Aircraft Technology Modeling and Assessment

Project 10

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## 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

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Georgia Tech</th>
<th>Purdue</th>
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<tr>
<td><strong>1</strong></td>
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<tr>
<td>Fleet Assumptions &amp; Demand Assessment</td>
<td>Identify supersonic demand drivers and supporting airports and project demand for all scenarios</td>
<td>Estimate latent demand and flight schedules for supersonic aircraft</td>
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<td>Expand to international airports</td>
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<td><strong>2</strong></td>
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<tr>
<td>Preliminary Vehicle Environmental Impact Prediction</td>
<td>Develop estimates of KEIs for supersonic aircraft relative to current technology subsonic aircraft, Develop estimates of likely operating altitudes</td>
<td>Support with expert knowledge</td>
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<tr>
<td>AEDT Vehicle Definition</td>
<td>Test current version of AEDT ability to analyze existing supersonic models, Work with AEDT developers to understand the required modifications to support supersonic vehicles</td>
<td>N/A</td>
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<tr>
<td>Vehicle and Fleet Assessments</td>
<td>Apply GREAT to estimate impact of supersonics in terms of fuel burn, water vapor, and LTO NOx for a combination of vehicles and scenarios</td>
<td>Apply FLEET to estimate impact of supersonics in terms of fuel burn, water vapor, and LTO NOx</td>
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<td><strong>5</strong></td>
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<tr>
<td>EDS Vehicle Modeling</td>
<td>Create 2 EDS supersonic vehicle models with boom signatures</td>
<td>Support with expert knowledge</td>
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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: 1.38x 1.46x 1.84x

Increased Demand: 1.66x 1.88x 2.75x

Simplified Demand Model

Supersonic Demand Curve

Subsonic Demand Curve

Ticket Price

P_{\text{Supersonic}}

P_{\text{Premium}}

Q_{\text{Premium}}

Q_{\text{Supersonic}}

Quantity of Tickets Sold
GT Task 2: Preliminary Vehicle Environmental Impact Prediction

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

- Developed conceptual design dashboard
  - Constraint analysis
  - Mission analysis
- Calibrated on Concorde data
GT Task 4: Fleet Impact Assessment

Large variability in 2050 fuel use due to assumptions…

Modeling Assumptions:

- Market Size
- Vehicle Technology
- Aviation Growth

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

1-2 Flights/day vs. ~1000 Flights/day

Meeting Aggressive NASA Goals vs. Current Technology Only

Low Growth vs. High Growth

Potential Market Share

Current Trends “Best Guess”

Goal: Reduce uncertainty by improving estimates
Task 5: Supersonic EDS Vehicle Modeling

Develop Airframe Concept (OpenVSP)

- Perform Initial Wave Drag Analysis (Sears-Haack)
- Develop “Water Tight” Geometry (SolidWorks)
- Develop High Speed Drag Polar (Star-CCM+, Inviscid)

Synthesize & Size Vehicle

Acceptable Design?

- Change Vehicle Design Parameters
- Change Engine Design Parameters

Finalize Design

Develop On-Design Engine Cycle

- Develop Off-Design Power Management
- Develop Engine Multi-Design Point Logic
- Develop Engine Flowpath Model
- Develop Engine Deck

Develop Statistical Component Weight Estimation

Develop Design Mission Profile

Develop Engine Deck

Acceptable Design?

Completed
In Progress
Not Started
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 CO₂ 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 WWLINENET 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 CO₂ 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

<table>
<thead>
<tr>
<th>Route</th>
<th>Daily Demand</th>
<th># of Trips</th>
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<tbody>
<tr>
<td>HNL – LAX</td>
<td>634</td>
<td>11.33</td>
</tr>
<tr>
<td>HNL – SFO</td>
<td>382</td>
<td>6.67</td>
</tr>
<tr>
<td>HNL – NRT</td>
<td>298</td>
<td>5.33</td>
</tr>
<tr>
<td>JFK – LHR</td>
<td>296</td>
<td>5.33</td>
</tr>
<tr>
<td>NRT – SFO</td>
<td>256</td>
<td>4.67</td>
</tr>
</tbody>
</table>

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

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

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