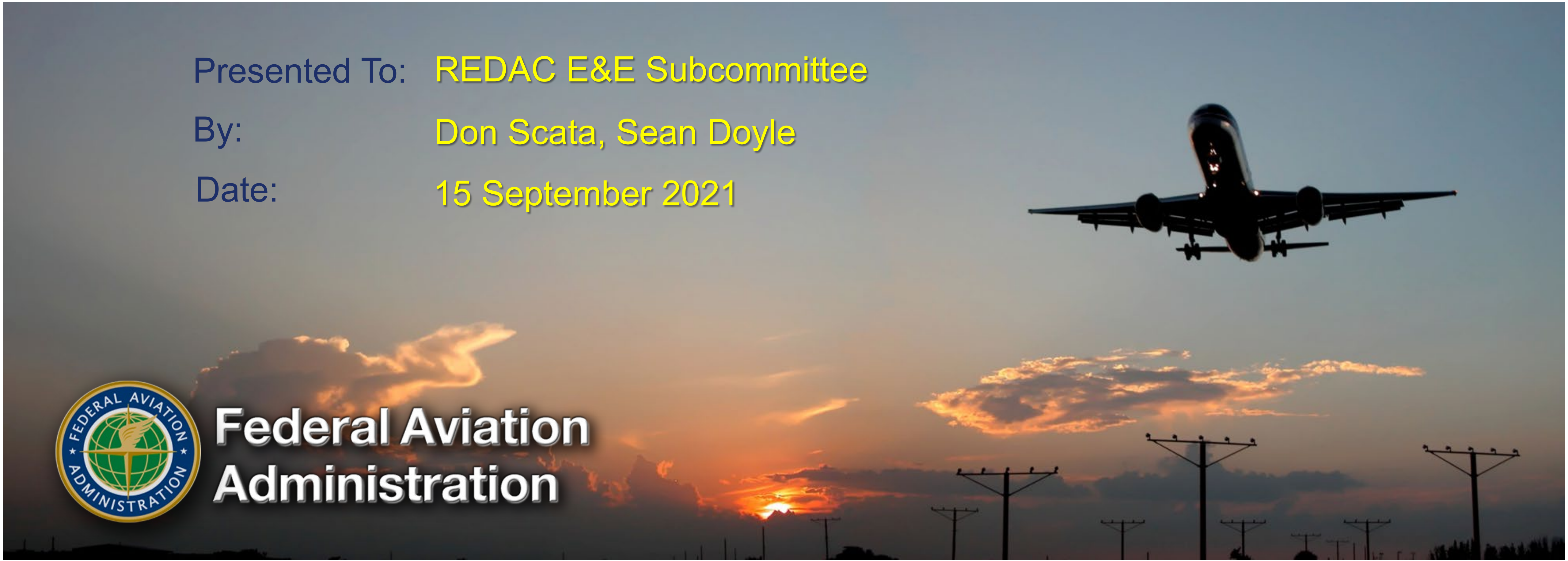
Noise Research – Briefing and Discussion



Presented To: REDAC E&E Subcommittee

By: Don Scata, Sean Doyle

Date: 15 September 2021

Federal Aviation Administration

Topics

- **New Entrants and Noise Certification- Don**
- Aircraft Noise Impact Research - Sean

New Entrants & Noise Certification

- Advanced Air Mobility
- Civil Supersonics
- Noise Certification Streamlining

Efforts Related to UAS Noise Measurement

Measurements

- Measurement Campaigns in Oklahoma, North Caroling and Massachusetts (Sept)
- Increasing database of vehicle types measured
- Expanding coverage of noise emissions
  - Larger microphone arrays
  - Suspending microphones from cranes to capture full 3D directivity about the vehicle
  - More operating procedures (mass, speed, altitude)
- Working with applicants for noise type certification to obtain more measurements and supplemental procedures

Acoustic Propagation

- Using fundamental acoustics with measurements of more operating procedures to arrive at noise metric relationships to assist regulations as well as environmental analysis

Environmental Analysis

- Estimating noise from different types of operations using measured and noise certification data – distributed versus narrow flight tracks
- Leveraging measurements of more operating procedures to estimate noise from entire flight profile (launch, en route, and delivery)

Measurement Campaign at Causey Aviation Services

Measured

- Quadcopter (NCDOT)
- Hexcopter (Flytrex)
- Combo (Volansi)

5 Days of Measurements

- Did not need extra weather day
- Accomplished because quadcopter only had one weight range

Status

- Contractor processing tracking data
- Contractor processing mic data

Next Steps

- Analyze noise emissions
- Focus on directivity (do we need a crane?)
- Find relationships between metrics and geometry

Fly Neighborly Program

Rotorcraft RE&D

Goals:

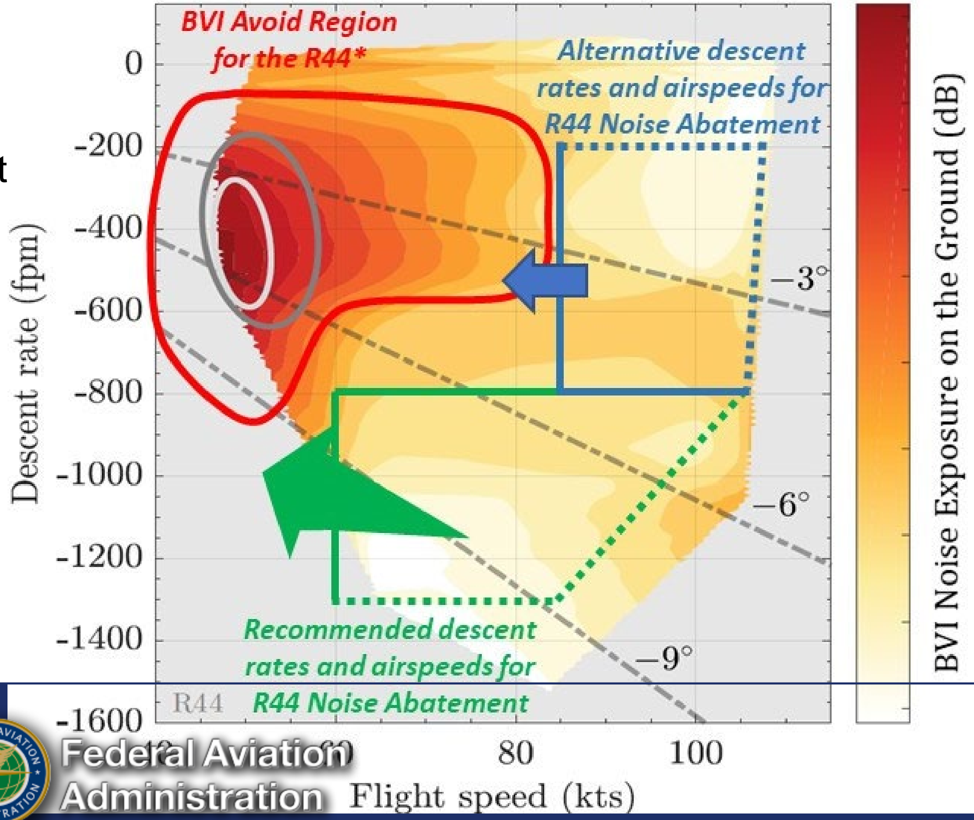
- Reduce noise from helicopters flying over communities through development of Noise Abatement Procedures (NAPs) and their voluntary use by pilots
- Improve community acceptance of helicopter noise

Approach:

- Utilize modeling and flight testing to develop noise abatement procedures (NAP)
- Tailor NAP for a variety of helicopter types
- Team with Helicopter Association International (HAI) to train pilots how to fly NAP
- Provide materials and promote best practices to engage communities concerning helicopt noise in order to foster better relationships

Status:

- A Fly Neighborly general Tips document has been developed and widely circulated.
- Model-specific approach NAPs have been developed for 9 helicopters
- NAP for classes of helicopter types, which will extend the capability to define NAPs for other helicopter models and variants are currently being researched.
- Capability to automate NAP and route planning guidance is being researched and may evolve from this work



ASCENT # 38 (PSU)
Rotorcraft Noise Abatement Procedure Development

Goals:

- Compare effectiveness of noise abatement procedures by helicopter weight class
- Validate noise predictions with 2017 & 2019 flight test data
- Develop noise abatement procedures by helicopter type

Approach:

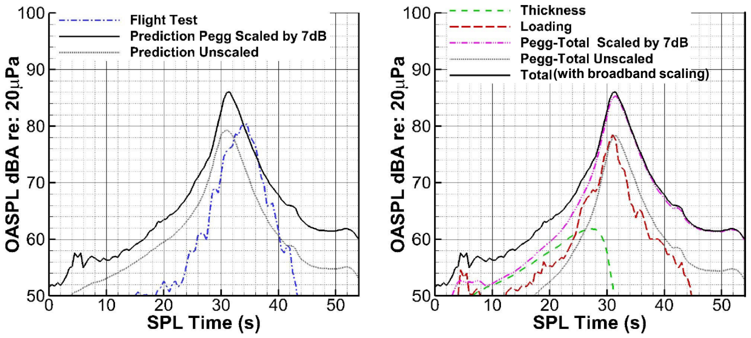
- Build on success of noise prediction system developed under ASCENT Projects 6 & 38 work
- Develop models for 2019 FAA/NASA flight test
  - Focus on S-76D and Bell 205 helicopters
  - Validate models for a subset of flight procedures
- Compare medium and light helicopters
  - S-76D with Bell 407 (both 4-bladed main rotors)
  - Bell 205 with Bell 206 (both 2-bladed main rotors)

Status:

- Noise predictions have been made for S-76, Bell 205, 206, and 407 aircraft for several flight conditions
- Comparisons between light and medium weight aircraft are underway

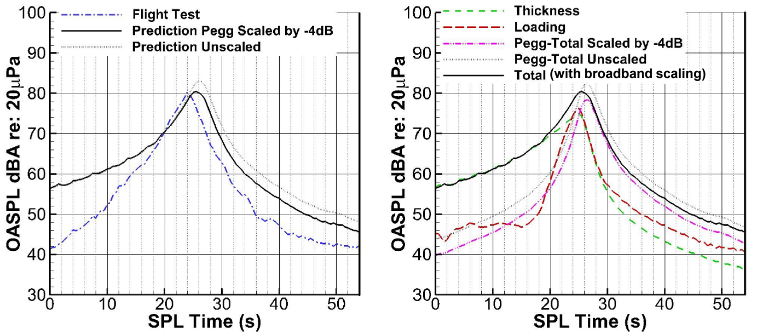
Sikorsky S-76D
medium weight

Bell 407
light weight



(a) Comparison to Flight Test Spectrum (b) Prediction Spectrum Components

Figure 1: A-weighted OASPL results for an 88 knots, level flight case at microphone 18. Measured S-76D vs S-76 model. Pegg broadband noise predictions scaled by 7 dBA.



(a) Comparison to flight test spectrum (b) Prediction spectrum components

Figure 2: A-weighted OASPL results for an 80 knots, level flight case at microphone 29. Measured vs predicted Bell 407 results. Pegg broadband predictions scaled by -4 dBA.

ASCENT# 49 (PSU) Urban Air Mobility Noise Reduction Modeling

Goals:

- Develop initial capability to predict UAM acoustics
- Improve understanding of UAM noise characteristics
- Identify noise reduction opportunities

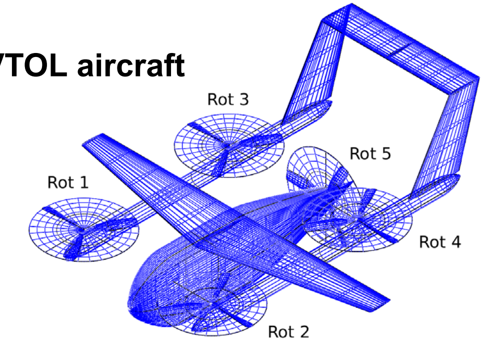
Approach:

- Build on success of helicopter noise prediction system developed under ASCENT Projects 6 & 38
- Tailor approach to the unique characteristics of UAM
  - PSU DEPSim for flight state of multirotor vehicles
  - Unsteady loading with CDI's CHARM
  - Increase efficiency of PSU-WOPWOP for many rotors
  - Generalize broadband noise models for UAM

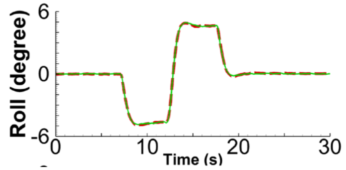
Status:

- System is nearly working (broadband noise prediction currently being tested); results for lift + cruise vehicle shown on the right
- Evaluation of time varying rotor speed suggests variation slow compared to rotor period
  - Quasi-periodic assumption may be possible
  - Significant computation time reduction with quasi-periodic approximation

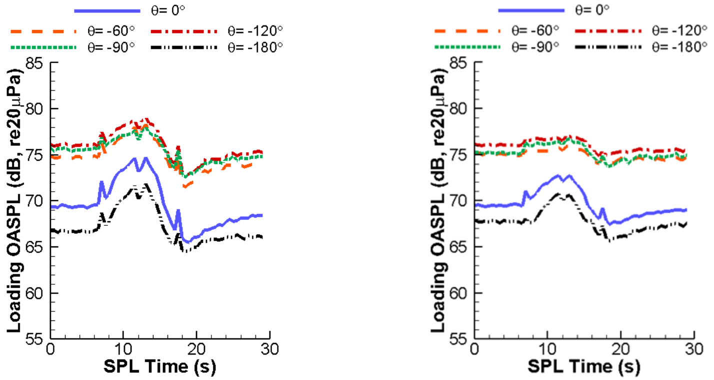
Generic eVTOL aircraft



Noise was computed for model conducting a 5° roll angle doublet in 10 knots steady level flight, using **two control schemes:**



1. **Variable rotor speed** and constant pitch
2. **Variable collective pitch** and constant rotor speed



Loading noise predictions at 5 elevation angles

ASCENT Project #77 (PSU)

Measurements to Support Noise Certification for UAS/UAM Vehicles and Identify Noise Reduction Opportunities

Use extensive lab and field measurement, assisted by numerical modeling, to *reliably* characterize in-flight UAS/UAM noise sources and noise variation

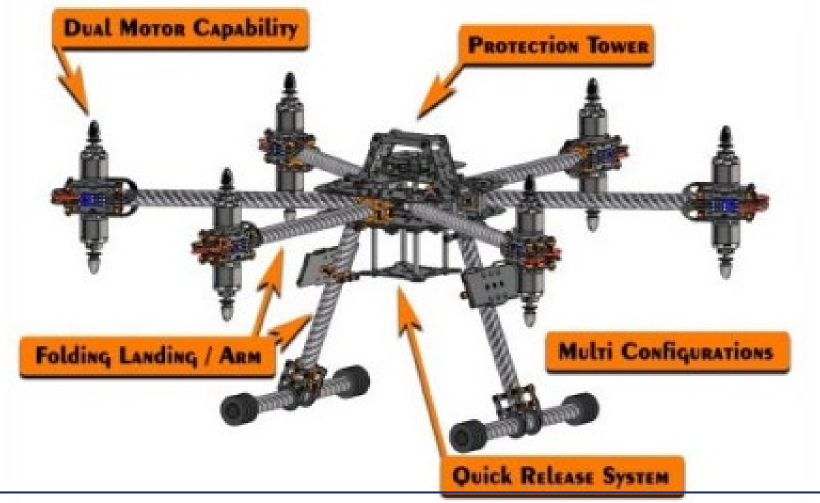
<u>2020-2021</u>

- Develop source separation process for “nearly-coherent” noise
- Collect noise data on a variety of UAS and UAM platforms, including parametric variations of a reconfigurable UAS

<u>2022-2023</u>

- Identify the minimum set of instrumentation required to accurately and reliably characterize UAS and UAM noise
- Develop low noise flight procedures for over-actuated vehicles
- Explore low noise design changes and “acoustically aware” flight control laws

Anechoic chamber and rotor test stand (above)
Reconfiguration UAV (below)



ASCENT# 77 (PSU) – Noise Source Characterization and Assessment

- Develop noise source separation for distributed propulsion vehicles (ongoing)
- Simulate UAS and UAM noise measurements (ongoing)
- Measure noise from a reconfigurable multirotor UAS vehicle (planned)
- Collect noise data on UAS and UAM vehicles (ongoing)

Field measurement since late July of 2021

- Several multirotor and fixed-wing designs
- Takeoff, hover, flyover, maneuver, etc.
- Matrix of flight altitudes, speeds, & weights
- 63 runs of acoustic test data so far
- More testing in the fall, including on a UAM vehicle

Field measurement in August of 2021 (flyover test shown here)

M: microphone locations

Blue: UAS trajectory

Red: target ground track

ASCENT Supersonics Noise Projects

ASCENT	Universities	Research Title
# 57	Pennsylvania State U.	Support for Supersonic Aircraft En-route Noise Efforts in ICAO CAEP
# 59 B	Georgia Tech	(Experimental) Jet Noise and Measurements to Support Reduced LTO Noise of Supersonic Aircraft Technology Development (modeling)
# 59 A/E	Pennsylvania State U./ Georgia Tech	Jet Noise Modeling To Support Low Noise Supersonic Aircraft Technology Development.
# 59 C	U. of Illinois-Urbana Champaign	Modeling Supersonic Jet Noise Reduction with Global Resolvent Modes
# 59 D	Stanford U.	Physics-based Analysis and Modeling for Supersonic Aircraft Exhaust Noise

ASCENT Project 57

ASCENT Project 57

Support of Supersonic Aircraft En-route Noise Efforts in ICAO CAEP

Pennsylvania State University, Queensborough Community College, Volpe

PI: Victor Sparrow, Penn State

PM: Sandy Liu, FAA

Cost Share Partners: Boom, Gulfstream

Objective:

- Research continues to support FAA in the development of technical standards for civil supersonic aircraft under the ICAO CAEP
  - Task 1: Efforts focus primarily in the area of en-route sonic boom noise assessment
  - Task 2: Testing capability of PCBoom software to model secondary sonic booms

Project Benefits:

- Predictive capabilities for sonic boom impacts
- Continued study of secondary sonic boom prediction
- Applicability of certain metrics
- Testing of signal processing methodologies for sonic boom signals
- Scheme assessment for sonic boom certification

Research Approach:

- Task 1: Simulate the effects of turbulence on shaped sonic boom within the atmospheric boundary layer
  - Propagate from cruise altitude to ABL with no-turbulence tool and ABL to ground with turbulence tool (involving both vector and scalar types)
- Task 2: Currently looking at prediction of secondary sonic boom for supersonic aircraft approaching U.S. coastlines, using flight conditions similar to Concorde.
- Task 3 (Volpe): Recover Concorde secondary boom signatures recorded by Volpe in 1979.

Major Accomplishments (to date):

- Using extended shaped boom input waveform file provided by NASA and tapers before and after propagation prevented artifacts before and after shocks
- Performed secondary sonic boom predictions for U.S. west coast for the first time

Future Work / Schedule:

- Determine sources of non-physical spiking in KZKFourier produced signatures
- Diagnose PCBoom secondary boom signal amplitude anomalies

This research was funded by the U.S. Federal Aviation Administration Office of Environment and Energy through ASCENT, the FAA Center of Excellence for Alternative Jet Fuels and the Environment, project 57 through FAA Award Number 13-C-AJFE-PSU under the supervision of Sandy Liu. Any opinions, findings, conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the FAA.

ASCENT Project 59B

JET NOISE MODELING AND MEASUREMENTS TO SUPPORT REDUCED LTO NOISE OF SUPERSONIC AIRCRAFT TECHNOLOGY DEVELOPMENT

Georgia Institute of Technology

PI: Krish Ahuja (PI), D. Mavris and Jimmy Tai (Co-PIs)

Experimental support: Aharon Karon, Robert Funk and Nate Ramsey (GTRI)

Cost Share Partner: Gulfstream (POC: Brian Cook)

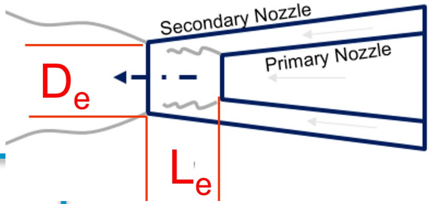
PM: Sandy Liu

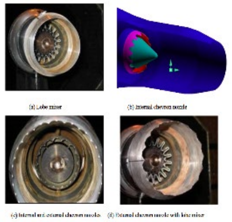
Objective:

To acquire acoustic and flow measurements to be used by Project 59 jet noise modelers for the validation of low, medium, and high-fidelity jet noise prediction methods for supersonic transport applications (SST).

Project Benefits:

The validation of these prediction codes will give confidence in the noise prediction, which will aid in the design of low noise engines for reduced landing and takeoff noise of supersonic aircraft





Research Approach:

- Design and fabricate a simple model-scale test nozzle made of a round core primary nozzle buried in a coaxial secondary flow with the mixed flow exhausting some distance downstream of the primary nozzle exit.
  - Geometry was designed as a scaled model of a paper engine design
- Acquire acoustic and related flow measurements as a function of mixing distance between the primary nozzle exit and the final exhaust nozzle exit
- Provide the measured data to modeling teams for validation of prediction codes

Major Accomplishments (to date):

- The test nozzle designed and fabricated
- The model design shared with the modelers
- Acoustic data acquisition is in progress and initial data shared with the modelers

Future Work / Schedule:

- Complete the acoustic and flow measurement acquisition (5-15-2021)
- Share all data with modelers and be available for interactions (present through (5-28-2021)
- Select a mixer design for the Year 2 effort (5-28-2021)

ASCENT Project 59A/E

Jet Noise Modeling To Support Low Noise Supersonic Aircraft Technology Development.

**Georgia Institute of Technology &
Penn State University**

PI: Dimitri Mavris, GT
Philip J. Morris, PSU

Co-I: Jimmy Tai & Josh Brooks, GT

PM: Sandy Liu

Cost Share Partner: Georgia Institute of Technology & Penn State University

Objective:

To develop and assess computational tools to simulate the flow and noise of Civil Supersonic Aircraft engines.

To assess the impact of noise reduction methods on the overall engine performance

Project Benefits:

The developed tools will enable airframe and engine manufacturers to assess the noise impacts of engine design changes and to determine if particular designs will meet current or anticipated noise certification requirements

Research Approach:

Perform steady and unsteady numerical simulations of the internal and external flow from dual-stream, subsonic and supersonic jet nozzles using a commercial CFD application

Predict the radiated noise using an acoustic analogy and compare with experimental measurements

Select operating conditions for initial experimental geometry. (Project 59B).

Assemble zeroth-order methods for predicting supersonic inlet performance.

Determine installed thrust loss by jet noise reducing nozzles and find inlet designs that overcome this.

Major Accomplishments (to date):

Grids generated and boundary conditions specified for the Georgia Tech nozzles (Project 59B)

Reynolds-averaged Navier-Stokes solutions performed

Initial zeroth-order supersonic inlet performance and structural analysis complete for 2D inlets.

Future Work / Schedule

Improve grids for Large Eddy Simulation (LES) of jet exhaust flow and use Ffowcs Williams & Hawkings acoustic analogy to predict radiated noise (3/22)

Dual-stream nozzle noise predictions (7/22)

Convert inlet analysis into design environment, including axisymmetric configurations

Incorporate inlet sizing and installation performance

ASCENT Project 59C

Modeling Supersonic Jet Noise Reduction with Global Resolvent Modes

University of Illinois at Urbana-Champaign

PI: Daniel J. Bodony

PM: Sandy Liu

Cost Share Partner: Boom (in negotiation)

Objective:

Develop a rapid prediction capability to estimate changes in jet take-off noise due to design features and parameter modifications

Project Benefits:

Reduce sound environmental impact due to anticipated return of supersonic civilian transport aircraft

Research Approach:

Utilize input-output (resolvent) descriptions of the jet aeroacoustics to link nozzle design choices to their impact on the radiated noise.

Envisioned usage:
1. Compute RANS of baseline nozzle with identified design parameters
2. Compute input-output operator and its derivatives wrt design parameters
3. Select new design parameters that reduce far-field noise
4. Return to 1.) with new nozzle and repeat

Major Accomplishments (to date):

- Python-based nozzle CAD → RANS grid ready
- RANS solver modified for hot jet flows and verified
- Input-output operator code developed and verified
- Evaluation of input-output gain sensitivities to
- nozzle design demonstrated

Future Work / Schedule

- Develop self-consistent scaling of resolvent amplitudes on RANS TKE
- Develop automated design workflow

ASCENT Project 59D

Physics-based Analysis and Modeling for Supersonic Aircraft Exhaust Noise

Stanford University

PI: Sanjiva K. Lele, Juan J. Alonso

PM: Sandy Liu

Cost Share Partner: TBA

Objective:

In collaboration with ASCENT partners in Project 59, develop multi-fidelity physics-based analyses for supersonic aircraft exhaust noise.

The main goals are to develop improved jet noise prediction methods and better understand the uncertainty associated with the noise predictions, for a range of engine cycle parameters and operating conditions relevant for commercial supersonic aircraft.

Project Benefits:

Aircraft and engine companies, and organizations such as NASA, FAA, and DoD R&T community would also benefit from the improved methods and tools. Ultimately, supersonic jet noise tools with predictive capabilities can be used to design better noise mitigation systems and to provide estimates of noise for certification studies.

Research Approach:

- In consultation with Project 59 and other project partners in ASCENT define the plans for high-fidelity simulations and jet noise modeling.
- Develop and validate high-fidelity jet noise predictions for baseline configurations
- Develop and validate RANS-based jet noise predictions for baseline configurations
- Develop and validate high-fidelity jet noise predictions for configurations with noise mitigation concepts
- Develop and validate RANS jet noise predictions for configurations with noise mitigation concepts

Major Accomplishments (to date):

Preliminary LES of primary nozzle and primary+secondary buried nozzle (GaTech geometry)

Development and validation of far-field noise propagation model (Adjoint-Green’s function)

Future Work / Schedule:

Noise prediction for selected cases from GaTech baseline experiments using LES (Year 2)

Development and validation of RANS based approach

Noise source model improvements (Year 3)

Noise predictions for noise mitigation concepts (Year 3)

ASCENT Project 61

Noise Certification Streamlining

Georgia Institute of Technology

PI: Dimitri Mavris, Jimmy Tai, Michael Balchanos

PM: Sandy Liu

Cost Share Partners: Boeing, Bell, Gulfstream, Rolls-Royce

Industry Partners: Boeing, Bell, Gulfstream, Rolls-Royce Embraer, Cessna/Textron, De Havilland Canada

Objective:

Examine current noise certification procedures and identify opportunities to streamline the noise certification process in addition to recommending methodologies for building the needed flexibility to accommodate all air vehicle types

Project Benefits:

Recommendations towards a more efficient, streamlined, and flexible aircraft noise certification:

- Proposition of equivalent procedures, supported by latest technologies and hardware
- Evaluation of alternative practices through a Model-Based Systems Engineering (MBSE) model of the noise certification process (in SySML)
- Analysis techniques to support certification of future air vehicles types

Research Approach (Year 1 Tasks)

Task 1: Interview Industrial Partners on Current Noise Certification Process
- Task 1.1: FAA Noise Certification Regulation Review
- Task 1.2: Industrial Partner Interviews via Workshops

Task 2: Develop a Streamlined Noise Certification Procedure for Existing Aircraft
- Task 2.1: Current Process Assessment
- Task 2.2: Streamlined Process Definition

Task 3: Develop a Flexible Noise Certification Procedure for New Aircraft
- Task 3.1: Flexibility Assessment of Streamlined Process

Task 4: Simulate Streamlined and Flexible Noise Certification Procedure
- Task 4.1: Identify Modeling Approach
- Task 4.2: Noise Certification Process Metric Definition

Major Accomplishments (to date):

- Completed documentation of current noise certification regulatory framework (14 CFR Part 36 , AC 36-4D)
- Hosted workshops/interviews with Industry Partners for transport category aircraft (jet & turboprop)
- Benchmarking of current practices in certification flight testing and identification of improvement opportunities
- Baseline certification process model in SySML

Future Work / Schedule (Year 1 Tasks):

- Planned workshop/interview for rotorcraft and small propeller-driven vehicle categories
- Improvements on the SySML certification process model
- Exploration of lateral microphone equipment options, conformity, NAC substantiation methods, and > 0.1 db certification by analysis

- New Entrants and Noise Certification - Don
- **Aircraft Noise Impact Research - Sean**

Aircraft Noise Impact Research Efforts

Effects of Aircraft Noise on Individuals and Communities

- Speech Interference and Children's Learning
- Neighborhood Environmental Survey
- **Health and Human Impacts Research**
  - Impacts to Cardiovascular Health
  - Economic Impacts
  - **Sleep Disturbance**

Effects of Aircraft Noise on Individuals and Communities

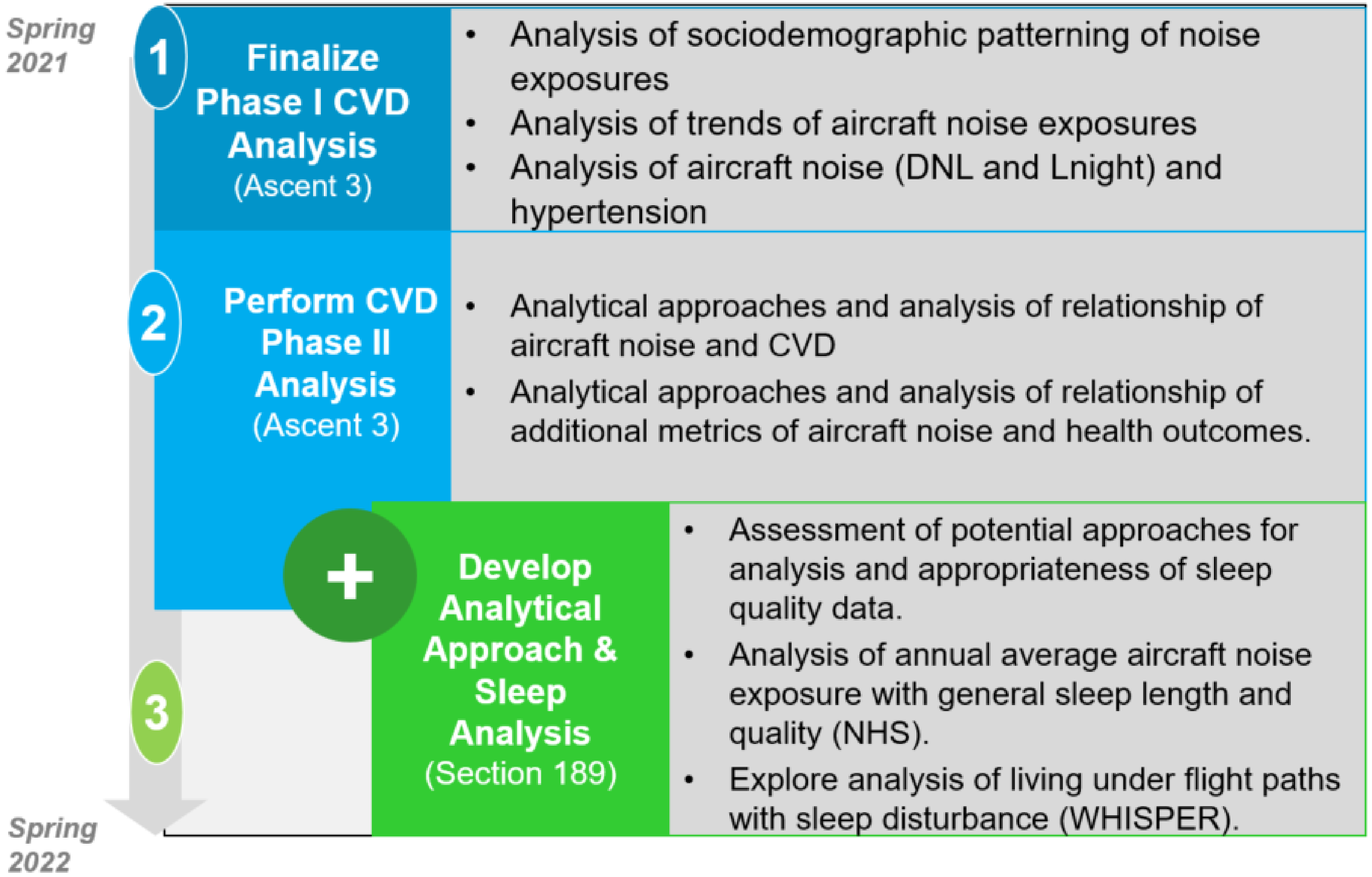
- Aviation Environmental Design Tool
- Noise Screening
- Environmental Data Visualization
- Supplemental Noise Metrics

Reduction, Abatement, and Mitigation of Aviation Noise

- Aircraft Source Noise Reduction
- Noise Abatement
- Noise Mitigation Research

See backup slides for additional information on health and human impacts research

Cardiovascular Disease & Aircraft Noise



ASCENT 3 Boston University

Objective: Evaluate associations between aircraft noise and cardiovascular outcome

Methods: Use existing health cohorts to evaluate link between health outcomes and noise exposure while accounting for wide range of factors

National longitudinal health cohorts:

- Medicare database
- Women's Health Initiative
- Nurses' Health Study /Health Professional Follow-up Study

Team: Research being conducted by Boston University

Aircraft Noise Exposure – Impacts of Noise on Businesses

Objective: To conduct an empirical assessment of the economic impacts of aircraft noise on businesses located underneath flight paths at selected U.S. airports, including the trade-off between impacts on businesses

Methods: Consider changes in noise for airport communities that were previously relatively quite, then conduct economic assessments for each community

- Will also look cross-comparisons between communities and between different economic sectors

Status: Data acquisition and identification of business locations and geospatial analysis for economic changes during the 2010s for eight major U.S. airports

- FAA is now working with the research team to review preliminary results

Team: Research being conducted by Massachusetts Institute of Technology

Reauthorization Connection: HR 302 § 189 – Study on Potential Health and Economic Impacts of Overflight Noise

National Sleep Study (NSS) Overview

Objective: To generate a dose-response relationships between aircraft noise exposure and sleep disturbance

Research Plan: Develop and use a scientifically sound, yet inexpensive, study methodology to obtain objective measures of sleep disturbance

Timeline:

Pilot Studies:

- 2016 - 1st airport: establish feasibility of unattended acquisition of acoustic and physiological field data, unattended sleep measurements
- 2017 - 2nd airport: determine field study recruitment methodology that maximizes response rate and minimizes cost; no staff; all equipment is mailed

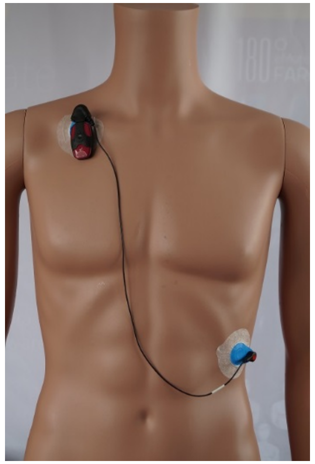
National Sleep Study:

- 2021 - National field study sampling around 77 U.S. Airports: acquire current objective sleep disturbance data relative to varying degrees of exposure at many airports; 2-year data collection effort

Research team led by University of Pennsylvania School of Medicine through ASCENT Project 17 and the FAA Technical Center

Study Methodology and Approach

- Field studies are needed to acquire current US data on sleep disturbance relative to varying degrees of aircraft noise exposure
- An inexpensive methodology of using actigraphy and electrocardiography (ECG) has previously been found to provide a sensitive measure of awakenings



- Equipment is mailed to participant's homes
- An instruction manual and videos are provided on how to use the equipment
- Physiological Monitoring: 2 cable (1 channel) ECG (1 kHz) and body movements (10 Hz)
- Sound recording equipment: Portable audio recorder with class 1 microphone
- Total equipment cost for 1 setup ~$1500
- Participants take part for 5 consecutive nights (M-F)
- Staff will be available 24/7by cell-phone to answer questions

Slide From ASCENT University of Pennsylvania

NSS Noise Exposure Analysis and Noise Metrics

- Participants will be selected from around 77 U.S. airport communities based on expected night time (10pm-7am) noise exposure
- 400 eligible subjects will be chosen from areas exposed to aircraft L_{night} noise levels between 40dB and 55+ dB in 5dB strata
- A dose-response curve for percent awakenings will then be based on L_{Amax} noise levels recorded from measurements taken in the participates home

NSS Current Status and Next Steps

- The Study design has been reviewed by the University of Pennsylvania and Westat Institutional Review Boards as well as the DOT Bureau of Transportation Statistics

- The Executive Office of Information and Regulatory Affairs under the Office of Management and Budget has reviewed and provided collection authority approval under the requirements of the Paperwork Reduction Act

- The study team began issuing the first recruitment letters via mail in early September 2021
- Once recruitment targets are met, field measurements will begin and be ongoing for 50 weeks per year with four set of subjects per week recoding measurements
- Measurements for a total target of 400 subjects over the course of two years will be administered
- The expected study completion date is currently September 2024

NSS Covid-19 Considerations

Actual air traffic volumes will be checked after year 1 of data acquisition and compared to 2018 traffic data used to inform sampling:

- Up to 30% reduction → **no action necessary**
- 30%-40% reduction → **increase sample size to 450**
- 40%-50% reduction → **increase sample size to 500**
- >50% reduction → **consider suspending study**

Traffic Scenario	Sample Size			
	400	450	500	550
100% traffic	0.0143	0.0134	0.0129	0.0120
20% reduced traffic	0.0144	0.0139	0.0129	0.0130
30% reduced traffic	0.0148	0.0143	0.0142	0.0128
40% reduced traffic	0.0154	0.0150	0.0140	0.0138
50% reduced traffic	0.0162	0.0153	0.0144	0.0142
60% reduced traffic	0.0166	0.0158	0.0156	0.0151
70% reduced traffic	0.0187	0.0166	0.0164	0.0152
80% reduced traffic	0.0205	0.0186	0.0181	0.0172

Table entries show half-width of 95% confidence interval of the exposure –response function at $L_{AS, max}$ 50 dB (a priori set goal was <0.015).

Questions?