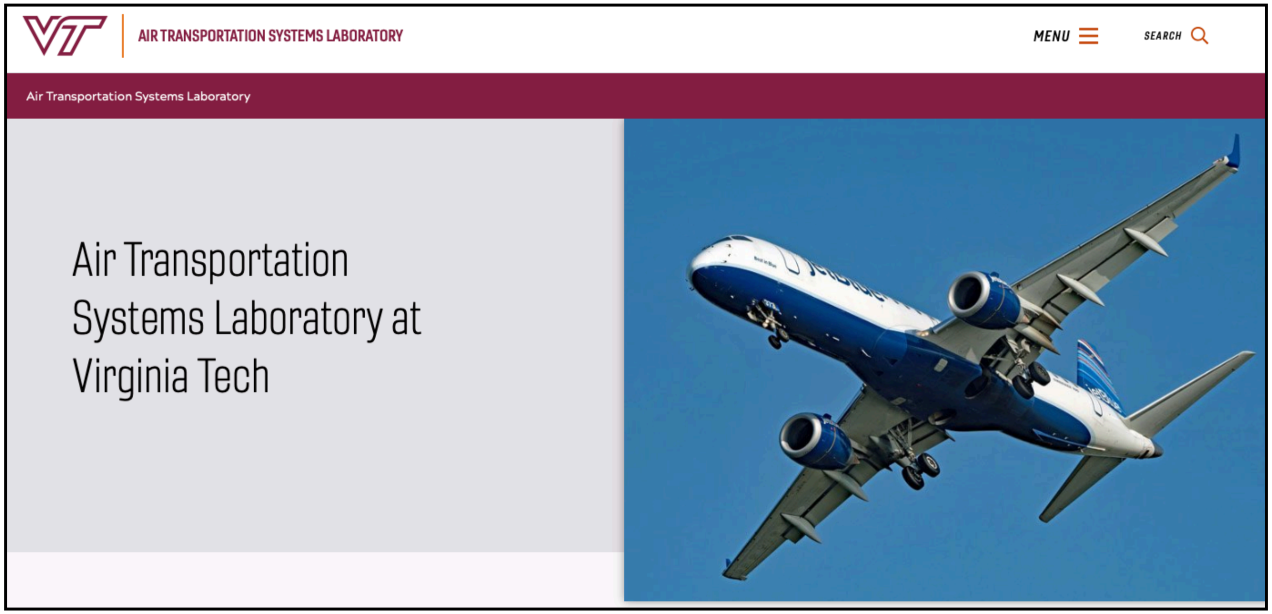
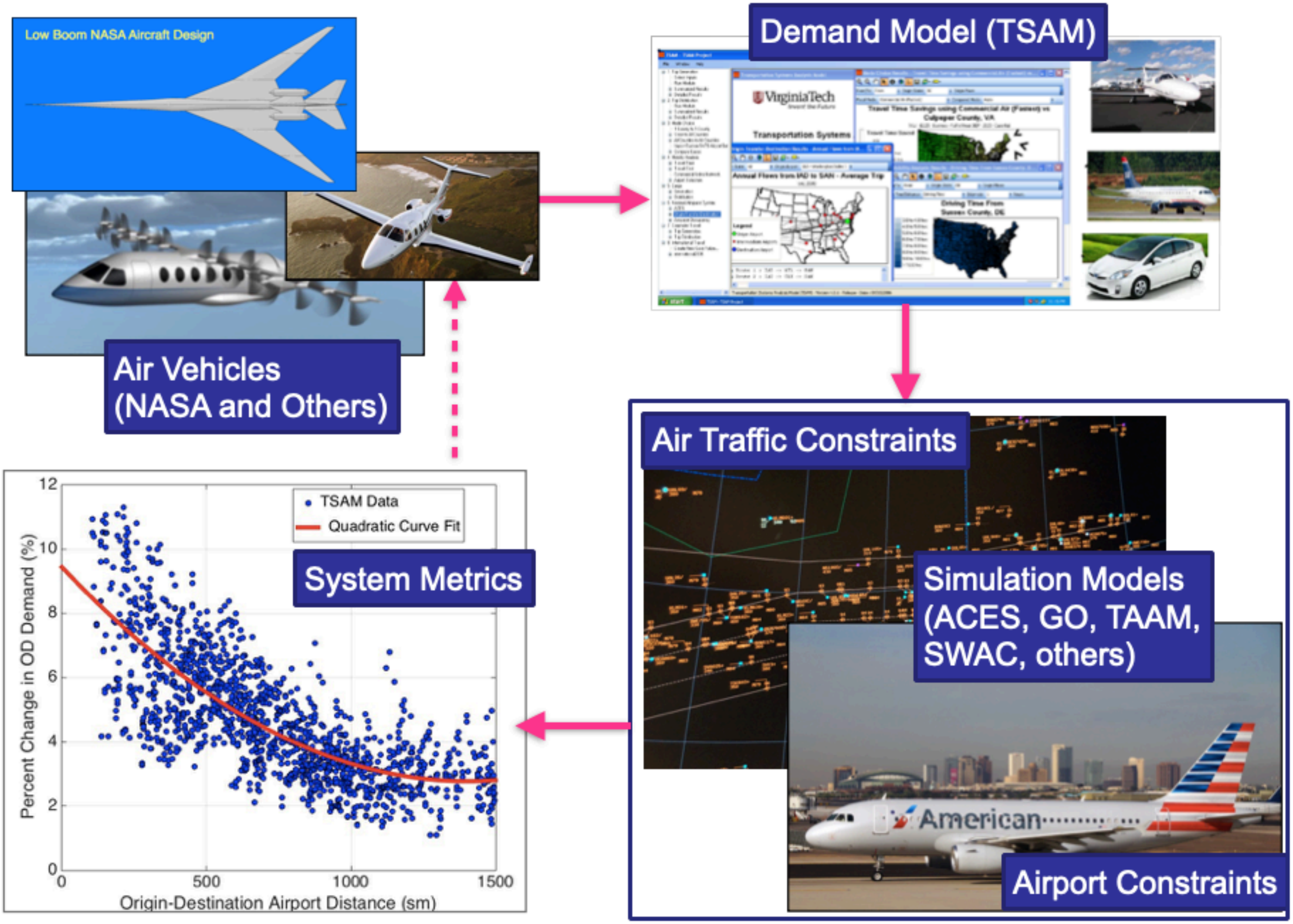
Recent Air Transportation Demand Modeling in the Air Transportation Systems Laboratory

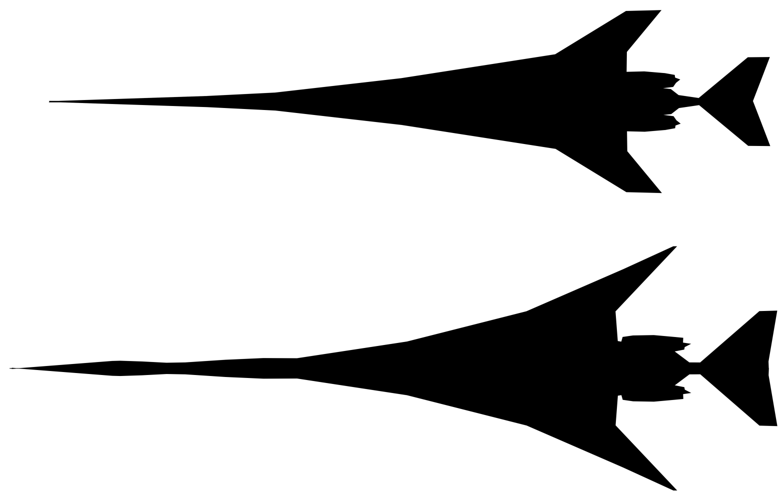


Presented by: A.A. Trani
Air Transportation Systems Laboratory
Virginia Tech
May 2, 2023

Air Transportation Systems Analysis



Supersonic Air Transportation Demand Modeling



Z. Wang, N. Hinze, and A.A. Trani
Air Transportation Systems Laboratory
Virginia Tech
March 15, 2023

Acknowledgements

- Virginia Tech would like to acknowledge the technical and financial support of the following individuals and organizations:

- Ty Marien (NASA Langley Research Center)
- Jonathan Seidel (NASA Glenn Research Center)
- Wu Li (NASA Langley Research Center)
- Karl Geiselhart (NASA Langley Research Center)
- Sam Dollyhigh (Contractor to NASA Langley)
- National Institute of Aerospace (NIA)

Project Objectives

- Estimate worldwide demand of various low-boom and non low-boom supersonic aircraft concepts including worldwide network modeling effects including:
  - Aircraft fleet size
  - Airport curfews
  - Runway length limitations
- Develop models to predict optimized supersonic fleet network utilization
- Integrate the technical outputs of FLOPS into a model that permits NASA engineers to quantify changes in potential markets for various supersonic aircraft concepts

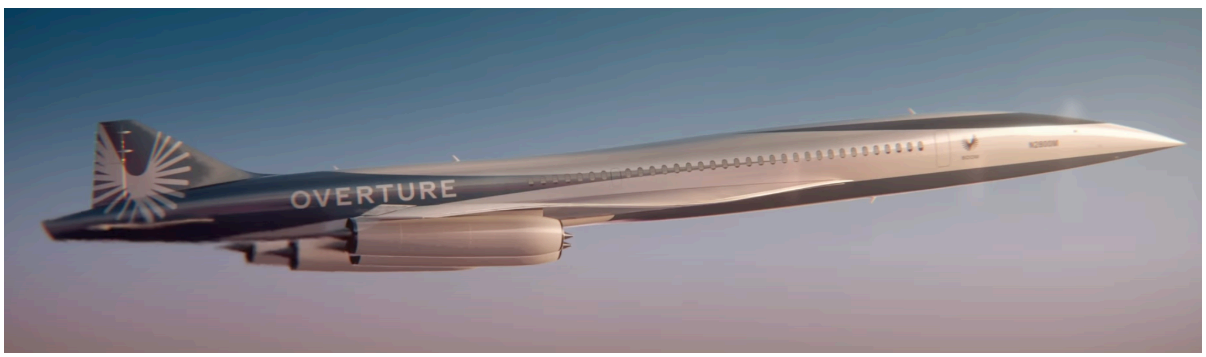
- Model is written in MATLAB ™

MATLAB is a trademark of the Mathworks

Supersonic Aircraft

British/ French Concorde
Mach 2.0 (more than twice the speed of regular subsonic aircraft)
110 passengers
First Flight: 1969

Source: https://www.baesystems.com/en/heritage/bac-concorde

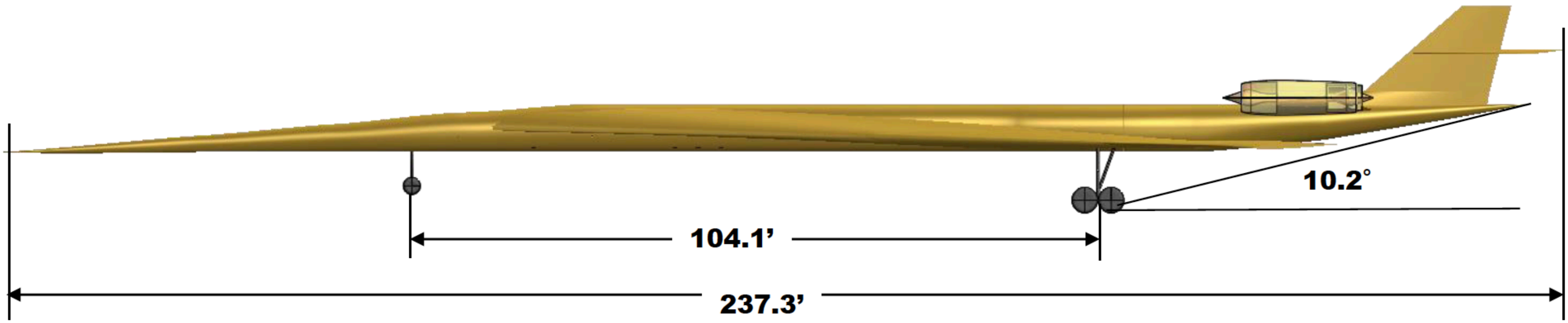


Source: https://boomsupersonic.com/overture

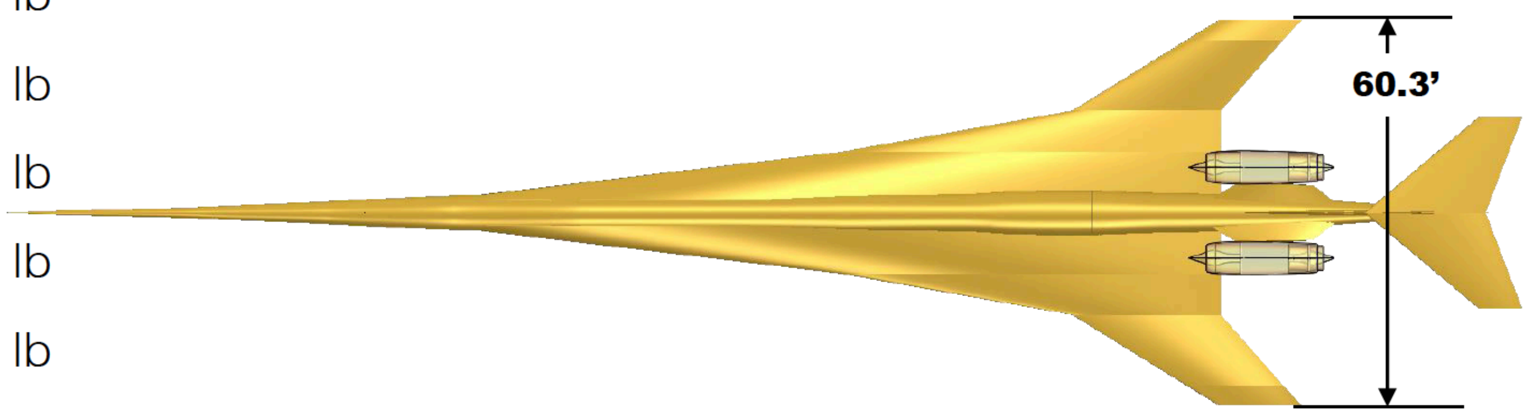
Boom Overture
Mach 1.7
65 passengers
First Flight: 2029 (Estimated)

- Concorde and Overture are traditional supersonic designs
- Traditional supersonic aircraft generate strong shock waves that create unacceptable pressures on the ground

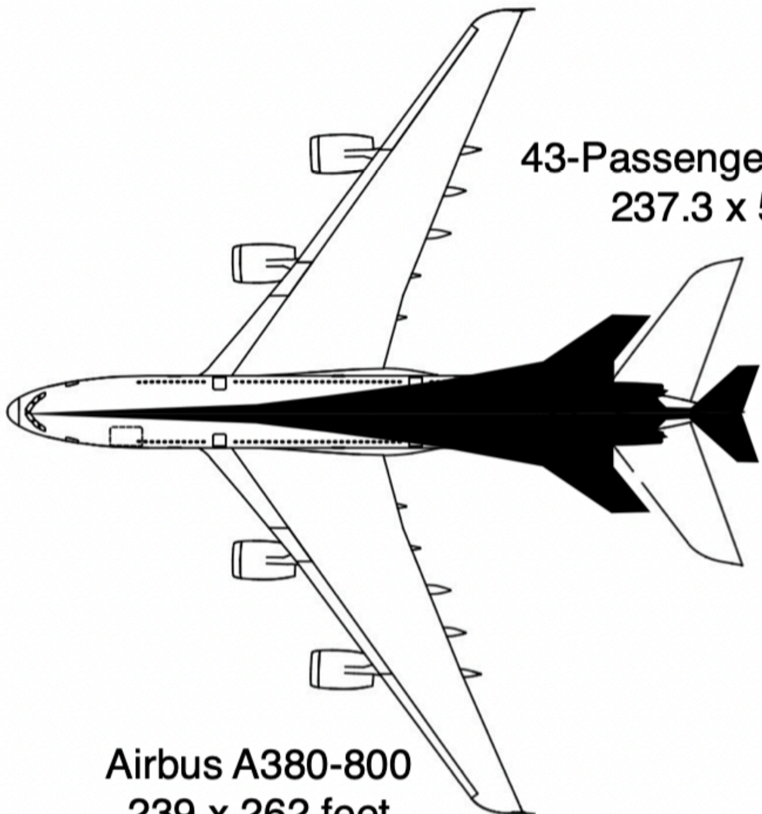
NASA 43- Passenger Low-Boom Aircraft



Wing Area	2,917 ft^2
MTOGW	154,510 lb
OEW	69,072 lb
Payload	8,987 lb
Max Fuel	79,887 lb
Block Fuel	70,571 lb
ATA Range	3,000 nmi



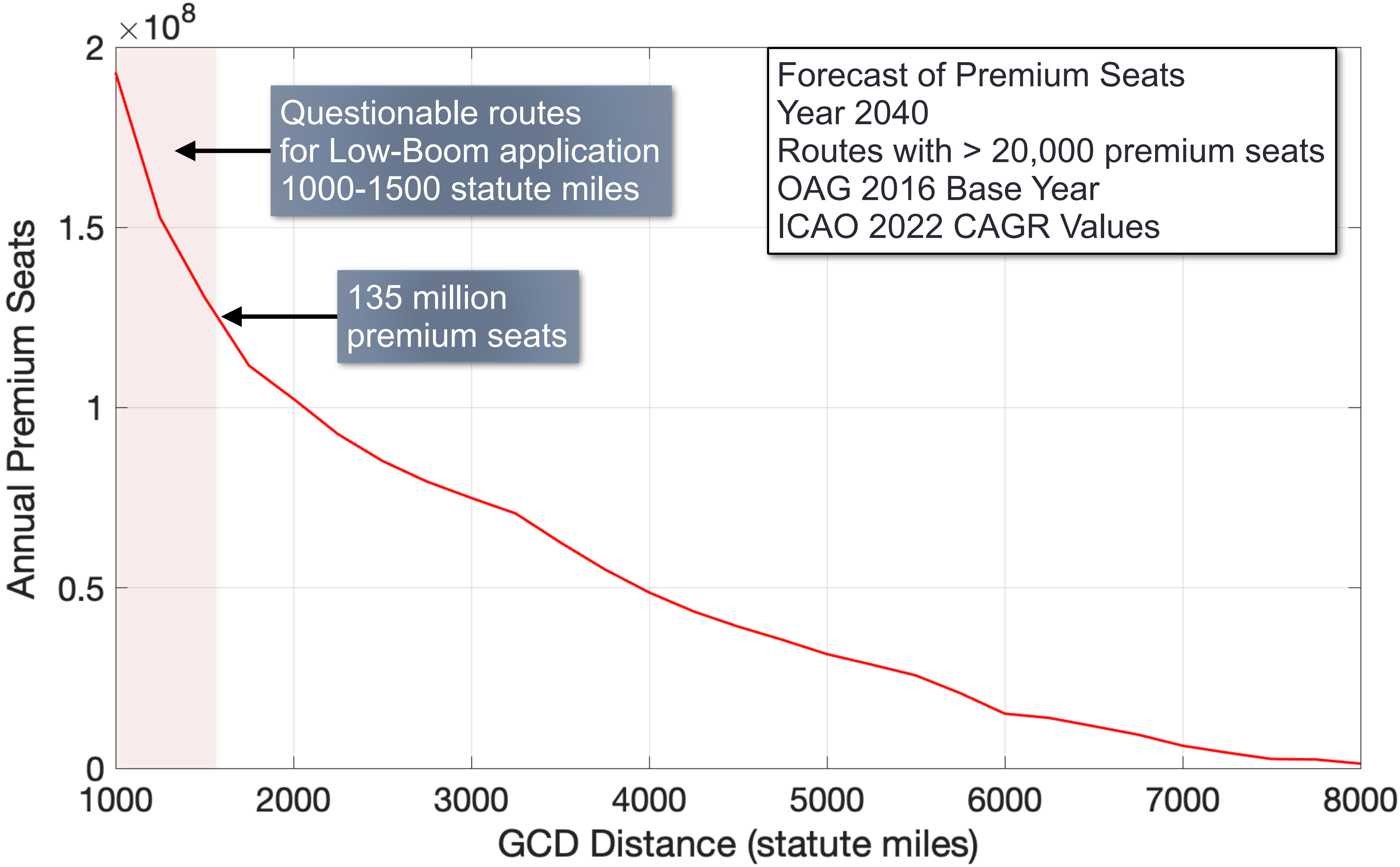
The Low-Boom Aircraft is as Long as the Airbus A380



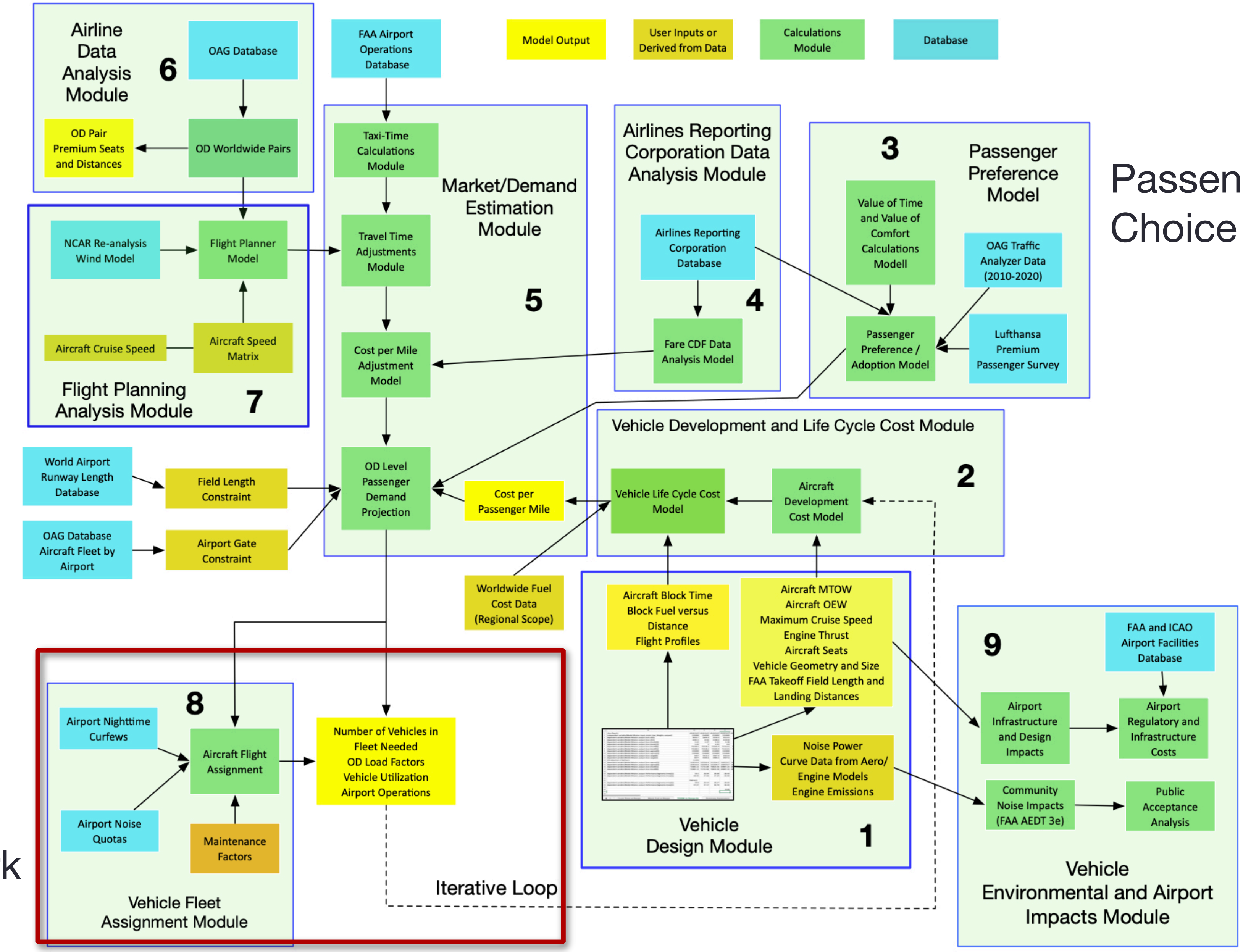
Supersonic flight requires large fuselage lengths and small cross sectional area to reduce drag

Airbus A380-800 (520 passengers typical)

Market of Premium Seats versus Distance



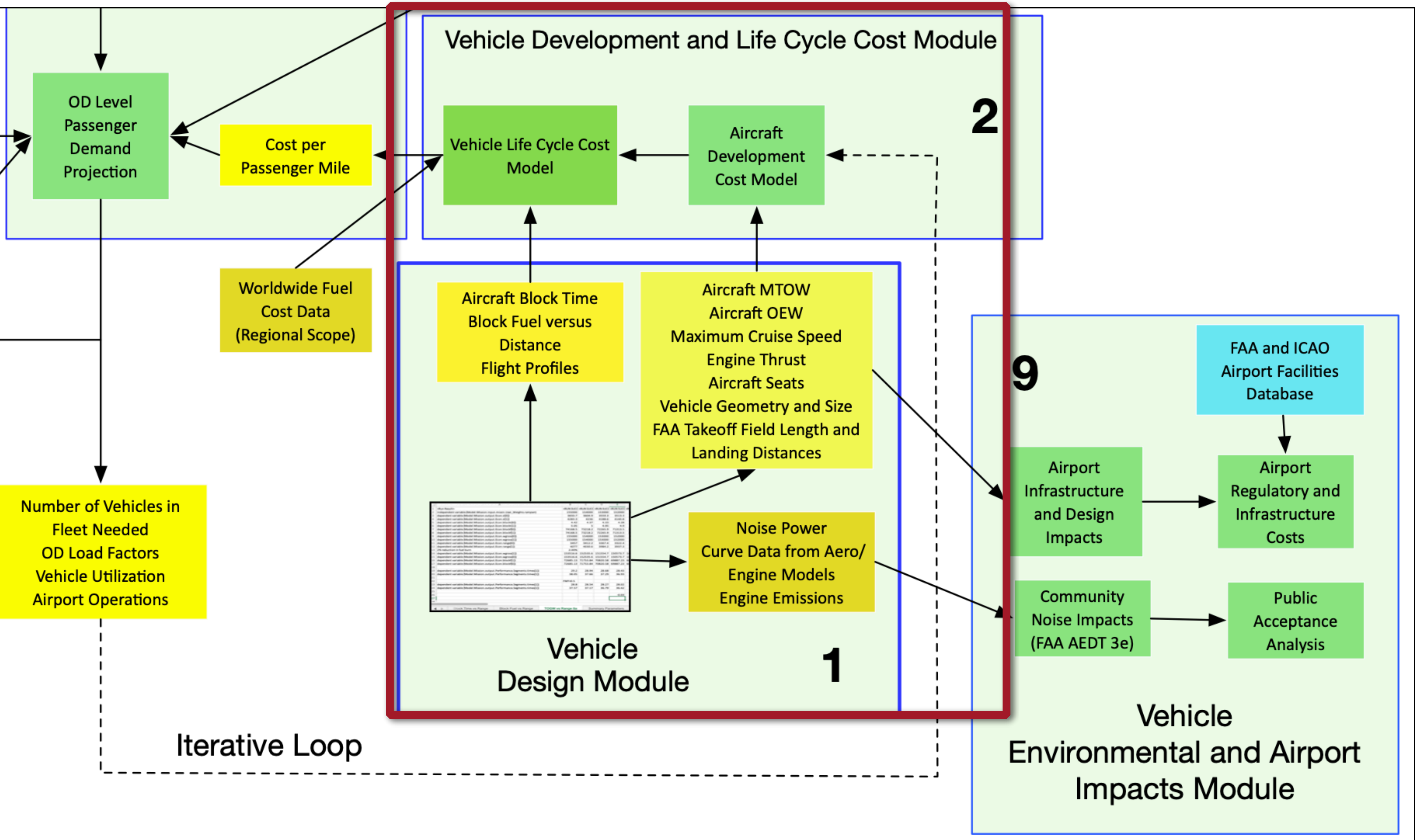
LBSAM2 Model Uses an Iterative Procedure to Estimate Air Transportation Demand



Passenger Choice Model

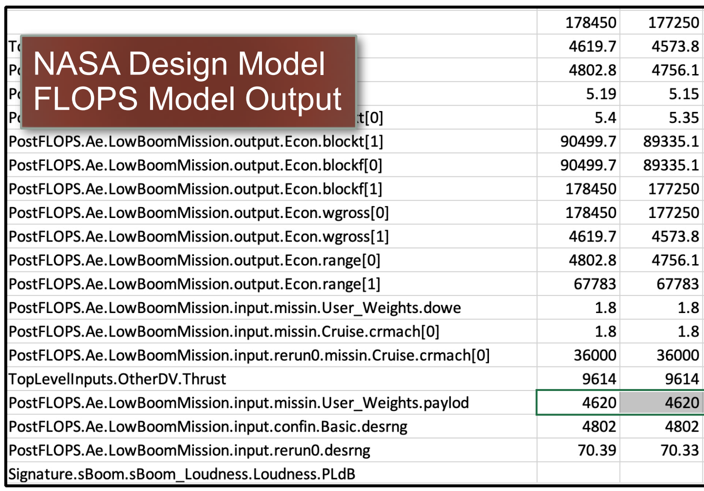
Flight Scheduling Analysis and Network Module

Vehicle Development and Life Cycle Cost Module

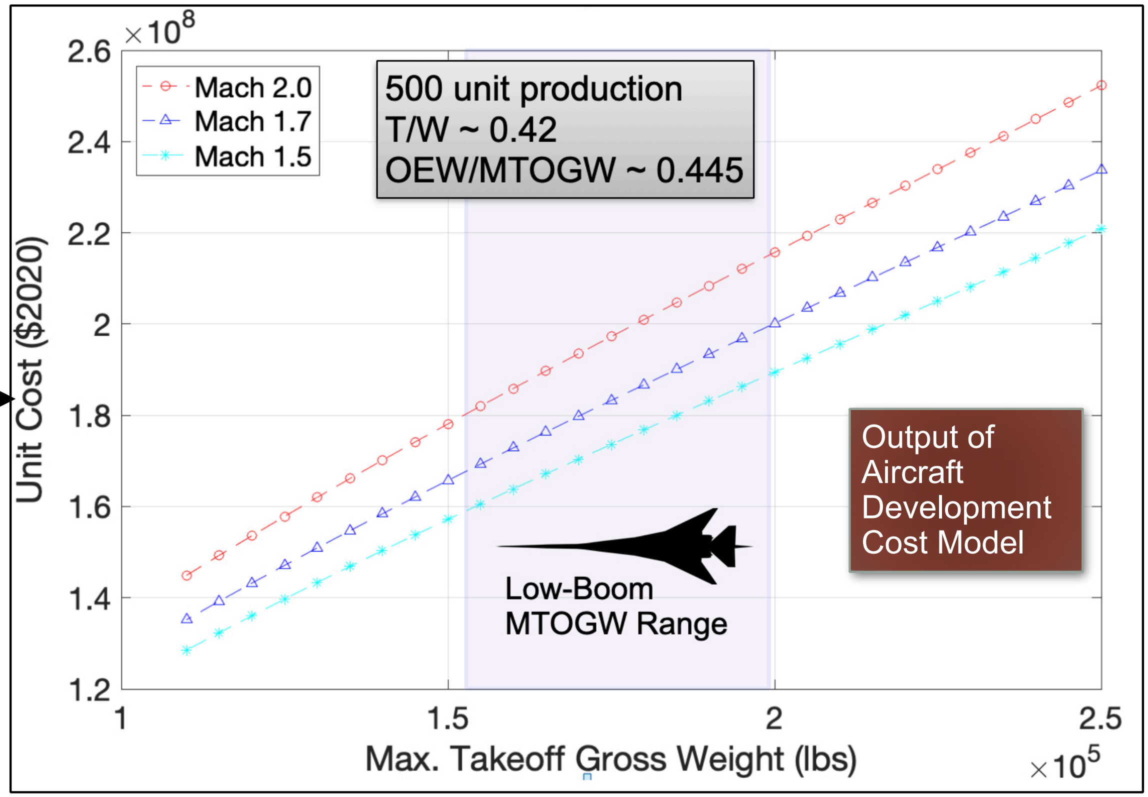


Aircraft Development Cost Module

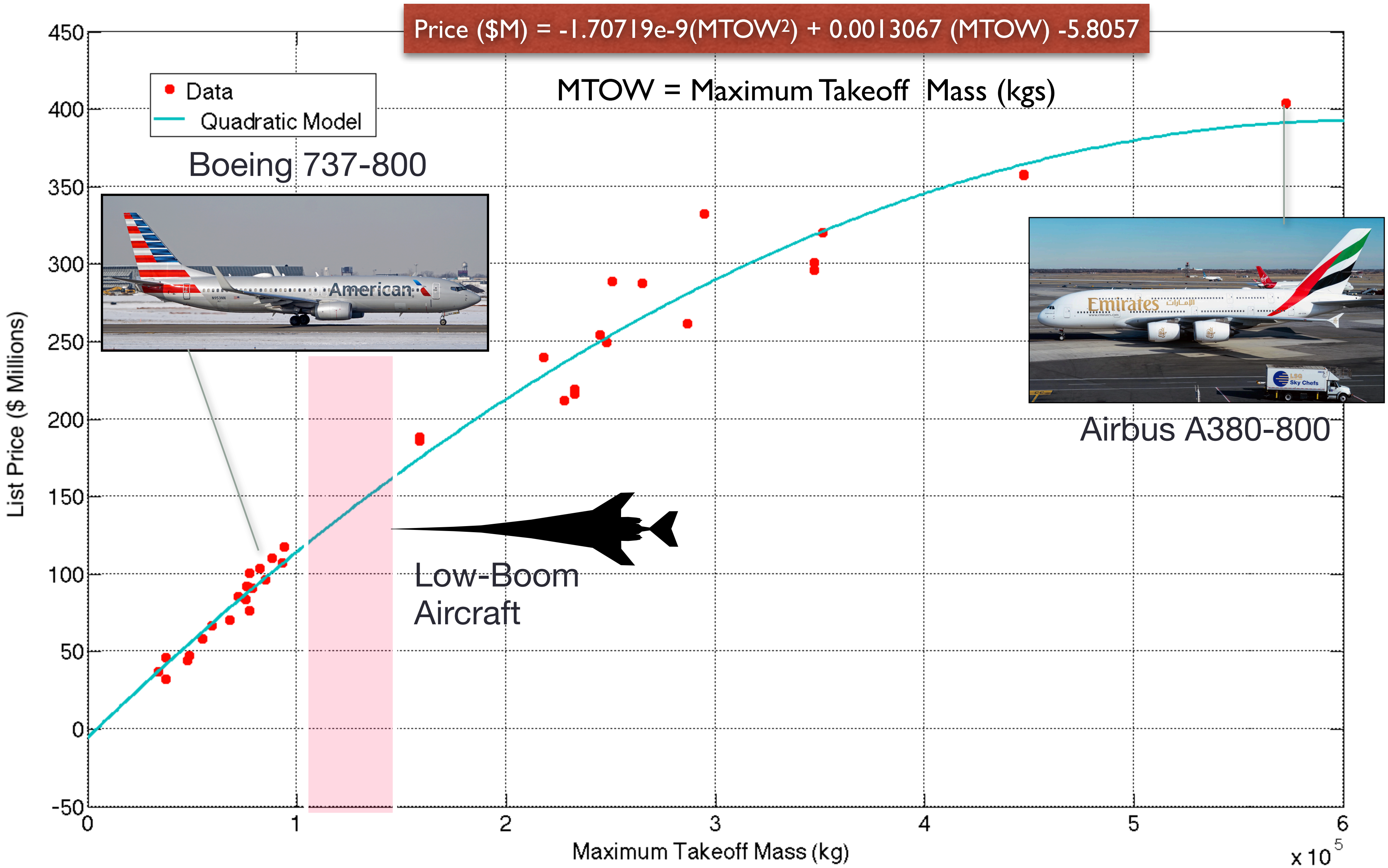
- Aircraft speed, quantity produced, takeoff and empty weights, and other technical parameters produced by FLOPS are used to estimate the vehicle development costs using non-linear regression equations adapted from a RAND cost model
- An operational aircraft life cycle cost model is used to estimate the Cost per Passenger Mile (CPM) based on the initial vehicle cost estimate
- The CPM cost is used by the **Passenger Choice and Market Demand modules**



	178450	177250
T	4619.7	4573.8
P	4802.8	4756.1
P	5.19	5.15
P ... t[0]	5.4	5.35
PostFLOPS.Ae.LowBoomMission.output.Econ.blockt[1]	90499.7	89335.1
PostFLOPS.Ae.LowBoomMission.output.Econ.blockf[0]	90499.7	89335.1
PostFLOPS.Ae.LowBoomMission.output.Econ.blockf[1]	178450	177250
PostFLOPS.Ae.LowBoomMission.output.Econ.wgross[0]	178450	177250
PostFLOPS.Ae.LowBoomMission.output.Econ.wgross[1]	4619.7	4573.8
PostFLOPS.Ae.LowBoomMission.output.Econ.range[0]	4802.8	4756.1
PostFLOPS.Ae.LowBoomMission.output.Econ.range[1]	67783	67783
PostFLOPS.Ae.LowBoomMission.input.missin.User_Weights.dowe	1.8	1.8
PostFLOPS.Ae.LowBoomMission.input.missin.Cruise.crmach[0]	1.8	1.8
PostFLOPS.Ae.LowBoomMission.input.rerun0.missin.Cruise.crmach[0]	36000	36000
TopLevelInputs.OtherDV.Thrust	9614	9614
PostFLOPS.Ae.LowBoomMission.input.missin.User_Weights.paylod	4620	4620
PostFLOPS.Ae.LowBoomMission.input.confin.Basic.desrng	4802	4802
PostFLOPS.Ae.LowBoomMission.input.rerun0.desrng	70.39	70.33
Signature.sBoom.sBoom_Loudness.Loudness.PLdB		



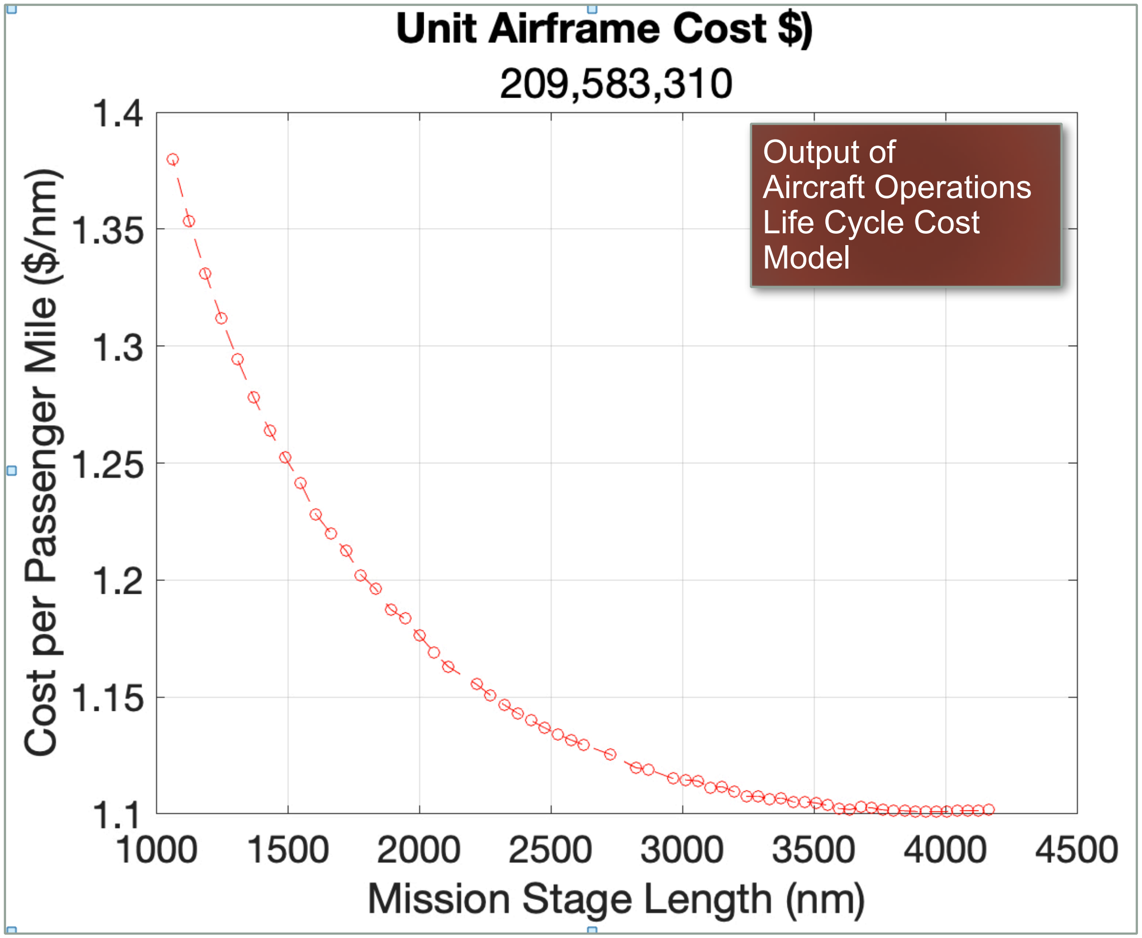
Aircraft Cost (Reality Check)



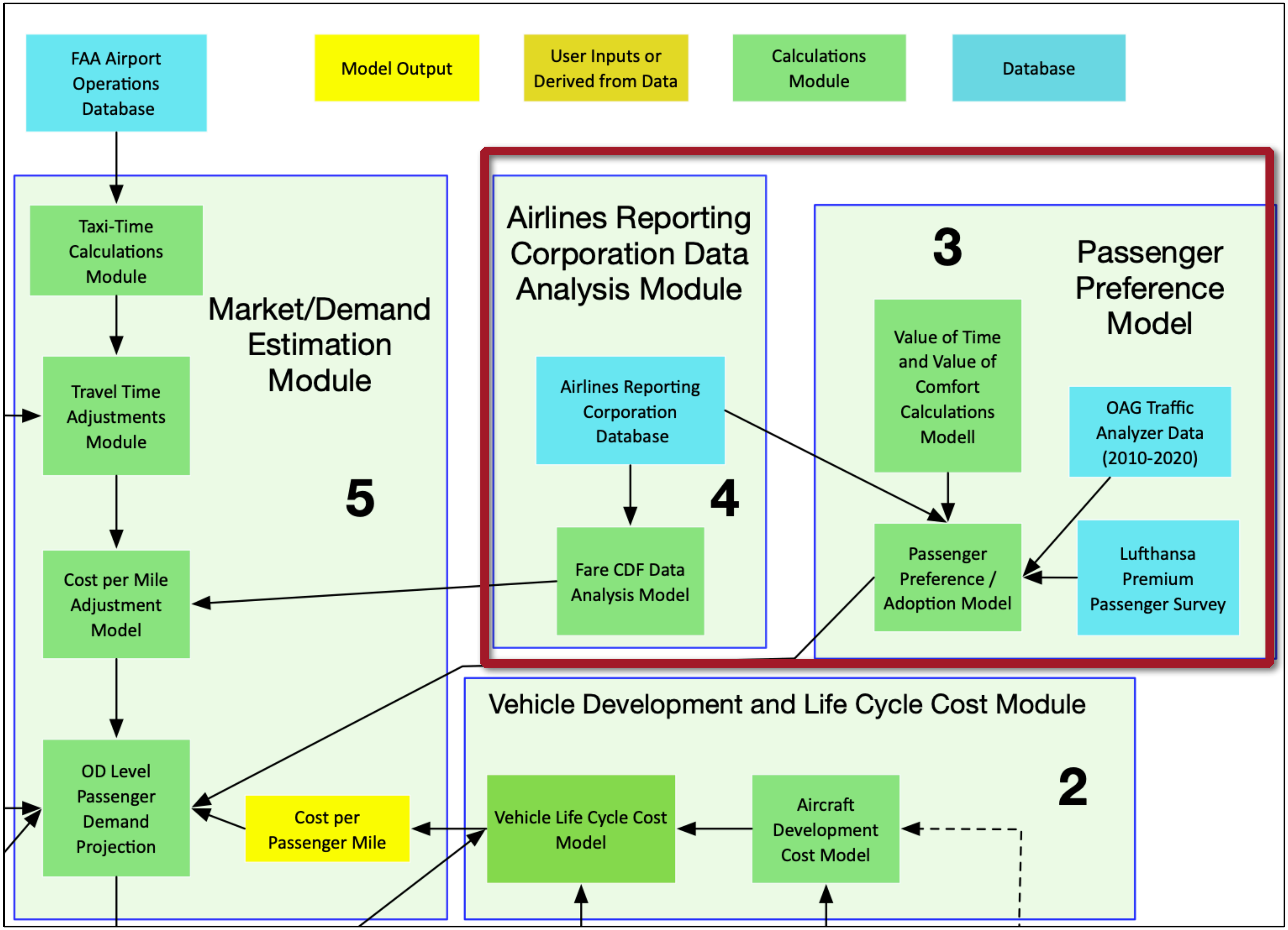
Aircraft Operations Life Cycle Cost Module

Supersonic aircraft operations life-cycle cost model include the following:

- Vehicle unit cost
- Number of annual operations
- Maintenance hours per flight hour
- Engine overhaul costs
- Time between overhauls
- Landing fee per landing
- Percent of repositioning flights
- Stage length flown
- Fuel consumption and fuel cost
- Hangar cost
- Crew and maintenance personnel
- Avionics and interior refurbishing costs
- Load factor per flight
- Depreciation
- Life-cycle time
- Landing fees and ground handling costs
- Airport emission fees
- Navigation fees
- Insurance costs (liability and hull)
- Taxes airline passenger facility fees



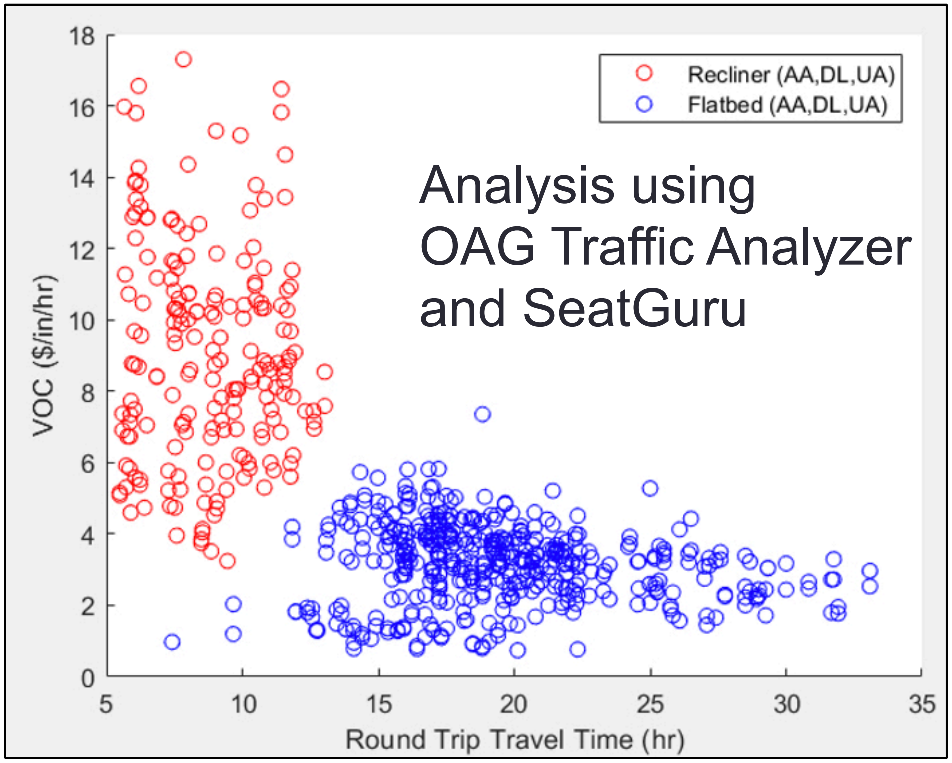
Passenger Preference Module



Passenger Preference Module

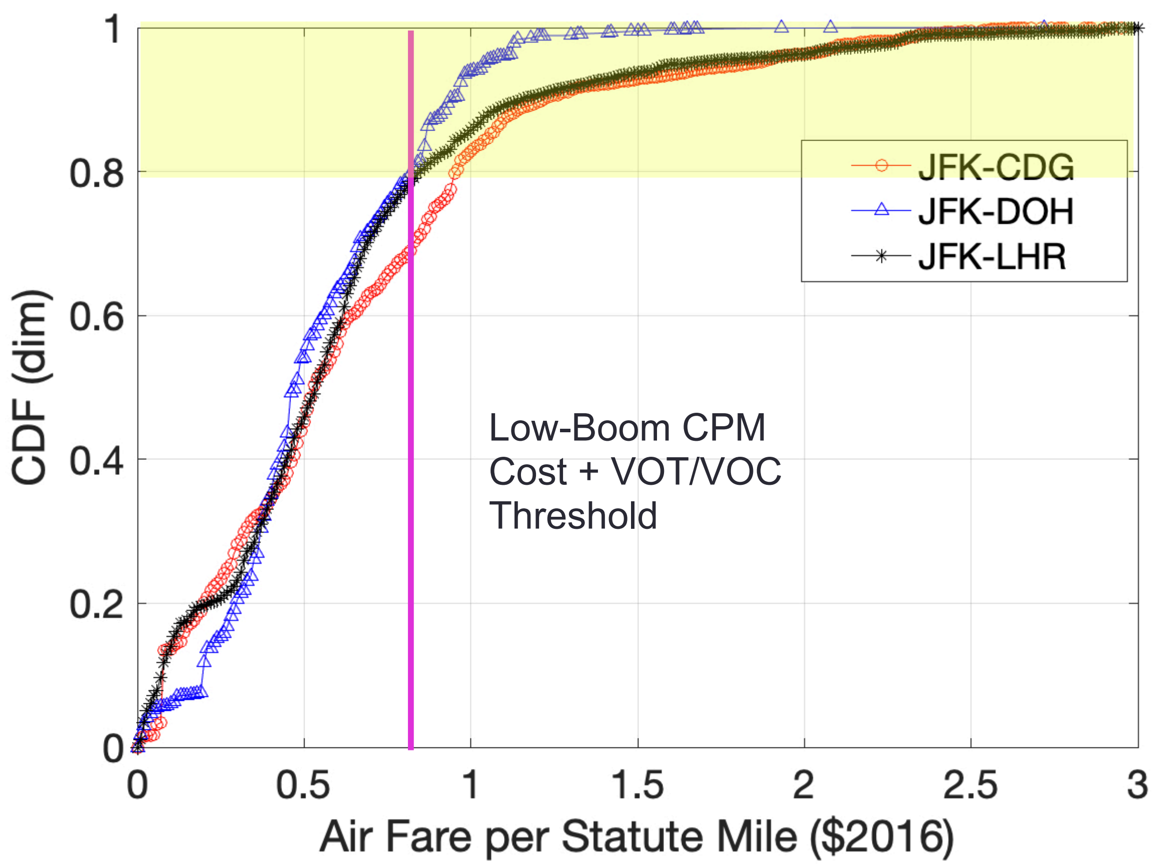
- Estimates the fraction of passengers willing to switch from subsonic to high-speed commercial services using Value of Time (VOT) and Value of Comfort (VOC)
- Estimates the tradeoffs between the travel time advantages of high-speed travel and the potential disadvantages of traveling in a more confined seat typically found in supersonic vehicles

Estimated Values of Time for premium seats range from $120-$240/hr using a Lufthansa passenger survey and OAG Traffic Analyzer airfare analysis



Market Demand Estimation Module

- Estimates the number of passengers traveling in the high-speed vehicle at the route level.
- Employs the Airline Reporting Corporation (ARC) database with **46 million premium class airline tickets** (first and business class) to estimate the number of passengers switching to high-speed commercial service



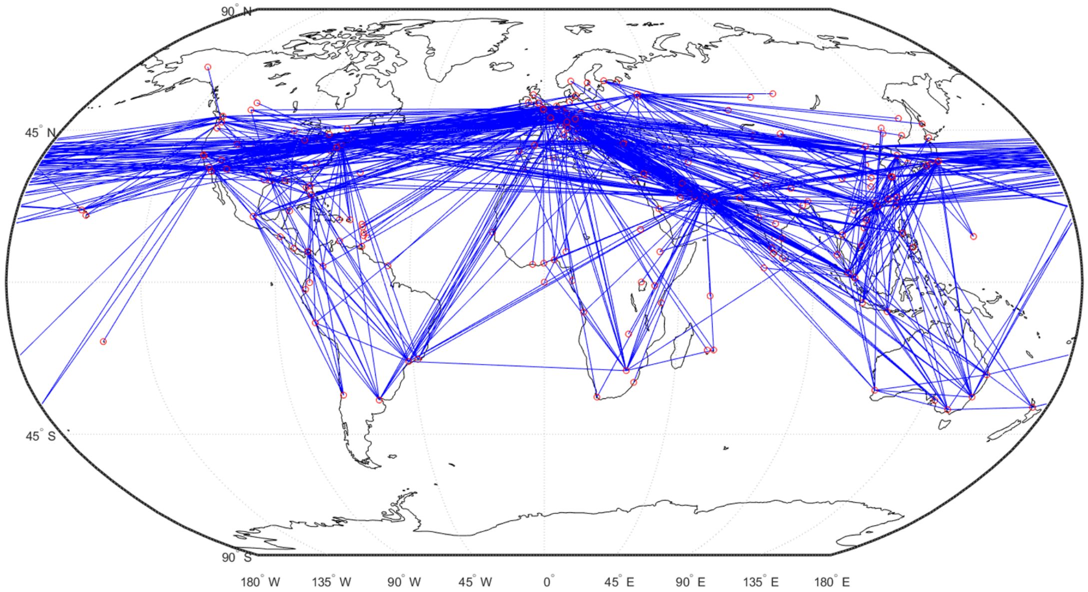
Market	Airports	OD Pairs	Records
US	135	1,535	8.14 million
US-International	327	2,709	9.89 million
International	1,008	12,176	27.19 million

Airline Reporting Corporation (ARC) datasets

Example: Considering Value of Time and Value of Comfort, 20% of the premium passengers in the JFK-LHR route may be willing to switch to supersonic aircraft

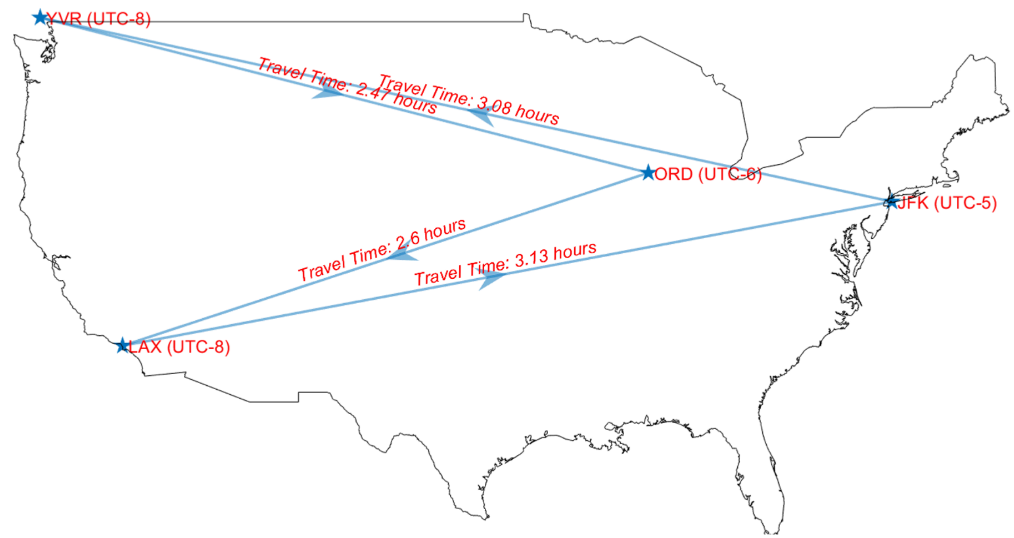
Vehicle Assignment and Network Model

- LBSAM2 includes a mathematical programming module to schedule supersonic flights worldwide
- The LBSAM2 flight scheduling and network model considers the following operational effects:
  - Curfew constraints
  - Maximum daily utilization
  - One and two-day cycles
  - Demand at origin-destination level (determined using the passenger choice model developed in LBSAM2)
  - Maintenance times



Example Network Analysis Metrics Produced in LBSAM2 Flight Scheduling/Network Model

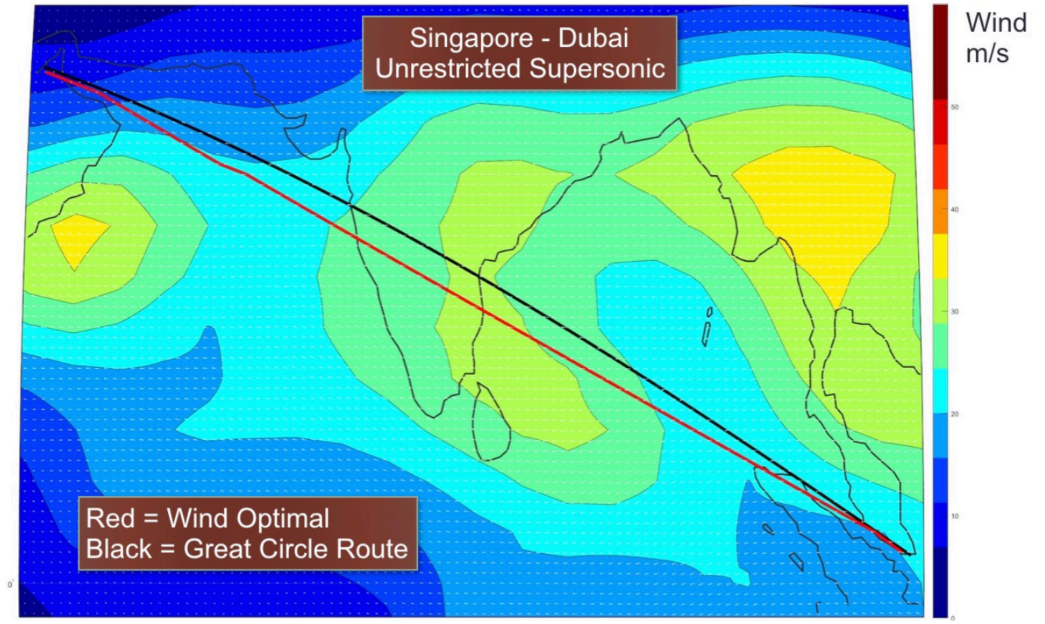
Metric
Weighted Average OD Pair Length
Flights per Day per Vehicle
Passenger Cost per Mile
Load Factor
Daily Vehicle Utilization
Number of Airframes Needed
Passenger Spillover
Origine-Destination Demand
Origin-Destination Seats Offered
Revenue Passenger Kilometers

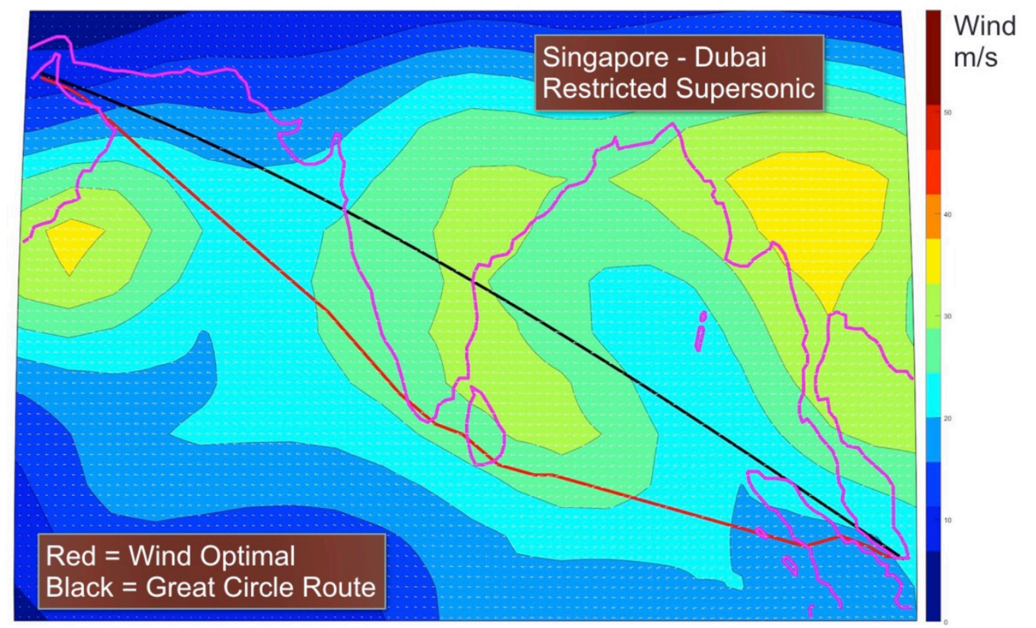


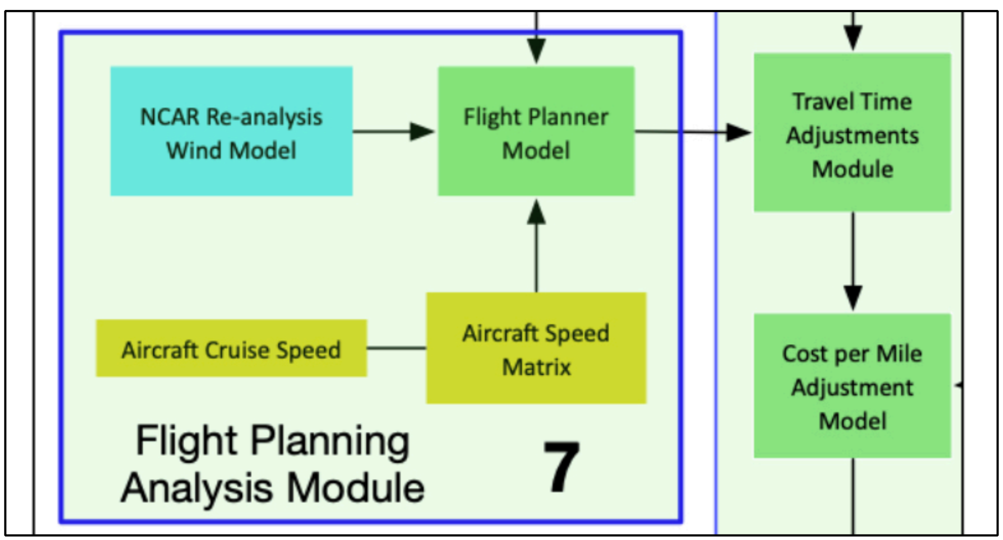
Low-boom supersonic aircraft one-day cycle

Overland/Overwater Flight Planning

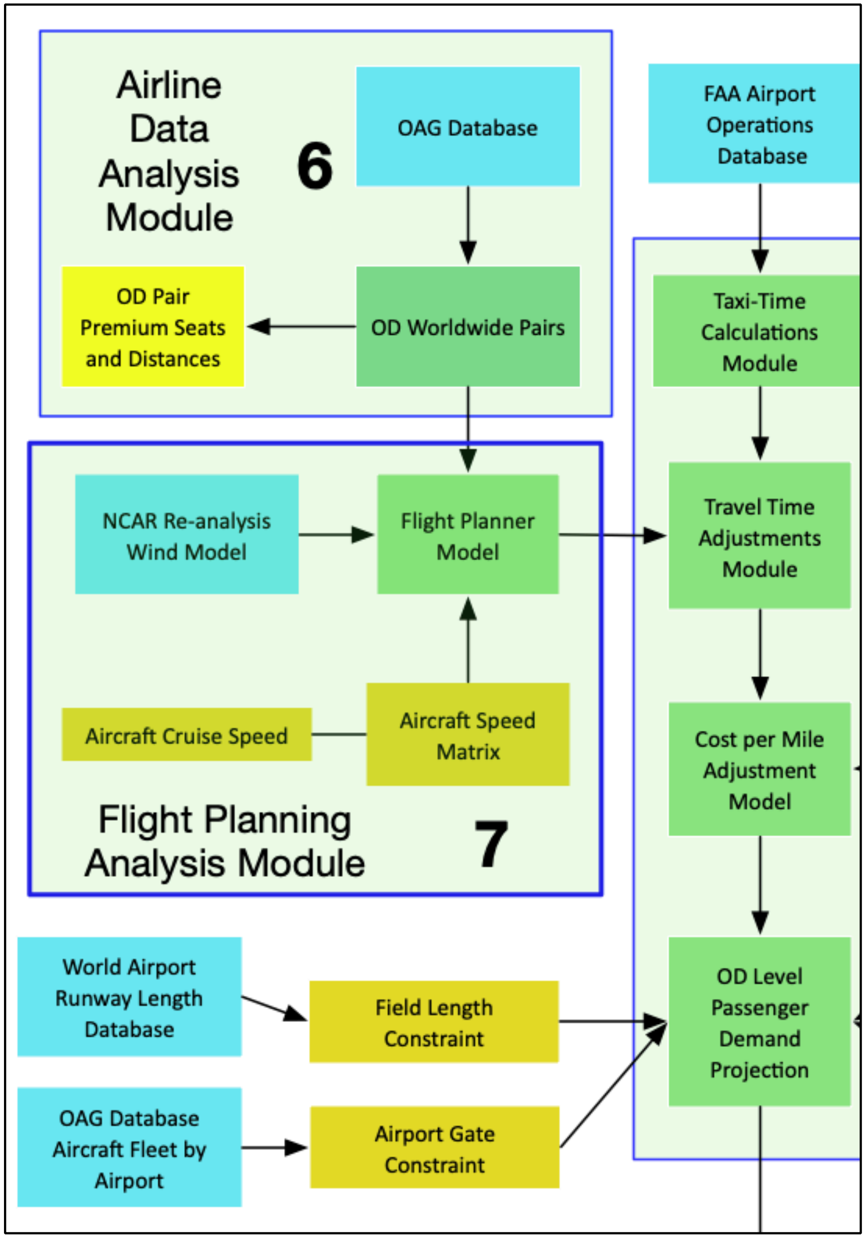
- Estimates flight trajectories for supersonic aircraft considering supersonic overland restrictions (if applicable)
- Flight planner uses NOAA Re-analysis wind data sets
- Runway length and airport gate compatibility analysis are considered in the selection of candidate OD airport pairs



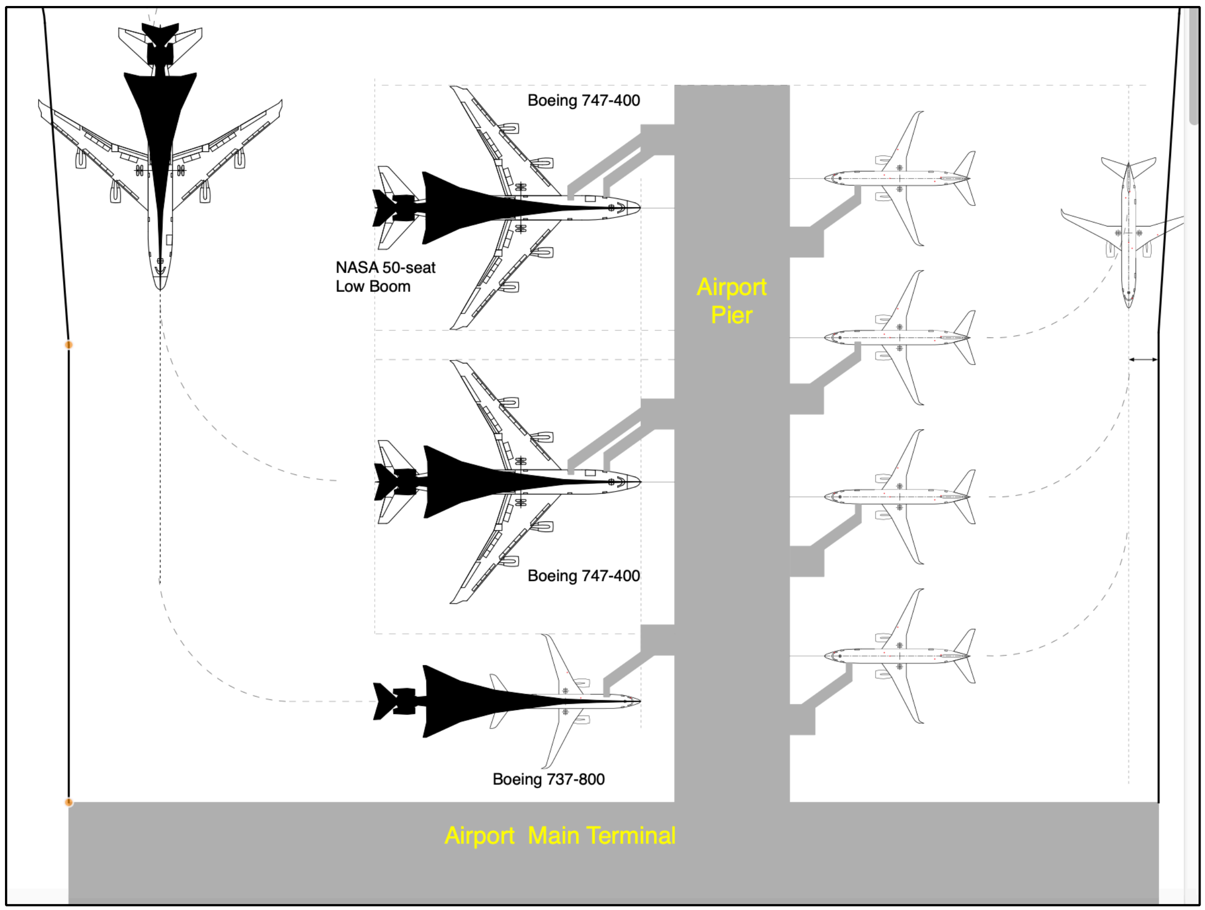




Airport Compatibility Impacts



LBSAM2 checks for runway length and gate size compatibility

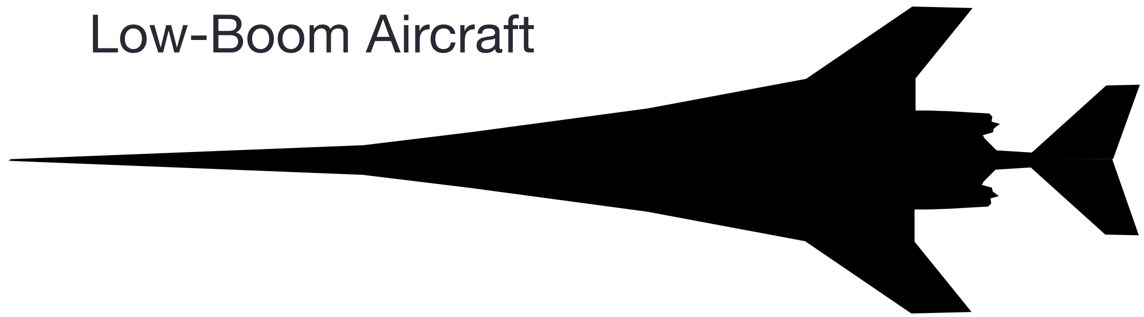


Using the LBSAM2 Model to Study NASA Concepts

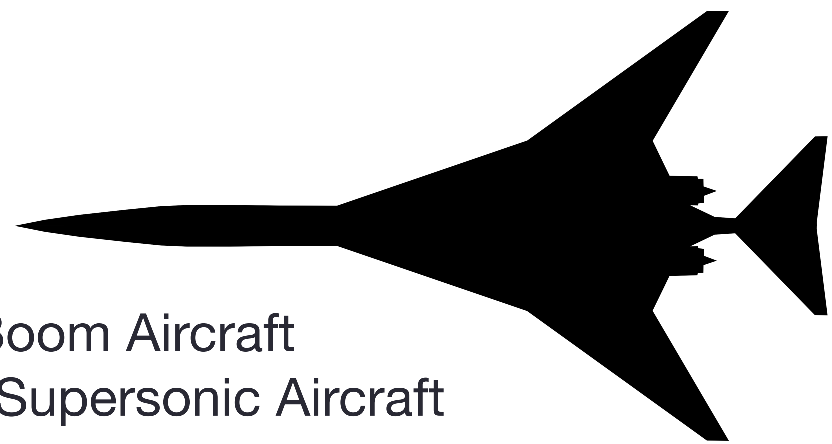
- Compare Low-Boom (LB) versus non-low-boom (NLB) aircraft designs

Specifications
Mach 1.8 overland
Mach 1.8 overwater
43 seats
20% heavier than NLB

Low-Boom Aircraft

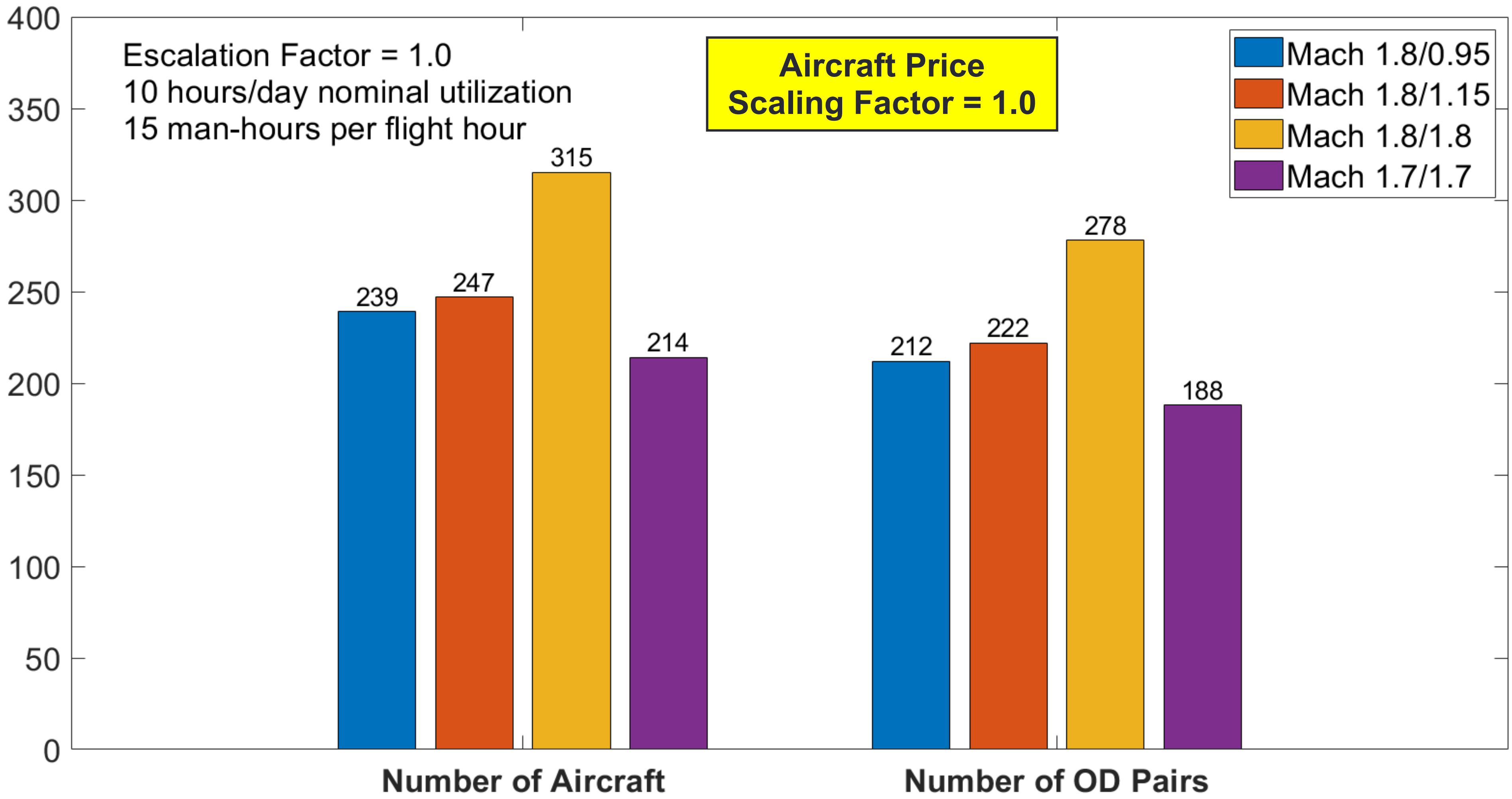


Specifications
Mach 0.95/1.15 overland
Mach 1.8 overwater
43 seats
20% lighter than LB

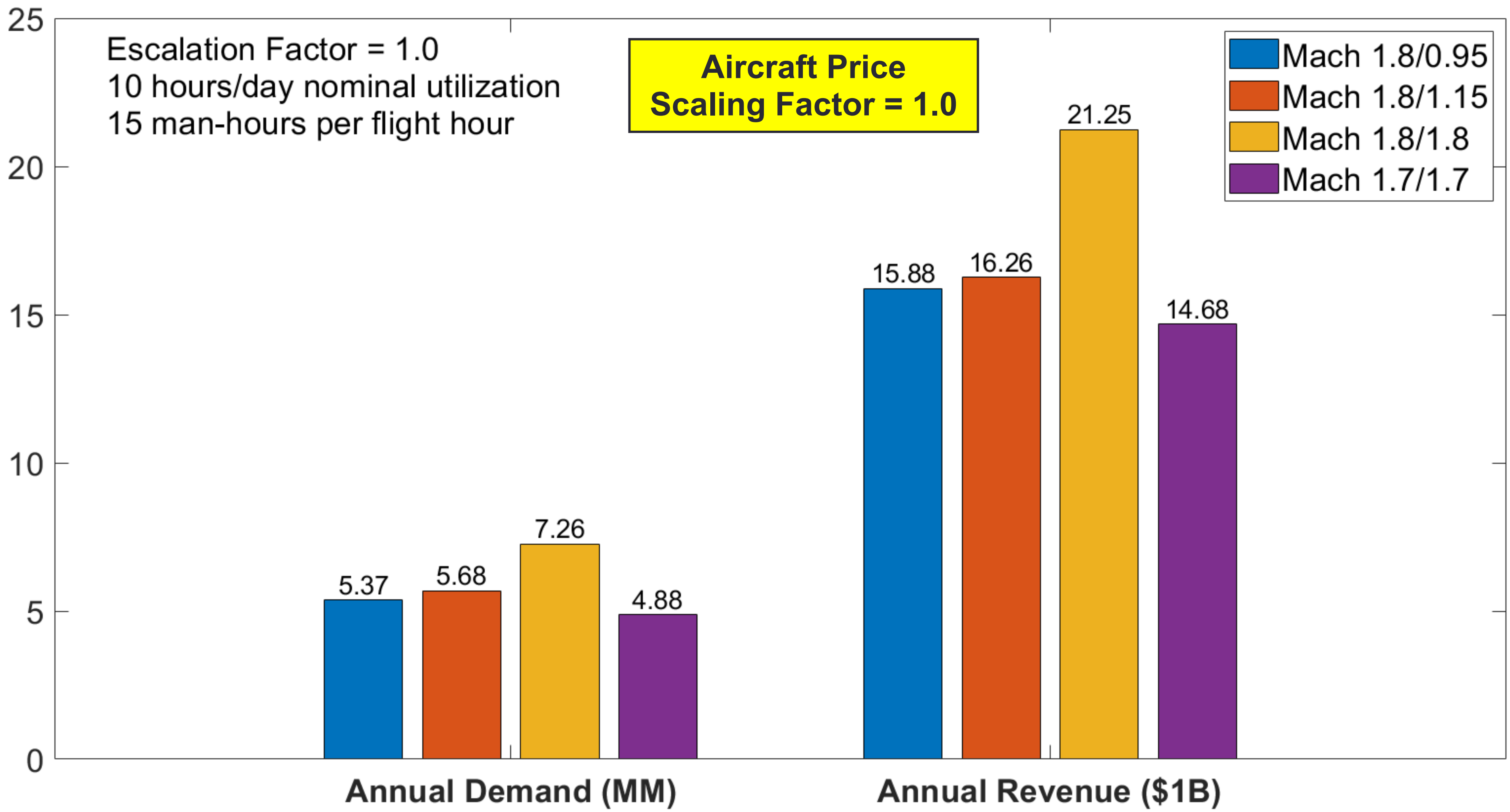


Non Low-Boom Aircraft
Traditional Supersonic Aircraft

The Mach 1.8 low-boom design is expected to serve more OD pairs compared to a NLB design able to cruise at Mach 1.15 overland



The Mach 1.8 low-boom design has the potential to attract 27% more passengers worldwide compared to a NLB design able to cruise at Mach 1.15 overland



Main Conclusions

- The enhanced LBSAM2 models offers an integrated approach to study worldwide demand for supersonic aircraft concepts
- Model includes network effects and captures the dynamics between fleet size, aircraft unit cost, aircraft economics, and passenger preference
- Model runs converge (demand-supply) in 5-12 iterations
- **Using baseline operational parameters in the model, we estimate between 315-350 low-boom supersonic airframes may be needed in the year 2040**
- **Using baseline operational parameters in the model (i.e., high daily utilization), low-boom supersonic aircraft could transport between 7-8 million passengers annually in 2040**
- Using very optimistic parameters in the model (including $2.5/gallon fuel prices) we estimate up to 700 low-boom supersonic airframes may be needed in the year 2040
- Producing 350 low-boom aircraft over a life cycle of a program is challenging (costs are high)

Other Studies Using Components of the LBSAM2 Model

LBSAM2 Flight Scheduling and Network Analysis Module to Estimate Regional Air Mobility

- TSAM predicts door-to-door travel behavior (US scope)
- TSAM uses an external life cycle cost model to predict airfares (cost per mile) for user-defined aerospace vehicles **(no network effects modeled directly)**
- Use the LBSAM2 network model to predict realistic network costs for regional air mobility aircraft vehicles
- LBSAM2 network analysis model can solve problems with thousands of OD pairs to assess realistic network costs and predict schedule or on-demand travel

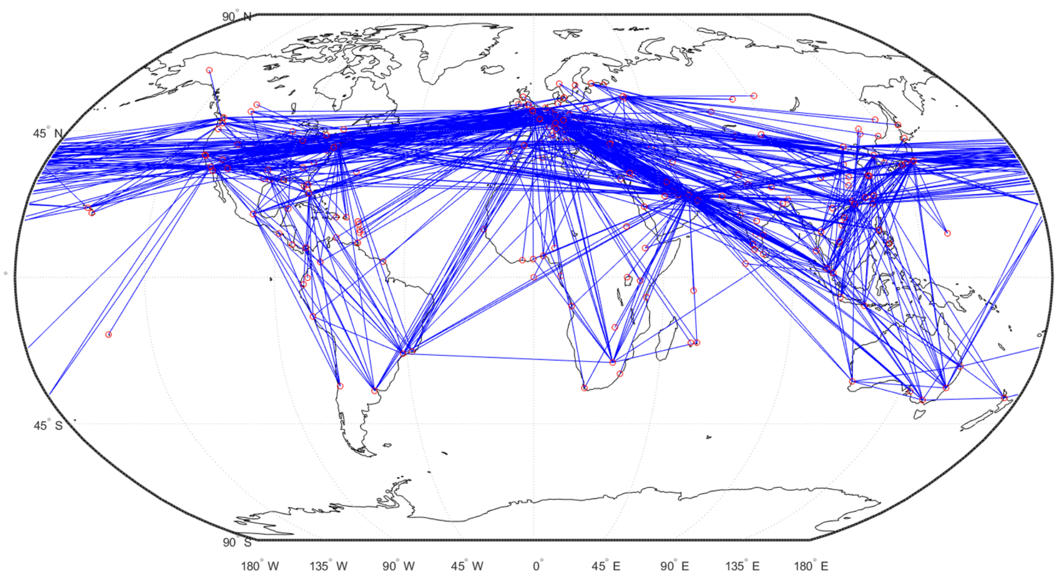
Heart Aerospace

Eviation Alice

Use the LBSAM2 Framework to Predict Advanced Subsonic Demand

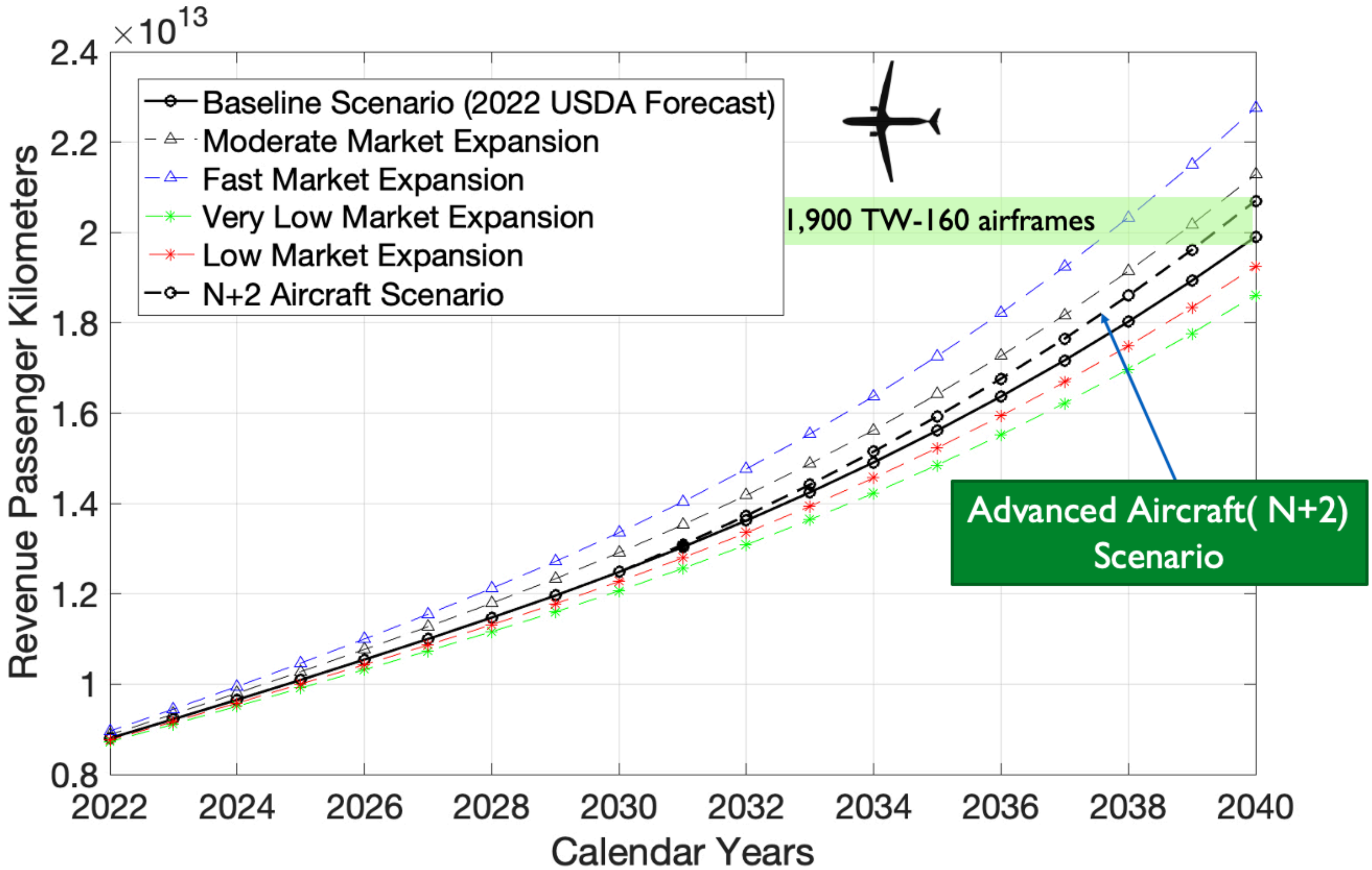
- LBSAM2 passenger choice and network analysis models can be used to predict worldwide subsonic aircraft demand using advanced aircraft designs such as the proposed Boeing/NASA VS-1 and VS-2
- The introduction of advanced subsonic aircraft can be studied regionally because the practical range of such aircraft confines them to a region

BoeingVS-1 and VS-2 truss-braced subsonic aircraft (Source: Boeing)

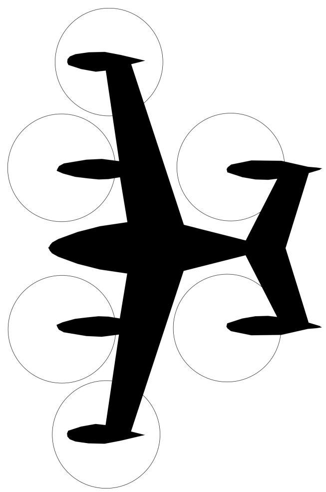


LBSAM2 Worldwide Network Analysis for Low-Boom Aircraft

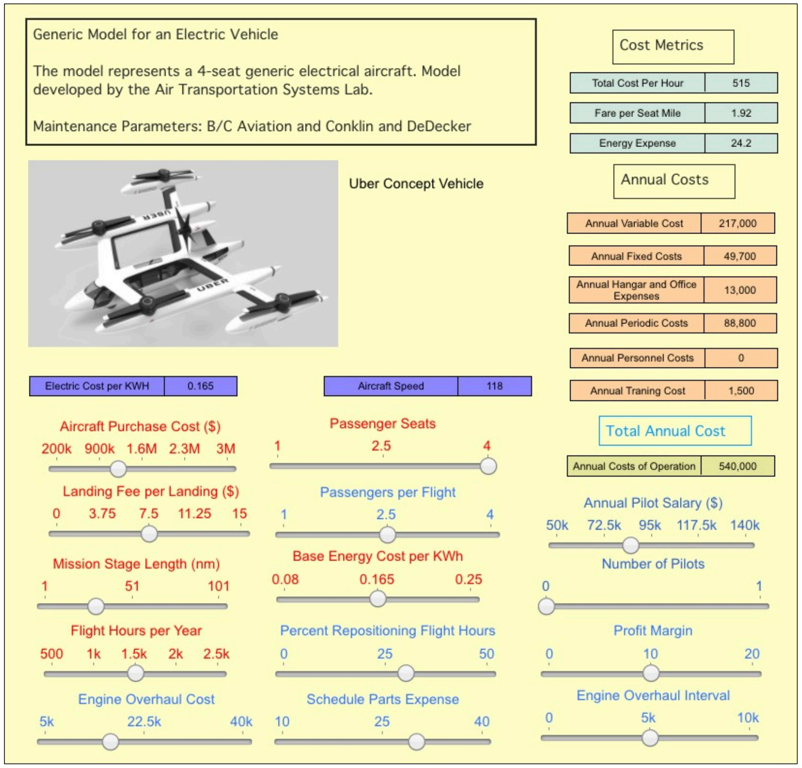
Use the LBSAM2 Framework to Predict Advanced Subsonic Demand



Metropolitan Area eVTOL Demand (NASA Study)



UAM Aircraft
Life Cycle Cost
Model



Presented by Antonio Trani

Research Team: Dr. M. Rimjha, Dr. S. Hotle, N. Hinze, A. Antonis, A. Olamai, T. Sayantan, and Dr. A. Trani

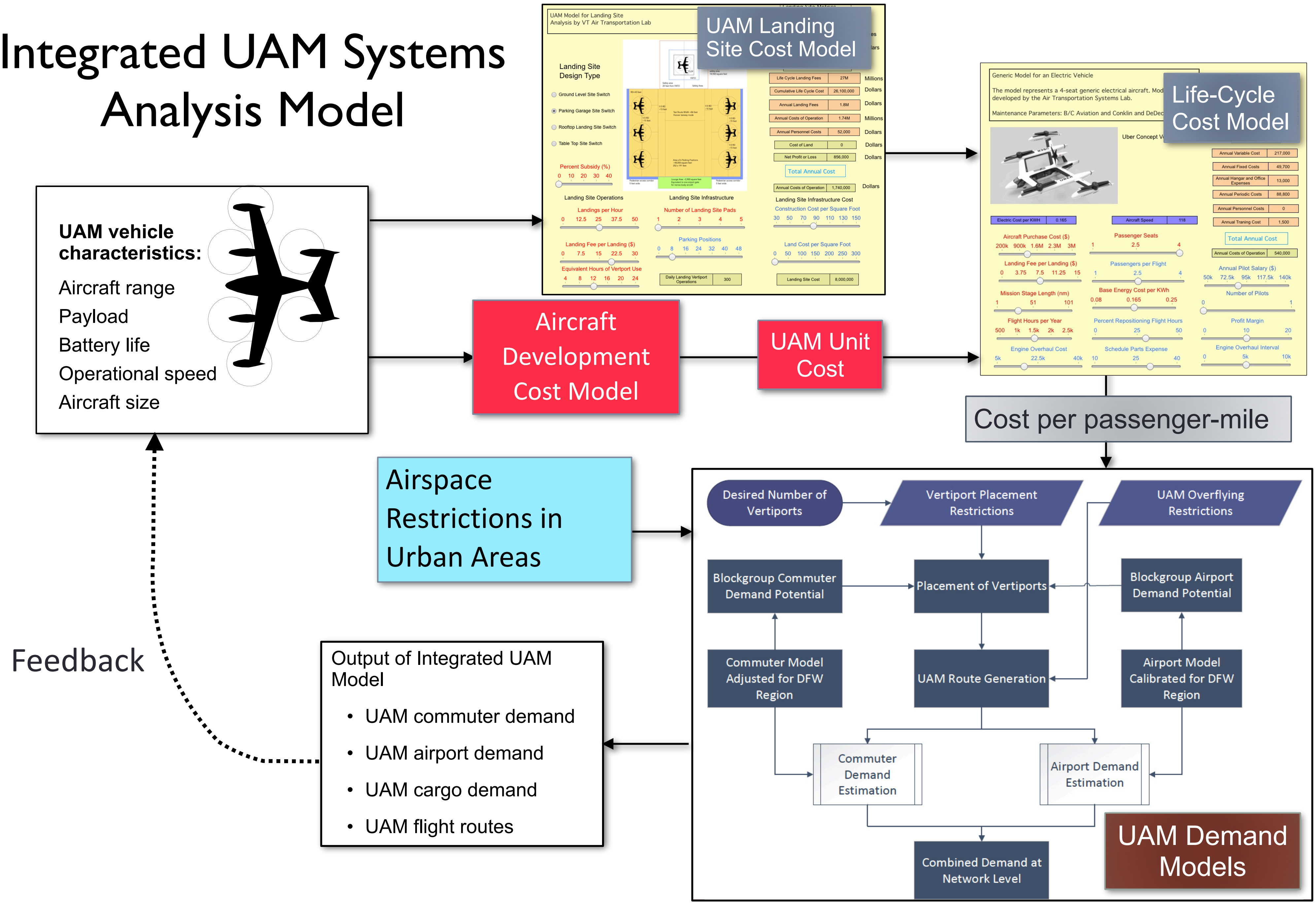
January 5, 2023

Acknowledgements

- **Jeremy Smith and Ty Marien** at NASA Langley Research Center (Project technical monitors)
- **Sam Dollyhigh** - contractor to NASA Langley Research Center
- **Dr. Laurie Garrow** for sharing data on the stated preference survey
- **NASA Ames** - provided Dallas-Fort Worth airport airspace restrictions
- Los Angeles World Airports, Dallas-Fort Worth International Airport, New York, Texas, and California for providing extended NHTS data

- Work funded under a National Institute of Aerospace Grant Number NNL13AA08B Task Order Number 80LARC18F0120

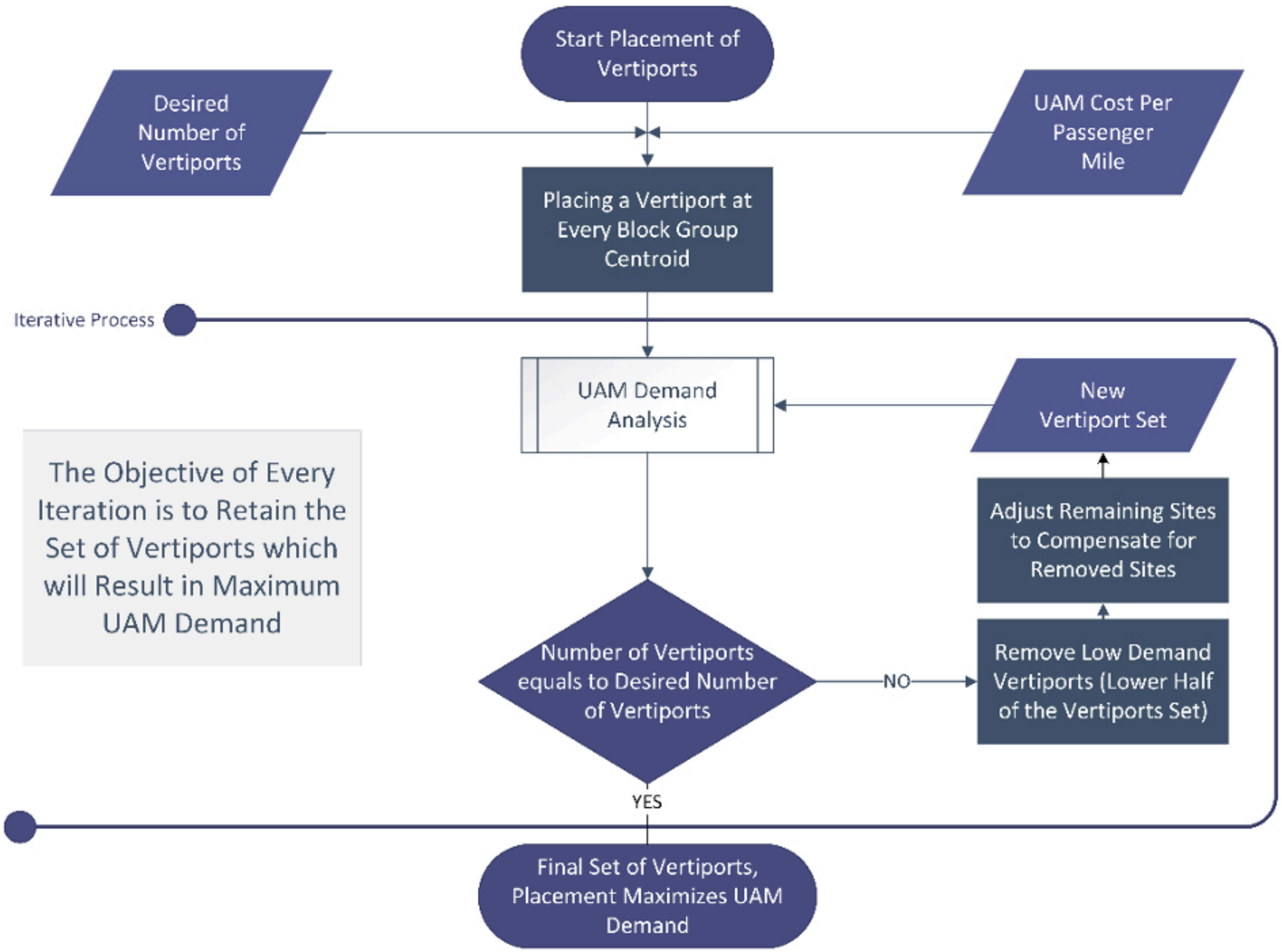
Integrated UAM Systems Analysis Model

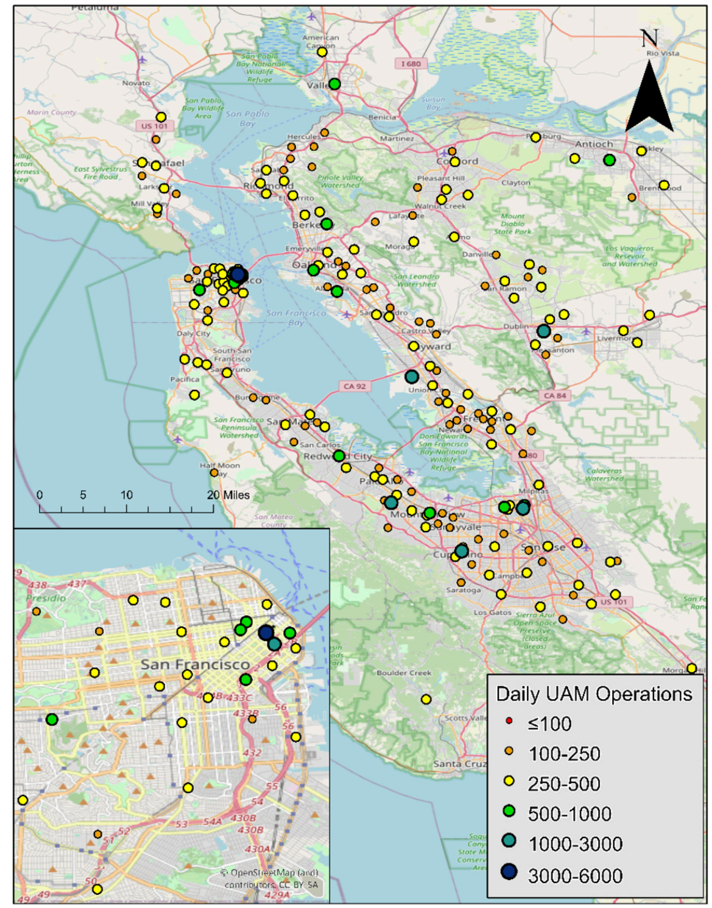


UAM Areas of Study at Virginia Tech for NASA

UAM Landing Site Placement Model, Landing Site Space Requirements, and Landing Site Cost Model

Demand-Driven, Iterative UAM Landing Site Vertiport Location Method

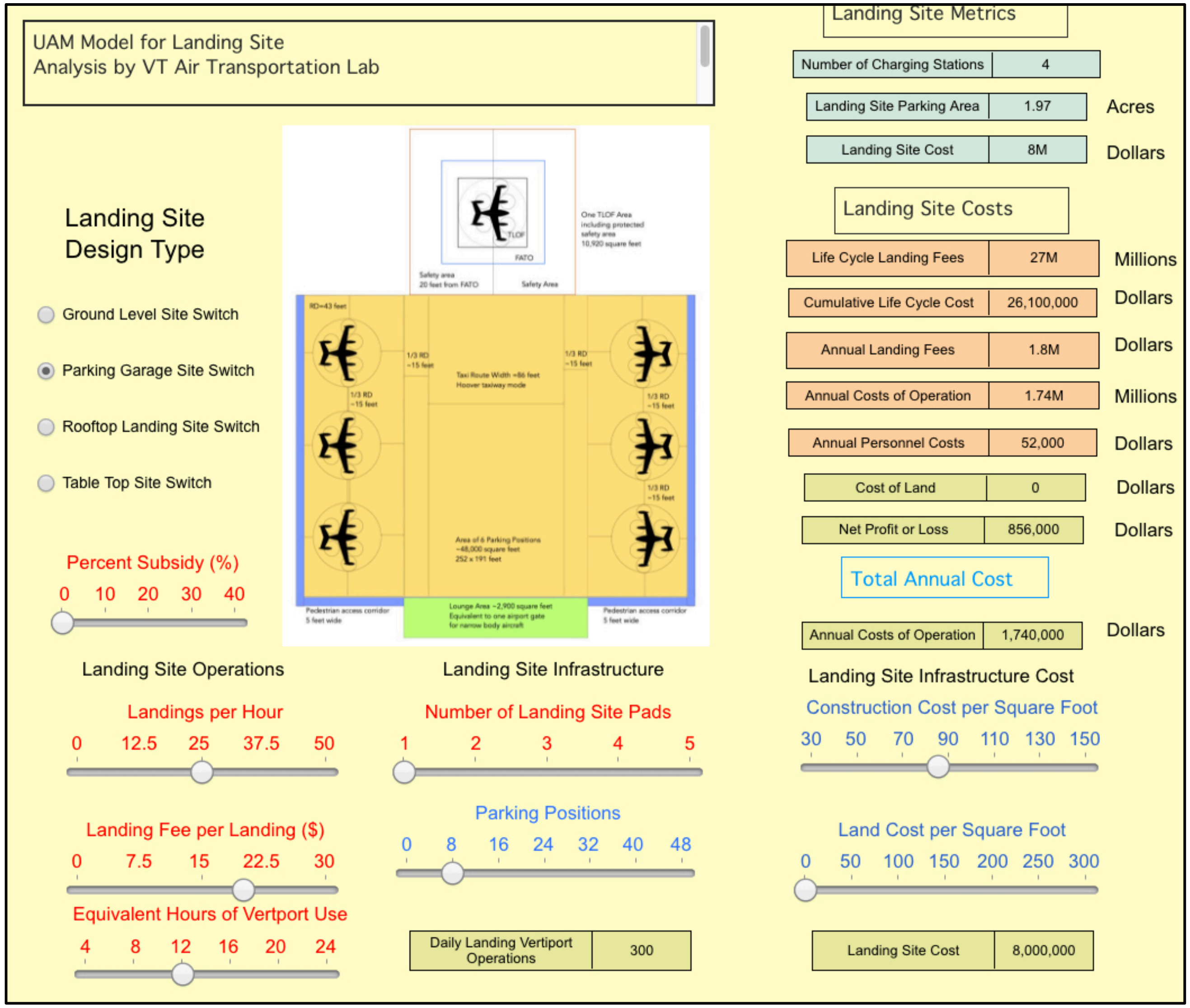




UAM Landing Site Life-Cycle Cost Model

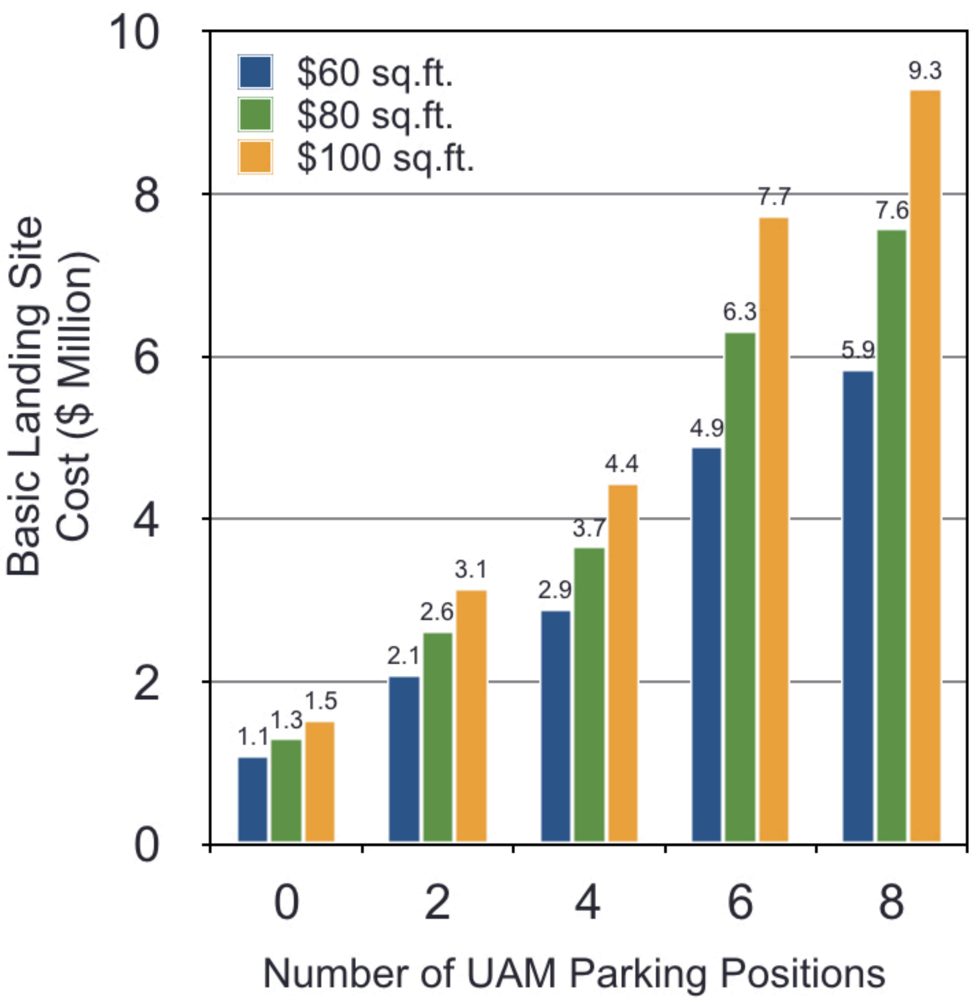
The building blocks of the life-cycle cost model include the following:

- Landing area type (vacant land, rooftop, parking lot)
- Critical vehicle dimensions
- Number of landing pads
- Number of parking stalls
- Number of charging stations
- Staffing of landing site
- Lounge areas for waiting passengers
- Lighting requirements
- Number of hours of operation per day for the landing site)
- Landing fees
- Percent subsidy to build the landing site

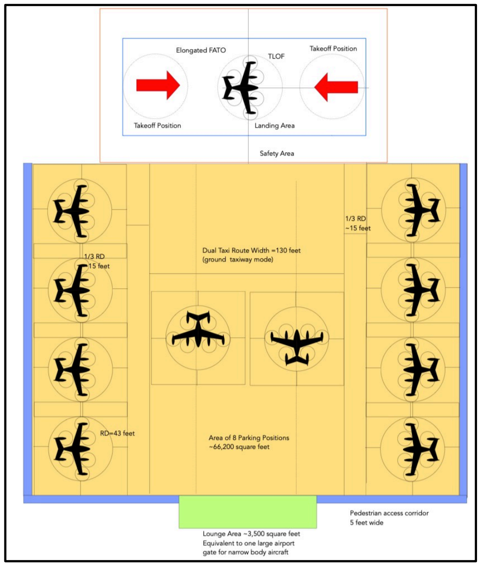


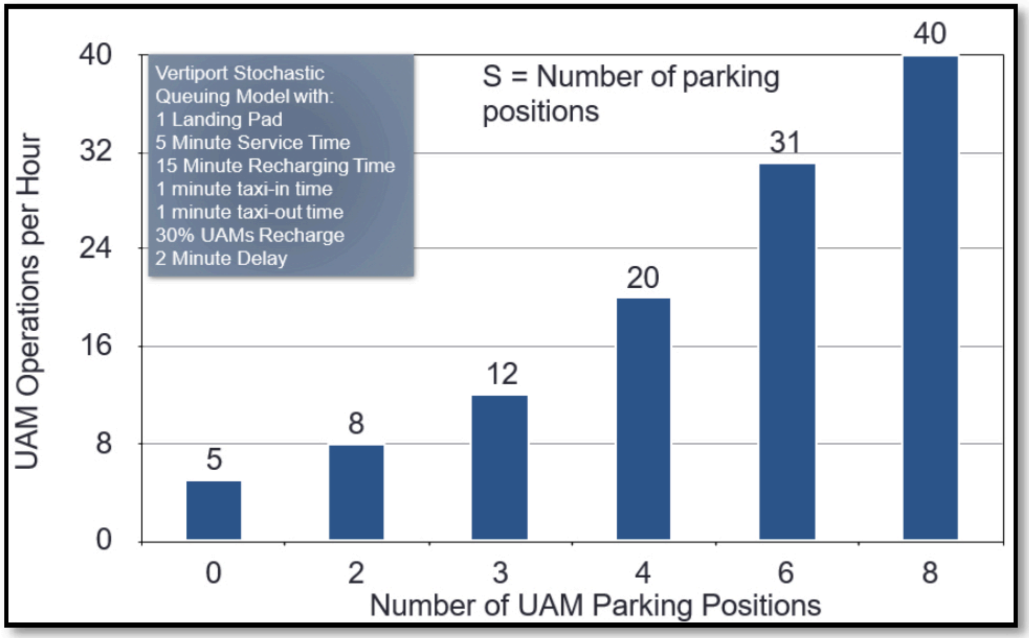
Model developed in STELLA Author

UAM Vertiport Capacity and Cost Analysis



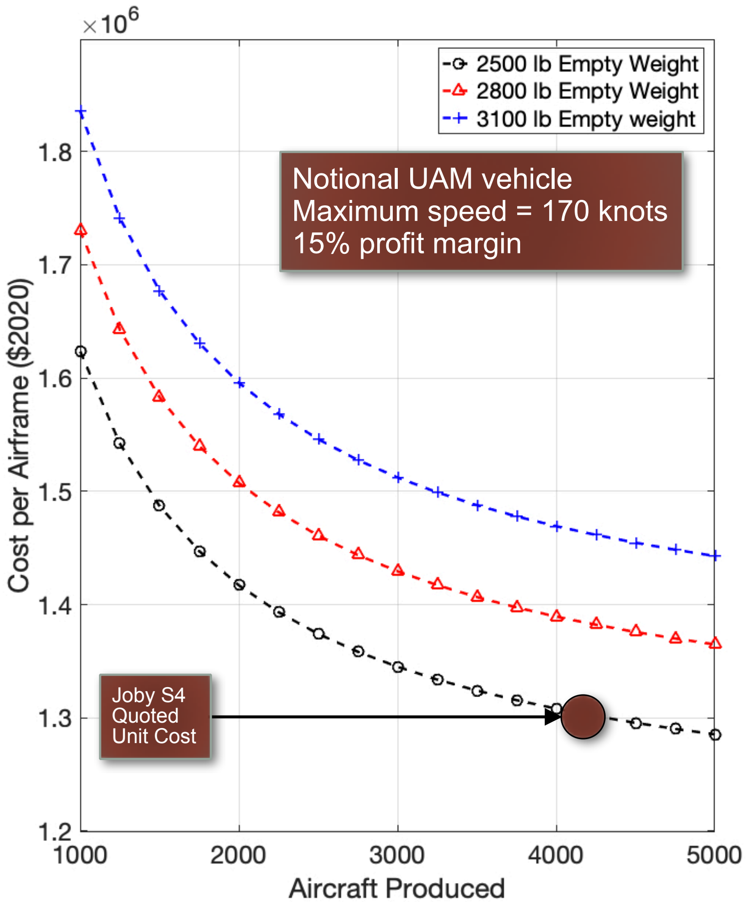
Stochastic Queueing Model with:
1 Landing Pad
8 Parking Positions
5 Minute Service Time
15 Minute Recharging Time
1 minute taxi-in time
1 minute taxi-out time



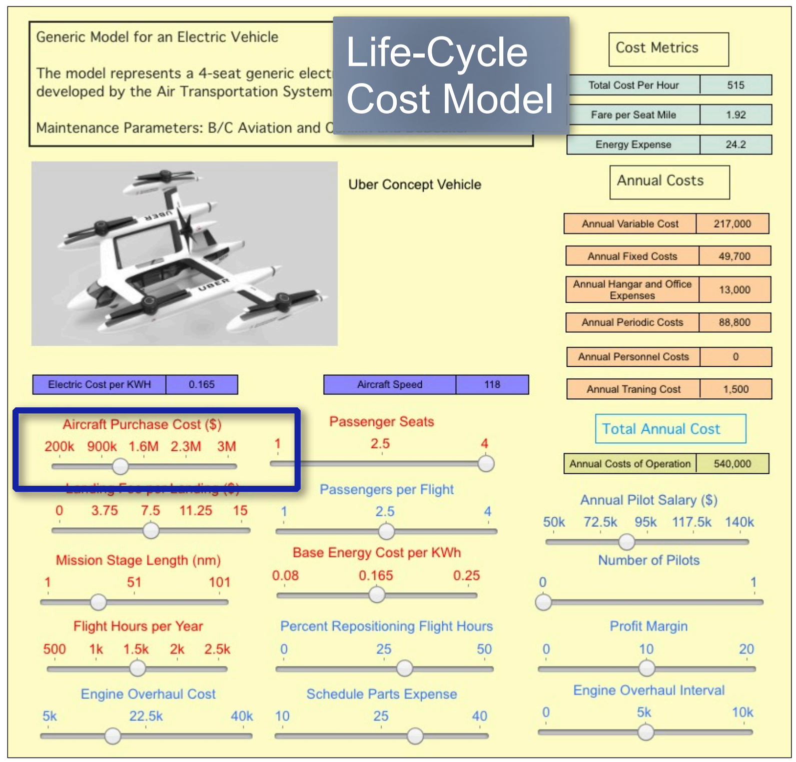


UAM Vehicle Development Cost and Operational Cost Models

UAM Vehicle Development and Operational Life Cycle Cost Models



Aircraft development cost equations adapted from Nicolai and Carichner (2012)



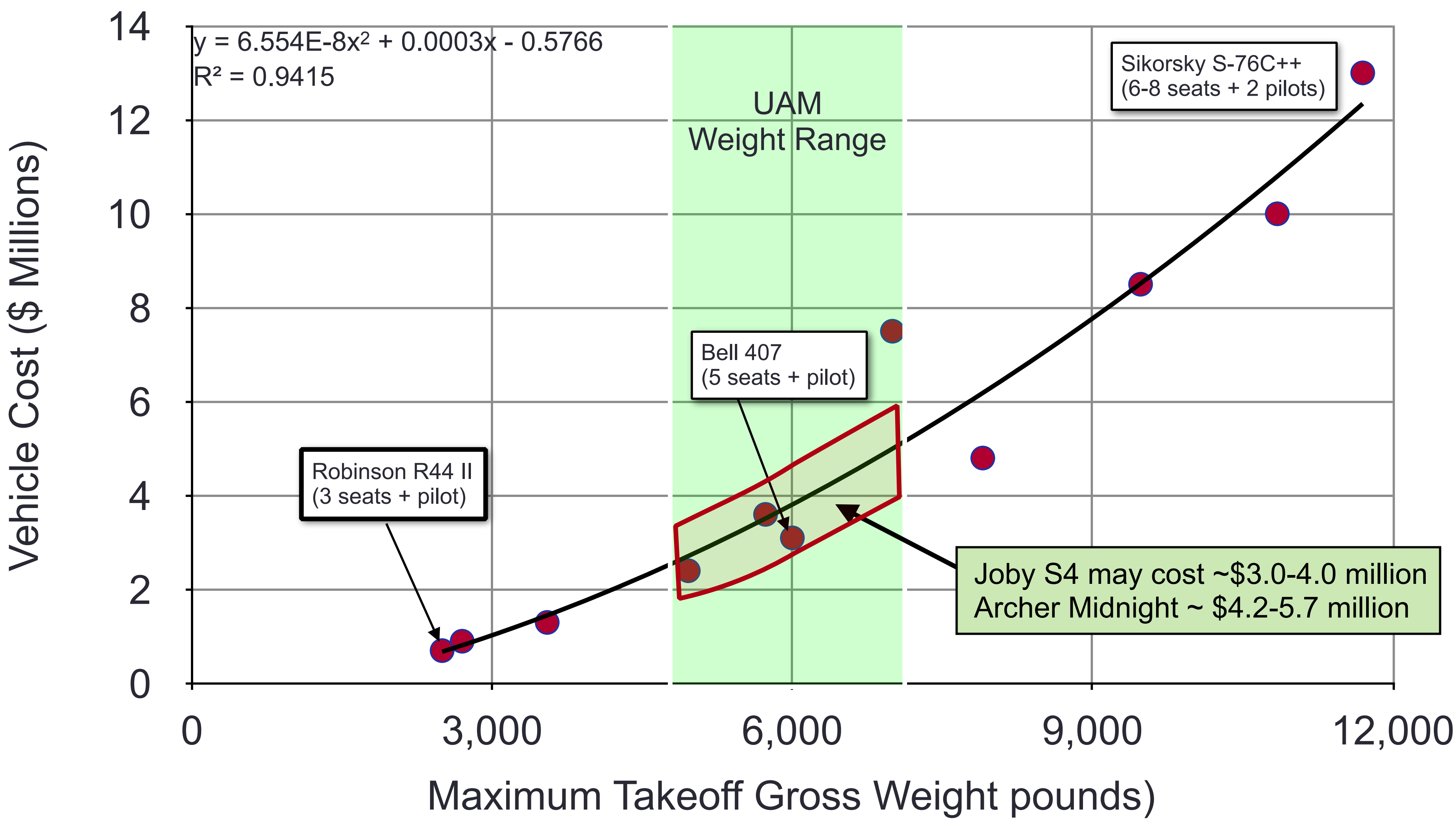
Maintenance data adapted from Conklin and deDecker (rotorcraft technology)

UAM aircraft life-cycle cost model include the following:

- Vehicle unit cost
- Number of annual operations
- Maintenance hours per flight hour
- Engine overhaul costs
- Time between overhauls
- Landing fee per landing
- Percent of repositioning flights
- Energy consumption performance (vs. block speed)
- Energy cost ($/kW-hr)
- Hangar cost
- Pilot vs no pilot switch
- Avionics and interior refurbishing costs
- Load factor per flight
- Depreciation
- Life-cycle time

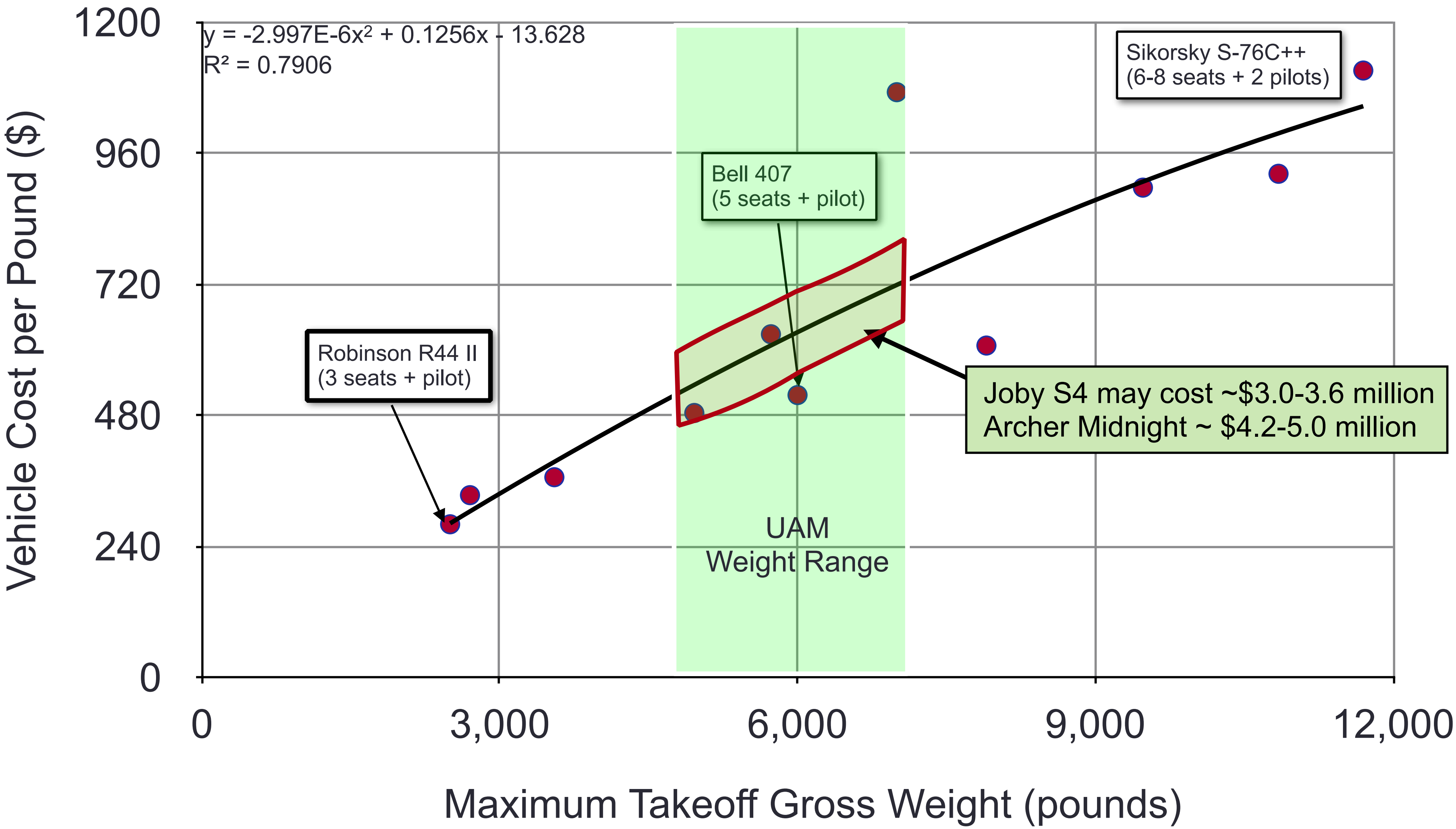
Joby's projections are optimistic because they assume Large numbers of aircraft produced

VTOL Technology Cost is Quadratic with MTGOW



Considering battery weight, UAM technology may follow the same weight and cost trends

VTOL Technology Costs per Pound



UAM Vehicle Costs in the Literature

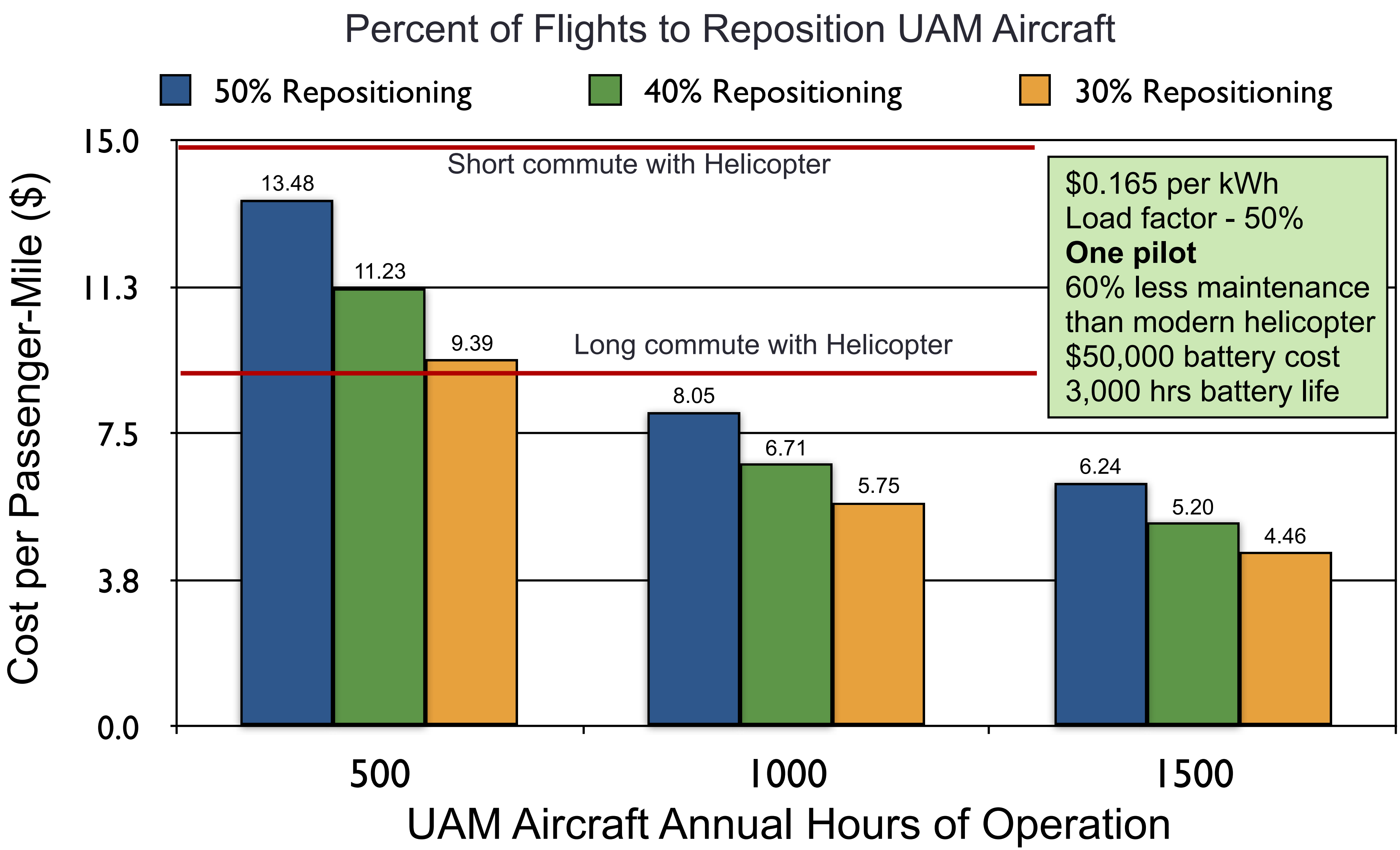
Source		UAM Cost per Passenger Mile ($)	Trip Purpose
Lilium		$4.40	Airport
Joby Aviation		$3.80	Not Specified
Ehang		$2.28 - $2.74 Per Available Seat Mile	Not Specified
BAH (5-seat eVTOL)		$6.25 (near-term) $2.5 (long-term)	General
Goyal et al. (2021)		~$2.50 - $2.85	General
Archer		$3.0 - $4.0	Airport
LEK		$7.68 (2025) $1.76 (2040)	General
Brown and Harris (2020)	Lift + Cruise Compound Heli Tilt Wing Tilt Rotor	$4.86 $5.12 $4.33 $3.80	Not Applicable (Systems Study)

Source: Air Traffic Management Exploration (ATM-X) UAM Demand Analysis: Deliverable 1.2

UAM Operational and Cost Uncertainties

1. UAM vehicle production and certification costs
2. Maintenance costs and cycles
   - UAM engines are electric and, in principle, are more reliable
   - UAM aircraft have 6-12 engines that need to be maintained
     - Even with high Mean Time Between Failures (MTBF) for the engines, many engines would require spares and maintenance actions
3. No-pilot option would require additional redundancy in systems for certification (an additional cost)
   - Additional automation cost would be needed for certification under remote pilot operations (assuming a pilot supervises/controls multiple UAM vehicles)
4. Battery life and costs
   - Our analysis uses $50,000 to replace batteries after 3,000 hrs
5. Design for large number of daily cycles
   - Experience shows that commercial aircraft are designed for 40-60K cycles
   - It is unclear UAM aircraft would be economical if designed for 10-20K cycles
   - Blade helicopters (Bell 407) typically do 8-10 missions a day

Four-Seat UAM ($3 Million Dollar Unit Cost)



Analysis using the Virginia Tech UAM Life Cycle Cost model

Blade Services to Airports in New York

- **$195 per seat from Manhattan to JFK airport ($15/passenger mile)**
  - Bell 407 helicopters (single engine) operated under 14 CFR 135
  - Five passenger seats (1 pilot + 5 passengers configuration)
  - Typical six minute trip from JFK to two Manhattan heliport locations
  - Typical daily use of Bell 407 helicopters is 177 minutes (2.95 hrs)
  - **12,000 passengers per year (40 passengers per day)**

Bell 407 helicopter
Single Allison 250-C47B engine (813 HP)
6,000 lbs. maximum takeoff weight

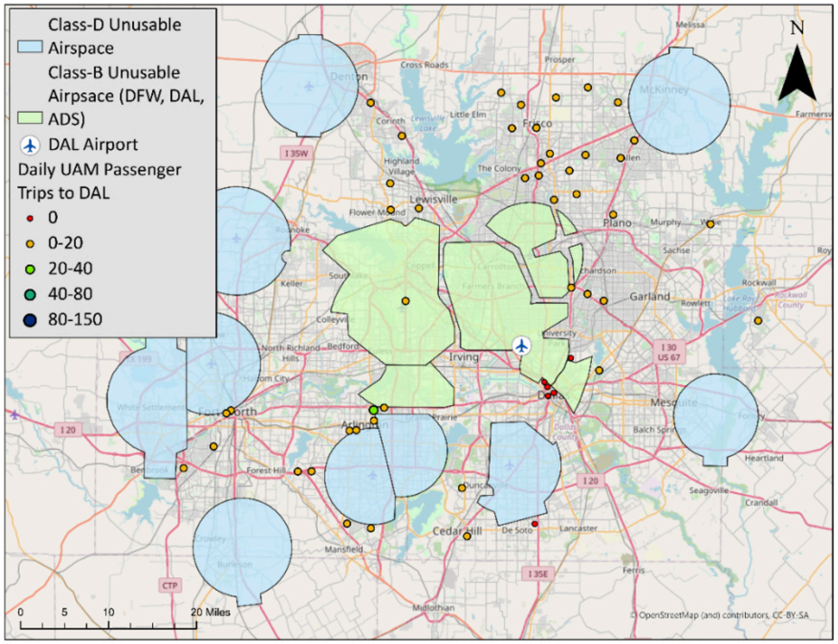
Blade Lounge East
East 34th Street with two
Sikorsky S-76C++ helicopters

Calibrated UAM Demand Models

Calibrated Logit and Mixed Logit Models to Predict UAM Demand

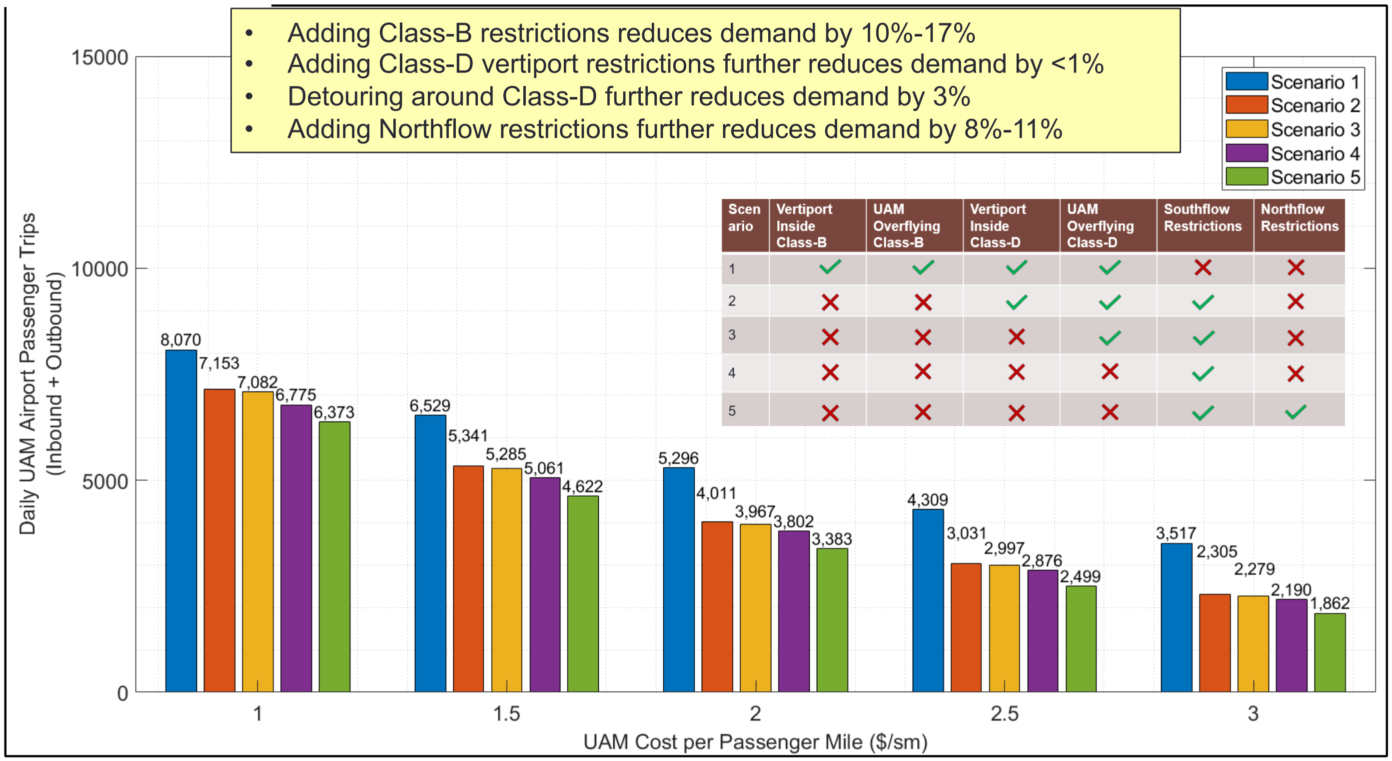
Metropolitan Area	UAM Model	Model Structure	Attributes Considered	Model Scope	Value of Time
Northern California	Commuter trips	Mixed Conditional Logit	In-vehicle travel time, Out-of-vehicle travel time, Number of transfers. Income level (3 categories)	4.3 million commuters 17 counties around San Francisco Bay Area	Out-of-Vehicle VOTs Low Income $15.7/hr Medium Income $18.22/hr High Income $29.30/hr
	Cargo	Parametric Market Share Model	High value goods	High-value air freight Time-sensitive shipments	Not applicable
Southern California	Commuter trips	Mixed Logit Model	Travel time, number of transfers,	9.1 million commuter trips 15 counties	
	Airport trips	Conditional Logit Models	Travel time, Travel cost, Resident, Non-resident, Business, Non-business, submodes constants	99,250 daily airport trips	Business travelers $52/hr. Non-business travelers $22/hr.
	Cargo	Parametric - Market Share Model	High value goods	High-value air freight Time-sensitive shipments	Not applicable
Dallas-Forth Worth	Commuter trips	Mixed Logit Model	Travel time, number of transfers	2.9 million commuter trips	
	Airport trips	Conditional Logit Models	Travel time, Travel cost, Resident, Non-resident, Business, Non-business, submodes constants	45,750 daily airport trips	Business travelers $57/hr. Non-business travelers $36/hr.
Miami	Commuter trips	Mixed Logit Model calibrated in Northern California	Travel time, number of transfers	2.5 million commuter trips	
	Airport trips	Conditional Logit Models	Travel time, Travel cost, Resident, Non-resident, Business, Non-business,	35,600 daily airport trips	Business travelers $57/hr. Non-business travelers $36/hr.

Class B Airspace Restrictions Reduce Airport UAM Trip Demand by 17% in the Dallas Area



- Longer UAM travel times due to airspace class B and D restrictions affect trip cost
- UAM vertiport placement affected by airspace restrictions

Airspace restrictions developed by NASA Ames Research Center



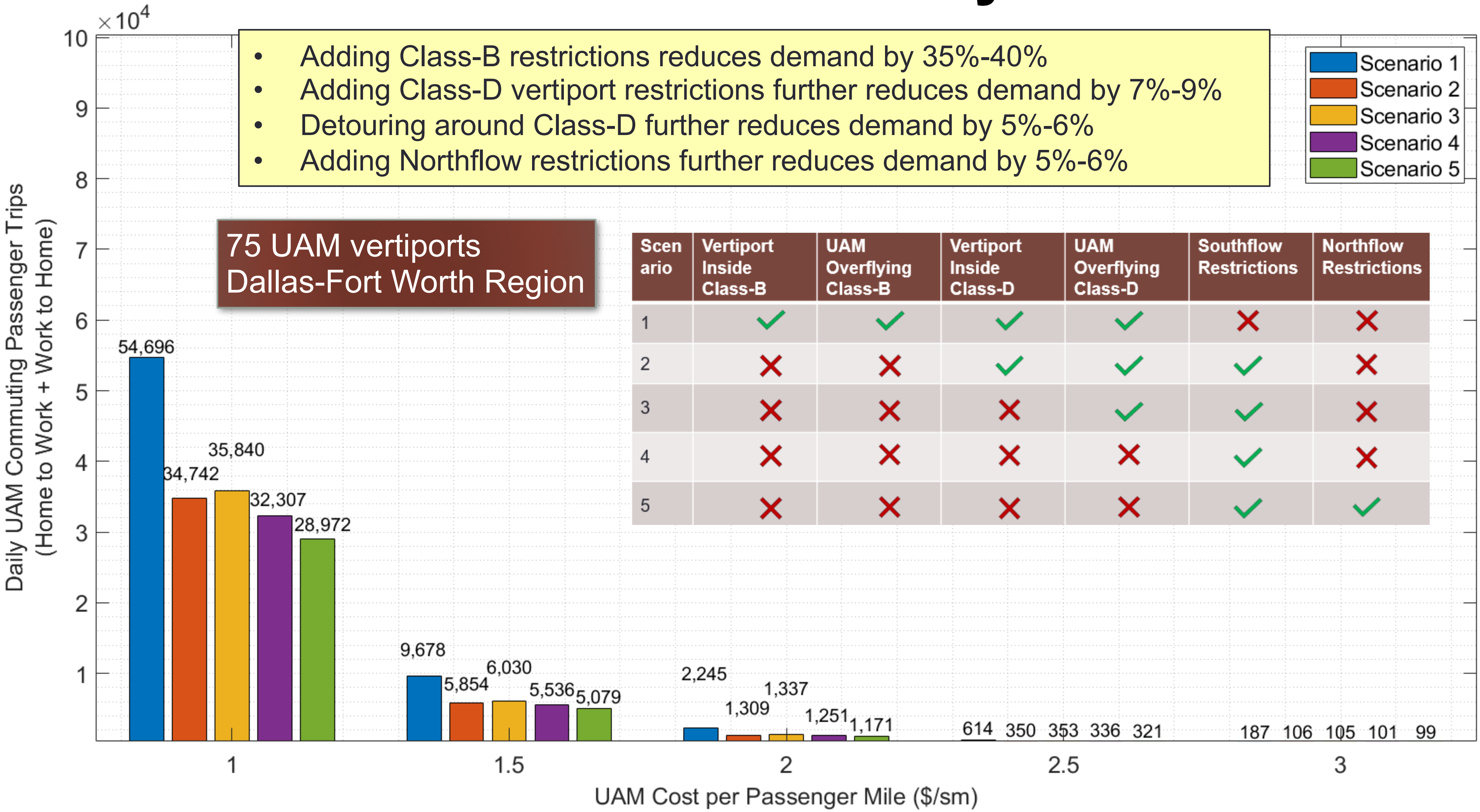
Scenario	Vertiport Inside Class-B	UAM Overflying Class-B	Vertiport Inside Class-D	UAM Overflying Class-D	Southflow Restrictions	Northflow Restrictions
1	✓	✓	✓	✓	✗	✗
2	✗	✗	✓	✓	✓	✗
3	✗	✗	✗	✓	✓	✗
4	✗	✗	✗	✗	✓	✗
5	✗	✗	✗	✗	✓	✓

Class B Airspace Restrictions Reduce UAM Commuter Demand by 40%

- Adding Class-B restrictions reduces demand by 35%-40%
- Adding Class-D vertiport restrictions further reduces demand by 7%-9%
- Detouring around Class-D further reduces demand by 5%-6%
- Adding Northflow restrictions further reduces demand by 5%-6%

75 UAM vertiports
Dallas-Fort Worth Region

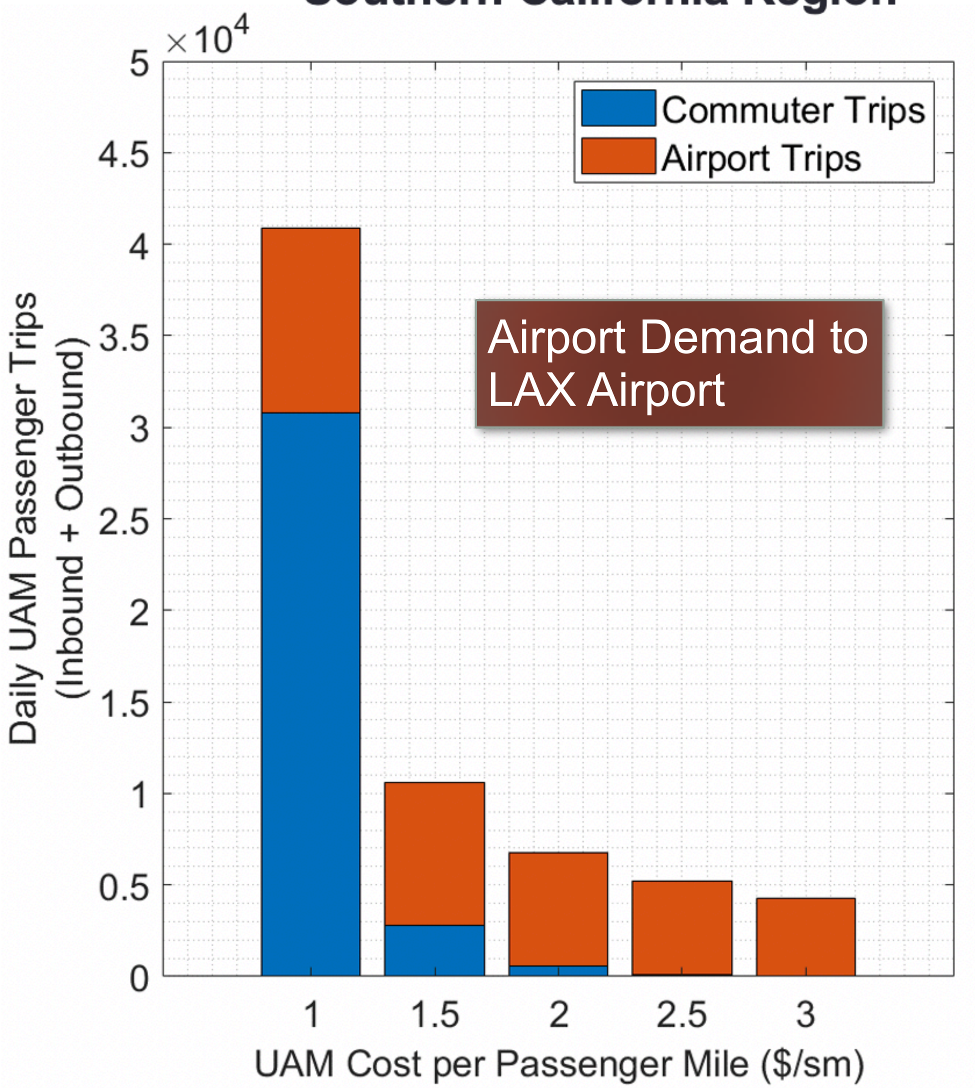
Scenario	Vertiport Inside Class-B	UAM Overflying Class-B	Vertiport Inside Class-D	UAM Overflying Class-D	Southflow Restrictions	Northflow Restrictions
1	✓	✓	✓	✓	✗	✗
2	✗	✗	✓	✓	✓	✗
3	✗	✗	✗	✓	✓	✗
4	✗	✗	✗	✗	✓	✗
5	✗	✗	✗	✗	✓	✓



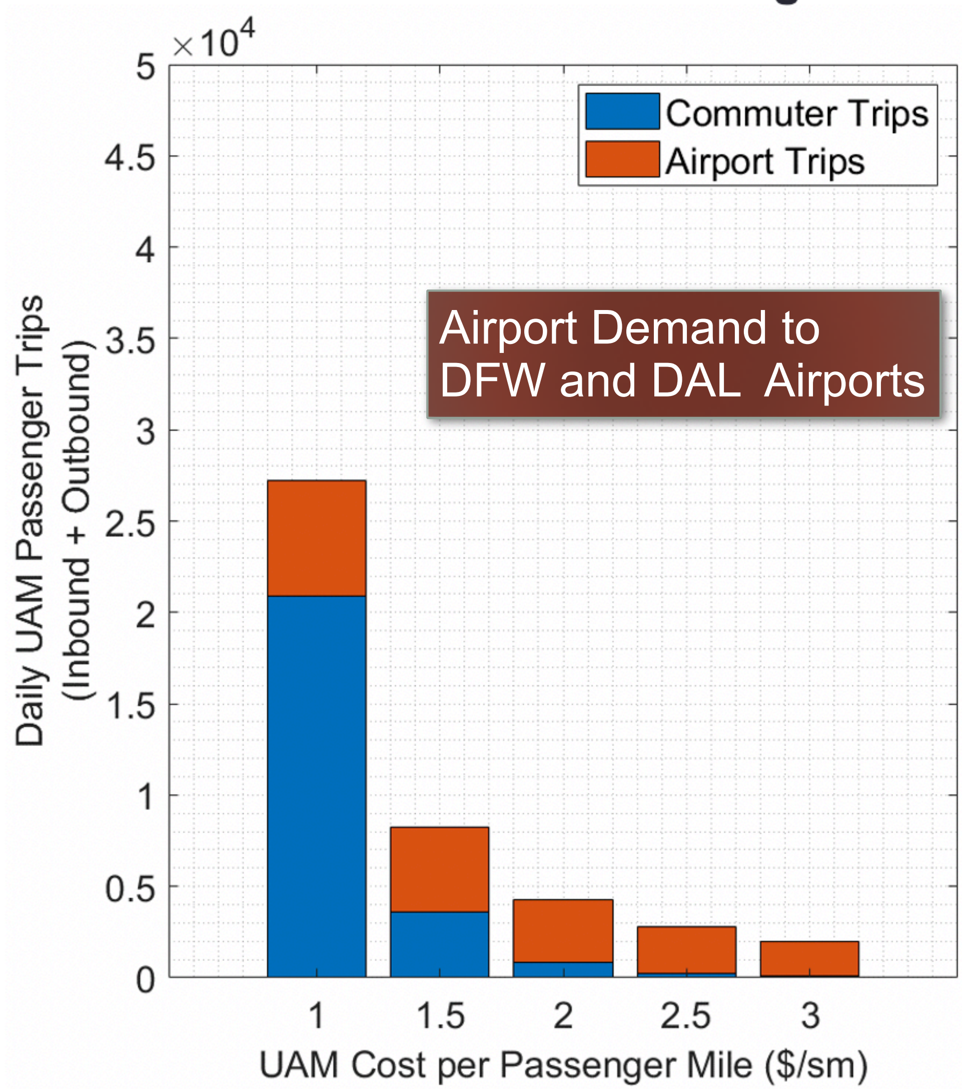
At $3 per Passenger-Mile and Airspace Restrictions UAM Trips to Airport Remain Feasible

50 UAM vertiports and airspace restrictions

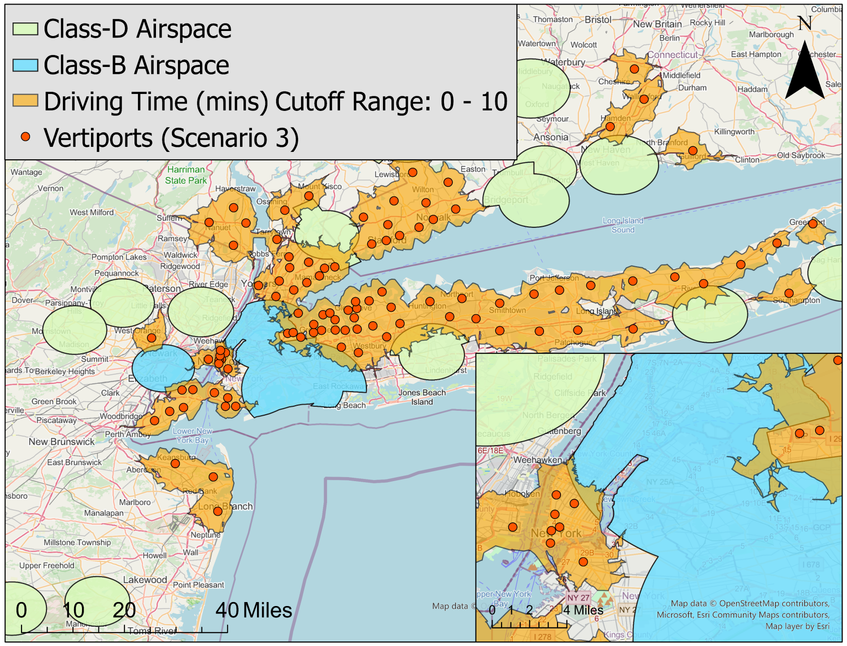
Southern California Region



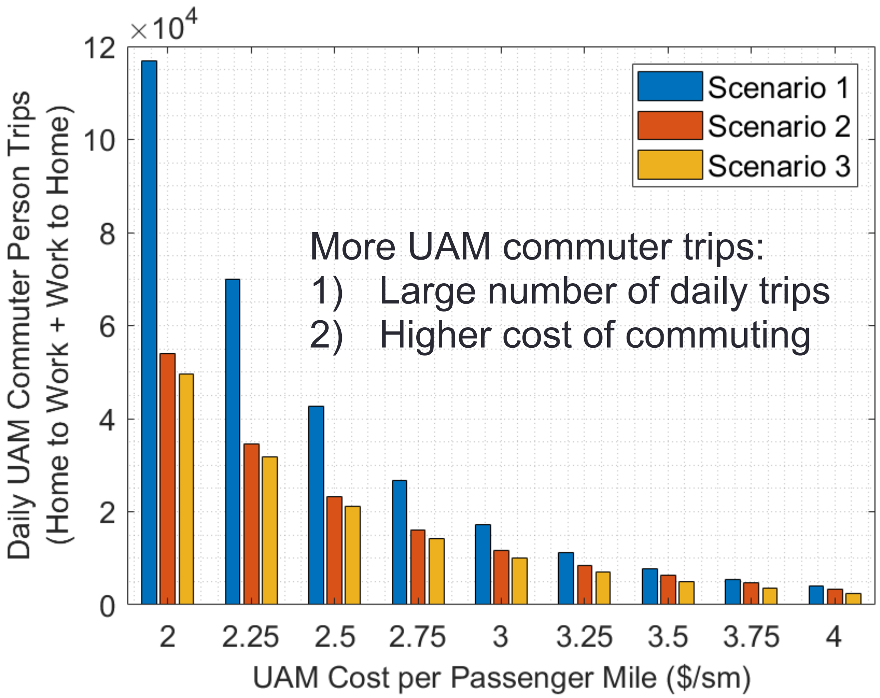
Dallas-Fort Worth Region

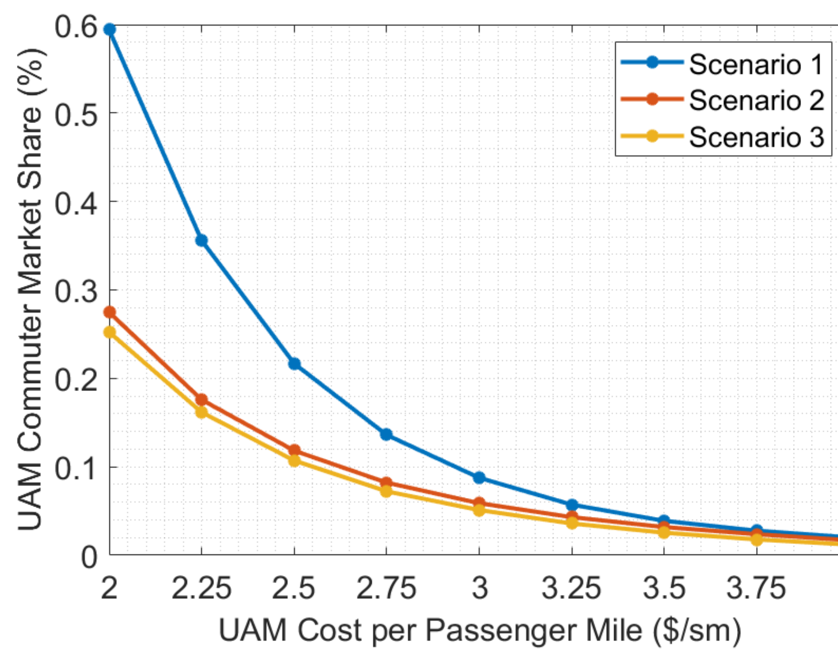


For New York Commuter Demand is Reduced by 55% if Airspace Restrictions are Applied



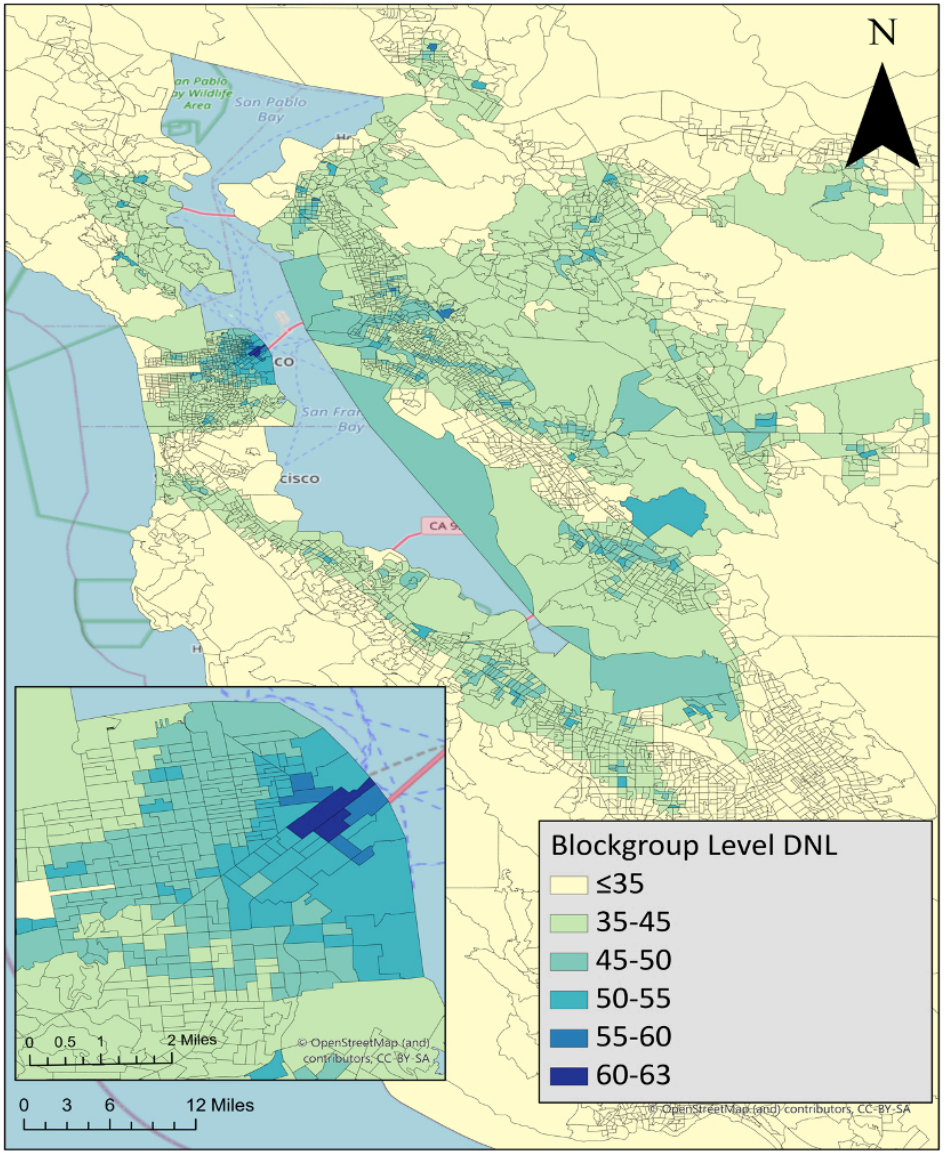
Scenario	Restrictions	
	Vertiport Placement	**UAM Overflying**
Scenario 1	None	None
Scenario 2	Only in Class-B Airspace	Only in Class-B Airspace
Scenario 3	In Class-B and Class-D Airspace	In Class-B and Class-D Airspace



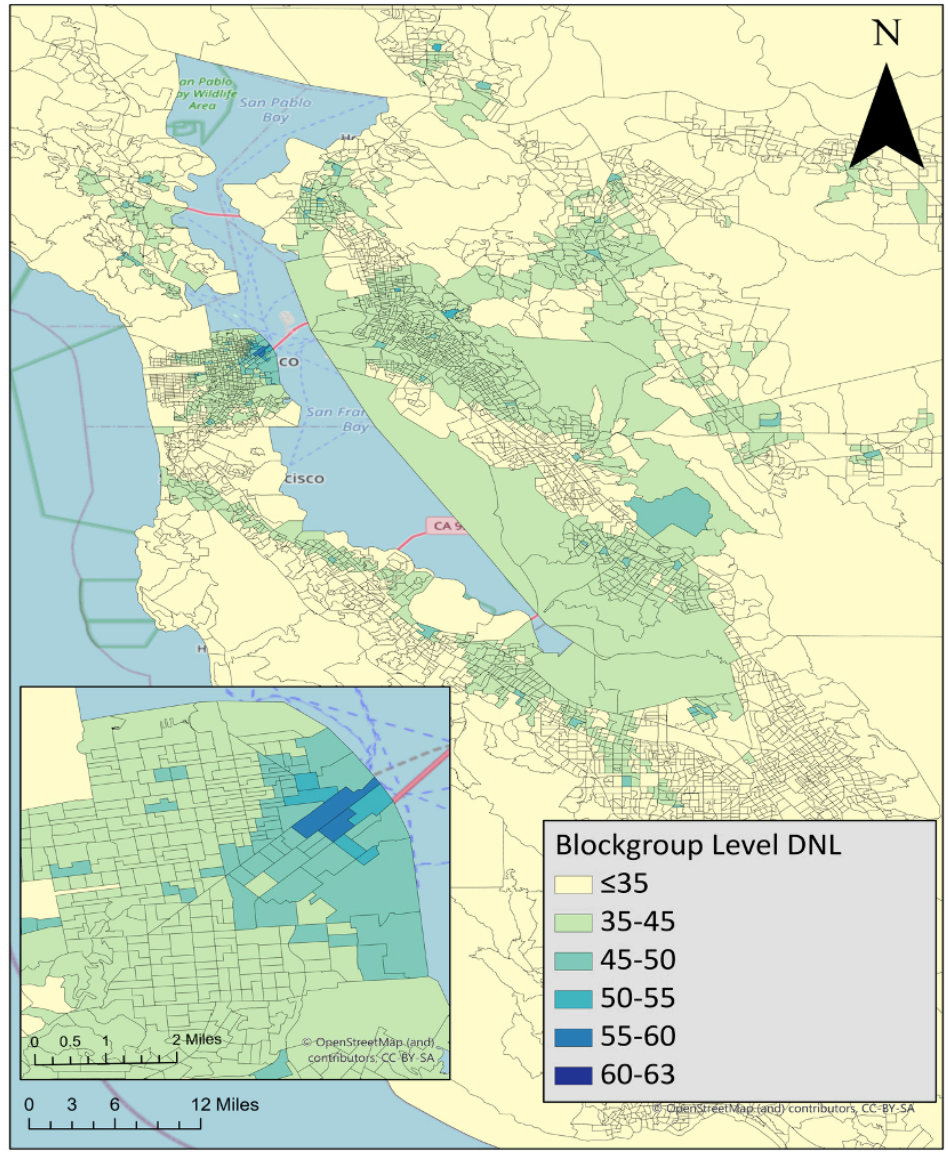


VirginiaTech
Invent the Future

Preliminary Assessment of UAM Noise (Northern California)



10 dBA Reduction compared to R44

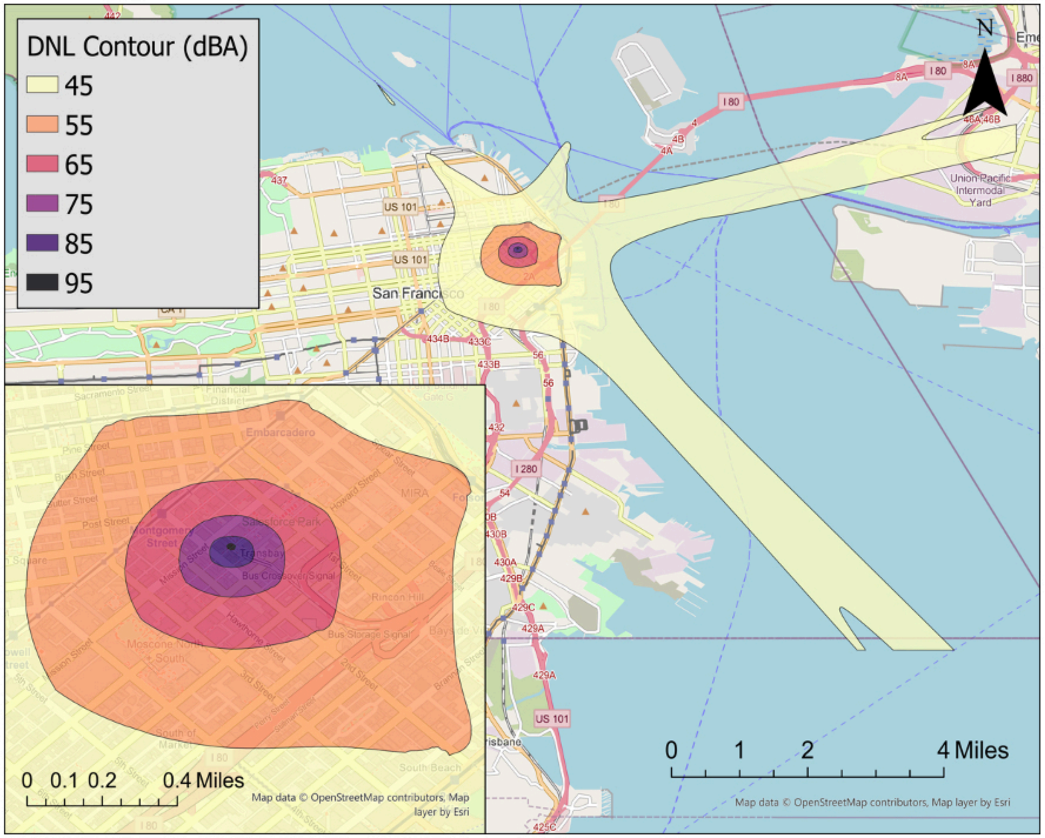


15 dBA Reduction compared to R44

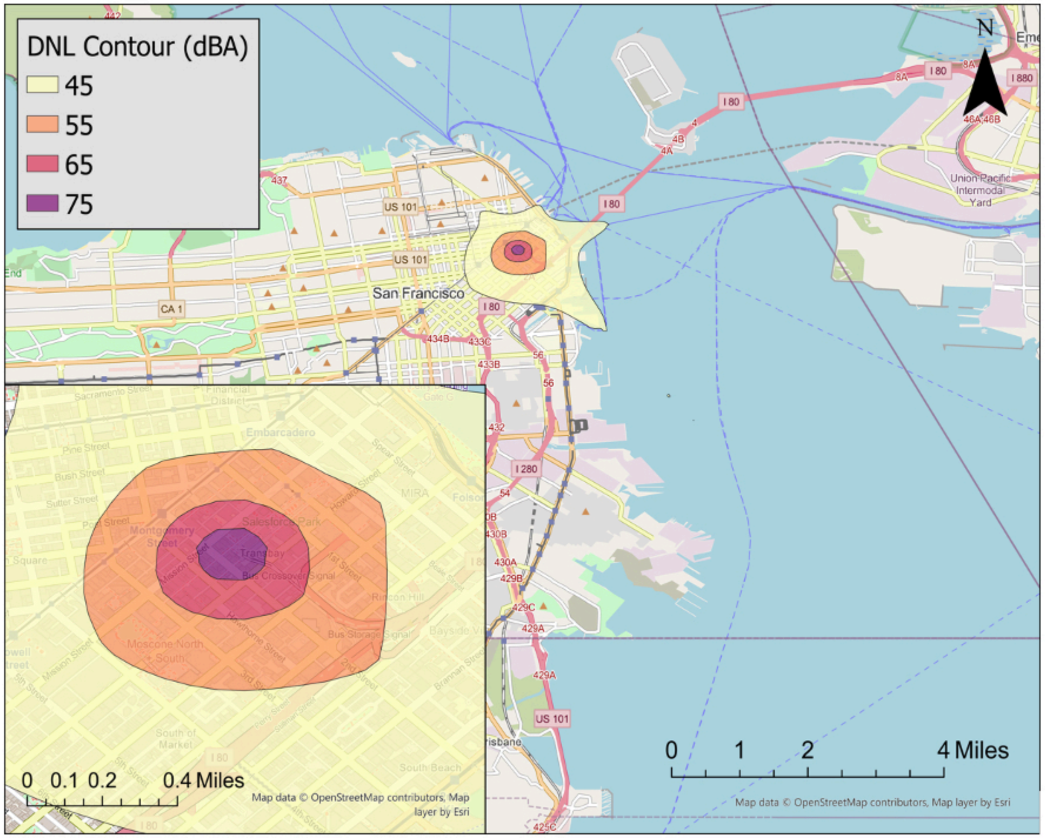
Noise Impacts Using the FAA Aviation Environmental Design Tool Analysis

900 daily UAM operations

DNL	Area under DNL Contour (sq. mi.)		Population under DNL Contour		Highly Annoyed Population	
Reduction Scenario	10-dBA	15-dBA	10-dBA	15-dBA	10-dBA	15-dBA
45	10.89	1.81	110,811	28,764	21,133	5,485
55	0.70	0.33	11,655	4,213	5,687	2,055
65	0.16	0.08	1,596	677	1,267	537
75	0.03	0.0155	272	93	256	87
85	0.006	-	2	-	2	-
95	0.0002	-	-	-	-	-



15 dBA Reduction compared to R44



10 dBA Reduction compared to R44

Conclusions

- An integrated approach to study UAM operations has been developed
  - Model considers landing site placement, landing site cost and capacity limits
  - UAM demand is estimated using Conditional Logit or Mixed Logit models
- For UAM to be successful, the analysis shows cost per passenger mile needs to be contained at or below $3 per passenger-mile
- Beyond $3 per passenger mile, the commuter demand is relatively low
  - New York may see a few hundred person trips of airport demand in the $5-7 per passenger mile range (high driving cost and high congestion)
- Airspace restrictions result in 20-55% fewer demand trips compared to unrestricted scenarios investigated

Relevant Technical Publications

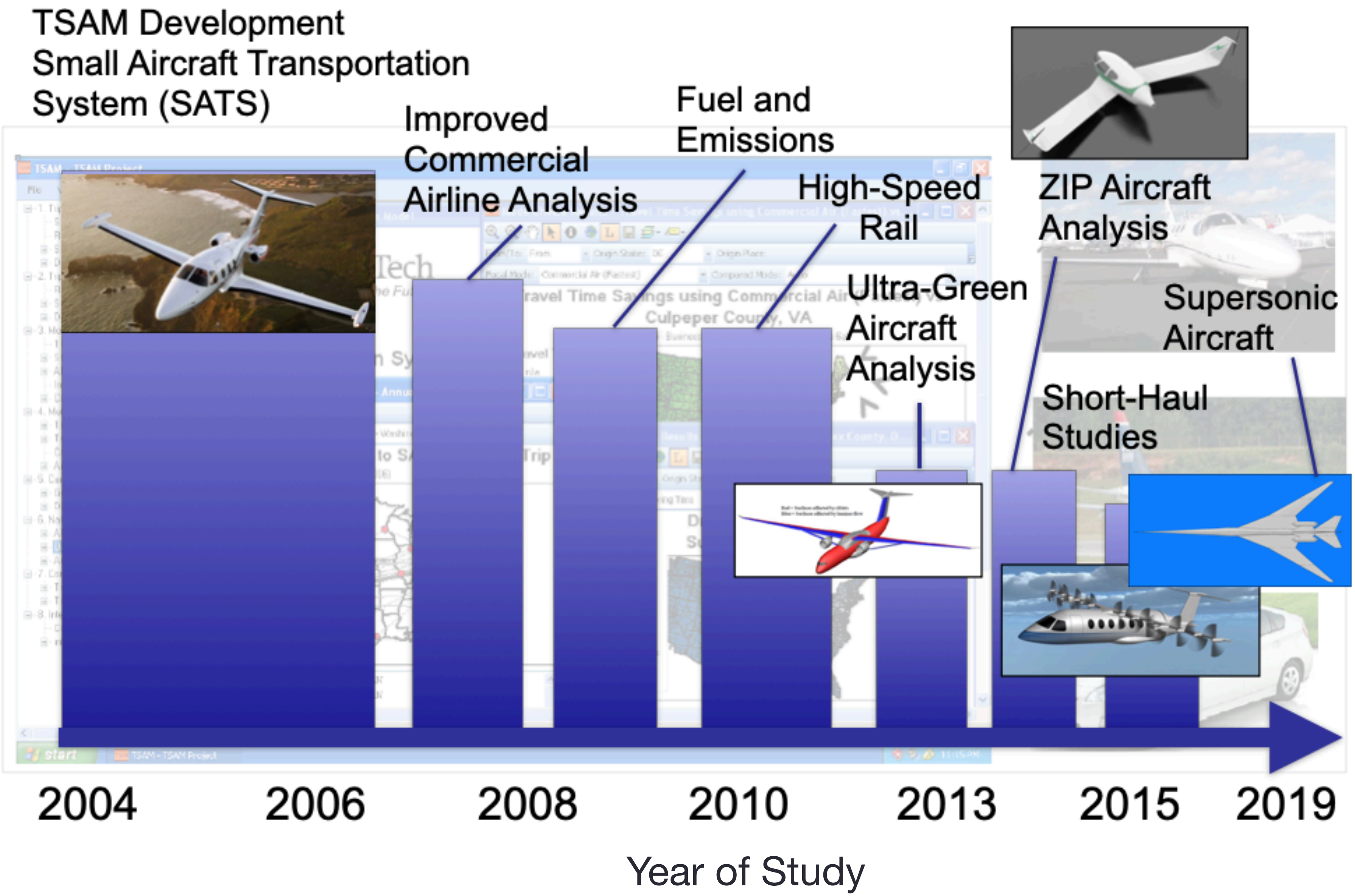
1. Rimjha, M., A., Trani, and S. Hotle, Urban Air Mobility: Preliminary Noise Analysis of Commuter Operations, AIAA 2021, July28, 2021, American Institute of Aeronautics and Astronautics, https://doi-org.ezproxy.lib.vt.edu/10.2514/6.2021-3204
2. Rimjha, M., Hotle, S., A., Trani, A.A, Hinze, N. and J. Smith, Urban Air Mobility Demand Estimation for Airport Access: A Los Angeles International Airport Case Study, Integrated Communications, Navigation and Surveillance Conference, ICNS, v 2021, April 19-23, 2021, Institute of Electrical and Electronics Engineers Inc.
3. Rimjha, MA. And A.A. Trani, Urban Air Mobility: Factors Affecting Vertiport Capacity, Integrated Communications, Navigation and Surveillance Conference, ICNS, v 2021, April 19-23, 2021, Institute of Electrical and Electronics Engineers, Inc.
4. Rimjha, M., Hotle, S., Trani, A.A, and Hinze, N., Commuter Demand Estimation and Feasibility Assessment for Urban Air Mobility in Northern California, Transportation Research Part A: Policy and Practice, Volume 148, June 2021, Pages 506-524, Elsevier (https://doi.org/10.1016/j.tra.2021.03.020).
5. Sayantan, T., Rimjha, M., Hinze, N., Hotle, S. and Trani, A. A. Urban Air Mobility Regional Landing Site Feasibility and Fare Model Analysis in the Greater Northern California Region, Integrated Communications, Navigation and Surveillance Conference, ICNS, v 2019-April, April 2019.
6. Rimjha, M., Tarafdar,S.,Hinze, N., Trani, A.A., Swingle, H., Smith, J., Marien, T., and S. Dollyhigh., On-Demand Mobility Cargo Demand Estimation in Northern California Region, Integrated Communications, Navigation and Surveillance Conference, v 2020-September, September 2020, Institute of Electrical and Electronics Engineers, Inc.
7. Syed, N., Rye, M., Ade, M., Trani, A., Hinze, N., Swingle, H., Smith, J., Dollyhigh, S. & Marien, T. (2017). Preliminary Considerations for ODM Air Traffic Management based on Analysis of Commuter Passenger Demand and Travel Patterns for the Silicon Valley Region of California. In 17th AIAA Aviation Technology, Integration, and Operations Conference (p. 3082), https://doi.org/10.2514/6.2017-3082

Transportation Systems Analysis Model (TSAM)

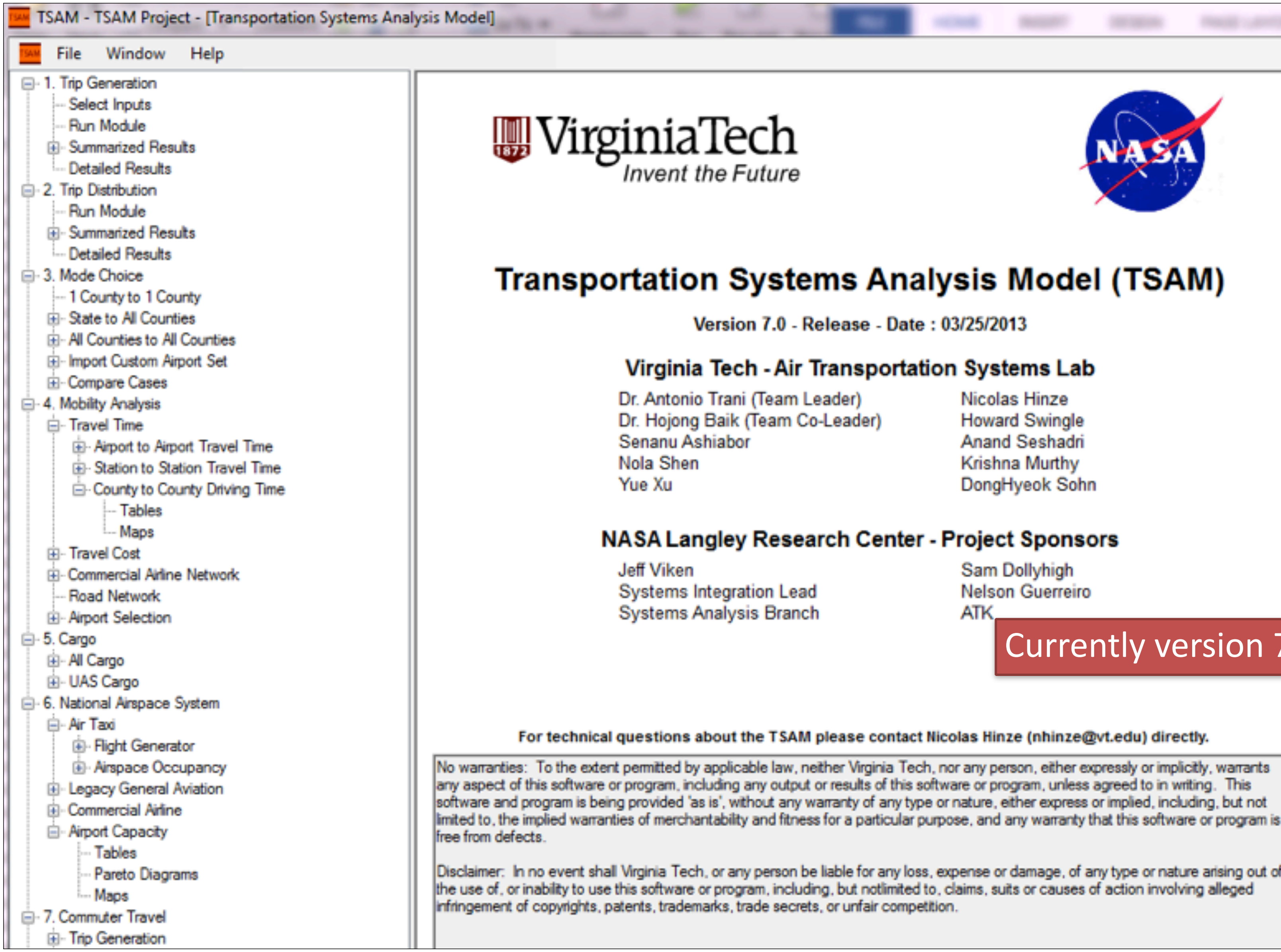
The TSAM Model

- 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.
- Employs a multi-step, multi-modal transportation planning framework where trips are: produced, distributed, split into modes, and assigned to routes
- TSAM model can predict intercity travel in the presence of multi-mode alternatives (auto, commercial air, high-speed rail and air taxi modes)
- Mode choice of travelers based on trip characteristics (business and noon-business) and traveler demographics (income level)
- Mode choice is sensitive to vehicle performance, level of service and mode cost characteristics
- County-to-county spatial model
- Accepts user-defined airport sets
- Mode has airport capacity curves derived using the Enhanced Airfield Capacity

Application of the TSAM Model

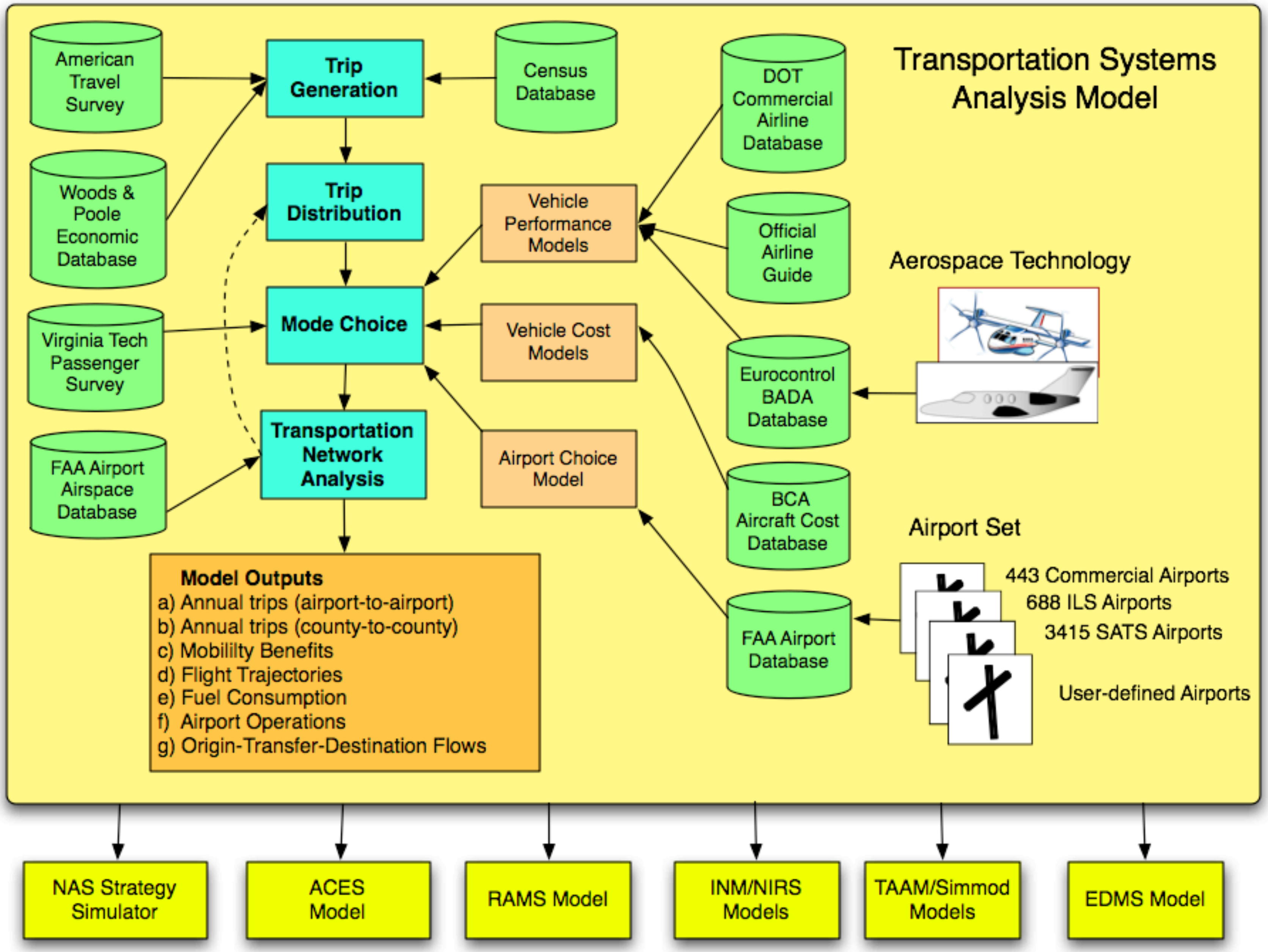


TSAM is a 64-bit Stand-alone Application

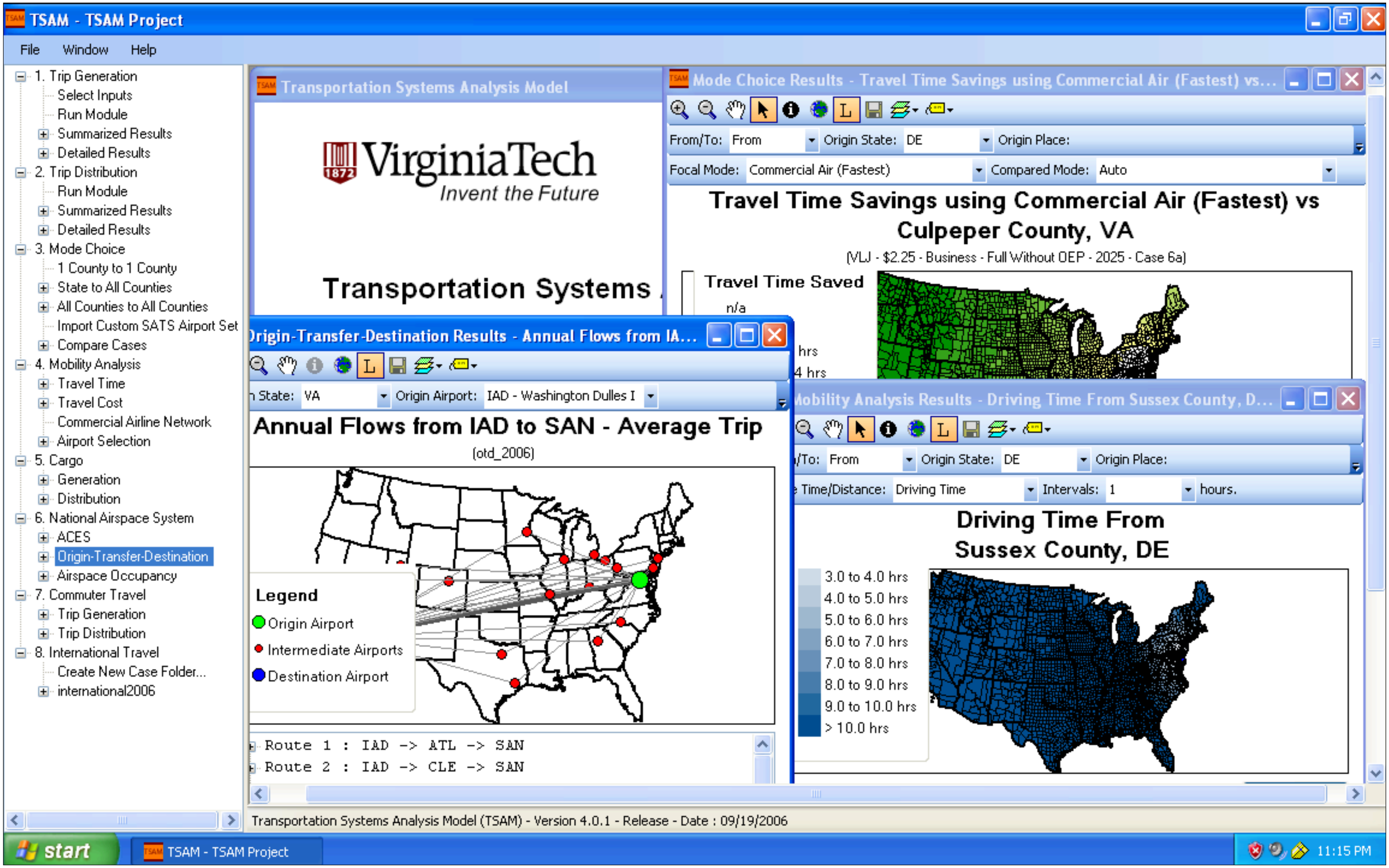


Currently version 7.7

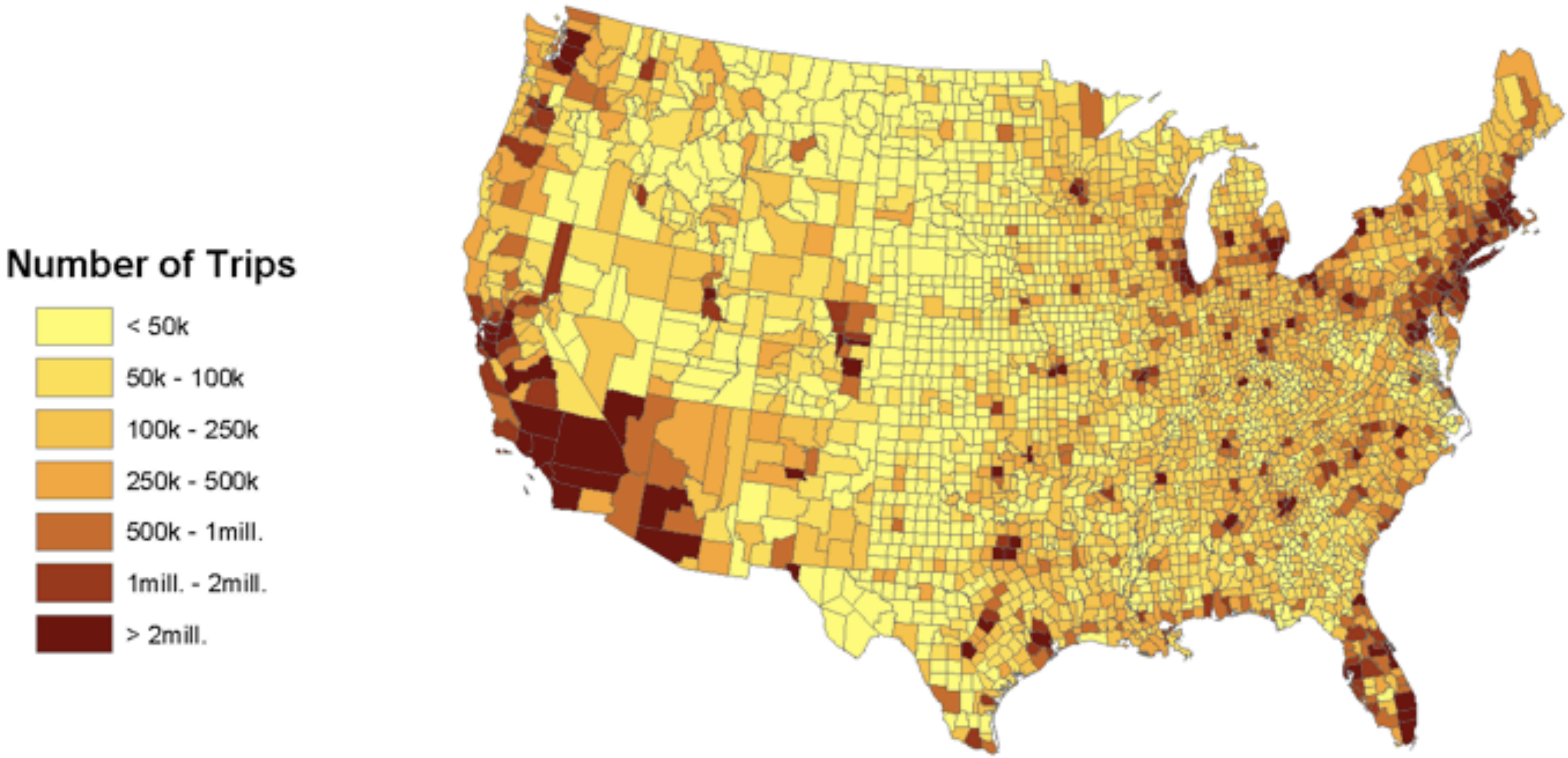
TSAM Model Flowchart



TSAM Computer Model Application

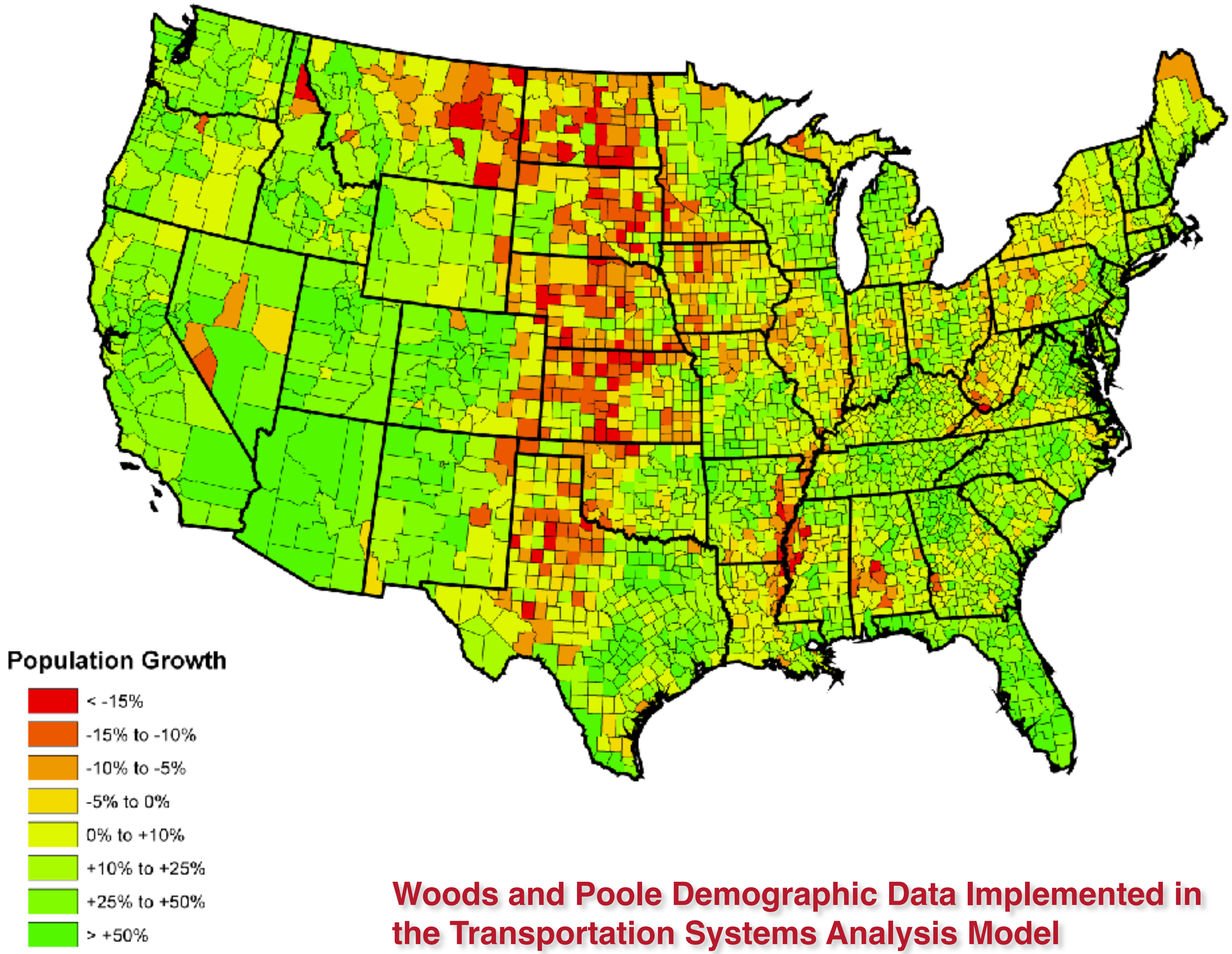


TSAM Trip Generation



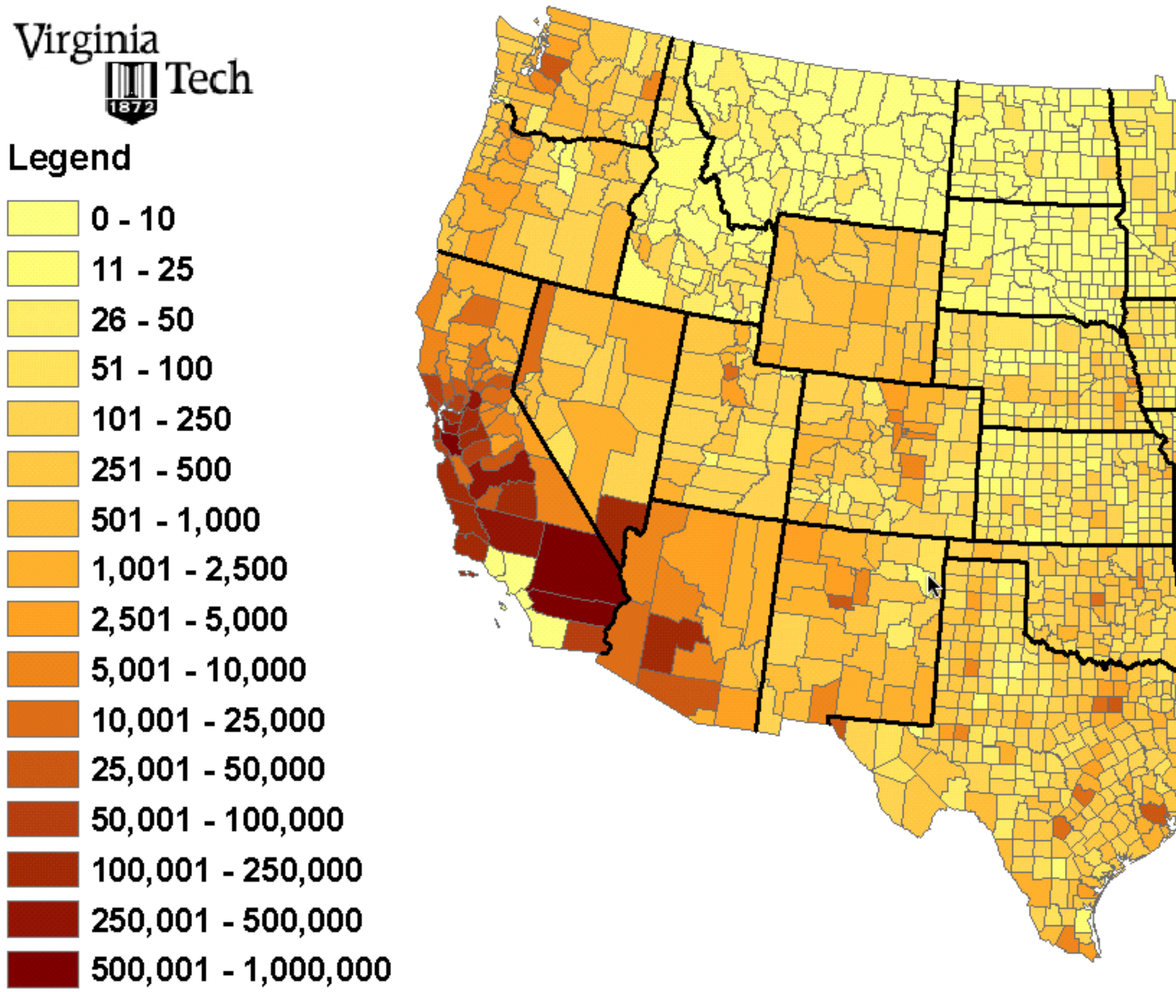
Total Intercity Trips Generated by County (Business + Non-Business Trips)

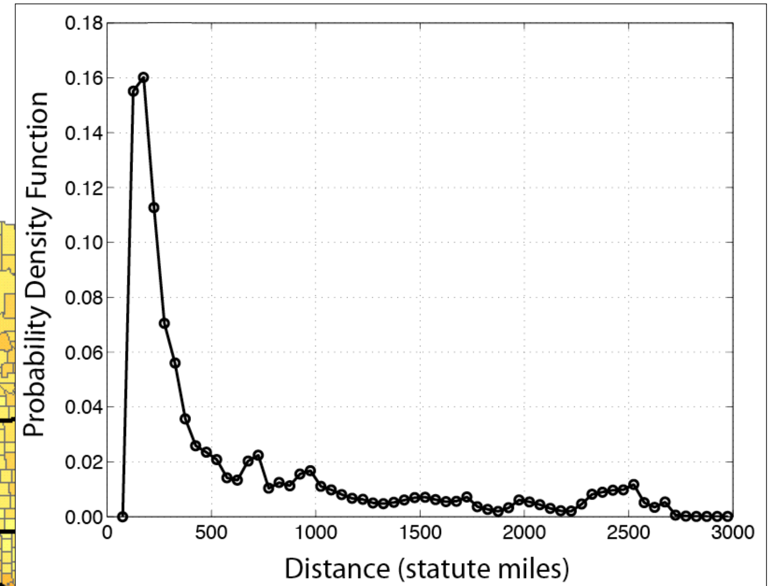
Socio-Economics Behind TSAM



Woods and Poole Demographic Data Implemented in the Transportation Systems Analysis Model

Trip Distribution Step

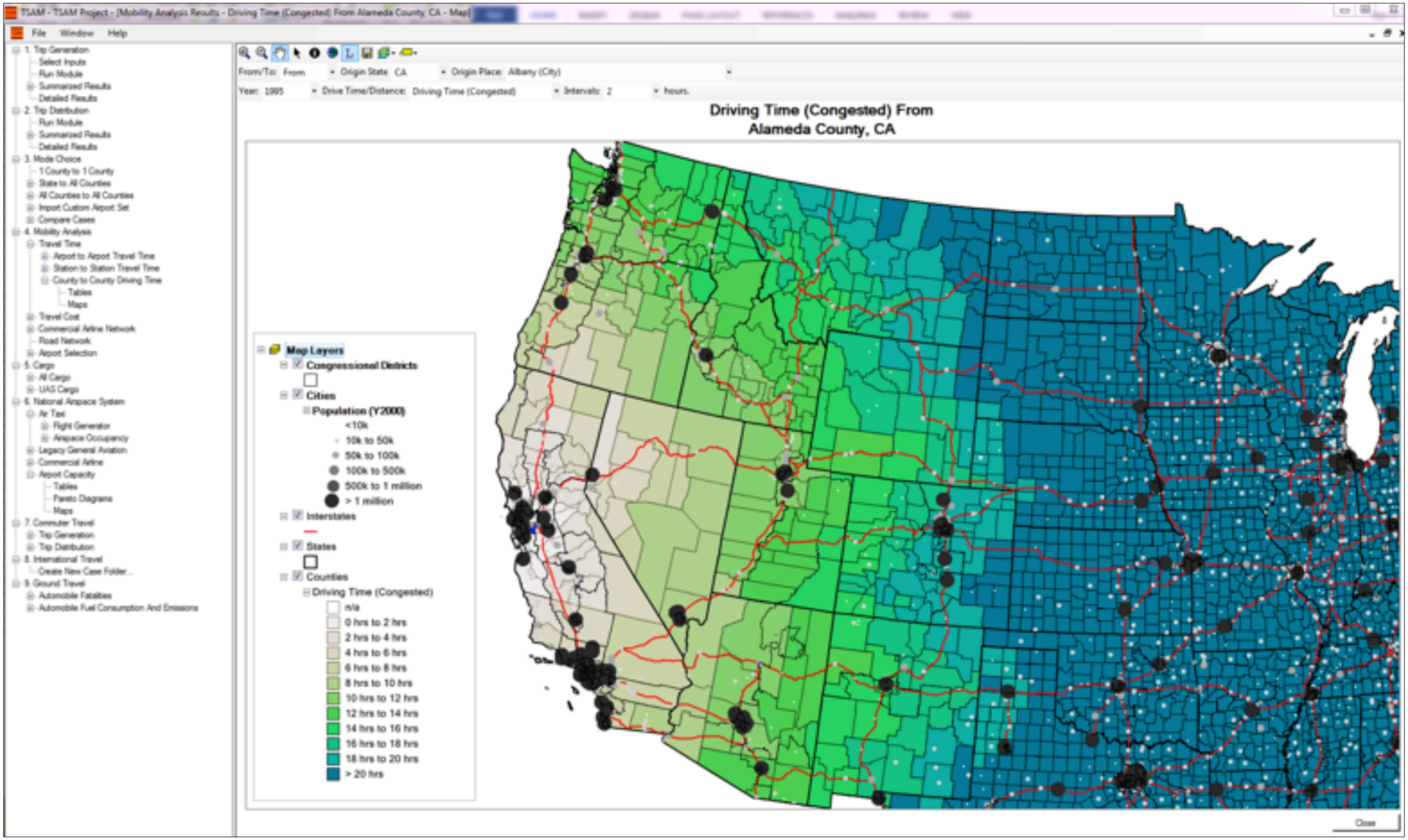




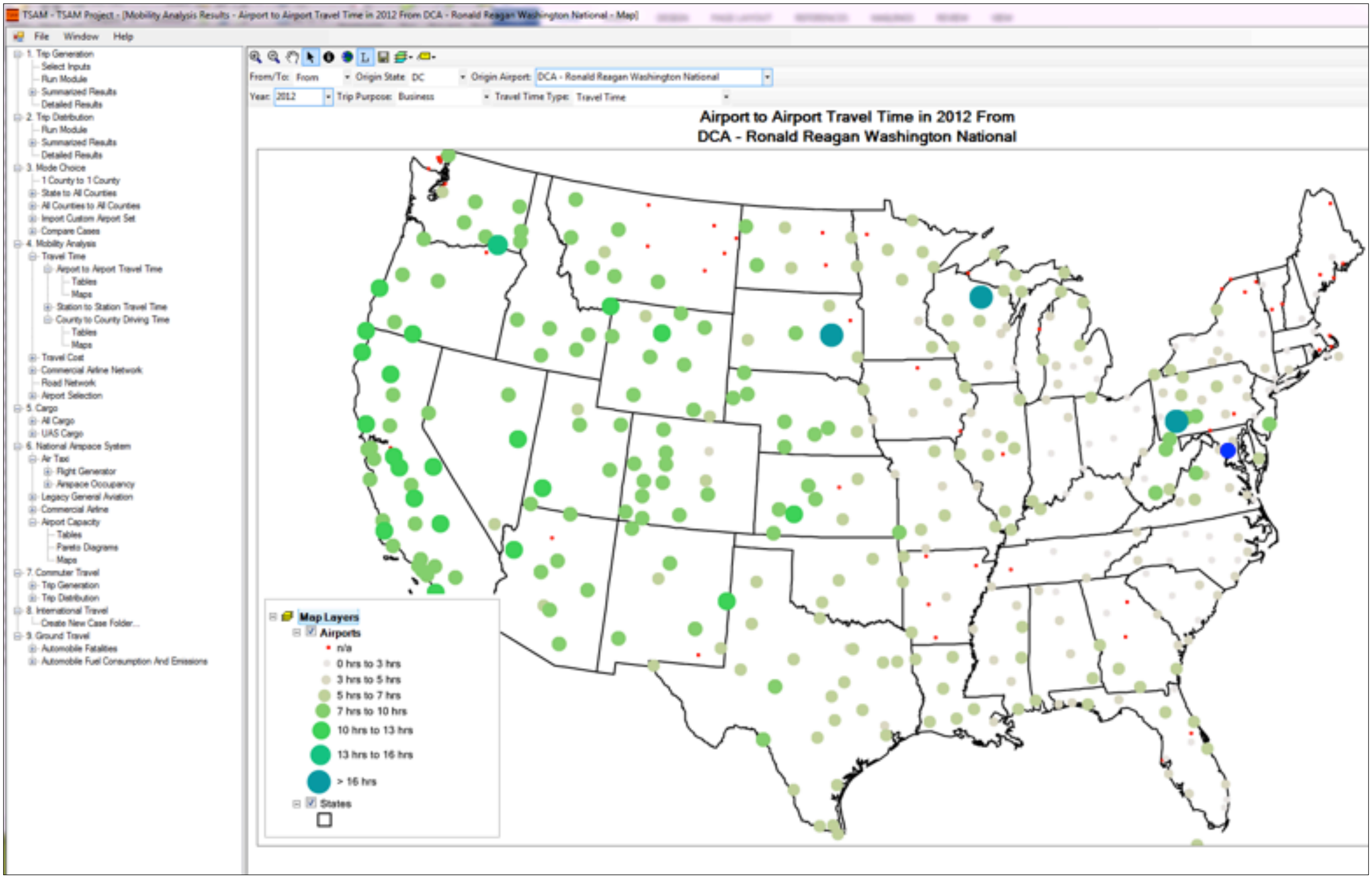
Gravity Model

$$T_{ij} = \frac{P_i A_j F_{ij} K_{ij}}{\sum_j A_j F_{ij} K_{ij}}$$

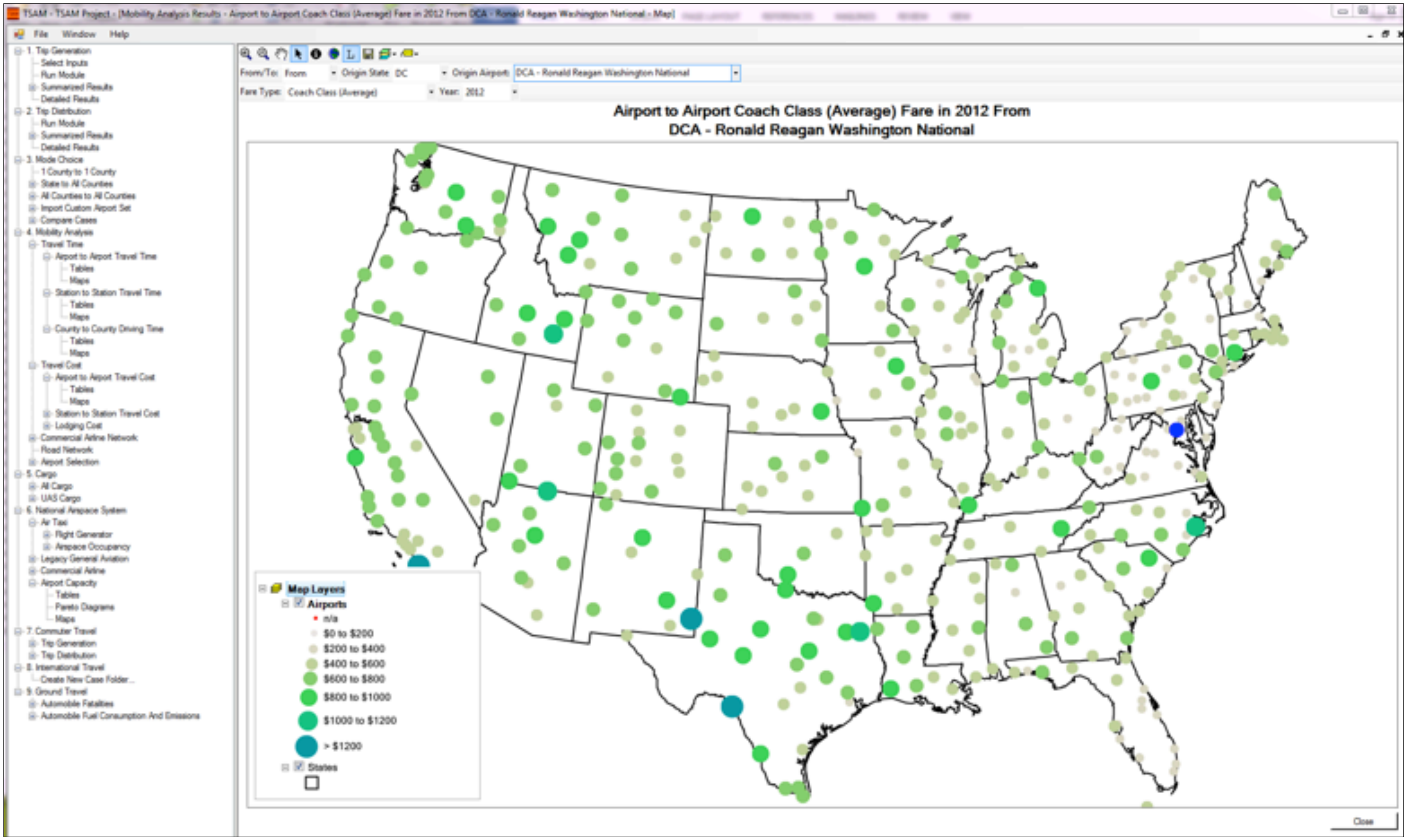
Sample TSAM Map: Auto Driving Time



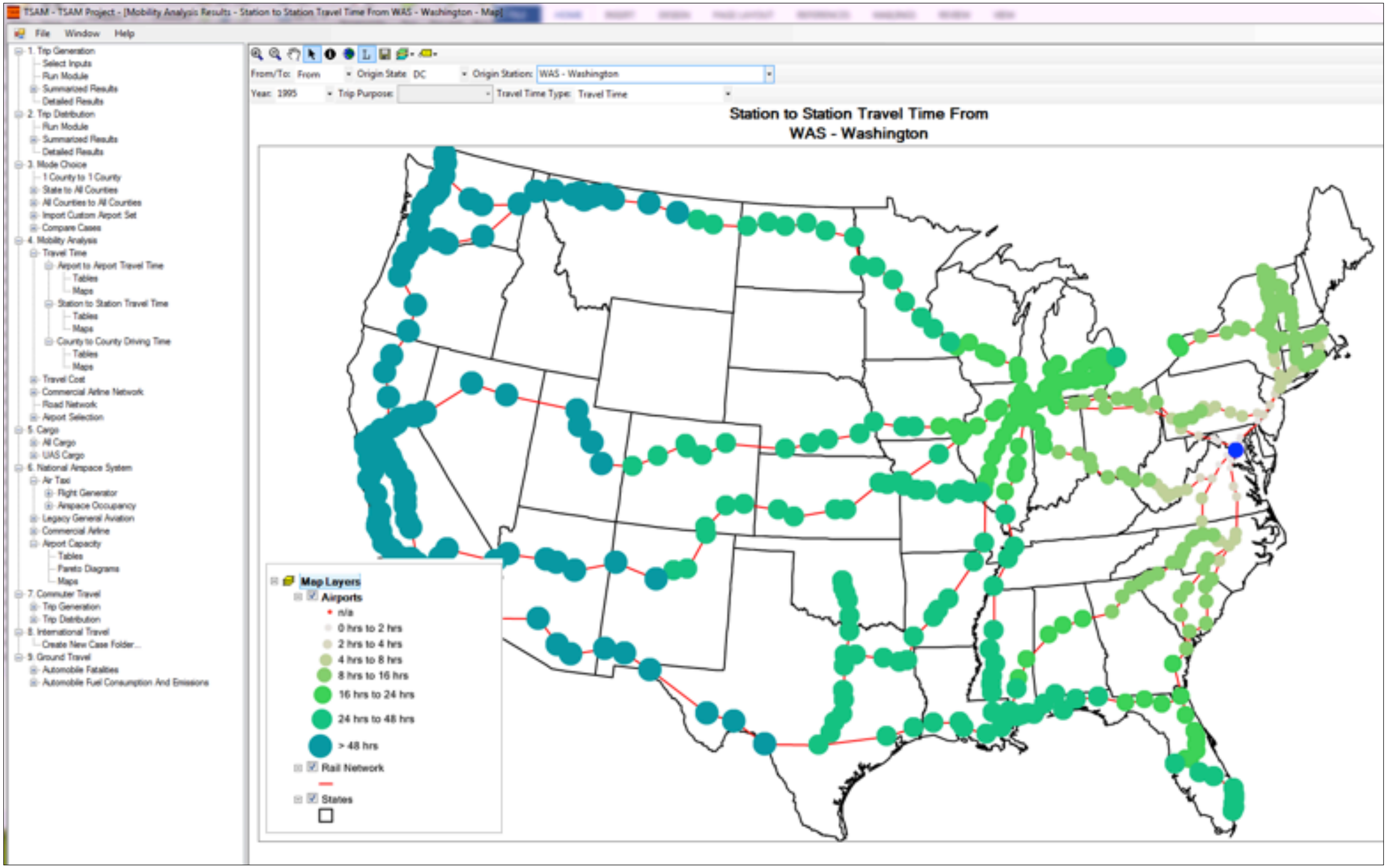
Sample TSAM Map: Airport-to-Airport Travel Time



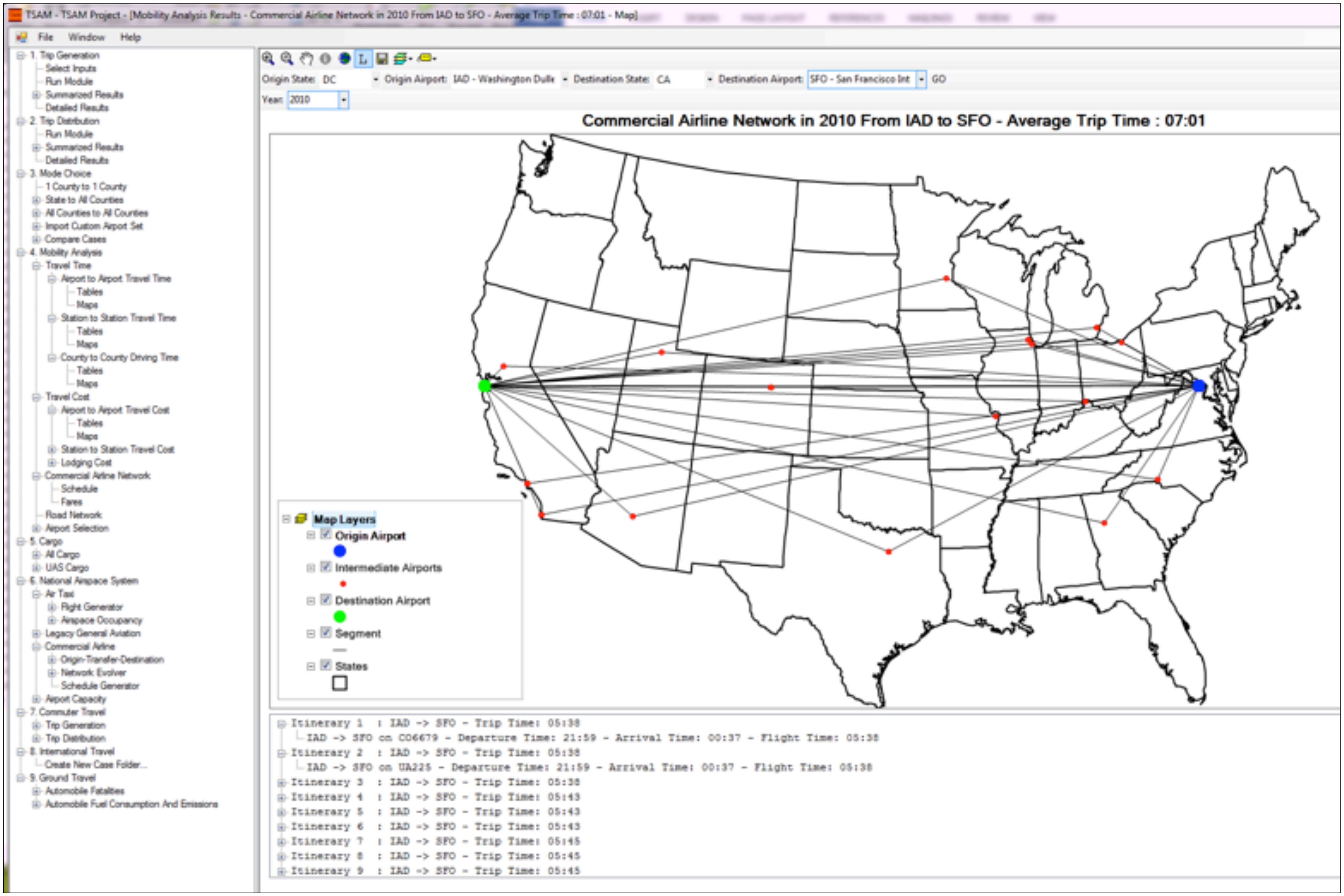
Sample TSAM Map: Airport-to-Airport Average Coach Fares



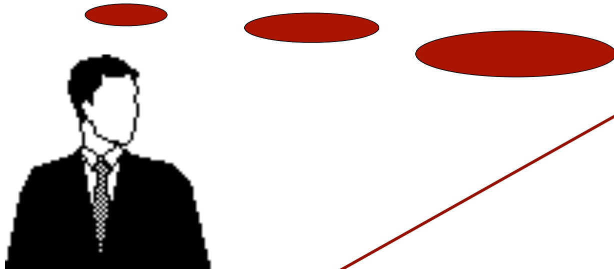
TSAM Map: US Rail System Travel Time



Sample TSAM Map: Commercial Airline Network (IAD-SFO)



Mode Choice Analysis



Auto | **Avi. General** | **Commercial Aviation**

Route1 | Route2... | Route n

Includes Airport Choice

Factors considered in mode split:

- **Travel time**
- **Travel cost**
- **Value of time**
- **Route convenience**
- **Trip type**

TSAM employs a family of Logit Models (Box-Cox and C-Logit)

Variables Used in Utility Functions

Authors	Variables in the Utility Function
Stopher and Prashker (1976)	Relative time, relative distance, relative cost, relative access–egress distance, departure frequency
Alan Grayson (1982)	Travel time, travel cost, access time, and departure frequency
Morrison and Winston (1985)	Travel time, cost, party size, average time between departures
Koppelman (1990)	Travel time, cost, departure frequency, distance between city pairs, household income

Logit Model in TSAM

- Logit model

$$P_i = \frac{e^{U_i}}{\sum_i e^{U_i}}$$

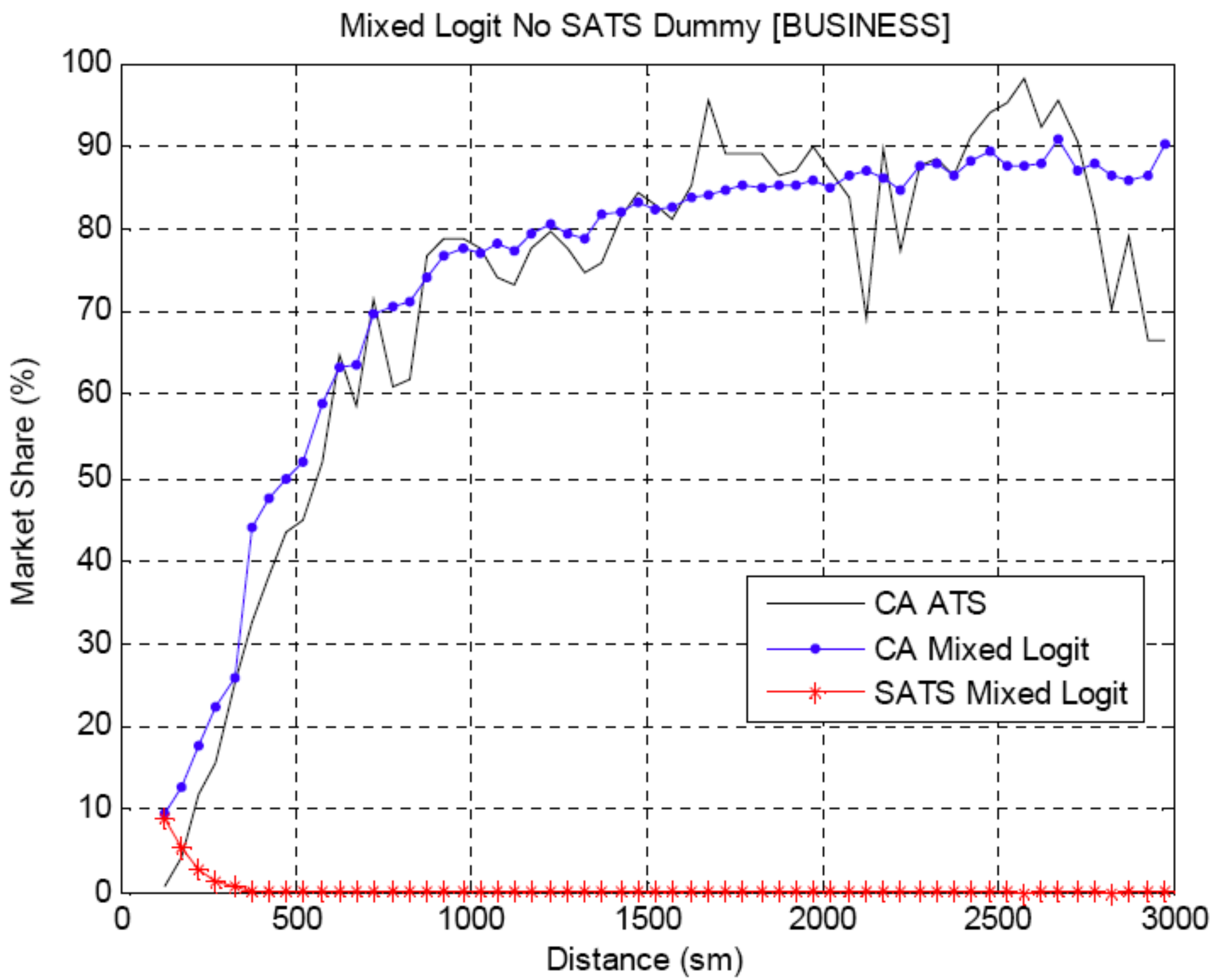
- Nested logit utility function

$$U_{ij}^{kl} = \alpha_0\ Travel\ Time_{ij}^{k} + \alpha_1\ Travel\ Cost_{ij}^{k1} + \alpha_2\ Travel\ Cost_{ij}^{k2} + \alpha_3\ Travel\ Cost_{ij}^{k3}$$
$$+ \alpha_4\ Travel\ Cost_{ij}^{k4} + \alpha_5\ Travel\ Cost_{ij}^{k5} + \alpha_6 shortTripDummy_{ij}^{m} + regionDummy_{ij}^{k}$$

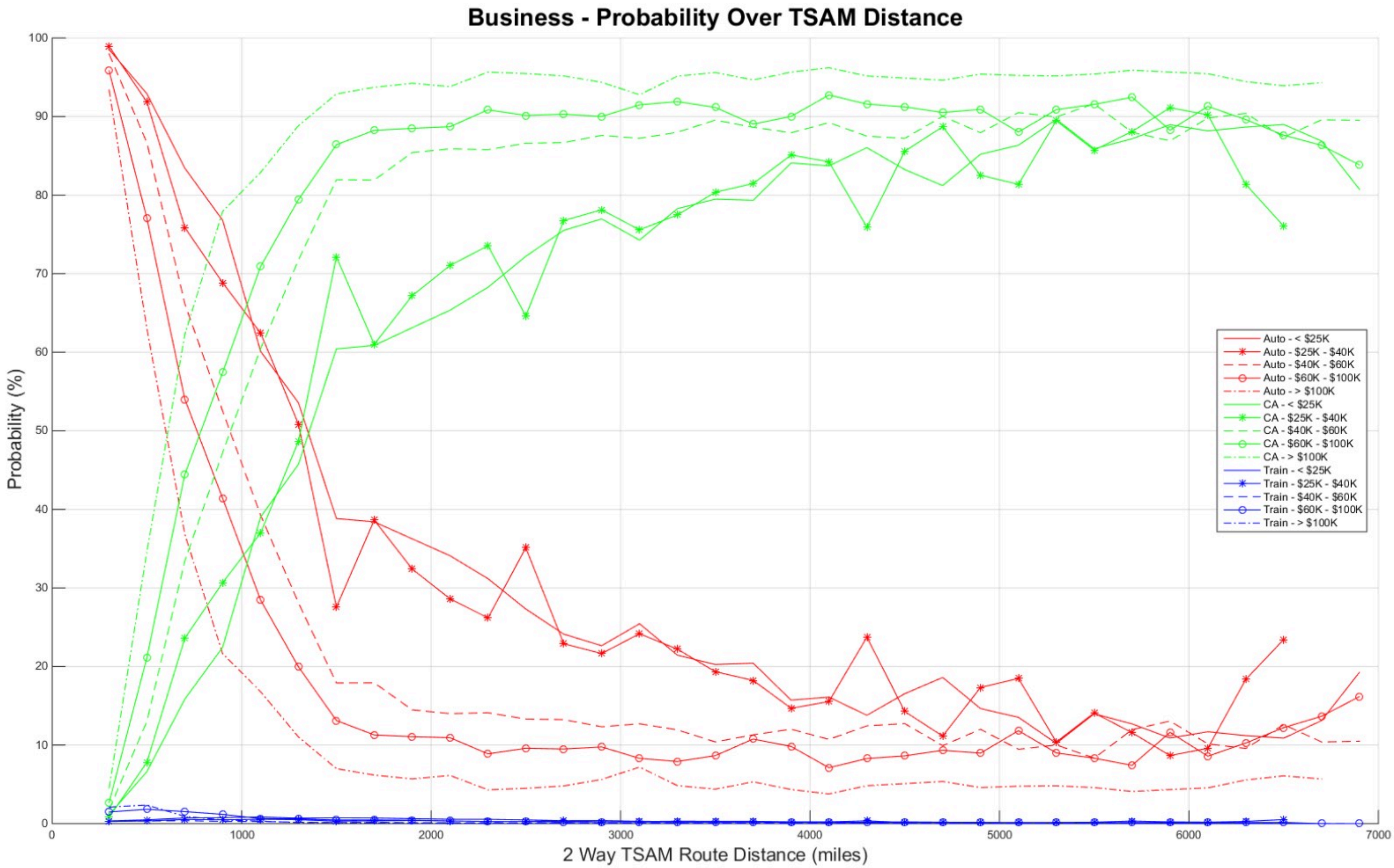
- Mixed logit utility function

$$U_{ij}^{klm} = \alpha_0\ Travel\ Time_{ij}^{k} + \alpha_0^{'} + \alpha_1\ Travel\ Cost_{ij}^{k1} + \alpha_2\ Travel\ Cost_{ij}^{k2} + \alpha_3\ Travel\ Cost_{ij}^{k3} \ldots$$
$$+ \alpha_4\ Travel\ Cost_{ij}^{k4} + \alpha_5\ Travel\ Cost_{ij}^{k5} + \alpha_6 shortTripDummy_{ij}^{m}$$

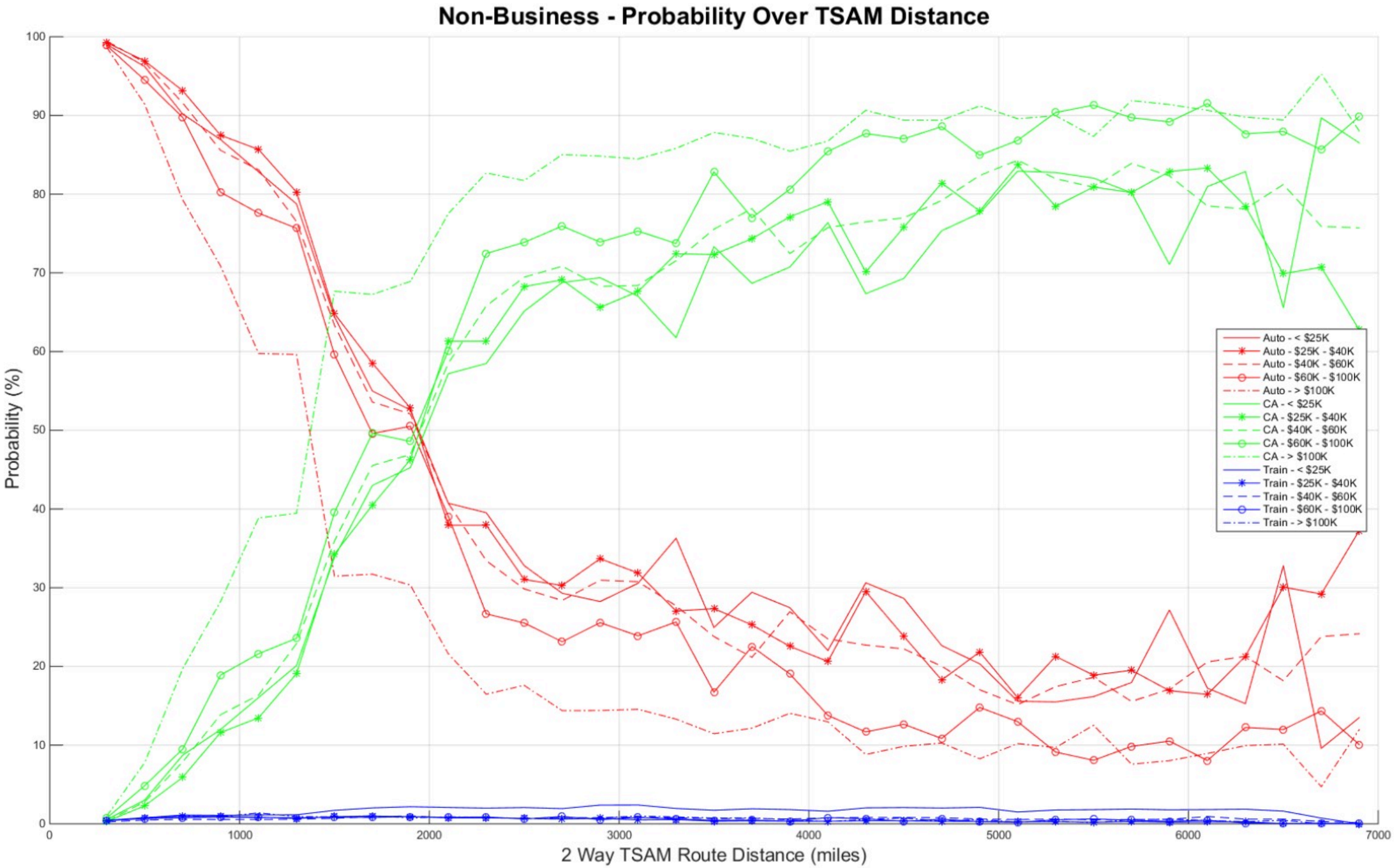
Initial Model Calibration

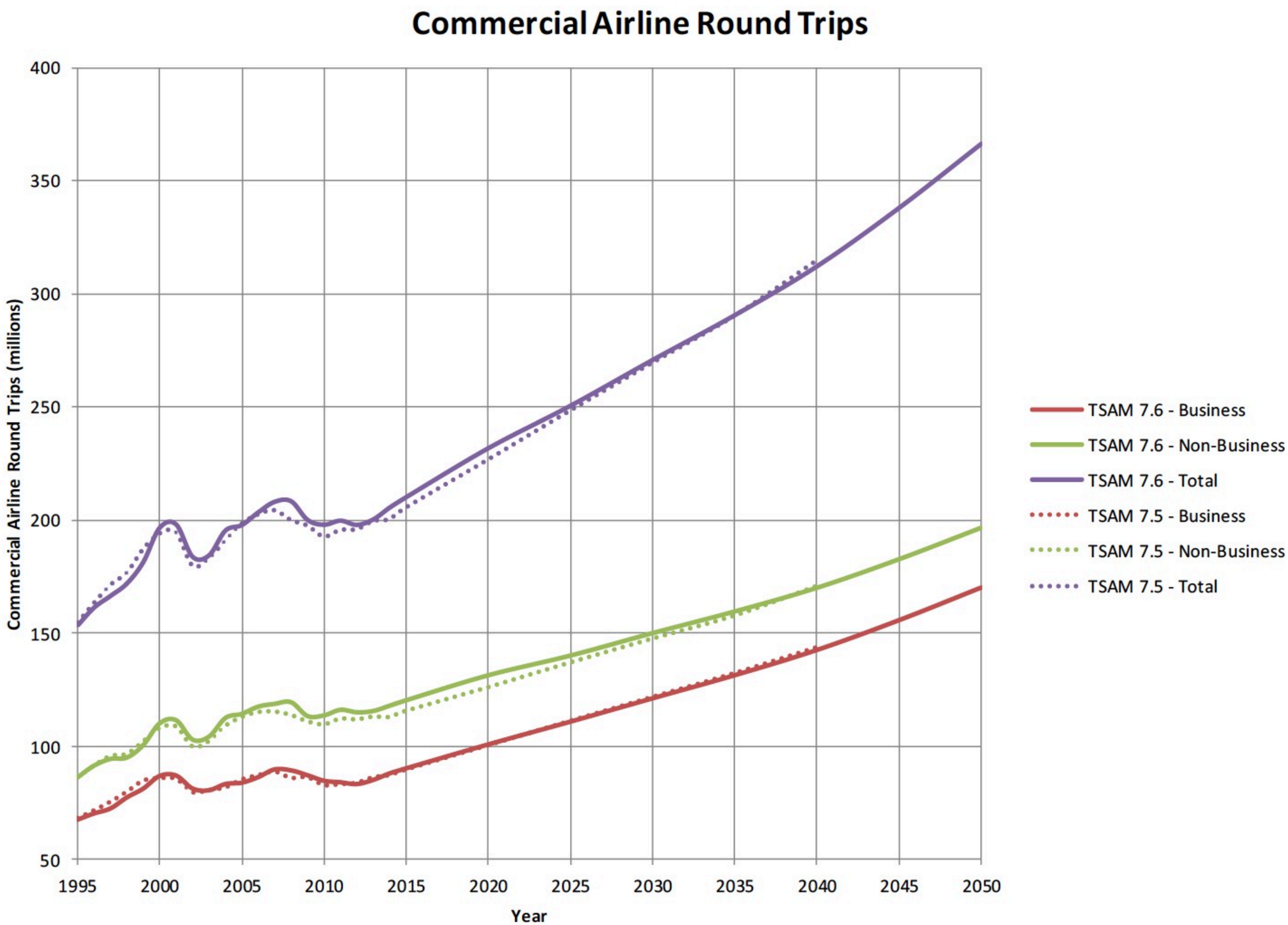


TSAM 7.6 Calibration (Business Travel)

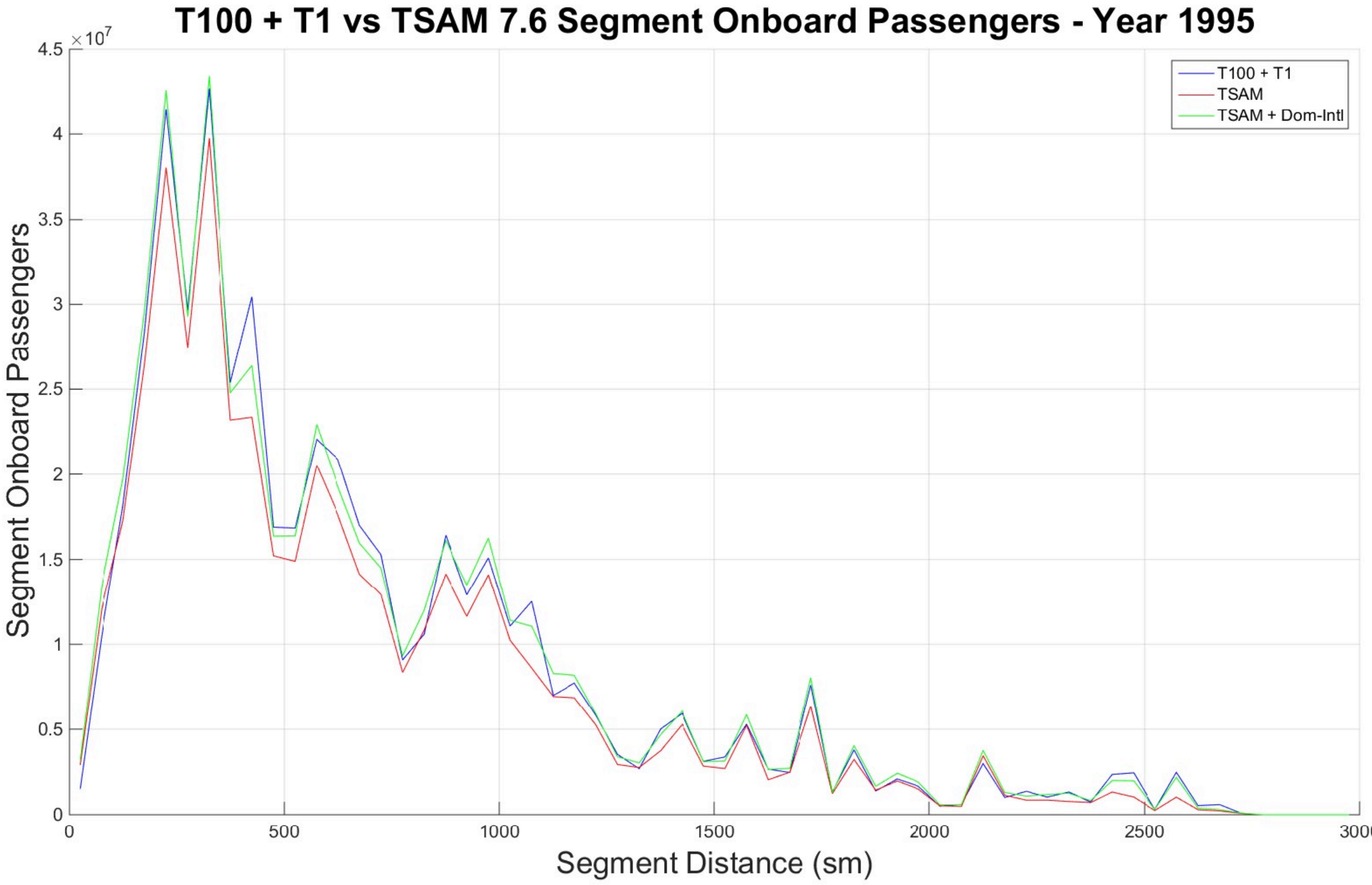


TSAM 7.6 Calibration (Non-Business Travel)

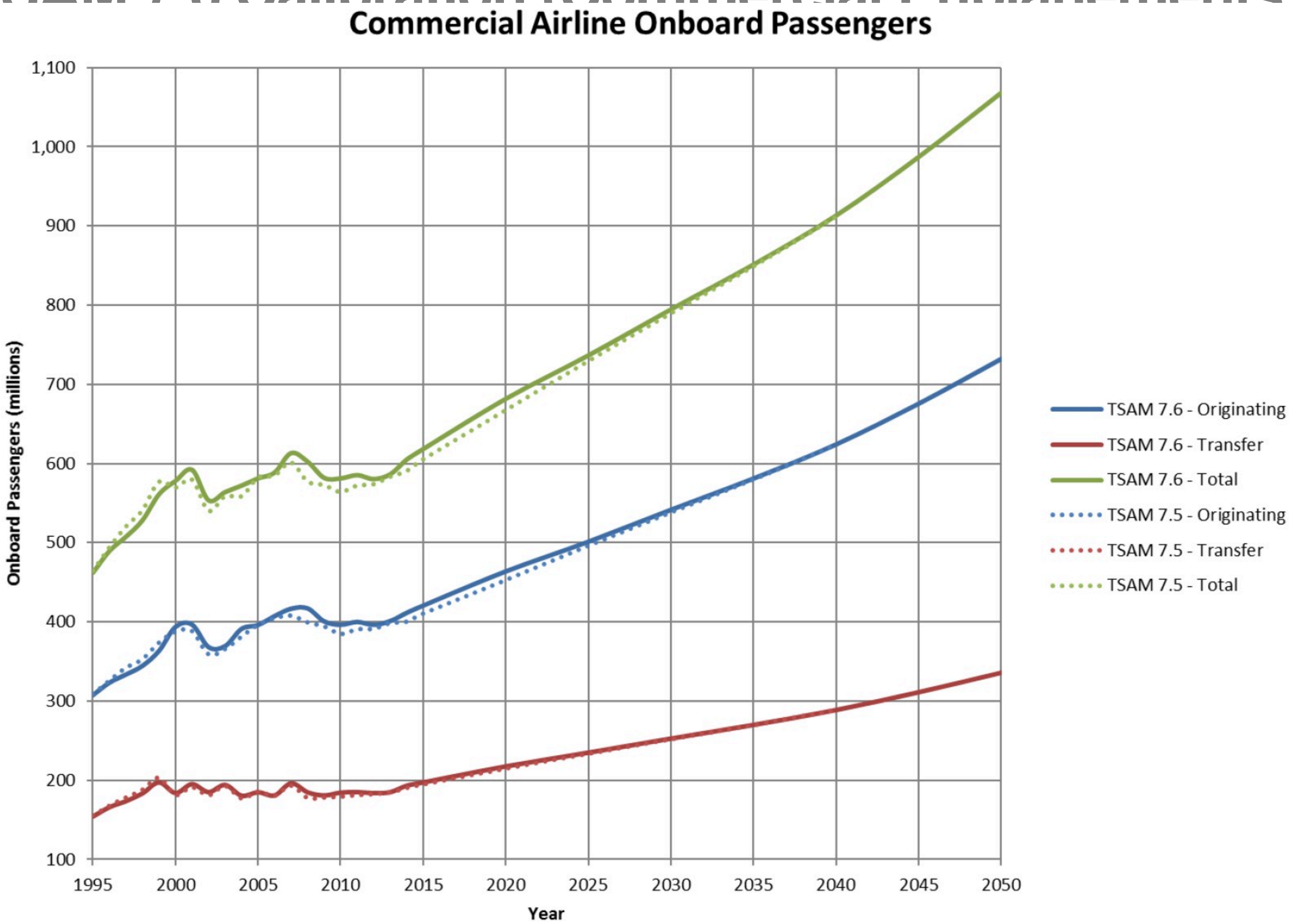



Commercial Airline Round Trips
400
350
300
250
200
150
100
50
Commercial Airline Round Trips (millions)
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Year
TSAM 7.6 - Business
TSAM 7.6 - Non-Business
TSAM 7.6 - Total
TSAM 7.5 - Business
TSAM 7.5 - Non-Business
TSAM 7.5 - Total

TSAM 7.6 Calibration (Segment Passengers)



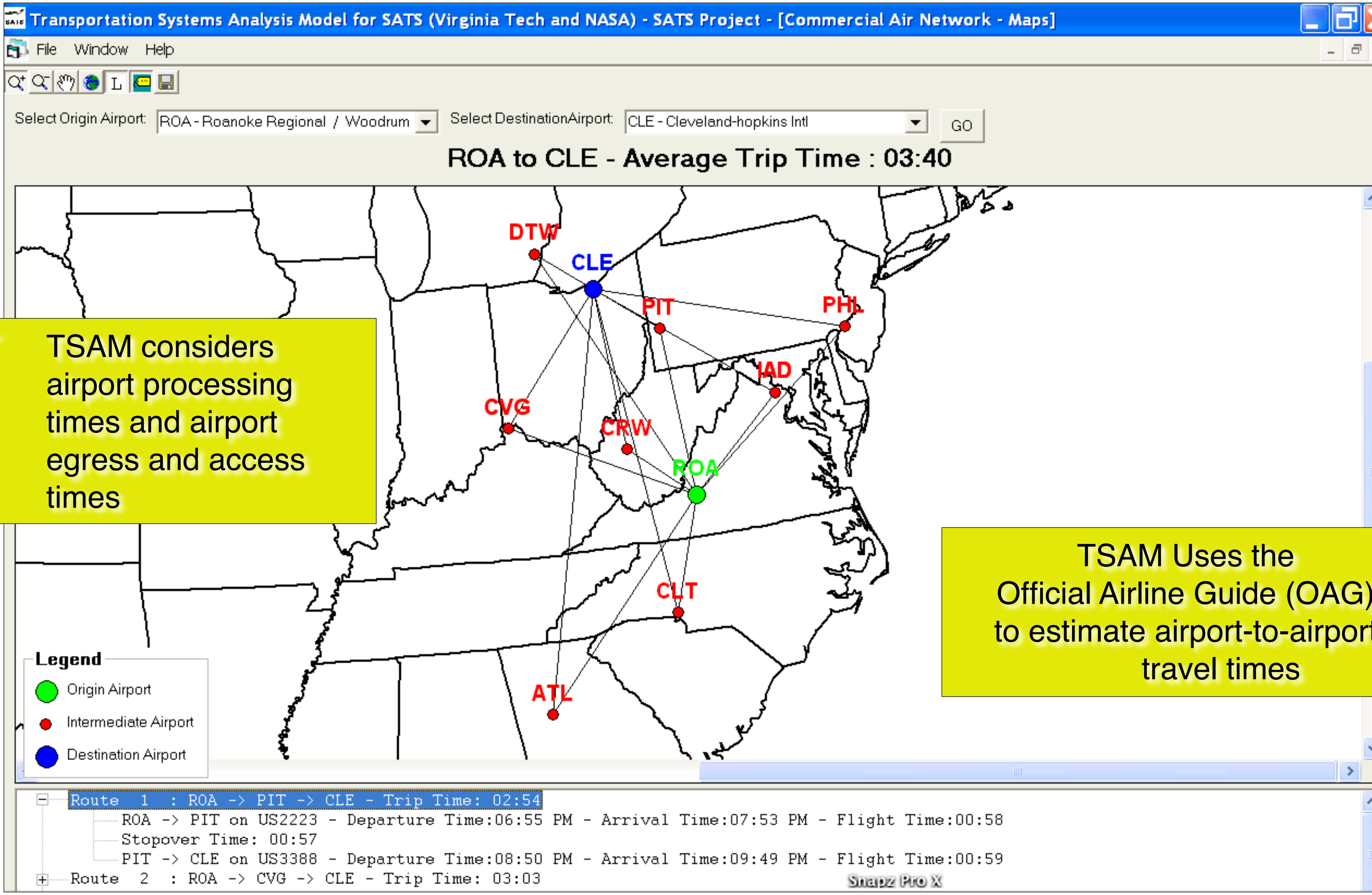
TSAM 7.6 Calibration (Commercial Enplanements)



Example Travel Evaluation in TSAM
Travel from Blacksburg to Cleveland OH

- Suppose three possible travel alternatives are:
  - Auto
  - Commercial Air
  - On-demand service using VLJ aircraft (future NAS)
- To make a mode selection a user could consider:
  - Travel time
  - Travel cost (including lodging and rentals)
  - Duration of stay

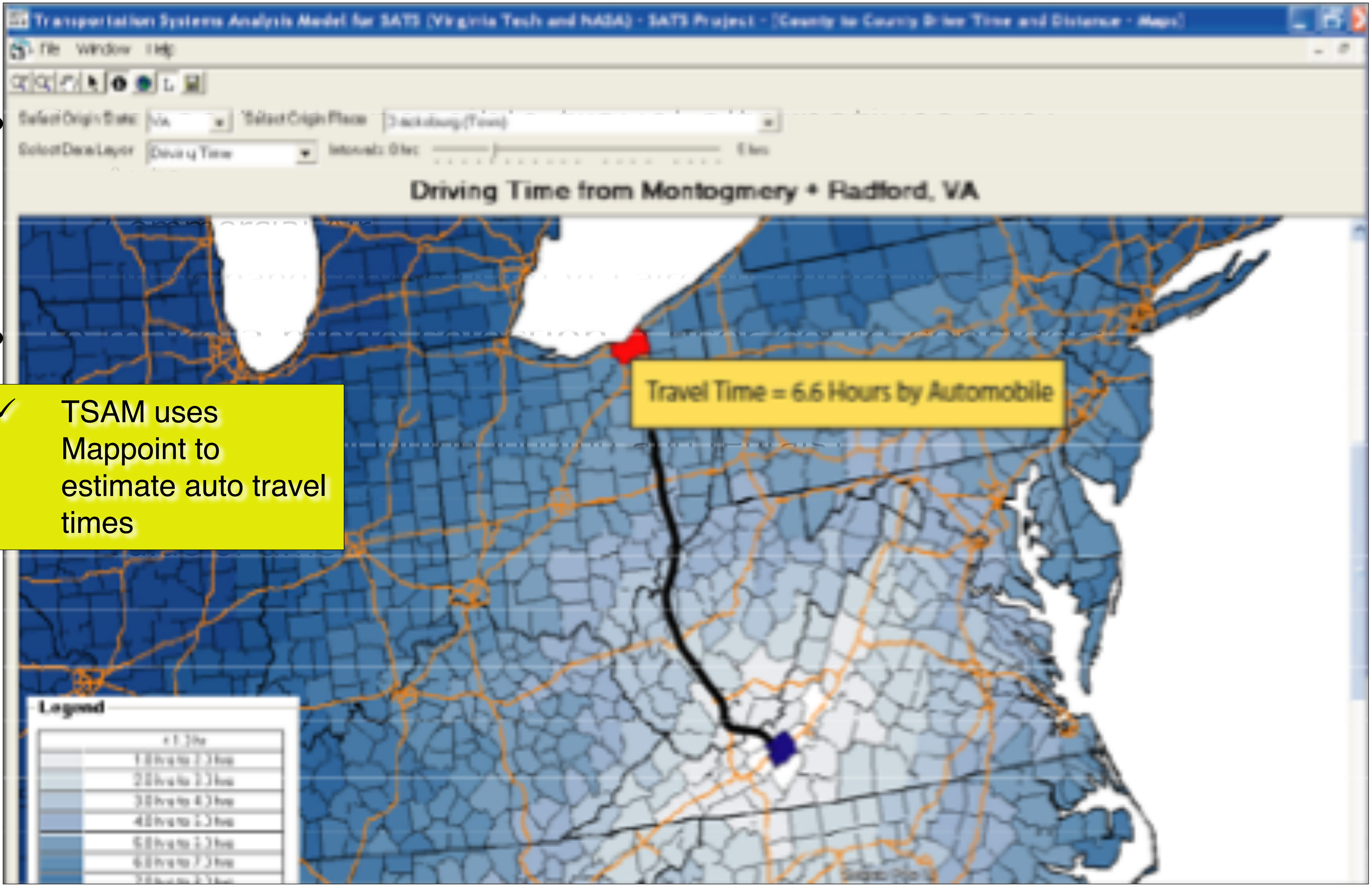
Example Travel Evaluation in TSAM
Travel from Blacksburg to Cleveland OH



- ✓ TSAM considers airport processing times and airport egress and access times

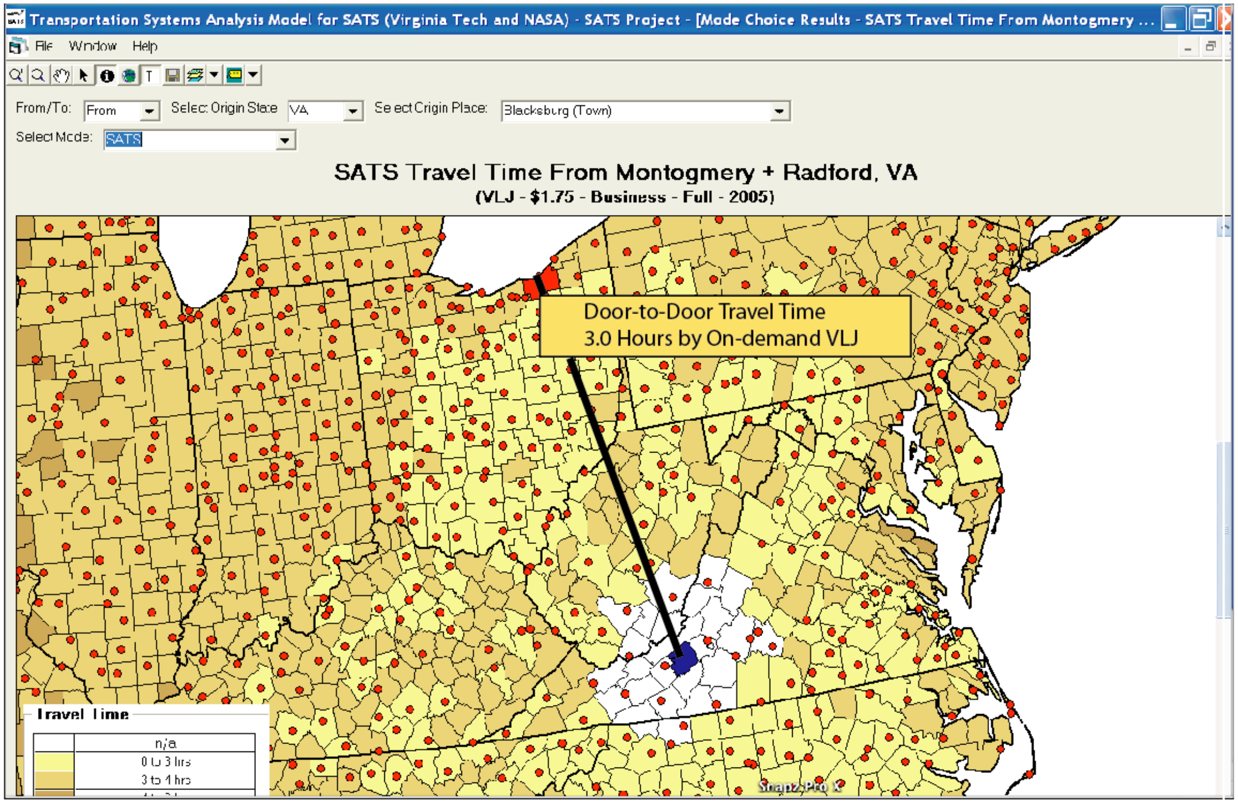
TSAM Uses the Official Airline Guide (OAG) to estimate airport-to-airport travel times

Example Travel Evaluation in TSAM
Travel from Blacksburg to Cleveland OH



✓ TSAM uses Mappoint to estimate auto travel times

Example Travel Evaluation in TSAM
Travel from Blacksburg to Cleveland OH



- Suppose three possible travel alternatives are:
  - Auto
  - Commercial Air
  - On-demand service using VLJ aircraft (air taxi)
- To make a mode selection a user could consider:
  - Travel time
  - Travel cost (including lodging and rentals)
  - Duration of stay
  - Value of time

Example Travel Evaluation in TSAM
Travel from Blacksburg to Cleveland OH

From Blacksburg, VA To Cleveland, OH (391 miles)

Roundtrip Travel Time Savings Using 7 hrs 2 min + 2 extra nights compared to automobile
7 hrs 16 min + 1 extra night compared to fastest airline route

SATS Trip Details

	Origin Airport	Destination Airport	Travel Time (Outbound)	Travel Time (Return)	Travel Cost (Roundtrip)	Average Travel Speed	Cost for Speed	Nights Away
SATS	BCB, Virginia Tech / Montgomery Executive, Blacksburg, VA	BKL, Burke Lakefront, Cleveland, OH	2 hrs 59 min	2 hrs 59 min	$1,093	131 mph	$8.33/mph	0

Car Trip Details

	Origin	Destination	Travel Time (Outbound)	Travel Time (Return)	Travel Cost (Roundtrip)	Average Travel Speed	Cost for Speed	Nights Away
Auto	Blacksburg, VA	Cleveland, OH	6 hrs 30 min	6 hrs 30 min	$493	60 mph	$5.20/mph	2

Commercial Air Trip Details

	Origin Airport	Destination Airport	Travel Time (Outbound)	Travel Time (Return)	Travel Cost (Roundtrip)	Average Travel Speed	Cost for Speed	Nights Away
Route 1	ROA, Roanoke, VA	CLE, Cleveland, OH	6 hrs 37 min	6 hrs 36 min	$526	59 mph	$7.39/mph	1
Route 2	ROA, Roanoke, VA	CAK, Akron, OH	6 hrs 50 min	7 hrs 15 min	$528	57 mph	$7.65/mph	1
Route 3	CLT, Charlotte, NC	CLE, Cleveland, OH	7 hrs 38 min	7 hrs 12 min	$638	51 mph	$10.71/mph	1

Market Share Details*

Household Income Group	<$30K	$30K - $60K	$60K - $100K	$100K - $150K	>$150K
Auto	82 %	76 %	64 %	53 %	51 %
Airline	18 %	24 %	30 %	32 %	31 %
SATS	0 %	0 %	5 %	16 %	18 %

*Numbers rounded to nearest percent.

Print Results Close

Mode Choice Analysis in TSAM