FAA CENTER OF EXCELLENCE FOR ALTERNATIVE JET FUELS & ENVIRONMENT

Aircraft Technology Modeling and Assessment

Project 10

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ASCENT

AVIATION SUSTAINABILITY CENTER

Team Approach to Tasks

Overall Objective: Investigating fleet impact of introducing supersonic transport (SST) in terms for fuel burn, emissions and noise, including sonic boom for various scenarios

	Objectives	Georgia Tech	Purdue
1	Fleet Assumptions & Demand Assessment	Identify supersonic demand drivers and supporting airports and project demand for all scenarios Expand to international airports	Estimate latent demand and flight schedules for supersonic aircraft
2	Preliminary Vehicle Environmental Impact Prediction	Develop estimates of KEIs for supersonic aircraft relative to current technology subsonic aircraft, Develop estimates of likely operating altitudes	Support with expert knowledge
3	AEDT Vehicle Definition	Test current version of AEDT ability to analyze existing supersonic models Work with AEDT developers to understand the required modifications to support supersonic vehicles	N/A
4	Vehicle and Fleet Assessments	Apply GREAT to estimate impact of supersonics in terms of fuel burn, water vapor, and LTO NOx for a combination of vehicles and scenarios	Apply FLEET to estimate impact of supersonics in terms of fuel burn, water vapor, and LTO NOx
5	EDS Vehicle Modeling	Create 2 EDS supersonic vehicle models with boom signatures	Support with expert knowledge

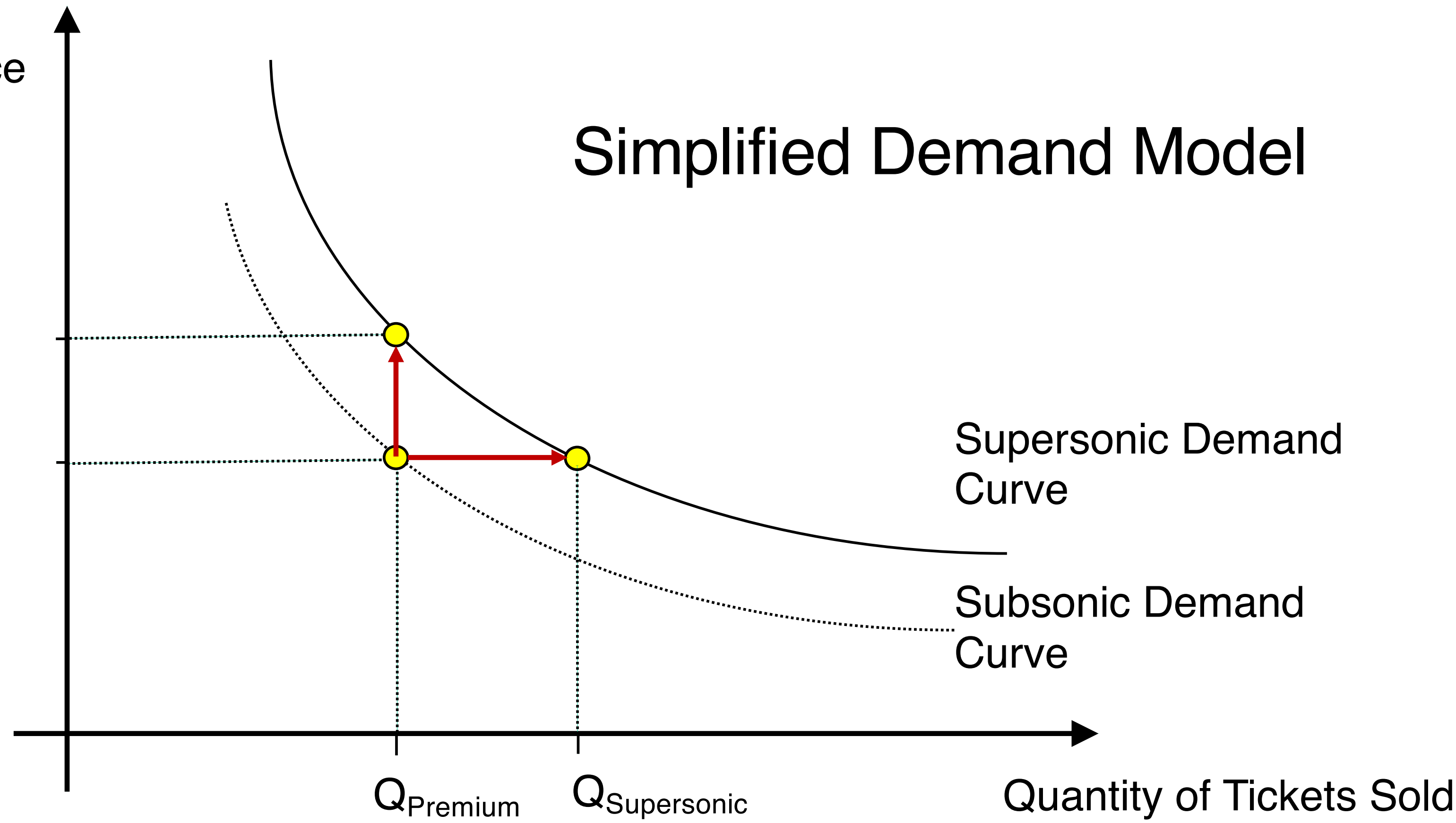
GEORGIA TECH EFFORTS

GT Task 1: Potential Supersonic Routes

“Will Boom Supersonic’s new aircraft have the same fate as the Concorde?”
3/5/2018, boomsupersonic.com

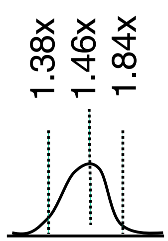
2015 to 2050 Forecast   >55 Passengers Daily Each Way, >1500nmi, Great Circle, Unrestricted

GT Task 1:
Fleet Assumptions and Demand Assessment

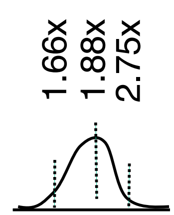


For a single example market, fixed speed, 100% switching

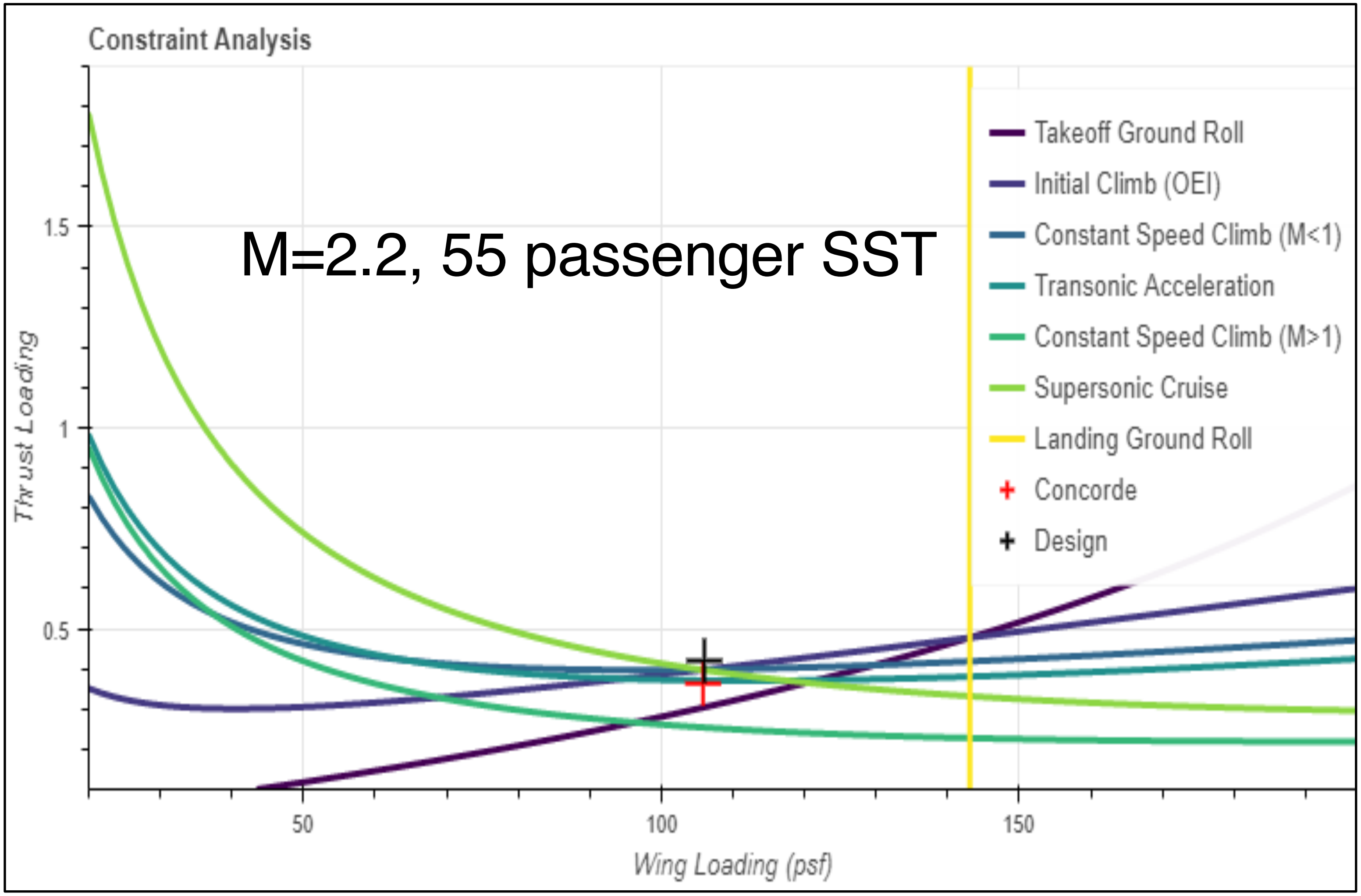
Increased Price:



Increased Demand:



GT Task 2:
Preliminary Vehicle Environmental Impact Prediction



- Developed conceptual design dashboard
  - Constraint analysis
  - Mission analysis
- Calibrated on Concorde data

M=1.4 10 passenger SST
- Larger wing
- Larger engine (3 vs 4)
- Improved SFC
- Improved L/D

M=2.2 55 passenger SST
- Larger engine (3 vs 4)
- Improved SFC
- Improved L/D

GT Task 4:
Fleet Impact Assessment

Large variability in 2050 fuel use due to assumptions…

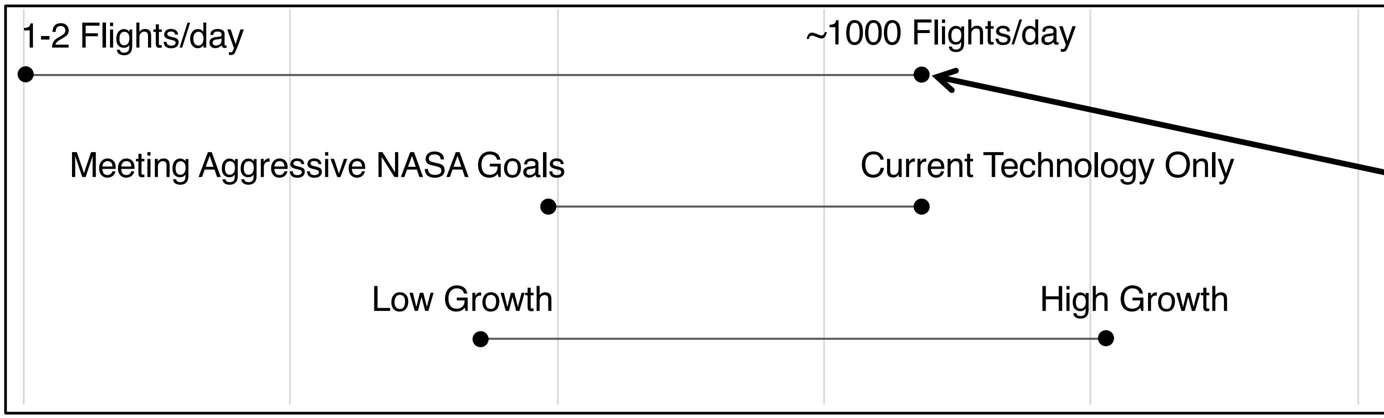
Modeling Assumptions:

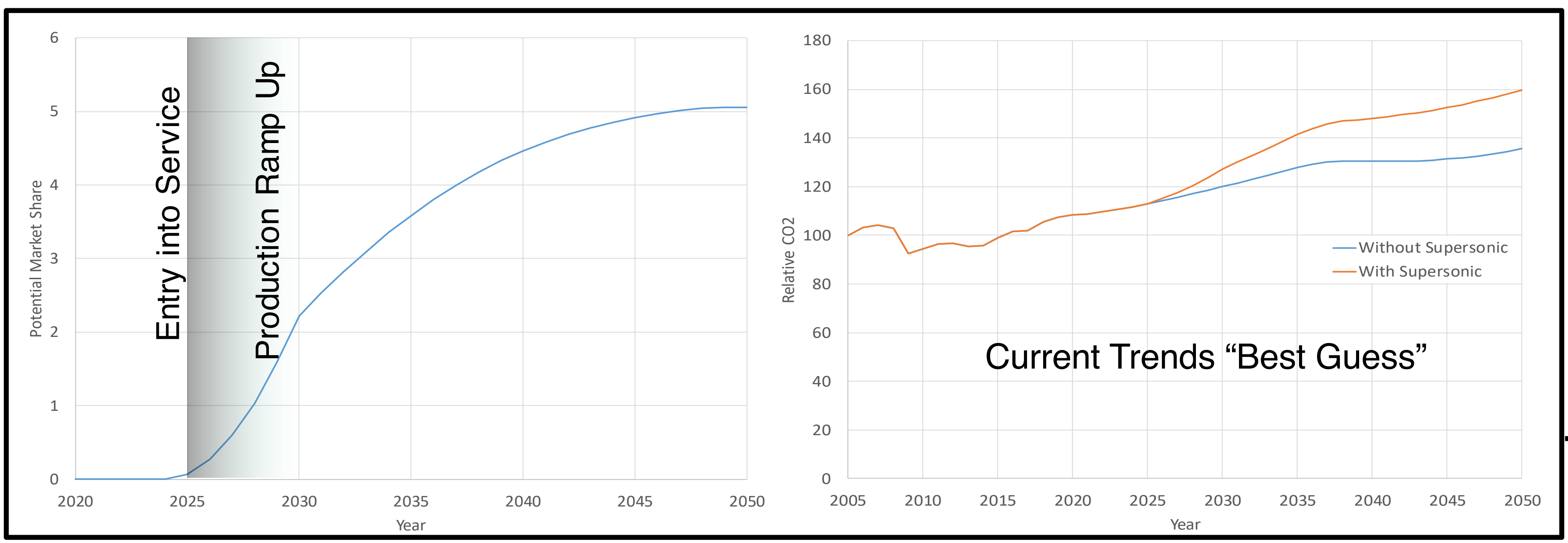
Relative increase in 2050 fuel used (rel. 2005 %) due to supersonic flights

Market Size

Vehicle Technology

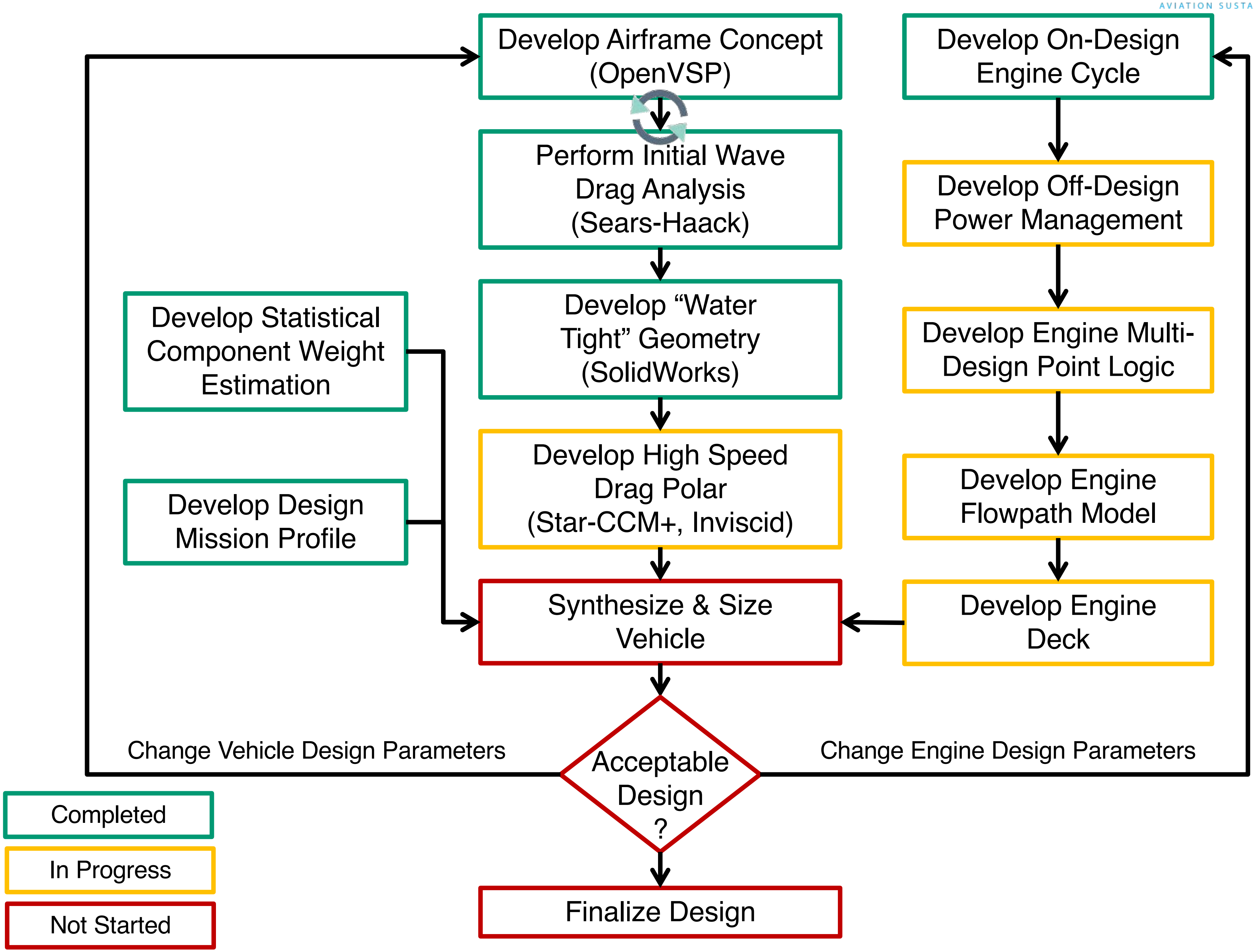
Aviation Growth





Goal: Reduce uncertainty by improving estimates

Task 5: Supersonic EDS Vehicle Modeling

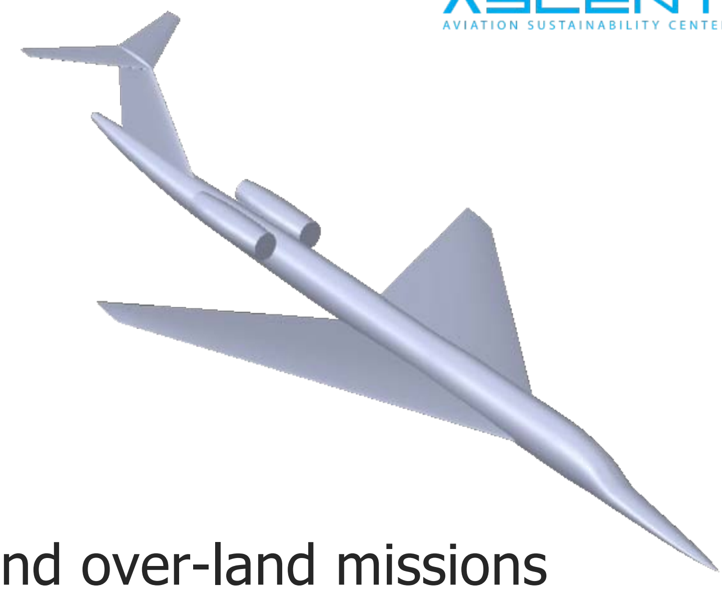


GT Task 5: EDS Vehicle Modeling

- Two classes: 10 & 55 Passenger Class SSTs
- Aircraft Design (OpenVSP & StarCCM+)
  - Geometry definition
  - High speed drag polars (inviscid)
  - Preliminary stability analysis
  - Shock locations
- Engine Design (NPSS)
  - Mixed Flow Turbofan architecture
  - Size engine for multiple design points
  - Power managed for mission analysis
- Mission Analysis (FLOPS)
  - Weights estimation
  - Mission profile
  - Overall synthesis and sizing

- OpenVSP = Open Vehicle Sketch Pad
  - Conceptual, parametric geometry tool
- StarCCM+
  - Commercial (Siemens PLM) CFD tools
- FLOPS = FLight OPtimization System
  - NASA mission analysis tool
- NPSS = Numerical Propulsion System Simulation
  - Object oriented framework used for engine simulation

GT Task 5:
EDS Vehicle Modeling

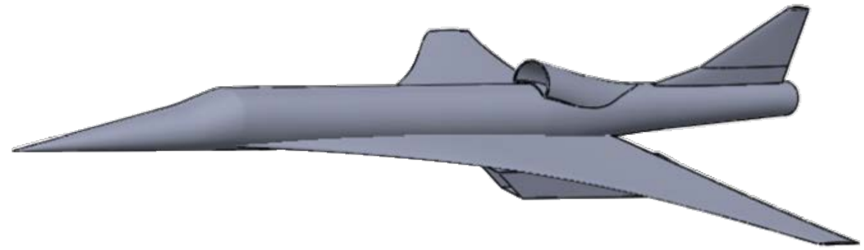


10 Passenger Class SST

- Mission Definition:
  - Design Range: 4000 nmi
  - Cruise Altitude: 55,000 ft
  - Supersonic cruise: Mach 1.4
  - Subsonic cruise: Mach 0.95
- Two cruise Mach numbers for over-water and over-land missions
- Wing trailing edge sweep selected to control leading edge vortex separation
- 30 ft cabin
- Aft-podded engines to avoid landing gear interference
- Area-ruled body to minimize wave drag and shocks
- 60 deg single-swept wing to balance low and high-speed cruises
- T-tail to avoid horizontal tail masking from engines & wings

GT Task 5: EDS Vehicle Modeling

55 Passenger Class SST



- Mission Definition
  - Design Range: 4500 nmi
  - Cruise Altitude: 55,000 ft
  - Cruise Mach number: 2.2
- Cabin length: 70 ft
- Engine inlet on top of the fuselage to avoid landing gear interference and some noise shielding
- Area-ruled body to minimize wave drag and shocks
- Double delta wing to accommodate performance at both supersonic and subsonic cruise
- Horizontal tail not included because trailing edge of wings are aft enough to be used as both ailerons and elevators
- Three engines to reduce risk in the event of OEI (one engine inoperative)

Summary: Georgia Tech Efforts

- Improved demand modeling
  - Distributional analysis of Value of Travel Time Savings
  - Reference demand model development to be applied to all potential markets
- Tool Development
  - Conceptual trade-offs for supersonic vehicle designs
    - Lots of technical lessons learned
  - Expanding scope of GREAT capabilities
    - Additional classes of vehicle and regions
  - 55 passenger class vehicle model anticipated to be by second quarter of 2019
- Fleet-level CO_2 emissions
  - GREAT can predict supersonic fleet
    - Trying to reduce uncertainties on key assumptions
      - Demand
      - Interactions with subsonic scenarios
      - Vehicle environmental performance

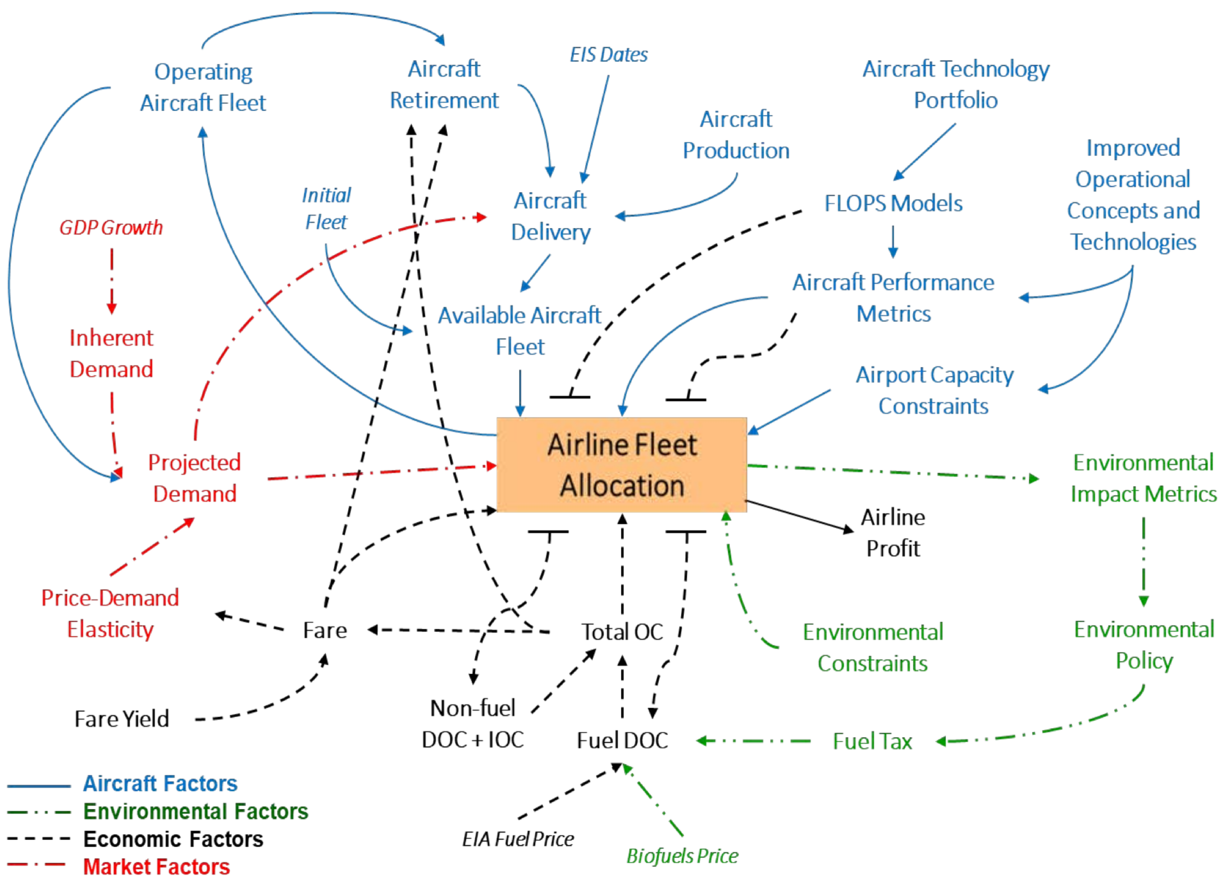
Next Steps – Georgia Tech

- Task 1:
  - Investigate demand and subsonic service response options
  - Apply generalized demand switching model to potential routes
  - Finalize SST business jet forecast model
- Task 2:
  - Support design trade offs for task 5
- Task 3:
  - Finalize white paper
  - Support AEDT future capability planning
- Task 4:
  - Update fleet analysis with improved demand model and high fidelity vehicle data
- Task 5: EDS Vehicle Modeling
  - Complete engine modeling
  - Initiate LTO noise modeling
  - Initiate boom modeling
  - Test out AEDT coefficient generator
  - Begin coordination with ASCENT project 47

PURDUE EFFORTS

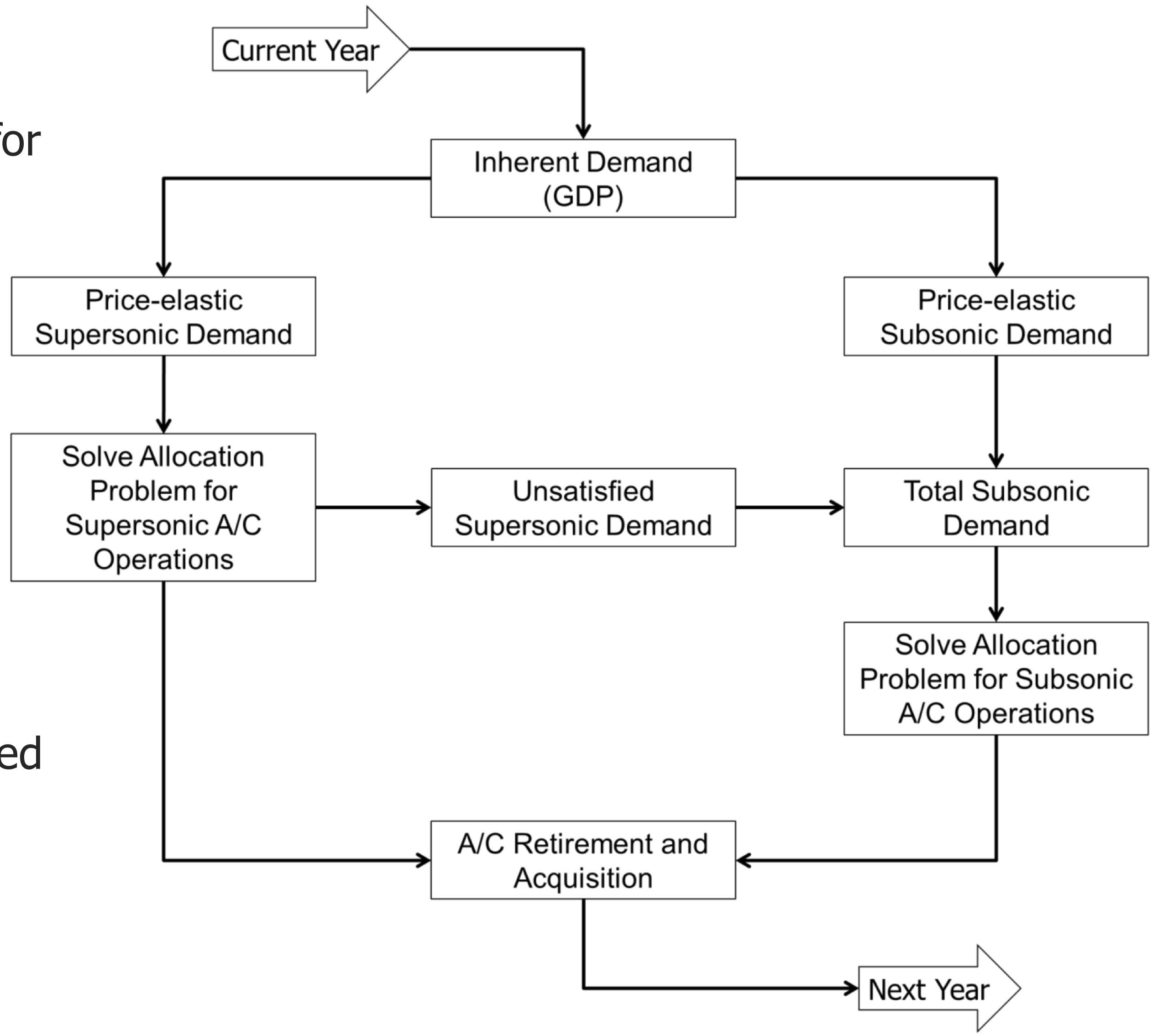
Fleet-Level Environmental Evaluation Tool - FLEET

- A system dynamics-inspired simulation to evolve airline fleet, passenger demand, environmental impact over time
- At core is an allocation problem to simulate a profit-seeking airline
  - 1,940 routes connects a subset of WWLMINET 257 airports
  - **US-domestic routes**
  - **Int'l routes with direct flight originating or ending at US airport**
- FLEET represents aircraft by class (number of seats) and by technology age



Task 1: Incorporating Supersonic Aircraft in Allocation Problem for FLEET

- Motivation for separate supersonic allocation
  - Passengers willing to pay for supersonic are a subset of all passengers
  - Allocation requires ticket price for aircraft; historical data unavailable for international flights
- Impacts
  - Gives priority to serving supersonic demand
  - Supersonic passenger demand not met with supersonic aircraft combined with subsonic demand
  - "Unsatisfied Supersonic Demand" also drives acquisition of new supersonic aircraft



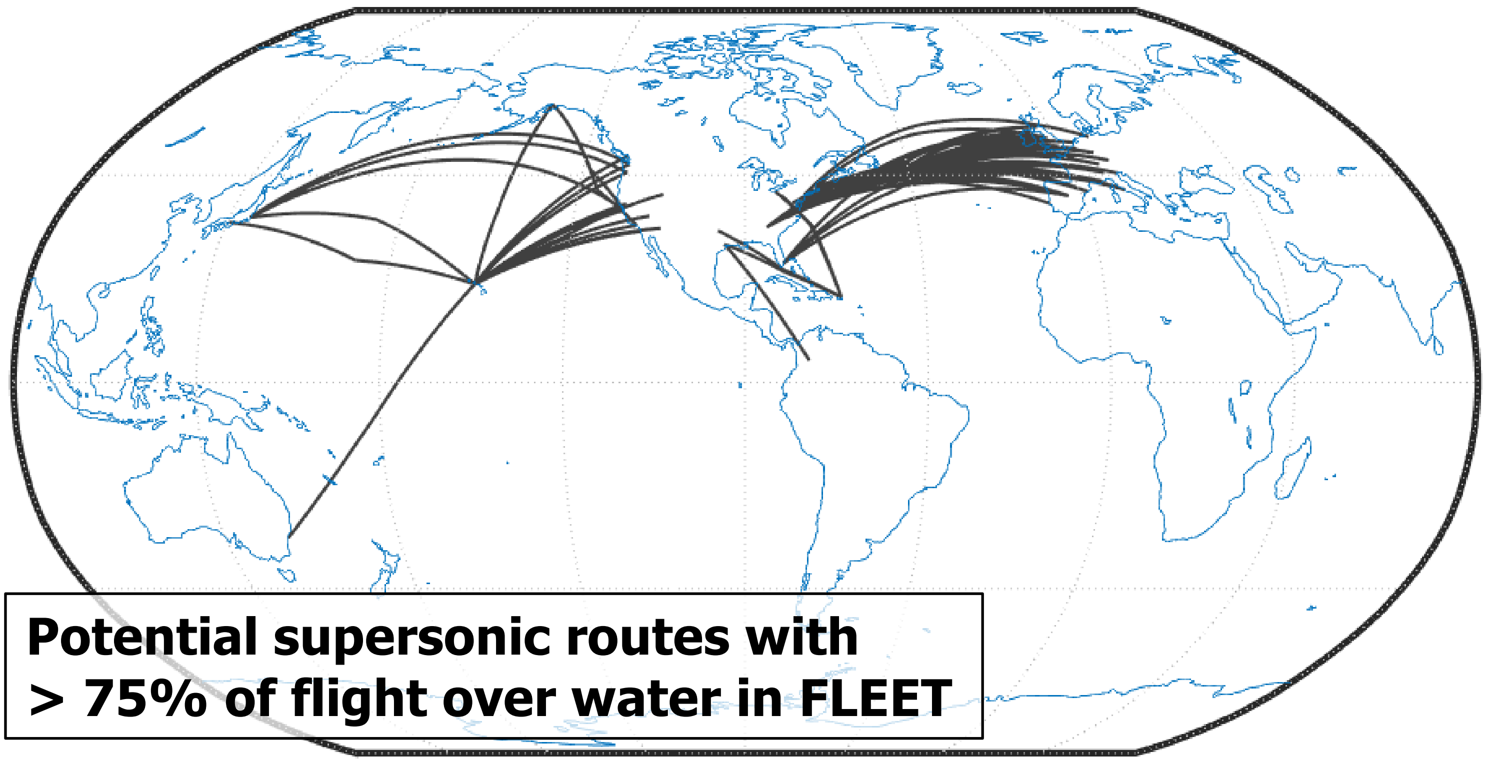
Task 1: Characterizing Supersonic Demand and Routes

- As a starting point to estimate demand, build on BOOM statement about same fares as today's business class
  - 5% of passengers on a given flight pay business class or above
    - 5% correlates with data for domestic flights (DB1B 2016)
      - All domestic flights, 4.3% of reported tickets business or above
      - Domestic flights between 2350 and 4500 nmi, 6.89% business or above
    - For FLEET, these are the only potential supersonic passengers
  - FLEET uses BTS reported demand as the basis for the allocation problem, so supersonic FLEET demand reflects passengers carried on US-touching routes by US flag carriers
- Apply filters to identify potential supersonic routes
  - Great circle distance between 1,500 and 4,500 nmi
  - Routes with ≥ 75% overwater; 75% chosen using team's engineering judgement
  - Distance flown adjustment to minimize block time
- 98 potential routes in FLEET network

Simple overwater route adjustment strategy using JFK-LHR

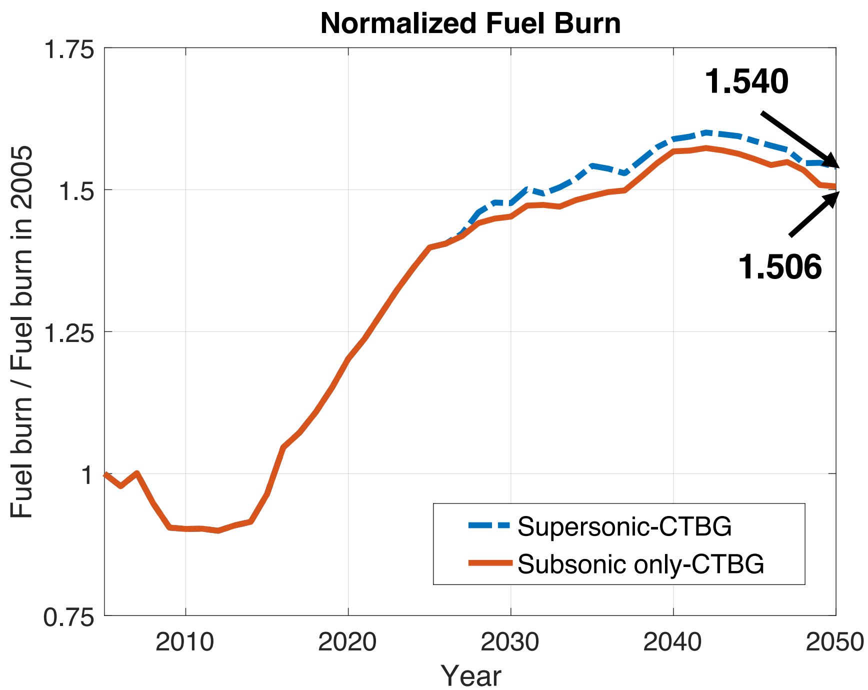
Task 1: Supersonic Route Network for FLEET

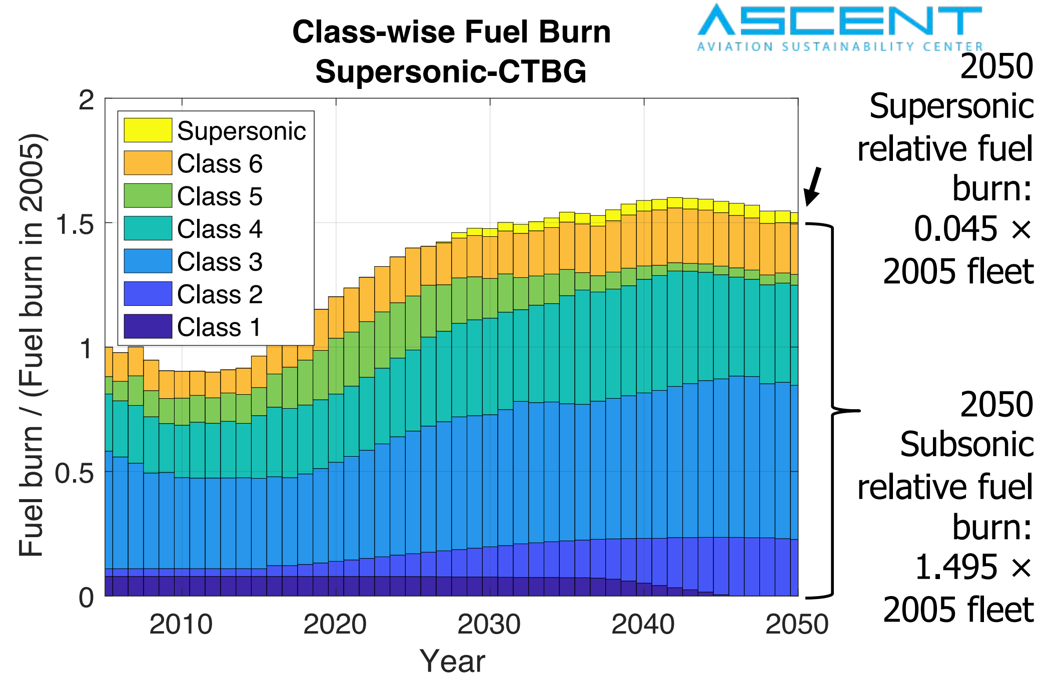
- Placeholder 55-pax supersonic aircraft model for initial studies
  - Assumes “noisy” aircraft, can only fly supersonic over water at M = 2.2 (subsonic overland at M = 0.95)
  - Supersonic aircraft fuel burn currently uses the Class 5 (large twin aisle) subsonic fuel burn on the minimum flight time routes as a placeholder
  - Will replace with refined vehicle model when available



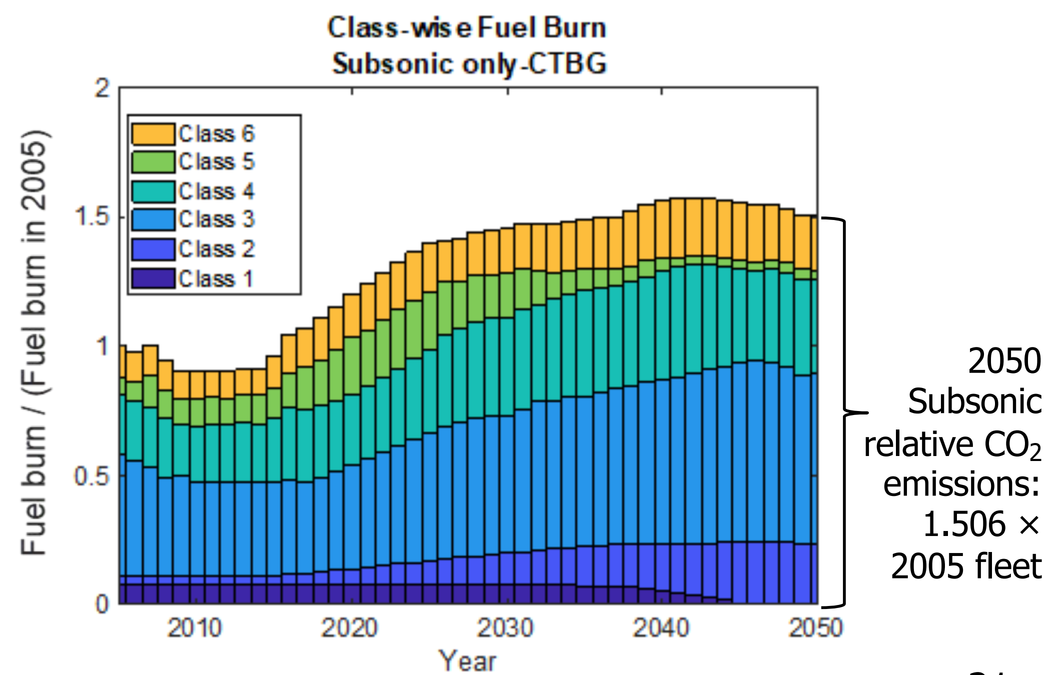
Potential supersonic routes with > 75% of flight over water in FLEET

Task 4: Fleet Impact Assessment





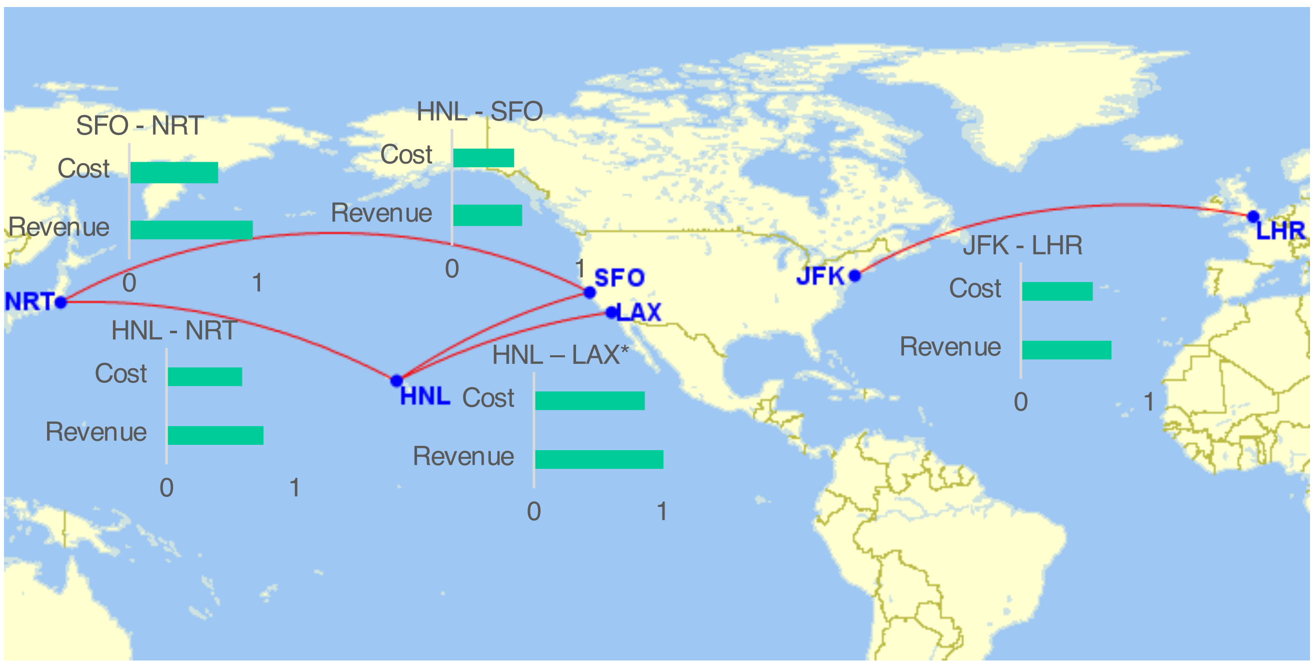
- Current Trends Best Guess (CTBG) scenario from subsonic-only ASCENT 10 work
  - Supersonic EIS in 2025, 2035, 2045
  - Supersonic allocation before subsonic
- With current modeling:
  - 2050 fleet CO_2 emissions higher with supersonic aircraft than subsonic only
  - Supersonic aircraft changes utilization, retirement and acquisition of subsonic aircraft



Preliminary data – do not cite or quote

Task 4: Fleet Supersonic Allocations – Year 2038

- 2038 selected as a year of interest; second generation supersonic aircraft just entering service in this simulation
- Airline serves 75 of 98 routes with supersonic aircraft
- Top 5 high-demand supersonic routes in FLEET network
  - Only US-touching routes, operated by US flag carriers only
  - FLEET passenger demand builds upon reported BTS data



* Revenue and cost data normalized w.r.t. to HNL – LAX revenue data (supersonic only)

Route	Daily Demand	# of Trips
HNL – LAX	634	11.33
HNL – SFO	382	6.67
HNL – NRT	298	5.33
JFK – LHR	296	5.33
NRT – SFO	256	4.67

Number of trips indicates allocated trips between cities per day, over three-day period, for aircraft type

Preliminary data – do not cite or quote

Summary: Purdue Efforts

- Purdue efforts in three areas for current phase of project
  - Characterizing supersonic demand and routes
    - US-touching routes, US flag carriers
    - "Business class and above" concept for 5% of demand
    - Route-filtering with percentage of flight overwater
  - Supersonic ticket price model
    - Range-dependent model based upon "as offered" prices for business class and above
  - Including supersonic aircraft
    - Allocation approach that first satisfies supersonic demand then subsonic demand to serve all total demand
    - Supersonic aircraft production and acquisition model
- Recent results show the ability of FLEET to allocate supersonic aircraft on profit-earning routes only
  - Introduction of supersonic aircraft leads to different allocation of subsonic aircraft
  - Allocation results give a pseudo-schedule for the FLEET airline

Next Steps - Purdue

Short Term (Remainder of Year 2):

- Examine transpacific supersonic routes with refuel stop
- Replace Purdue placeholder aircraft with multiplier approach to match GT early fleet studies
- Higher density subsonic aircraft to FLEET airline on routes where supersonic aircraft also operate

Long Term (Year 3):

- Develop and implement passenger "effective cost" model
- Commercial supersonic vehicle types and operations
  - Type 1 aircraft: subsonic overland
  - Type 2 aircraft: Mach cut-off (say M=1.15) overland, higher M over ocean
  - Type 3 aircraft: High supersonic entire mission
  - Larger capacity aircraft as needed / desired
- Implement other emissions & airport noise predictions (contingent on receiving supersonic aircraft and powerplant models from Georgia Tech colleagues)
- Business jet class supersonic vehicle types and operations