Future On-demand (VLJ) Aviation Forecasts Using TSAM
Report to JPDO

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September 16, 2005

Purpose: This document provides a preliminary order of magnitude estimate of the number of Very Lights Jet aircraft (VLJ) that will be flying in the future National Airspace System (NAS). The paper addresses the potential impacts of VLJ aircraft on NAS airports and recommends actions JPDO should take now to develop the analytical capability to address VLJ.

Background: VLJ aircraft have been in development since 1999. There has been considerable skepticism in the aviation community about the technical and economic feasibility of VLJ vehicles. However development has continued with start-up as well as established companies now developing VLJ aircraft. Eclipse announced its entry into the market in 1999, with Adam following in 2001. More recently established aircraft manufacturers announced their entry in to the market: Cessna, in 2002; and recently Embrear, an established air transport manufacturer, announced its entry in the market. In addition, Honda, a Japanese manufacturer of automobiles has developed a flying prototype VLJ, and has used it in image advertising.

Modeling Framework

The modeling framework employs the Transportation Systems Analysis Model (TSAM), a model developed jointly by Virginia Tech and NASA Langley Research Center to study the potential demand of new aerospace technologies (1, 2). In past studies, TSAM has been applied to estimate the demand for the Small Aircraft Transportation System (SATS) (2). The modeling effort presented here supports the mission of the Joint Planning and Development Office (JPDO) to develop a future Next Generation Air Transportation System (NGATS).

The Transportation Systems Analysis Model is a multi-mode intercity trip demand model that predicts long distance travel (one-way route distance greater that 100 miles) in the continental U.S. The model follows a traditional multi-step, multi-modal transportation planning framework where trips are: 1) produced, 2) distributed, 3) split into modes, and 4) assigned to routes. One key element of the TSAM model is its ability to predict intercity travel in the presence of multi-mode alternatives. The model in essence predicts the mode choice of travelers based on trip characteristics and traveler demographics. The framework of the model is shown in Figure 1.

Four key computational modules comprise TSAM. Each module represents one of four transportation planning steps (1). These modules are shown in blue in Figure 1. All four modules are described in more detail in a companion document to this paper. The model employs several databases shown in the green cylindrical shape containers in Figure 1. Databases include socio-economic data (Census, American Travel Survey and Woods and Poole), airline schedules and travel times (Official Airline Guide), airline fares (Department of Transportation), auto travel times and routes (MapPoint), airports and their characteristics (FAA database), and aircraft technology and their corresponding travel time information.

Future On-demand Air Transportation Estimation

Future demand scenarios of air taxi operations using VLJ technologies have been developed using the TSAM model. The VLJ population considered in the analysis includes proposed very light jets weighing less than 3,181 kg (7,000 lb) and operating in an on-demand air taxi service. The VLJ modeled is a pressurized, all-weather aircraft with five or six seats (including pilots), with a cruising speed of 676 km/hr (365 knots) and a range of 2,037 km (1,100 nautical miles) with four occupants (two pilots and two passengers). The VLJ is equipped with two medium by-pass ratio turbofans producing 1100-lb takeoff thrust at sea level static conditions. These characteristics represent the smallest and most economical VLJ aircraft.

The VLJ modeled has modest approach and takeoff speeds thus making possible to operate these vehicles from 3,415 public airports with paved 3,000 ft. runways (2). The 3,000 kg VLJ aircraft used in this analysis has an approach speed of 166 km/hr (90 knots) at maximum landing weight and thus conforms to airport design group A-I standards. The concept of operations adopted for the VLJ modeling is that of on-demand air taxi service. Life cycle costs analysis indicates that such service might be available at a cost of $1.75 per passenger mile (2). This cost includes some network inefficiencies where 20% of the flights are repositioning flights. Some of the new generation VLJ aircraft are priced at a third of the purchase value of today's light jet, and offer the possibility of an attractive and new opportunity for lower costs air transportation services by-passing hubs.

Using the performance and costs of the VLJ vehicle described in the previous section, we exercise TSAM to predict annual demand for on-demand air taxi services. The analysis is done for years 2009 (a projected 1.2X scenario) through 2047 when a 3X aviation demand scenario is expected to occur. Table 1 presents the current estimates of VLJ demand predicted by TSAM version 3.45 considering aircraft production capacity estimates in the future. The values of production capacity have been derived assuming a maximum production rate of 1,500 VLJ's per year. An S-shape production rate model is assumed in the first five years of the program starting in 2006, the year when the first three VLJ aircraft could be certified. Thereafter, the maximum production capacity is assumed to be the cumulative production of VLJ aircraft per year of five aircraft manufacturers likely to produce VLJ aircraft: Eclipse Aviation, Cessna, Adam, Embraer (Brasil), and Grob (Germany).

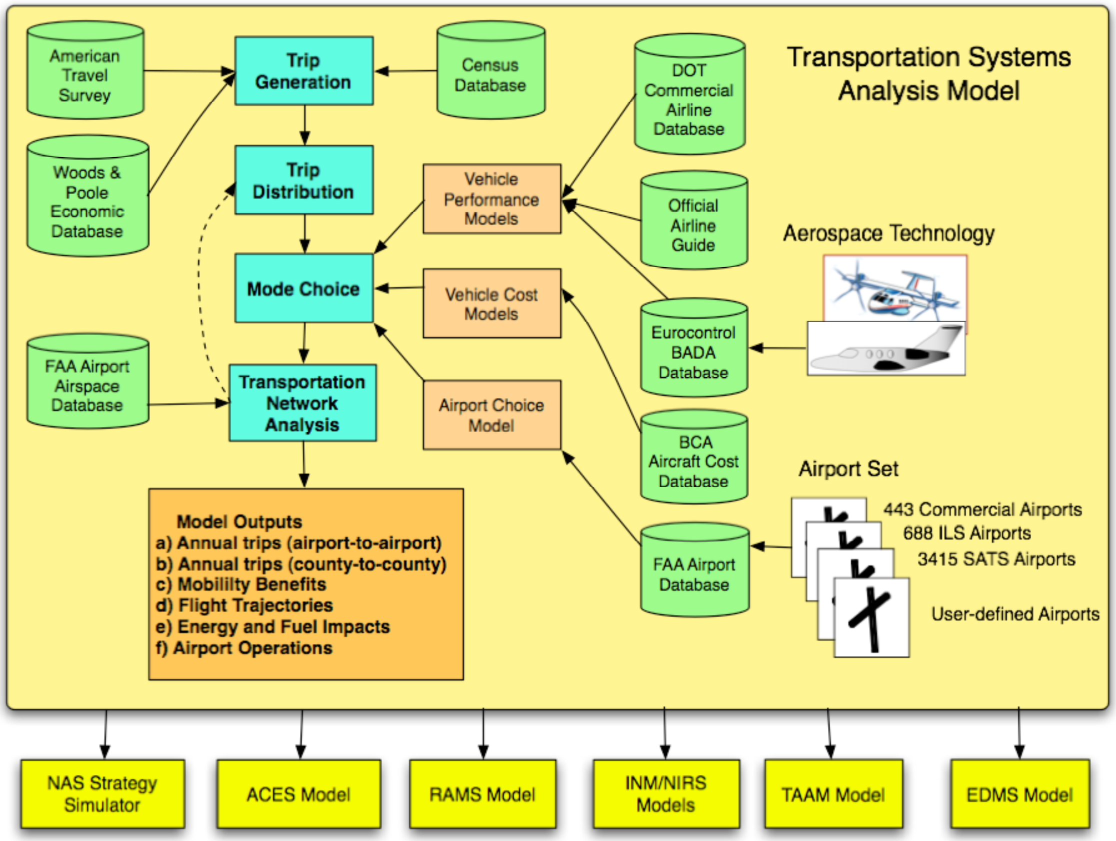

Figure 1. TSAM Model Structure.

Table 1. Nationwide On-demand Air Transportation Estimates Using VLJ Aircraft.

Year	Annual Air Taxi Demand (person trips) without OEP Airports
2009	8,900,000
2012	9,600,000
2014	10,200,000
2025	14,000,000
2047	31,800,000

Conversion of TSAM Annual Demand to Daily Flights

TSAM predicts annual demands between counties and between airports. These demand values are manipulated outside the model to produce daily demands and eventually daily flights scheduled between origin and destination airport pairs. Figure 2 illustrates the procedure to convert annual demand into daily flights. The flowchart starts on the left hand side with annual person trips produced by the model. Airport-to-airport matrices by aviation mode of travel are standard outputs of the model. A study of seasonal effects using ATS data is used to adjust the number of travelers for each quarterly period in the typical year. This seasonal variation is important because non-business travel patterns show substantial variations through the four quarters of the year. Business travel patterns are nearly equally distributed across the four quarters of the year.

Quarterly demands are then converted into daily demands using a simple proportional allocation scheme. For example, the quarterly demand values are adjusted by a factor of 1/90 to reflect daily demands. All the current calculations with TSAM, and therefore the demand estimates, are for the first quarter of the year. However, the TSAM model can be run to estimate flight activities for other quarters. Daily on-demand services are distributed across time (24 hour period) using a Monte Carlo distribution scheme. This approach uses an empirically-derived hourly demand distribution of travel behavior obtained from the FAA Enhanced Air Traffic Management System (ETMS) data. This approach produces demands for VLJ services by the hour at a maximum of 3,415 airports (or at any airport set studied). Passengers are grouped in travel parties at each airport to consolidate passengers willing to travel from similar origins to similar destinations at with similar departure times. Party size information obtained from ATS records is used to produce passenger loads and predict flights needed to satisfy the demand function. . The average business party size is 2.13 and the average non-business party size is 3.40.

An acceptance factor of 76% for VLJ has been used in the final estimation of VLJ demand based on a survey conducted by Virginia Tech to understand the percent of the flying population who would be willing to fly in VLJ aircraft. Table 2 shows the estimated daily VLJ flights for four key years in the JPDO analysis. The number of flights in Table 2 is constrained by the number of VLJ aircraft expected to be operational during four years of analysis. In the year 2014 a total demand of 18,576 flights are expected at a cost for service of $1.75 per passenger mile.

The aircraft production constraint is considered in the analysis to understand the effects of supply-demand imbalance for the new on-demand VLJ business model. Figure 3 illustrates three possible outcomes over time of the VLJ market. A high production rate scenario (1,500 aircraft per year after the third year of initial production and certification) builds up the supply of VLJ aircraft quickly to satisfy the potential on-demand services by the year 2012 (see Figure 3). A moderate demand scenario assumes a maximum of 750 aircraft per year. Finally a low-growth scenario with 450 aircraft per year production capacity for VLJ aircraft is also illustrated in the figure. However, aircraft manufacturers publicize that they will be able to produce several hundred more aircraft than our most optimistic projections.

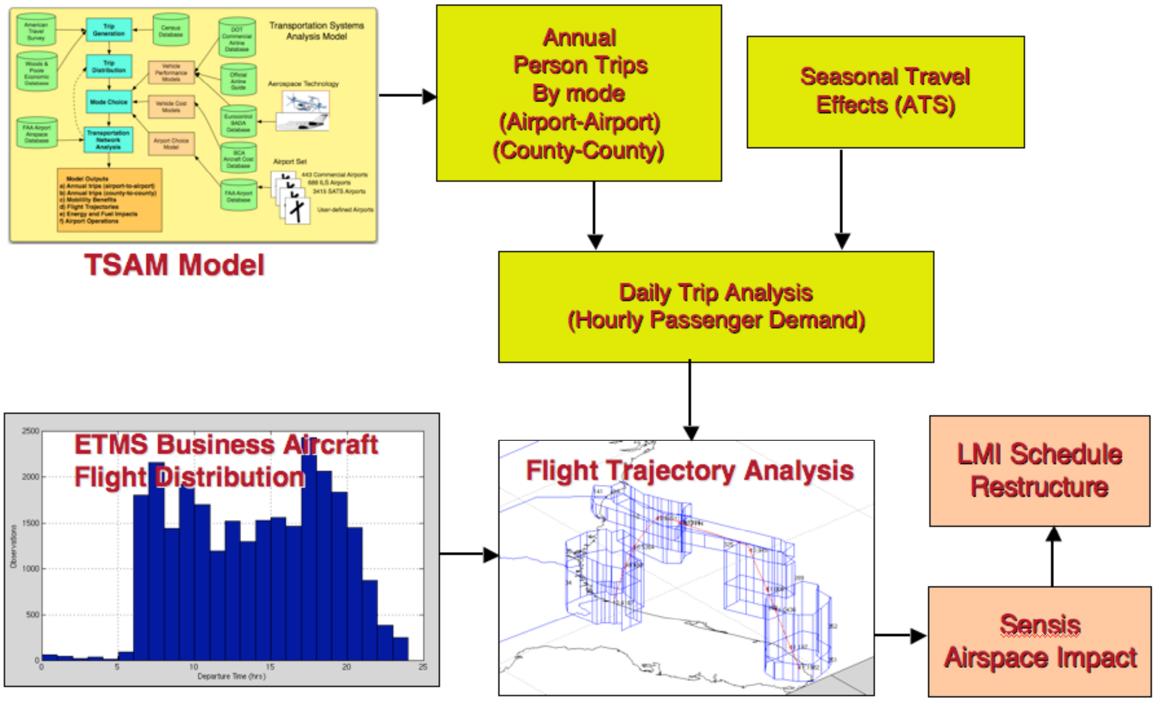

Figure 2. Conversion of TSAM Annual Demands to Daily Flights.

Table 2. Potential TSAM On-demand VLJ Flights.

Year	Daily VLJ Flights (High Production)	Daily VLJ Flights (Moderate Production)
2009	7,600*	3,800*
2012	17,836	9,000*
2014	18,576	16,000*
2025	25,800	25,800
2047	58,744	58,744

* Number of flights limited by aircraft production rate.

In future analyses, the manufacturer intentions should not be take lightly and at least contingency plans should be made for the possibility that the market will consume their supply of aircraft. To study the next generation air transportation system, we further study the system with the highest impact scenario (high-production capacity). The scenarios depicted in Figure 3 evolve from the same demand model at $1.75 per passenger-mile. Other business models can be analyzed with TSAM to quantify demand scenarios with lower and higher unit costs per passenger-mile.

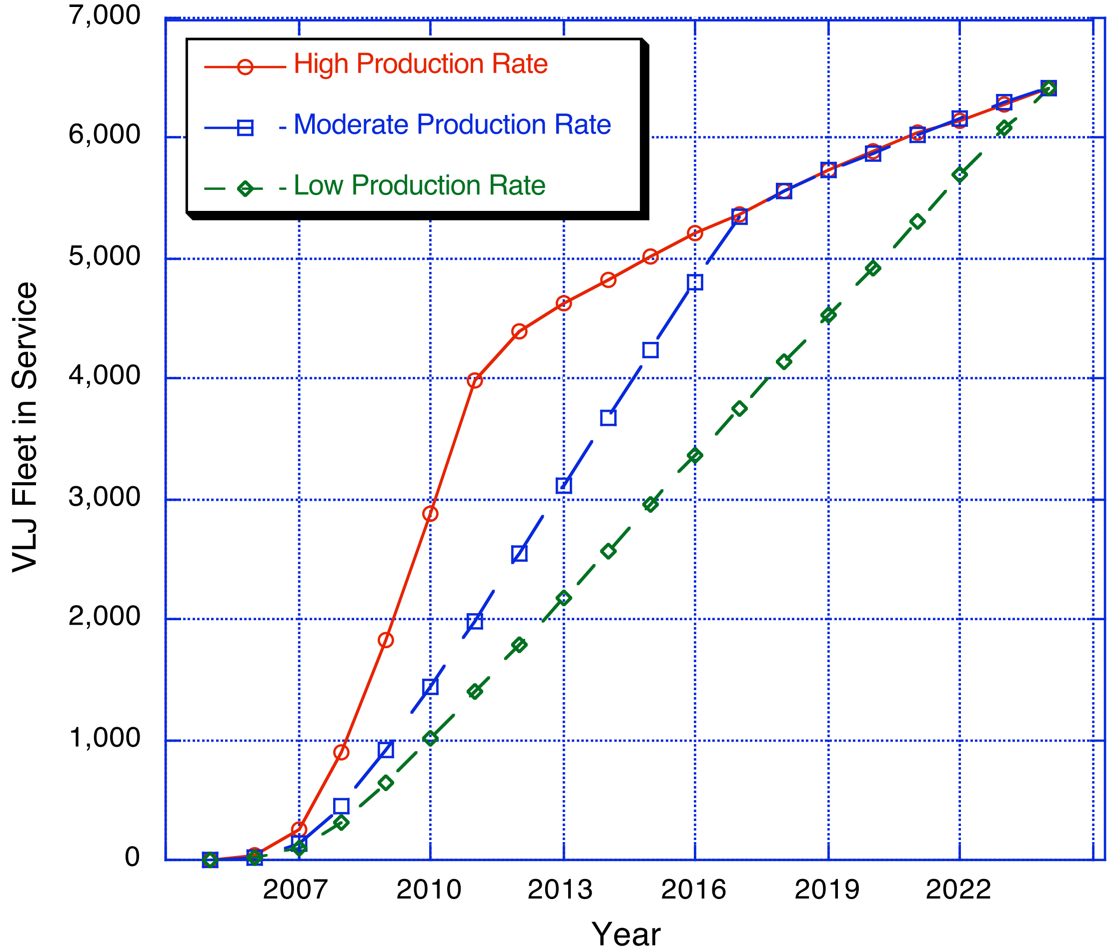

Figure 3. Three Evolution Scenarios for VLJ Aircraft (Same Long-Term Demand Function and Constant Cost for Service - $1.75 per passenger-mile).

Flight trajectories are generated using the performance of the VLJ vehicle. The current flight profiles generated use a great circle route trajectory approach. However, navigational-aid waypoint flight paths can be used in more detailed analyses within densely populated airspace where free flight is not possible. Trips beyond the range of the vehicle are assigned a stop-over, and travel times are adjusted accordingly. The flight trajectory is flown using a nominal performance profile consistent with the Eurocontrol Base of Aircraft Data model guidelines (8). The VLJ performance analysis was conducted at Virginia Tech (2).

Figure 4 illustrates VLJ flights in the NAS to demonstrate the spatial distribution of origins and destination airports using on-demand air transportation. The figure illustrates the high incidence of VLJ flights near populated areas of the United States. In TSAM, the air travel patterns are correlated with the proximity of population centers and high-income levels. Figure 5 illustrates the distribution of distances flown using VLJ equipment in the NAS. The figure portrays a distance histogram of 18,888 flights predicted in the year 2014. The average distance flown per VLJ flights is 222 statute miles (great circle distance between airports).

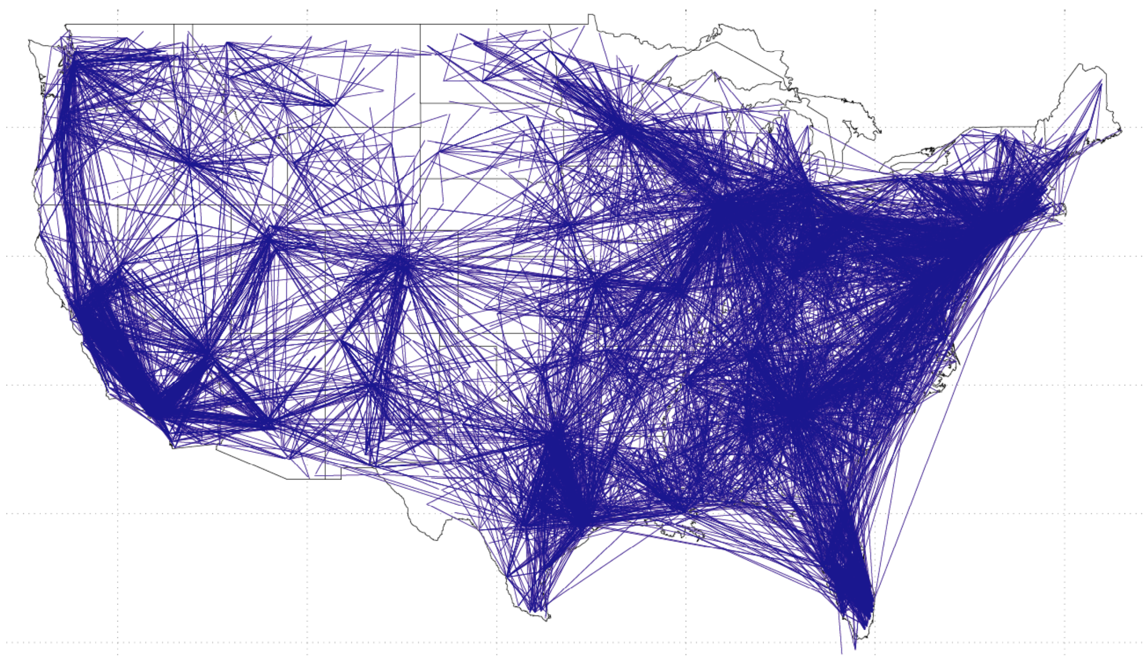

Figure 4. Distribution of VLJ Flights Across the NAS (Scenario: 2014 with OEP Airports). The Distribution and the Absolute Number of VLJ Flights Does not Change Appreciably without OEP Airports.

An important impact of VLJ operations would be number of flights and distribution of flight altitudes in regions of the NAS. The analysis using TSAM concludes that 82% of the VLJ flights predicted in 2014 could use flight levels below FL300 in the NAS (see Figure 6). This effect is the result of the distances flown by VLJ vehicles (see Figure 5). VLJ are designed to cruise at Mach 0.62-0.64 compared with mainline transport aircraft cruising at Mach 0.78-0.80. This effect and the distribution of the traffic require more detailed assessments of ATC workload.

Potential VLJ Impacts to Airports

TSAM assigns flights to different airports according to the demand function generated at nearby counties and according to the attractiveness of the airport. Figure 7 illustrates the VLJ impacts at OEP airports. The figure demonstrates that some OEP airports are more attractive than others. For example; Midway (MDW), Reagan National (DCA), Las Vegas (LAS), Salt Lake City (SLC), and Miami (MIA) are attractive for VLJ traffic. These airports are centrally located near large population and business activity centers and some currently have substantial business jet and multi-engine aircraft activity at the airport. Airports like Chicago O'Hare and Atlanta are less attractive because better airport alternatives exist (i.e., airports closer to the county population centers where air travelers would save intermodal connection times on the ground) to travel to those destinations.

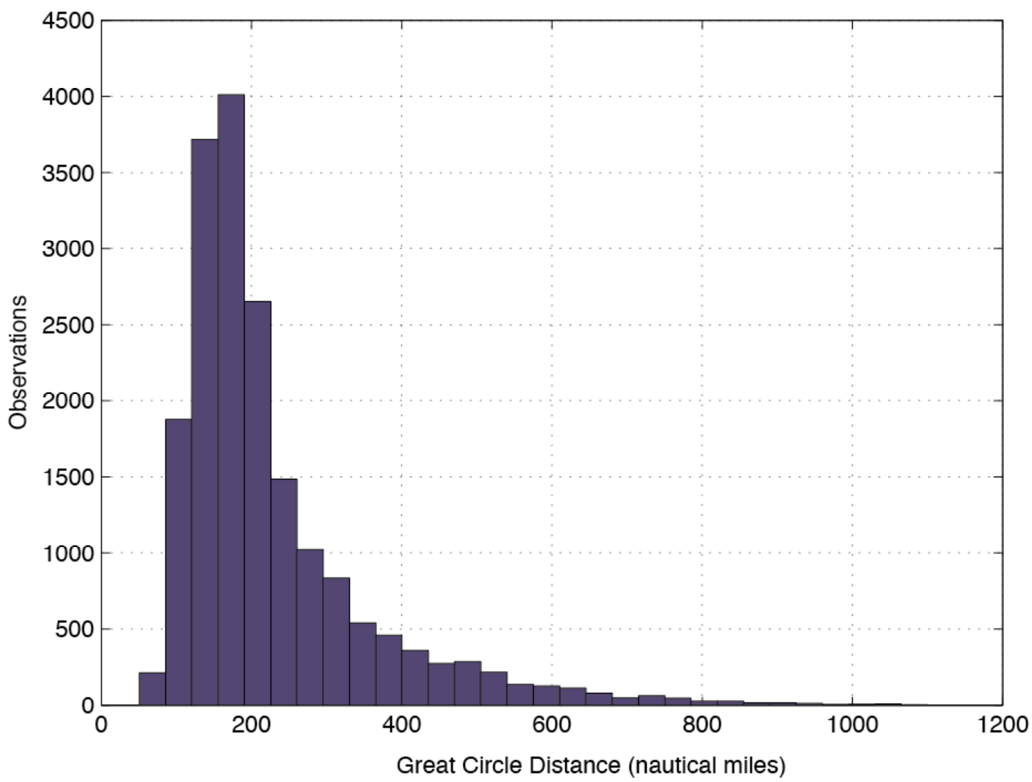

Figure 5. Distance Distribution of VLJ Flights Across the NAS (Scenario: Year 2014 with OEP Airports)

The results shown in Figure 7 do not consider airport capacity limits. Airport capacity constraints and their effect in the future flight schedules are being studied by the Logistics Management Institute (LMI) with LMINet and Sensis Corporation using ACES for JPDO. The results of LMI and Sensis could be incorporated into future analyses in TSAM to refine our estimates of future air travel considering airspace and airport delays. In general, delays in air transportation encourage air travelers to switch to other modes of transportation.

Figure 8 illustrates the impacts of VLJ operations in the year 2014 at the top 30 airports with significant number of VLJ operations. The attractiveness of airports like Dallas Love Field (DAL), Houston Hobby (HOU), Farmingdale (FRG), Westchester County (HPN), Peachtree (PDK), and Teterboro (TEB) is evident due to their close proximity to large population centers and the large business aircraft activity at these airports. The initial vision of the SATS program did not envision using OEP airports for on-demand services. This vision is clearly supported by the results obtained using the TSAM model. The total number of VLJ trips nationwide does not change appreciably when the OEP airports are included in the solution set. The use of OEP airports for VLJ operations would have to be justified only for those airports having enough excess capacity in the future, and having an attractive position with respect to the center of business activity. Glancing at Figure 7, it is clear that the first seven OEP airports listed all have more than 100 VLJ daily operations which could lead to significant impacts due to VLJ aircraft flights. Other OEP airports could probably cope with the potential increase on VLJ traffic for some time into the future.

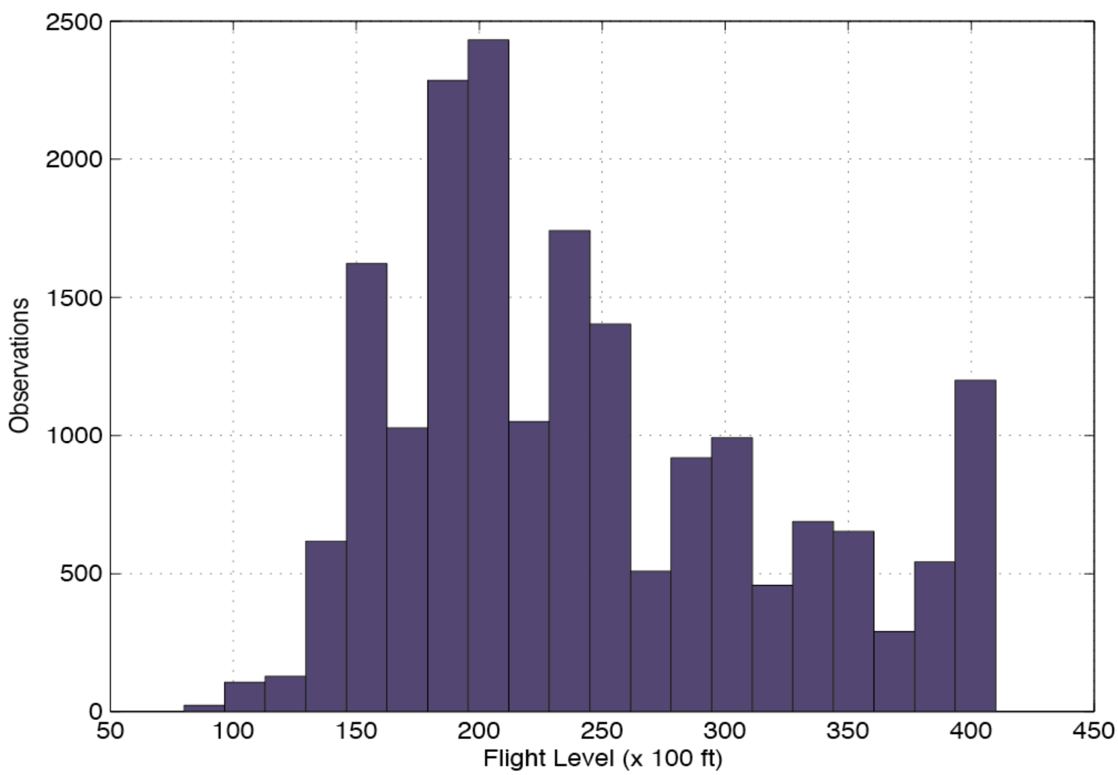

Figure 6. Distribution of VLJ Flight Assigned Altitudes in the NAS (Scenario: Year 2014 with OEP Airports).

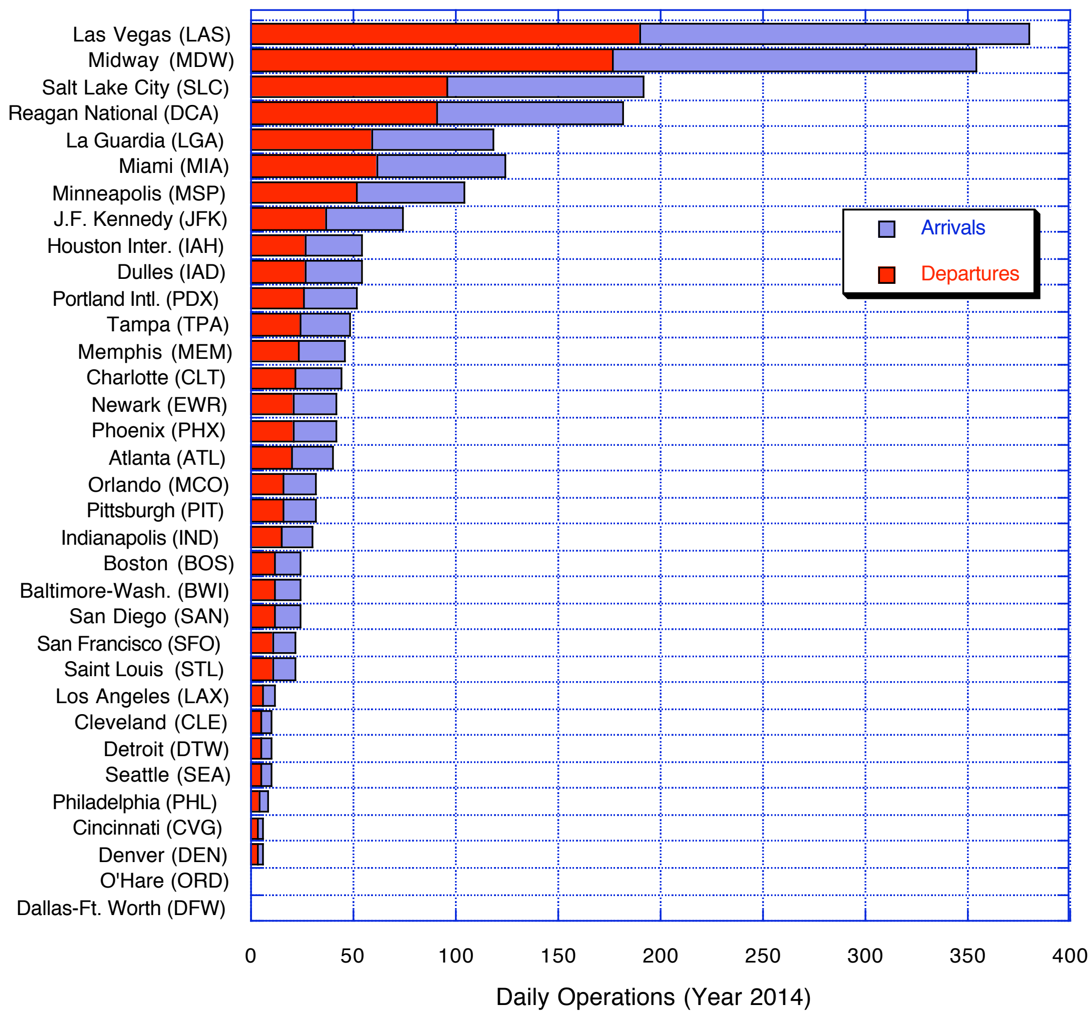

Figure 7. Predicted 2014 VLJ Demand at 34 OEP Mainland U.S. Airports (without Capacity Constraints). Honolulu International (HNL) is not included in the plot because VLJ flights do not have the range to fly to Hawaii from the mainland U.S.

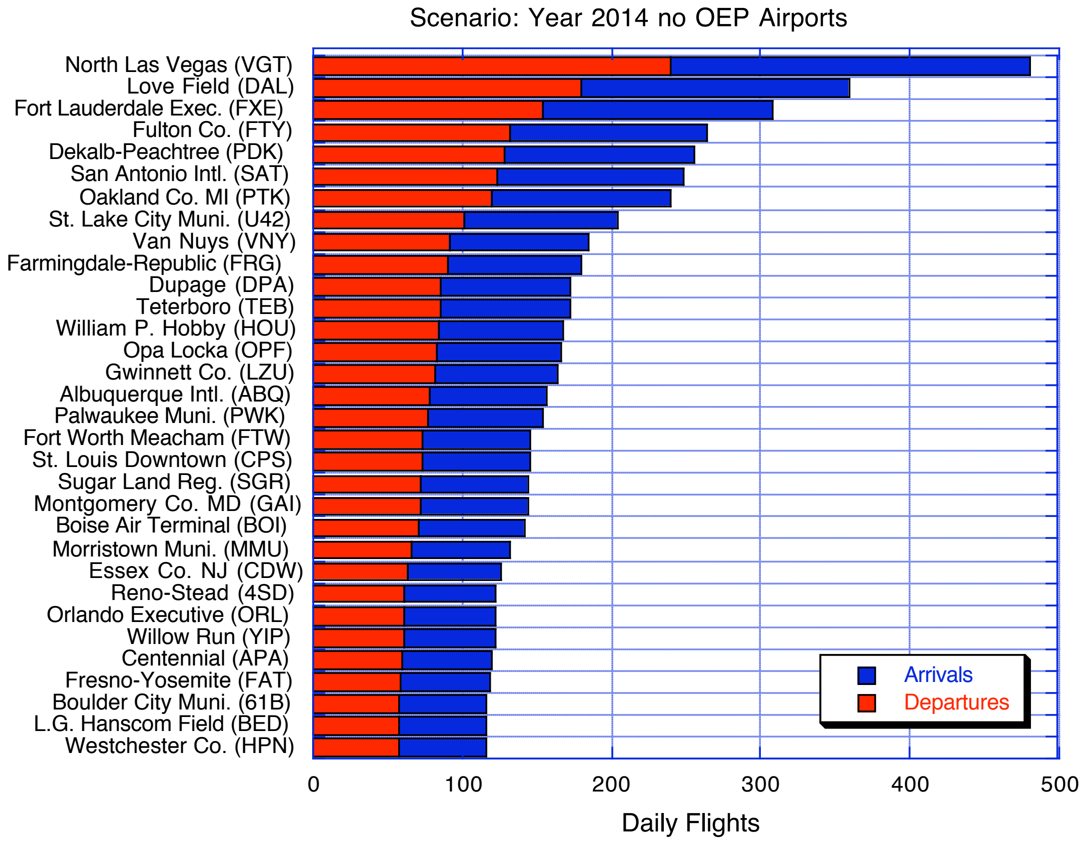

Figure 8. Predicted 2014 Demand at the Top Airports with VLJ Traffic (Scenario: Year 2014, No Capacity Constraints, No OEP Airports).

Acknowledgement

The authors would like to thank Stuart Cooke (NASA Langley Research Center) for his leadership and technical oversight in the development of TSAM for the SATS Program.

Conclusions

1) A flight schedule scenario has been derived for future JPDO studies considering a new on-demand air transportation business model using TSAM.

2) The analysis for on-demand services has uncertainty, as the market is untested. Nevertheless, there is an indication that VLJ aircraft could have a significant impact in the future NAS based on our demand estimates using a cost for service of $1.75 per passenger mile. As a result, national planning should consider projected traffic into account.

3) The current FAA TAF forecast does not reflect potential VLJ scenarios in the future NAS. The TAF forecast appears to be based on historical development of corporate aviation (e.g., business jets costing five million dollars and more) without consideration of a new business model using lower costs for service.

4) Based on TSAM estimates supported by backlog orders of the three leading contenders for the current VLJ market (i.e., Eclipse, Cessna and Adam), it is possible to envision up to 4,600 VLJ aircraft flying in the NAS by 2014, if production rates achieve 1,500 per year and if the estimated demand materializes. This is the scenario studied for future JPDO analyses.

5) The use of reliever airports around metropolitan areas would help mitigate the impact at large OEP airports. The key to the success of the concept is the balance between accessibility to airports near business centers and terminal procedures that do not disturb airspace patterns at busy hub airports.

6) OEP airports do not have a significant effect in VLJ demand nationwide. However, at the regional level some OEP airports could see a substantial number of VLJ operations due to their attractive location near large metropolitan centers.

Recommendations

Based on the analysis presented in this paper we make the following recommendations.

1) JPDO should consider VLJ scenarios as part of future NAS architecture studies. These vehicles could have a significant effect in NAS operations, ATC workload, airspace delays, etc.

2) Future JPDO VLJ scenarios could consider VLJ activity at OEP airports where excess capacity exists. Some busy OEP airports, should be excluded from VLJ traffic to avoid congestion problems.

3) Airport and airspace capacity constraints and delays should be integrated in the analysis of VLJ demand, as well as commercial airport demand, in a direct fashion. Current techniques to estimate air travel demand close the loop between demand and supply in an indirect fashion (usually demand is restricted after being compared with the supply function offered by airlines or airports).

4) As traffic congestion and delays are expected to increase in the NAS with the introduction of VLJ aircraft, planning for this activity should be undertaken as part of NGATS. Significant jet traffic volumes below flight level 300 will occur with the introduction of VLJ aircraft.

5) Further refinements to the interaction between VLJ and transport aircraft should be carried out using real-time flight simulators to estimate the workload impacts of mixing VLJ traffic and transport in the NAS. Precursor studies done by the FAA and the SATS program can shed some light on these effects.

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Appendix A. Summary of VLJ Operations Modeled

The following tables summarize the findings of the VLJ demand analysis described in the paper. This table expands on Table 2 presented in the report and includes flight parameters, operational factors, and fuel efficiency metrics for the VLJ operations studied.

Table A.1 Flight Operations.

Year	Daily VLJ Flights	~ Fleet Required (aircraft) *	Daily Hours Flown by Fleet (hours)	Revenue Hours Flown
2009	7,600*	1,720	6,713	5,594
2012	17,836	4,220	16,638	13,865
2014	18,576	4,540	17,342	14,452
2025	25,800	6,207	24,428	20,357
2047	59,744	14,500	58.400	48,300

* Refined numbers from Figure 3 after simulation of all VLJ flights.

Table A.2 Operational Factors.

Year	Average Distance Flown (GCD nm)	Average Cruise Flight Level (x 100 ft.)	Average Block Speed (knots)	Average Travel Time per Segment (hours)
2009	206.1	233	297.7	0.736
2012	221.6	241	300.8	0.777
2014	221.9	241	300.9	0.778
2025	225.8	243	302.0	0.789
2047	238.3	251	305.1	0.822

Table A.3 Fuel and Efficiency Productivity Factors.

Year	Average Cruise Specific Air Range (nm/lb)	Cruise Fuel Flow (lb/min)
2009	0.751	397.7
2012	0.752	400.3
2014	0.750	400.1
2025	0.751	400.1
2047	0.752	405.3