Integrated Model for Predicting Demand of Supersonic Transports

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- National Institute of Aerospace (NIA)

Summary of FY 2022-2023 Analysis

- **Based on the study of four conceptual supersonic designs**
  - Low-boom aircraft could attract 28% more demand worldwide compared to optimized Mach cut-off design because of the additional travel time-saving benefits on overland routes
- **Optimistic economic assumptions ($2.50 per gallon of jet-A fuel)**
  - Low-boom supersonic worldwide demand varies from 12.3 to 16.6 million passengers annually
  - 500 to 710 airframes needed in 2040
- **Conservative economic assumptions ($3.50 per gallon of jet-A fuel)**
  - Low-boom supersonic worldwide demand varies from 7.6 to 10.2 million passengers annually
  - 310 to 420 airframes needed in 2040

Low-Boom Systems Analysis Model (version 2) Accomplishments in FY 2022-2023

LBSAM2 estimates worldwide demand of various low-boom and non low-boom supersonic aircraft concepts

- **Vehicle Fleet and Network Assignment Module**
  - Development of detailed worldwide network analysis to estimate number of airframes needed to satisfy demand considering:
    - Aircraft fleet size
    - Airport curfews
    - Aircraft utilization
    - Runway length limitations
- **Passenger Preference Module**
  - Estimates the fraction of passengers willing to switch from subsonic to supersonic commercial services using Value of Time (VOT) and Value of Comfort (VOC)
  - ARC database with 46 million premium class airline tickets
  - OAG Traffic Analyzer (average fares)
  - SeatGuru data with seat pitch information

An Integrated Model to Estimate Supersonic Market Share Worldwide and Fleet Analysis

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Integrated Model for Predicting Demand of Supersonic Transports under Low-Boom Constraint

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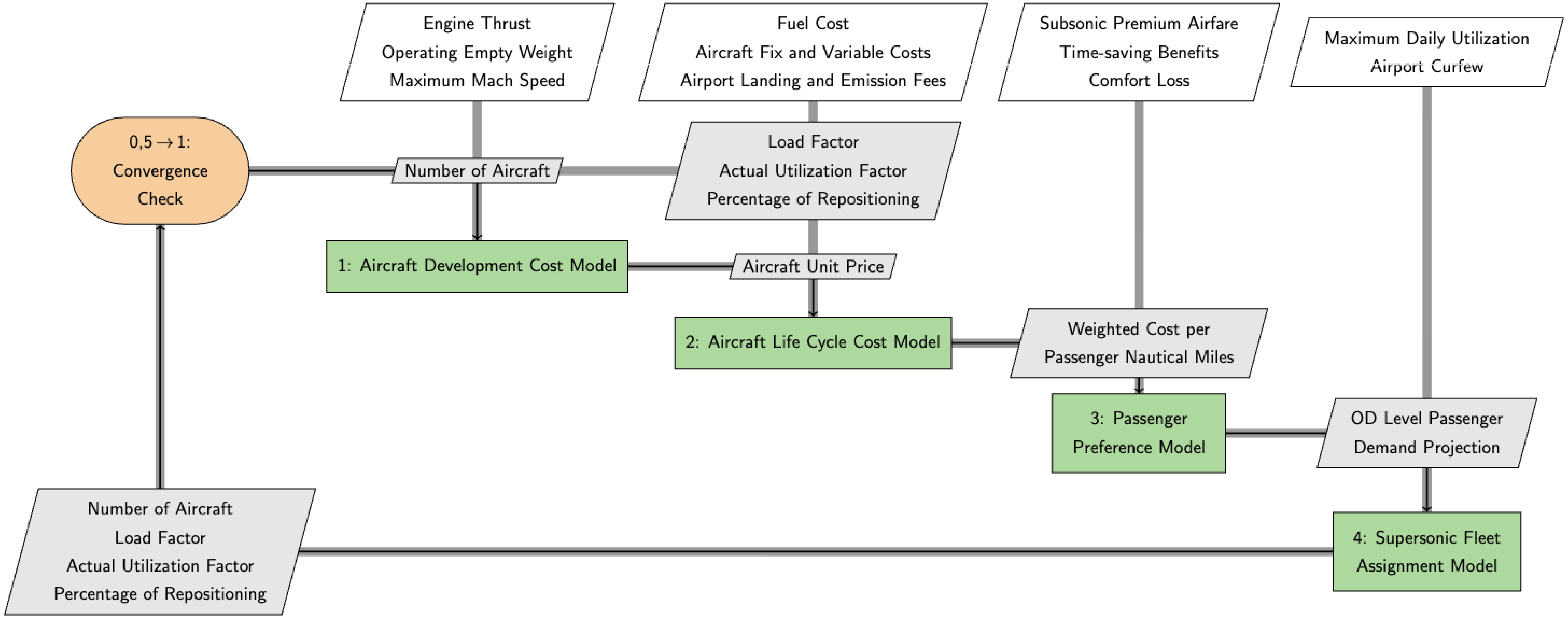
Commercial supersonic aircraft could return between 2035 and 2040 due to our desire for fast travel and advancements in technology that could reduce the cost of supersonic transport. Nevertheless, several challenges remain to make supersonic travel a reality. The model presented, LBSAM2, ties the aircraft preliminary design process, the economics of aircraft development and operations, and passenger preferences to estimate worldwide demand for subsonic overland,

Low-Boom Systems Analysis Model (LBSAM2) Model Integration

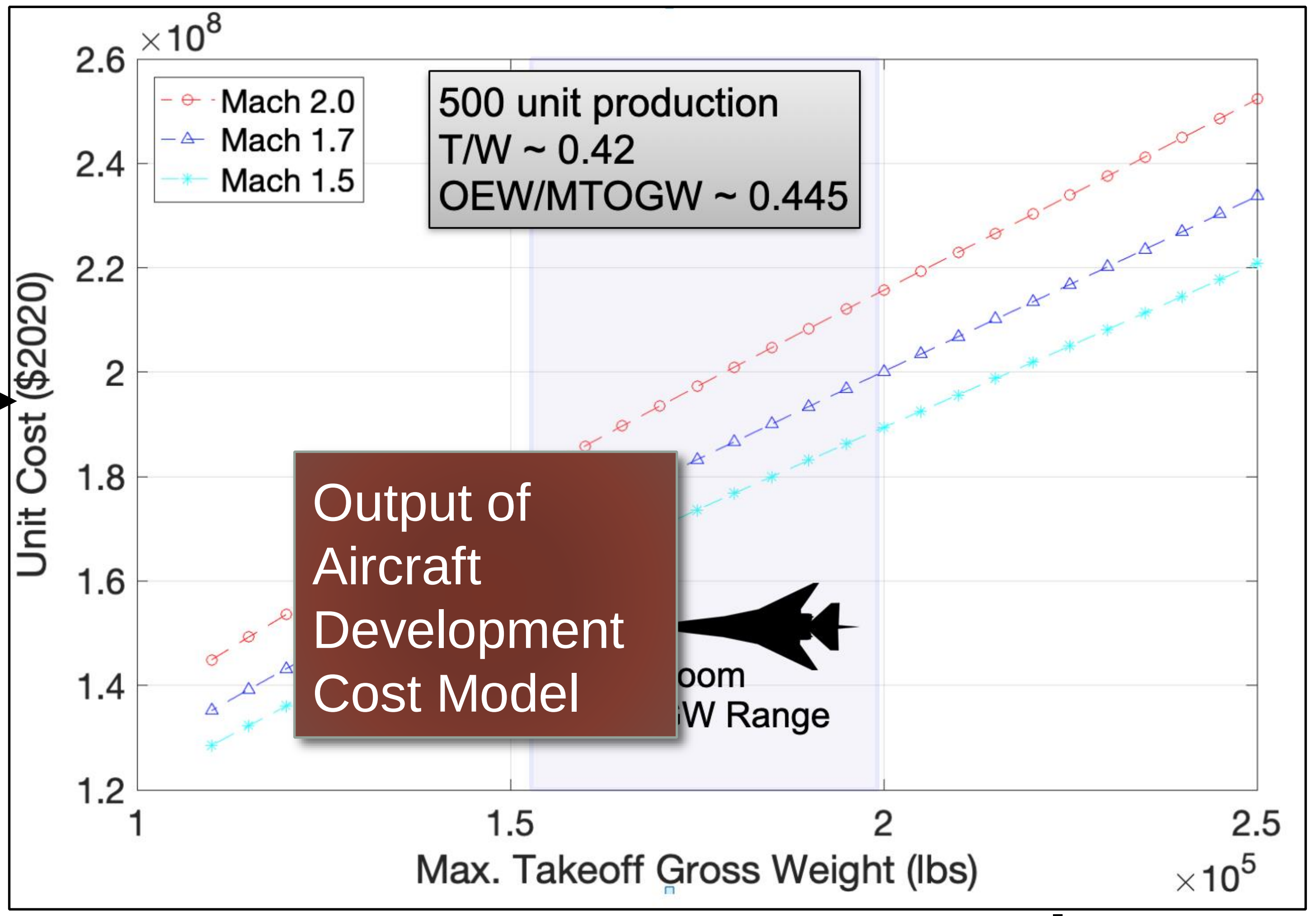
- Four-discipline coupled system
- The off-diagonal nodes in the shape of the parallelograms are the external inputs which consist of design variables (white) and system coupling variables (grey)

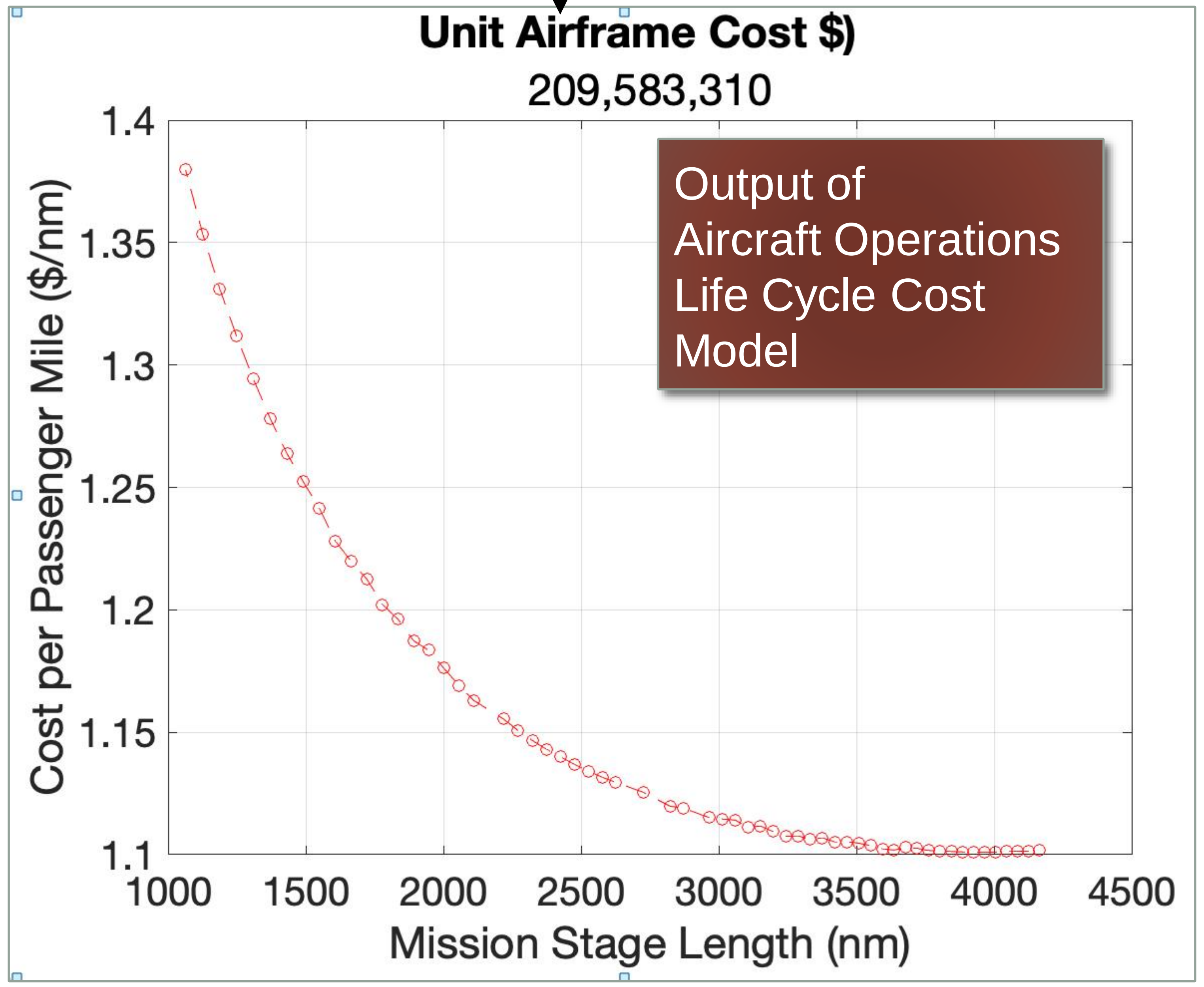


Aircraft Development and Life Cycle Cost Modules

FLOPS Model Output

	178450	177250
TopLeve	4619.7	4573.8
PostFLO	4802.8	4756.1
PostFLOPS.Ae.LowBoomMission.output.Econ.sl[1]	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		





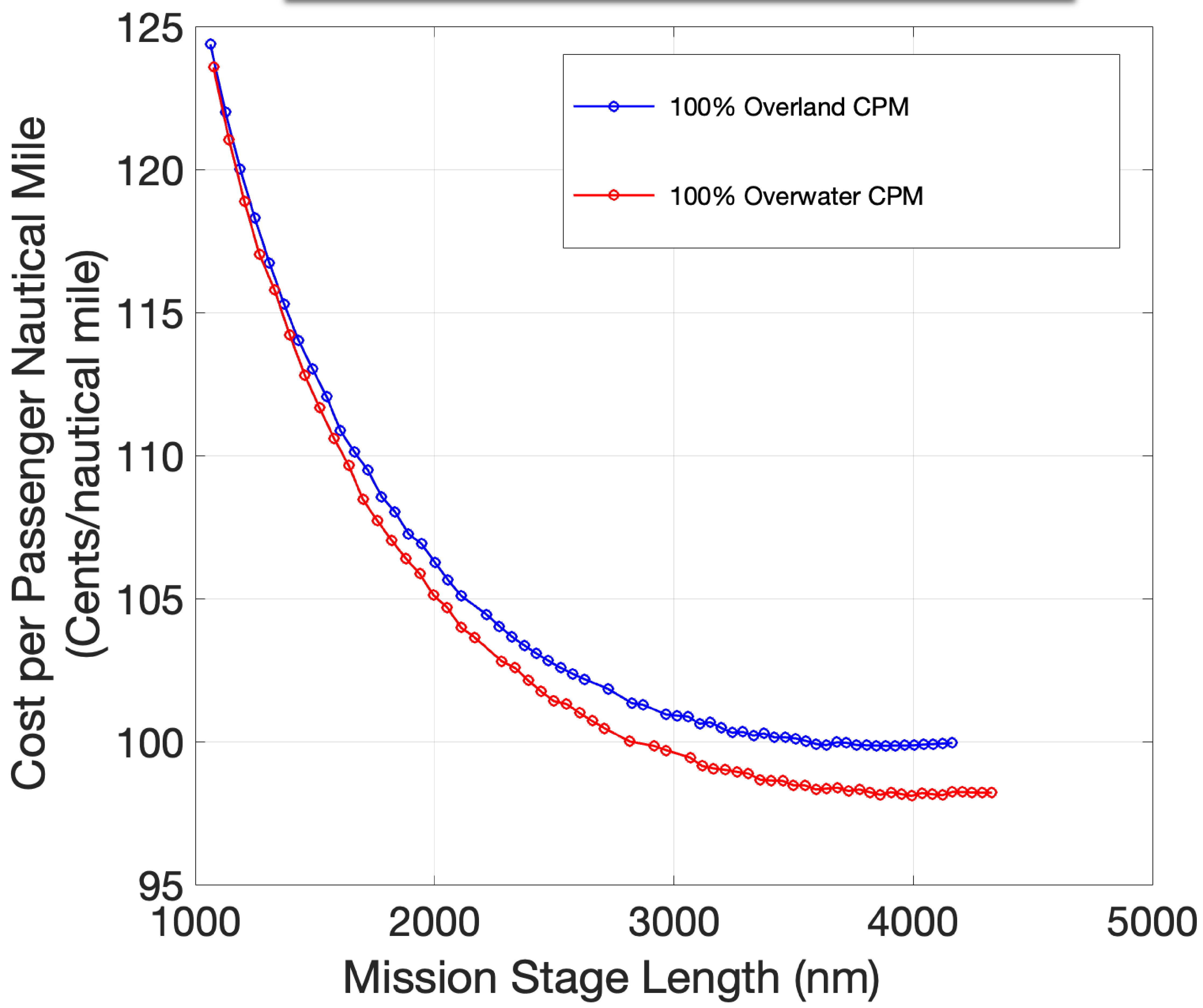
- Aircraft speed, quantity produced, takeoff and empty weights, and other technical parameters produced by FLOPS are used to estimate the vehicle development costs using non-linear regression equations adapted from a RAND Corporation cost model
- An operational aircraft life cycle cost model is used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

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

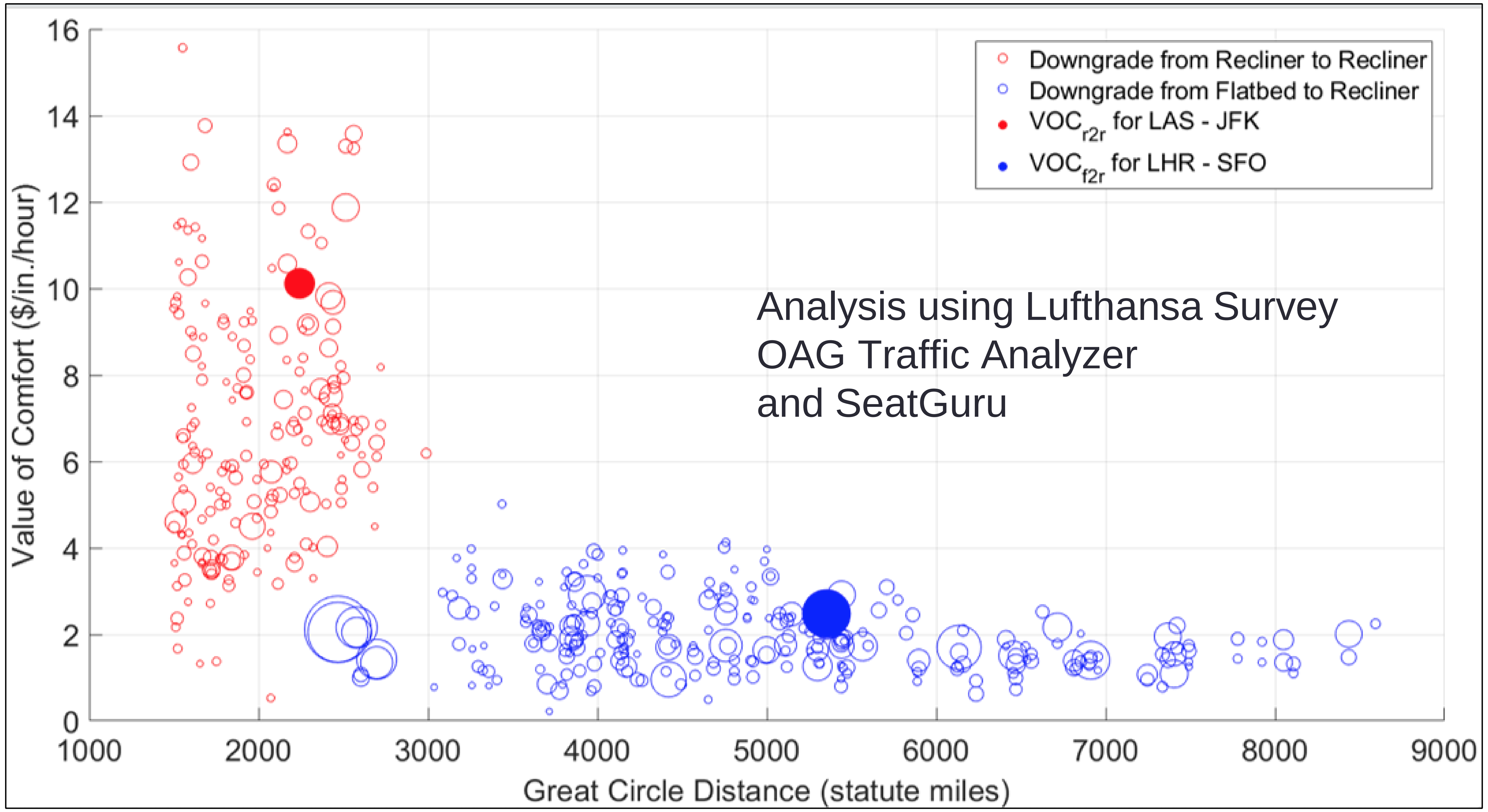
Output of Aircraft Operations
Life Cycle Cost Model
Mach 1.8/1.8 Low-Boom Aircraft



Passenger Preference Module

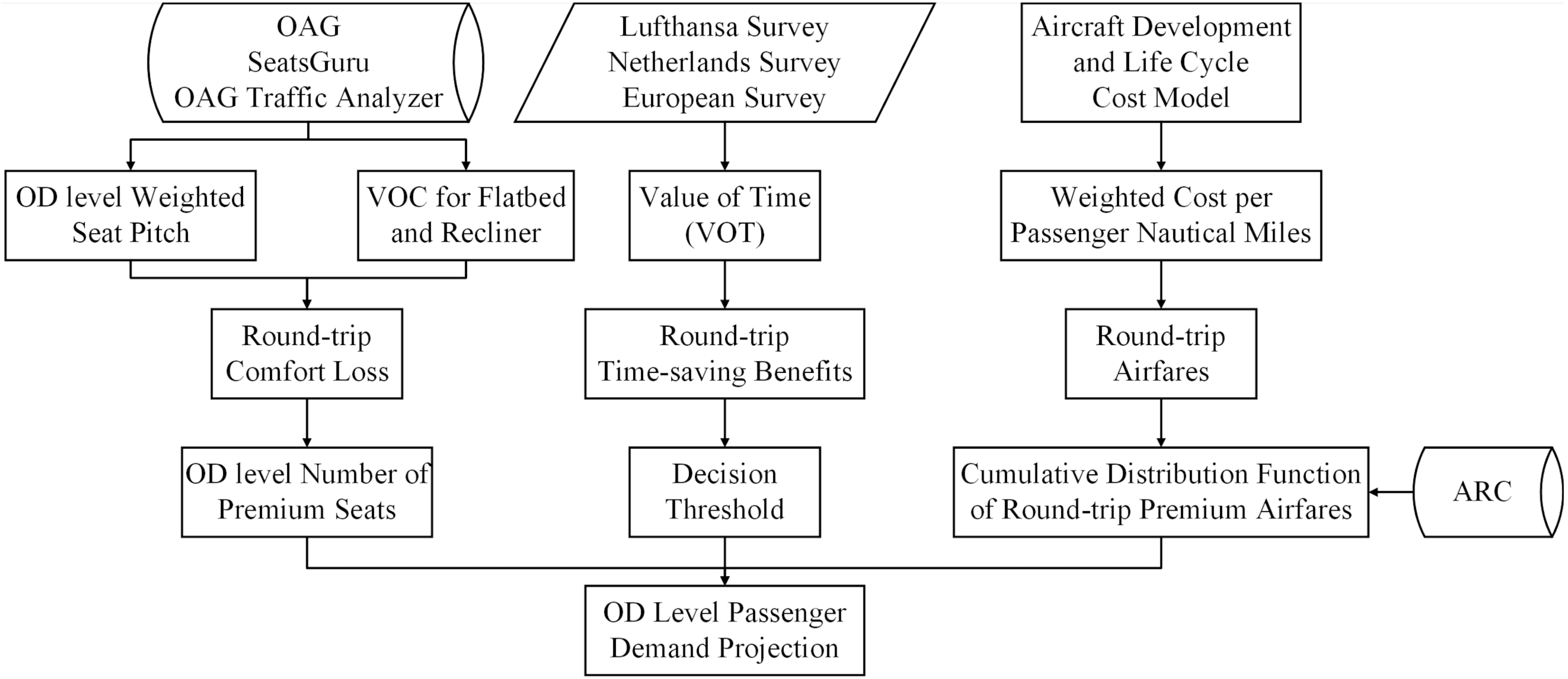
- Estimates the fraction of passengers willing to switch from subsonic to high-speed commercial services using Value of Time (VOT) and Value of Comfort (VOC)

Estimated Values of Time for premium seats range from $120-$240/hr



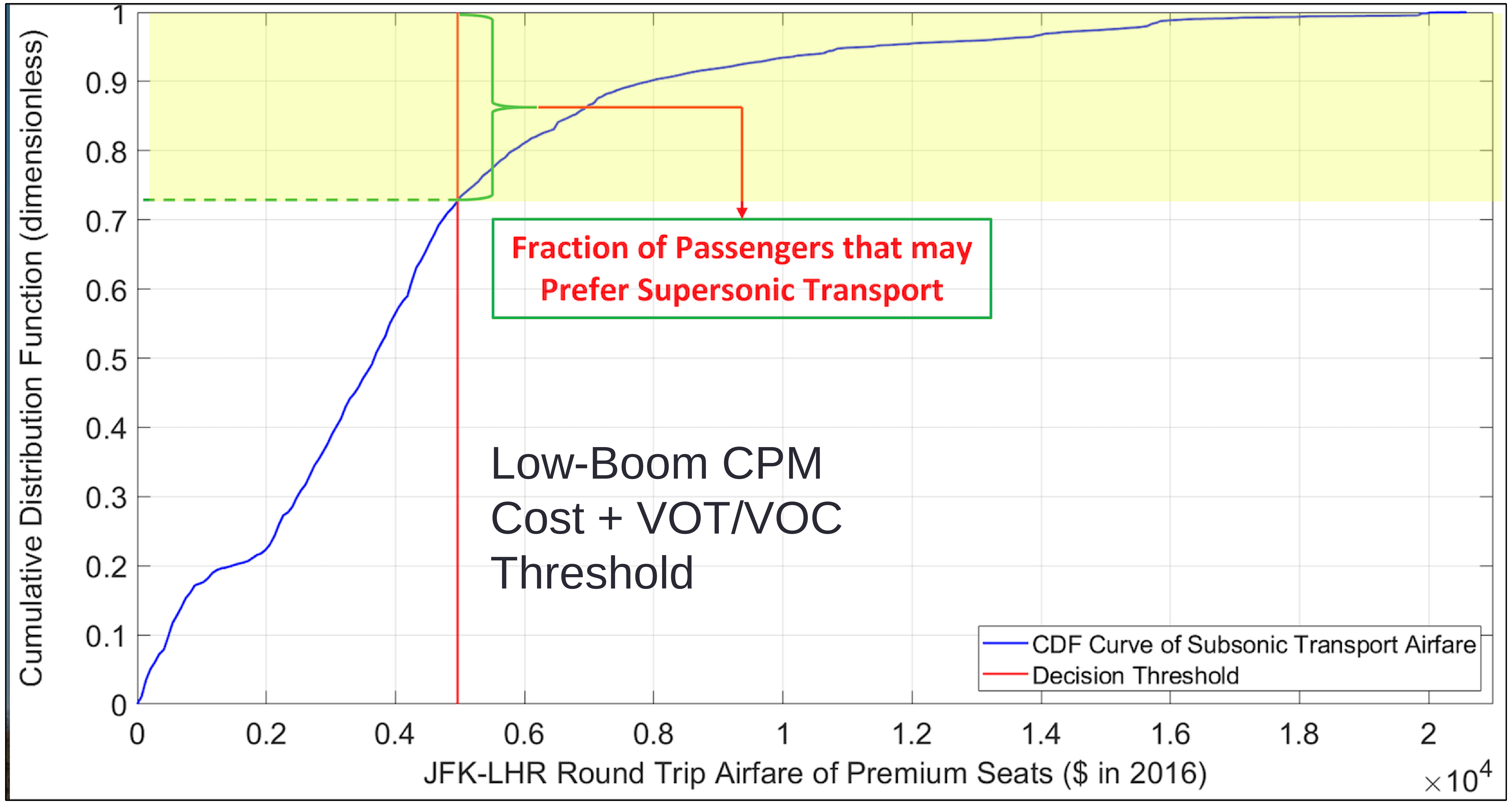
Passenger Preference Module

- Estimates the number of passengers traveling in supersonic aircraft at the OD airport-pair level
- Employs databases such as the Lufthansa premium passenger survey, Seat Guru and the Official Airline Guide Traffic Analyzer



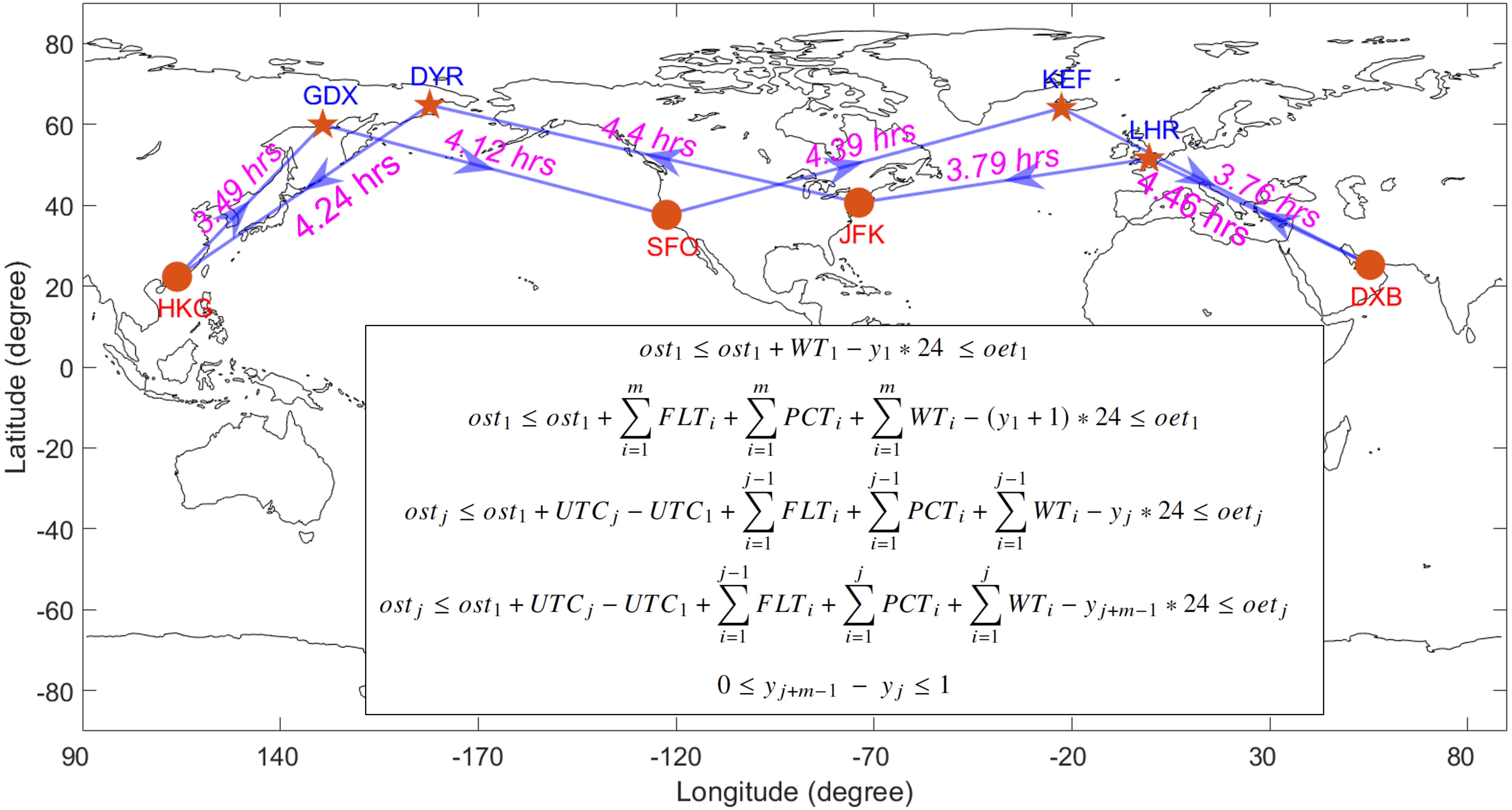
Passenger Preference Module

- Estimates the number of passengers traveling in supersonic aircraft at the route level
- Employs the Airline Reporting Corporation (ARC) database with 46 million premium class airline tickets



Vehicle Fleet and Network Assignment Module

- Estimates the number of airframes needed to satisfy worldwide origin-destination demand
- Employs a **Mix-integer programming solution** to create daily schedules worldwide (one and two-day networks)
- **Model outputs:** vehicle utilization, load factors at the OD airport and network levels, revenue, passenger spill-over, and repositioning flights



$$ost_1 \le ost_1 + WT_1 - y_1 * 24 \le oet_1$$

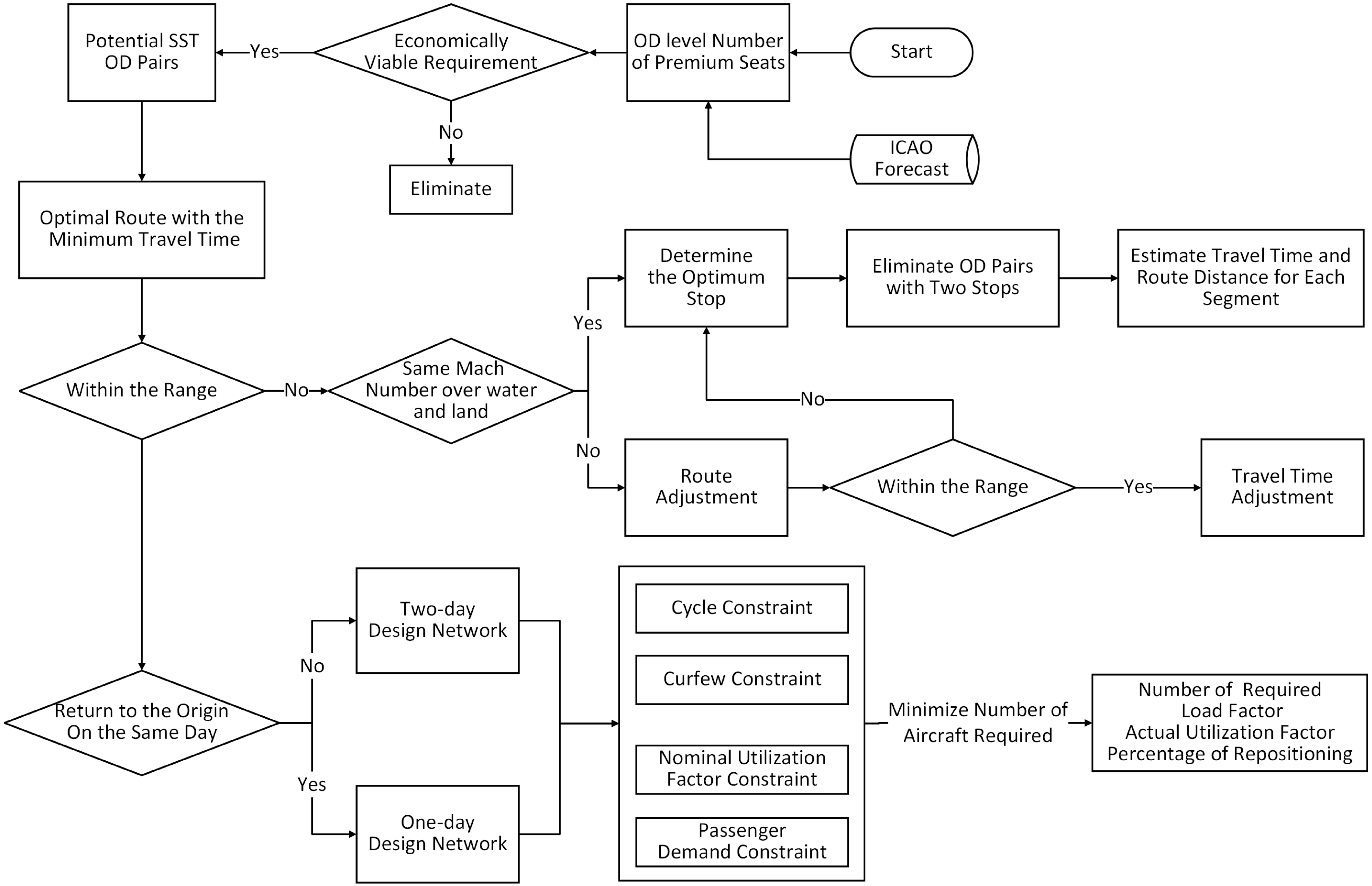
$$ost_1 \le ost_1 + \sum_{i=1}^{m} FLT_i + \sum_{i=1}^{m} PCT_i + \sum_{i=1}^{m} WT_i - (y_1 + 1) * 24 \le oet_1$$

$$ost_j \le ost_1 + UTC_j - UTC_1 + \sum_{i=1}^{j-1} FLT_i + \sum_{i=1}^{j-1} PCT_i + \sum_{i=1}^{j-1} WT_i - y_j * 24 \le oet_j$$

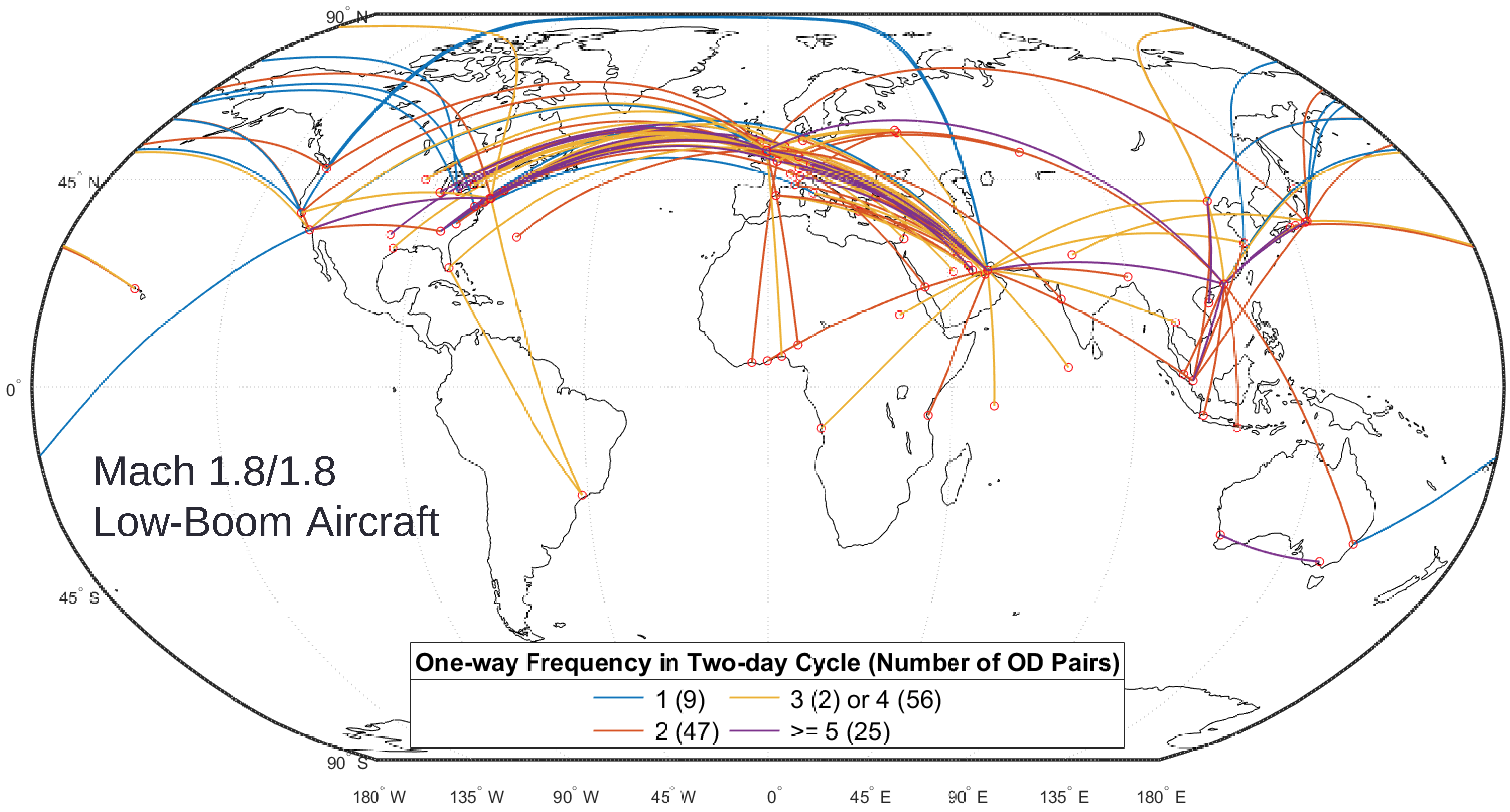
$$ost_j \le ost_1 + UTC_j - UTC_1 + \sum_{i=1}^{j-1} FLT_i + \sum_{i=1}^{j} PCT_i + \sum_{i=1}^{j} WT_i - y_{j+m-1} * 24 \le oet_j$$

$$0 \le y_{j+m-1} - y_j \le 1$$

Vehicle Fleet and Network Assignment Module



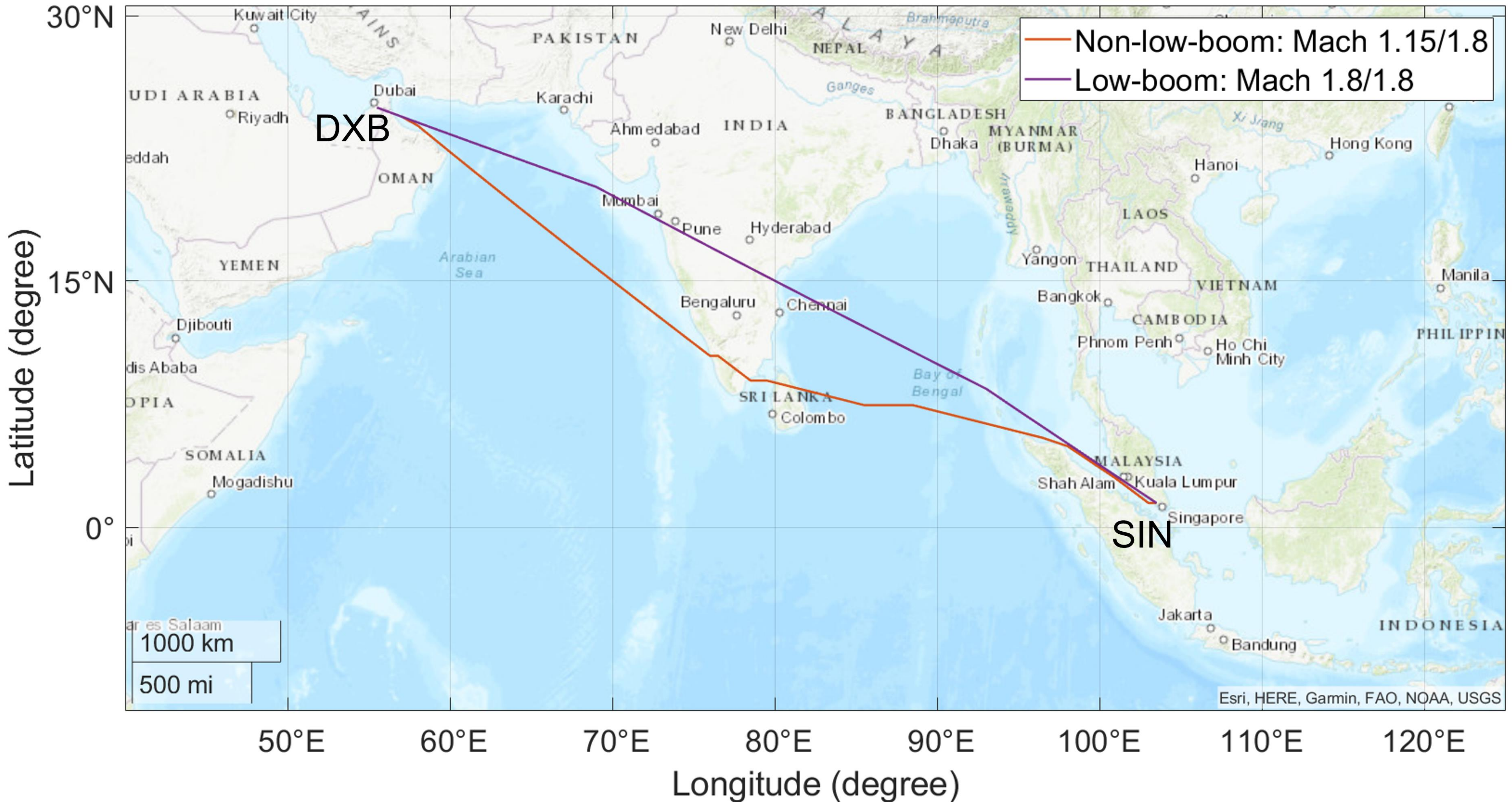
Low-Boom World Network in 2040



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

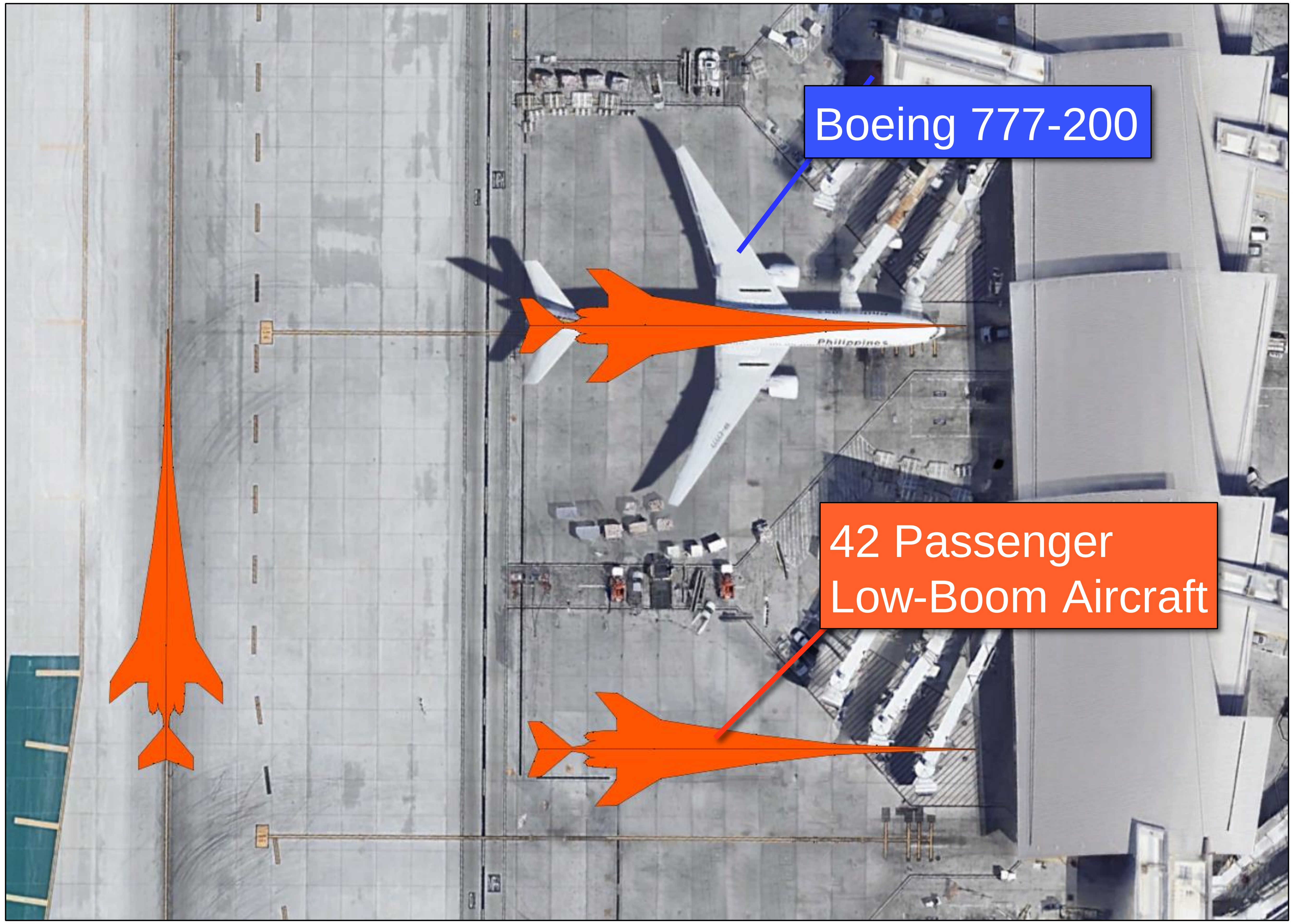
Flight Planner with Overland/Overwater Restrictions

- Flight trajectories of supersonic aircraft consider overland restrictions (if applicable)
- Flight planner uses NOAA Re-analysis wind data sets



Airport Compatibility Impacts

Runway length (>8,000 feet) and airport gate compatibility analysis are considered in the selection of candidate OD airport pairs



A 42-passenger low boom aircraft will use airport gates compatible with FAA Aircraft Design Group V (ICAO Code E)

The taxiway Design Group Classification (TDG 6) of the low-boom aircraft is similar to that of large wide-body aircraft

Anticipate small departure runway capacity reductions (~2-4%) with low-boom operations

Low-boom supersonic aircraft parked at the Tom Bradley International Terminal at the Los Angeles Airport

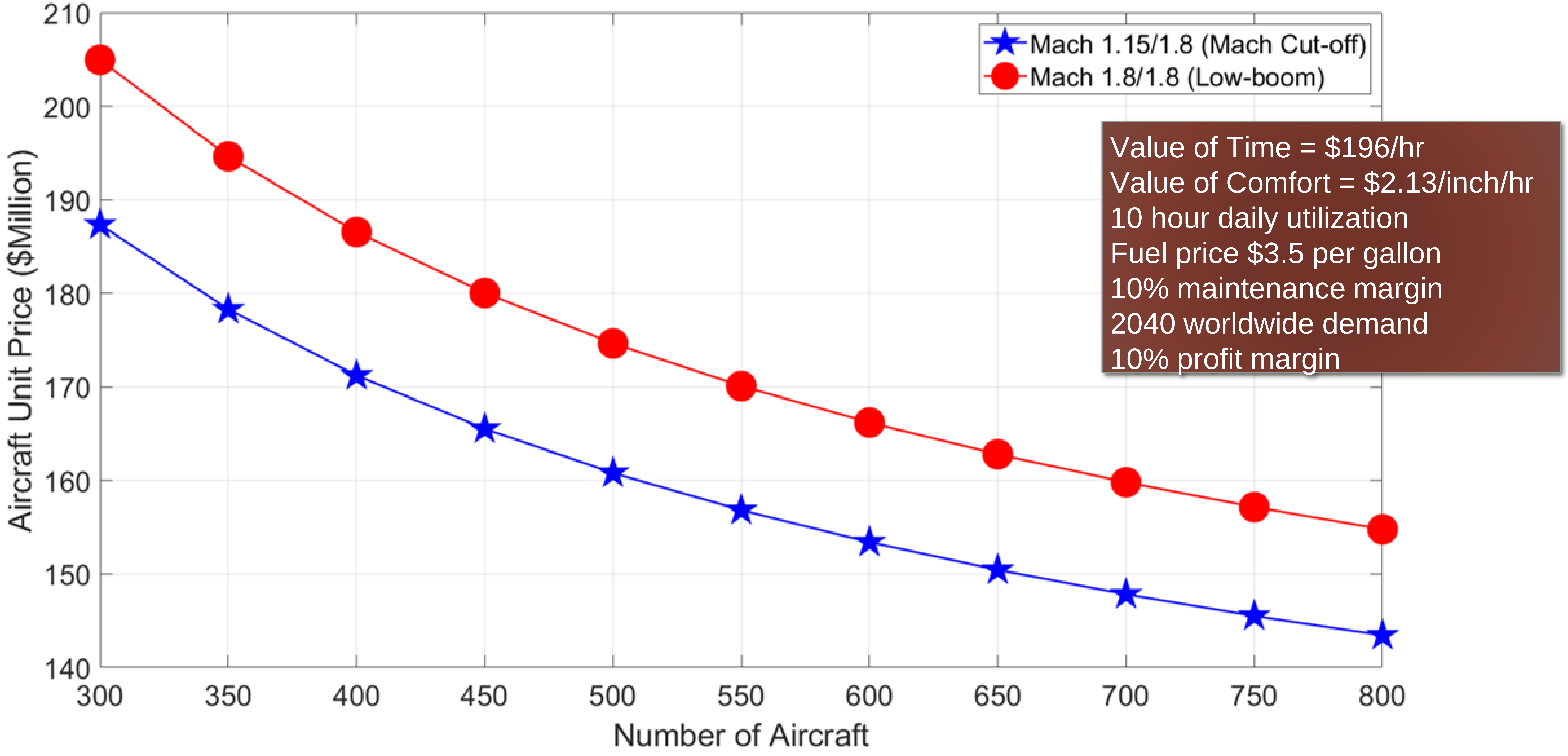
Application of LBSAM2 to Various Supersonic Concepts

Evaluated the following supersonic supersonic aircraft concepts produced by NASA Langley Research Center

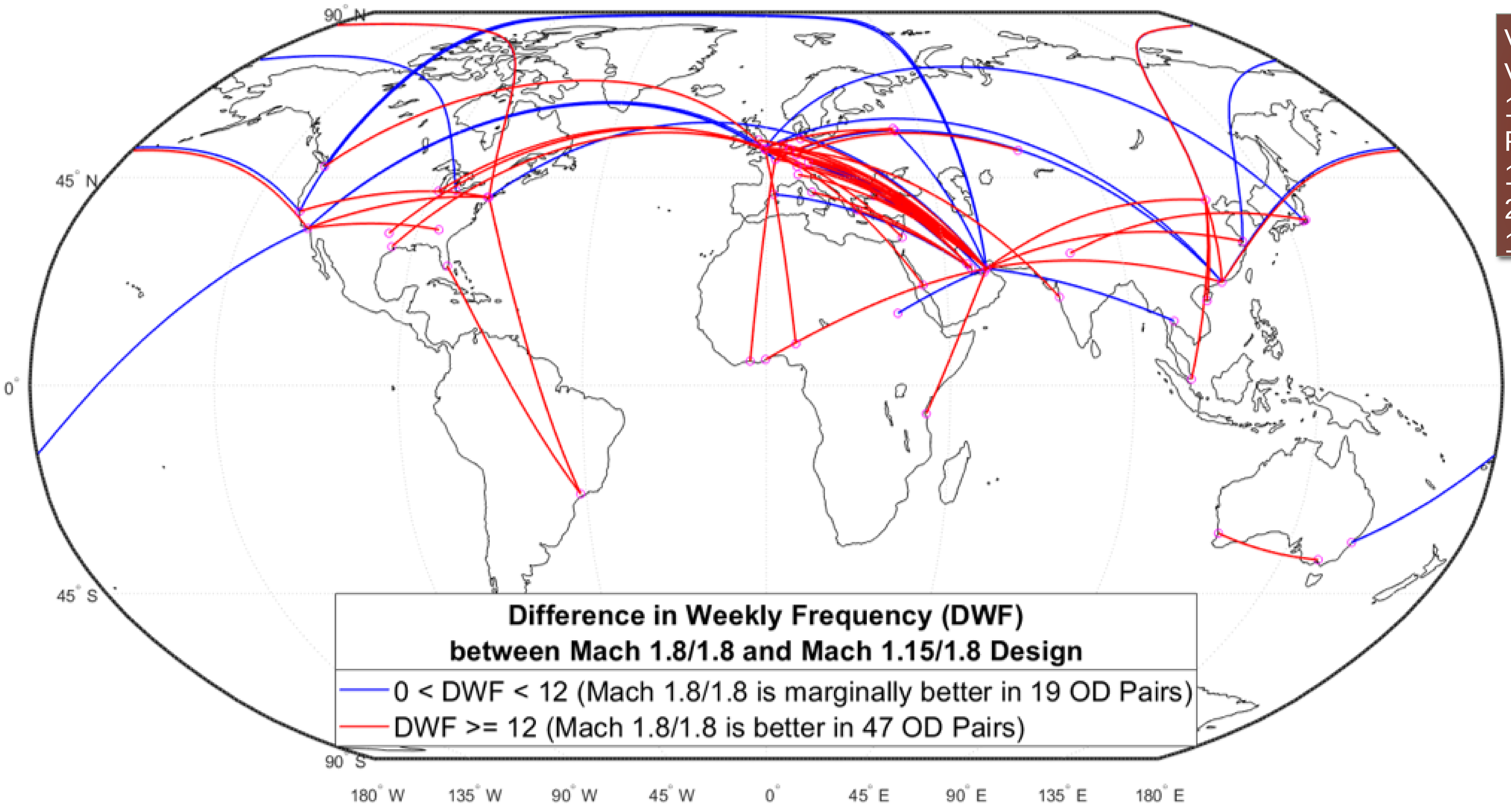
Ways of satisfying low-boom constraint	Subsonic overland	Mach cut-off	Low-boom	
Short name	Mach 0.95/1.8	Mach 1.15/1.8	Mach 1.7/1.8	Mach 1.8/1.8
Overland cruise Mach	0.95	1.15	1.7	1.8
Overwater cruise Mach	1.8	1.8	1.8	1.8
Overland cruise range, n mile	4,343	3,706	3,622	4,163
Overwater cruise range, n mile	4,225	4,225	3,572	4,329
Overland block time, hour	8.43	6.15	4.42	4.74
Overwater block time, hour	4.83	4.83	4.19	4.91
Overland block fuel, lb	62,586	62,586	61,665	79,339
Overwater block fuel, lb	62,586	62,586	61,667	79,339
OEW, lb	56,444	56,444	66,518	67,433
MTOGW, lb	135,902	135,902	147,600	167,250
Payload, lb	10,450	10,450	10,450	10,450
Sonic boom loudness, PLdB	100	100	69.9	69.9
Number of engine	2	2	2	2
Thrust per engine, lbf	34,596	34,596	34,000	36,000

A 10% increase in Aircraft Unit Price Decreases Passenger Demand by 9.5%

- Aircraft development cost is critical to a feasible supersonic aircraft program
- The elasticity of annual passenger demand with aircraft units cost is -0.95



Low-Boom Supersonic versus Fuel-Efficient Supersonic Aircraft Demand



Value of Time = $196/hr
Value of Comfort = $2.13/inch/hr
10 hour daily utilization
Fuel price $3.5 per gallon
10% maintenance margin
2040 worldwide demand
10% profit margin

Low-boom aircraft is better in 47 worldwide OD pairs

Low-Boom Aircraft are Better in Routes with More than 55% of the Flight Track Overland

Value of Time = $196/hr
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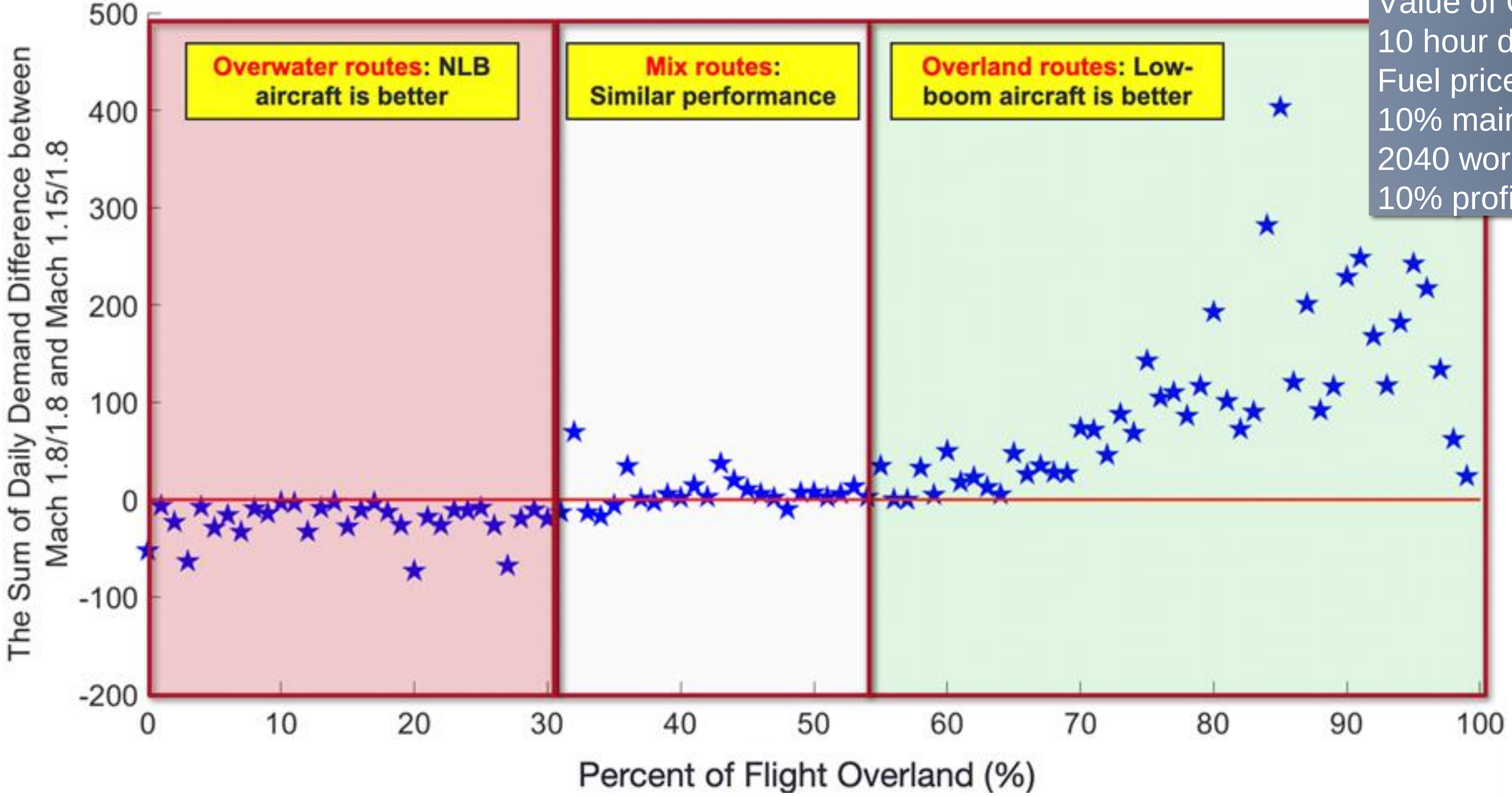

Sensitivity Analysis of Supersonic Passenger Demand to Various LBSAM2 Input Parameters

LBSAM2 parameters	Baseline setting	Optimistic setting	Percentage of change (%)
Maintenance labor expense, $\$*hour^{-1}$	180	150	-20
Maintenance Frequency, $hour*flight\ hour^{-1}$	15	10	-50
Overhaul Interval, $hours*interval^{-1}$	5,000	6,000	17
Emission fee, $\$*kilogram^{-1}$	22.2	10	-122
Noise fee, $\$*operation^{-1}$	2,000	1,200	-67
Landing fee, $\$*1000lb^{-1}$	7.3	6	-22

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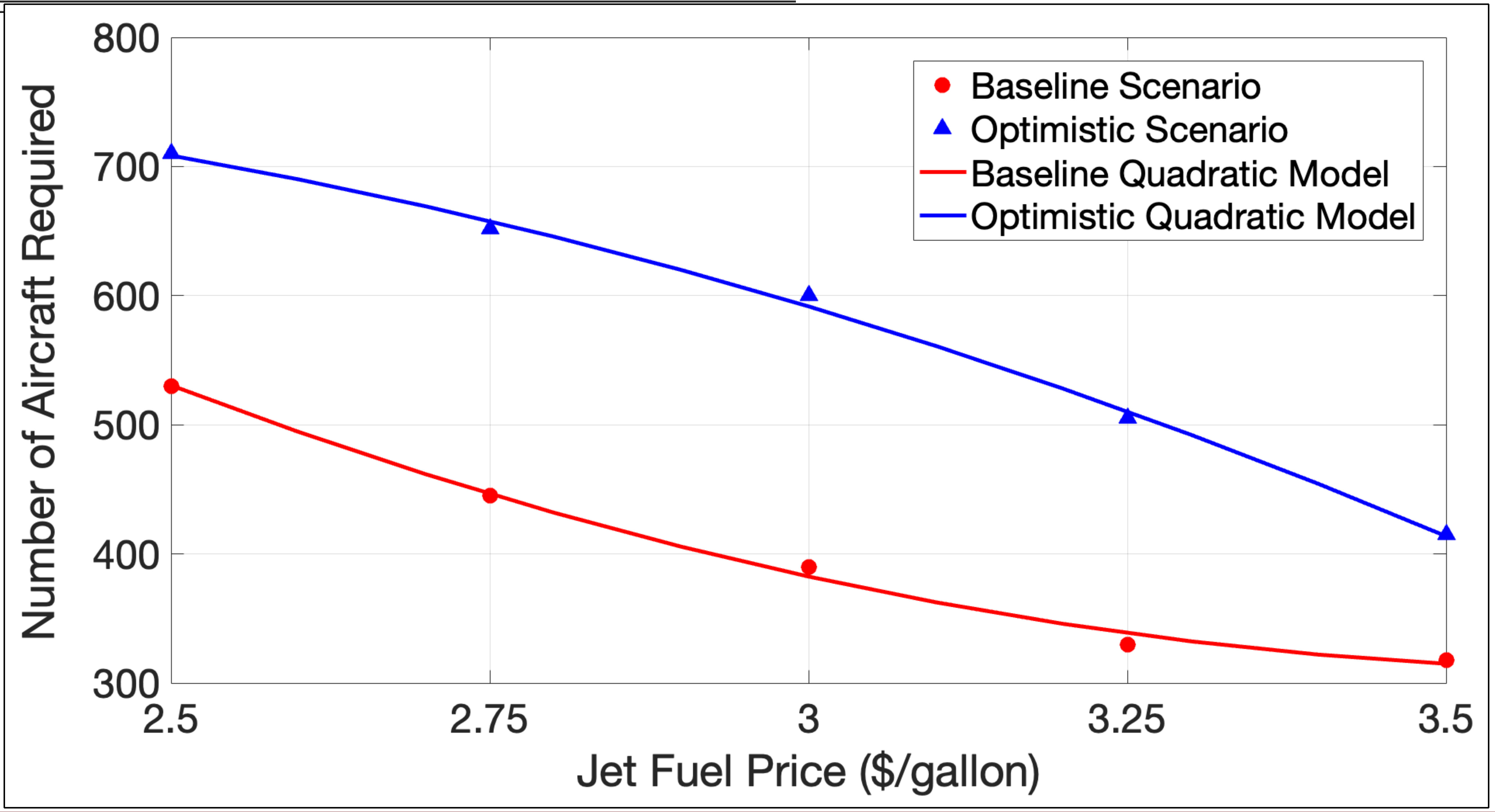
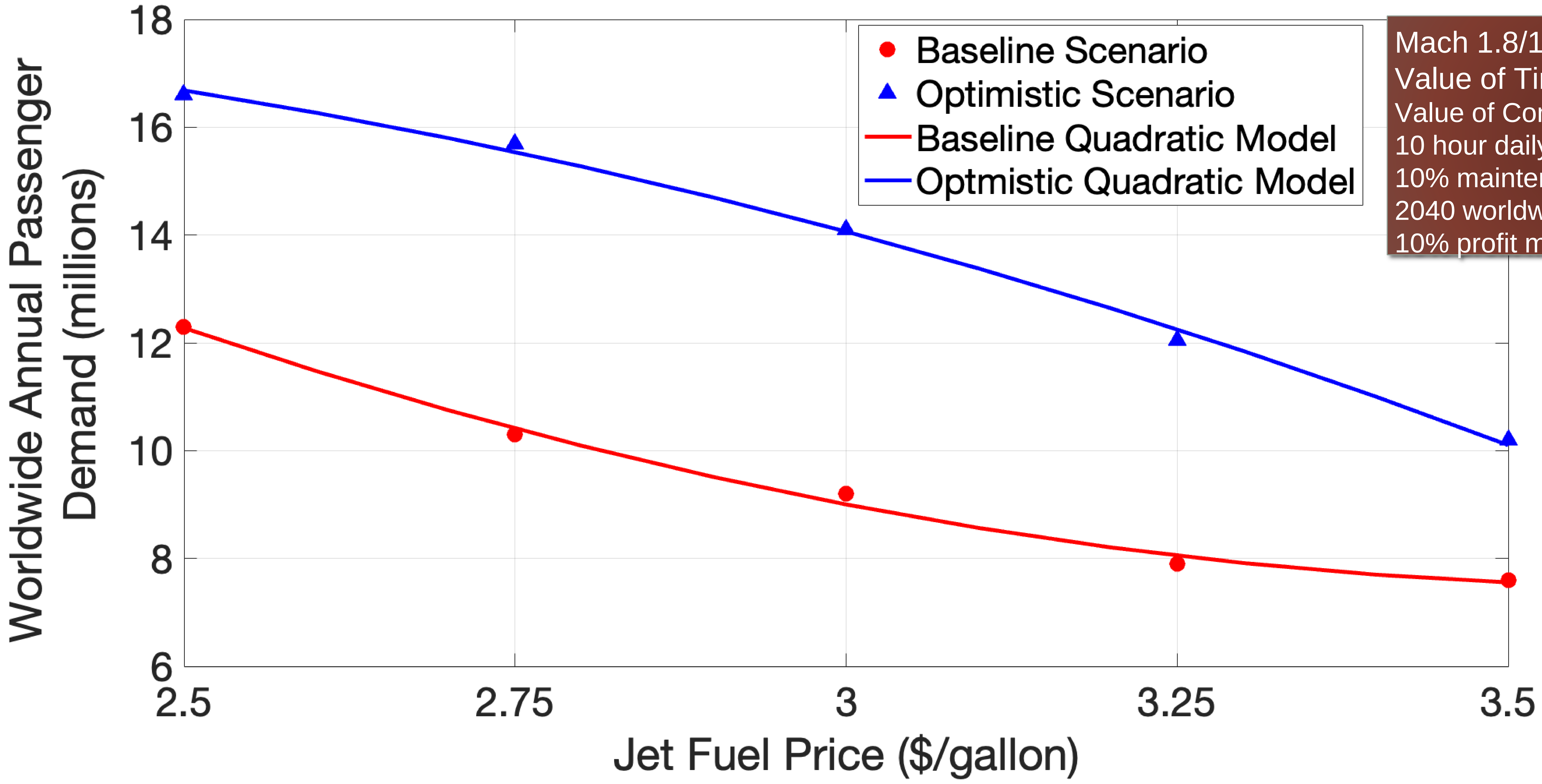


At a Price of Jet-A Fuel of $2.5 per Gallon, Supersonic Worldwide Demand Varies from 12.3 to 16.6 Million Passengers Annually



Mach 1.8/1.8 Low-Boom Aircraft
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Conclusions of FY 2022-2023 Analysis

- **Based on the study of four conceptual supersonic designs**
  - Low-boom aircraft could attract 28% more demand worldwide compared to optimized Mach cut-off design because of the additional travel time-saving benefits on overland routes
- **Optimistic economic assumptions ($2.50 per gallon of jet-A fuel)**
  - Low-boom supersonic worldwide demand varies from 12.3 to 16.6 million passengers annually
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- **Conservative economic assumptions ($3.50 per gallon of jet-A fuel)**
  - Low-boom supersonic worldwide demand varies from 7.6 to 10.2 million passengers annually
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- LBSAM2 offers valuable guidance to aircraft designers by explicitly tying the technical parameters of a design and the potential market demand
- LBSAM2 streamlines the aircraft design cycle by quantifying fleet size as part of an integrated modeling process