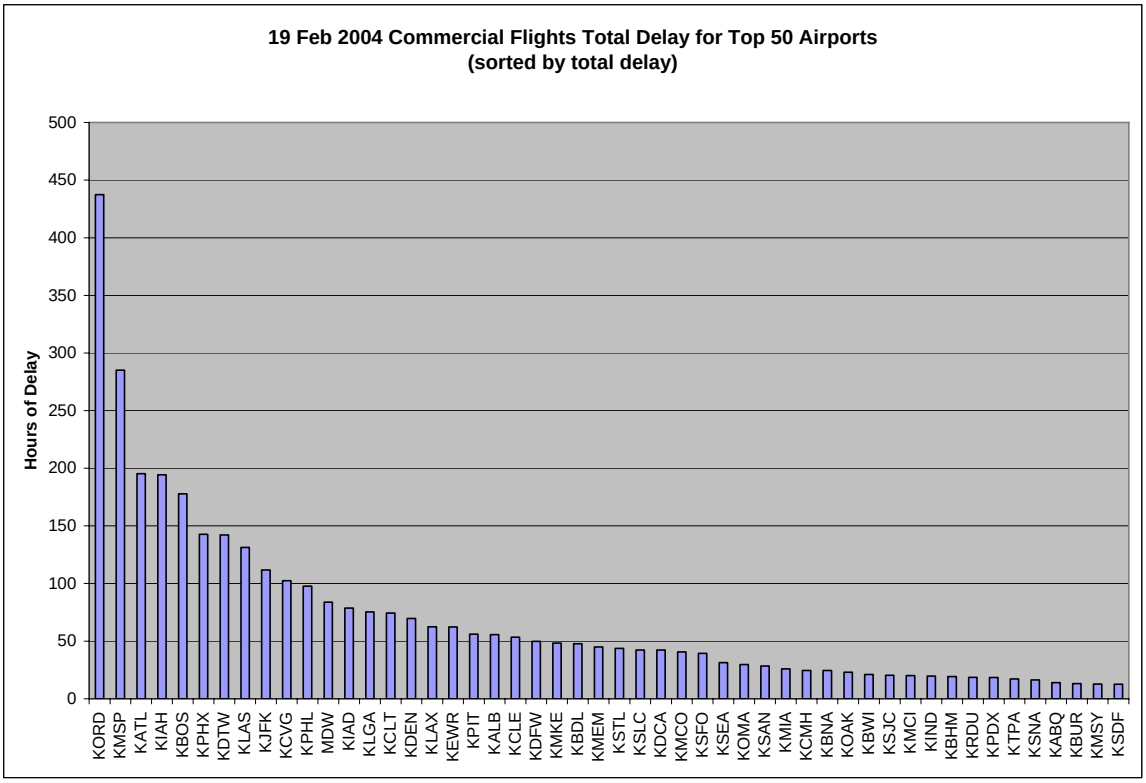

Figure 11 Commercial Flights Total Hours of Delay at Top 50 Airports for 19 Feb 2004 Demand

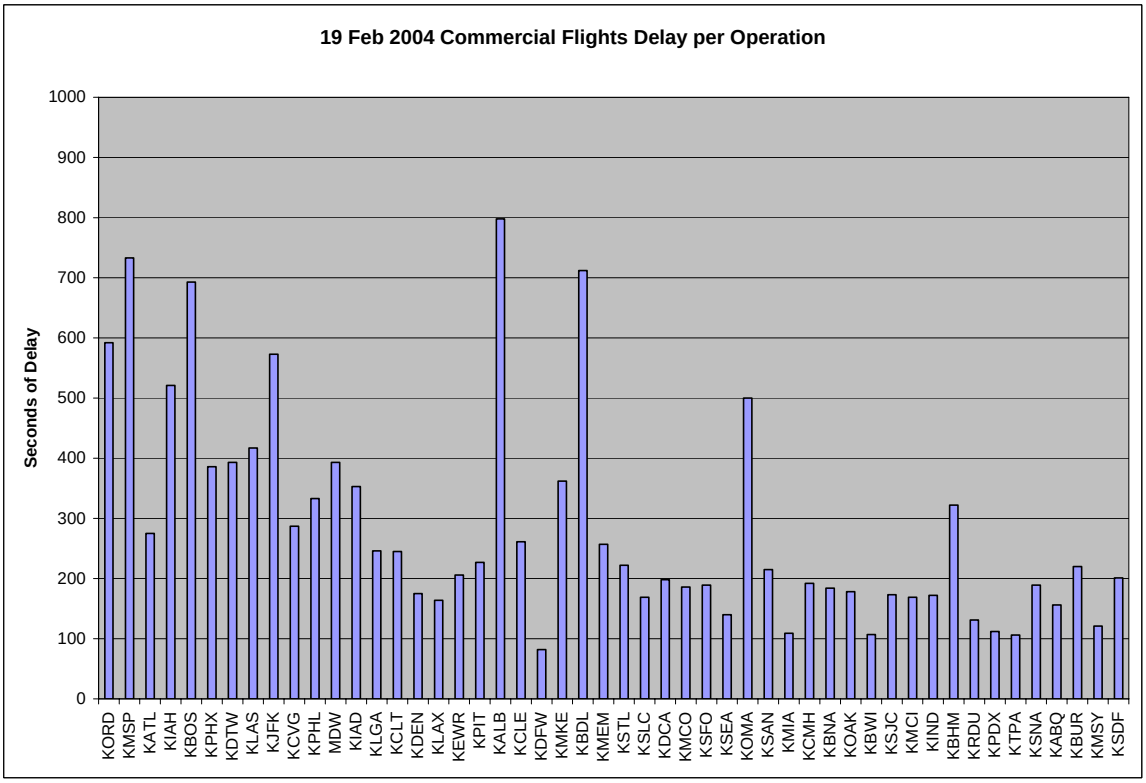

Figure 12 Commercial Flights Mean Delay per Operation at Top 50 Airports for 19 Feb 2004 Demand

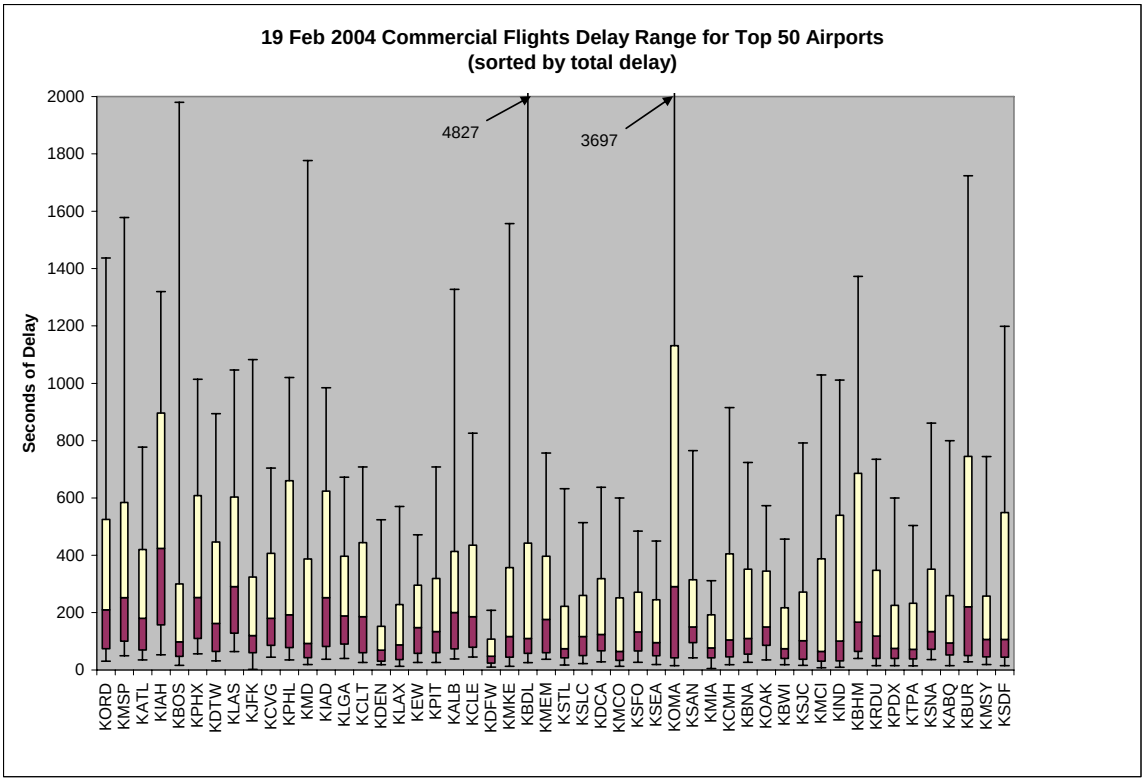

Figure 13 Commercial Flights Delay Range at Top 50 Airports for 19 Feb 2004 Demand

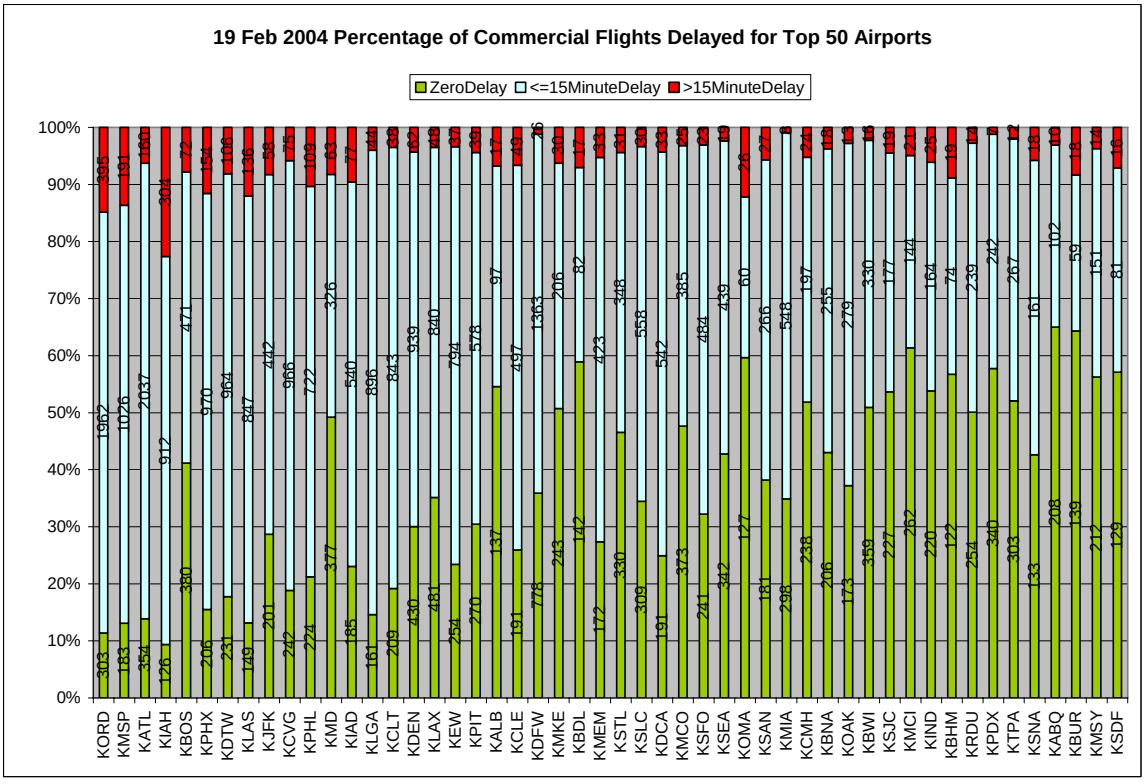

Figure 14 Percentage of Commercial Flights Delayed at Top 50 Airports for 19 Feb 2004 Demand

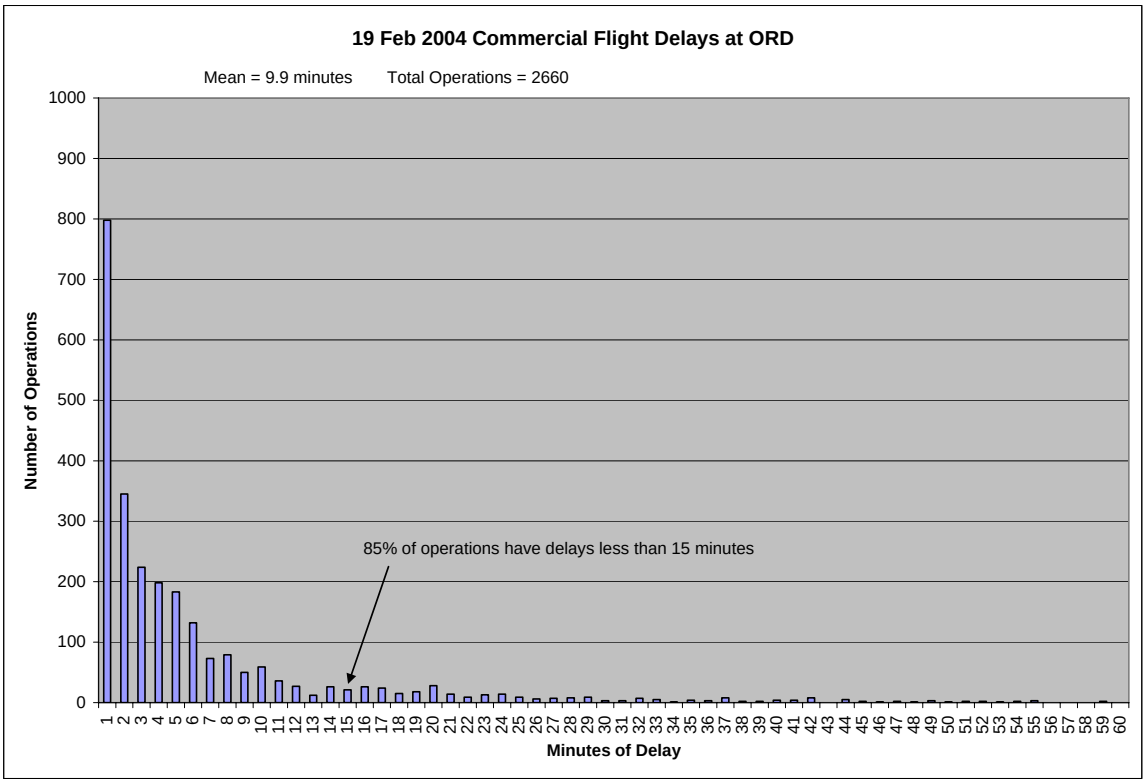

Figure 15 Statistical Distributions of Delays at ORD for 19 Feb 2004 Demand

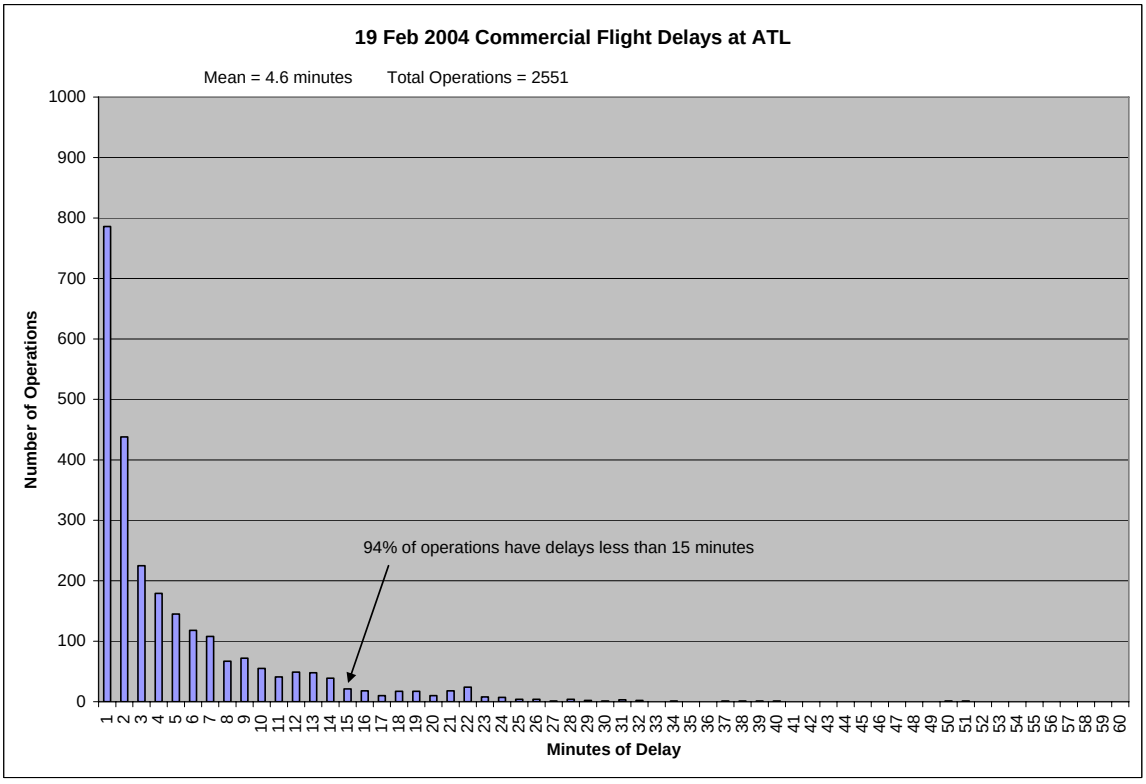

Figure 16 Statistical Distributions of Delays at ATL for 19 Feb 2004 Demand

Analysis of 2025 Demand

Number of Operations in 2025

Figure 17 shows the number of daily flight operations (departures plus arrivals, excluding cargo) at the busiest 50 airports in the 2025 demand set (Case ID 9)

Included on the same figure for comparison are the commercial, GA and VLJ operations. The busiest commercial airports are ORD, ATL and DFW. The top 3 airports all have a very small number of GA flights and only ATL attracts a few VLJ flights, at 32 VLJ operations total.

Figure 18 shows the VLJ operations sorted in order of busiest VLJ airports, with VLJs at OEP airports.

The airport with most VLJ operations is HOU (William P. Hobby Airport, Houston TX) at 435 daily operations closely followed by PDK (Dekalb-Peachtree Airport, Atlanta, GA) at 384 operations and TEB (Teterboro Airport, NJ) at 336 operations. VGT (North Las Vegas Airport, NV) and DAL (Dallas Love Field Airport, TX) both have more than 300 daily operations. These airports are all situated close to major population centers and currently have significant GA operations.

The OEP airports that attract most VLJ operations are LAS (McCarran International Airport, Las Vegas, NV) at 265 operations, MDW (Chicago Midway International Airport, IL) at 260 operations and IAD (Washington Dulles International Airport, DC) at 204 daily operations.

Figure 19 shows the VLJ operations when VLJs are excluded from OEP airports. Note that the number of operations varies somewhat even for the same non-OEP airports for the two cases. This is due to dynamic effects of shifting demand, not allowing the use of OEP airports may make some non-OEP airports more or less attractive as the origin or destination of VLJ flights.

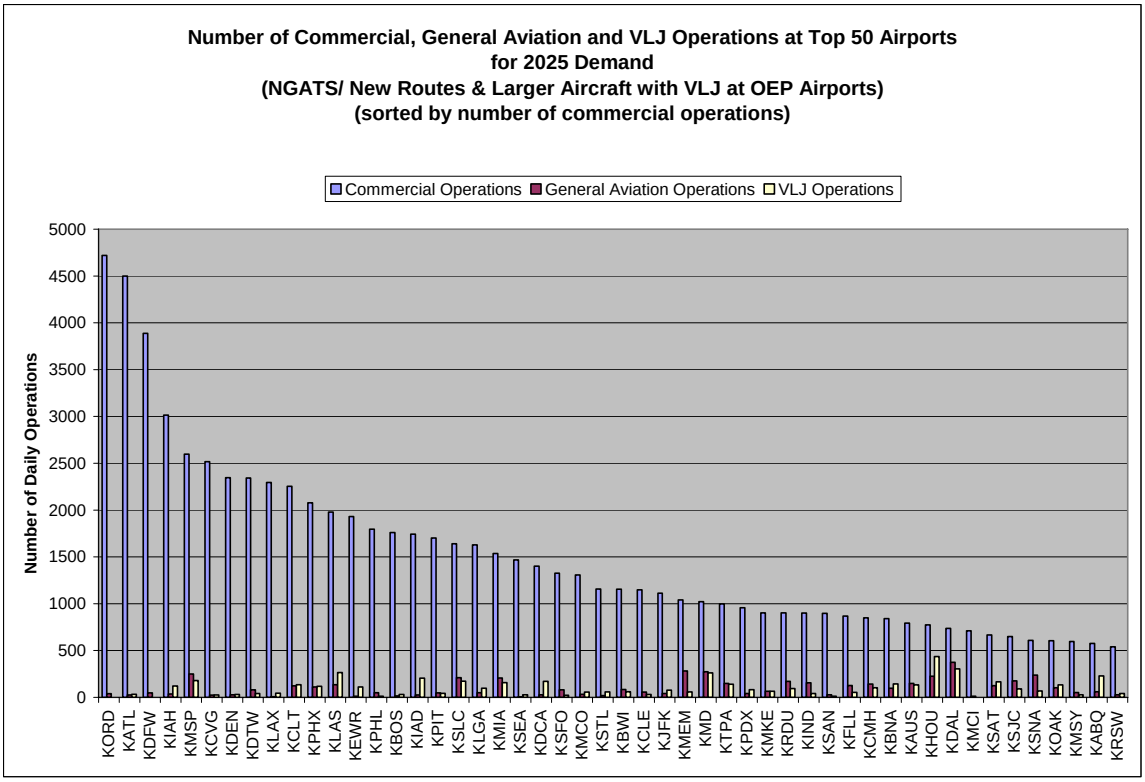

Figure 17 Number of Commercial, GA and VLJ Operations at Top 50 Busiest Airports in 2025

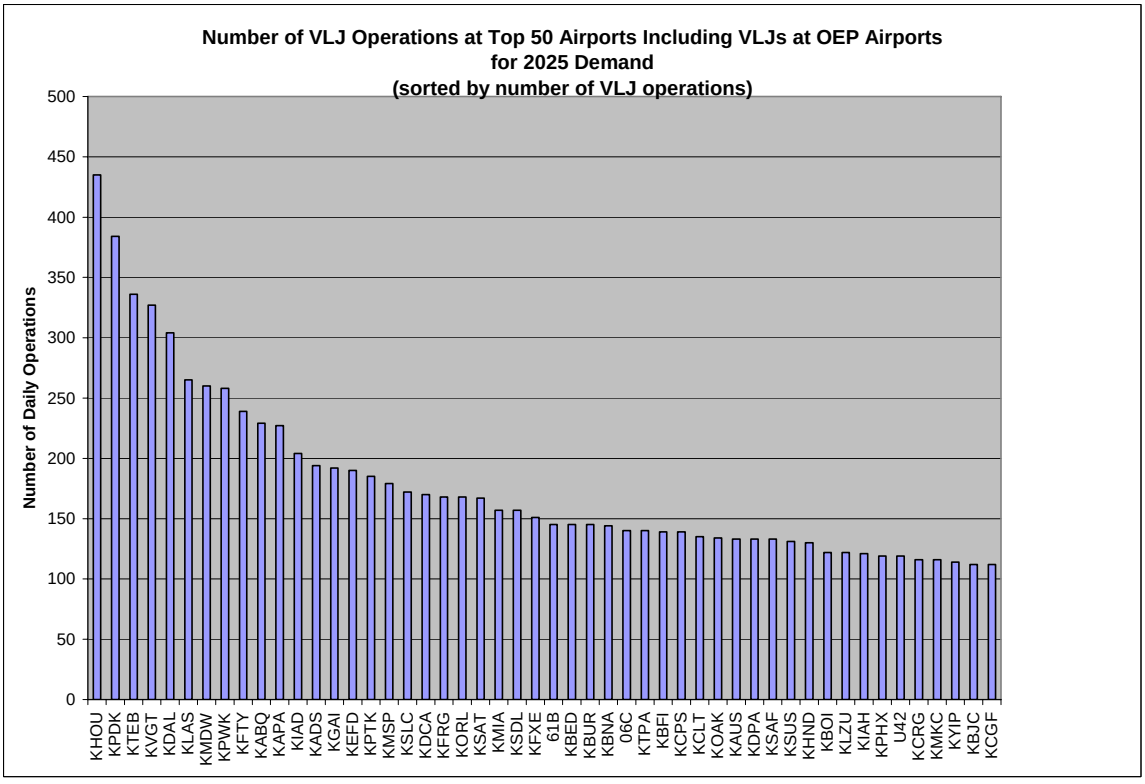

Figure 18 Number of VLJ Operations at Top 50 Busiest Airports for VLJ Air Taxis in 2025 (VLJs at OEP Airports)

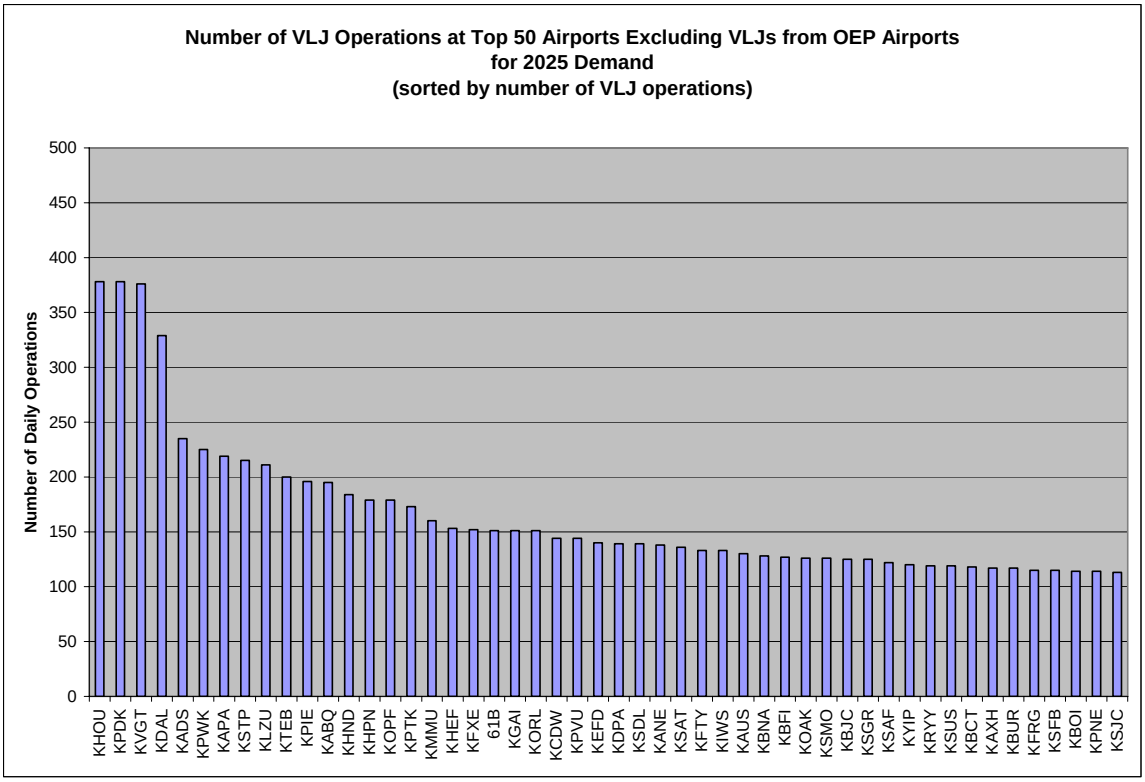

Figure 19 Number of VLJ Operations at Top 50 Busiest Airports for VLJ Air Taxis in 2025 (VLJs excluded from OEP Airports)

2025 Delays without VLJ Air Taxis

Various 2025 demand sets are used as input for ACES simulations see Table 8.

All 2025 simulation runs used 3X sector capacities and 1.4X airport capacities over and above OEP version 5 airport capacity improvements as described previously in this report. Non-OEP airports capacities are also increased by 1.4X.

Figure 20 shows the commercial flights total delay for each test case.

The 2025 base demand set without new routes and larger aircraft (Case ID 2) results in large delays at many airports, even with the substantial increases in airport capacity. The total delay at ATL is 2,110 hours and at ORD is 1,634 hours.

Figure 21 shows the commercial flights delay per operation for each test case.

For the 2025 base demand set without new routes and larger aircraft (Case ID 2) delay per operation has increased substantially at many airports compared to the 19 Feb 2004 day. At ATL the delay per operation is now nearly 1,373 seconds, a factor of five increase. At ORD the delay per operation is 1,175 seconds, a factor of two increase.

However, Case ID 2 is not realistic, since it is based on today's fleet mix and routes. Airlines will introduce larger aircraft and new direct routes as demand increases. The results from this more likely demand set (Case ID 3) are also shown on the same figure. For most airports the delays are much reduced compared to Case ID 2; the delays per operation at the larger airports are now at or below the 19 Feb 2004 levels. A few of the smaller non-OEP airports, SYR (Syracuse Hancock International Airport, NY), ROC (Greater Rochester International Airport, NY), and PWM (Portland Intl Jetport Airport, ME) have mean delays per operation that are above 15 minutes; these airports did not have significant delays in the 19 Feb 2004 demand. The increase in delays at these smaller airports is not due to growth in flights exceeding capacity; it is due to congestion at destination airports and is further investigated later in this section.

The NGATS reduced curb-to-curb times (Case ID 7), leads to an increase in passenger demand; increased demand has the effect of increasing delays unless corresponding improvements in capacity are made. The figures below show the increased delays which result. The increases are quite substantial at many airports; in fact this increased delay due to congestion would tend to offset some of the improvement in airport processing time. This means that the assumed curb-to-curb time improvements may not be fully realizable; i.e. the NGATS goal of 30% improvement may not be realized unless airport capacity is increased beyond the 1.4X assumed.

This study did not address the feedback effect of increased demand leading to increased delays which tends to suppress demand until equilibrium is reached. Future studies could use delays from ACES to modify TSAM trip times and generate a modified demand set.

The delays are reasonable at most of the larger airports even with NGATS reduced times; mean delay per operation at ATL is 278 seconds, about the same as the 19 Feb 2004 value. The exception is ORD; the mean delay per operation is now 892 seconds, a 50% increase compared to 19 Feb 2004.

With NGATS reduced curb-to-curb times, the delays at smaller airports are beginning to get quite large, SYR has 2,168 seconds mean delay per operation, ROC has 2,004 seconds and PWM has 1583 seconds. The reasons for the large delays are investigated further since these airports have sufficient capacity for the demand. Table 12 shows the delays by flight segment for each of these three airports. In each case the delay is almost all departure delay which is due to ACES Traffic Flow Management (TFM) holding aircraft at the gate. Once the aircraft are released the delay is minimal since the airports have more than adequate capacity; Figure 22 for SYR shows that departure demand is well within capacity. The reason for holding flights at the gate is due to congestion at the destination airports. (Sector congestion is not a factor, since sector capacities are generally adequate, see section on sector analysis.) For example, SYR has 24 flights to ORD and these flights account for 199 hours of the total 208 hours of departure delay.

Airport	Departure Delay (hrs)	Take Off Delay (hrs)	Landing Delay (hrs)	Arrival Delay (hrs)	Total Delay (hrs)	Number of Commercial Operations	Delay Per Op (secs)
SYR	208.0	0.8	0.2	0.0	209.0	347	2168
ROC	161.1	0.6	0.3	0.0	162.0	291	2004
PWM	110.2	1.1	0.4	0.0	111.7	254	1583

Table 12 Commercial Flight Delays at Selected Small Airports (without VLJs)

Figure 23 is a representation of the distribution of delays for the NGATS reduced times demand set (Case ID 7). Only flights with delay are included in this chart, flights with zero delay are excluded from the statistics. The intersection of the solid bars represents the Median (mid-point of the data, half the delays are larger and half smaller). The limits of the solid bars represent the 25th percentile and 75th percentile of the data and the end point lines represent the 10th percentile and 90th percentile of the data.

This chart shows that for most airports 75% of flights have delays below 15 minutes, with the exception of ORD and MSN (Dane County Regional Airport, WI). However, the 90th percentile of delays is high for many smaller airports; these airports have several flights with very long delays.

SYR has 15 flights with delays of more than 6 hours out of a total of 347 commercial operations and the maximum delay for a flight was 17 hours 29 minutes. ROC has 12 flights with delays of more than 5 hours out of a total of 291 commercial operations and the maximum delay for a flight was 17 hours 18 minutes. PWM has 9 flights with delays of more than 5 hours out of a total of 254 commercial operations and the maximum delay for a flight was 16 hours 6 minutes.

ACES TFM is not being equitable in holding flights since these few small airports have much more delay per operation than other airports with flights into ORD. Holding flights for 16 or 17 hours is not realistic.

ACES has the option of using a model of an Airlines Operations Center, which was not used for this analysis. This would have cancelled flights which are excessively delayed. However in the case analyzed here only a few flights are excessively delayed and a more sophisticated TFM model could have created an arrival slot by slightly increasing delay to one or more flights with much less delay to the same destination airport and allowed the few flights with large delay to take-off much earlier.

The delay distribution chart only includes flights with delays, for some airports a significant number of flights do not have any delay. Figure 24 shows the percentage of flights with delays. ORD has the highest percentage of flights with delays of more than 15 minutes. ORD has a total of 4720 commercial operations, 330 with zero delay, 2652 with delays of 15 minutes or less and 1738 with delays of more than 15 minutes. The percentage of flights at ORD with delays of more than 15 minutes has increased from 15% for the 19 Feb 2004 to 36% for the 2025 case.

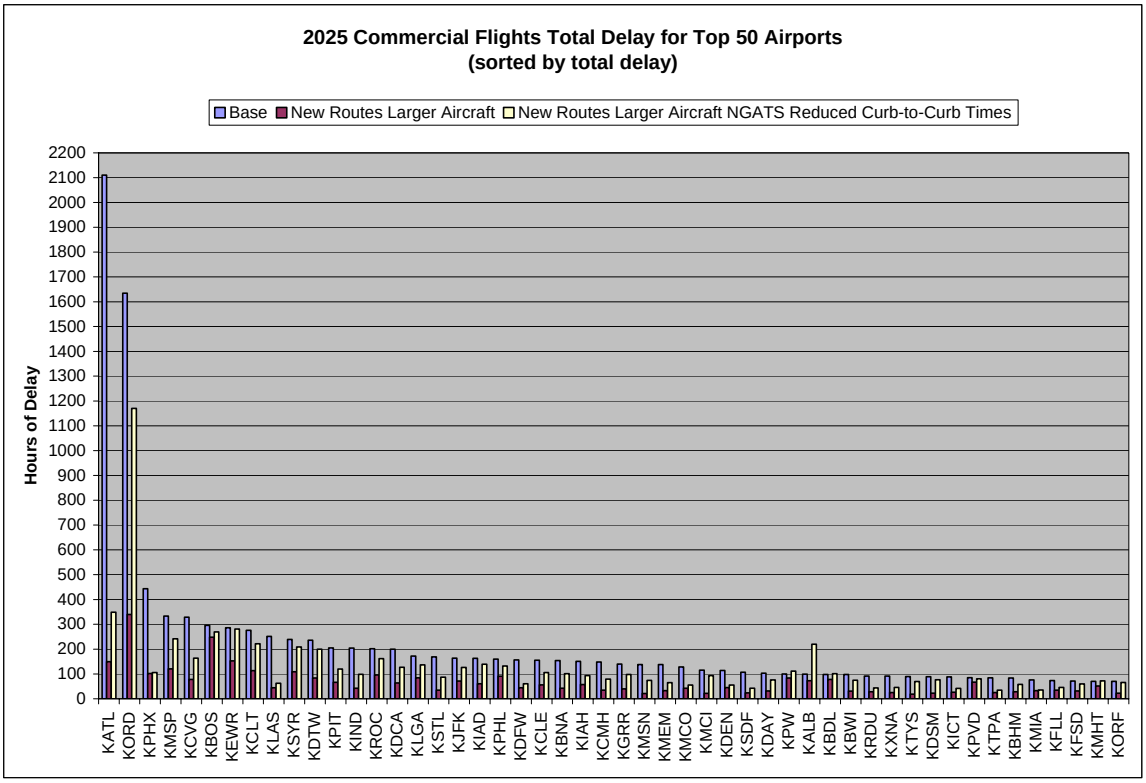

Figure 20 Commercial Flights Total Hours of Delay at Top 50 Airports for 2025 Demand Sets (without VLJs)

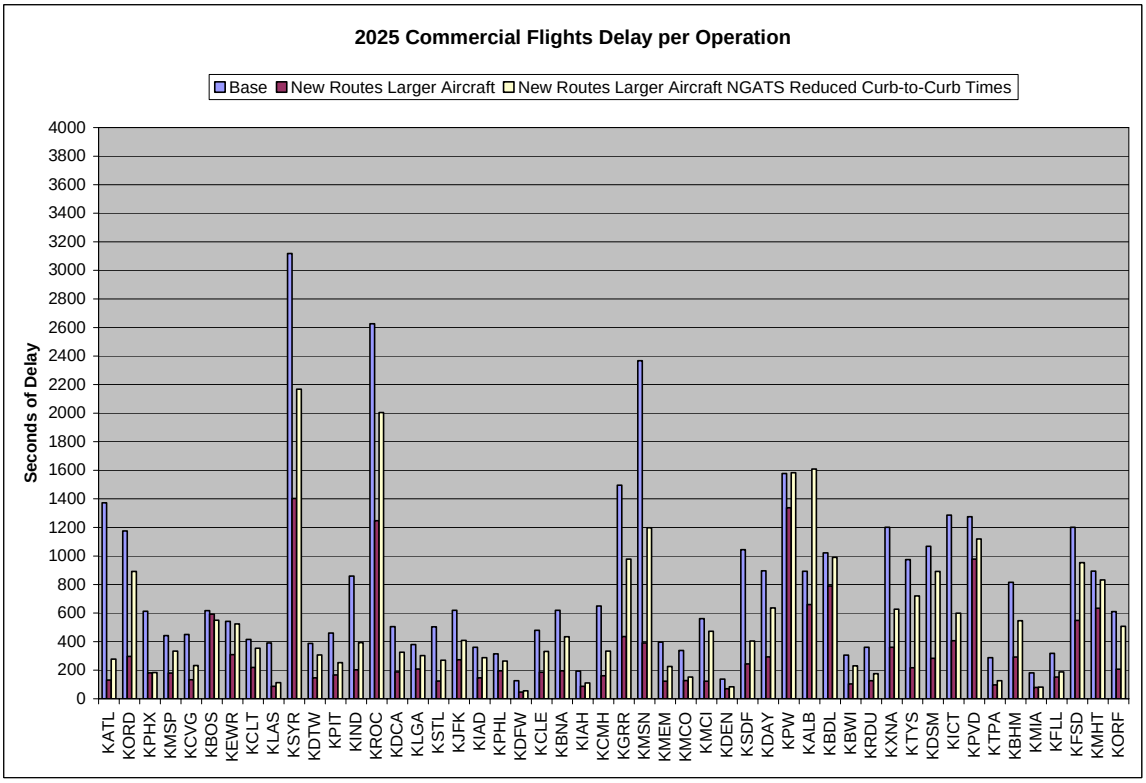

Figure 21 Commercial Flights Mean Delay per Operation at Top 50 Airports for 2025 Demand Sets (without VLJs)

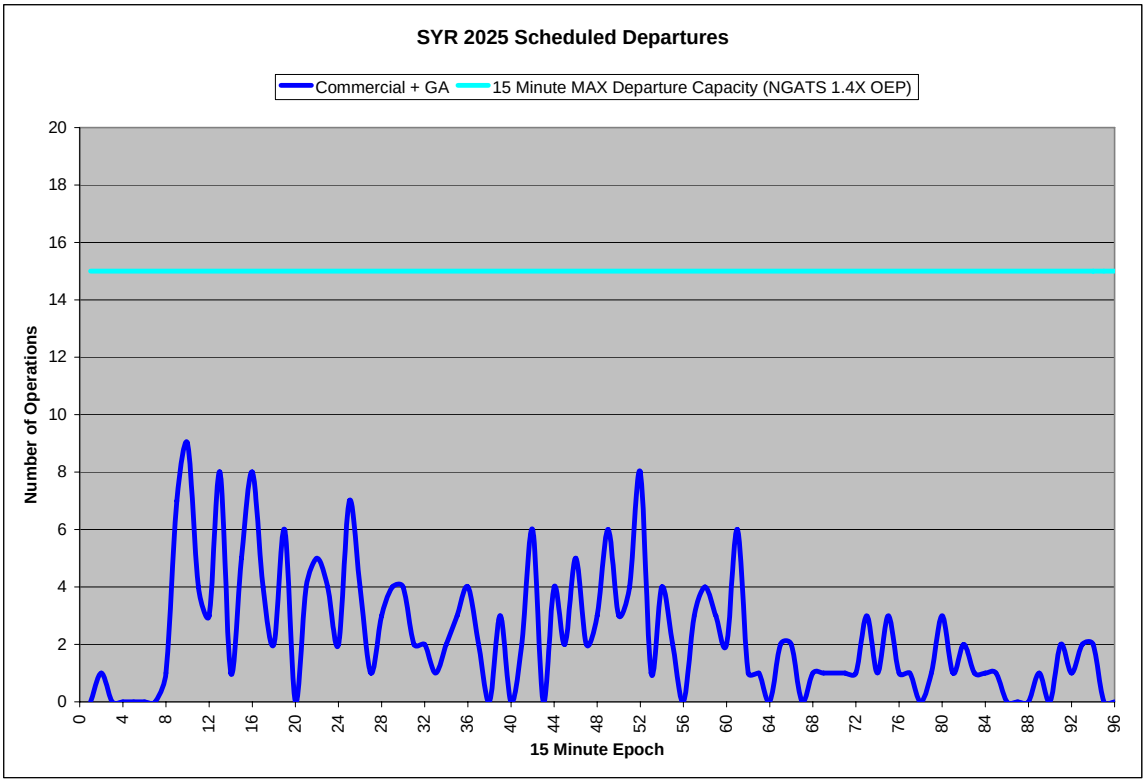

Figure 22 SYR 2025 Scheduled Departures (without VLJs)

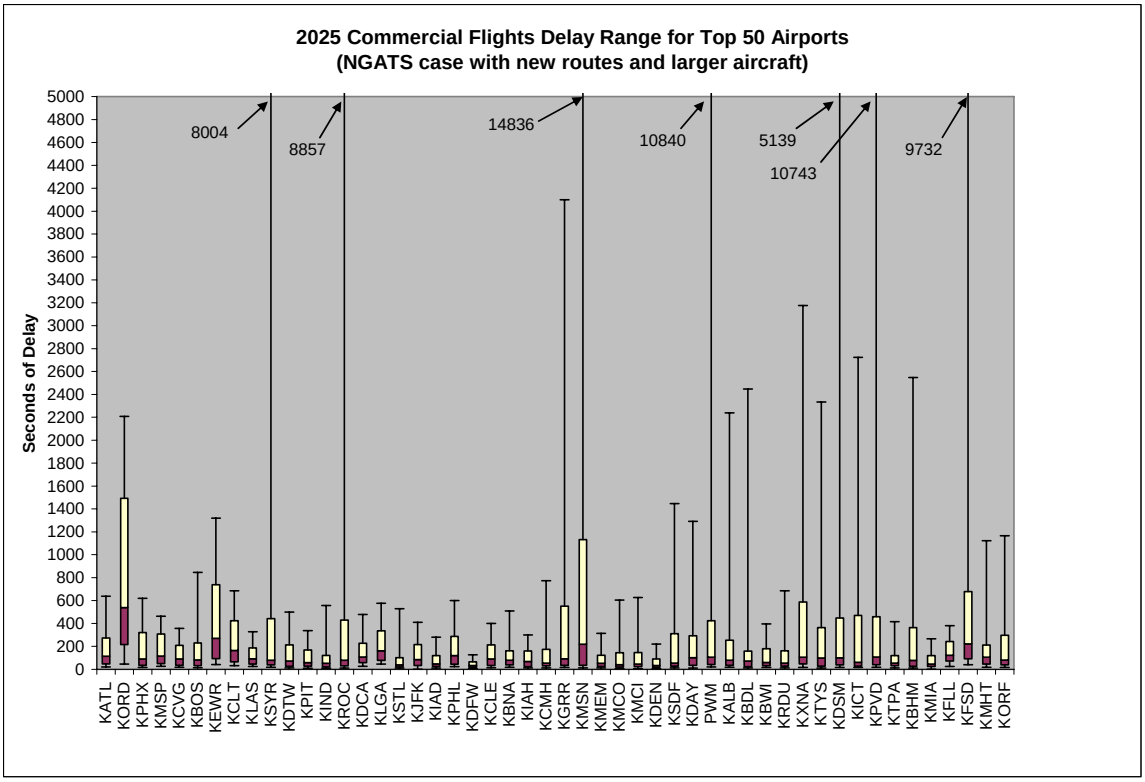

Figure 23 Commercial Flights Delay Range at Top 50 Airports for 2025 Demand (without VLJs)

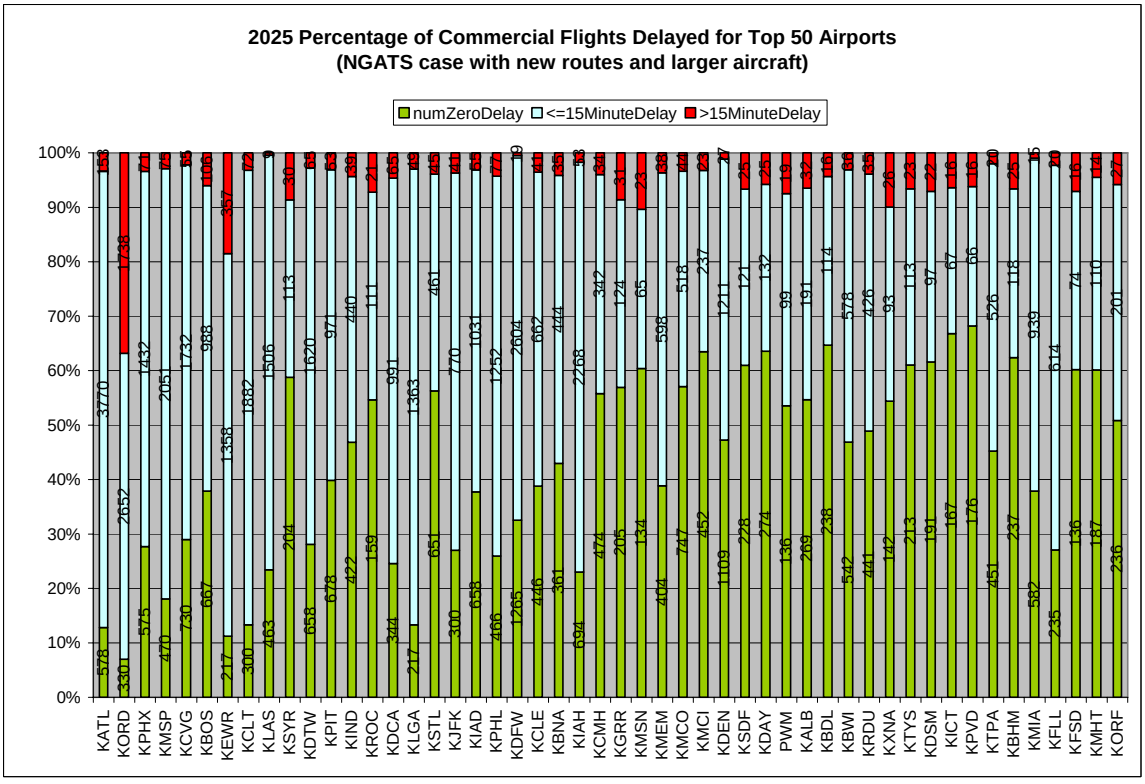

Figure 24 Percentage of Commercial Flights Delayed at Top 50 Airports for 2025 Demand (without VLJs)

2025 Delays with VLJ Air Taxis

The analysis in this section is for the cases with NGATS reduced curb-to-curb times only since this is the scenario which meets the JPDO goals (Case ID 8 OEP case and Case ID 9 non-OEP case), see Table 8. These are compared to the case without VLJs (Case ID 7).

Delays at Airports with the Most VLJ Operations (VLJs at OEP Airports)

Figure 25 below shows the total delay at the top 50 airports with the most VLJ operations. The figure shows the delay attributable to commercial flights only, not including GA and VLJs and the delay for all flights. Note that some airports do not have commercial airline operations, so have zero delay for the commercial only case. (See Figure 18 for the number of VLJ operations at each airport).

Figure 26 shows the mean delays per operation for commercial only and all flights. All of the top 50 VLJ airports, including the OEP airports with VLJ operations have mean delays per operation below 7 minutes. Note that the mean delays per operation for all flights (commercial plus GA, VLJ and Cargo) is often lower than for commercial only – this is because GA and VLJ flights generally have lower delays than commercial flights since the majority fly to smaller less congested airports.

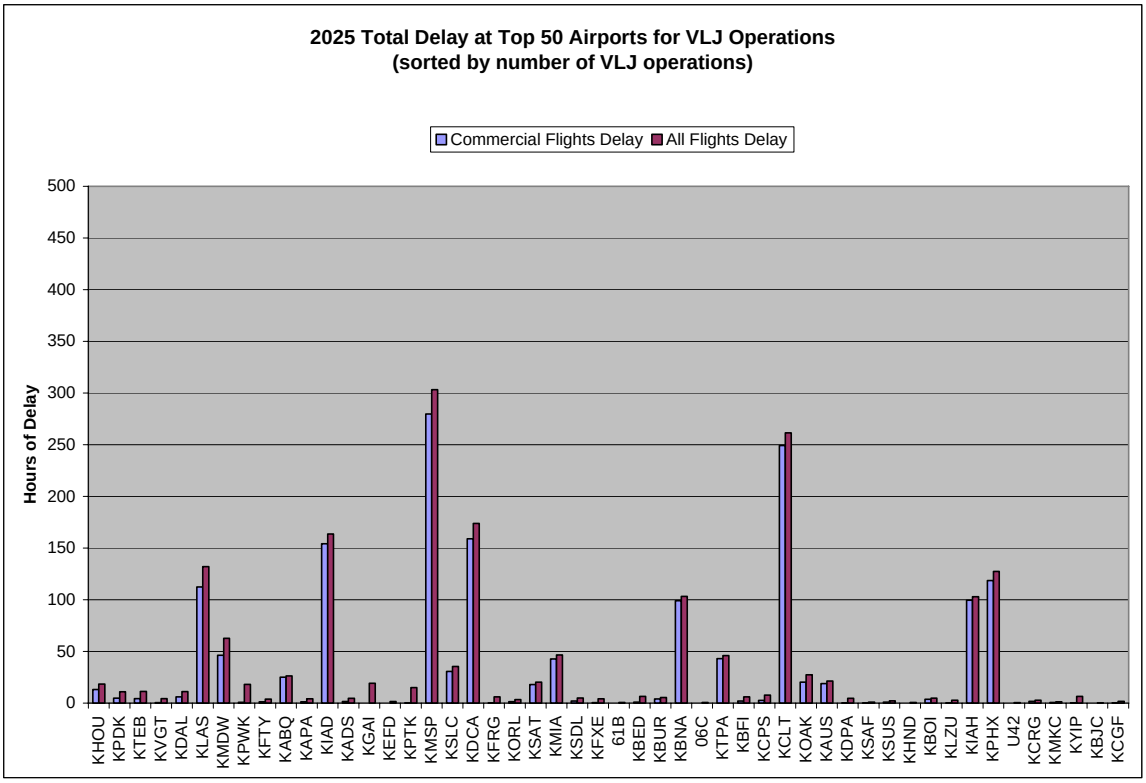

Figure 25 Total Hours of Delay at Top 50 Airports with most VLJ Operations for 2025 Demand Set (VLJs at OEP Airports)

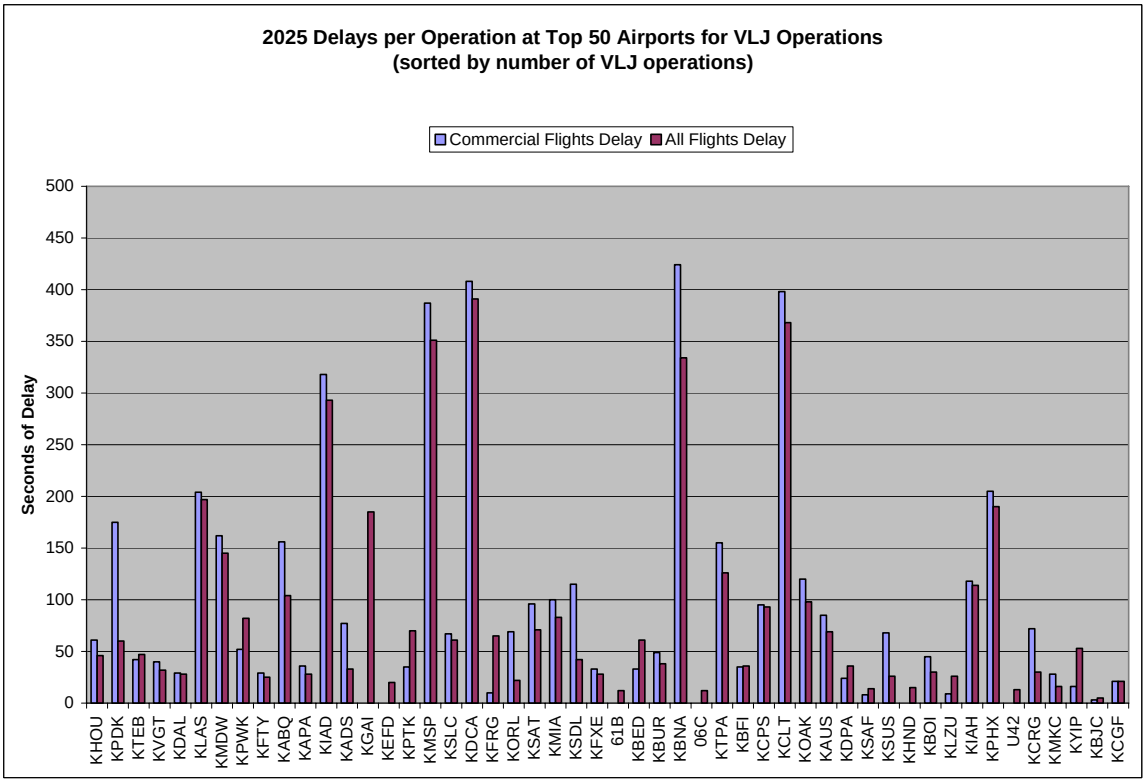

Figure 26 Mean Delay per Operation at Top 50 Airports with most VLJ Operations for 2025 Demand Set (VLJs at OEP Airports)

Delays at Airports with Largest Increase in Commercial Flights Total Delay (VLJs at OEP Airports)

Figure 27 shows the airports with the largest increase in commercial flights total delay due to VLJ operations. Figure 28 shows the corresponding increase in mean delay per operation. (Case ID 9 compared to Case ID 7).

EWR has the largest total increase in delay of 118 hours with a corresponding increase in mean delay per commercial flight operation of 219 seconds. EWR has 111 VLJ operations per day. The second largest increase in total delay is 60 hours at ORD with a corresponding increase in delay per operation of 45 seconds. This is an interesting result, since ORD does not have any VLJ operations. The reason for the increase in delay is due to network wide effects of VLJs at other airports that have flights to or from ORD. The effect on ORD is investigated in more detail later in this section. LAS shows an increase in total delay of 50 hours with an increase in delay per operation of 91 seconds. LAS is the 6th busiest airport for VLJ operations at 265 operations per day.

Figure 29 shows the actual mean delays per commercial operation for the airports with the largest increase in total delay. A number of the airports have mean delays per operation of more than 15 minutes. In particular some of the smaller airports, SYR, ALB (Albany International Airport, NY), PWM have very large delays. However, all of these airports had large delays before the addition of VLJ operations; see Figure 21. SYR shows an increase in delay per operation due to VLJs of 78 seconds which is only 3.7%. The delays at these airports are unrealistically high, due to simplistic ACES TFM modeling as explained previously.

Figure 30 is a representation of the distribution of delays.

This chart shows that the Median delay at EWR has increased by 63% and the 90^{th} percentile of delay has increased by 38% due to VLJs, compared with Figure 23.

Figure 31 shows the percentage of flights with delays.

The number of flights with delays of more than 15 minutes at EWR has increased by 39% from 357 flights to 497 flights, compared with Figure 24.

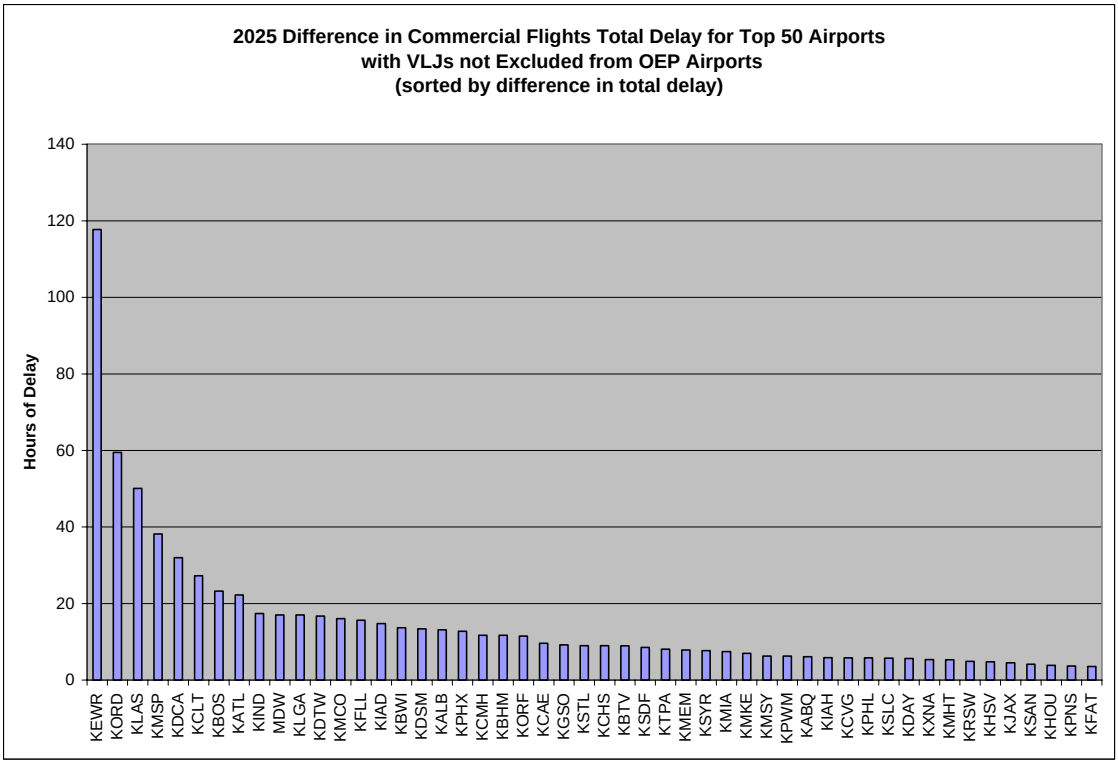

Figure 27 2025 Commercial Flights Difference in Total Delay at Top 50 Airports with Largest Increase in Delay (VLJs at OEP Airports)

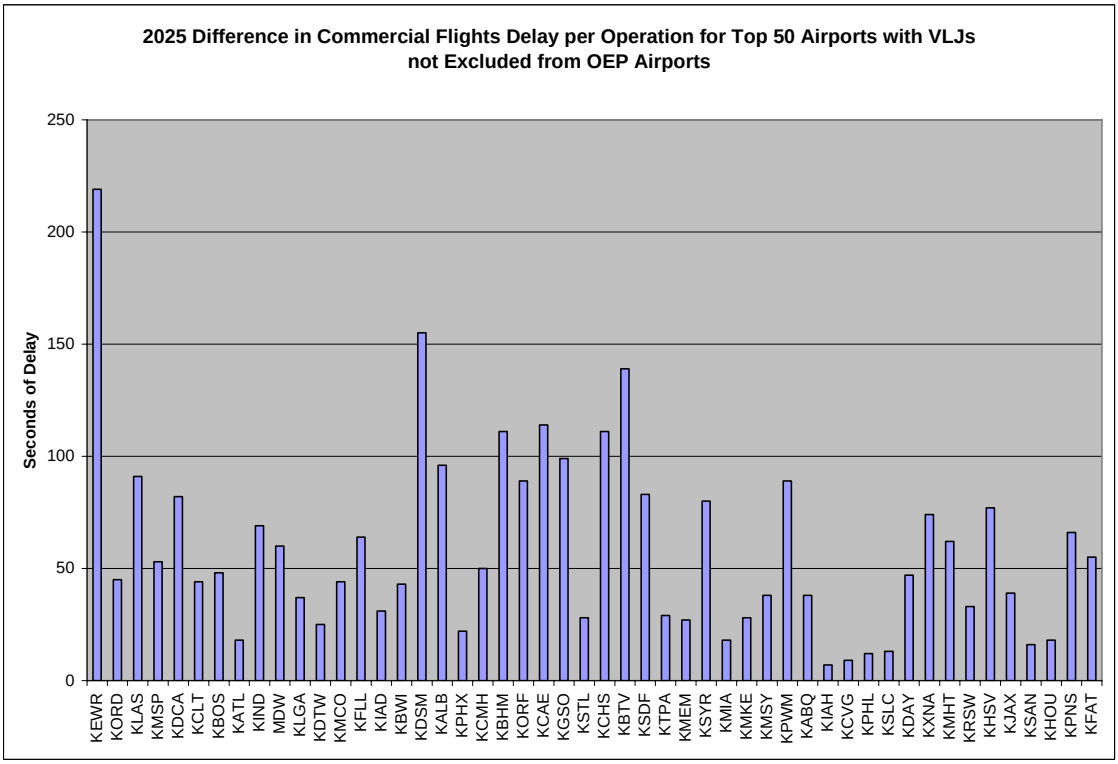

Figure 28 2025 Commercial Flights Difference in Mean Delay per Operation at Top 50 Airports with Largest Increase in Delay (VLJs at OEP Airports)

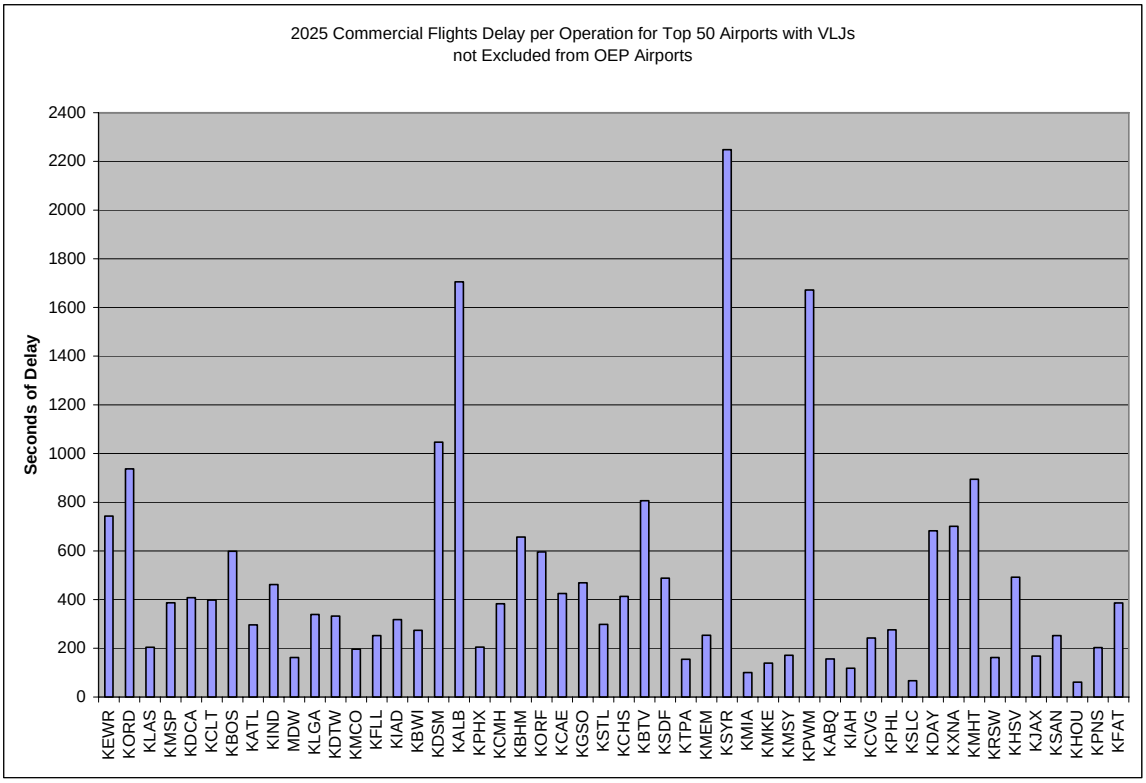

Figure 29 2025 Commercial Flights Mean Delay per Operation at Top 50 Airports with Largest Increase in Delay (VLJs at OEP Airports)

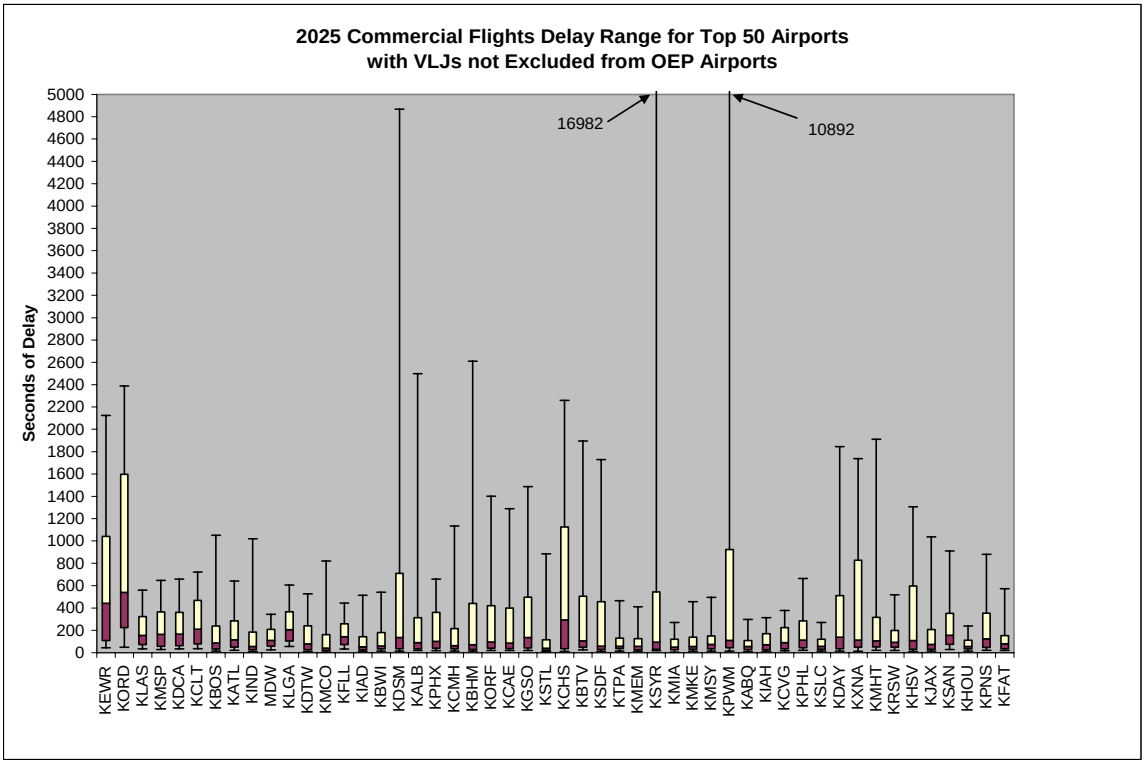

Figure 30 2025 Commercial Flights Delay Range at Top 50 Airports with Largest Increase in Delay (VLJs at OEP Airports)

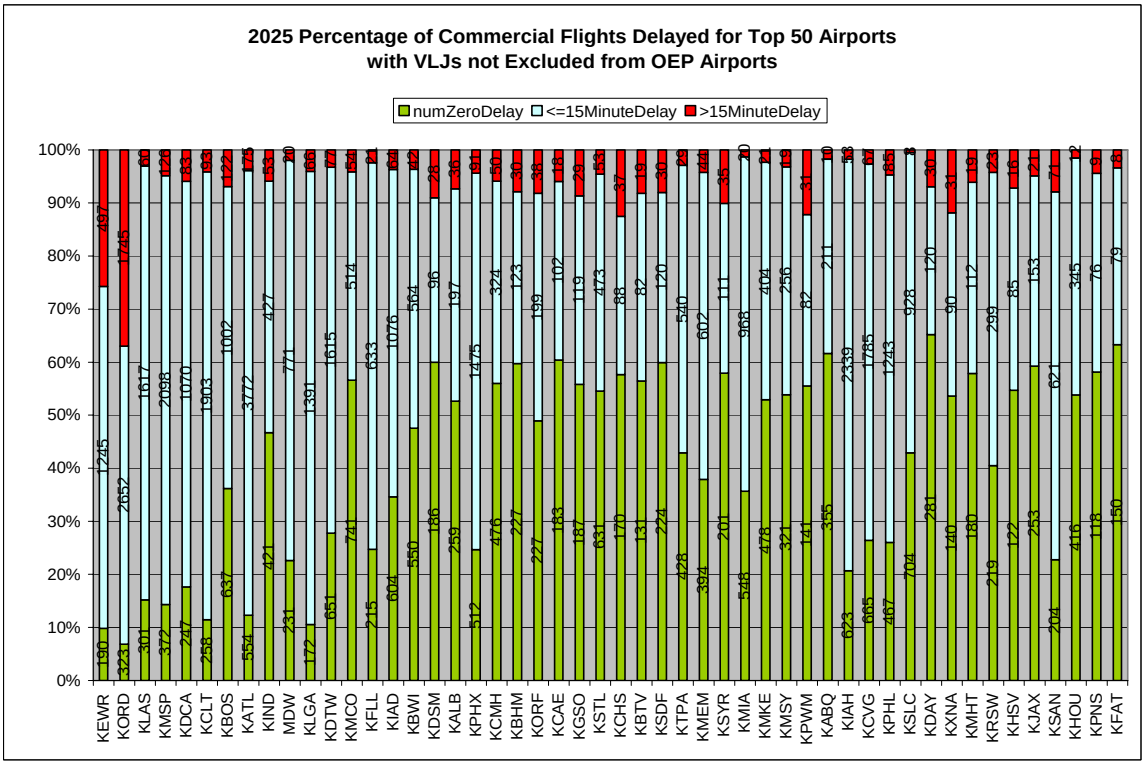

Figure 31 2025 Percentage of Commercial Flights Delayed at Top 50 Airports with Largest Increase in Delay (VLJs at OEP Airports)

Delays at Airports with Largest Increase in Commercial Flights Total Delay (VLJs excluded from OEP Airports)

Figure 32 shows the airports with the largest increase in commercial flights total delay due to VLJ operations with VLJs excluded from OEP airports. Figure 33 shows the corresponding increase in mean delay per operation (Case ID 8 compared to Case ID 7).

ORD now has the largest total increase of 103 hours with a corresponding increase in mean delay per commercial flight operation of 78 seconds.

The result for ORD for this test case is considered to be anomalous and is not used for computing the delays and costs to commercial air carriers. The reasons for this anomalous result from ACES are investigated later in this section.

The second largest increase in total delay is 18 hours at DCA with a corresponding increase in delay per operation of 47 seconds. BWI shows an increase in total delay of 14 hours with an increase in delay per operation of 43 seconds.

Figure 34 shows the actual mean delays per operation for the airports with the largest increase in total delay. As in the OEP case some small airports have large delays; all of these airports had large delays before the addition of VLJ operations.

Figure 35 shows the airports which had the largest increase in total delay with VLJs at OEP airports compared to excluding VLJs from OEP airports. The previous results showed that EWR was the airport with the largest increase in total delay, but now that VLJ flights are excluded from EWR and other OEP airports, this airport is not significantly impacted by VLJ operations. The number of OEP airports with an increase in total delay of more than 10 hours has reduced from 17 to 3 (ORD, DCA, BWI) by excluding VLJs. Excluding VLJs is beneficial for most OEP airports as would be expected; the exception is ORD. There are not any VLJ operations at ORD even for the case where VLJs are not excluded from OEP airports. Despite this, ORD is impacted by VLJ operations and the impact actually increases from 60 hours to 103 hours total delay for the OEP excluded case. *This is counter-intuitive; the reason for this increase is due to an artifact of ACES TFM as investigated later in this section*.

Figure 36 is a representation of the distribution of delays.

This chart can be compared to Figure 30, the Median delay at ORD has increased from 539 seconds to 590 seconds and the 90^{th} percentile of delay has increased from 2338 seconds to 2444 seconds compared to the case with VLJs excluded from OEP airports.

Figure 37 shows the percentage of flights with delays. The number of flights with delays of more than 15 minutes at ORD has increased from 1745 flights to 1789 flights, compared with Figure 31.

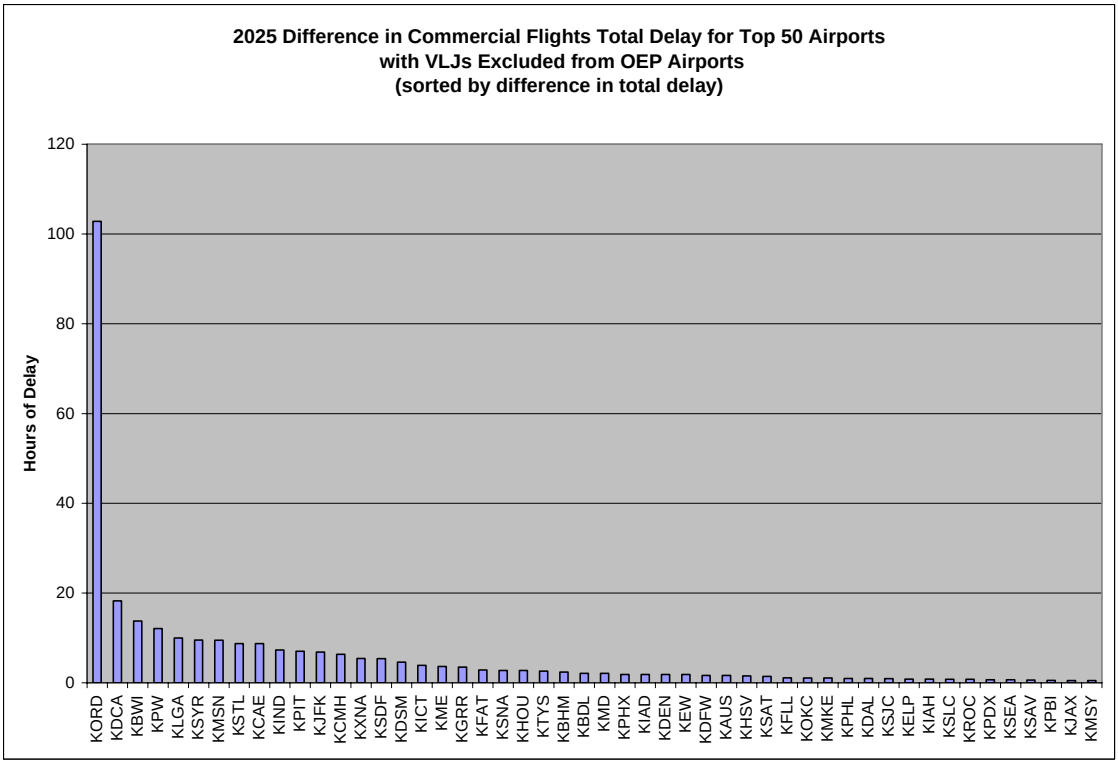

Figure 32 2025 Commercial Flights Difference in Total Delay at Top 50 Airports with Largest Increase in Delay (VLJs Excluded from OEP Airports)

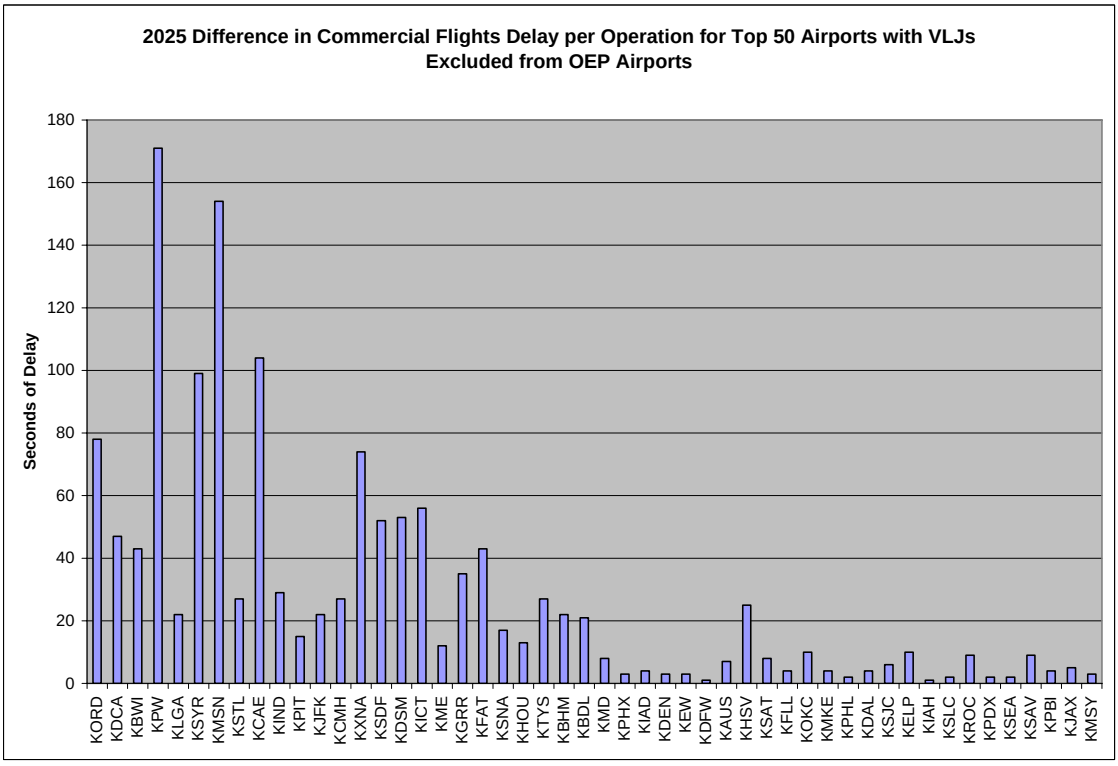

Figure 33 2025 Commercial Flights Difference in Mean Delay per Operation at Top 50 Airports with Largest Increase in Delay (VLJs Excluded from OEP Airports)

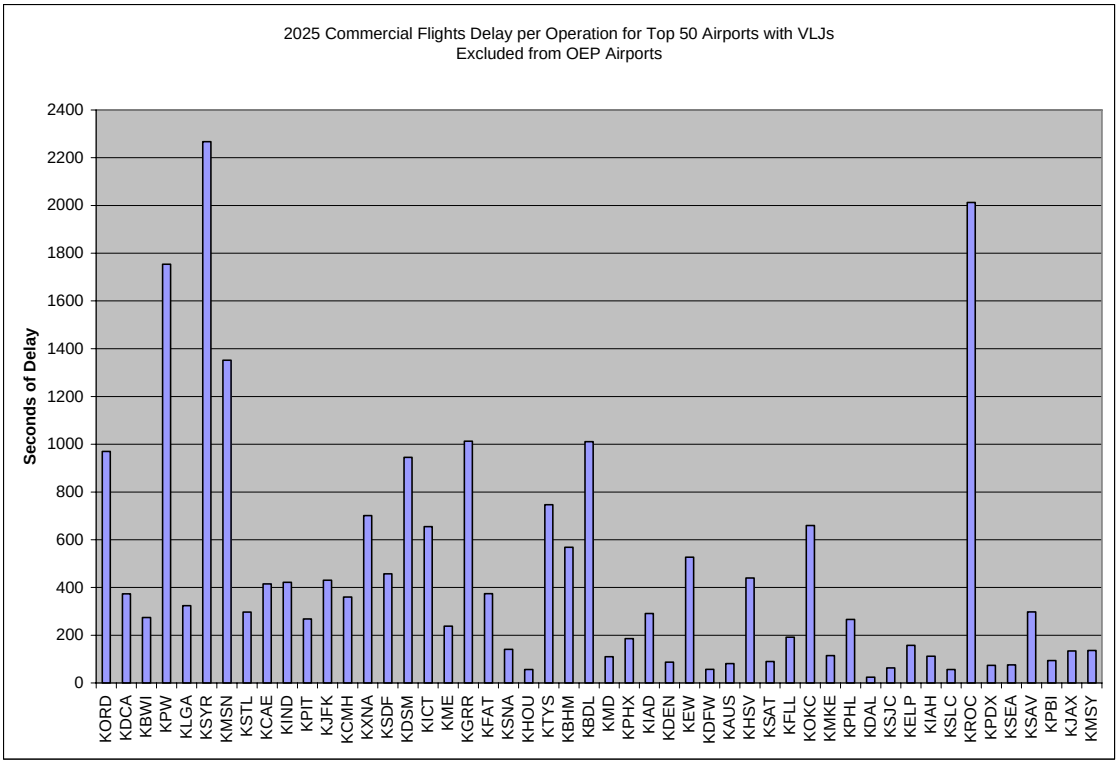

Figure 34 2025 Commercial Flights Mean Delay per Operation at Top 50 Airports with Largest Increase in Delay due to VLJs (VLJs Excluded from OEP Airports)

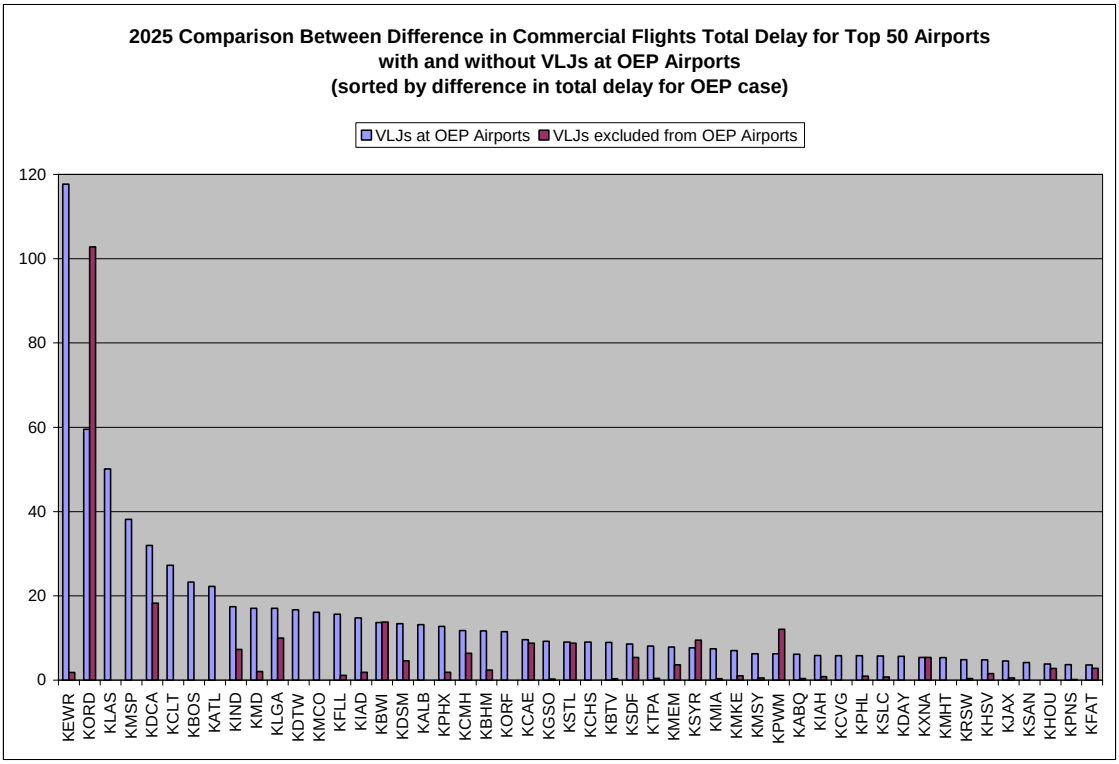

Figure 35 2025 Commercial Flights Difference in Hours of Total Delay due to VLJs with and without VLJs at OEP Airports

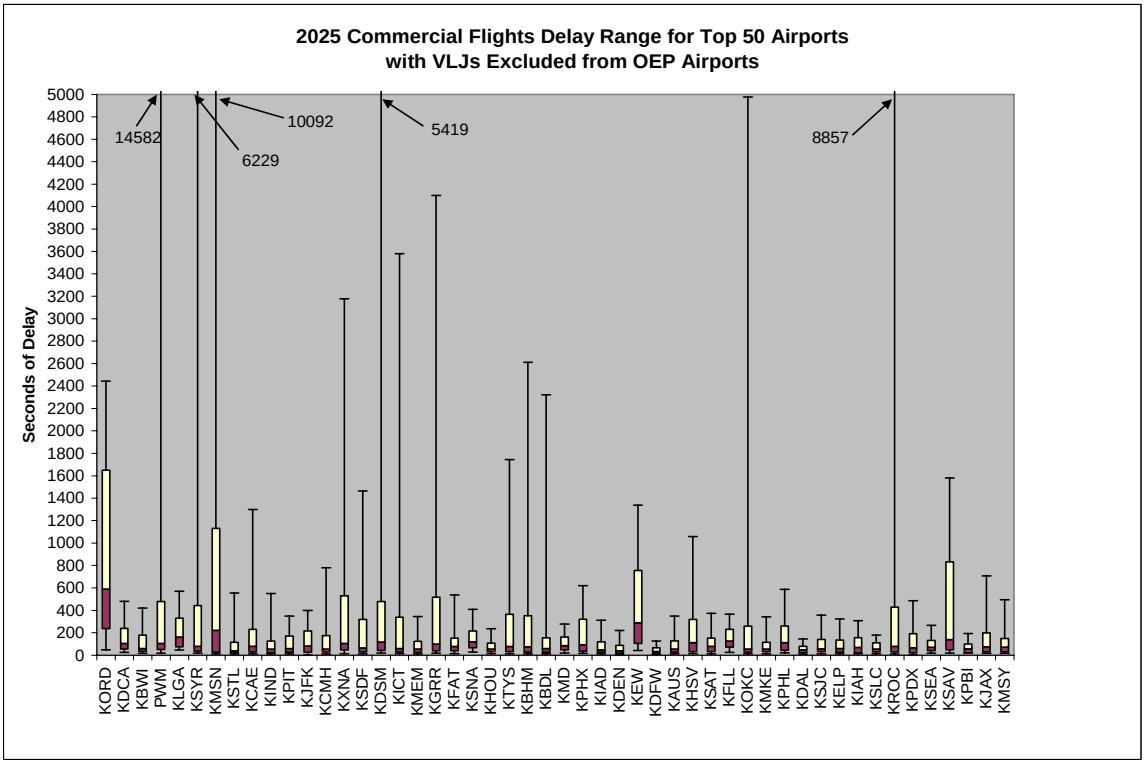

Figure 36 2025 Commercial Flights Delay Range at Top 50 Airports with Largest Increase in Delay (VLJs Excluded from OEP Airports)

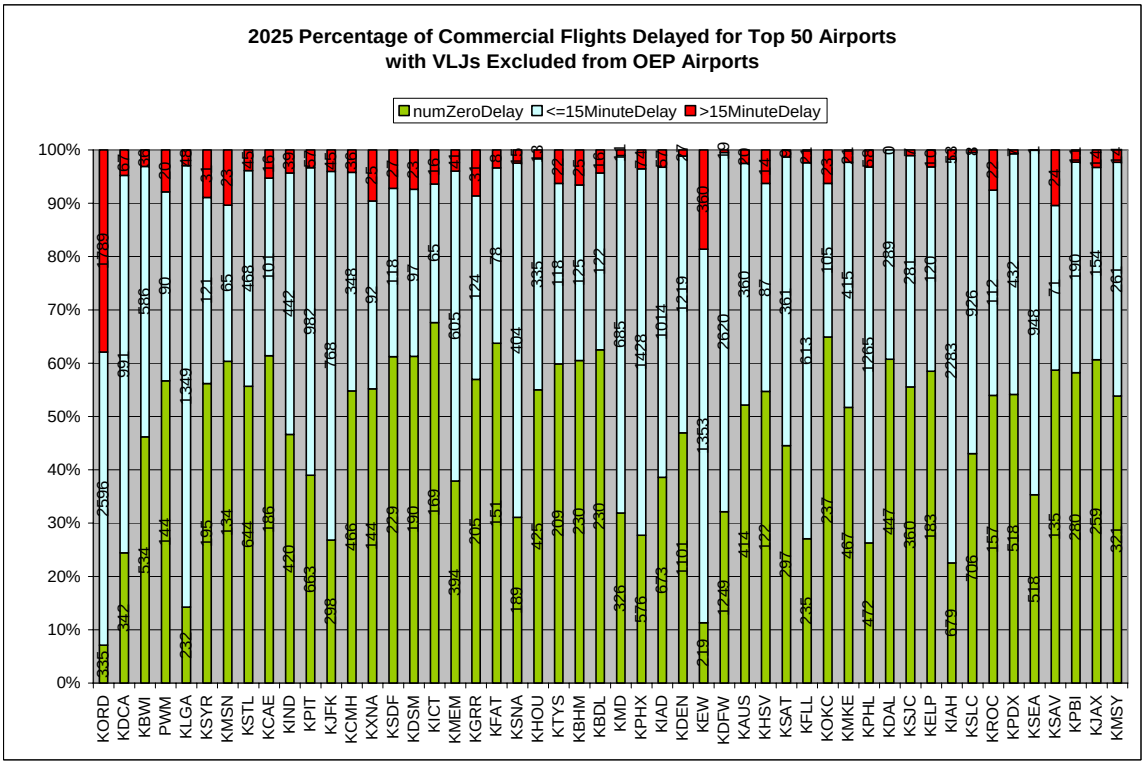

Figure 37 2025 Percentage of Commercial Flights Delayed at Top 50 Airports with Largest Increase in Delay (VLJs Excluded from OEP Airports)

2025 Delays at Chicago O'Hare (ORD)

The increase in commercial flights total daily delay at ORD due to VLJ operations is 60 hours (5.1%) with VLJs at OEP airports (OEP case) and 103 hours (8.8%) with VLJs excluded from OEP airports (non-OEP case), see Table 13. The commercial flights mean delay per operation increases from 892 seconds without VLJs (Case ID 7) to 937 seconds for the OEP case (Case ID 9) and 970 seconds for the non-OEP case (Case ID 8).

These are significant increases and are not caused by VLJ operations at ORD, since there are none for both cases, see Table 14. Figure 38 shows the scheduled departure operations at ORD for commercial and GA traffic. The maximum departure capacity and actual allocated departure capacity used by ACES are shown for comparison. The actual departure capacity is frequently less than the maximum. ACES selects departure and arrival priorities to best meet the demand, if there is significant arrival demand, the capacity allocated to departures can be less than the maximum. Demand is exceeding allocated capacity at many points throughout the day.

The reason for increased delays at ORD is that destination airports may experience increased congestion due to VLJ operations, leading to increased ground hold delay at ORD. (Sector congestion could also cause increased delay, but since the sector capacities were increased by 3X for this analysis, this is not the cause of increased delay at ORD, see section on sector analysis later in this document.)

Although the increase in delay at ORD due to VLJ operations is understandable, the increase in the delay of 43 hours between the OEP and non-OEP cases is not easy to explain, note that ORD has no VLJ operations for either case.

The largest single source of delay for both cases is take-off delay, which is due to taxi and runway queues. Figure 39 shows the actual number of aircraft in the take off queue, but due to the randomness small differences are obscured. For this reason Figure 40 shows the cumulative total of aircraft in the take off queue. It is now clear that the queue without any VLJ operations in the NAS is slightly smaller with a cumulative total of 1246 aircraft, compared to the OEP VLJ case with 1326 aircraft. A slightly higher cumulative total of 1365 aircraft results when VLJs are excluded from OEP airports.

For the non-OEP compared to the OEP case the take off delay has increased from 34 to 59 hours accounting for 25 hours of the 43 hours total difference between cases. The departure delay, which is due to aircraft being held at the gate, has actually decreased by 8 hours for the non-OEP case. This means aircraft are being released sooner which accounts for the increased taxi and runway queues. The reason for less ground hold delay is due to there being less congestion at the destination airports, due to VLJs being excluded from OEP airports. Figure 41 shows the take off delays for individual flights from ORD for both the OEP and non-OEP cases. Overall the departure delay is lower for the non-OEP case by 8 hours and of this difference, 5 hours is accounted for by flights to

EWR. For the OEP case, EWR has 111 VLJ operations, so removal of these operations allows ACES TFM to release flights to EWR earlier.

The explanation for the increase in delay between the non-OEP and OEP cases seems to be therefore, that less congestion at destination airports leads to earlier release of aircraft at ORD; this causes an increase in take off delay, and because more departing aircraft are using the taxi-ways and runways also increases landing and arrival delay. It seems that ACES TFM is not optimally scheduling aircraft release from the gate at ORD since delaying the gate departure time slightly as for the OEP case would have resulted in less overall delay at ORD.

However the differences are small compared to the total delay and overall ACES TFM has to take into account network wide effects. In fact the mean delay per commercial flight, network-wide decreases from 603 seconds to 562 seconds when VLJs are excluded from OEP airports indicating that ACES TFM appears to be working well at the network-wide level[1].

1. There are several TFM components (agents) implemented within ACES and the interactions are complex, see the system design document, reference 6.

	Departure Delay (hrs)	**Take Off Delay (hrs)**	**Landing Delay (hrs)**	**Arrival Delay (hrs)**	**Total Delay (hrs)**	**Delay Per Op (secs)**
No VLJ	49	552	380	189	1,170	892
VLJ OEP	64	586	381	199	1,230	937
Increase over NO VLJ	*15*	*34*	*1*	*10*	*60*	*45*
VLJ NO OEP	56	611	395	211	1,273	970
Increase over NO VLJ	*7*	*59*	*15*	*22*	*103*	*78*

Table 13 Increase in Delays at ORD

Number of Operations	**Commercial**	**GA**	**VLJ**	**Total**
ORD	4720	39	0	4759

Table 14 Number of Commercial, GA and VLJ Operations at Airports within the Chicago TRACON

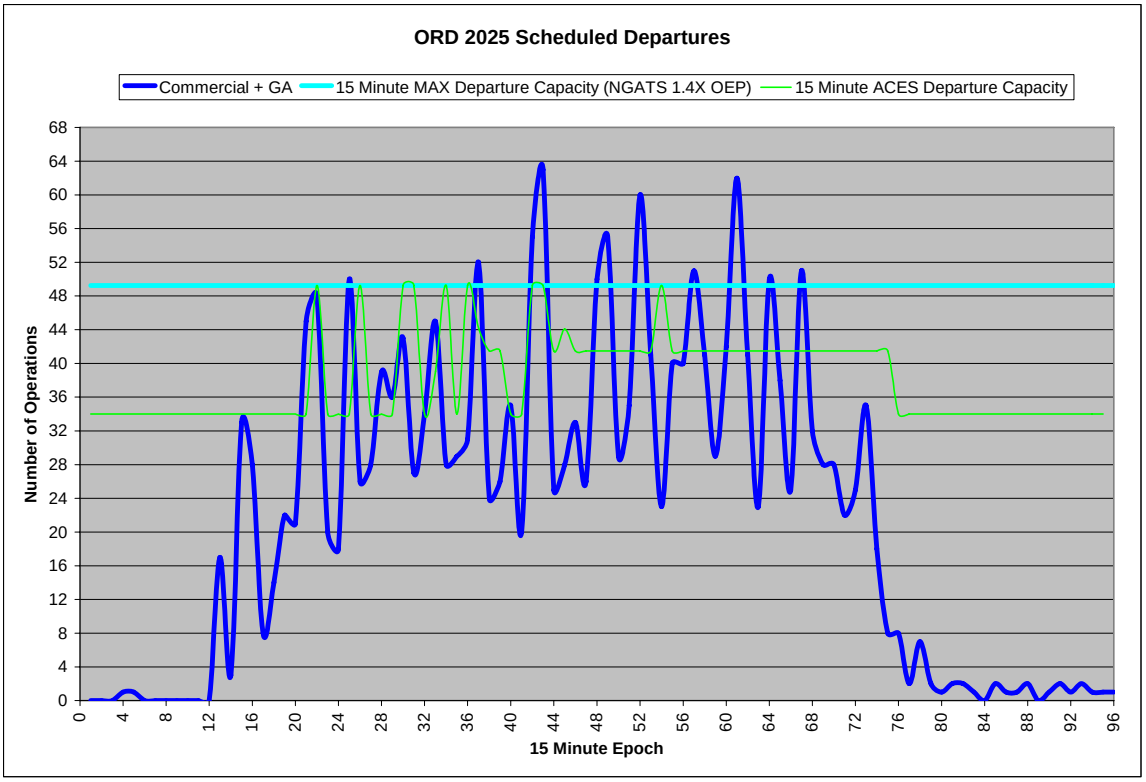

Figure 38 ORD 2025 Scheduled Departures

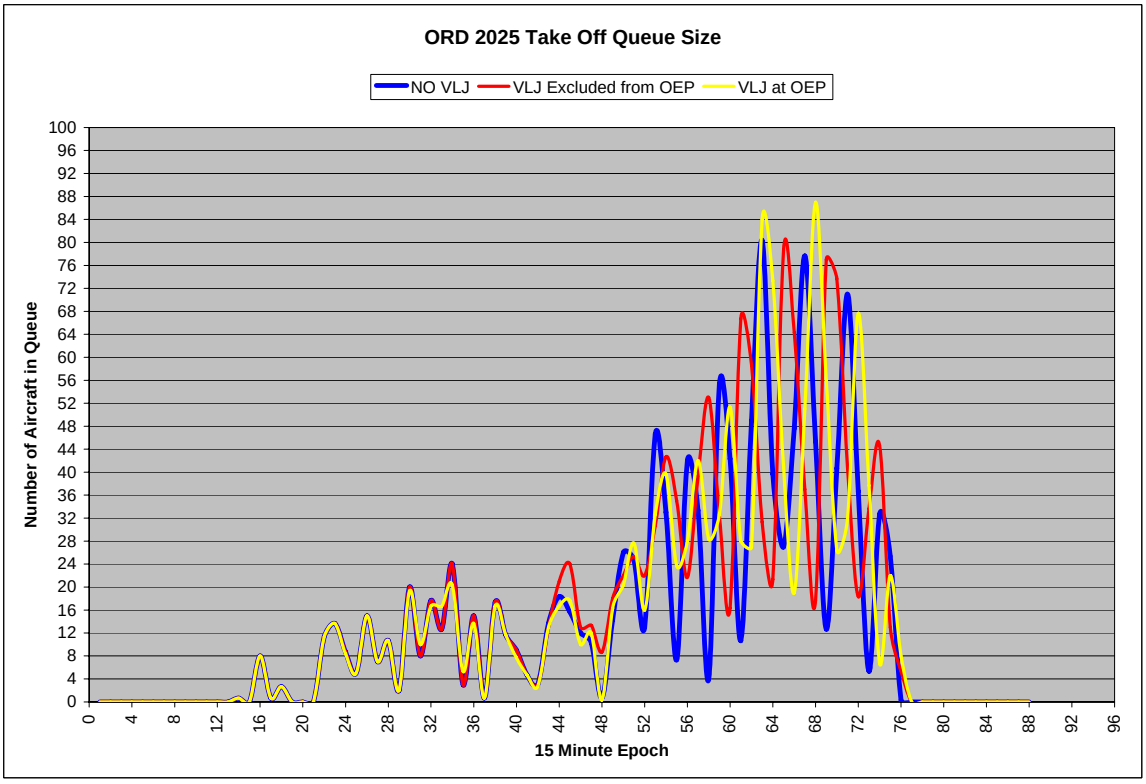

Figure 39 ORD 2025 Take Off Queue Size

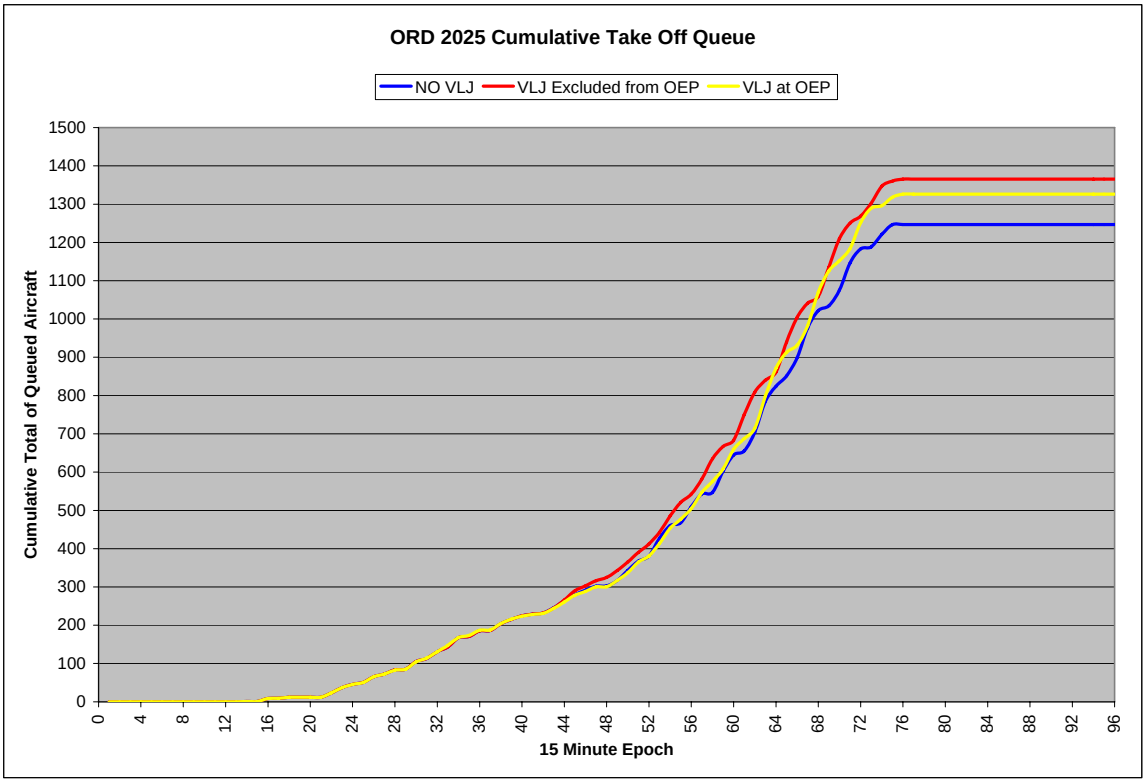

Figure 40 ORD 2025 Cumulative Total of Aircraft in Take Off Queue

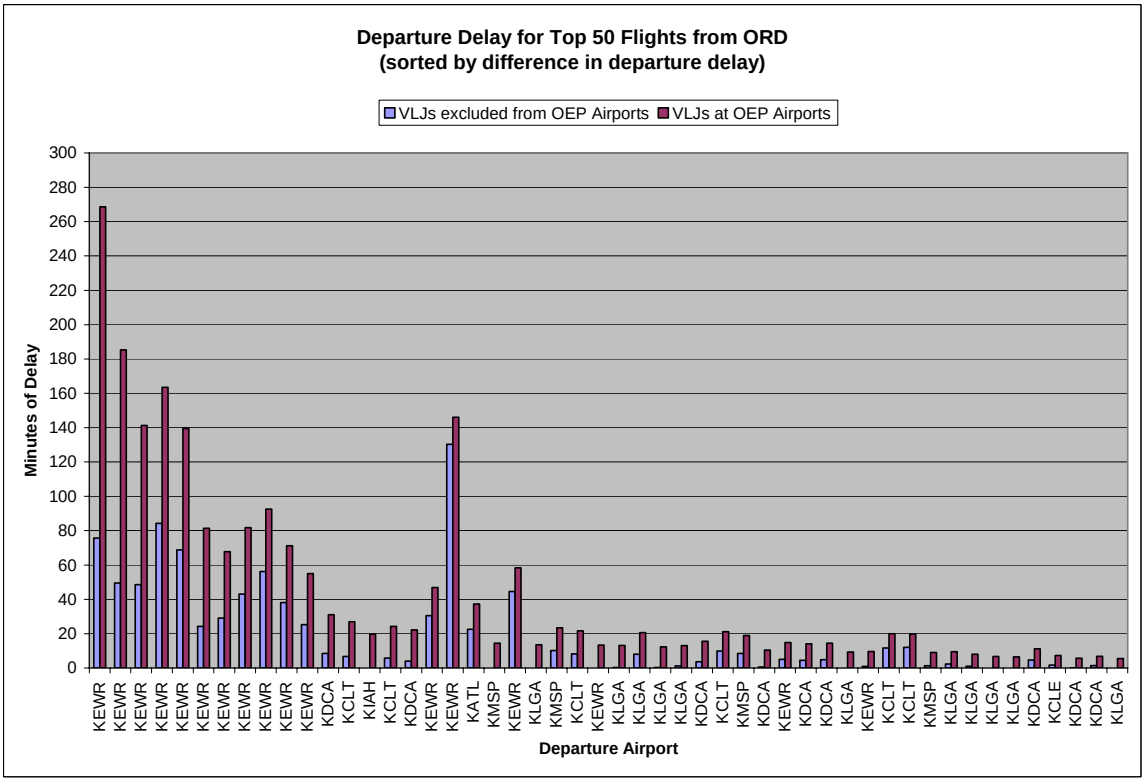

Figure 41 ORD 2025 Departure Delays

Analysis of Delays at Newark (EWR)

EWR has the largest increase in both total delay and mean delay per operation of all airports due to VLJ operations when VLJ operations are not excluded from OEP airports.

The increase in commercial flights total delay at EWR due to VLJ operations is 118 hours (42%) with VLJs at OEP airports and increases by a negligible 2 hours with VLJs excluded from OEP airports, see Table 15. The mean delay per operation increases from 524 seconds without VLJs (Case ID 7) to 985 seconds for the OEP case (Case ID 9) and is almost unchanged at 527 seconds for the non-OEP case (Case ID 8).

The increase in delay for the OEP case is large and is mainly due to take off delay, 80 hours additional, which is due to taxi and runway queues. EWR has 111 VLJ operations per day; see Table 16 which is a 5.7% increase in the total. The airport is already heavily loaded by the increase in commercial operations for 2025 and the increase in VLJ operations is causing significant additional delay.

Figure 42 shows the scheduled departures at EWR for commercial and GA traffic and for the case with VLJs. There are 56 additional departures and although this is only a 5.7% increase of the total the result is a large increase in the queue for take off. Figure 43 shows the number of aircraft in the take off queue reported by ACES for the case with and without VLJs. The maximum queue size increases from 25 aircraft to 36 aircraft for the VLJ case. This large increase occurs because EWR is near capacity. When an airport is near capacity a small increase in the number of operations will cause a disproportionately large increase in delay.

The additional delay at EWR is eliminated if VLJs are excluded from OEP airports. This behavior is not the same as was observed at ORD. The cumulative total of aircraft in the take off queue differs by only 3 aircraft for the case without any VLJs and the case with VLJs, but excluded from OEP airports, see Figure 44. For ORD there was an additional cumulative total of 119 aircraft in the take off queue.

The explanation for this is that most of the additional delay at EWR is caused by VLJ operations at EWR itself. ORD does not have any VLJ operations and the additional delay at ORD must therefore be caused by network wide interactions with other airports which do have VLJ operations.

	Departure Delay (hrs)	Take Off Delay (hrs)	Landing Delay (hrs)	Arrival Delay (hrs)	Total Delay (hrs)	Delay Per Op (secs)
No VLJ	59	127	79	16	281	524
VLJ OEP	64	207	87	40	399	985
Increase over NO VLJ	*5*	*80*	*8*	*24*	*118*	*461*
VLJ NO OEP	55	129	82	17	283	527
Increase over NO VLJ	*-4*	*2*	*3*	*1*	*2*	*3*

Table 15 Increase in Delays at EWR

Number of Operations	Commercial	GA	VLJ	Total
EWR	1932	13	111	2056

Table 16 Number of Commercial, GA and VLJ Operations at Airports within the New York TRACON

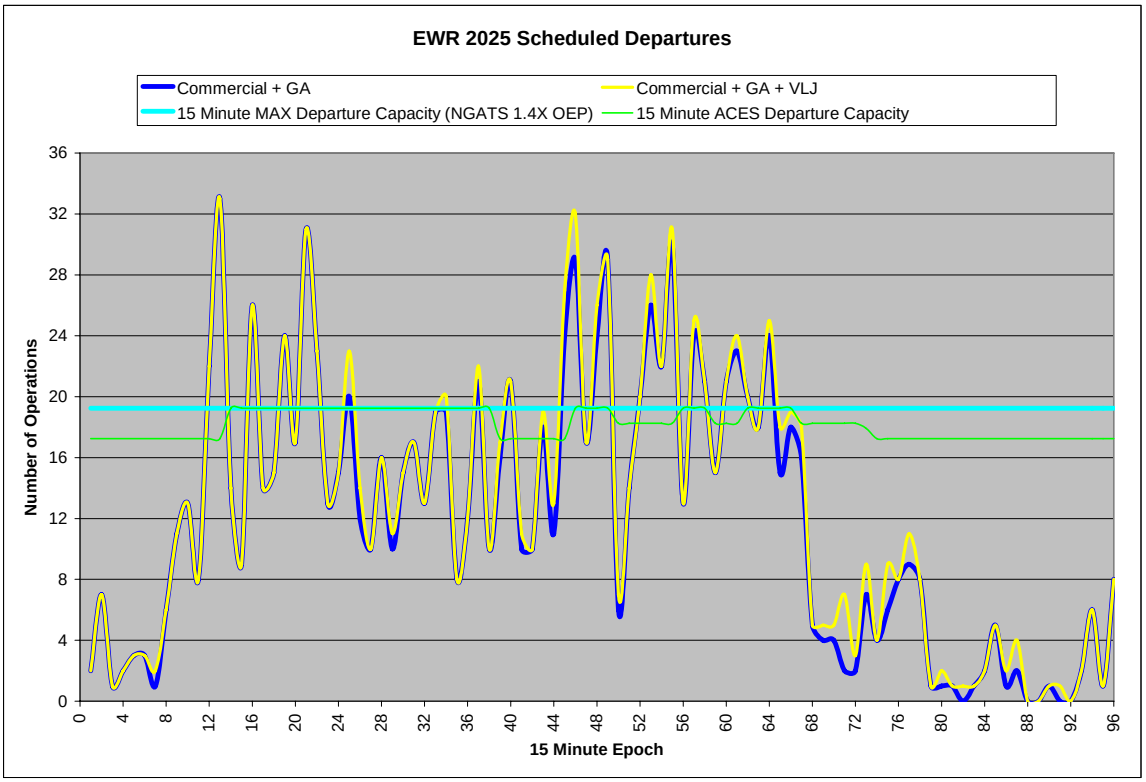

Figure 42 EWR 2025 Scheduled Departures

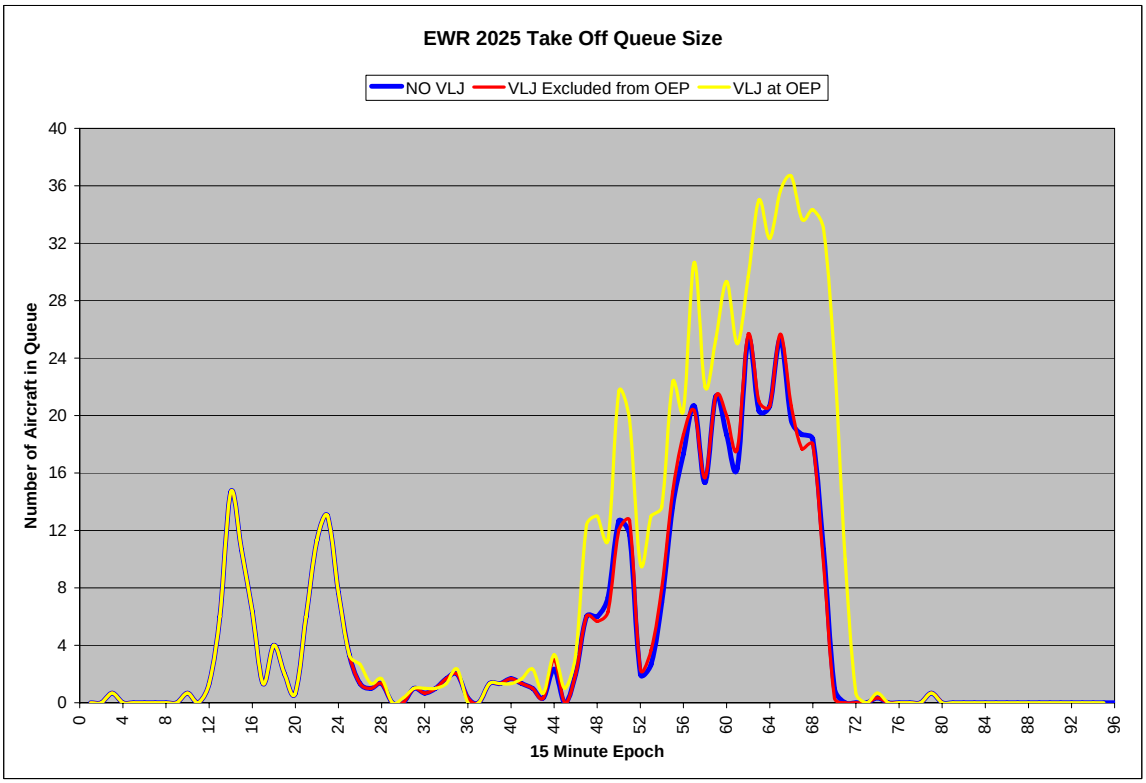

Figure 43 EWR 2025 Take Off Queue Size

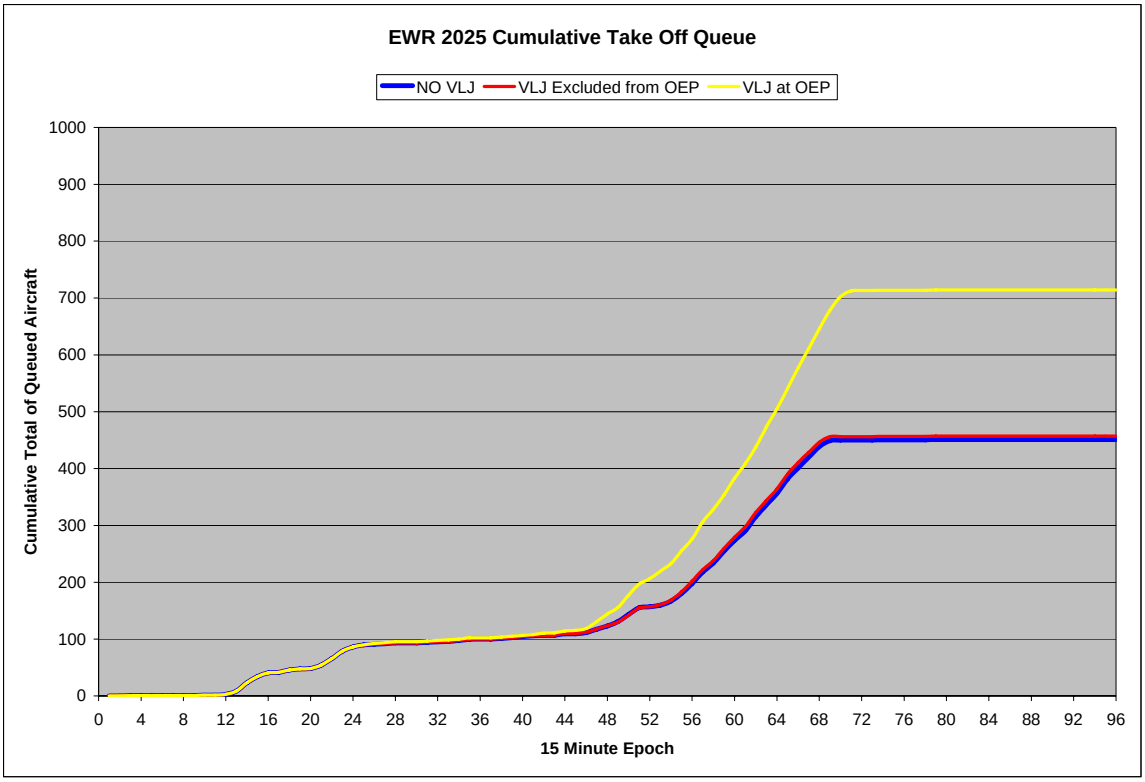

Figure 44 EWR 2025 Cumulative Total of Aircraft in Take Off Queue

2025 Delays at Las Vegas (LAS)

The increase in commercial flights total delay at LAS due to VLJ operations is 50 hours (81%) with VLJs at OEP airports; with VLJs excluded from OEP airports there is no increase in delay, see Table 17. The mean delay per operation increases from 113 seconds without VLJs (Case ID 7) to 204 seconds for the OEP case (Case ID 9) and does not increase for the non-OEP case (Case ID 7).

The percentage increase in delay for the OEP case is large, although the actual delay per operation is still reasonable at 204 seconds. The largest component of the increase is take-off delay, 36 hours additional, which is due to taxi and runway queues. LAS has 265 VLJ operations per day, see Table 17, which is a 12.5% increase in the total. The airport is already heavily loaded by the increase in commercial operations for 2025 and the increase in VLJ operations is causing significant additional delay.

Figure 45 shows the scheduled departures at LAS for commercial and GA traffic and for the case with VLJs. There are 133 additional departures and the result is a large increase in the queue for take off. Figure 46 shows the number of aircraft in the take off queue reported by ACES for the case with and without VLJs. The maximum queue size increases from 13 aircraft to 19 aircraft for the VLJ case. Figure 47 shows that cumulative total of aircraft in the take off queue increases from 146 for the case without VLJs to 319 with VLJs at OEP airports.

The departure schedule for LAS shows two large peaks in demand at epoch 49 and 92. It is likely that re-scheduling a number of flights into the preceding or following hours would reduce delay since there is some spare capacity at LAS in the hour before and after the main peaks.

LAS actually does have sufficient capacity to handle the demand (assuming a 1.4X increase in capacity is feasible) even with the addition of VLJ air taxi operations, since delays remain reasonable. However the large percentage increase in delay that occurs indicates that LAS is nearing capacity, a more evenly distributed schedule will be necessary to avoid peaks in demand causing unacceptable delays.

	Departure Delay (hrs)	Take Off Delay (hrs)	Landing Delay (hrs)	Arrival Delay (hrs)	Total Delay (hrs)	Delay Per Op (secs)
No VLJ	8	37	17	0	62	113
VLJ OEP	9	73	25	6	112	204
Increase over NO VLJ	*1*	*36*	*8*	*6*	*50*	*91*
VLJ NO OEP	9	36	17	0	62	113
Increase over NO VLJ	*1*	*-1*	*0*	*0*	*0*	*0*

Table 17 Increase in Delays at LAS

Number of Operations	Commercial	GA	VLJ	Total
LAS	1978	135	265	2378

Table 18 Number of Commercial, GA and VLJ Operations at LAS

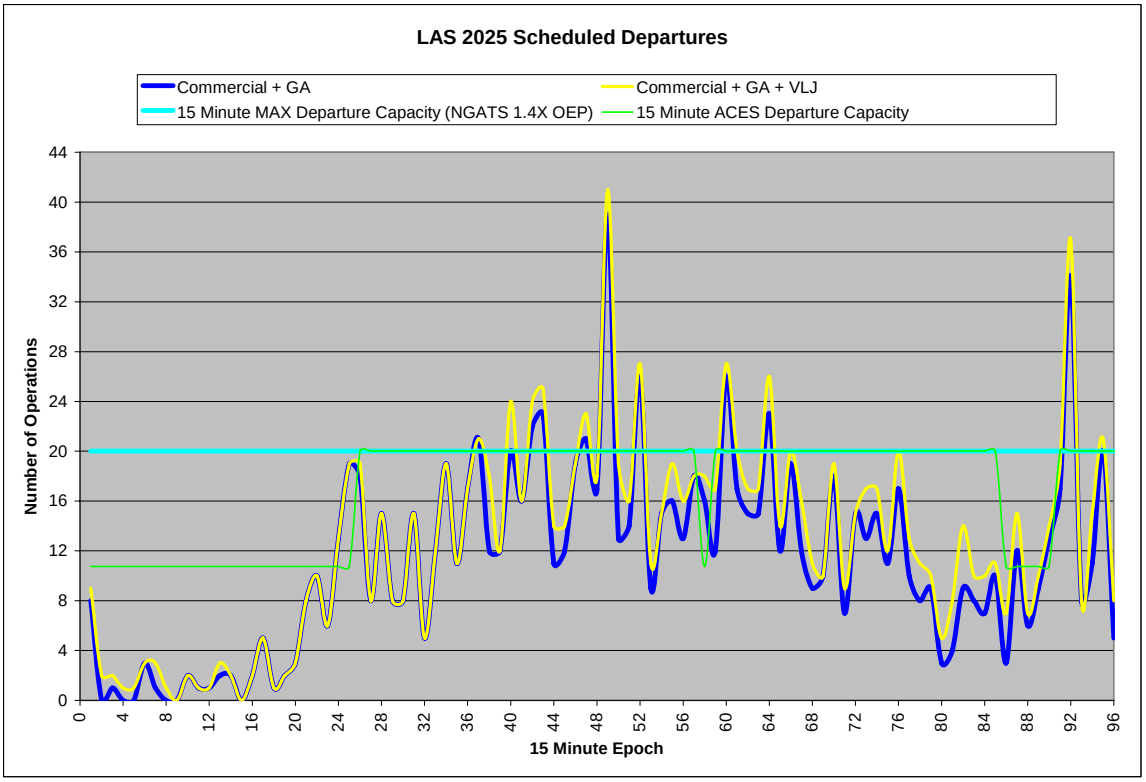

Figure 45 LAS 2025 Scheduled Departures

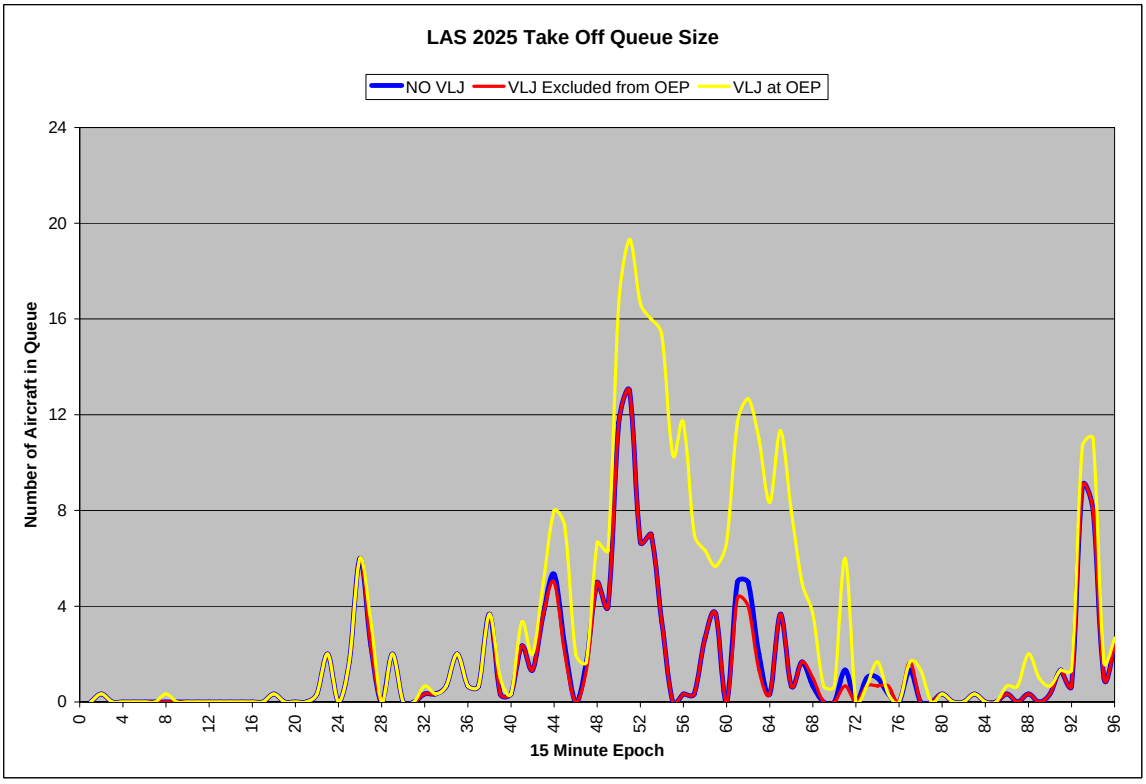

Figure 46 LAS 2025 Take Off Queue Size

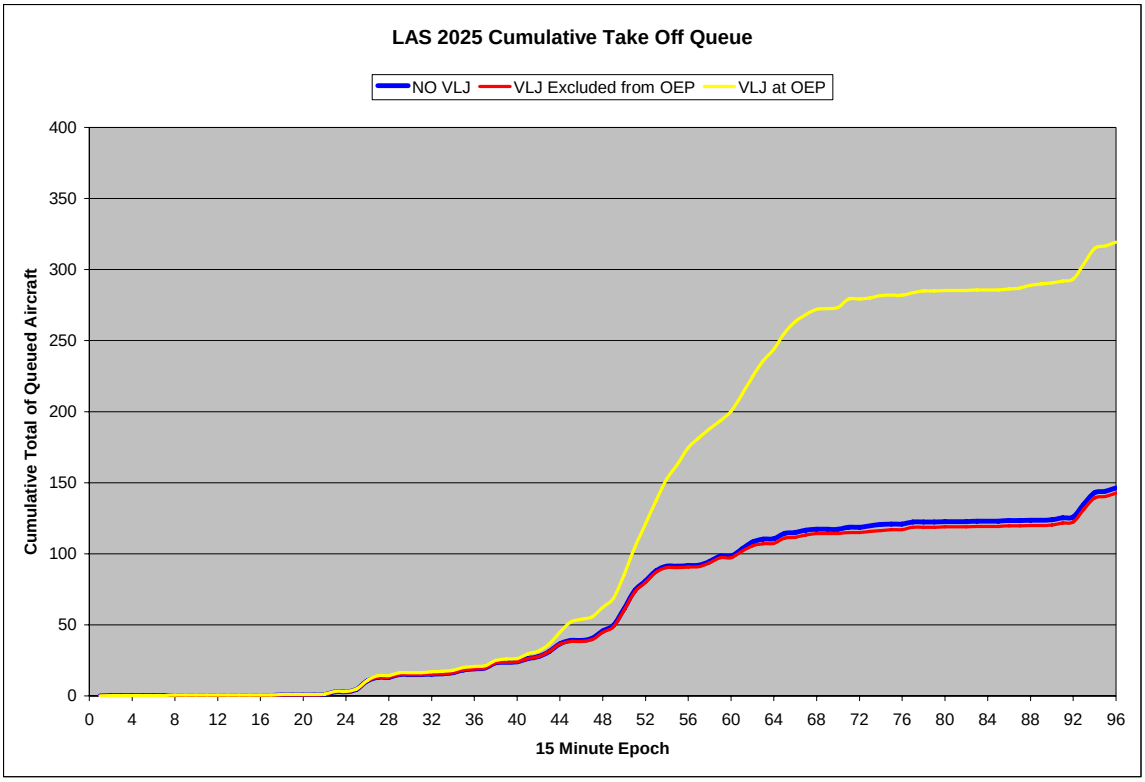

Figure 47 LAS 2025 Cumulative Total of Aircraft in Take Off Queue

ACES Enhanced TRACON Modeling

ACES can model airports and TRACONS at different levels of fidelity, see the user guide reference 5. The main choices are:

1. Simple airport nodal queuing model, single airport circular boundary, 4 equally spaced departure and 4 arrival fixes, no fixes shared with other airports;
2. Simple airport nodal queuing model, multiple airport actual TRACON boundary with actual departure and arrival fixes, fixes can be shared with other airports;
3. As per (2) with the addition of runway spacing tables.

ACES currently models most airports as per option (1) and this was the option used as the default for all airport models for the main results presented in this report to ensure consistency. The only TRACONS currently available in ACES with more detailed modeling are Chicago and New York.

Chicago TRACON contains airports ORD, MDW (Chicago Midway Airport, Illinois) and PWK (Palwaukee Municipal Airport, Illinois). The Chicago TRACON is known as C90 and a useful description can be found at http://www.faa.gov/ats/c90/. The C90 arrival and departure fixes as used in ACES are shown in Table 19 below.

TrconId	FixId	FixName	TrcRefPt	FixLocationLatitudeLongitu...	FixRadius	FixBearingDist...	FixOperType	FixEngineType	airportIDs
C90	KUBBS-ORD	KUBBS-ORD	KORD	42:17:53.24/-087:24:11.69			A	JTP	KORD
C90	BEARZ-ORD	BEARZ-ORD	KORD	41:33:36.28/-087:16:32.86			A	*	KORD
C90	PLANO-ORD	PLANO-ORD	KORD	41:36:45.07/-088:36:53.12			A	*	KORD
C90	KRENA-ORD	KRENA-ORD	KORD	42:22:29.57/-088:29:58.04			A	*	KORD
C90	KUBBS-SAT	KUBBS-SAT	KORD	42:17:53.24/-087:24:11.69			A	*	KPWK
C90	BEARZ-SAT	BEARZ-SAT	KORD	41:33:36.28/-087:16:32.86			A	*	KPWK
C90	PLANO-SAT	PLANO-SAT	KORD	41:36:45.07/-088:36:53.12			A	*	KPWK
C90	KRENA-SAT	KRENA-SAT	KORD	42:22:29.57/-088:29:58.04			A	*	KPWK
C90	JOT	Joliet	KORD	41:32:47.01/-088:19:06.34			A	*	KMDW
C90	CGT	Chicago Heights	KORD	41:30:36.01/-087:34:17.56			A	*	KMDW
C90	toBAE	toBADGER	KORD		35	346	D	JTP	KORD, KMDW, KPWK
C90	toPETTY	toPETTY	KORD		35	13	D	*	KORD, KMDW, KPWK
C90	toELX	toKEELER	KORD		35	82	D	*	KORD,KPWK
C90	toGIJ	toGIPPER	KORD		35	100	D	*	KORD, KMDW, KPWK
C90	toEON	toPEOTONE	KORD		35	173	D	*	KORD,KPWK
C90	toGUIDO	toGUIDO	KORD		35	179	D	*	KORD,KPWK
C90	toRBS	toROBERTS	KORD		35	188	D	*	KORD, KMDW, KPWK
C90	toMZV	toMOLINE	KORD		35	253	D	*	KORD,KPWK
C90	toIOW	toIOWA CITY	KORD		35	262	D	*	KORD, KMDW, KPWK
C90	toPLL	toPOLO	KORD		35	270	D	*	KORD,KPWK

Table 19 ACES Definition of Arrival and Departure Fixes in Chicago TRACON C90

New York TRACON contains airports EWR, FRG (Farmingdale, New York), TEB, JFK, and LGA. This model is of lower fidelity than Chicago since it only includes the actual arrival and departure fixes for EWR, not the other airports within the TRACON.

This more detailed level of modeling may be expected to capture the effects of VLJs in the TRACON more effectively than the simple nodal model option (1). For this reason a set of ACES runs was performed using the option (2) model and the results are presented below. Even with the enhanced TRACON models ACES still does not completely capture the effects of VLJs since it does not model trajectories within the TRACON

boundary. This means that spacing between flights and interaction between arrival and departure streams is not modeled and any potential conflicts, resolution actions and losses of separation can not be quantified.

Analysis of Delays using the Chicago Enhanced TRACON Model Including Airports ORD, MDW, PWK

The Chicago enhanced TRACON model shows higher delays than the simple model for all test cases. Total commercial flights delay at ORD is 16.1% higher without VLJs, 15.5% higher with VLJs at OEP airports and 5.5% higher with VLJs excluded from OEP airports compared to using the simple TRACON model. Compare results in Table 13 and Table 20.

Using the enhanced model, the increase in commercial flights total delay at ORD due to VLJ operations is 62 hours (4.6%) with VLJs at OEP airports (OEP case) and actually reduces slightly by 15 hours (-1.1%) with VLJs excluded from OEP airports (non-OEP case). The mean delay per operation increases from 1033 seconds without VLJs (Case ID 7) to 1080 seconds for the OEP case (Case ID 9) and reduces slightly to 1021 seconds for the non-OEP case (Case ID 8).

The increase in delays due to VLJs for the enhanced TRACON model compared to the simple model is similar for the OEP case (4.6% compared to 5.1%) but are completely different for the non-OEP case (-1.1% compared to 8.8%).

For the simple TRACON model the increase in delays for the non-OEP case compared to the OEP case is understood to be an artifact of ACES TFM, see previous section. It is likely that the enhanced model result is more realistic.

With the enhanced TRACON model, interactions between flights from airports within the C90 TRACON can occur. For the non-OEP case 260 VLJ flights from MDW have been excluded, see Table 21. Since MDW and ORD share several departure fixes, excluding VLJ flights from MDW would be expected to reduce delays for flights departing from ORD. This does appear to be the case, departure delay has reduced by 20 hours from 85 hours to 65 hours and take off delay has reduced by 50 hours from 571 to 521 hours, comparing the OEP to non-OEP cases in Table 20. Some of this reduction in delay can also be attributed to less congestion at destination airports, since test cases with the simple TRACON model showed 8 hours reduction in departure delay between the non-OEP and OEP cases.

Since the results for the non-OEP case are quite different for the simple and enhanced TRACON models, this indicates that it is necessary to carefully model the TRACON to fully capture the effects of VLJs at specific TRACONS. It may well be that a high fidelity model which includes trajectory propagation within the TRACON boundary is necessary to fully capture the effects of VLJs, and this is not currently available within ACES.

Redesign of the TRACON could also be a significant factor in reducing the effects of VLJs on commercial traffic. Currently MDW traffic is handled by the C90 TRACON controllers and shares departure fixes with ORD. In 2025, with the projected increased volume of traffic it might well be that MDW should not share any fixes with ORD and perhaps could even be part of a new TRACON. The effect of VLJs for specific TRACONS, including possible TRACON redesign requires a high fidelity model and should be the subject of a future study.

	Departure Delay (hrs)	**Take Off Delay (hrs)**	**Landing Delay (hrs)**	**Arrival Delay (hrs)**	**Total Delay (hrs)**	**Delay Per Op (secs)**
No VLJ	54	564	552	188	1358	1033
VLJ OEP	85	571	578	188	1421	1080
Increase over NO VLJ	*30*	*7*	*25*	*0*	*62*	*47*
VLJ NO OEP	65	521	584	174	1344	1021
Increase over NO VLJ	*10*	*-44*	*32*	*-13*	*-15*	*-12*

Table 20 Increase in Delays at ORD using Enhanced TRACON Model

Number of Operations	**Commercial**	**GA**	**VLJ**	**Total**
With OEP				
ORD	4720	39	0	4759
MDW	1022	274	260	1556
PWK	57	476	258	791
DPA	30	293	133	456
06C	0	33	140	173
Without OEP				
ORD	4720	39	0	4759
MDW	1022	274	0	1296
PWK	57	476	225	758
DPA	30	293	139	462
06C	0	33	86	119

Table 21 Number of Commercial, GA and VLJ Operations at Airports within the Chicago TRACON

Airspace Sectors Analysis

For this analysis the maximum number of flights in a sector sustained for a 5 minute interval is the metric analyzed as peak load, since this is in line with the FAA facility use of Monitor Alert Parameter (MAP) values.

MAP values are not used directly by sector controllers; they are used by TFM to ensure that as far as possible a sector does not become significantly overloaded. Sector controllers will use their own judgment as to when to start refusing handoffs, request assistance or use other techniques to ensure that they can handle the traffic. They may handle more aircraft than the MAP value suggests for short periods.

The ACES MAP values are not dynamic (they can be changed by scripting, but this feature was not used for this analysis) and may not be the actual values used on the 19 Feb 2004 baseline day at any specific time of day.

For the above reasons MAP values should not be taken as absolute, exceeding the MAP value by a few flights at peak times is not significant for this analysis.

Note the following from FAA Order 7210.3U Facility Operation and Administration see *http://www.faa.gov/ATpubs/fac/Ch17/s1707.html*

"The Monitor Alert Parameter (MAP) establishes a numerical trigger value to provide notification to facility personnel, through the MA function of the ETMS, that sector/airport efficiency may be degraded during specific periods of time."

"The ability of a functional position or airport to provide air traffic services may be affected by a variety of factors (i.e., NAVACase IDs, meteorological conditions, communications capabilities, etc.); therefore MAP is a dynamic value which will be adjusted to reflect the capabilities of the functional position or airport."

"Baseline MAP values may be adjusted $^{+}/_{-}3$."

"TM initiatives should be primarily for those time frames when the MAP value will be equaled or exceeded for a sustained period of time (usually greater than 5 minutes)."

19 Feb 2004 Baseline Day Sector Load

The peak number of flights in a sector for the 2004 baseline demand day is shown in Figure 48 compared to the MAP value. The peak load exceeds the MAP value by up to 4 flights for several of the sectors and is at or slightly below the MAP value for the rest of the top 50 most heavily loaded sectors.

This indicates that the most heavily loaded sectors are at full capacity in today's NAS at peak times and would not be able to accommodate an increase in load. This is not unexpected since it would be wasteful of controller resources to design sectors with significant excess capacity. The most heavily loaded sectors are mainly high sectors (generally these are above 24,000 ft), low sectors are not congested. The most heavily loaded sector for this analysis of 19 Feb 2004 is ZAU76. This is a high altitude Chicago sector that transitions ORD westbound departures climbing to altitude and works a large volume of over-flight traffic.

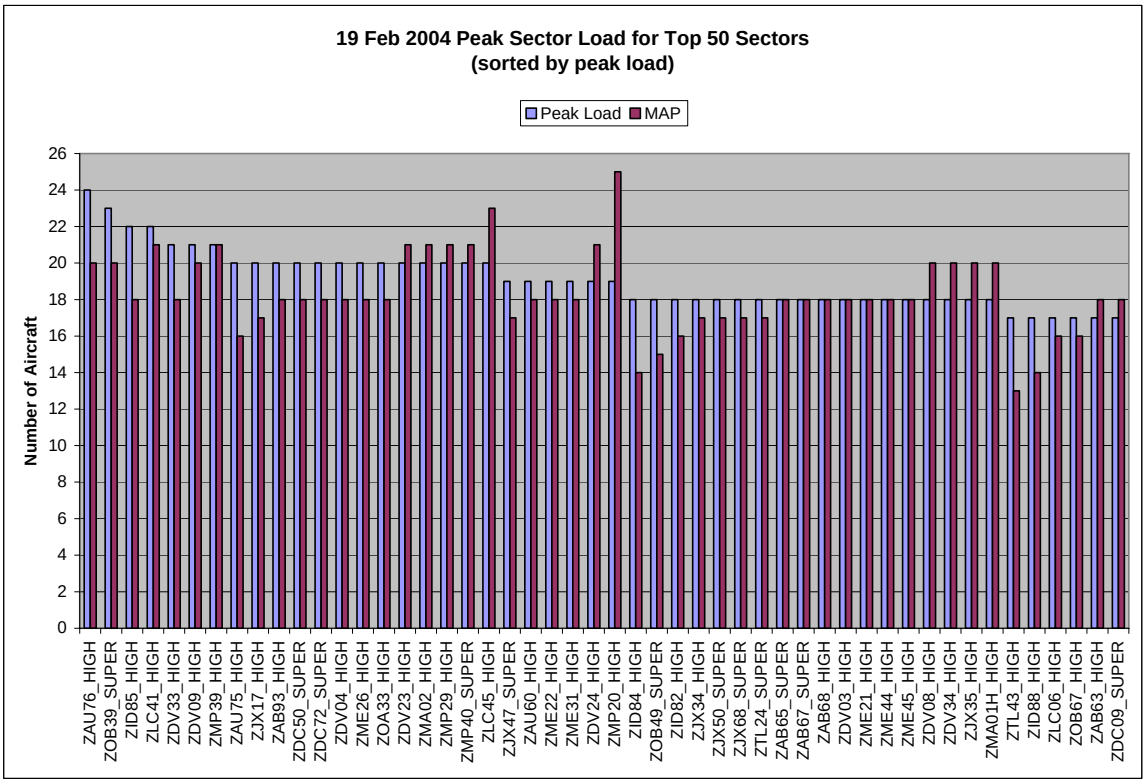

Figure 48 19 Feb 2004 Peak Sector Load for Top 50 Sectors

2025 Sector Load without VLJ Air Taxis

The peak number of flights in a sector for the 2025 demand day without VLJ air taxis is shown in Figure 49 compared to the MAP value, which is 3X the ACES current day value. The busiest sectors are nearly all high sectors. In ACES, these sectors mainly have altitudes that start at 24,000 ft, although there are a number of high level sectors that start below that altitude, they are classed as high because the maximum altitude of the sector is above 24,000 ft.

With two exceptions, the sector load does not exceed the MAP value, indicating that 3X sector capacities are generally adequate for the 2025 demand without VLJs. In fact for many of the top loaded sectors 2X sector capacity would be sufficient.

The busiest sector is Chicago ZAU76, the same as 19 Feb 2004, but the second busiest is now ZAU75. Chicago sector ZAU75 is a high-altitude sector, for jet arrivals into O'Hare from the West and Southwest US. This sector has a 2025 peak load of 55 aircraft which is 7 aircraft greater than the 3X MAP value. Chicago sector ZAU46 also has a peak load over the MAP value, but only by 4 aircraft. The locations of these sectors are shown in Figure 50.

Since the 3X sector capacities used for the 2025 demand exceed the peak load for the majority of the sectors, with the exception of the few Chicago sectors, airspace congestion is not a significant cause of delays, for this analysis.

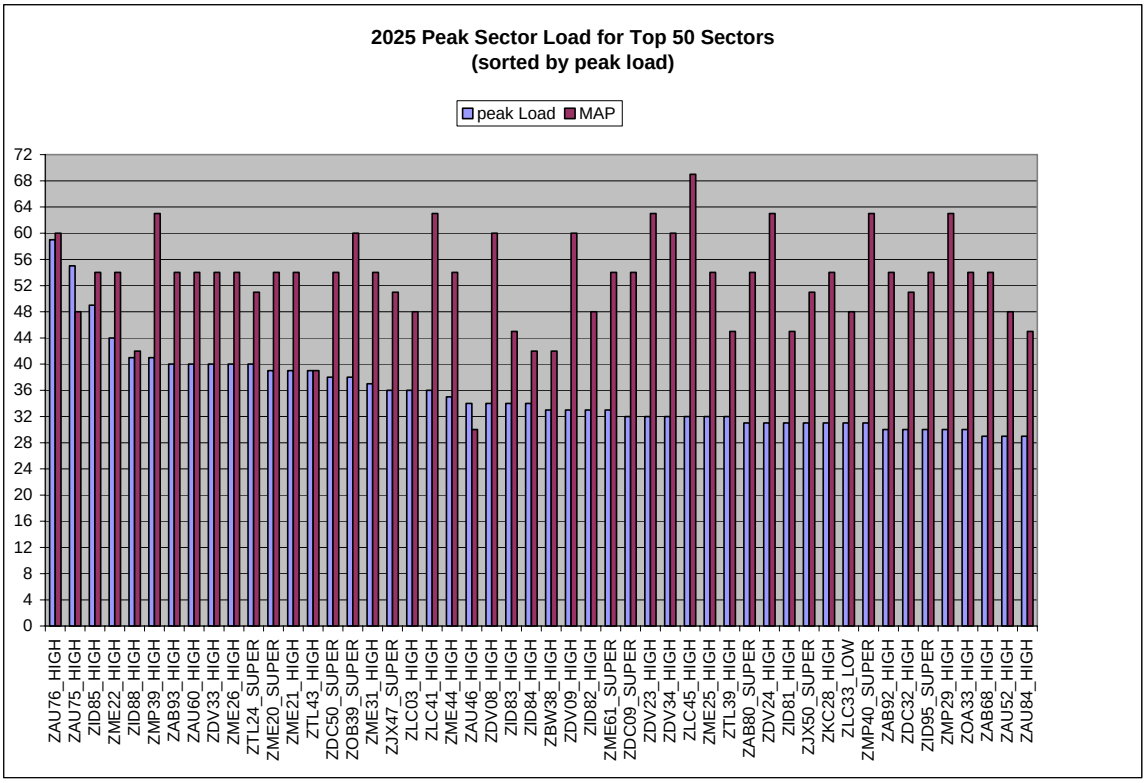

Figure 49 2025 Peak Sector Load without VLJ Air Taxis for Top 50 Sectors

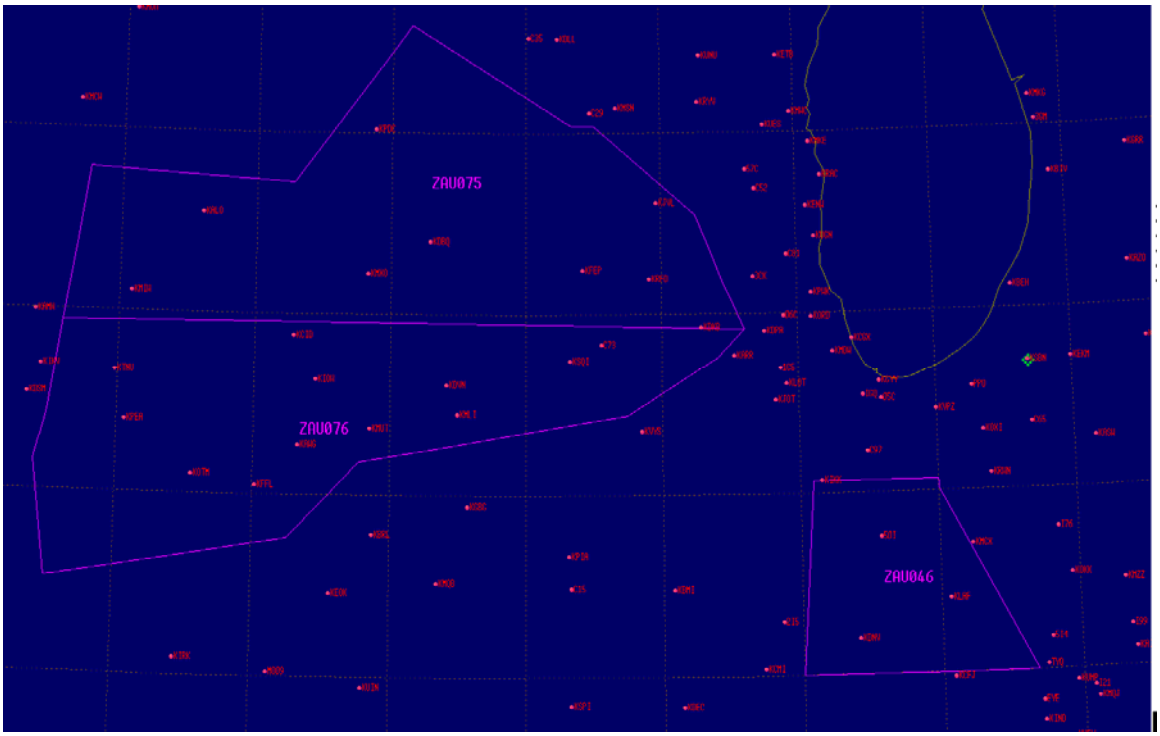

Figure 50 Locations of Top 3 Busiest Chicago Sectors

2025 Sector Load with VLJ Air Taxis

Sector Load with VLJs not excluded from OEP Airports

The peak number of aircraft in a sector for the 2025 demand day with VLJs not excluded from OEP airports is shown in Figure 51 compared to the load without VLJs and to the MAP value. Figure 52 shows the difference in peak load. The top 3 sectors with the largest increase in load are low sectors; in the ACES default input data set these sectors generally have maximum altitudes below 24,000 ft. The low sectors are most impacted because nearly 60% of the VLJ flights in the demand set have cruise altitudes below 24,000 ft due to the relatively short distances flown compared to commercial flights.

There are a number of high sectors, and two super high sectors with significant increases in VLJs. Several of the high sectors with significant increases in peak load actually have low minimum altitudes; in fact 34 out of the top 50 sectors with increased load have altitudes starting below 24,000 ft. In ACES the super high sectors have maximum altitudes at or above 35,000 ft. The demand set contains nearly 11% of VLJ flights with cruise altitudes at or above 35,000 ft, so this explains why a few of the super high sectors show a slight increase in load with VLJ operations.

The sector with the largest increase in peak load due to VLJs is Miami sector ZMA47 which adds 12 aircraft, but the peak load of 27 aircraft is well within the 3X MAP value of 47 aircraft. The second largest increase is for Houston sector ZHU86, with 9 additional aircraft and the third largest is another Miami sector, ZMA66 with 6 additional aircraft peak load. For all of the sectors with the largest increases in peak load due to VLJ operations the MAP value is never exceeded. In fact there is plenty of spare capacity in the sectors most impacted, assuming that the NGATS goal of 3X sector capacity is achieved.

The busiest sectors are not significantly impacted by VLJ operations, Chicago ZAU76 (not shown on figure) is still the busiest sector; peak load only increases by 1 aircraft due to VLJs. Within the top 50 busiest sectors VLJs add the most peak load to Oakland ZOA33, 7 aircraft, but the load of 37 aircraft is well within the MAP value of 54 aircraft.

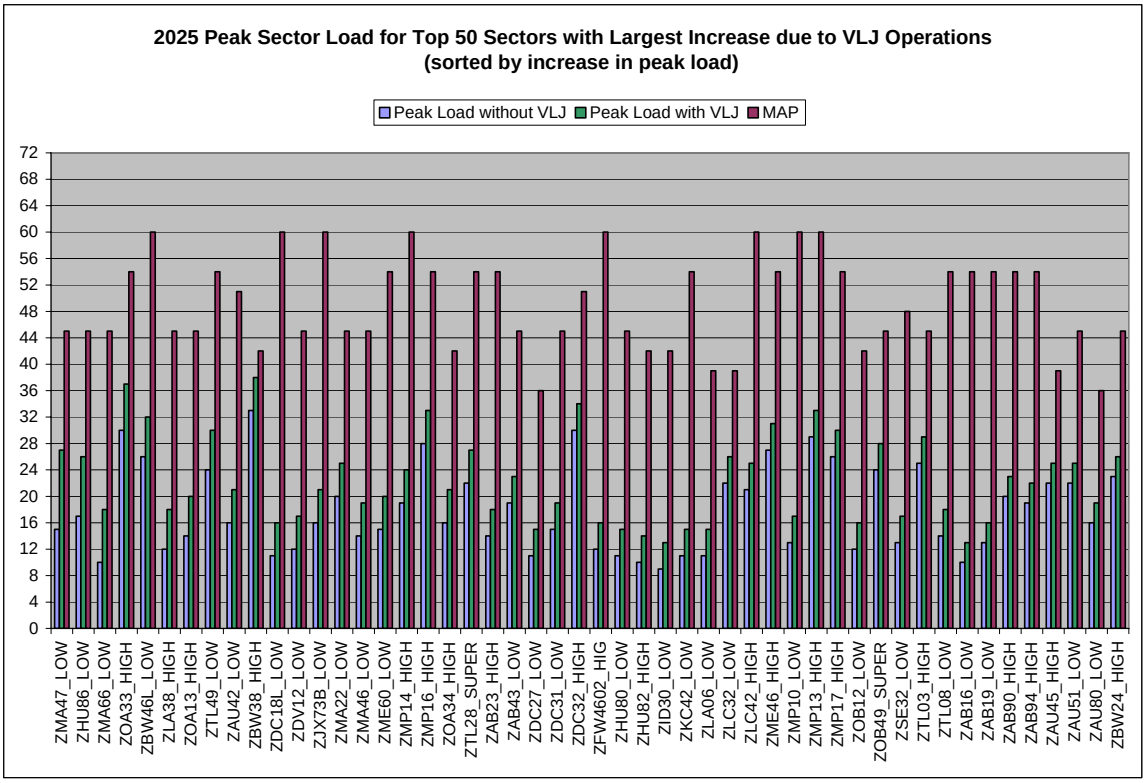

Figure 51 2025 Peak Sector Load with VLJ Air Taxis for Top 50 Sectors (VLJs at OEP airports)

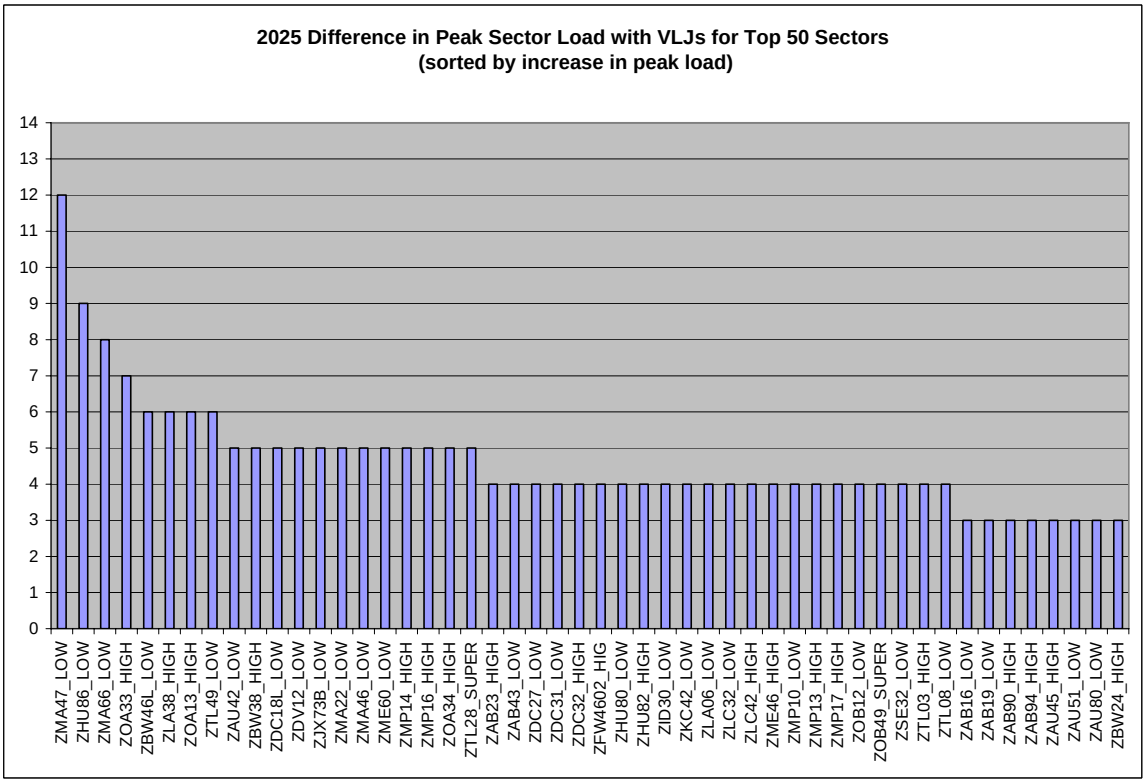

Figure 52 2025 Peak Sector Load Difference with VLJ Air Taxis for Top 50 Sectors (VLJs at OEP airports)

Sector Load with VLJs excluded from OEP Airports

The peak number of aircraft in a sector for the 2025 demand day with VLJs is shown in Figure 53 compared to the load without VLJs and to the MAP value. Figure 54 shows the difference in peak load. The sectors differ somewhat from the case with VLJs using OEP airports. There are more high sectors impacted than the non-OEP case, 23 out of the top 50 sectors with increased load have altitudes starting below 24,000 ft compared to 34 previously. This is not due to any significant change in the altitudes flown by VLJ air taxis, the distances flown and cruise altitudes are virtually unchanged when VLJ air taxis are excluded from OEP airports. It is just a result of the different flight routes in the non-OEP demand set.

The top 3 sectors with the largest increase in load are still low sectors. Miami sector ZMA47 still shows the largest increase in peak load, now with an additional 15 aircraft at the peak load.

Again, for all of the sectors with the largest increases in peak load due to VLJ operations the MAP value is never exceeded and the busiest sectors are little impacted by VLJ operations. Chicago ZAU76 (not shown on figure) is still the busiest sector; peak load shows no increase due to VLJs for the non-OEP case. Within the top 50 busiest sectors VLJs now add the most peak load to Salt Lake City sector ZLC33, 7 aircraft, but the load of 38 aircraft is well within the 3 X MAP value of 48 aircraft.

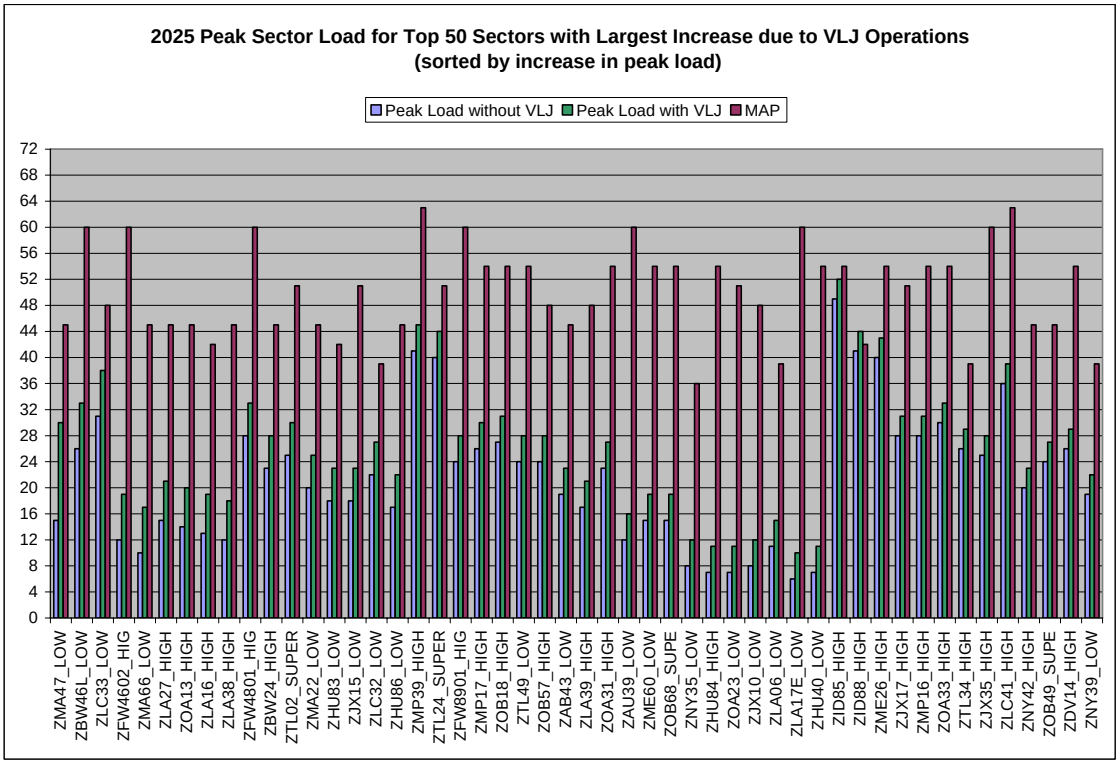

Figure 53 2025 Peak Sector Load with VLJ Air Taxis for Top 50 Sectors (VLJs excluded from OEP airports)

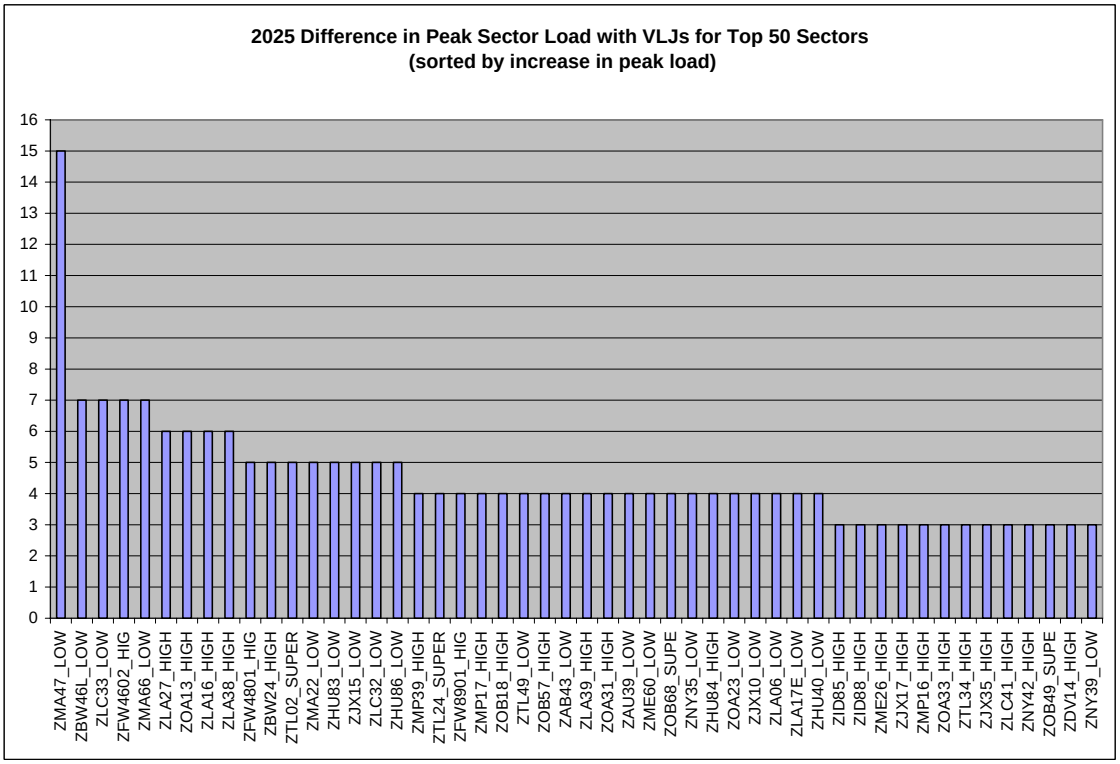

Figure 54 2025 Peak Sector Load Difference with VLJ Air Taxis for Top 50 Sectors (VLJs excluded from OEP airports)

En-route Conflicts Analysis

ACES does not model trajectories within a TRACON boundary, instead a queuing model is used to estimate delays. For this reason only en-route conflicts are reported. This is a limitation since VLJs operating within the same TRACON as a major OEP airport, even if excluded from the OEP airport may cause a significant increase in conflicts with commercial traffic.

The en-route conflict detection algorithm in ACES reports a conflict when aircraft are separated by less than 2000 ft in altitude and less than 7 nm in distance (default can be changed). The current FAA separation minimum is 5 nm so ACES is actually reporting *potential* conflicts; a 2 nm buffer is used to allow for conflict resolution. In addition ACES only allows specification of a single parameter for altitude separation so does not take into account reduced Vertical Separation Minimum which requires 1000 ft minimum between FL290–410. NGATS also expects future technology to enable en-route minimum lateral separations to be reduced; this was not evaluated in this study. For these reasons the actual conflict counts reported by ACES are only *potential* conflicts and also overstate the number of potential conflicts that require resolutions in the 2025 demand scenario.

Table 22 below shows the number of times an aircraft of each category was involved in a conflict for each of the demand sets analyzed. The most potential conflicts occurred for commercial aircraft, this is as expected since the largest single category of aircraft in the demand sets is commercial flights see Table 7. The addition of VLJs increases the number of potential conflicts by 6.6% for the non-OEP case and by 6.9% for the OEP-case, see Table 23. VLJs are directly involved in 2939 of the additional 5146 potential conflicts for the non-OEP case and 3286 of the additional 5349 potential conflicts for the OEP case. The reason that the increase in the total number of potential conflicts is greater than the number of potential conflicts where at least one of the aircraft is a VLJ is due to interactions between VLJs and other traffic. Secondary potential conflicts between non-VLJ traffic may be caused by solving a conflict involving a VLJ.

The largest increase in potential conflicts was for GA traffic, 5.6% and 5.8% for the non-OEP and OEP cases. The increase in commercial aircraft potential conflicts was much less at 2.1 and 1.9 % for the two cases analyzed. This indicates that VLJs interact more with other VLJs and other GA traffic than with commercial traffic, as expected since the majority of VLJ flights are at lower altitudes than most commercial traffic. Commercial traffic has a mean altitude of 26,200 ft for all commercial flights in the 2025 demand set, GA has a mean altitude of 24,000 ft and VLJ traffic has a mean altitude 24,200 ft, see section on distance distribution of air traffic. VLJs are flying at much the same altitudes as GA traffic, somewhat below the altitudes of the majority of commercial flights.

The VLJ variable cost business model results in slightly longer flight distances with a corresponding increase in mean altitude to 25,900 ft. This results in about the same total number of potential conflicts. There is a slight increase in the number of commercial aircraft potential conflicts and a corresponding decrease in GA potential conflicts due to the increased VLJ altitudes.

Run Case ID		**Commercial**	**GA**	**Cargo**	**VLJ**	**Total**
1	**19 Feb 2004**	16336	2747	768	0	19851
4	**2025 N/L NG**	58060	15945	3494	0	77499
6	**2025 N/L NG VLJ**	59282	16841	3583	2939	82645
8	**2025 N/L NG OVLJ**	59136	16868	3576	3268	82848
10	**2025 N/L NG OVLJ VC**	59428	16807	3583	3000	82818

Table 22 Total Potential Conflicts by Operator Type

	Commercial	**GA**	**Cargo**	**VLJ**	**Total**
+VLJ excluded from OEP Airports	2.1	5.6	2.5	n/a	6.6
+VLJ at OEP Airports	1.9	5.8	2.3	n/a	6.9
+VLJ Variable Cost at OEP Airports	2.4	5.4	2.5	n/a	6.9

Table 23 Percentage Increase in Potential Conflicts due to VLJs

Cost to Commercial Air Carriers

The commercial air carriers operating costs calculated in this analysis are based on the fleet and operations weighted air carrier costs contained in reference 7. From this FAA sponsored source, the average air carrier variable operating cost for aircraft adjusted to 2005 $ is $2284 per hour in the air, $1760 on the ground with engines operating while taxiing or waiting for takeoff and $880 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 24.

Cost per hr	Airborne	Ground	Ground Hold
Aircraft Average	$2,284	$1,760	$880

Table 24 Commercial Air Carriers Variable Operating Costs

These values are used to calculate the estimated cost to commercial air carriers due to additional delays caused by VLJ air taxi operations, according to the flight segment where the delay occurred. Only the variable operating costs are included, not fixed costs since only variable costs can be directly related to delays.

The estimated annual cost to commercial air carriers of delays in the NAS in 2025 is $4.04 billion without VLJ air taxi operations and this increases to $4.47 billion if VLJ Air taxi operations are not excluded from OEP airports. VLJ air taxi service operators may choose not to use OEP airports due to cost or because of congestion. In this case the annual cost of delays to commercial air carriers is estimated to be $4.08 billion.

The direct annual increase in operating costs to commercial air carriers attributable to the additional delays caused by VLJ air taxi operations is $425.6 million if VLJs are not excluded from OEP airports; this is a 10.5% increase. Excluding VLJs from OEP Airports reduces the annual increase in costs to $42.6 million; this is a 1.1% increases. Results are summarized in Table 25 which includes the costs by flight segment.

The costs for the non-OEP case exclude the result for ORD which is considered to be anomalous, see the Airports Analysis section of this report.

Although the total increase in cost is quite large for the OEP case, to put this into perspective, the 2025 projected daily flights in the NAS for commercial air carrier operations is 64,000 per day, see Table 7, so the mean increase in cost per flight is $18 for the OEP case and is $1.82 for the non-OEP case.

		Hours of Delay in Demand Day	Annual Hours of Delay	Cost of Delay	Increase due to VLJs	Percentage Increase
2004 NO VLJs	totalDelay	4,559	1,664,063	$2,075,458,316		
	airDelay	431	157,139	$358,904,756		
	grndDelay	1,216	443,705	$780,920,177		
	holdDelay	2,913	1,063,220	$935,633,384		
2025 NO VLJs	totalDelay	9,106	3,323,657	$4,042,054,262		
	airDelay	914	333,536	$761,795,961		
	grndDelay	2,020	737,445	$1,297,902,819		
	holdDelay	6,172	2,252,677	$1,982,355,483		
2025 VLJs Excluded From OEP	totalDelay	9,222	3,365,884	$4,084,623,164	$42,568,902	1.1%
	airDelay	926	337,890	$771,741,293		
	grndDelay	2,018	736,645	$1,296,494,535		
	holdDelay	6,278	2,291,349	$2,016,387,336		
2025 VLJs Not Excluded From OEP	totalDelay	9,999	3,649,753	$4,467,614,343	$425,560,081	10.5%
	airDelay	998	364,285	$832,026,490		
	grndDelay	2,317	845,882	$1,488,752,364		
	holdDelay	6,684	2,439,586	$2,146,835,489		

Table 25 Annual Costs of Delays to Commercial Air Carriers

Concluding Remarks and Recommendations for Future Studies

Conclusions

This study has shown that VLJ air taxi operations can potentially impact commercial air traffic leading to some increase in delay and consequently some increase in costs to commercial air carriers. Adding 20,000 additional VLJ flights per day in 2025 to a system projected to have close to 100,000 Commercial Airline, Scheduled Commuter, air taxi, General Aviation and Cargo flights per day in total is a significant additional load.

However, it is likely that VLJ air taxi service operators will choose not to use the top 35 (OEP) large airports due to cost or because of congestion and use smaller less congested airports. If this is the case, then the effects of VLJs could be fairly small.

The additional delays to commercial air traffic due to VLJs are mainly due to airport capacity limitations, but potentially can be mitigated. TRACON re-design could potentially reduce interactions between traffic using smaller airports within or close to a large airport, although this was not investigated for this study.

The addition of VLJ flights was found to not overload en-route sectors, although an increase in potential conflicts with commercial air traffic was observed. This result depends on the assumed 3X increase in sector capacity being achievable. If the sector capacities were only about 2X current values, then the additional VLJ traffic could significantly increase en-route delay. VLJs are projected to generally fly at lower altitudes than most commercial traffic, due to shorter average trips distances. The majority of lower level en-routes sectors are not heavily loaded, but some are, and a proportion of VLJs do fly at higher altitudes through the more heavily loaded sectors.

This study has been limited by the fidelity of ACES modeling, particularly within the terminal area, and this is where the effects of VLJs are expected to be most significant. For this reason the results should be treated with caution particularly for individual airports, although the overall system wide effects determined from the analysis shows an increase in system wide delays to commercial air traffic due to VLJs as expected.

On-demand air-taxi flights using VLJs are projected to become an increasingly important mode of the air transportation system and warrant further study.

Recommended TRACON Study

It is recommended that the effects of VLJs in the terminal area be investigated in detail using a higher fidelity model, ideally with trajectory propagation within the TRACON boundary. This model could be developed and incorporated into ACES or the use of alternative simulators could be considered. Specific TRACONS could be selected for study, for example Chicago C90 which has several airports attractive to VLJs in proximity to ORD; these include MDW, PWK, DPA and 06C. The New York TRACON is also of interest with 3 major airports, EWR, LGA, JFK in proximity to TEB and FRG which are attractive airports for VLJ operations.

This study should examine the effects on VLJs in the current TRACON design and should investigate theoretical re-designs and the use of NGATS technologies to indicate ways in which the effects of VLJs can be mitigated. Of particular interest would be the increase in potential conflicts within the TRACON that might occur due to increased traffic in general and increased complexity of traffic flows. The increased use of smaller airports in proximity to major airports, by VLJs may cause a more complex interaction between departure and arrival flows, from these airports and the major airport, where currently there is little traffic from the small airports.

Recommended En-route Airborne Separation Assurance System Study

It is recommended that the effects of VLJs in en-route airspace be investigated in detail. The assumption of 3X sector capacity should be examined and the need for sectorization of en-route airspace in a future NAS should be questioned.

The use of self separation by VLJs using a system such as NASA Langley's proposed 4D-Airborne Separation Assurance System (4D-ASAS) should be investigated. Although the assumed 3X sector capacity limits are generally not exceeded, the number of potential conflicts increases with VLJ air taxi operations. Most of the increase is due to interactions between VLJs and with GA traffic, since VLJs tend to fly at lower altitudes than commercial air carrier flights.

The effect of VLJs on other air traffic could be considerably reduced if VLJ air taxis were equipped to self separate. It may be feasible to allow self separation within a specific altitude band, perhaps 18,000 ft to 26,000 ft, for equipped aircraft. Other aircraft would not be excluded, but would be under positive control from controllers or ground automation. Equipped VLJs would be responsible for avoiding other traffic.

VLJs may be ideal candidates for adopting such a system. VLJs will be equipped with modern navigation and flight management systems and it may be feasible to incorporate a version of ASAS at reasonable cost - the study should include an estimate of the

approximate cost. The on-demand nature of air-taxi operations does not lend itself to longer-term planning as for scheduled flights and it may be advantageous to have the capability to operate autonomously, with a high degree of independence from ground based ATC and automation systems.

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14. ABSTRACT

This study investigates the potential effects of Very Light Jet (VLJ) air taxi operations adding to delays experienced by commercial passenger air transportation in the year 2025. The affordable cost relative to existing business jets and ability to use many of the existing small, minimally equipped, but conveniently located airports is projected to stimulate a large demand for the aircraft. The resulting increase in air traffic operations will mainly be at smaller airports, but this study indicates that VLJs have the potential to increase further the pressure of demand at some medium and large airports, some of which are already operating at or near capacity at peak times. The additional delays to commercial passenger air transportation due to VLJ air taxi operations are obtained from simulation results using the Airspace Concepts Evaluation System (ACES) simulator. The direct increase in operating cost due to additional delays is estimated. VLJs will also cause an increase in traffic density, and this study shows increased potential for conflicts due to VLJ operations.

15. SUBJECT TERMS

Commercial air traffic; Delays; Direct operating costs; SATS; Very Light Jet; VLJ

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