Supersonic Transport Scheduling and Fleet Analysis Model

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ISAT Supersonic Studies Background

For past few years, the PAMO/ISAT has sponsored a series of studies with the Virginia Tech Air Transportation Systems Laboratory to look at supersonic transport market demand through the contract with the National Institute of Aerospace.

Objectives:

- Determine the target size/range/speed of the low-boom “objective vehicle”
- Explore the market feasibility of supersonic transports
- Understand how low-boom designs compare to conventional designs in terms of vehicle economics.

Study Participants

- Study leads: Ty Marien (LaRC), Jon Seidel (GRC)
- Vehicle definition: Karl Geiselhart, Wu Li (LaRC)
- Demand prediction: Dr. Antonio Trani, Zhou Wang, Edwin Freire Nick Hinze (Virginia Tech), Sam Dollyhigh (Analytical Mechanical Associates)

FY22 Supersonic Transport Scheduling and Fleet Analysis Study

In previous work, Virginia Tech has developed a passenger demand methodology called the Low-Boom Systems Analysis Model (LBSAM). There were two areas we wanted to focus on for FY22:

- LBSAM incorporates an aircraft operations lifecycle cost model that depends in aircraft utilization and network efficiency as inputs. These values are not calculated.
- LBSAM doesn’t predict what percentage of passengers actually switch from subsonic to supersonic service, instead it predicts the percentage of passengers willing to pay the increased fare if value-of-time is factored in. The percentage of passengers who are willing to pay the increased fare and actually make the switch is handled parametrically.

Study Primary Tasks:

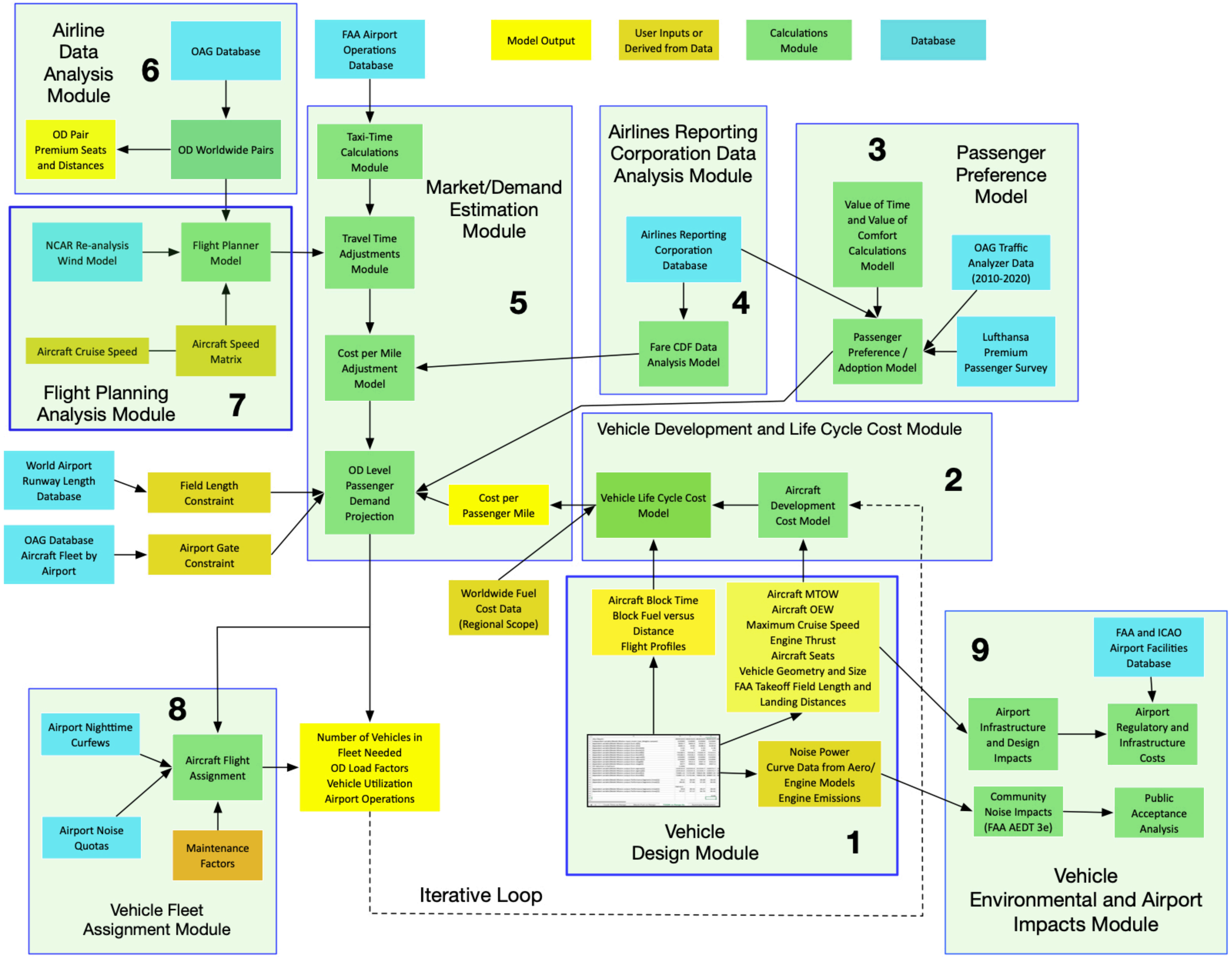
- Add a network model with tail tracking and feasible flight schedules to help verify our aircraft network utilization assumptions.
- Add a passenger preference model to LBSAM to better predict the passenger switch rate from subsonic to supersonic service.
- Run sensitivity studies of the integrated demand model to validate its operation.

Acknowledgements

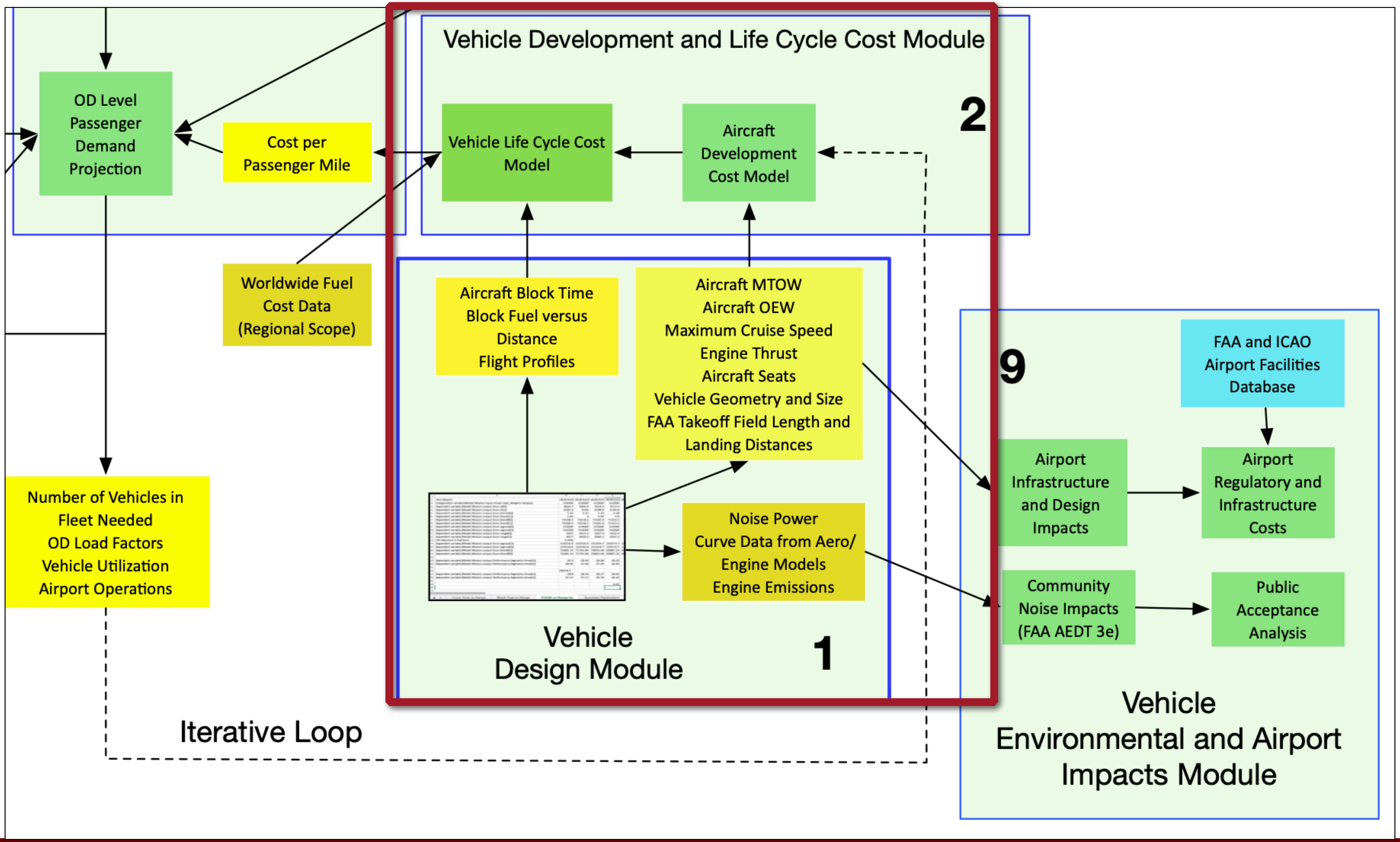
- Virginia Tech would like to acknowledge the technical and financial support of the following individuals and organizations:

- 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)

Low-Boom Systems Analysis Model (LBSAM)



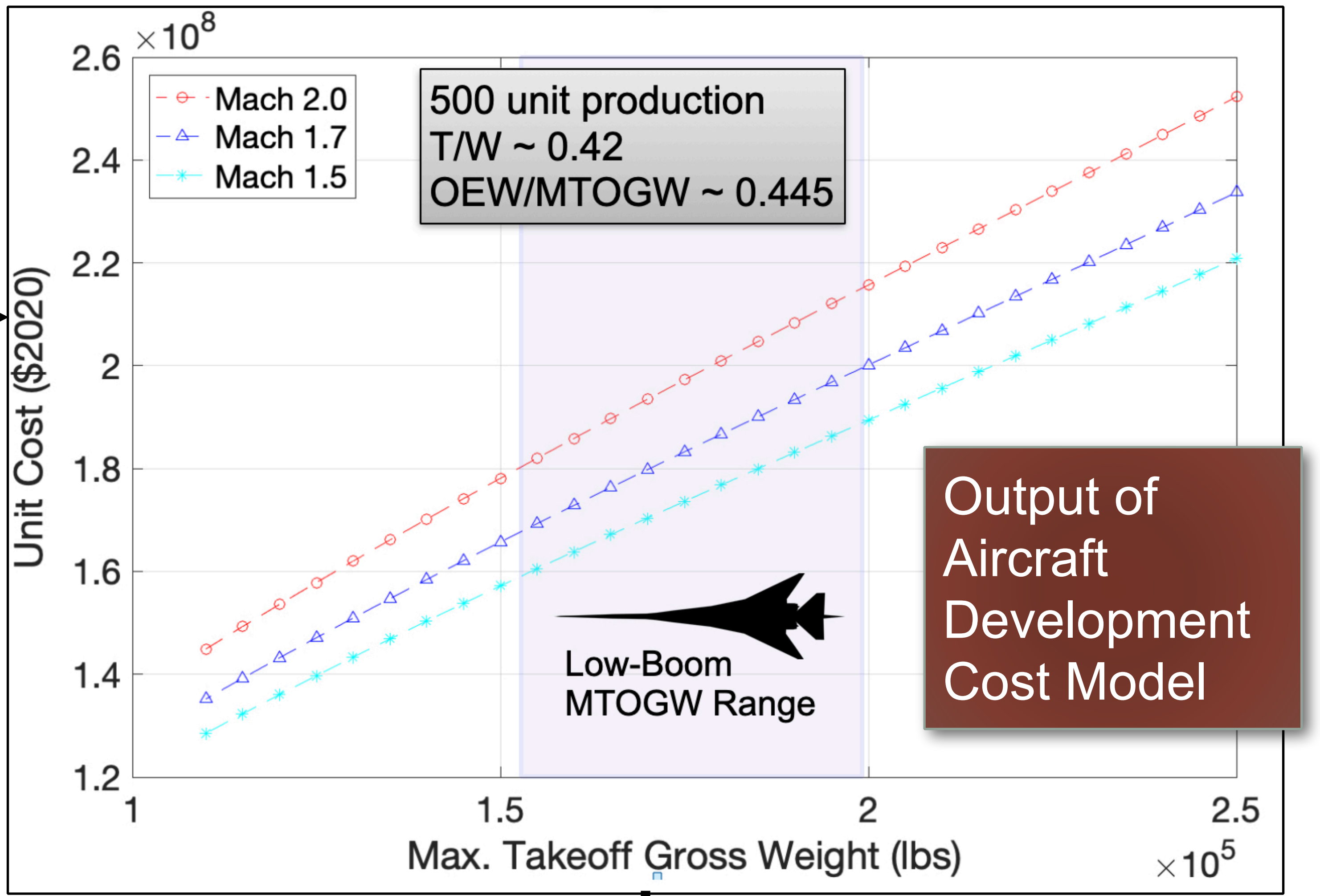
Vehicle Development and Life Cycle Cost Module



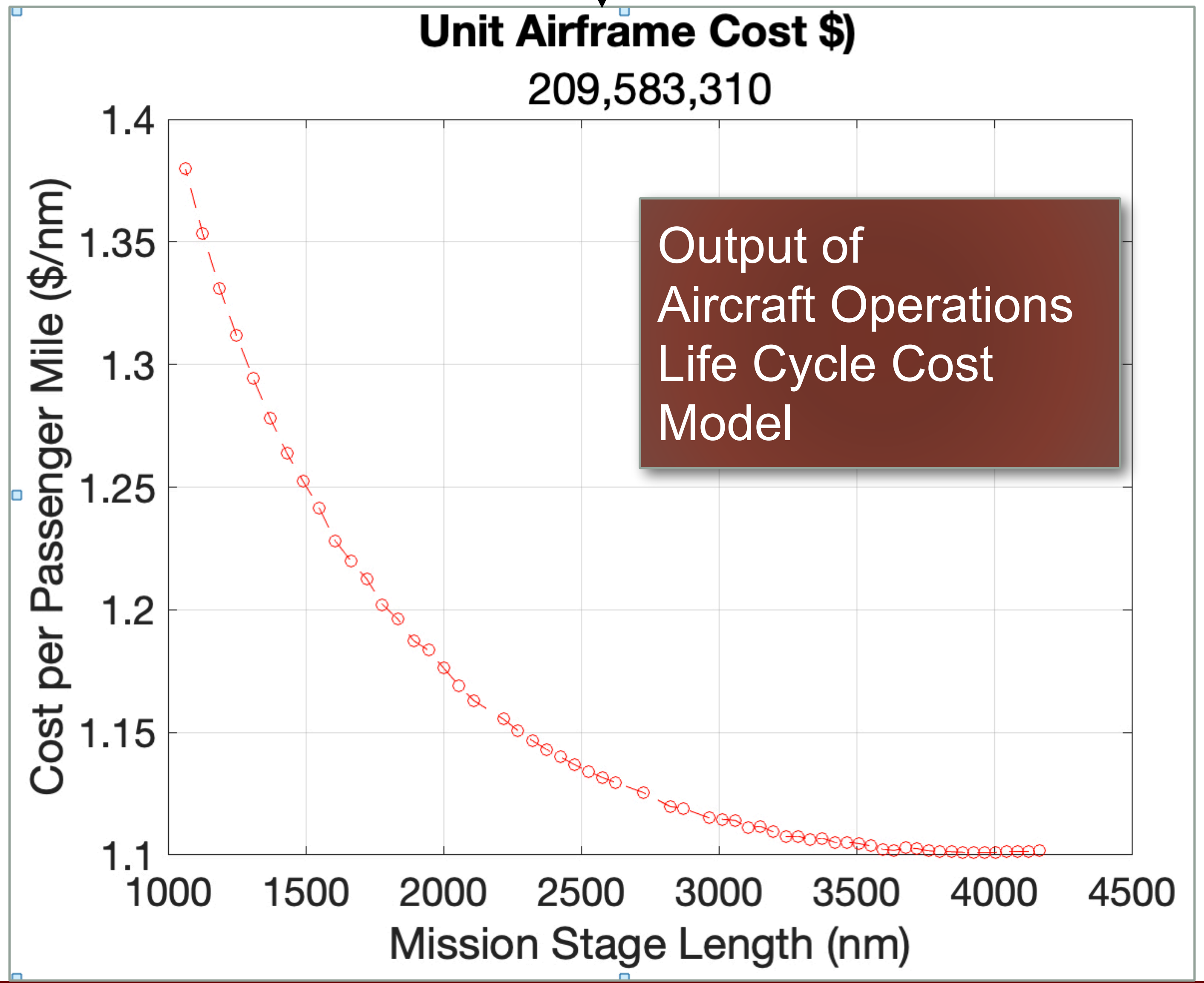
Aircraft Development and Life Cycle Cost Module

FLOPS Model Output

	178450	177250
Top	4619.7	4573.8
Pos	4802.8	4756.1
Pos	5.19	5.15
PostFLOPS.Ae.LowBoomMission.output.Econ.blockt[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		



Output of Aircraft Development Cost Model



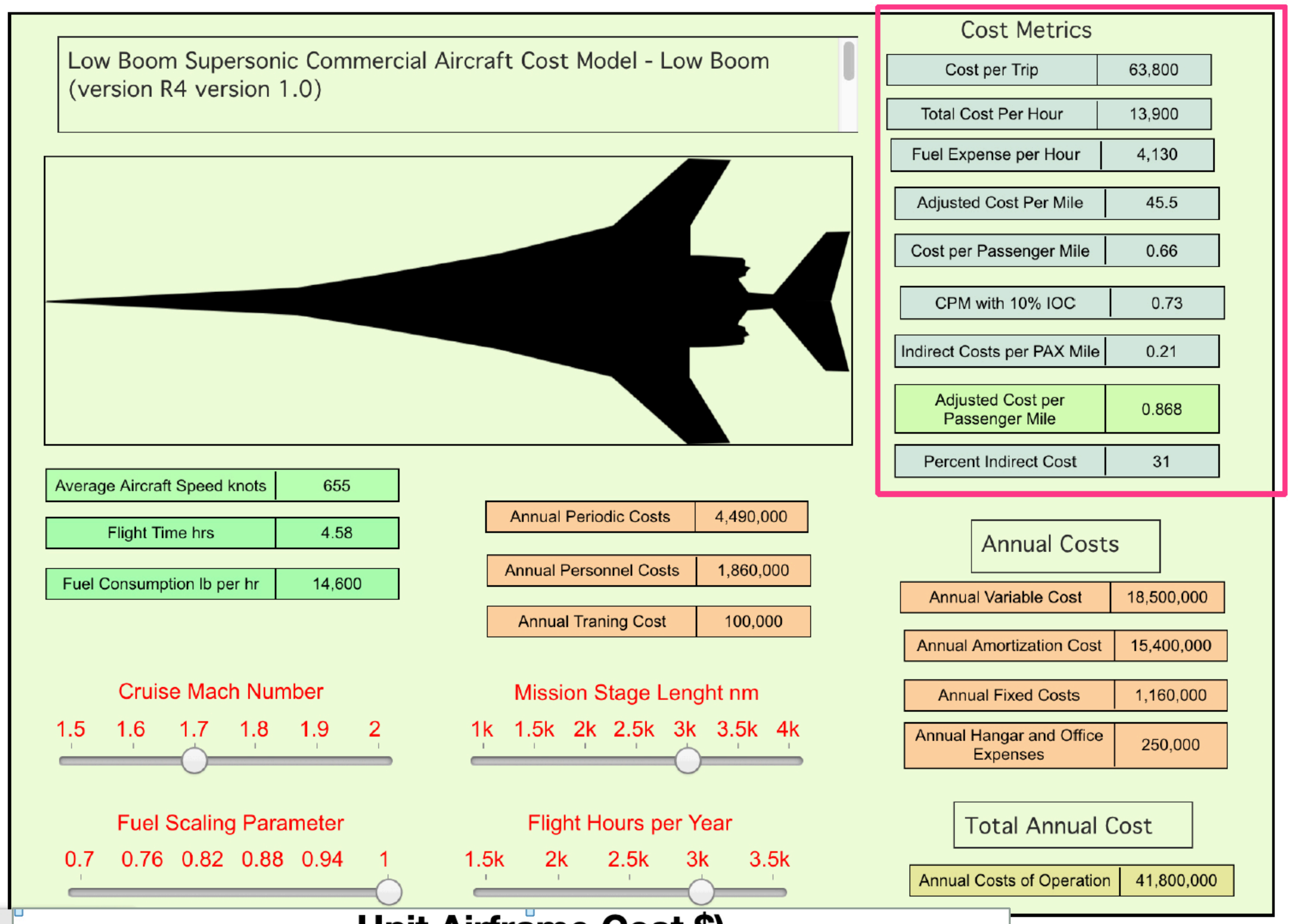
Output of Aircraft Operations Life Cycle Cost Model

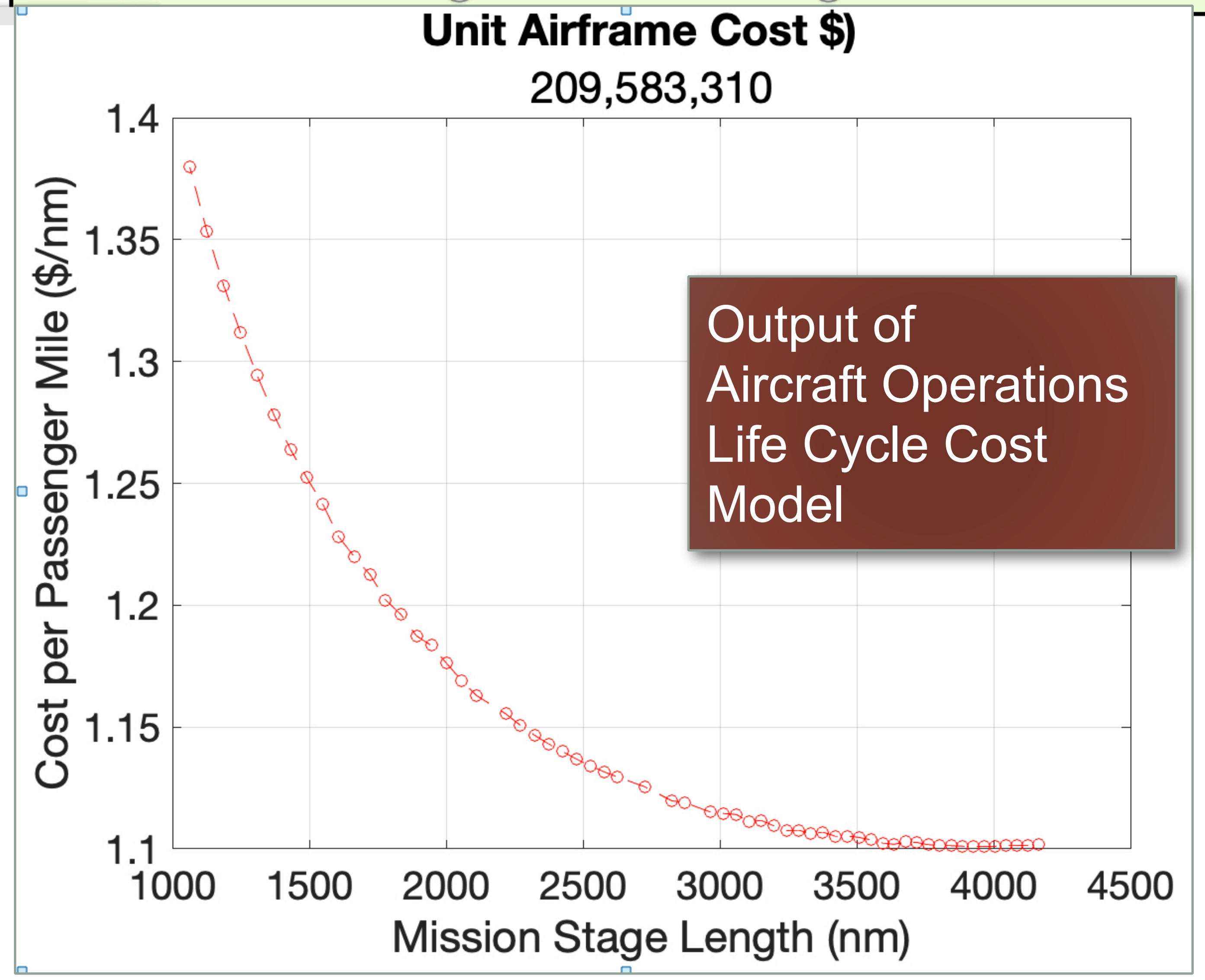
- Aircraft speed, quantity produced, takeoff and empty weights, and other technical parameters produced by FLOPS are used to estimate the vehicle development costs using non-linear regression equations adapted from a RAND cost model
- An operational aircraft life cycle cost model is used to estimate 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**

Aircraft Operations Life Cycle Cost Module

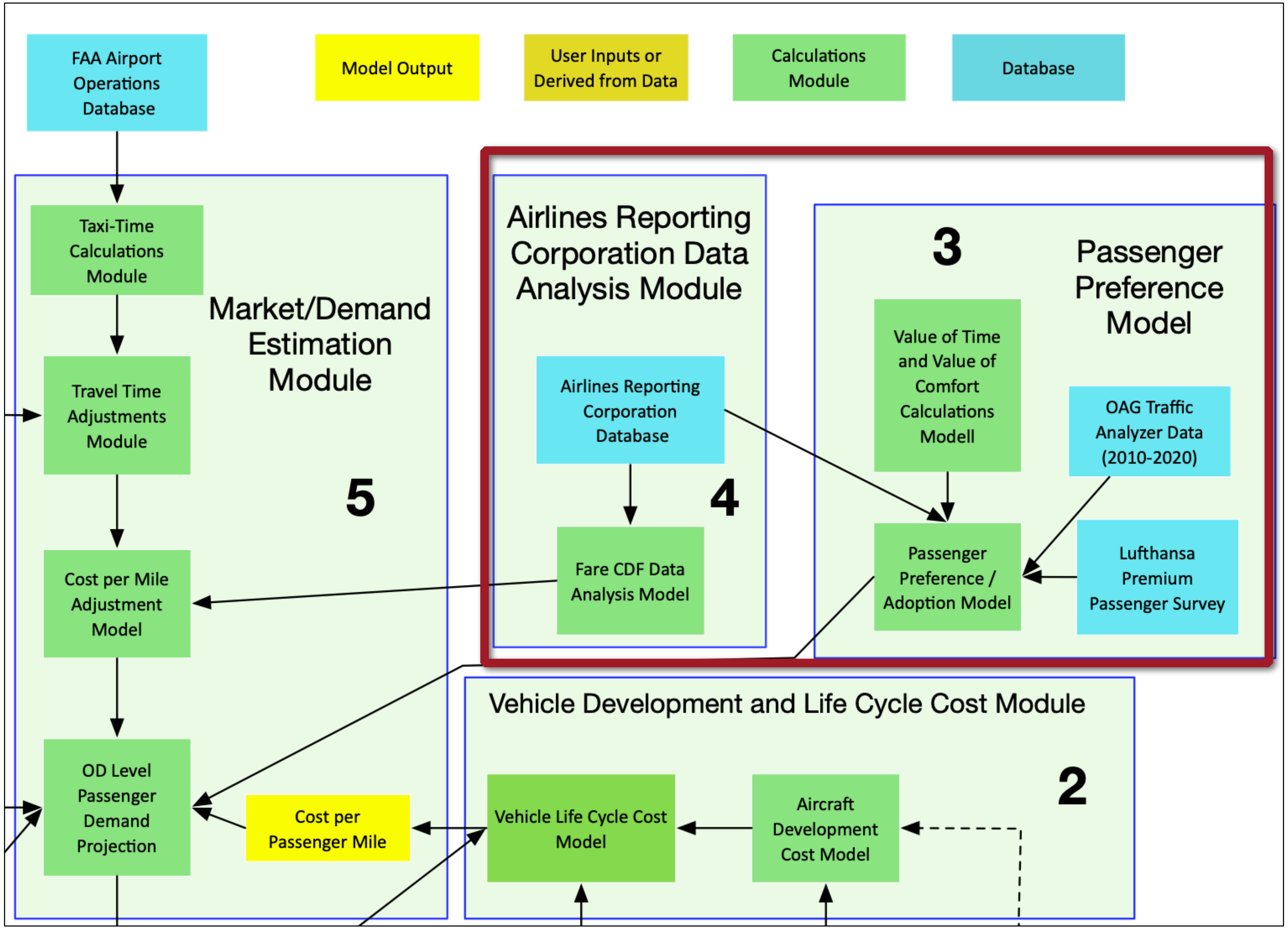
Supersonic aircraft operations life-cycle cost model include the following:

- 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





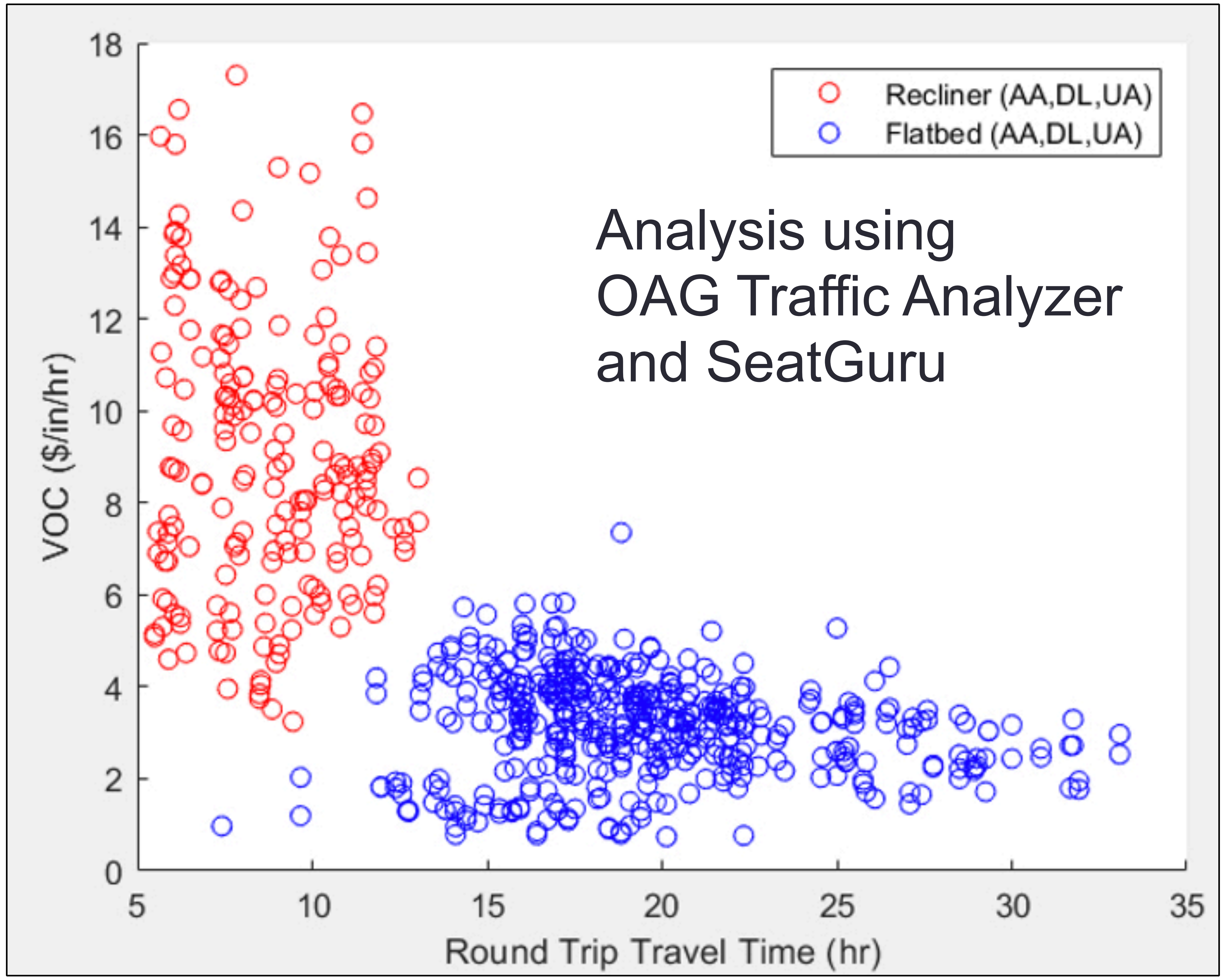
Passenger Preference Module



Passenger Preference Module

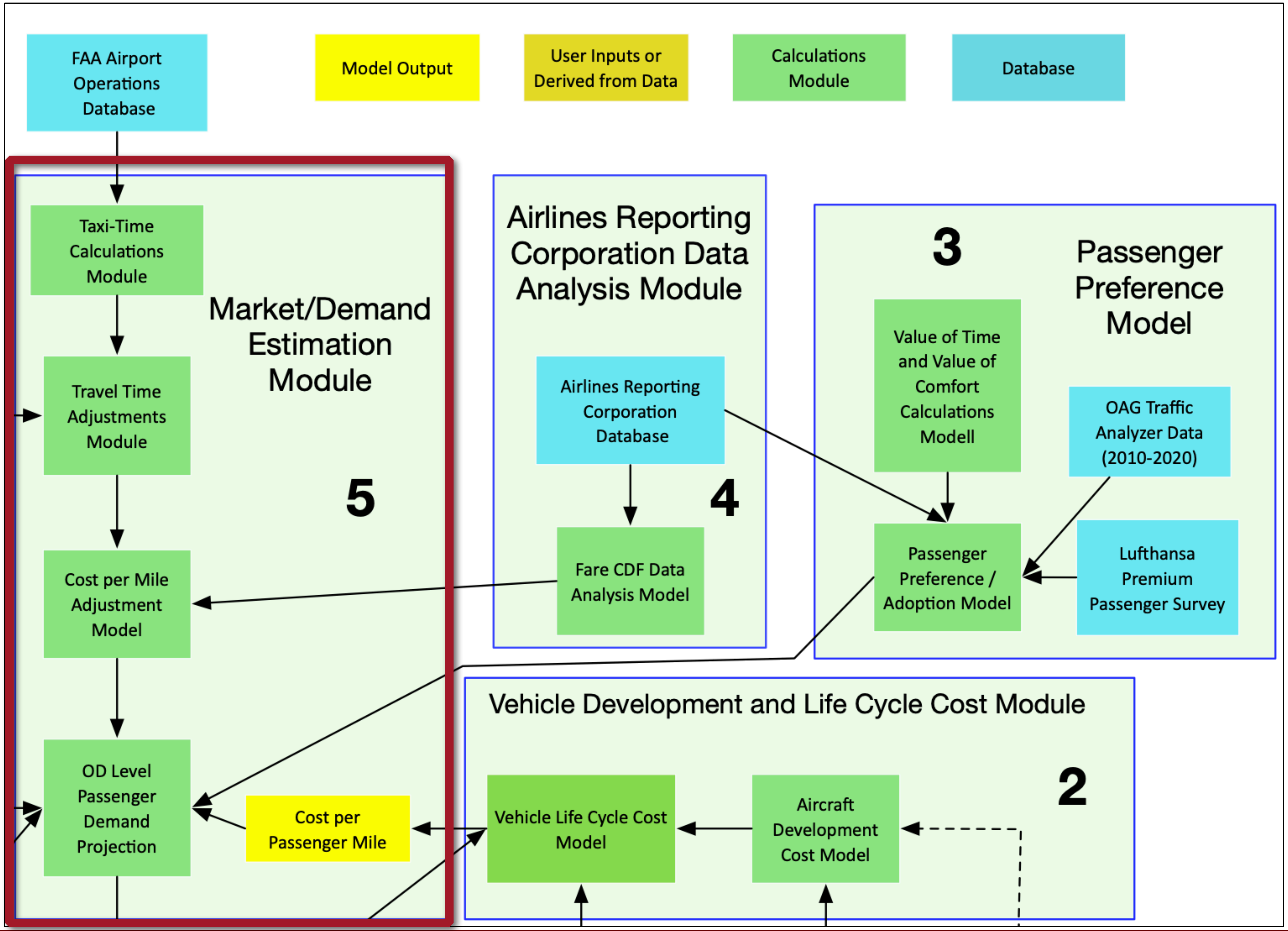
- Estimates the fraction of passengers willing to switch from subsonic to high-speed commercial services using Value of Time (VOT) and Value of Comfort (VOC)
- Estimates the tradeoffs between the travel time advantages of high-speed travel and the potential disadvantages of traveling in a more confined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



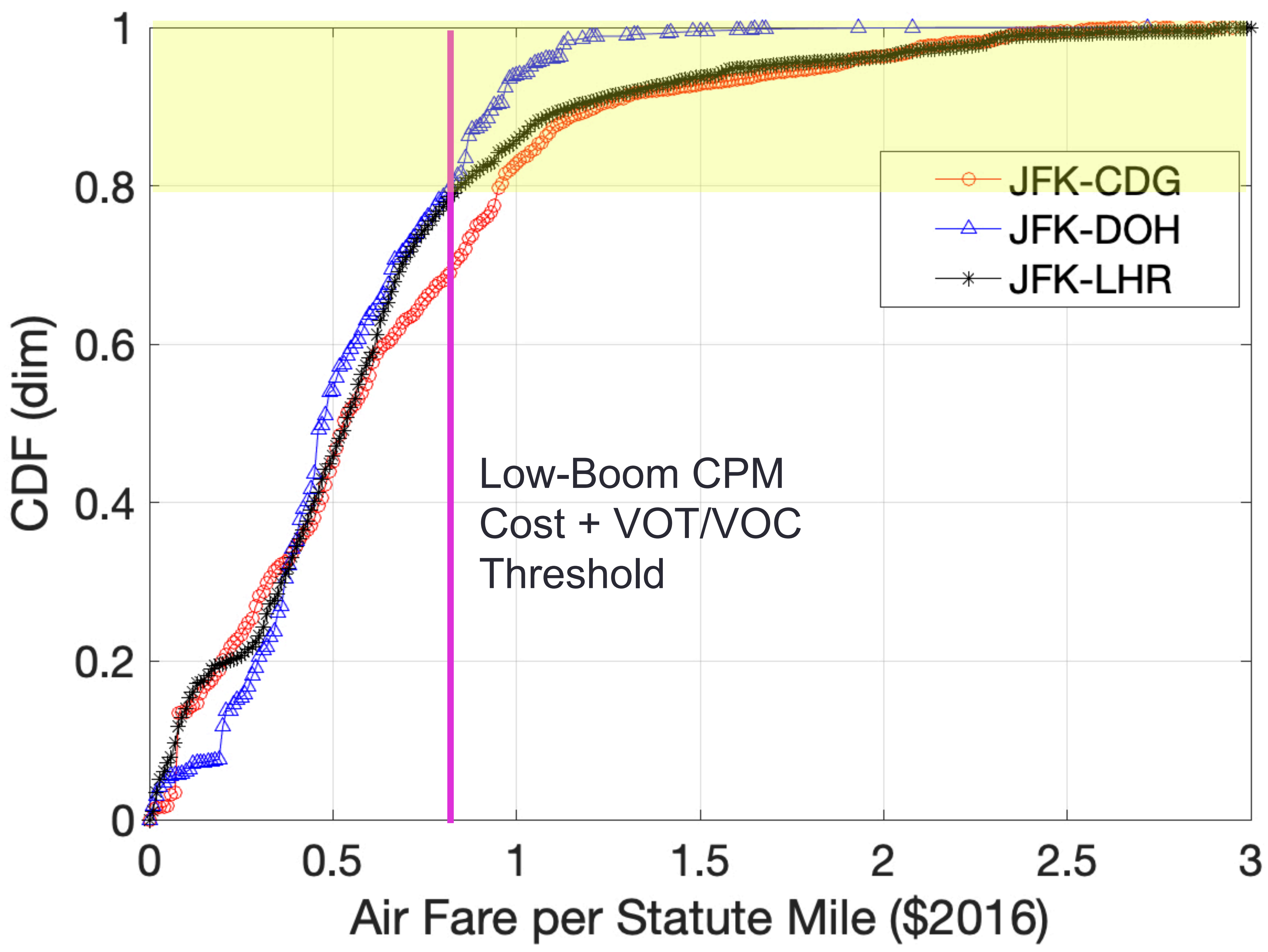
Lufthansa

Market Demand Estimation Module



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

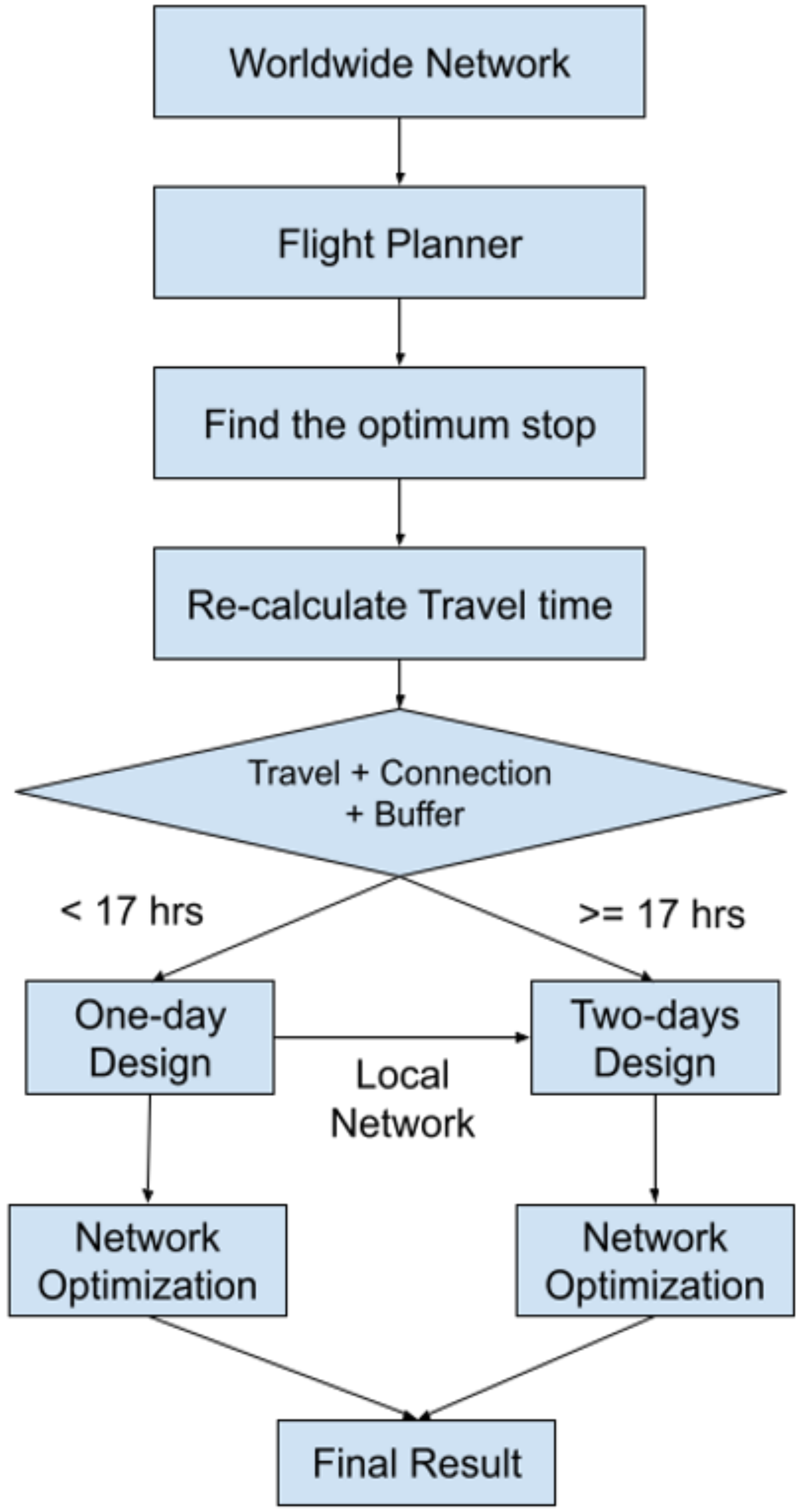


Market	Airports	OD Pairs	Records
US	135	1,535	8.14 million
US-International	327	2,709	9.89 million
International	1,008	12,176	27.19 million

Airline Reporting Corporation (ARC) datasets

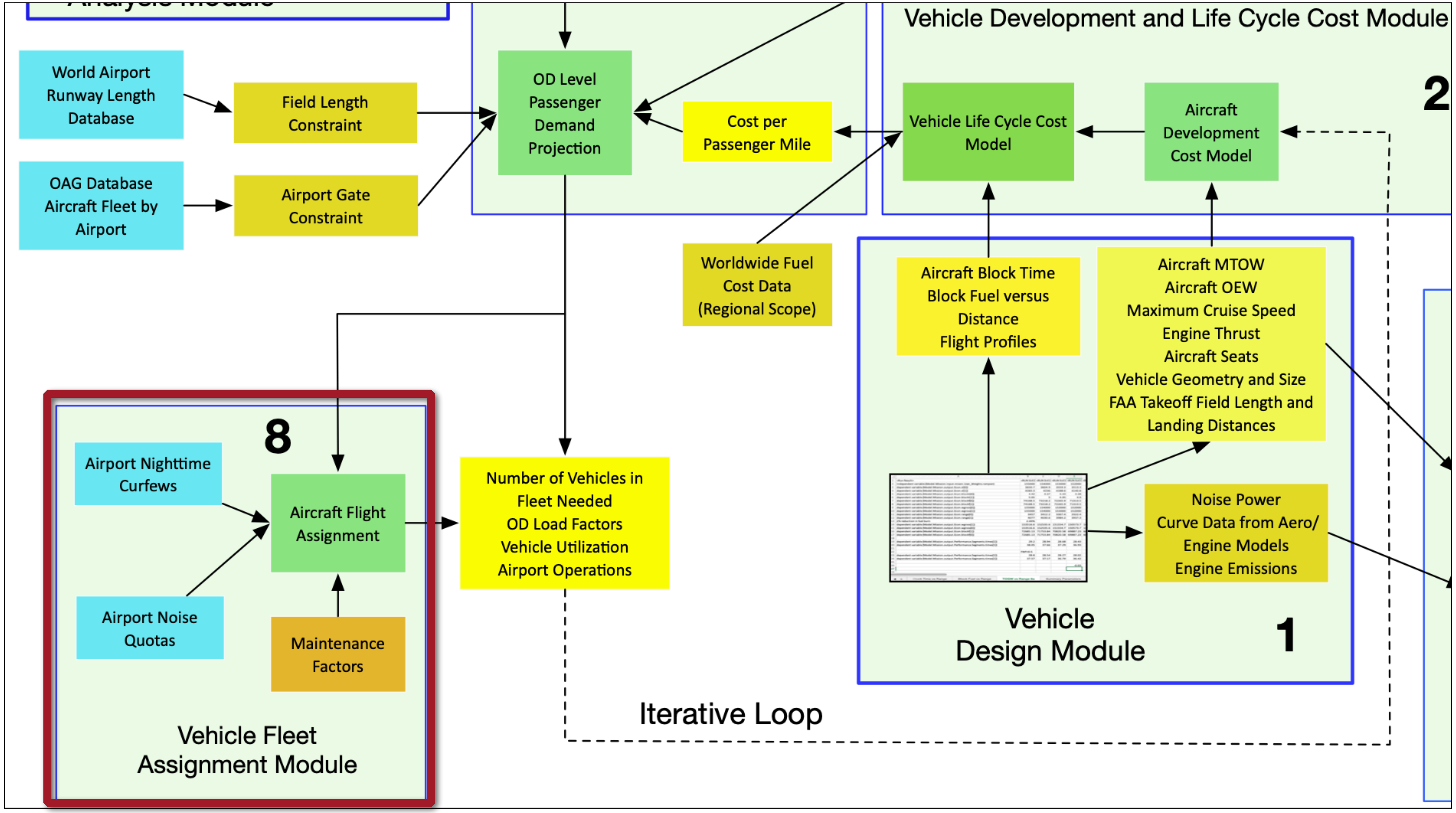
Example: Considering Value of Time and Value of Comfort
20% of the premium passengers in the JFK-LHR route may be willing to switch to supersonic aircraft if the supersonic air fare is $0.8/mile

Vehicle Fleet and Network Assignment Module

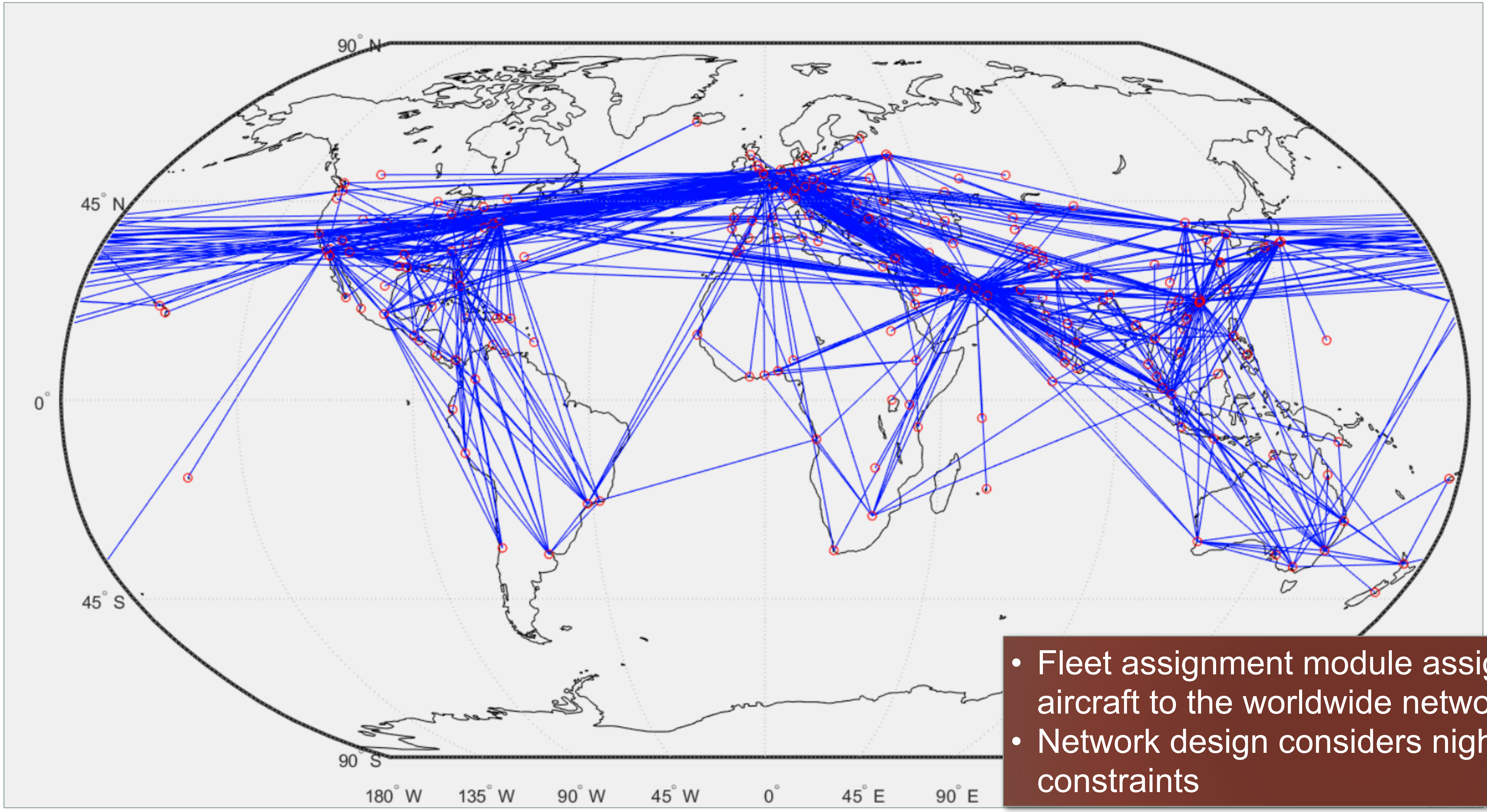


- Estimates the number of airframes needed to cover all the OD-level routes identified in the Market Demand Module
- Mix-integer programming technique creates daily schedules worldwide
- Predicts vehicle utilization, load factors at the OD airport and network levels, revenue, passenger spill-over, and repositioning flights
- The outputs are sent (via an iterative loop procedure) to the Vehicle Development and Life Cycle Cost Module until demand and supply are in equilibrium

Vehicle Fleet Assignment Module



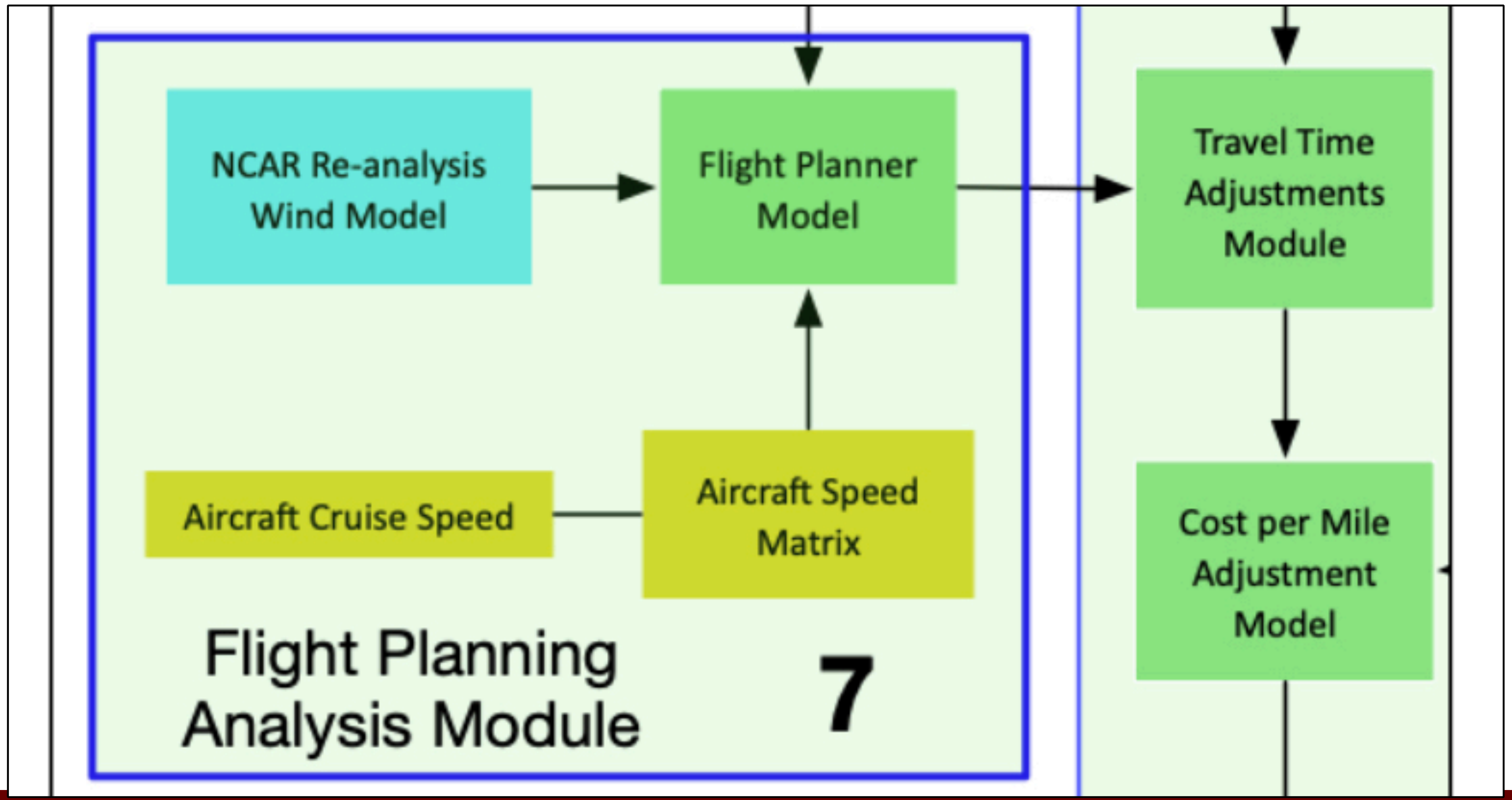
Sample Low-Boom World Network

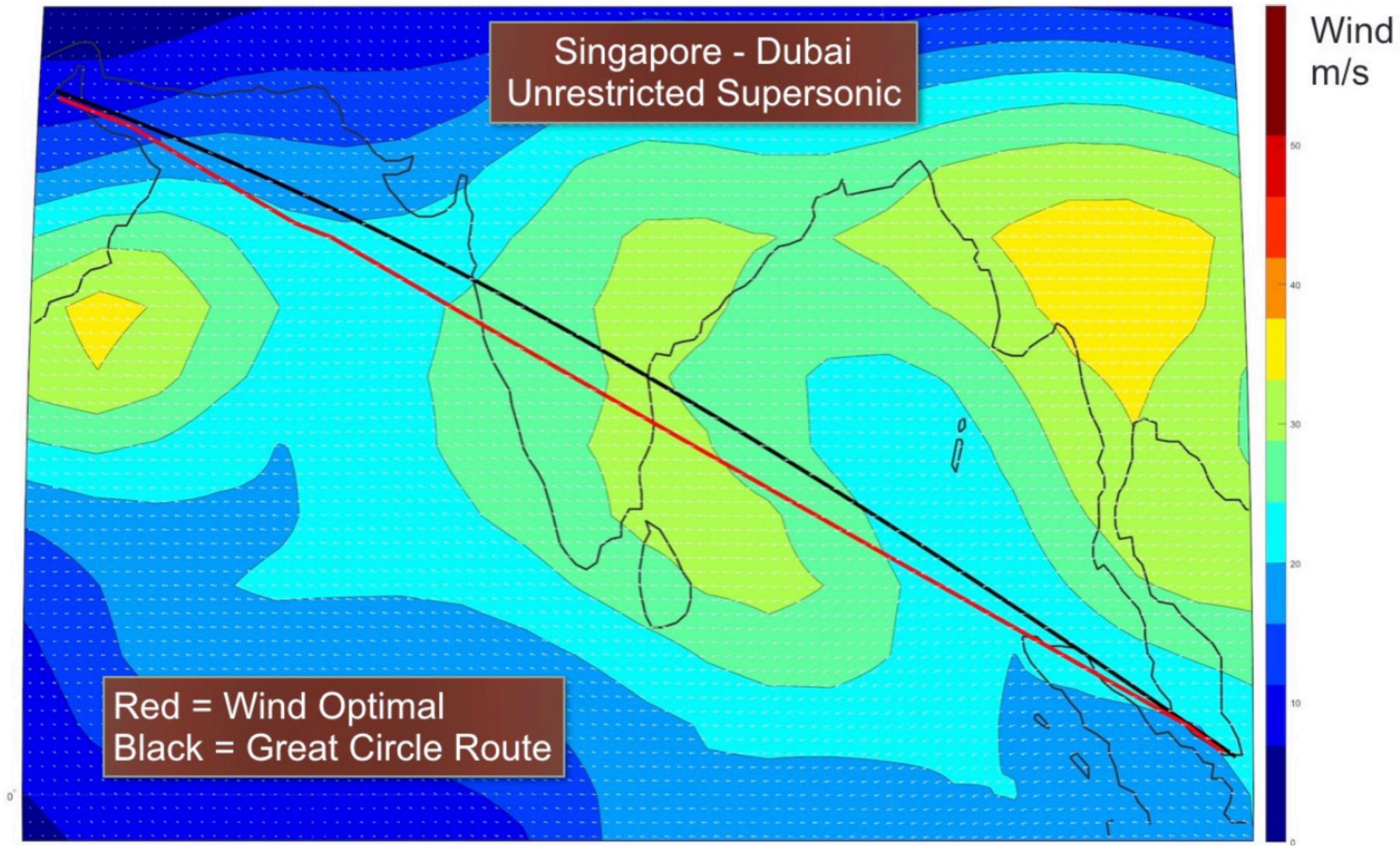


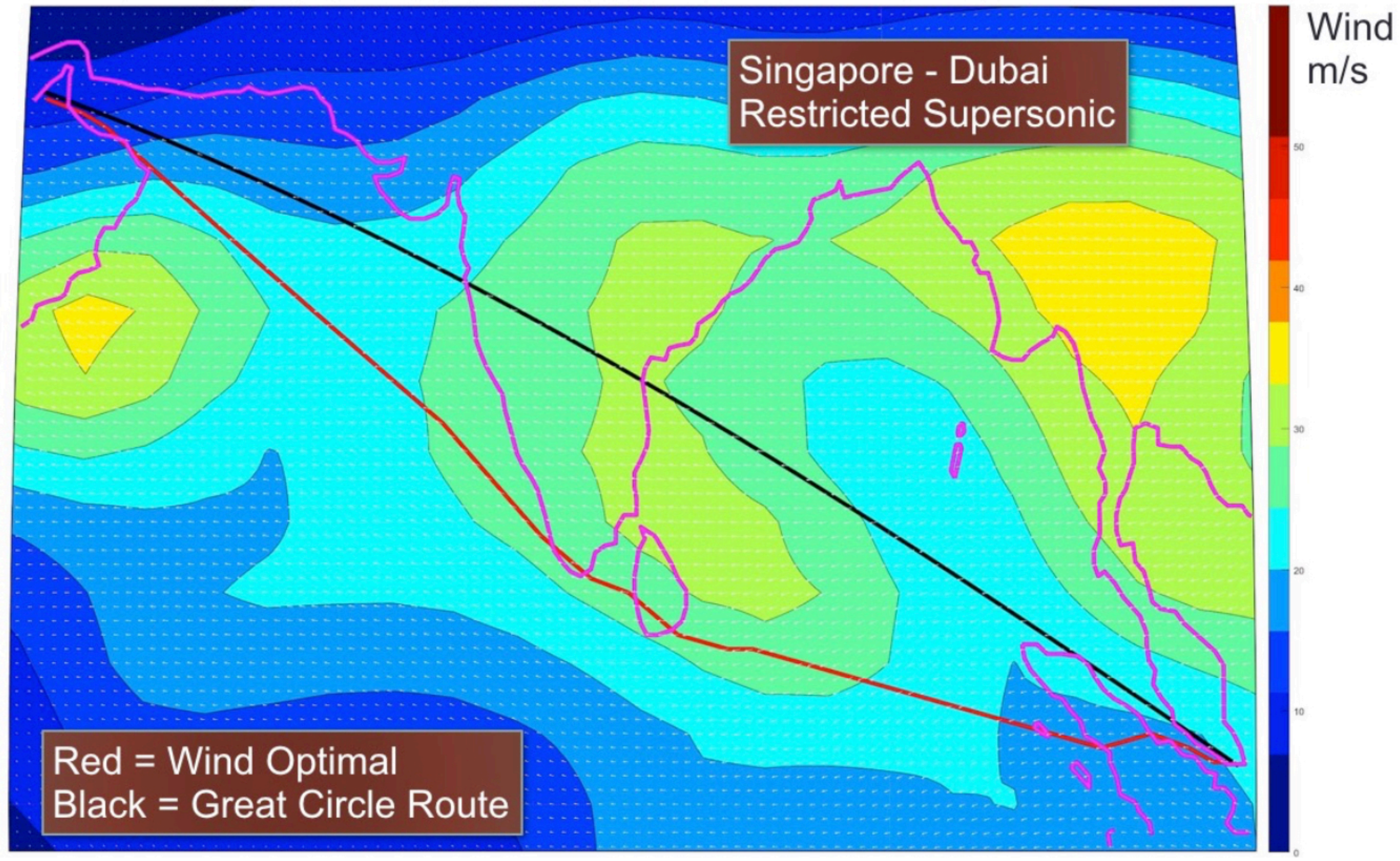
- Fleet assignment module assigns individual aircraft to the worldwide network
- Network design considers nighttime curfew constraints

Overland/Overwater Flight Restrictions

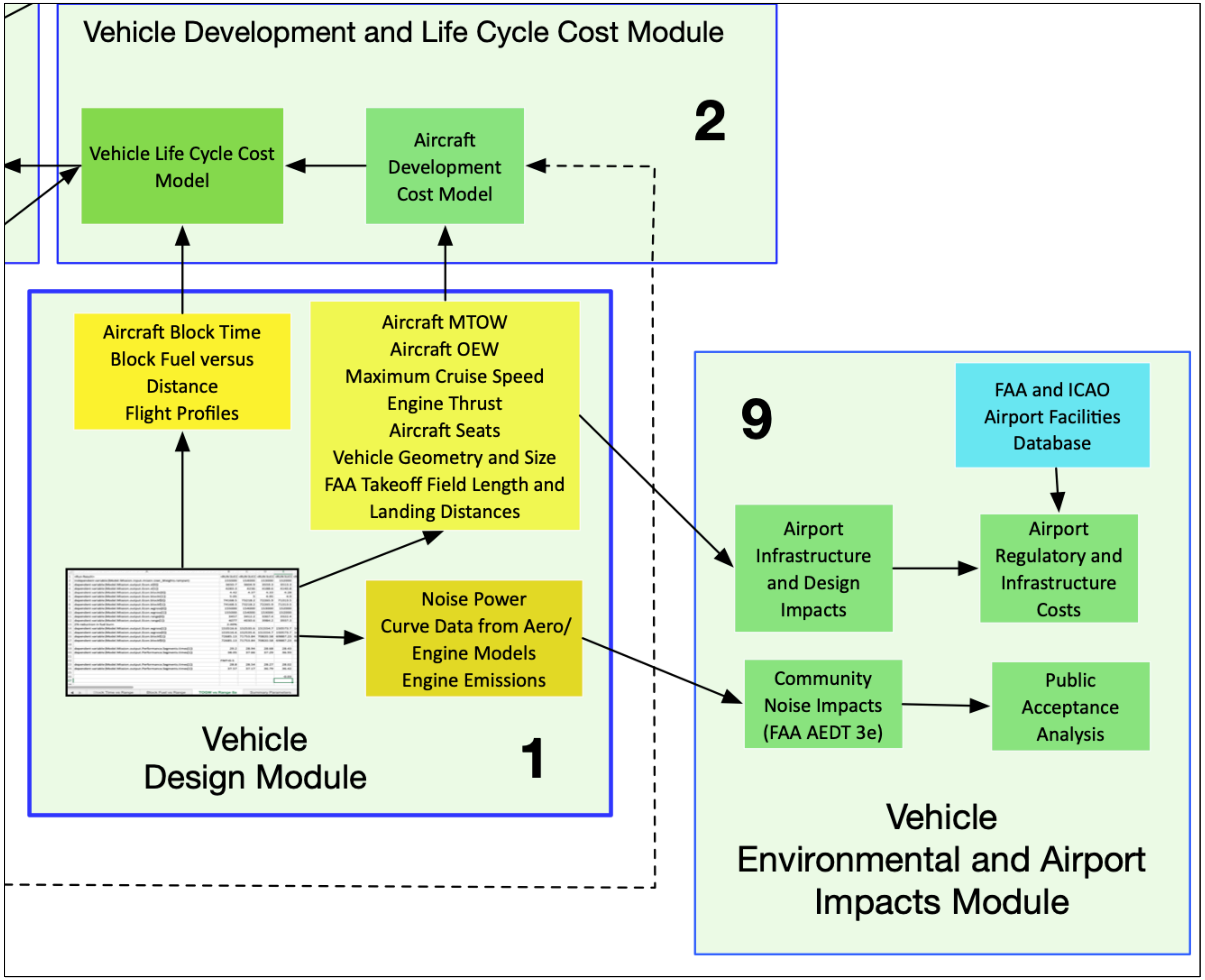
- Estimates flight trajectories for supersonic aircraft considering supersonic overland restrictions (if applicable)
- Flight planner uses NOAA Re-analysis wind data sets
- Runway length and airport gate compatibility analysis are considered in the selection of candidate OD airport pairs



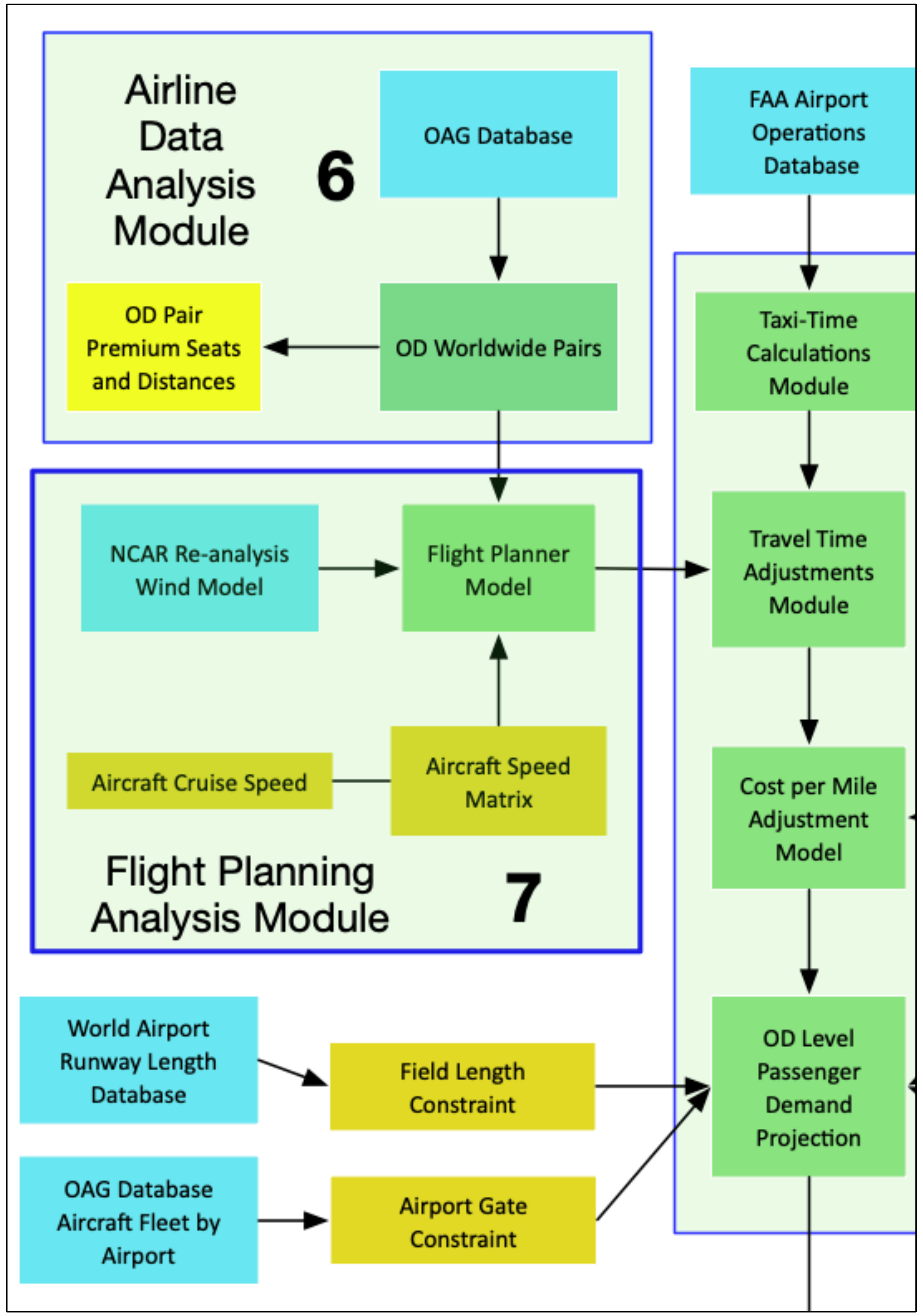




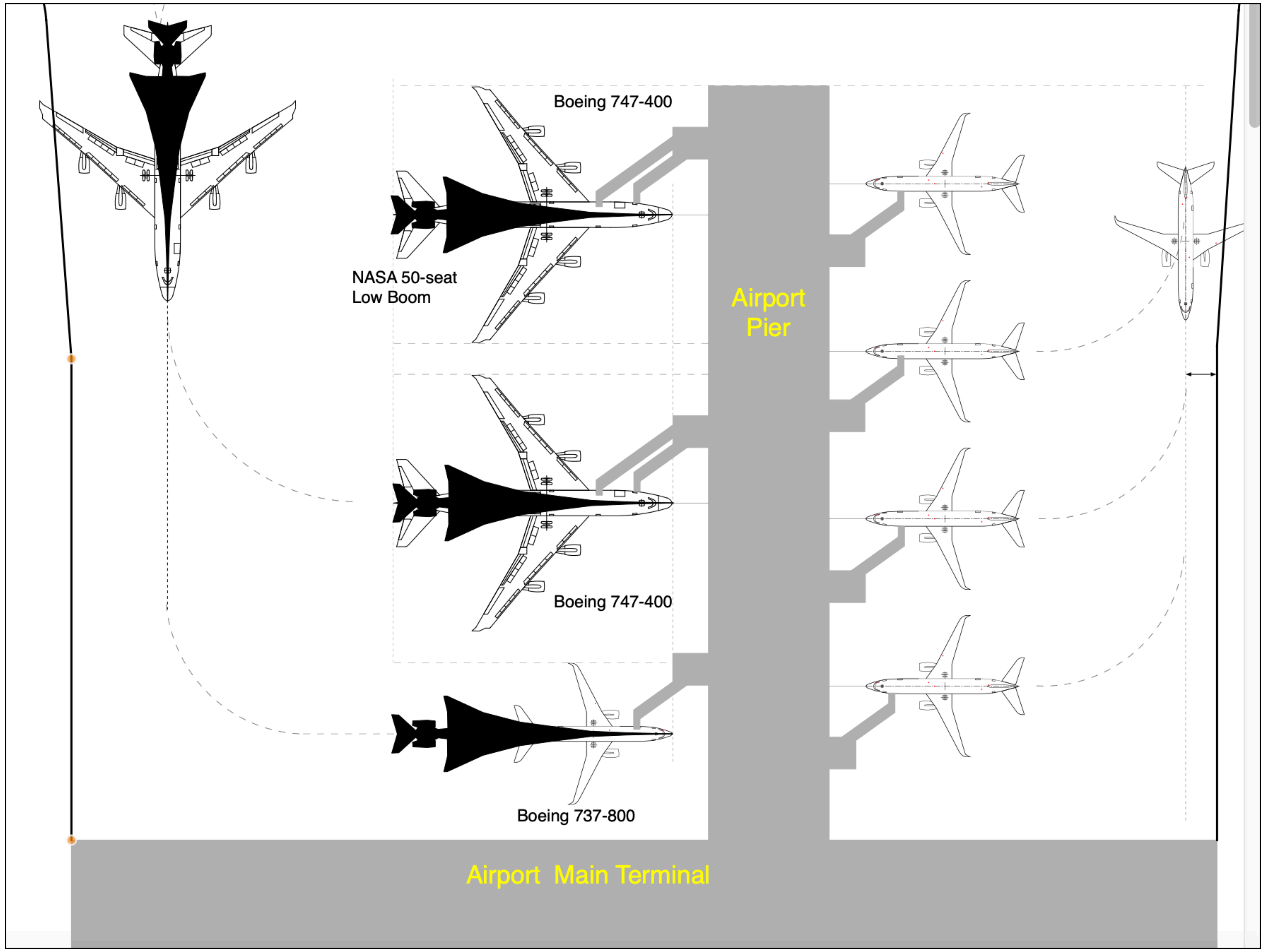
Vehicle Environmental and Airport Impacts Module



Airport Compatibility Impacts

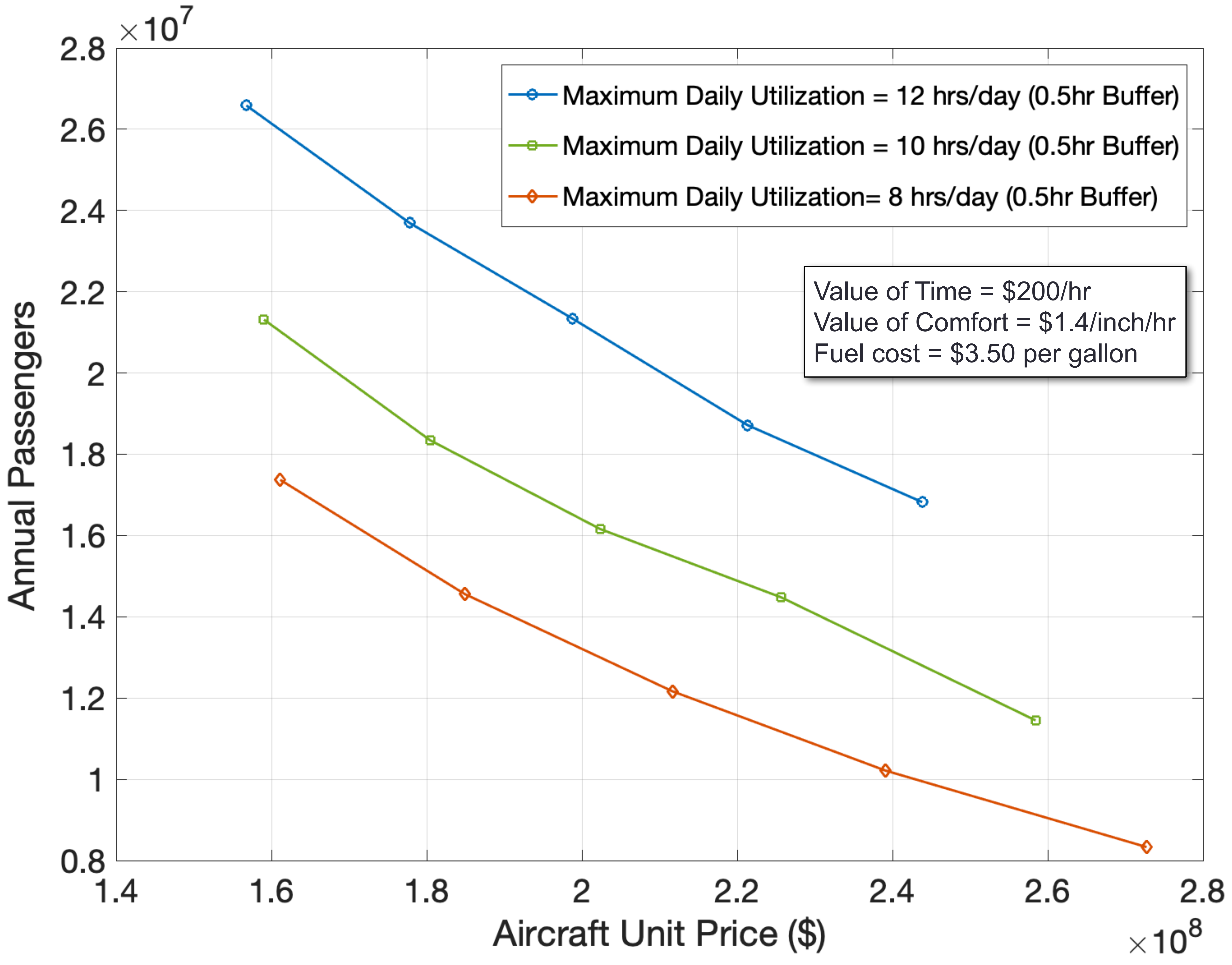


LBSAM OD airport pair candidates includes checks for runway length and gate size compatibility



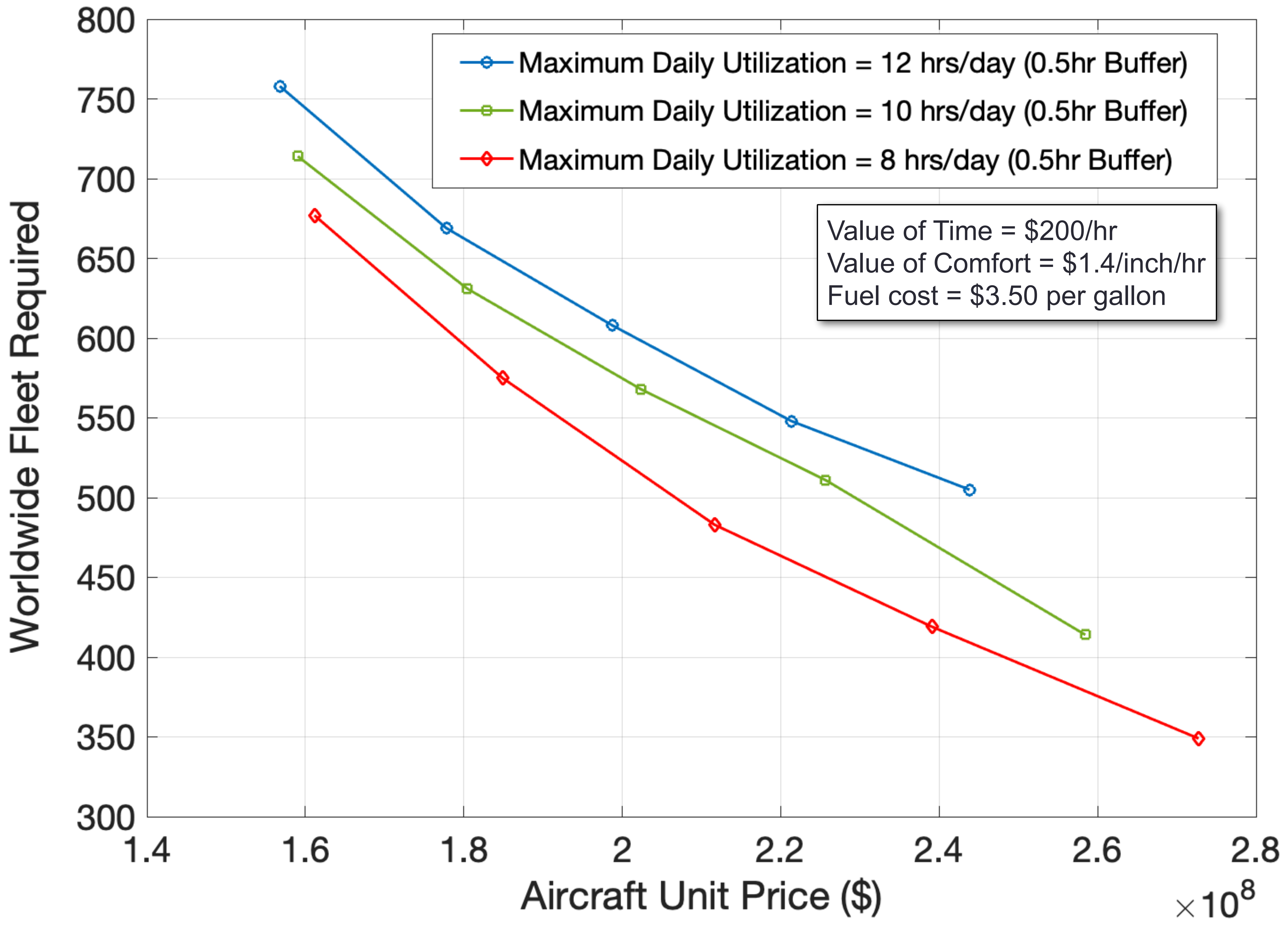
A 10% increase in Aircraft Unit Price Decreases Worldwide Passenger Demand by 7.5%

- Aircraft development cost is critical to a feasible supersonic aircraft program
- The elasticity of annual passenger demand with aircraft units cost is -0.75
- A 10% increase in aircraft unit price decreases worldwide demand by 7.5%



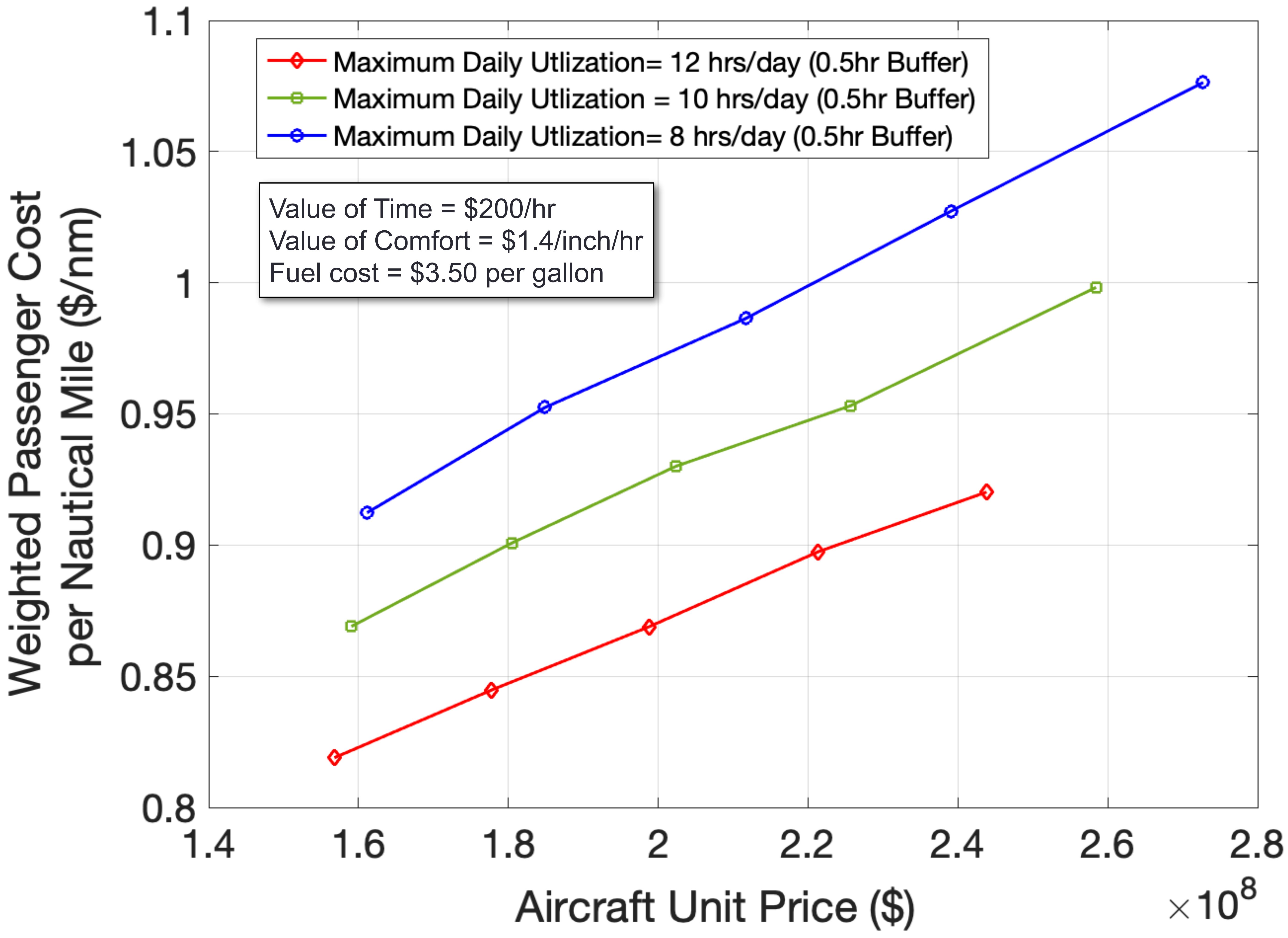
A 10% increase in Aircraft Unit Price Decreases the Number of Aircraft Needed by 11%

- Aircraft development cost is critical to attracting supersonic demand
- The elasticity of aircraft fleet size with aircraft unit cost is -1.1
- A 10% increase in aircraft unit price decreases the number of aircraft demand by 11%



Relationship Between Aircraft Unit Price and Weighted Cost per Passenger Mile

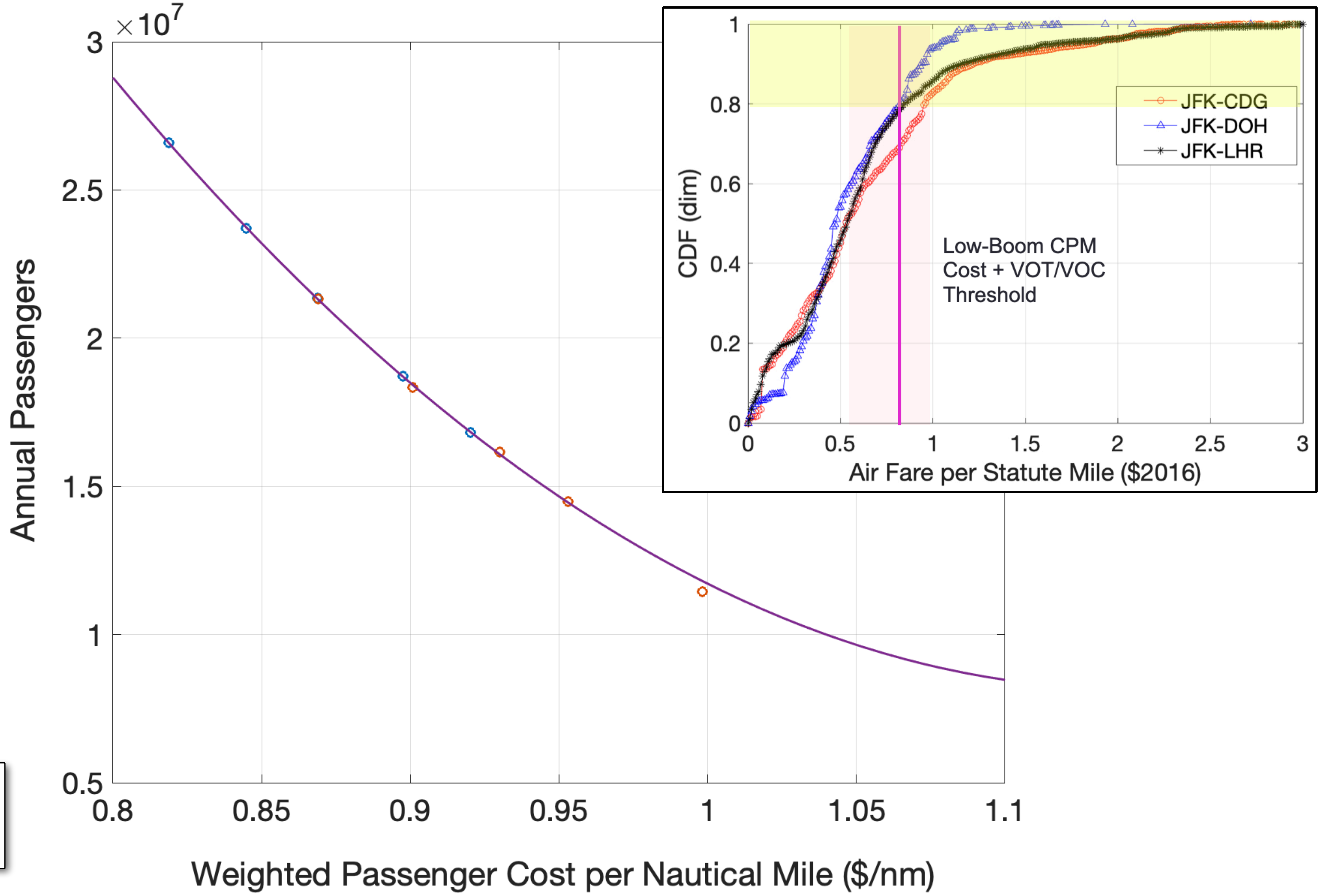
- Supersonic passenger demand if very sensitive to price
- The percent of passengers paying premium fares is nonlinear with air fare



A 10% increase in Cost per Passenger Mile Decreases the Worldwide Demand by 31%

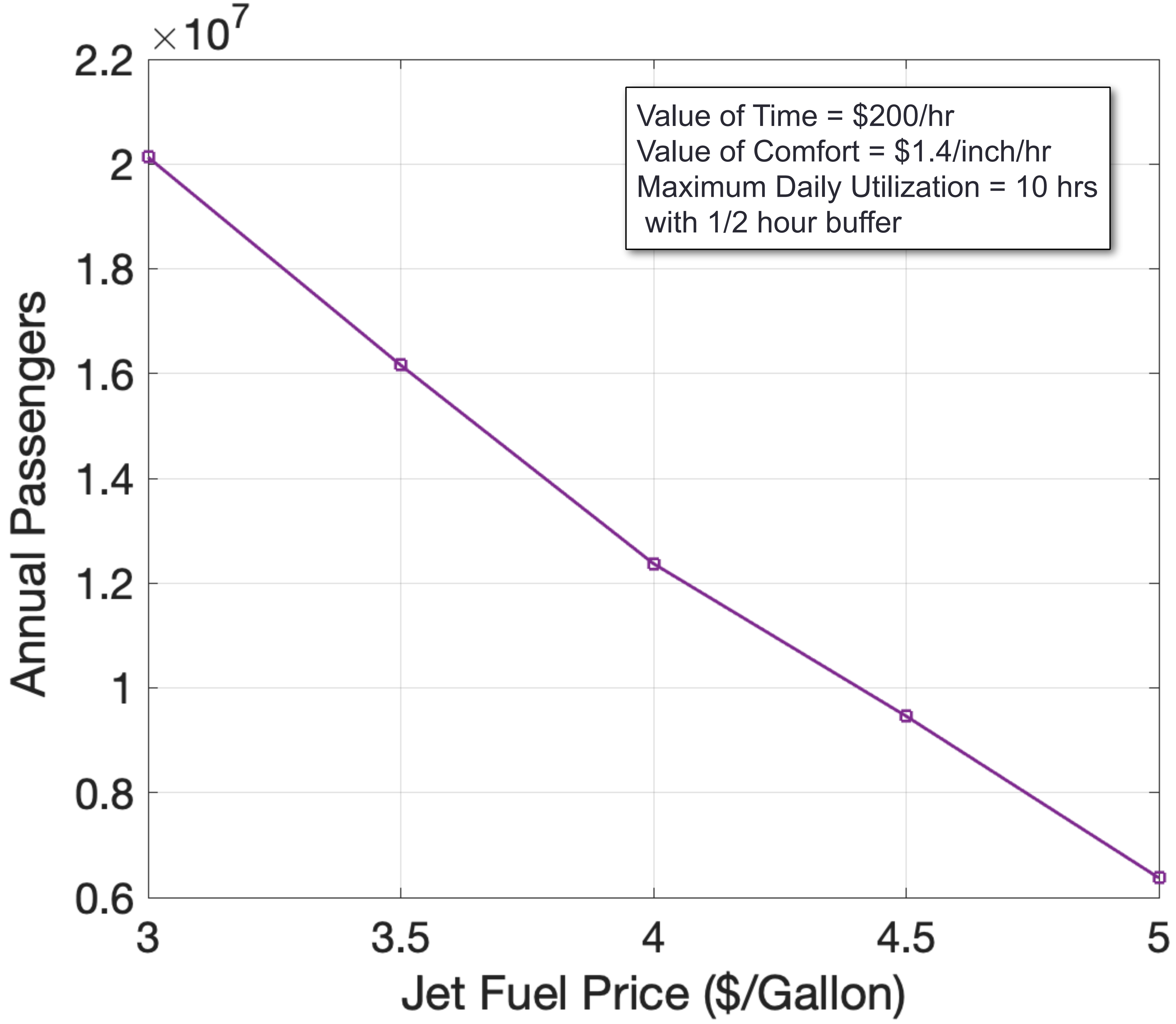
- Supersonic aircraft passenger demand if very sensitive to price (Cost per passenger Mile)
- The percent of passengers paying premium fares decreases very rapidly at high air fares

Value of Time = $200/hr
Value of Comfort = $1.4/inch/hr
Fuel cost = $3.50 per gallon



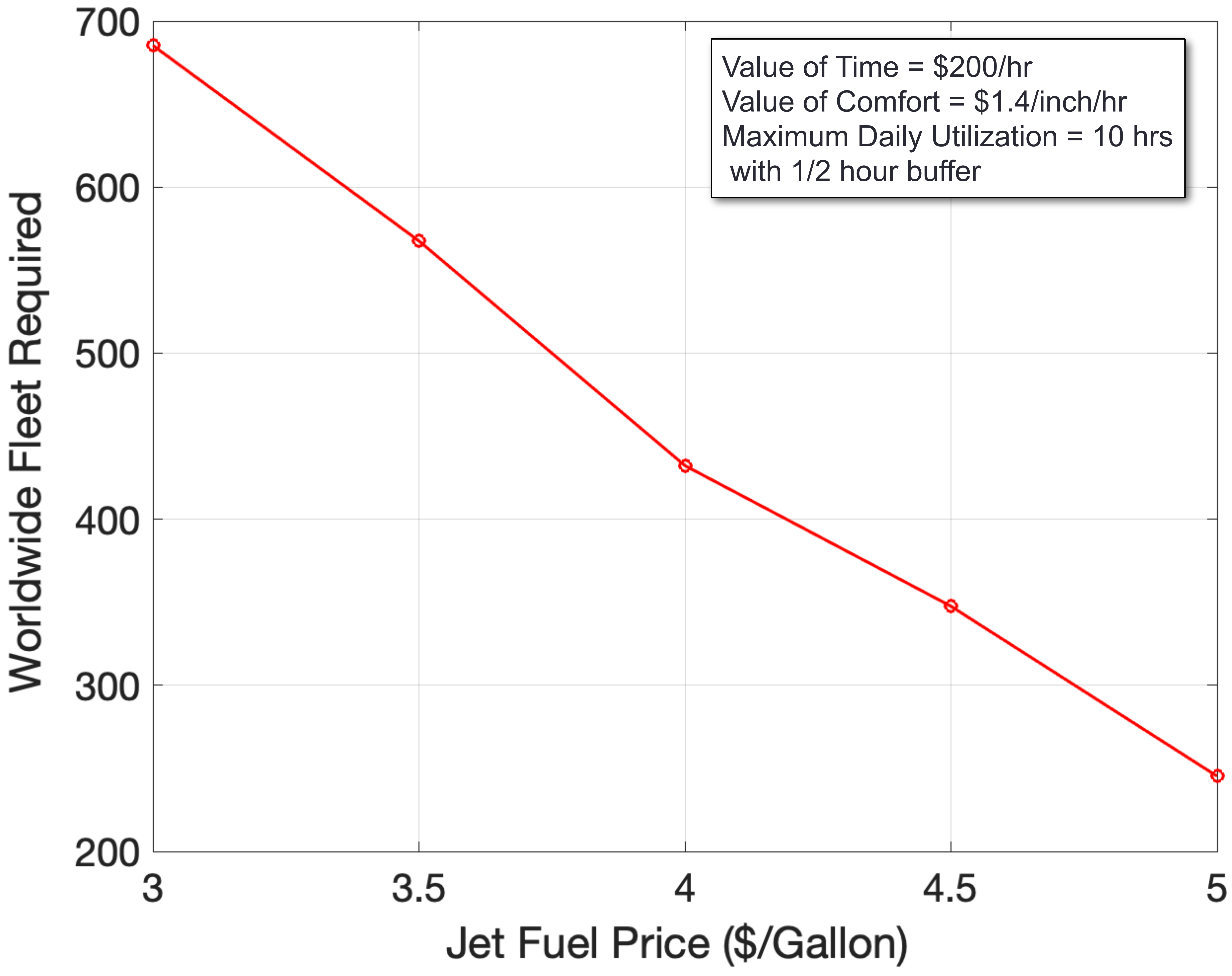
A 10% Increase in Jet-A Fuel Price Decreases the Worldwide Passenger Demand by 10.3%

- Fuel price is a very important parameter in the model to produce an economically feasible low-boom program
- The elasticity of aircraft fleet size with jet fuel cost is -1.03
- A 10% increase in jet-A fuel price decreases the number of aircraft demand by 10.3%



A 10% Increase in Jet-A Fuel Price Decreases the Number of Aircraft Needed by 10.6%

- Fuel price is a very important parameter in the model to produce an economically feasible low-boom program
- The elasticity of aircraft fleet size with jet fuel cost is -1.06
- A 10% increase in jet-A fuel price decreases the number of aircraft demand by 10.6%

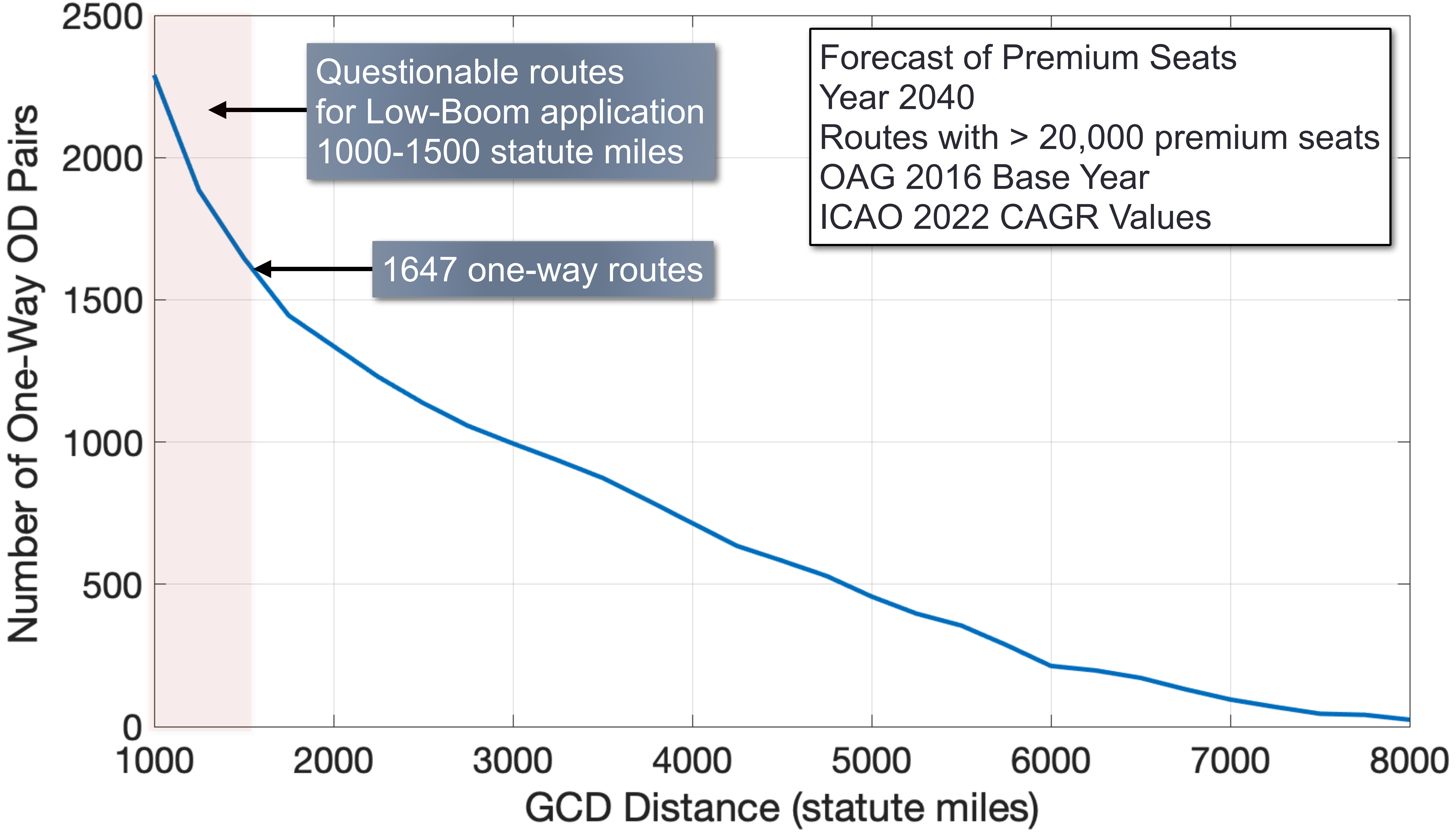


Conclusions

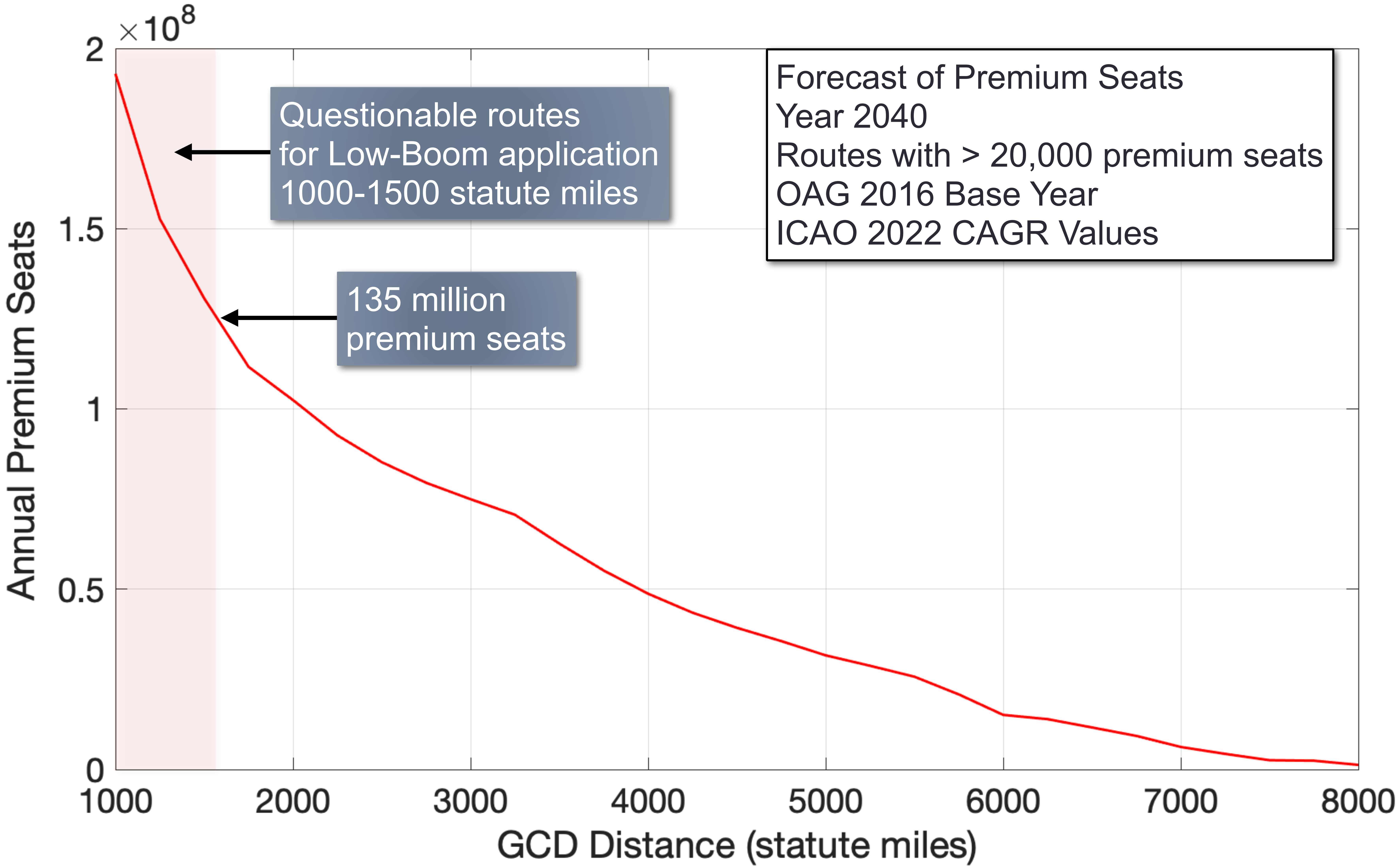
- The enhanced LBSAM models offers an integrated approach to study worldwide demand for supersonic aircraft concepts
  - Model includes network effects and captures the dynamics between fleet size, aircraft unit cost, aircraft economics, and passenger preference
- Model runs converge (demand-supply) in 5-12 iterations (2-4 hours of CPU time)
- Using optimistic parameters in the model development and aircraft operational cost, we estimate between 400-600 supersonic airframes may be needed in the year 2040
- Under optimistic model assumptions (i.e., high daily utilization and moderate fuel prices), low-boom supersonic aircraft could transport between 16-22 million annual passengers in 2040
- Faster supersonic aircraft concepts require re-examination of aircraft development cost equations and changes to the aircraft operations life cycle cost models

Backup Slides

Distribution of Worldwide OD Pairs versus Distance



Distribution of Premium Seats versus Distance



Distribution of OD Airport Pairs versus Distance