Aircraft Technology Modeling and Assessment

Project 10

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Overview

Objective:

- Identify fleet assumptions and assess demand for supersonic travel up to 2050
- Predict the environmental impact of supersonic aircraft relative to current technology subsonic aircraft for Key Environmental Indicators (KEI) such as fuel burn, CO_2, H_2O, NO_X and noise
- Test ability of current version of AEDT to analyze existing supersonic aircraft
- Estimate fleet-level impact of supersonic vehicles
- Create detailed aircraft models for two supersonic vehicles using the Environmental Design Space (EDS)

Approach:

1. Determine number of subsonic and supersonic aircraft needed for different scenarios and evaluate fleet-level impacts
2. Estimate performance and key environmental indicators for current and future technology aircraft
3. Perform tests with AEDT vehicle definitions. Develop recommendations on how to implement supersonic vehicles
4. Develop and calibrate aircraft models for a 50-passenger commercial jet and a 10-passenger business jet

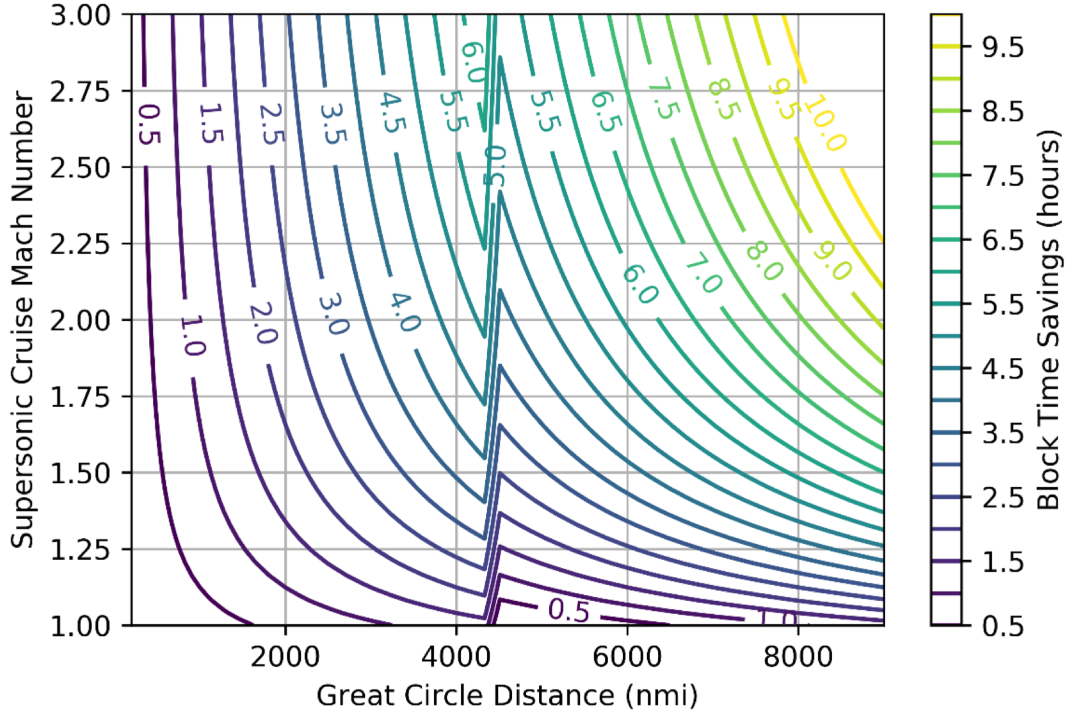
Team Approach to Tasks

Objectives		Georgia Tech	Purdue
1	Fleet Assumptions & Demand Assessment	Identify supersonic demand drivers and supporting airports	Estimate latent demand and flight schedules for supersonic aircraft
2	Preliminary Vehicle Environmental Impact Prediction	Develop estimates of Key Environmental Indicators (KEI) for supersonic aircraft relative to current technology subsonic, Develop estimates of likely operating altitudes (U.S)	Support with expert knowledge
3	AEDT Vehicle Definition	Test current version of AEDT ability to analyze existing supersonic models	N/A
4	Vehicle and Fleet Assessments	Apply GREAT to estimate impact of supersonics in terms of fuel burn, water vapor, and LTO NOx	Apply FLEET to estimate impact of supersonics in terms of fuel burn, water vapor, and LTO NOx

GEORGIA TECH EFFORTS

Task 1: Passenger Time Savings

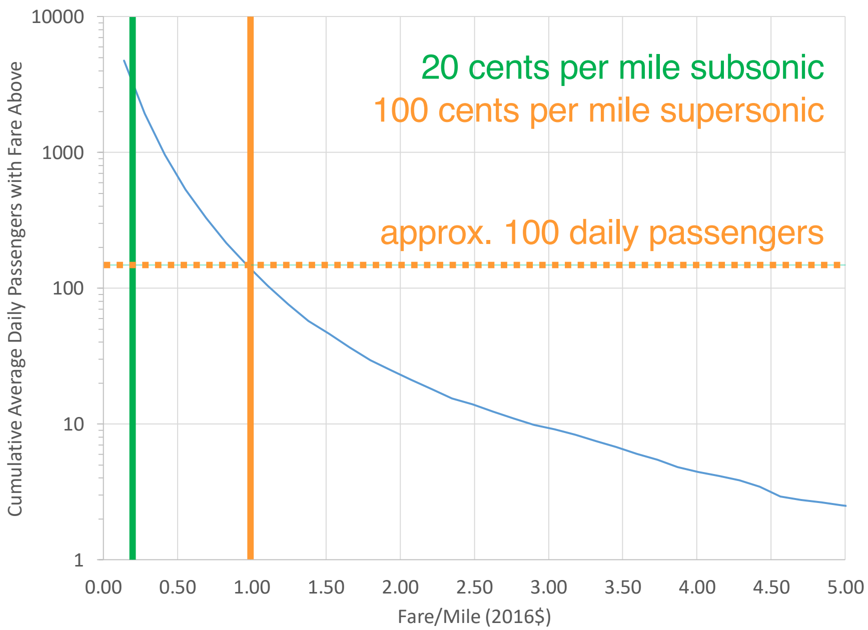
- Distances greater than 4,500 nmi require a refueling stop that decreases time savings significantly
- Also improved accounting for portal time

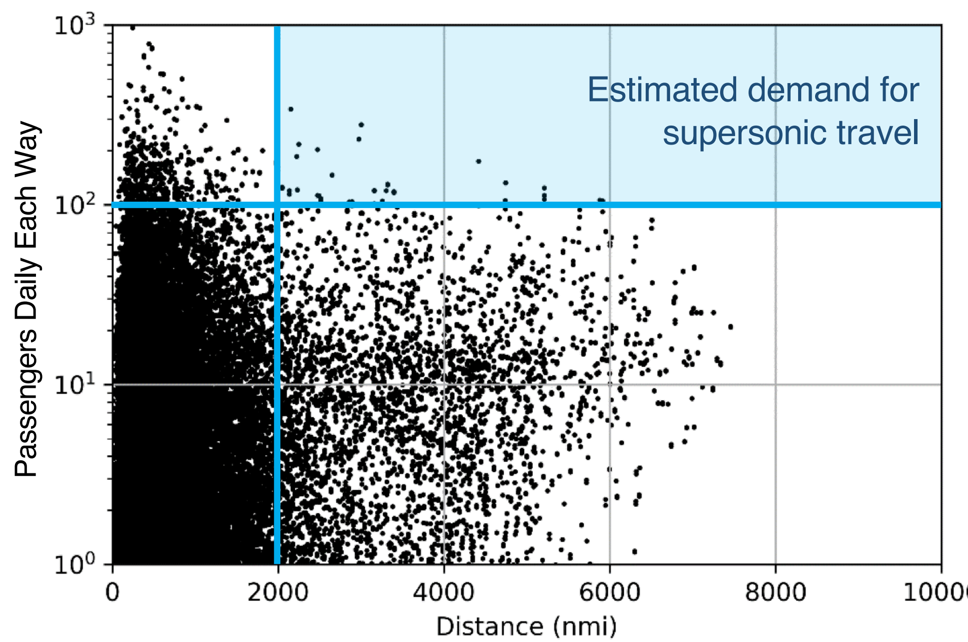


Preliminary data – do not cite or quote

Task 1: Supersonic Market

- What is the market for supersonic air travel?
  - Analyzed historical data to determine premium passengers
  - Identified domestic premium demand using 2016 ticket data
  - Identified international premium demand using 2015 global inventory of flights
  - Result: Long distance routes with an average demand of 100 premium passengers offer the biggest savings





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Task 1: Supersonic Market

Great Circle Routes Only
Does not exclude majority overland flights
Thickness of the lines correspond to Passengers Daily Each Way (PDEW)

- Long distance routes with an average demand of 100 daily premium passengers are plotted on the map above
- Busiest Routes:
  - JFK-LAX/SFO, LHR-JFK
- Many more high volume routes in Asia/South America excluded due to short distance, small time advantage

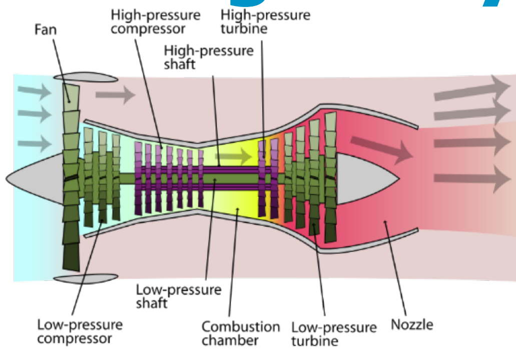
Task 2:
Performance Considerations

- Sizing conditions
  - Take-off ground roll, Landing
    - Need high lift at low speed at the same time as efficient supersonic wing
    - Can lead to large angle of attack, vision problems
  - Take-off, one engine inoperative
    - Relative loss of thrust and required excess power goes up substantially going from 4 -> 3 -> 2 engine aircraft
  - Transonic acceleration
    - Need to minimize thrust required
    - Need to minimize time spent in high drag transonic regime
  - Top of climb to initial cruise altitude
    - High altitude to minimize drag forces large thrust lapse
    - Highest weight at altitude
    - Still need sufficient excess power to satisfy climb rate
  - Cruise
    - Need high lift-to-drag at high Mach number

Task 2/3: Engine Cycle Design

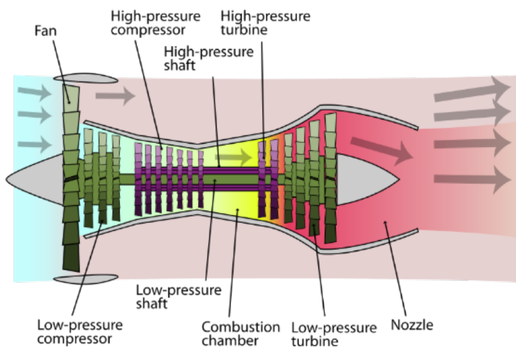
Subsonic Engine

Cruise



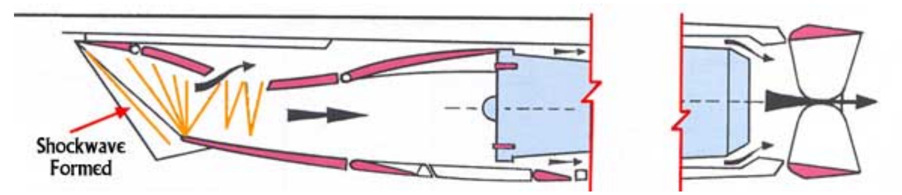
- Overall pressure ratio as designed
- Combustor inlet pressure & temperature scale down with altitude
- Typical design throttle setting ~80%
- Combustor exit temperature low

Take-Off

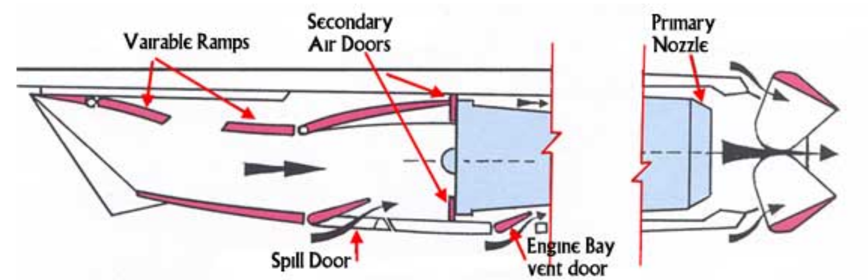


- Overall pressure ratio as designed
- Combustor inlet pressure and temperature at maximum
- Typical design throttle setting ~100%
- Combustor exit temperature at maximum

Supersonic Engine



- Overall pressure ratio from compressor is reduced but increased by inlet shockwave compression
- Combustor inlet pressure and temperature increase with Mach number
- Typical design throttle setting ~100%
- Combustor exit temperature at maximum



- Overall pressure ratio as designed
- Combustor inlet pressure and temperature reduced
- Typical design throttle setting ~100%, but limited by engine cycle control design
- Combustor exit temperature reduced

Important differences in ground test vs at cruise has implications for emissions

Image Source: Wikimedia

Image Source: concordesst.com

Task 2: Vehicle-level impacts of supersonic vehicles

- Current approach is to model vehicle-level impacts using multipliers on key environmental metrics

Data Sources and Caveats	1976 Concorde *	2005 Subsonic Reference Single Aisle	Current Technology Estimate
Fuel intensity (lb/seat/nmi)	Dispatch Data Flying Manual	Airport compatibility charts Certification data Operational data	Lift-to-Drag ratio estimates Engine SFC estimates
Cruise NOx emissions (g/kg of fuel)	Ground test with altitude correction Wake sampling	Boeing Fuel Flow Method Wake sampling	P3/T3/T4 correlation Boeing Fuel Flow Method
LTO NOx emissions (g)	EDMS subsonic(?) values Not clear if applicable to Chapter 3 supersonic LTO cycle	ICAO EEDB	P3/T3/T4 correlation
Cumulative airport noise margin - Stage 3 (EPNdB)	Advisory circular 36-1H values	Engine/Aircraft certification values	Jet velocity scaling
Sonic boom noise (PLdB)	Ground measurements	N/A	Signature scaling

* Concorde predates certification regulations, estimated based on known performance

Task 2: Vehicle-level impacts of supersonic vehicles

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- Current approach is to model vehicle-level impacts using multipliers on key environmental metrics

	1976 Concorde *	2005 Subsonic Reference Single Aisle	Current Technology Estimate	2025 NASA N+2 Goal Business Jet	2035 NASA N+3 Goal	beyond 2035 NASA N+3 Stretch Goal
Fuel intensity (lb/seat/nmi)	0.53	0.08-0.10	0.30-0.40	0.30	0.29	0.22
Cruise NOx emissions (g/kg of fuel)	20-23	–	–	Less than 10.0	Less than 5.0	Less than 5.0
LTO NOx emissions (g)	~30,000	6,000-9,000	–	–	–	–
Cumulative airport noise margin - Stage 3 (EPNdB)	– 43.2	+ 10-15	–	–	20	30
Sonic boom noise (PLdB)	105	N/A	N/A	N/A	Low Boom – 70 Unrestricted – 80	Low Boom – 65 Unrestricted – 75

Historical Performance (1976 Concorde *, 2005 Subsonic Reference Single Aisle)

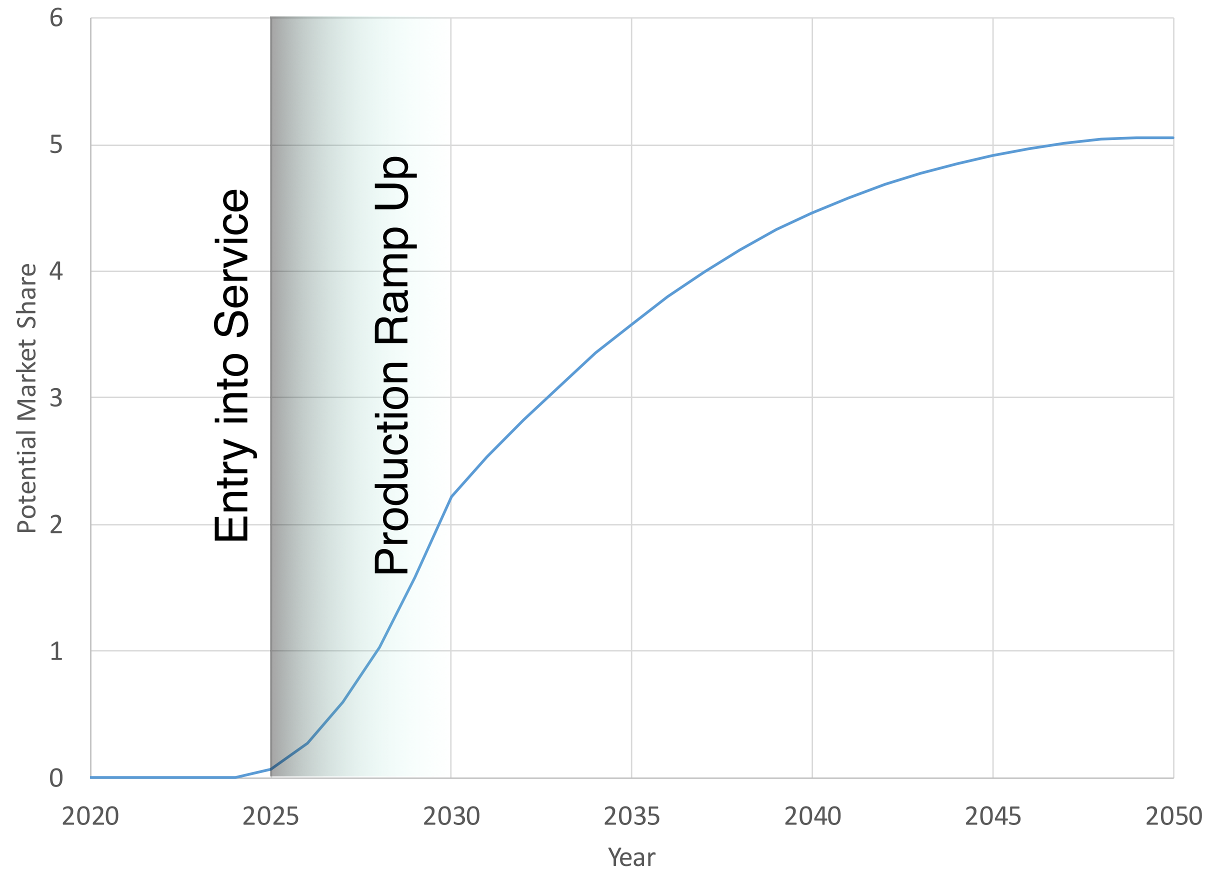
?? (Current Technology Estimate)

Targeted Performance (2025 NASA N+2 Goal Business Jet, 2035 NASA N+3 Goal, beyond 2035 NASA N+3 Stretch Goal)

* Concorde predates certification regulations, estimated based on known performance

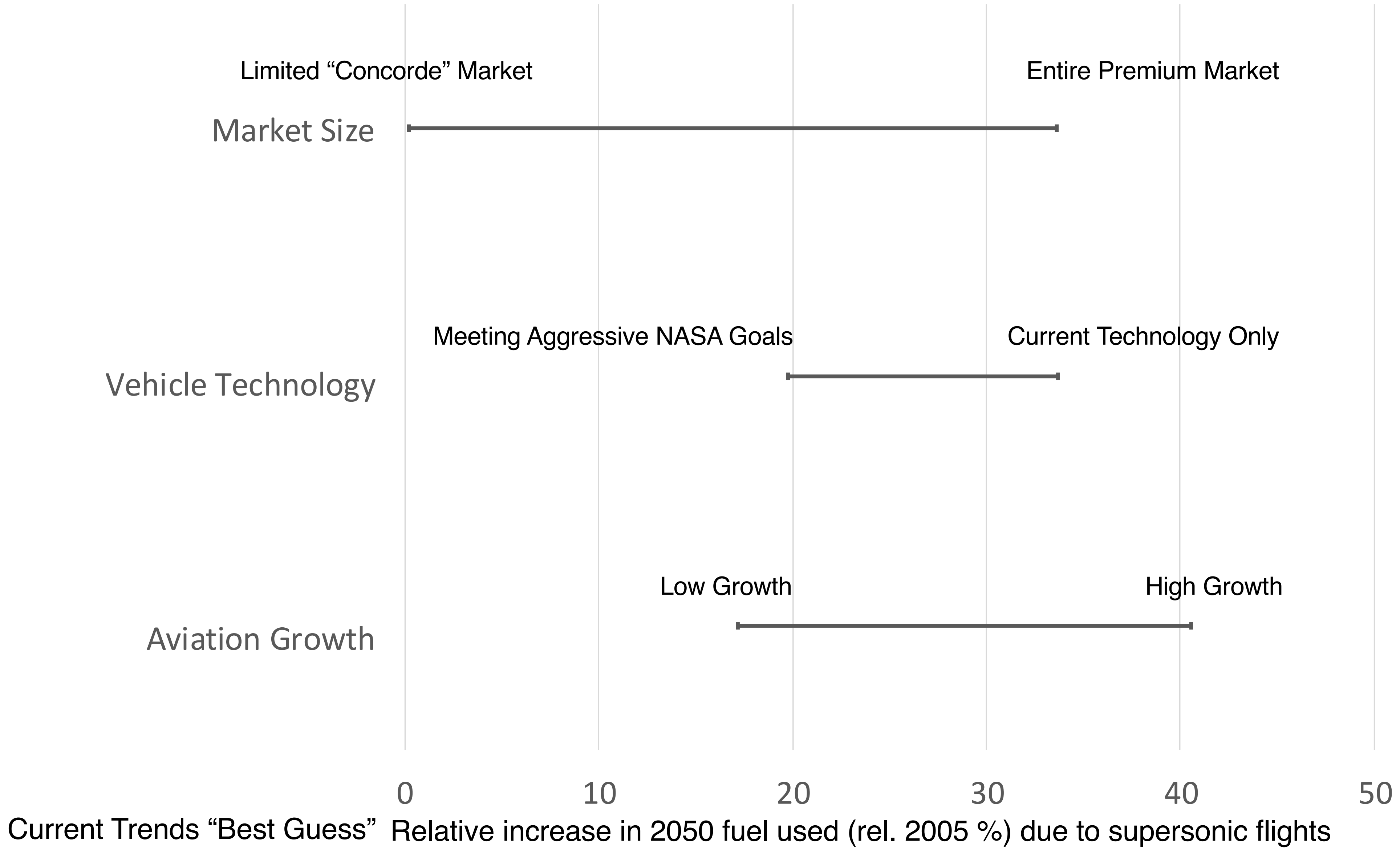
Task 4:
Fleet Analysis of Potential Market

- Example Market Scenario
  - 55 Seat aircraft
  - Conventional airline operations
  - Ramp to 11 aircraft/month production
  - Switch premium long distance passengers



Example of forcing market to match prior study

Task 4:
Fleet Analysis Uncertainty



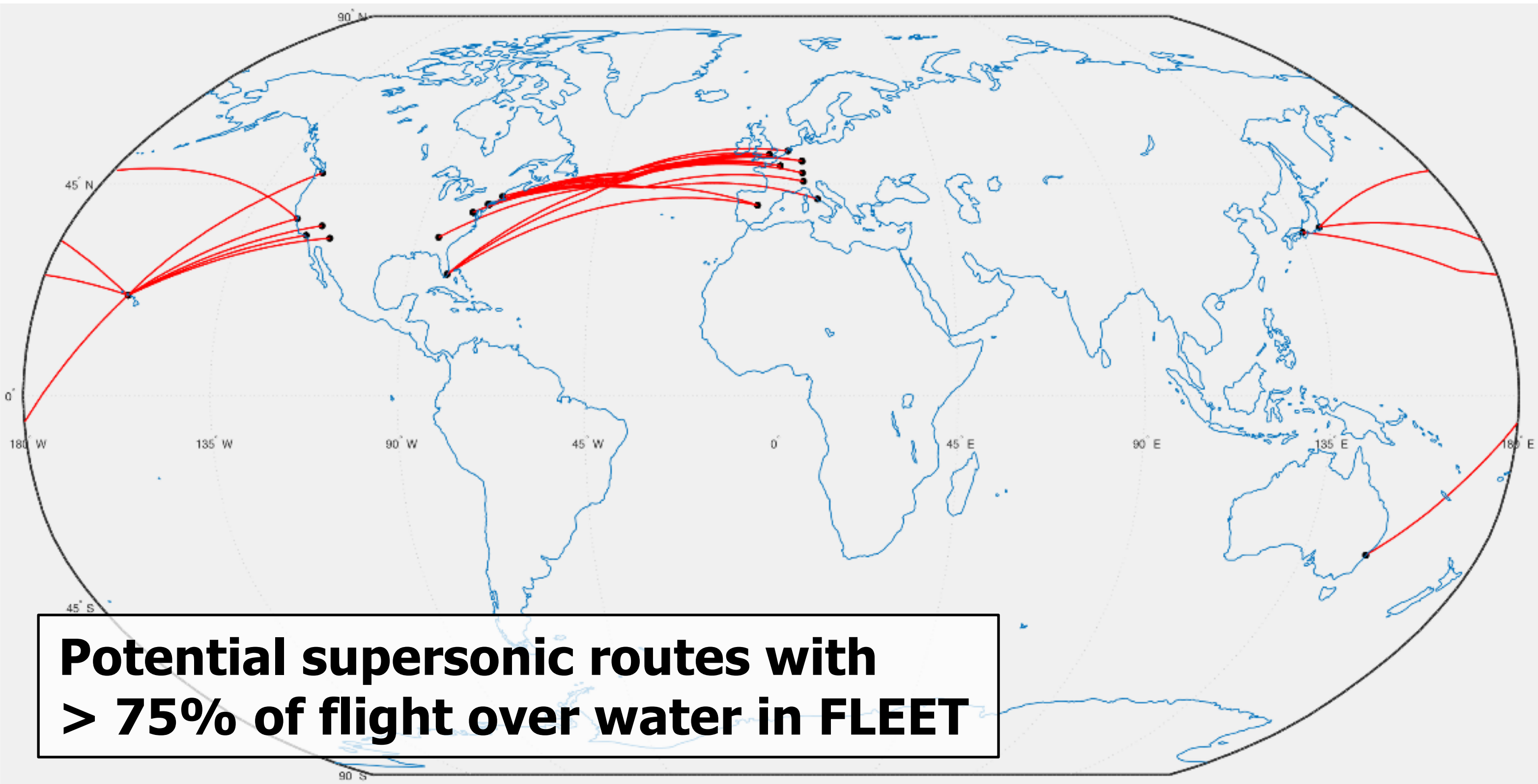
Goal: Reduce uncertainty by improving estimates

Preliminary data – do not cite or quote

PURDUE EFFORTS

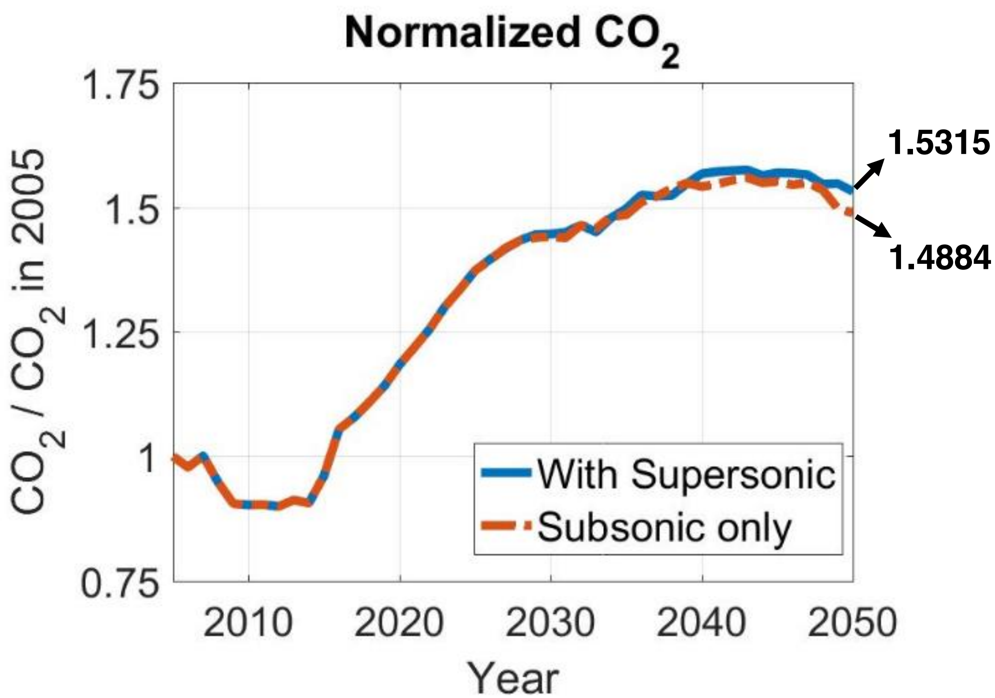
Task 1: Fleet Assumptions and Demand

- Using Fleet-Level Environmental Evaluation Tool for CO_2 predictions
  - 1,940 "US-touching" routes; allocation represents profit-seeking airline to meet passenger demand
  - Identified 26 routes in FLEET network for potential supersonic flights
    - Sufficient business-class and above demand; as offered fares in ticket price model
    - Routing includes accommodation for overwater at $M = 2.2$, subsonic overland
  - Placeholder 55-pax supersonic aircraft model for initial studies
    - Assumes "noisy" aircraft, can only fly supersonic over water
    - Will replace with refined vehicle model when available

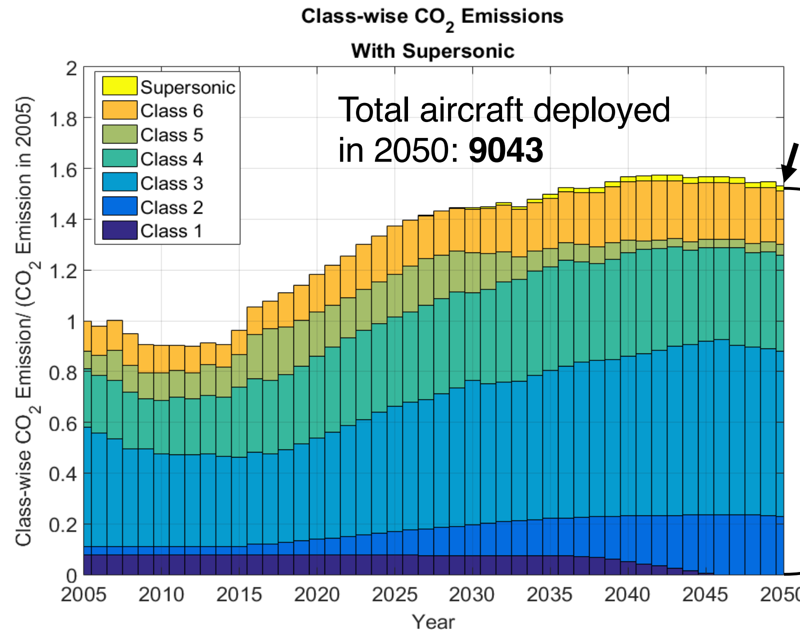


Potential supersonic routes with > 75% of flight over water in FLEET

Task 4: Fleet Impact Assessment

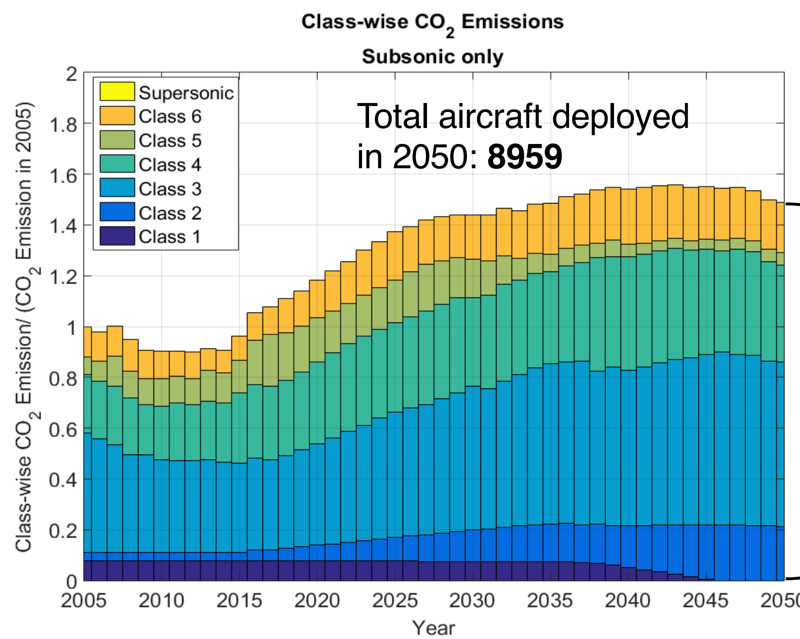


- Current trends – Best Guess scenario from previous subsonic-only ASCENT 10 work
  - Supersonic aircraft introduced in 2025
  - Supersonic allocation before subsonic – accommodating premium passengers first
- With current modeling:
  - 2050 fleet CO_2 emissions higher with supersonic aircraft than subsonic only
  - Some years show *slightly* lower fleet CO_2 emissions with supersonic aircraft
  - Supersonic aircraft changes use, retirement and acquisition of subsonic aircraft



2050 Supersonic relative CO_2 emissions: 0.0184 × 2005 fleet

2050 Subsonic relative CO_2 emissions: 1.5131 × 2005 fleet



2050 Subsonic relative CO_2 emissions: 1.4884 × 2005 fleet

Preliminary data – do not cite or quote

PROJECT SUMMARY

Summary

- Project outcomes
  - Task 1:
    - Developed initial estimates of demand for supersonic travel, likely airports and routes
    - Developed parametric airline cost model that can accommodate a large range of potential supersonic aircraft characteristics
    - Developed ticket-pricing strategy for FLEET using "as offered" business class and above fares
  - Task 2:
    - Developed key environmental indicators for supersonic aircraft
    - Understand bounding of supersonic technology
  - Task 3:
    - Tested AEDT with supersonic models
    - Developed white paper about how to implement supersonic aircraft in AEDT
  - Task 4:
    - Developed initial estimates of supersonic fleet impact using GREAT
    - Conducted initial FLEET simulations with supersonic aircraft, evolve airline fleet over time
- Next Steps
  - Task 1:
    - Improve demand estimates, expand to international airports
  - Task 2:
    - Improve vehicle estimates and expand metrics covered
  - Task 3:
    - Work with AEDT developers
  - Task 4:
    - Improve fleet estimates and expand metrics covered
  - Task 5:
    - Develop two calibrated EDS vehicle models