2019 Fall E&E REDAC

Civil Supersonic Transport R&D Efforts

Presented to: E&E REDAC

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Outline

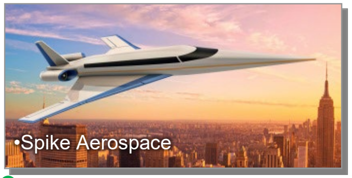
Supersonics

- Introduction
  - Congressional Mandate
  - Research Overview
- Emissions
- Noise and Sonic Boom
  - LTO Noise
  - Sonic Boom
  - Mach Cut-Off

Supersonic interest within the U.S….

- 35-70 PAX
- Low-Boom Airliner
- 4,000 nm @ Mach 1.6-1.8

- 8-12 PAX
- 4,200 nm
- Mach 1.4, 120k MRW



- 12-18 PAX
- Low-Boom SBJ
- 6,200 nm
- Mach 1.6, 115k MRW

- Low-Boom Demo
- Mach 1.4, 25k MRW
- Lockheed design
- Funded through PDR

- 80 PAX Low-Boom Airliner
- 5,000 nm @ Mach 1.7

- 45 PAX Airliner
- 4,500 nm @ Mach 2.2

- 8-12 PAX Low-Boom QSJ
- > 4,000 nm
- Mach 1.8, 100k MRW

Congressional Mandate – FAA Reauthorization of 2018 (Section 181)

- **FAA shall "exercise leadership"**
  - Consider needs of industry and stakeholders
  - Obtain input of aerospace industry regarding appropriate regulatory framework, operational differences with subsonic, costs & benefits, and public and economic benefits.
  - International leadership – demonstrate global leadership, address the needs of aerospace industry and protect the public health and welfare.
  - **Report to Congress on above – October 5, 2019**.
- **Long-Term Regulatory Reform**
  - Issue part 36 NPRM on LTO noise by March 31, 2020
  - Issue part 91 Appendix B NPRM by December 31, 2019 – Issued June 28, 2019
- **Near-Term Certification**
  - Rule of Particular Applicability
  - Overland Speed Limit

SST questions FAA is addressing…

- What noise levels should we expect?
- Where will they operate?
- What Airplane Design Group / Aircraft Approach Category will they have?
- How heavy are they?
- How many of them will there be?

U.S. Government Civil SST R&D Efforts

Projected Demand Scenarios

Tradeoff Analysis

LTO Noise

LTO/Full-flight Emissions

- **ASCENT A10: SST Demand & Technology Projection & Evaluation (GT)**
- **ASCENT A10: SST Demand Projection & Evaluation (Purdue)**
- **ASCENT A47: Clean Sheet SST Engine Design (MIT)**
- **NASA: Supersonic Concept Aircraft (STCA)**

LTO Jet Noise

- **ASCENT A59: Jet Noise Modeling to Support Low Noise Supersonic Aircraft Technology Development**

En-Route Noise

- **NASA / Virginia Tech: Low-Boom / Non Low-Boom Demand**
- **NASA: Low Boom SST Flight Demonstrator**
- **ASCENT A42: Mach Wave Cutoff (PSU)**
- **ASCENT A41/A57: En-Route Standard (PSU)**

Atmospheric Impacts

- **NASA / ASCENT A58: Climate/Ozone/Air Quality Impacts Evaluation (MIT)**

CAEP Analysis Support

- **FAA working in collaboration with Volpe Center, ASCENT Projects, and NASA**

Technology maturation will also be included in FAA CLEEN Phase III Solicitation

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Emissions

Current SST LTO Cycle Standards

Operating Mode	Engine Power	Time in Mode
Takeoff	100%	1.2 minutes
Climb	65%	2.0 minutes
Descent	15%	1.2 minutes
Approach	34%	2.3 minutes
Taxi/ ground idle	5.8%	26 minutes

14 CFR Part 34 based on Concorde & afterburning

Research

- HC, CO, SN, NOx, nvPM CAEP/10, nvPM mass, nvPM number
- For each Mach Number engine
- For each Technology response
- For different Times in Mode (TiM) /LTO --- current SST, current Subsonic and any potential “other” (including impacts due to noise procedures)
- Compare all technologies and Mach against each other --- show in one chart; break down due to LTO component, etc.
- Compare against standards Annex 16

ASCENT10 – Georgia Tech & Purdue

Objective: Investigate fuel burn, emissions and noise impacts from supersonic transport (SST) entering the fleet

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

GT: 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, with 2038 defined for CAEP

>55 Passengers Daily Each Way, >1500nmi, Great Circle, Unrestricted

Route optimization assessment to define trajectories

One hour minimum time savings

Georgia Tech: Vehicle Modeling

- Three SSTs: 10, 55 & 100 Passengers
- Using vehicle design tools and computational fluid dynamic tools perform
  - Aircraft Design
  - Engine Design
- Perform Mission Analysis using flight optimization tool
  - Weights estimation
  - Mission profile
  - Overall synthesis and sizing

Summary: Georgia Tech Efforts

Demand Modeling

- Distributional analysis of Value of Travel Time Savings
- Trajectory optimization analysis taken into account

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
- Medium 55 passenger SST anticipated by end of FY2019

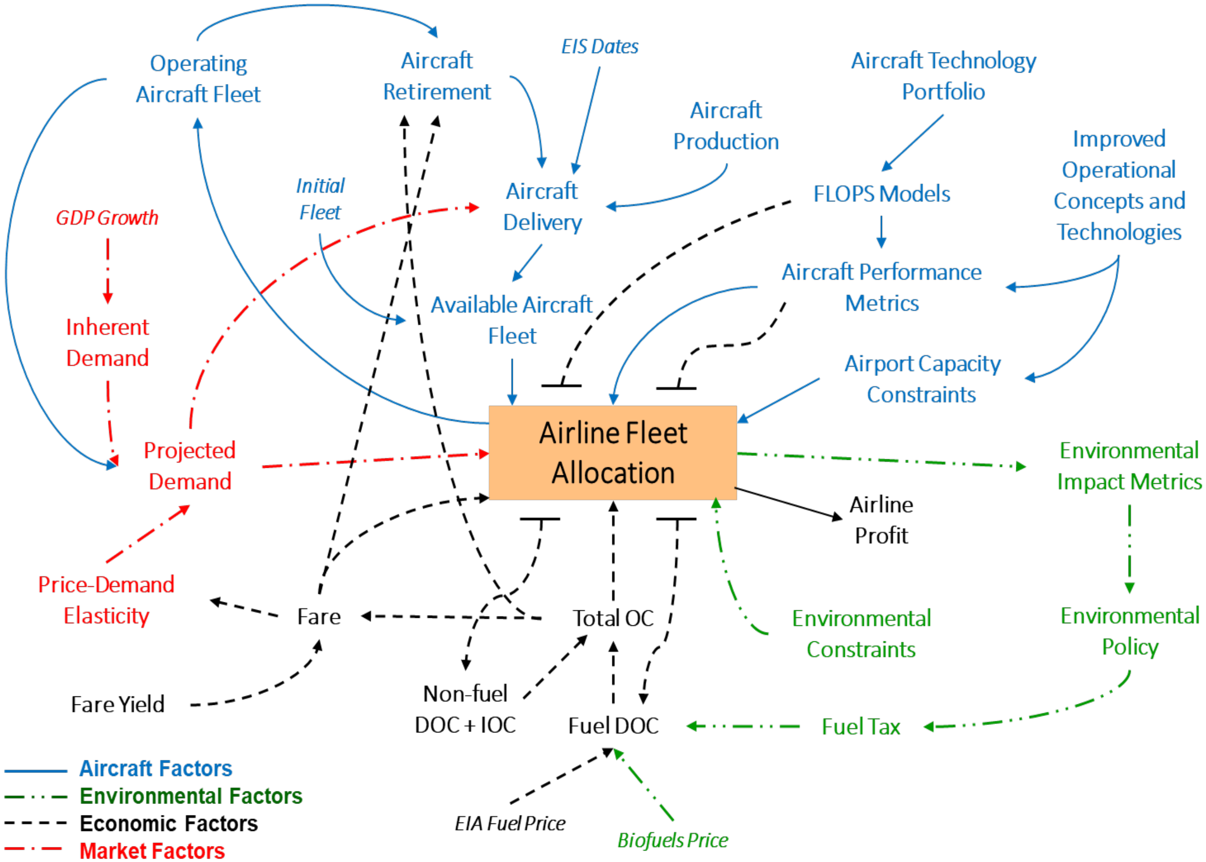
Fleet-level CO_2 emissions

- Trying to reduce uncertainties on key assumptions
  - Demand
  - Interactions with subsonic scenarios
  - Vehicle environmental performance

Purdue Efforts

Fleet-Level Environmental Evaluation Tool: FLEET

A system dynamics-inspired simulation to evolve airline fleet, passenger demand, environmental impact over time



Core is an allocation problem to simulate a profit-seeking airline

- 1,940 routes connects a subset of WWLMINET 257 airports
- **US-domestic routes**
- **US-touching international routes**, flights begin or end at US airport

FLEET represents aircraft by class (number of seats) and by technology age

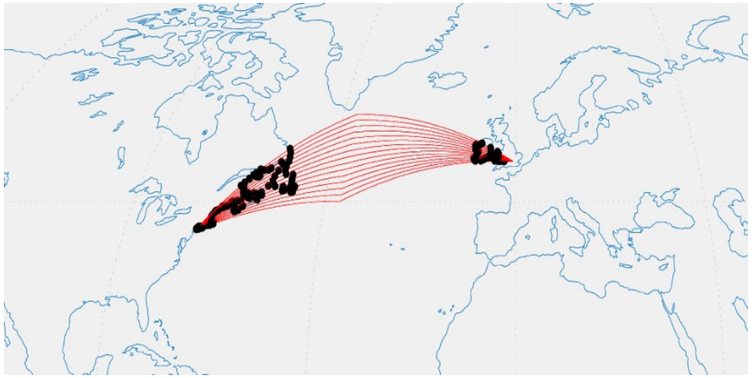
Purdue Potential Supersonic Routes

Filters to identify potential supersonic routes

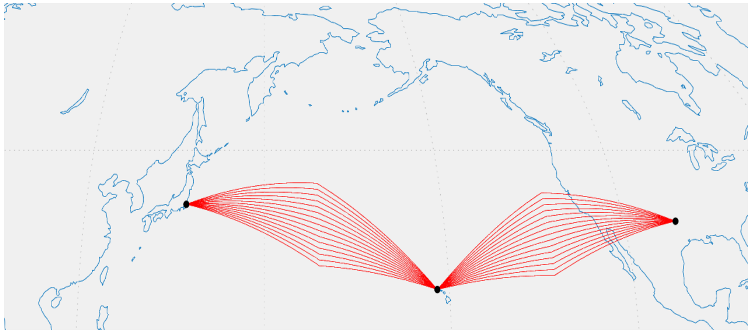
- Non-stop great circle distance between 1,500 and 4,500 nmi
- Routes with ≥ 75% overwater
  - $M > 1.0$ only over water
- Simple distance flown adjustment to minimize block time
- Transpacific routes over 4,500nmi with fuel stop

Potential SST routes in FLEET network

- 98 direct routes
- 11 transpacific routes with HNL fuel stop



•Simple overwater route adjustment strategy JFK-LHR



•Simple overwater route adjustment strategy with fuel stop DFW-(HNL)-NRT

Summary: Purdue Efforts

Characterizing supersonic demand and routes

- US-touching routes based on US flag carrier data
- Assume 5% of total demand shifts from business class and above to SST
- Route-filtering with percentage of flight overwater

Supersonic ticket price model

- Range-dependent model based upon "as offered" prices for business class and above

Supersonic aircraft enter the fleet

- Allocation approach that first satisfies supersonic demand then subsonic demand to serve all total demand
- Supersonic aircraft production and acquisition model
- FLEET allocates supersonic aircraft on profit-earning routes only
  - SST Introduction leads to different allocation of subsonic aircraft
  - Allocation results give a pseudo-schedule for the FLEET airline

ASCENT 47 – MIT

PRIMARY RESEARCH QUESTION:
What are the noise and emissions characteristics of clean-sheet and derivative engines designed for future civil supersonic transport aircraft?

- Identify operating requirements for propulsion system
- Build engine cycle model to explore the design space
- Quantify fuel burn, noise and emission characteristics
- Compare clean-sheet design to a re-purposed engine core

Outcomes:

- Understand the challenges of and the environmental impact mitigation options for supersonic aircraft engine technology
- Inform discussions regarding the technological basis for environmental regulations of engines on supersonic aircraft

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ASCENT P#41- Identification of Noise Acceptance Onset for Noise Cert Stds of Supersonic Airplanes

Goal:

Technical research to complement CAEP WG1 (noise) for en route supersonics and sonic boom certification procedures

Milestones (to-date):

- Supported downselection to 6 sonic boom noise metrics for En route SARP consideration. *[Metrics]*
- Identified that conventional corrections for off-reference conditions are not possible to apply due to the non-linear nature of supersonic shockwave propagation. *[Scheme]*
- Analyzed the robustness of sonic boom metrics due to signature distortions due to atmospheric turbulence, identifying B-SEL least sensitive. *[Turbulence]*
- A minimal # microphones was studied for the measurement of sonic boom noise. About 7 microphones provides a minimal 90% confidence interval, and additional microphones are unneeded. *[Test procedure]*

ASCENT P#41- Identification of Noise Acceptance Onset for Noise Cert Stds of Supersonic Airplanes (continued)

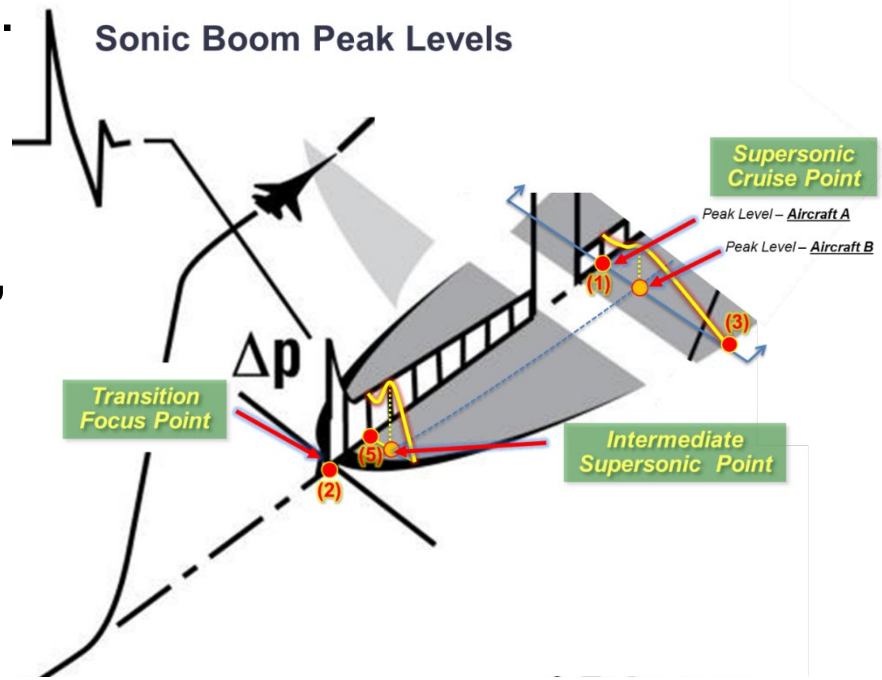
Status:

Expected completion by Winter 2019/Spring 2020 with final report.

Next Steps:

- New start specific to support WG-1 development of en-route, low boom certification standard for SST, plus other noise impacts at ICAO-CAEP.
- Understand and predict secondary sonic boom

  - Approach is to explore existing NASA/FAA capabilities



ASCENT P#57- En Route Noise Certification of Supersonic Airplanes to Support ICAO-CAEP

Status:

FAA proposing to fund grant ex by Spring 2020 until Dec 2021.

Objective:

- Continue support of WG-1 on development of en-route, low boom a certification standard for supersonic airplanes, plus other ICAO-CAEP impact activities.
- Understand and predict secondary sonic boom

  - Approach is to explore existing NASA/FAA capabilities

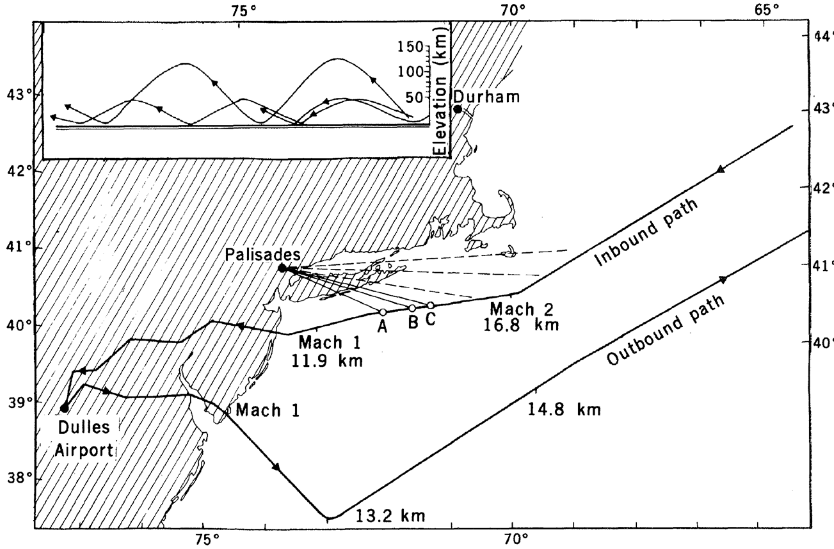
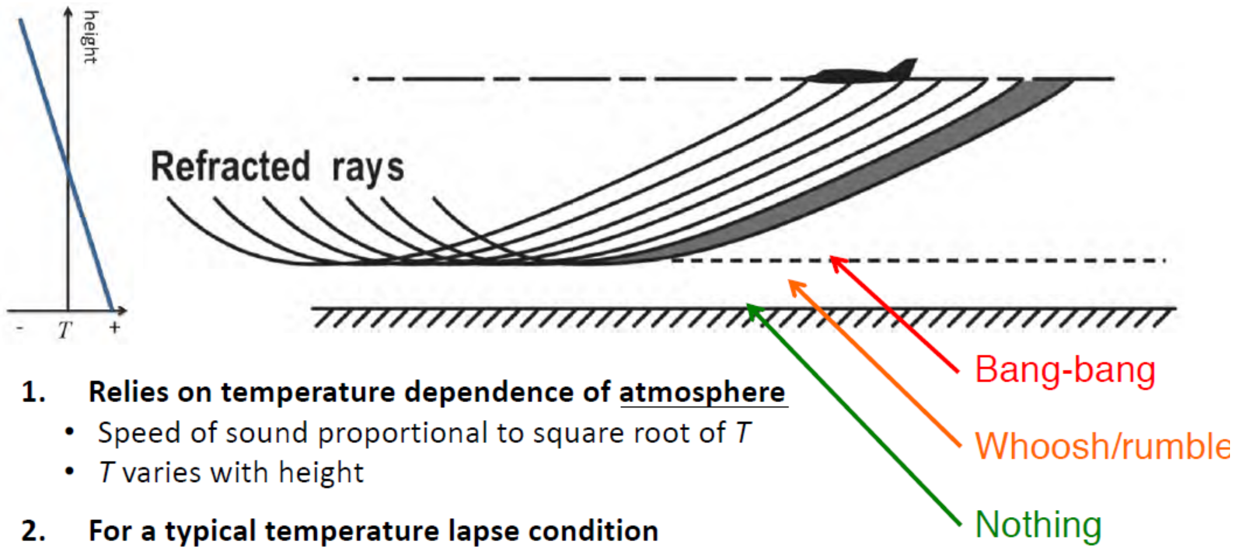


Fig. 2. Map showing the inbound and outbound flight paths of the Concorde supersonic transport. Elevation and speed are marked on the tracks. Points A, B, and C are average source locations for the first three signals received at Palisades. Although both inbound and outbound signals are recorded at Durham, instrumentation for directional determinations has not been completed at this site. The inset shows a schematic ray tracing indicating ray paths through the stratosphere (about 40 to 50 km) and the thermosphere (100 to 130 km).

III. Mach Cut-off Phenomenon

Mach cut-off occurs when the aircraft flies supersonically without producing a sonic boom on the ground



1. **Relies on temperature dependence of atmosphere**
   - Speed of sound proportional to square root of *T*
   - *T* varies with height
2. **For a typical temperature lapse condition**
   - Aircraft is supersonic at flight altitude, but not at ground
   - Rays refract upwards, so no boom on the ground
3. **What you hear depends on how close you are**

[4] HAGLUND, G., & KANE, E. (1973). Flight test measurements and analysis of sonic boom phenomena near the shock wave extremity. NASA Report CR-2167.

- MCO progress is being monitored by ICAO under WG-1 and tracking research.
- Discussions continue on how it would be deemed acceptable by NAAs.

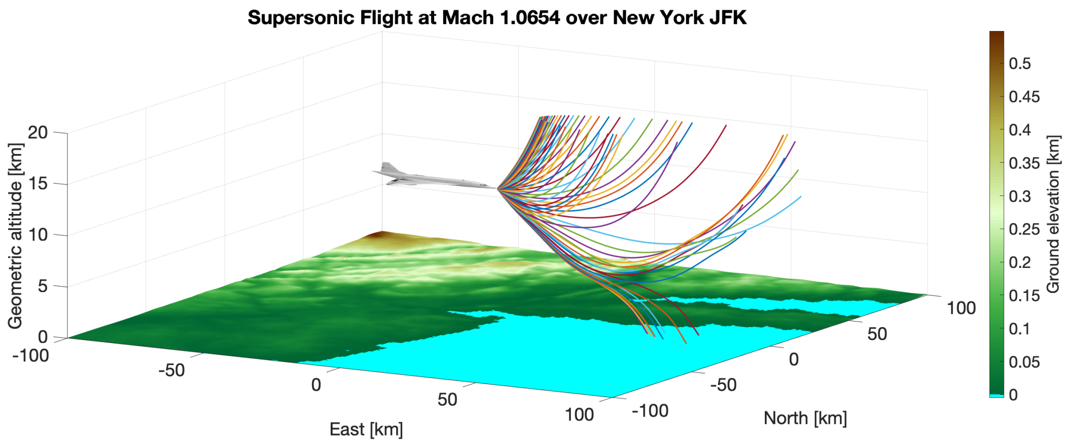
ASCENT #42- Model for Mach Cut-off Flight

Goal:

Develop an acoustical model to characterize Mach Cut-off flight of sonic boom mitigation (not reaching ground) and explore human response of "evanescent pressure wave" best defined by annoyance metric.

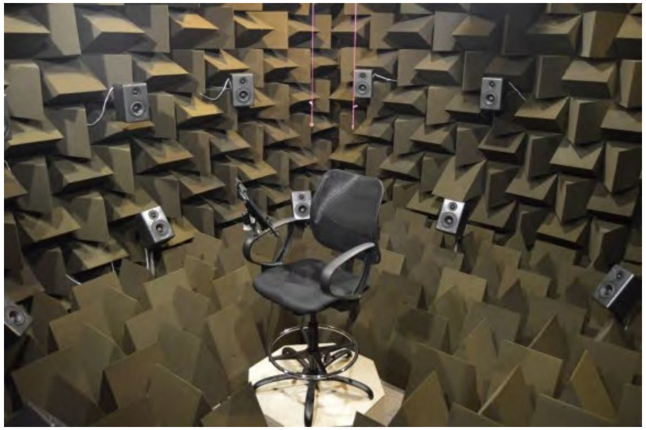
Milestones:

- Developed a 3-D ray-tracing computation program that uses numerical weather data to predict the focus booms on the ground due to atmosphere.



- Working on quantifying statistical occurrence of typical domestic flights.

ASCENT #42- Model for Mach Cut-off Flight



Status:

Anticipated completion by Winter 2019.

Final Steps:

- In process of predicting statistical occurrences on how often people would hear Mach cut-off sounds.
- Established a good handle on appropriate metrics for Mach cut-off - Loudness metrics, especially B- and E- weighted sound exposure level, identified as best candidates.
- Almost ready to state how annoying the sounds would be, compared to other transportation noise sources.

ASCENT SST NFOs - Summer 2019

COE-2019-A – Awarding 3 Teams under P59

Project Title: Jet Noise Modeling to Support Low Noise Supersonic Aircraft Technology Development

Nominal Funding Level: $200,000 per year

Period of Performance: 3 years

Project Description:

The goal of this new research project is to work in close collaboration with industry, NASA, and academia in order to leverage and further previous ASCENT work by Georgia Tech and MIT on Projects 10 and 47 respectively, to identify novel methods to reduce jet noise from Civil Supersonic Aircraft engines. Gas turbines for supersonic aircraft need to have a relatively small engine diameter to avoid large fuel burn penalties during supersonic cruise. To have sufficient thrust, the jet exit velocity needs to be relatively large (as compared to subsonic jet engines) resulting in substantial noise from the jet exhaust.

COE-2019-B - NO RESPONSES

Project Title: Evaluation and mitigation of airframe noise (on approach) from Civil Supersonic Aircraft

Nominal Funding Level: $200,000 per year

Period of Performance: 2 years

Project Description:

The goal of this new research project is to work in close collaboration with industry, NASA, and academia, and leverage existing research capabilities by Georgia Tech and MIT under ASCENT Projects 10 and 47 respectively, to quantify the sources of noise from the airframe of a modern Civil Supersonic Aircraft on approach and identify means to reduce these noise sources. Civil Supersonic Aircraft will differ from modern civil subsonic aircraft in terms of their wing architecture as well as the wing shape. As a result, there are additional noise sources (e.g., from wing leading edge vortex shedding) and the supersonic aircraft operates differently than its subsonic counterparts (e.g., by having a higher approach speed). This work needs to be closely coordinated with the airframe design efforts conducted by Georgia Tech and the supersonic engine design work of MIT, in order to develop holistic solutions to reduce the noise from future Civil Supersonic Aircraft.

Noise/Sonic Boom Stds Expectations

- Domestic noise effort progressing and synching so far with ICAO efforts.
  - Supersonics Exploratory Study
  - En route, low boom SARP by CAEP13-14
  - MCO process maybe by CAEP13-14
- Supporting ASCENT R&D continues to support anticipated needs.
- NASA X-59 demonstrator aircraft program on schedule to support proposed 2021-25+ timeframe of exploration of low boom threshold for en route SARP.

Path of Future SST

- **As a result of continued investments, enabling supersonic technologies are converging towards aeroplane configurations.**
- **Civil supersonic operations may come in phases:**
  - Over water
  - Over land (either by MCO augmented and/or Unrestricted low boom)
- **Aerion and Boom have publicized that certification of its supersonic aeroplanes could be achieved as early as 2023 (both designing for supersonic overwater cruise, and Aerion pursuing the potential for Mach cut-off flight over land).**
- **Aeroplane manufacturers interested in unrestricted over land supersonic operations seek a regulatory basis established prior to making the significant development programme investments that can bring low boom aeroplanes to market.**

Questions/Discussion