Acoustics Technical Working Group and UAM Noise Working Group Proceedings

Oct 18-20, 2022

NASA Glenn Research Center

Cleveland, OH

Acoustics Technical Working Group Agenda

NASA Glenn Research Center
October 18 & 19, 2022
Agenda as of 10-13-2022

	Tuesday		
Time	*Title*	*Speaker*	*Organization*
9:00AM	Welcome	Jordan Cluts	NASA
9:10AM	Overview of Aeronautics Research at NASA Glenn Research Center	Chris Williams	NASA
9:55AM	AATT Overview	Cliff Brown	NASA
10:25AM	ADP Fan Commissioning test in 9x15 Wind Tunnel	David Stephens	NASA
10:45AM	Break		
11:00AM	Progress towards a high-accuracy 4D prediction tool	Ray Hixon	NASA
11:25AM	Progress toward a New System Noise Liner Prediction Method	Jason June	NASA
11:45AM	Airframe Noise Prediction for the TTBW Aircraft via High-Fidelity Simulations	Mehdi Khorrami	NASA
12:15PM	Lunch		
2:15PM	Welcome Back		
2:20PM	CST Overview	James Bridges	NASA
2:45PM	Recent progress in community survey plans for NASA's Quesst mission	Aaron Vaugn	NASA
3:05PM	LearJet Test Update	Brenda Henderson	NASA
3:25PM	Weather Observation Methods Using UAS in Support of Acoustic Testing	Jacob Revesz	NASA
3:45PM	Break		
4:00PM	Towards a new Commercial Supersonic Fan Noise Model	Patrick Brandt	The Ohio State Univ.
4:20PM	Toward Development of an Improved Perforate Impedance Model	Mike Jones	NASA
4:40PM	Advanced Liner Testing with the Advanced Noise Control Fan (ANCF) Facility	Scott Morris	Notre Dame
5:00PM	Thanks and End of Day Information		
5:05PM	Day Concludes		

	Wednesday		
Time	*Title*	*Speaker*	*Organization*
9:00AM	Welcome	Jordan Cluts	NASA
9:05AM	Rocket Noise Models for USDOD	Alan Wall	Air Force Research Lab.
9:50AM	RVLT Project Overview	Benny Lunsford	NASA
10:05AM	Moog Surefly Hover Test Update	Brenda Henderson	NASA
10:20AM	Break		
10:35AM	PVTaudio: online psychoacoustic testing iOS app for evaluating AAM/UAM noise response.	Durand Begault	NASA
10:55AM	Initial Results from a Psychoacoustic Test for UAM Sound Quality	Andrew Christian	NASA
11:30AM	Tonality Perception Modeling Lessons Learned	Charles Oppenheimer	Oppenheimer Consulting
12:00PM	Lunch		
2:00PM	Welcome Back		
2:05PM	Status of UAM Proprotor Design Validation Campaign: Available Data and Computational Tools	Leonard Lopes	NASA
2:25PM	Improved sUAS Broadband Noise Calculations using Enhanced Very Large Eddy Simulation Paradigm	Chris Thurman	NASA
2:45PM	Evaluation of Aerodynamic Tools for Predicting UAM Vehicle Acoustcs: Best Practices to Date	Lauren Weist	NASA
3:05PM	Break		
3:20PM	Overview of Boeing and Wisk Concept of Operations for Urban Air Mobility	Stefan Hunkler	Boeing
3:50PM	Reduced-Order Acoustic Prediction Tool for Ducted Fan Noise Sources	Ricardo Burdisso	AVEC
4:10PM	Testing System to Enable Development of Active Noise Cancelation on Open Rotor Propulsion	Kevin Nelson	GLSV
4:30PM	Progress in eVTOL Rotor Noise Prediction	Charles Tinney	Univ. Texas
5:00PM	Thanks and End of Day Information		
5:05PM	Day Concludes		

All times are EDT (UTC -4)

Tuesday Morning

National Aeronautics and Space Administration

NASA Aeronautics Research

Chris Williams
(Acting) Deputy Director Aeronautics NASA Glenn Research Center
October 18, 2022

www.nasa.gov

Why is "Aeronautics" the First "A" in NASA?

The nation's early aeronautics research led to creation of NASA.

7,500 NACA employees
$300 million in NACA research facilities
(Langley, Lewis Field, Ames)
NACA research process

National Advisory Committee for Aeronautics
March 3, 1915

National Aeronautics and Space Administration
October 1, 1958

Aviation is Vital to our Nation’s Economy

Pre-COVID

- $78 billion positive trade balance; the largest positive trade balance of any U.S. manufacturing sector
- $1.8 trillion total U.S. economic activity
- 10.9 million direct/indirect jobs
- 21.3 billion tons of freight transported by U.S. airlines in 2019

Global growth in aviation

Opportunities and Challenges

2017

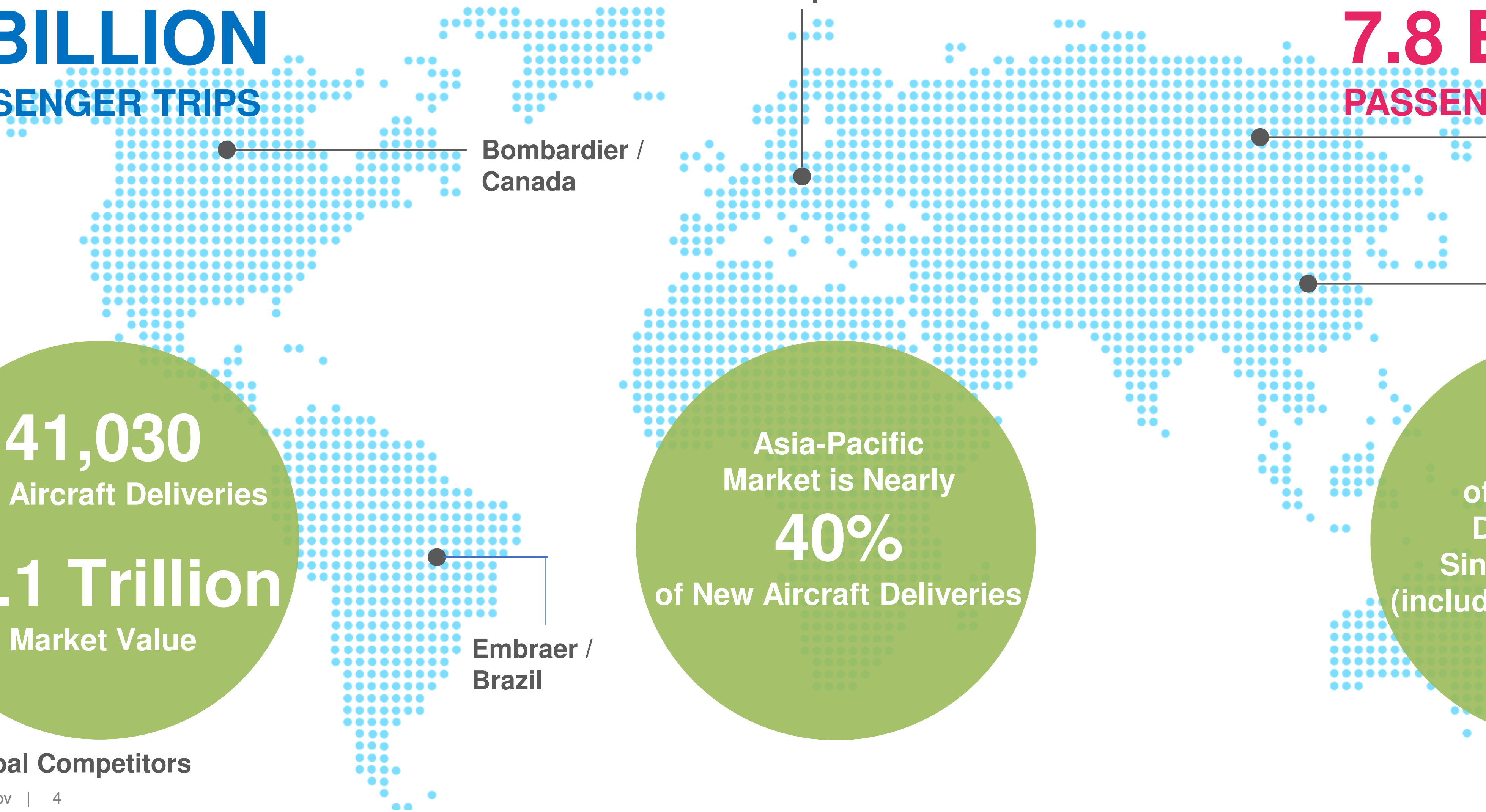
4 BILLION

PASSENGER TRIPS

2036

7.8 BILLION

PASSENGER TRIPS



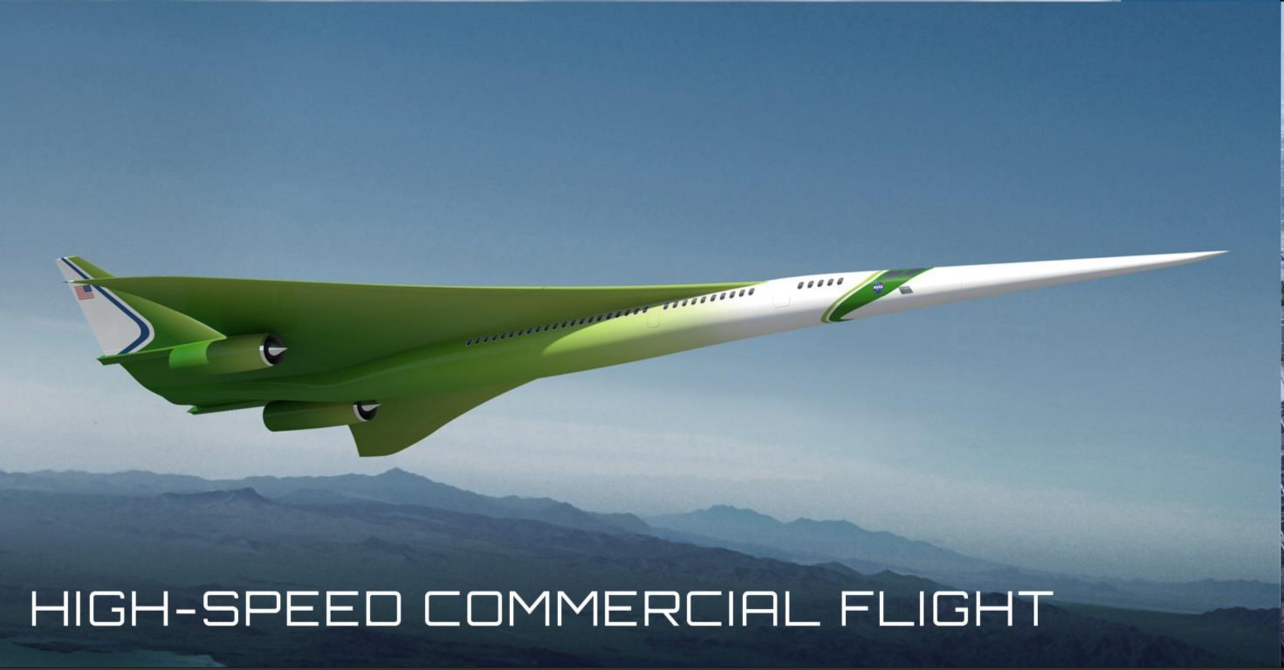
41,030
New Aircraft Deliveries

$6.1 Trillion
Market Value

Asia-Pacific
Market is Nearly
40%
of New Aircraft Deliveries

78%
of New Aircraft
Deliveries are
Single Aisle Class
(including Regional Jets)

● Global Competitors



Four Transformations for Sustainability, Greater Mobility, and Economic Growth

NASA Aeronautics – Vision for Aviation in the 21st Century

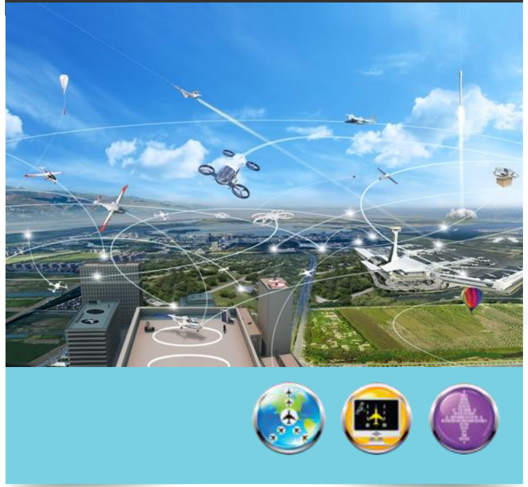
ARMD continues to evolve and execute the Aeronautics Strategy
https://www.nasa.gov/aeroresearch/strategy

6 Strategic Thrusts

- Safe, Efficient Growth in Global Operations
- Safe, Quiet, and Affordable Vertical Lift Air Vehicles
- Innovation in Commercial Supersonic Aircraft
- In-Time System-Wide Safety Assurance
- Ultra-Efficient Subsonic Transports
- Assured Autonomy for Aviation Transformation

U.S. leadership for a new era of flight

Airspace Operations and Safety Program



Advanced Air Vehicles Program

Integrated Aviation Systems Program

Transformative Aeronautics Concepts Program

Aerosciences Evaluation and Test Capabilities Portfolio

ARMD PROGRAMS

ARMD Research Programs Align with ARMD Strategy

MISSION PROGRAMS

AIRSPACE OPERATIONS & SAFETY

AOSP

PROJECTS

Advanced Air Mobility

Air Traffic Management–Exploration

System-Wide Safety

ADVANCED AIR VEHICLES

AAVP

PROJECTS

Advanced Air Transport Technology

Hybrid Thermally Efficient Core

Commercial Supersonic Technologies

Revolutionary Vertical Lift

High-Rate Composite Aircraft Manufacturing

Hypersonic Technology

INTEGRATED AVIATION SYSTEMS

IASP

PROJECTS

Flight Demonstrations and Capabilities

Low Boom Flight Demonstrator

Electrified Powertrain Flight Demonstration

SEEDLING PROGRAM

TRANSFORMATIVE AERONAUTICS CONCEPTS

TACP

PROJECTS

Convergent Aeronautics Solutions

Transformational Tools and Technologies

University Innovation and Challenges

Convergent Innovation and Revolutionary Analysis Tools

PORTFOLIO OFFICE

AEROSCIENCES EVALUATION & TEST CAPABILITIES

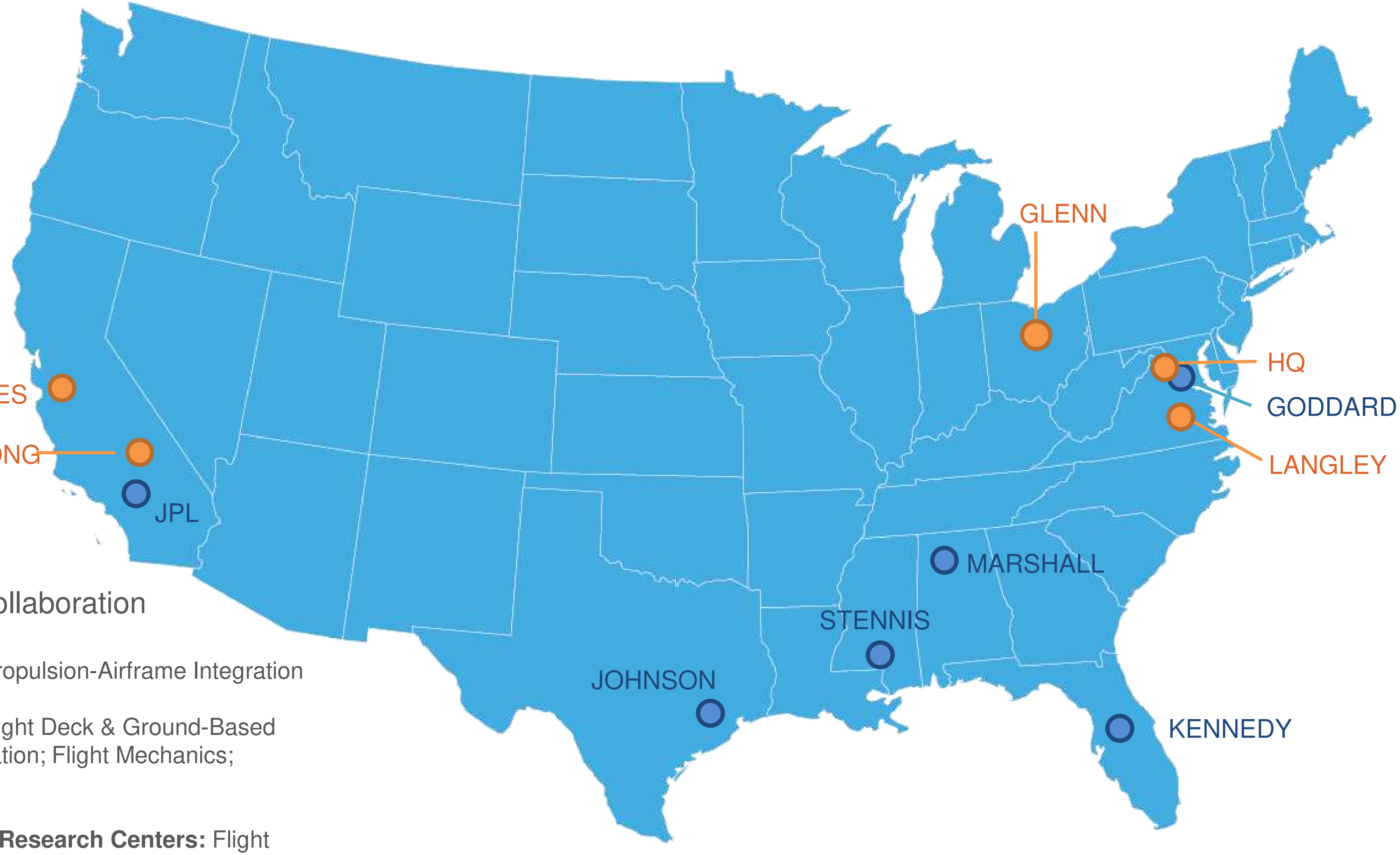
AETC

GROUND FACILITIES

Subsonic	Hypersonic
Transonic	Propulsion
Supersonic	Test Technology

Where does NASA aeronautics research happen?

Aeronautics research takes place at four of NASA’s centers.



Major Areas of Inter-Center Collaboration

Langley/Glenn: Propulsion-Airframe Integration

Ames/Langley: Flight Deck & Ground-Based Automation Integration; Flight Mechanics; Aerodynamics

Armstrong/Other Research Centers: Flight Experiment Integration

AMES

ATM Research and Technology & Integration

ARMSTRONG

Flight Research

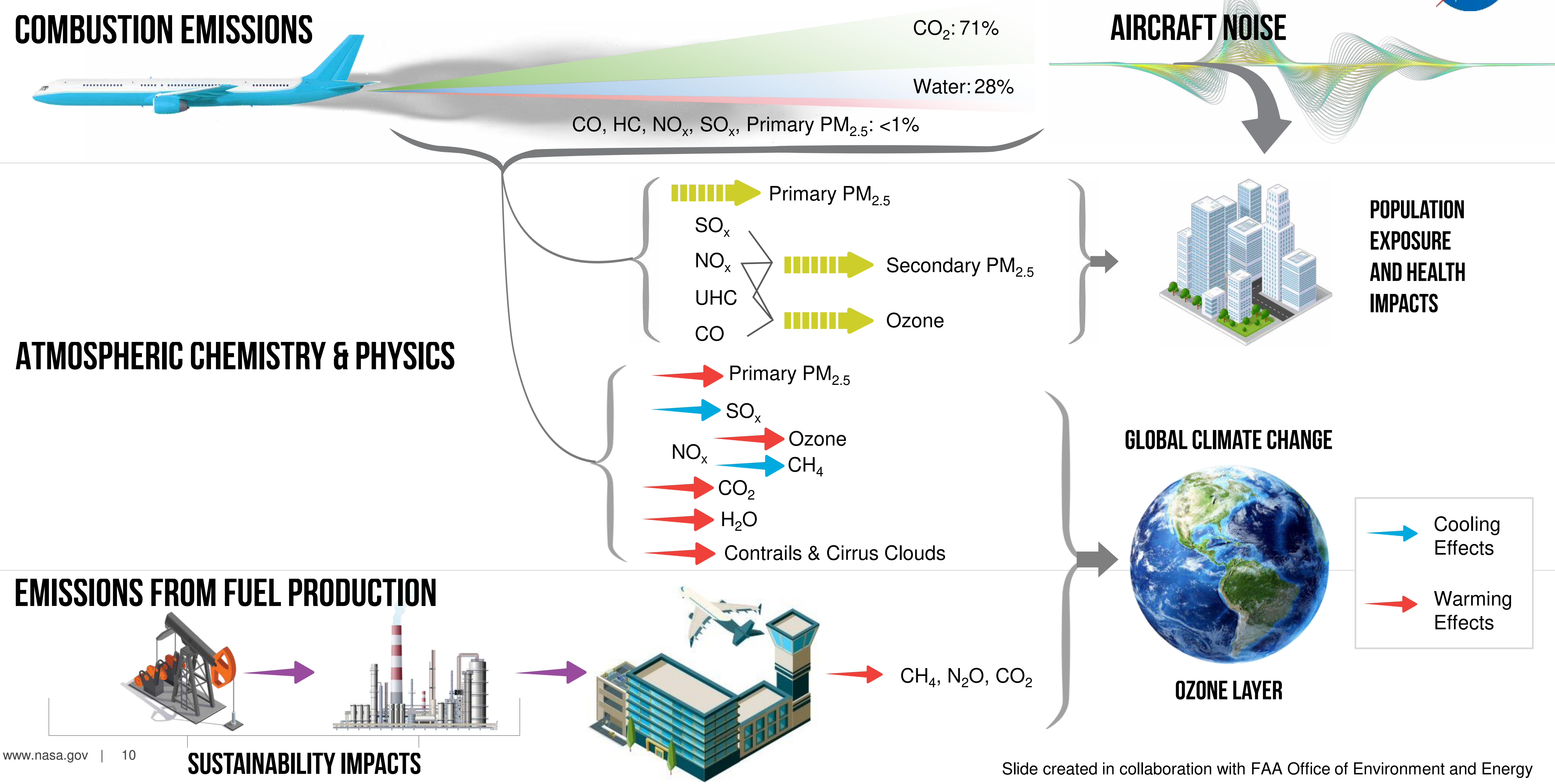
GLENN

Propulsion Research and Technology

LANGLEY

Vehicle Research and Technology

Environmental Impacts of Aviation



Slide created in collaboration with FAA Office of Environment and Energy

The Aviation Carbon Reduction Challenge

- By 2050, an estimated 10 billion passengers will fly each year a distance of 22 trillion revenue passenger kilometres.
- With today's fleet and operational efficiency, this activity would require over 620 megatonnes (Mt) of fuel and generate close to 2000 Mt of CO_2.
- Imagine enabling the same level of demand while reducing net CO_2 emissions to zero by 2050.

Meeting the challenge is the opportunity for the United States to lead the world in innovation and reductions in CO_2 aviation emissions, and to maintain economic competitiveness in a critical export industry ($6 trillion-plus market over the next 20 years).

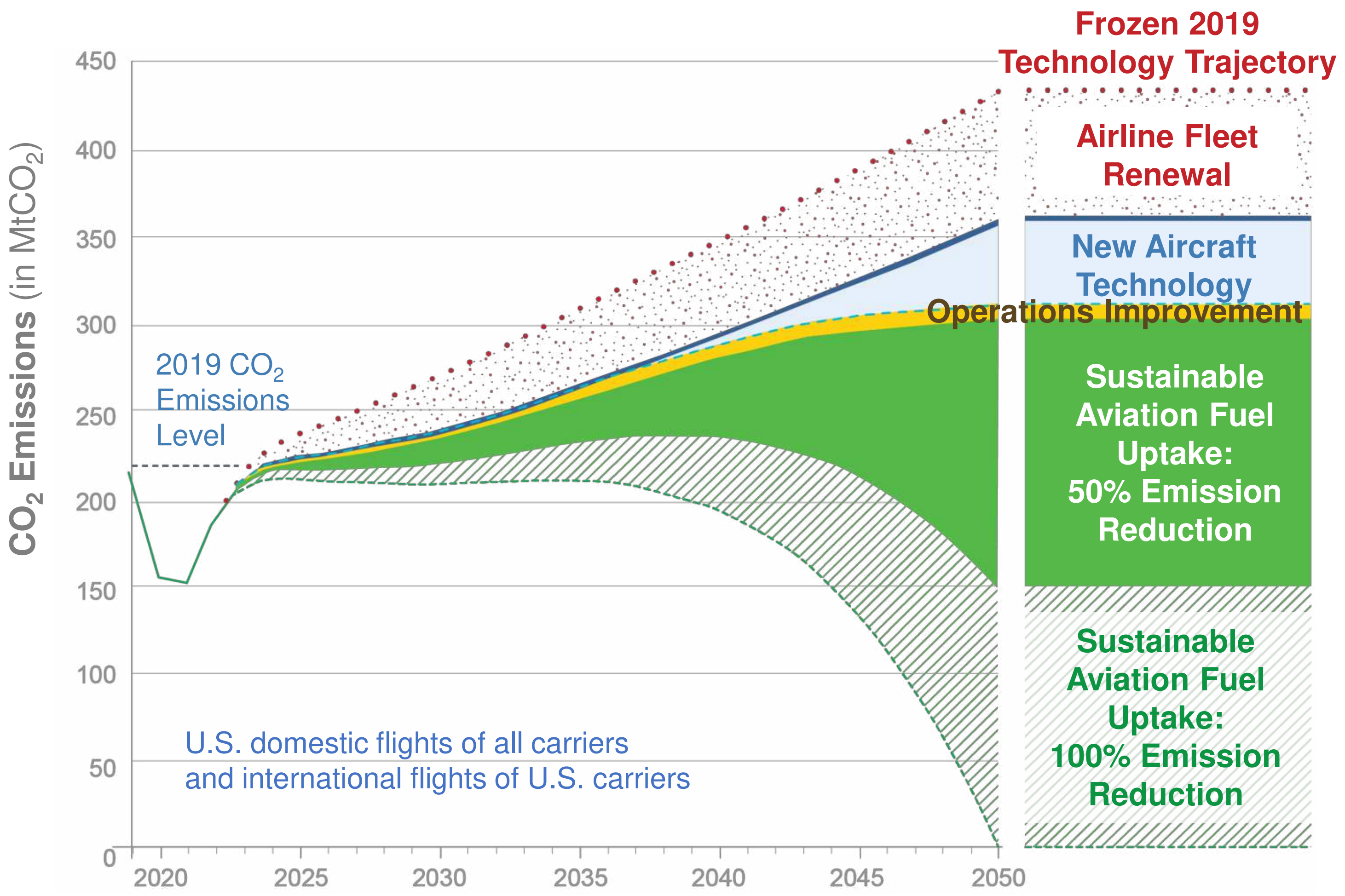
U.S. Aviation Climate Action Plan

Global Context for Sustainable Aviation

U.S. aviation goal is to achieve
net-zero greenhouse gas emissions by 2050.

U.S. Aviation Climate Action Plan is aligned with

- U.S. economy-wide goal
- International Civil Aviation Organization
- Air Transport Action Group

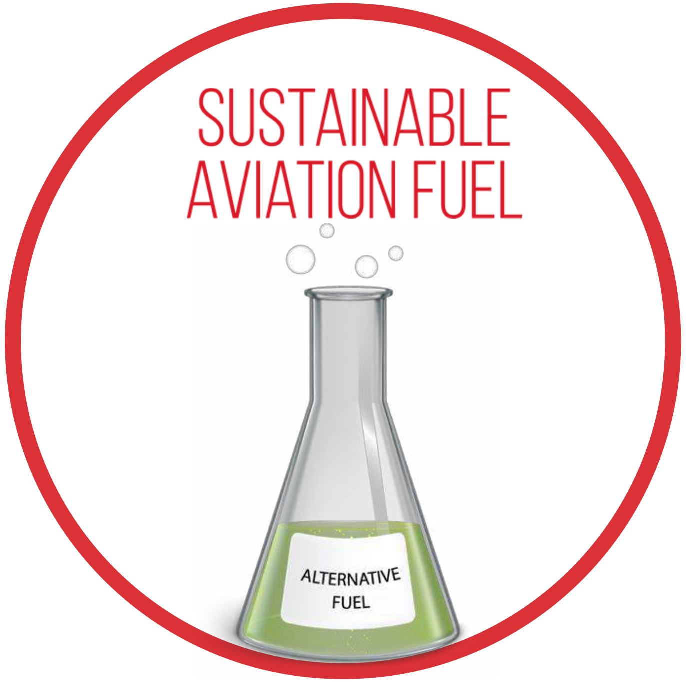


The U.S. is working with the global community to achieve net-zero greenhouse gas emissions by 2050 using a common basket of measures.

Aviation Pillars for a Sustainable Future

Global Aviation Industry GOAL: net-zero carbon emissions by 2050

NASA = Primary Role



NASA = Supporting Role

NASA = Primary Role

Sustainable Flight National Partnership

Partnership Focus

FEDERAL AVIATION ADMINISTRATION

INDUSTRY

ACADEMIA

Through advanced vehicle technologies, efficient airline operations and sustainable aviation fuels, collectively we aim to reduce carbon emissions from aviation to net zero by 2050.

Sustainable Flight National Partnership

Next-Generation Capability on the Path to Net-Zero Greenhouse Gas Emissions by 2050

Advance engine efficiency and emission reduction

Enable integrated trajectory optimization

Advance airframe efficiency and manufacturing rate

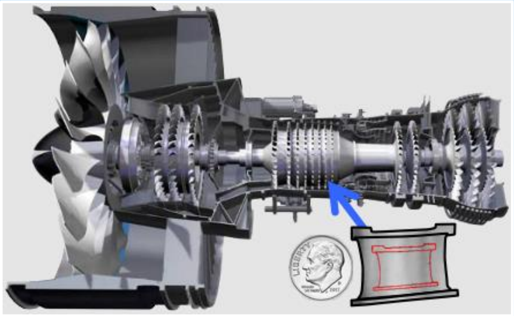
Enable use of 100% sustainable aviation fuels

Achieve net-zero greenhouse emissions by 2050 through 25-30% energy efficiency improvements in next-generation transports, 100% sustainable aviation fuel, and optimal trajectories.

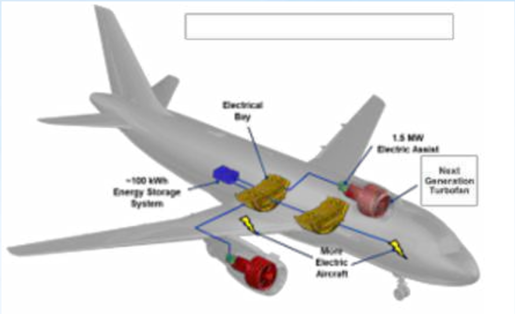
Subsonic Transport Technologies

Ensure U.S. industry is the first to establish the new “S Curve” for the next 50 years of transports

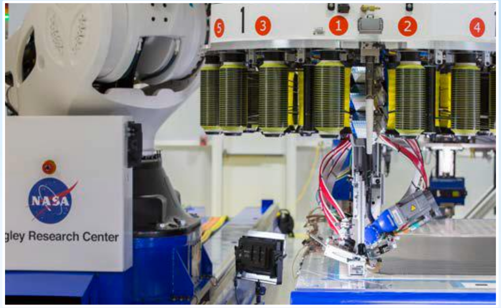
Transonic Truss-Braced Wing
5-10% fuel burn benefit



Small Core Gas Turbine
5-10% fuel burn benefit

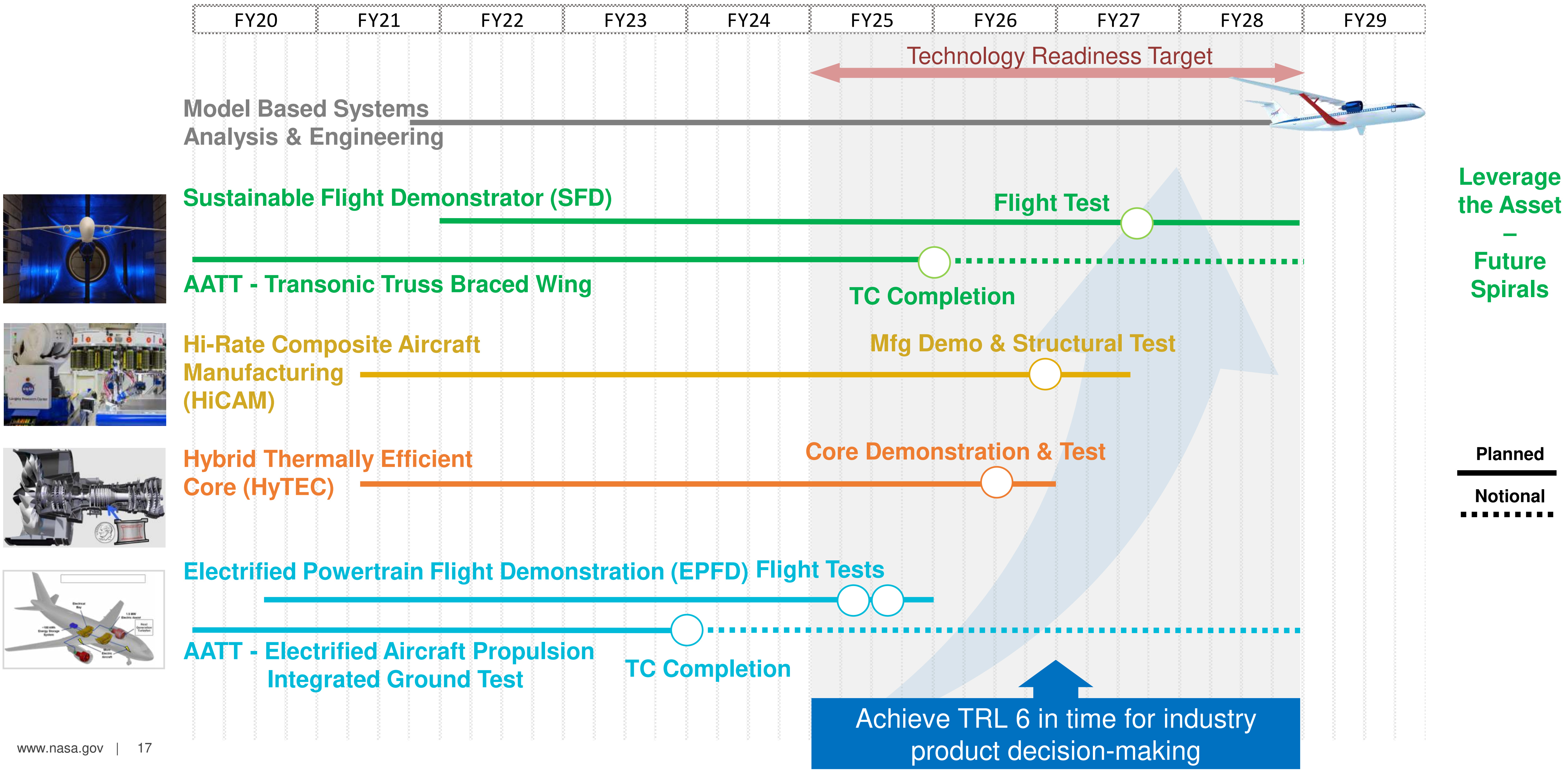


Electrified Aircraft Propulsion
~5% fuel burn and maintenance benefit



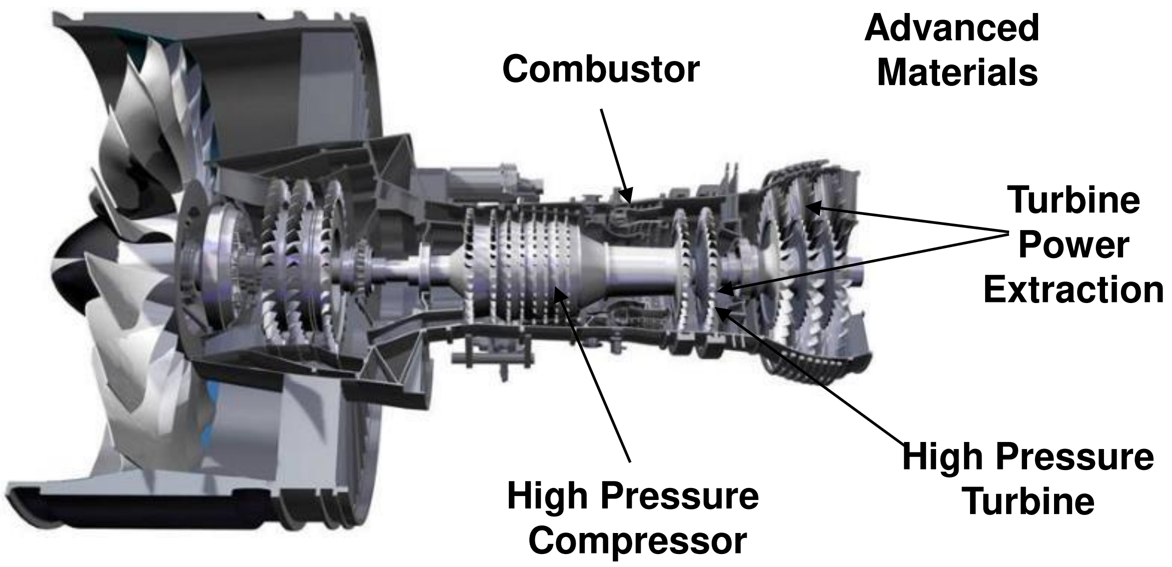
High-Rate Composite Manufacturing
4x-6x manufacturing rate increase

Subsonic Transports: Integrated Technology Development



Hybrid Thermally Efficient Core

Accelerate development and demonstration of advanced turbine engine technologies



HyTEC
Hybrid Thermally Efficient Core

Scope

- Develop and demonstrate in integrated ground tests engine core technologies to Increase thermal efficiency, reduce engine core size and facilitate hybridization

Benefit

- Achieve **5-10% fuel burn reduction** versus 2020 best in class
- Achieve **up to 20% power extraction** (4 times current state of the art) at altitude to optimize propulsion system performance and enable hybridization

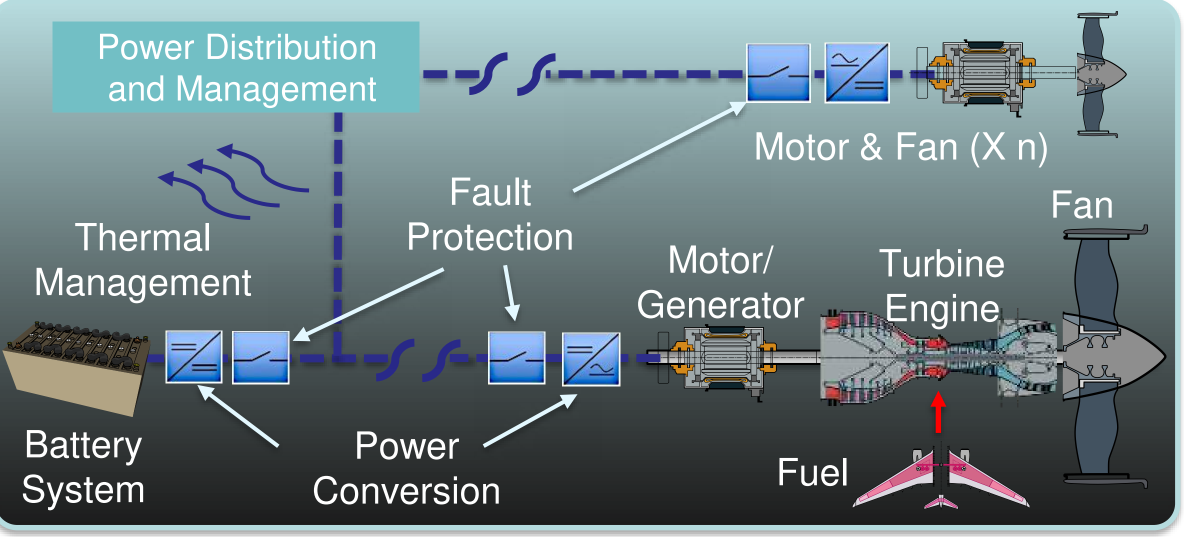
Approach

- Partner with industry to mature and demonstrate promising technologies

Small-core turbofan technology
contract awards were made in September 2021.

Focused Technologies for Electrified Aircraft Propulsion

Retire barrier technical and integration risks for megawatt-class electrified aircraft propulsion systems



Scope

- Address critical challenges for electrified aircraft propulsion by maturing and reducing risk for Electrified Aircraft Propulsion (EAP) technology, focused on:
  - Mass and weight reduction
  - Electrical losses
  - Reliability
  - EMI, power quality, dynamic stability
  - Limits on DC voltage levels
  - System design and integration

Benefit

- Accelerate U.S. industry readiness to transition to EAP-based commercial transport aircraft.
- Reduce key risks for a range of future applications and help enable new standards that are needed for EAP-based aircraft certification

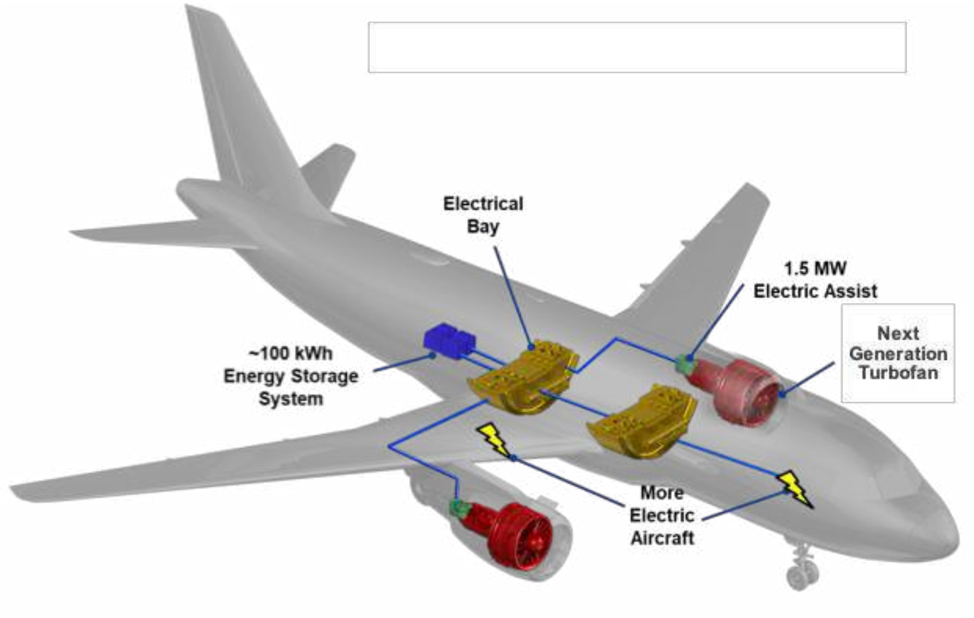
Approach

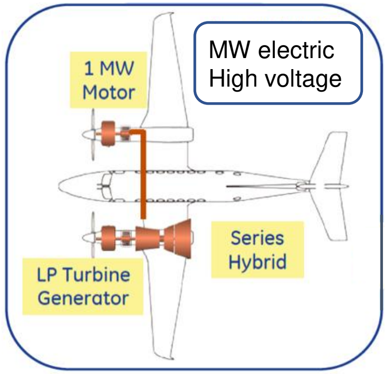
- Conduct technology-focused integrated ground tests
- Partner with industry on testing of electrified propulsion architectures and component technologies
- Leverage prior electric aircraft propulsion advances (TRL ~4)

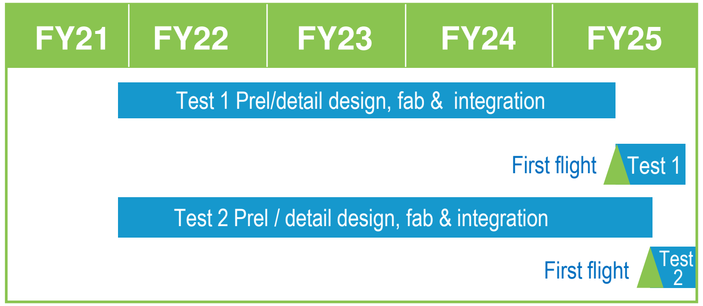
Architecture development and
high-power component tests are underway.

Electrified Powertrain Flight Demonstration

Demonstrate integrated electrified powertrains in flight using industry platforms







Scope

- Demonstrate practical vehicle-level integration of megawatt-class electrified aircraft propulsion systems, leveraging advanced airframe systems to reinvigorate the regional and emerging smaller aircraft markets and strengthen the single aisle aircraft market.
- Assess gaps in regulations/standards to support future Electrified Aircraft Propulsion (EAP) certification requirements.

Benefit

- Accelerate U.S. industry readiness to transition to EAP-based commercial transport aircraft.
- Enable new standards that are needed for EAP-based aircraft certification.

Approach

- Engage with U.S. industry to integrate and demonstrate megawatt-class EAP machines in flight.
- Engage with the FAA, SAE, ASTM, etc. to contribute data that inform EAP standards and regulations.

Two Flight Demonstration Contracts Awarded in September 2021

Planning to Achieve a Sky for All

Imagining tomorrow's aviation system today

Sustainable Solutions　　Seamless Skies

Ubiquitous and Resilient Operations　　Operator Optimization

Learning-Based Systems and Communities

- NASA-led effort to gather inputs from the aerospace community and FAA
- Co-developed vision of a mid-21st century shared airspace that is agile, scalable, optimizable, increasingly diverse, and equitable
- Evolution from trajectory-based operations to collaborative and highly automated operations
- Sky for All results will inform ARMD research and development portfolio and collaboration with FAA

SKY for ALL

A thriving airspace must be scalable, accessible, safe, sustainable, and resilient.

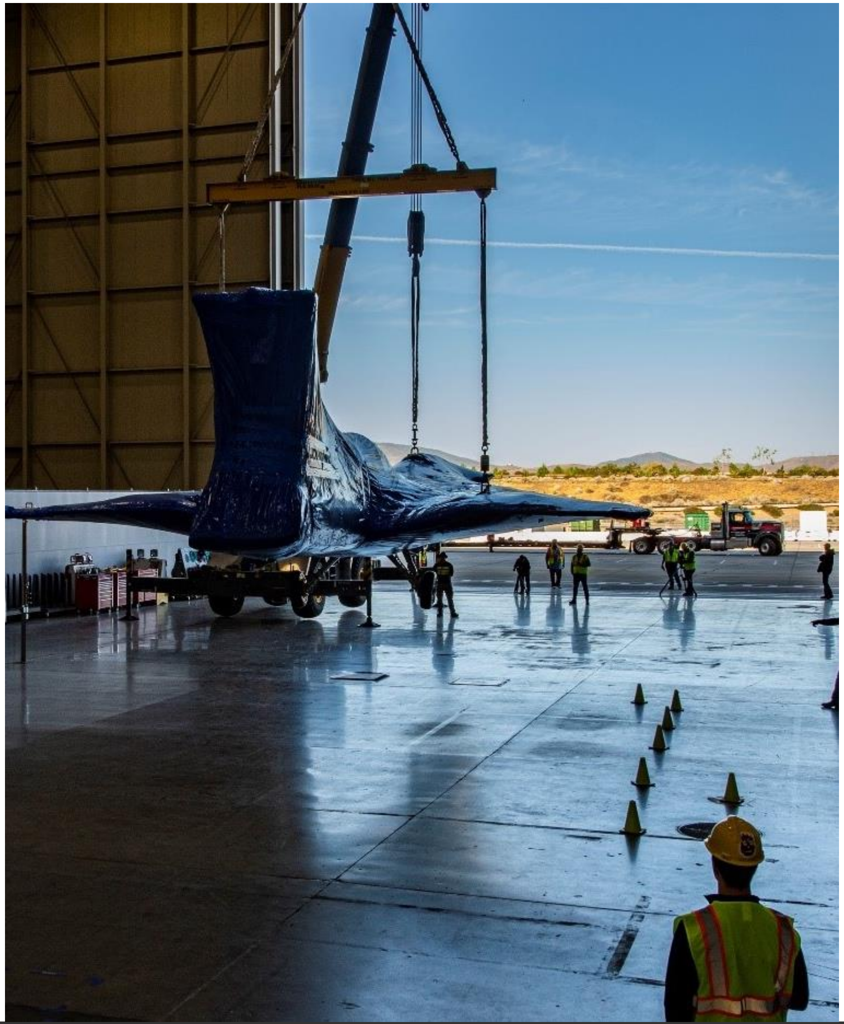
High-Speed Commercial Flight

Sustainable transformation of the speed of air travel

Addressing the unique barriers to sustainable, environmentally responsible high-speed flight

Generate key data to support development of en route certification standards based on acceptable sound levels

X-59 Construction and Testing



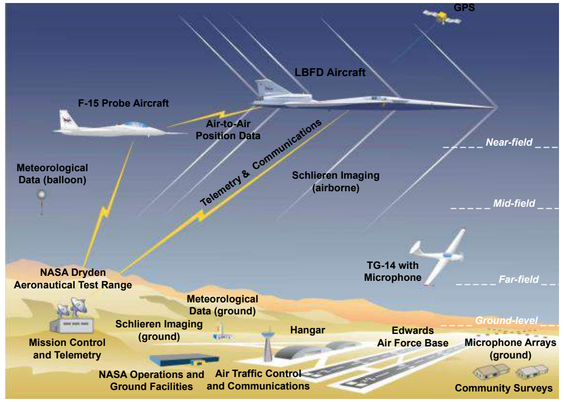
Complete X-59 Build and Achieve First Flight in Late 2022

Quesst Mission Overview

Phase 1 – Aircraft Development

In progress (FY18-23)

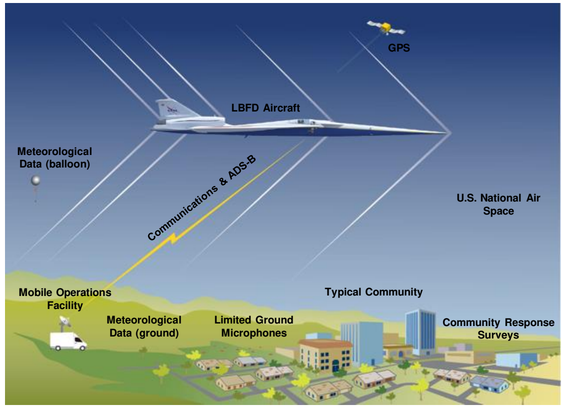
- Design, fabricate a quiet supersonic research aircraft
- Prove performance in test range flights
- Prove safety for flights in normal airspace



Phase 2 – Acoustic Validation

Preparation in progress (FY18-23), Execution FY23-24

- Prove the acoustic characteristics match design targets
- Detailed in-flight and ground measurements in test range



Phase 3 – Community Response Testing

Preparation in progress (FY19-23), Execution FY24-27

- Conduct community tests
  - Select communities
  - Outreach and engagement (including STEM)
  - Obtain necessary approval
  - Plan surveys and recruit participants
  - Collect ground measurements

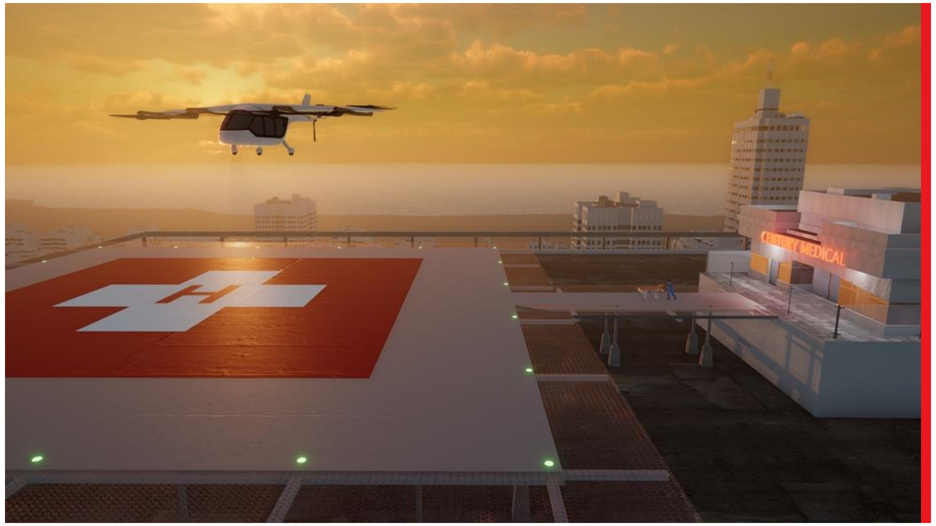
Systematic Approach Leading to Community Testing

Advanced Air Mobility Mission

Safe, sustainable, affordable, and accessible aviation
for transformational local and intraregional missions

Advanced Air Mobility Missions are Emerging

CARGO TRANSPORT



PUBLIC GOOD

CONSUMER/ ENTERPRISE GOODS AND SERVICES

PASSENGER TRANSPORT

Latest studies show an annual estimated advanced air mobility market of $115B by 2035.

NASA's X-57 is Pathfinder for Electric Propulsion

Ground and flight validation of electric motors, battery, and instrumentation

INDUSTRY

ACADEMIA

Enable new configurations

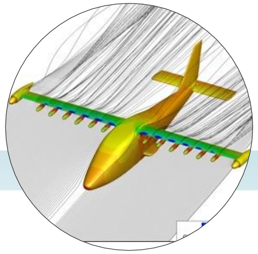
Share technical insights and lessons learned

LEAPTech experiment

Wind-tunnel validation

Motor nacelle design & testing

Structural testing



Computational simulations

Operational checkouts

Inform Small Electric Aircraft Propulsion Standards and Certification

Long-Term Transport Technology and Innovation

Generational studies to inform future technology investments

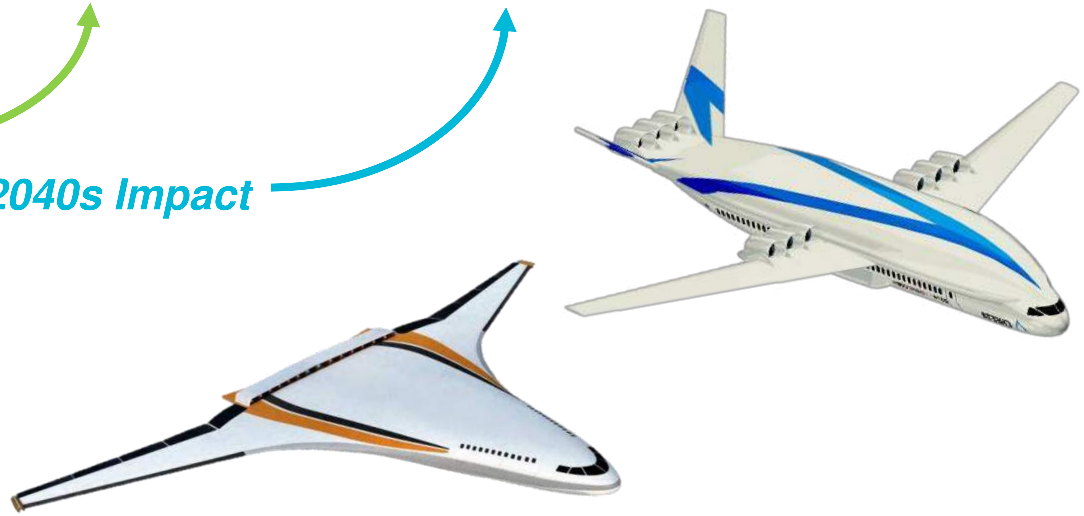
2008-2019 → 2020-2029 → 2030 - 2039 → 2040 - 2050

Subsonic Fixed Wing

N+2 Studies, ERA for the 2020s Impact

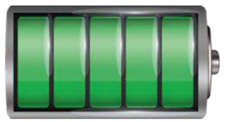
N+3 Advanced Concept Studies SFNP for 2030s Impact

Concept Studies and Technology Development Needed for 2040s Impact



Opportunities to Define Future Aviation Systems and Concepts

- Advanced Concept Studies for 2040+ EIS
- Net-Zero Emissions Concepts
- Promising Technologies and Architectures
- Support Aviation Community with NASA-unique Contributions



Innovations for 2040s and Beyond

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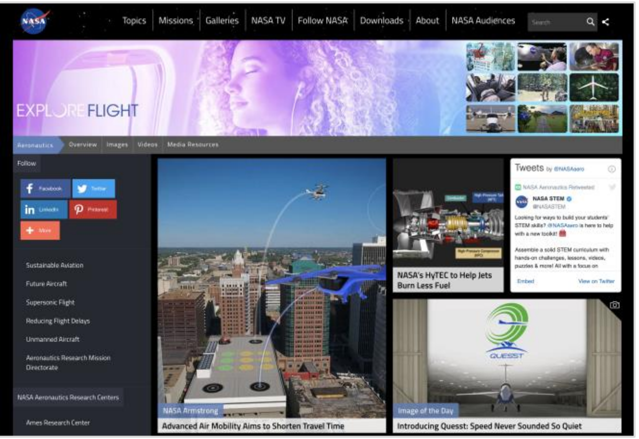
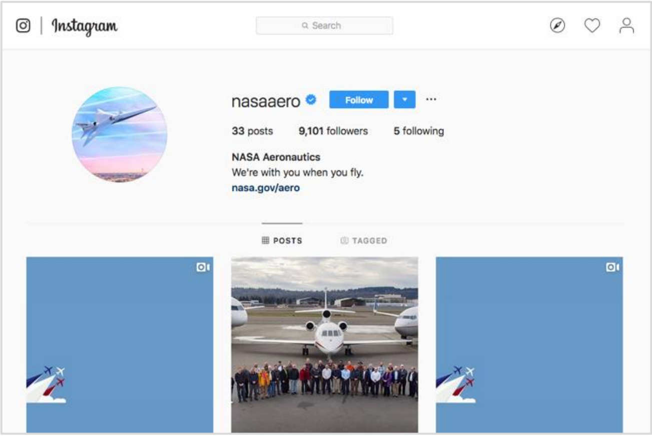




www.nasa.gov/aeroresearch/strategy | www.nasa.gov/aeroresearch/solicitations

Sky for All - Imagine What The Future Holds (nasa.gov)

Thank You!

National Aeronautics and Space Administration

NASA AATT Project Overview

Cliff Brown
Acoustics Technical Working Group
October 18, 2022

* clifford.a.brown@nasa.gov

Current AATT Project Organization (October 2022)

Project Manager	*Dale Van Zante (Acting)*
Deputy Project Manager	*Melinda Cagle*
Chief Technologists	*Scott Anders (Airframe)* *Julia Stephens (Acting,Propulsion)*
Flight Test Advisor	*Randy Thompson*
Business Manager	*Mark Monaco*

Center Integration Managers

Bruce Storms (ARC)	*Sam Simpliciano (AFRC)*
John Mudry (GRC)	*Marisol Garcia (LaRC)*

Center Resource Analysts

Eric Lee (ARC)	*Alejandra Pacheco (AFRC)*
Mark Monaco (GRC)	*vacant (LaRC)*

Project Coordinator	*Keshia Newsome*
Config. and Data Mgr.	*Mike Rogers*
Risk Facilitator	*Stephan Manchir*
Scheduler	*Leslie Letzinger*

Systems Analysis & Integration

Jesse Quinlan, Lead
Eric Hendricks, Co-Lead

Propulsion and Power (P&P) Subproject

Amy Jankovsky, SPM
Jessica Reinert, DSPM

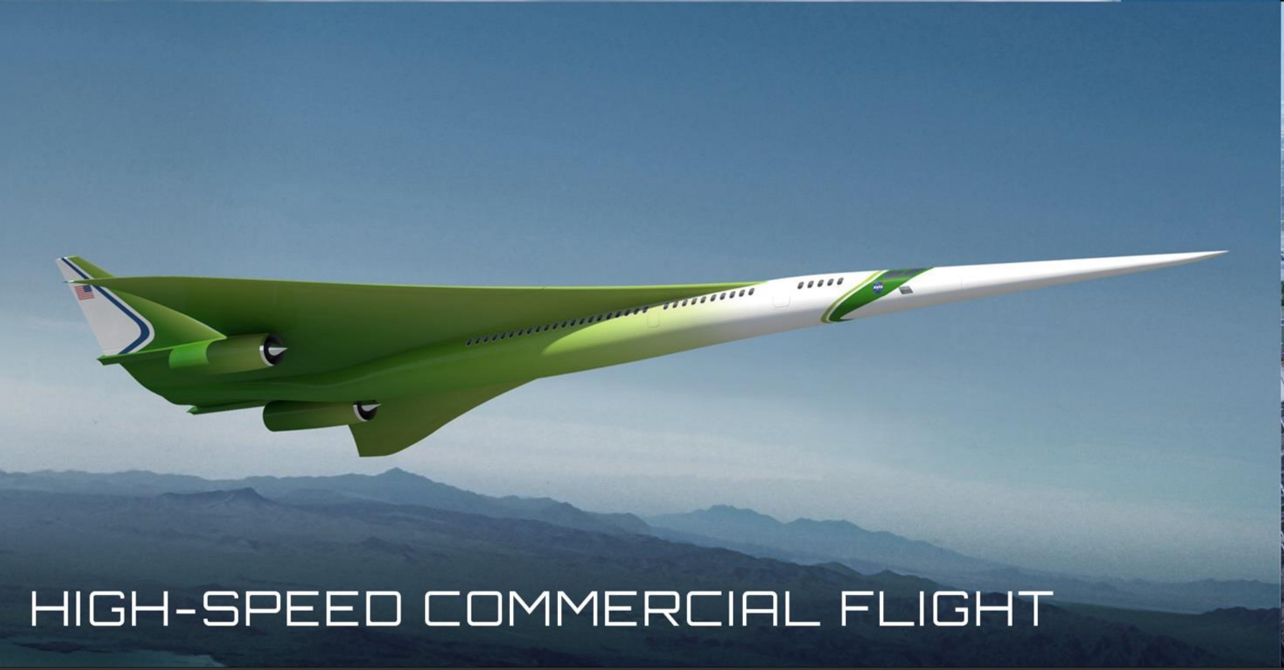
Technical Leads:
Cliff Brown, Rodger Dyson, Jennifer Klettlinger, Peter Struck, Andy Woodworth, Brian Howerton, Ezra McNichols

Vehicle Systems Integration (VSI) Subproject

Susan Wilz, SPM
Jim Moore, DSPM
Marisol Garcia, DSPM

Technical Leads:
Andy Broeren, David Chan, Latunia Melton, William Milholen, Shishir Pandya, Julia Stephens, Karen Taminger, Florence Hutcheson

Names shown in red new since last year



Four Transformations for Sustainability, Greater Mobility, and Economic Growth

NASA GLOBAL CLIMATE CHANGE
Vital Signs of the Planet

FACTS ARTICLES SOLUTIONS EXPLORE NASA SCIENCE MORE

Understanding our planet to benefit humankind

Carbon Dioxide
↑ 419 parts per million (current) +

Global Temperature
↑ 1.01 °C since 1880 +

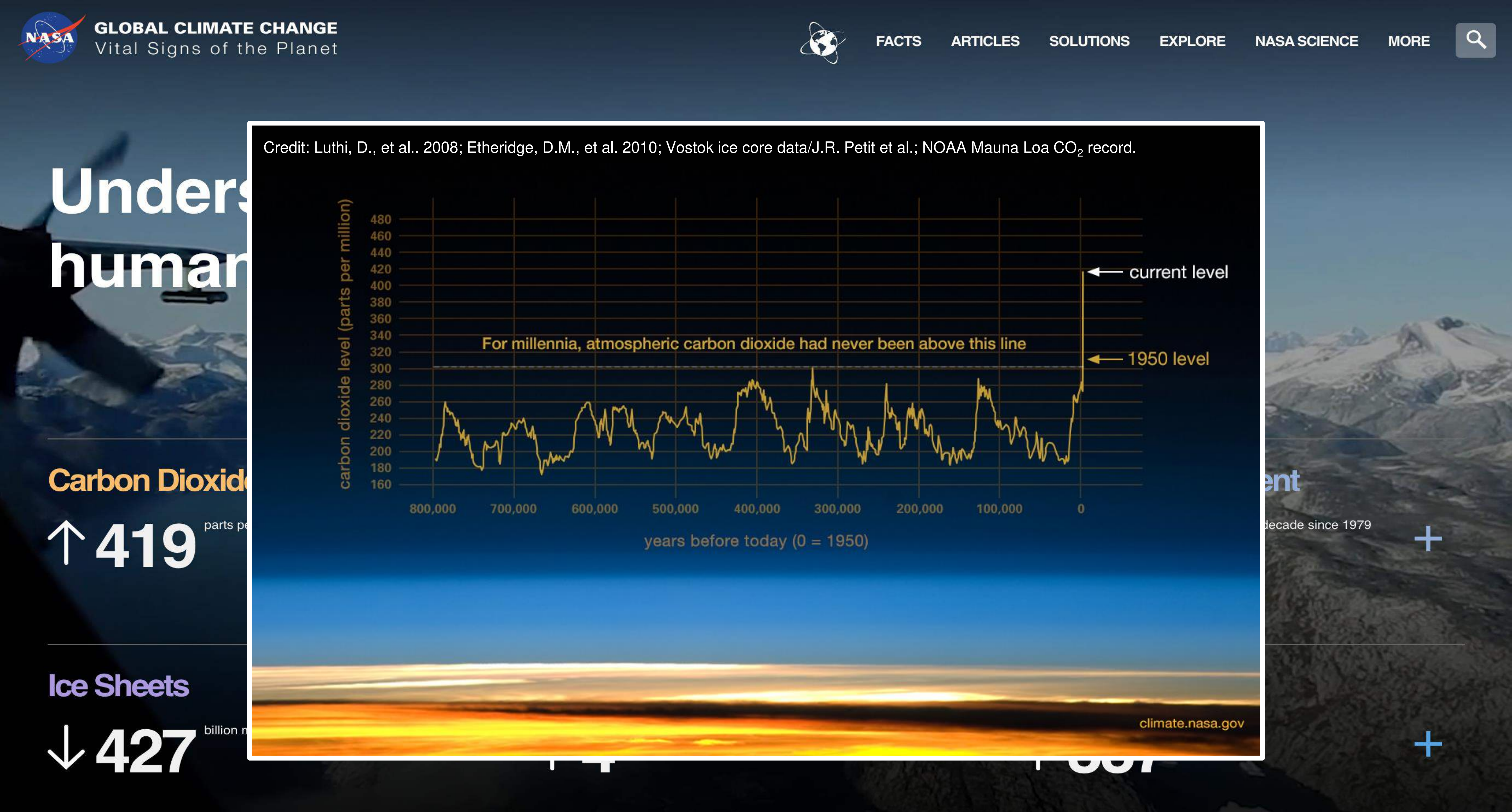
Arctic Sea Ice Extent
↓ 12.6 percent per decade since 1979 +

Ice Sheets
↓ 427 billion metric tons per year +

Sea Level
↑ 4 inches since January 1993 +

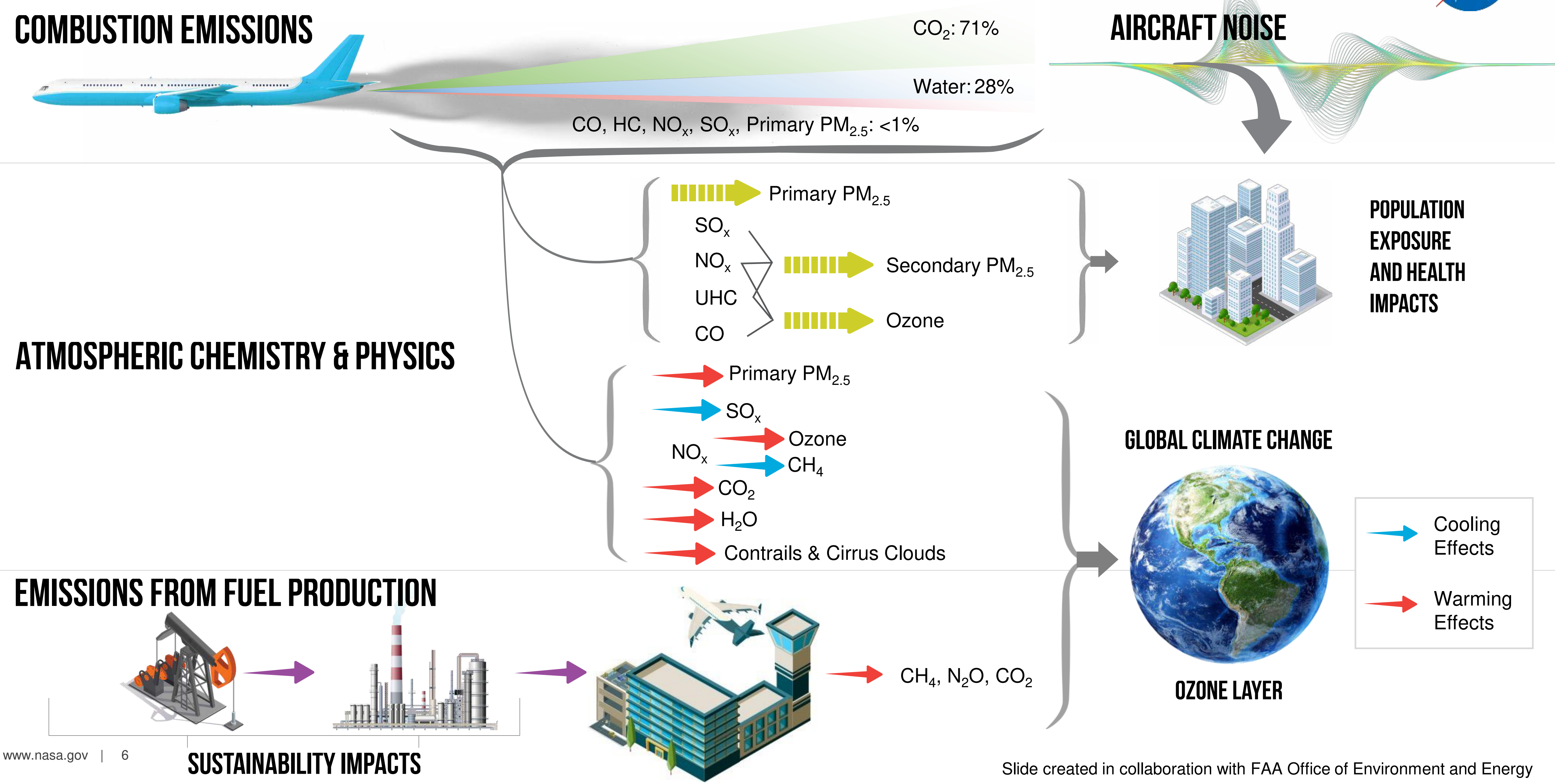
Ocean Warming
↑ 337 zettajoules since 1955 +

Source: climate.nasa.gov on Sept. 24, 2022



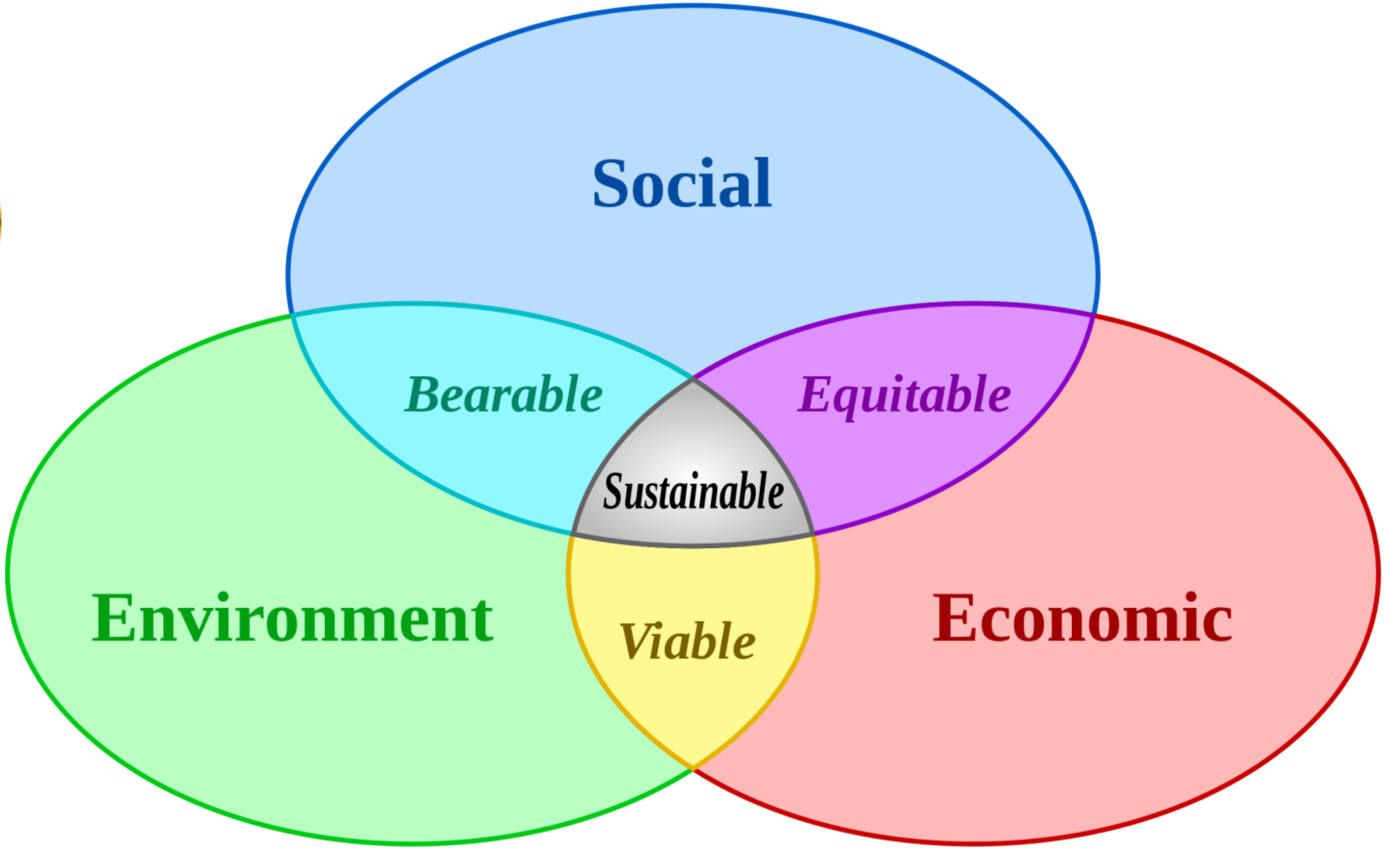
Source: climate.nasa.gov on Sept. 24, 2022

Environmental Impacts of Aviation



Slide created in collaboration with FAA Office of Environment and Energy

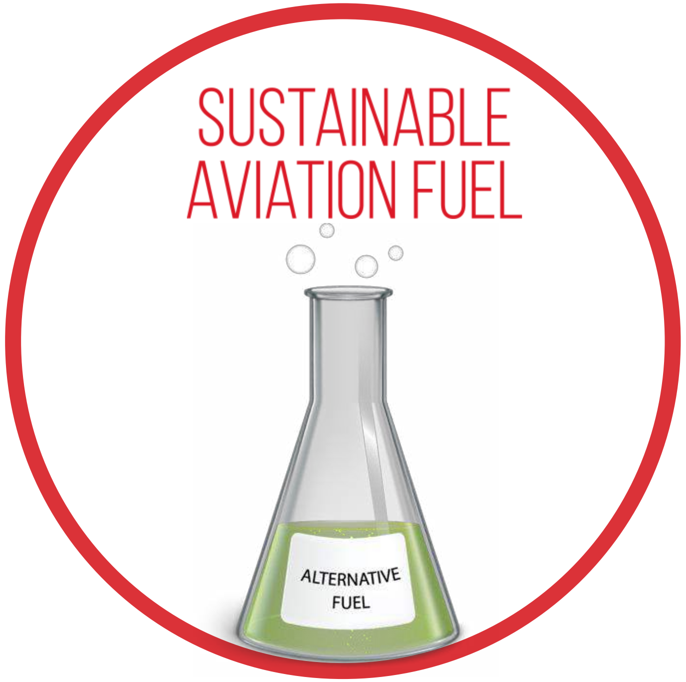
Sustainable Flight National Partnership (SFNP)



Sustainability is more than aircraft emissions;
it is at the intersection between environmental, social, and economic factors.

Aviation Pillars for a Sustainable Future

NASA = Primary Role



NASA = Supporting Role

NASA = Primary Role

Achieve net-zero greenhouse emissions by 2050 through 25-30% energy efficiency improvements in next-generation transports, 100% sustainable aviation fuel, and optimal trajectories

Sustainable Flight National Partnership Benefits

Small Core Gas Turbine for 5%-10% fuel burn benefit
(HyTEC Project)

Electrified Aircraft Propulsion for ~5% fuel burn and maintenance benefit
(EPFD & AATT Projects)

Sustainable Aviation Fuels for reduced lifecycle carbon emissions
(AATT Project)

Transonic Truss-Braced Wing for 5%-10% fuel burn benefit
(AATT Project)

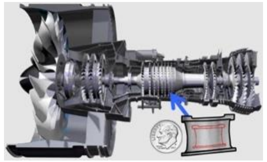
High-Rate Composites for 4-6x manufacturing rate increase
(HiCAM Project)

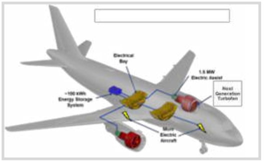
Integrated Trajectory Optimization for 1%-2% reduction in fuel required and minimization of contrail formation
(ATM-X Project)

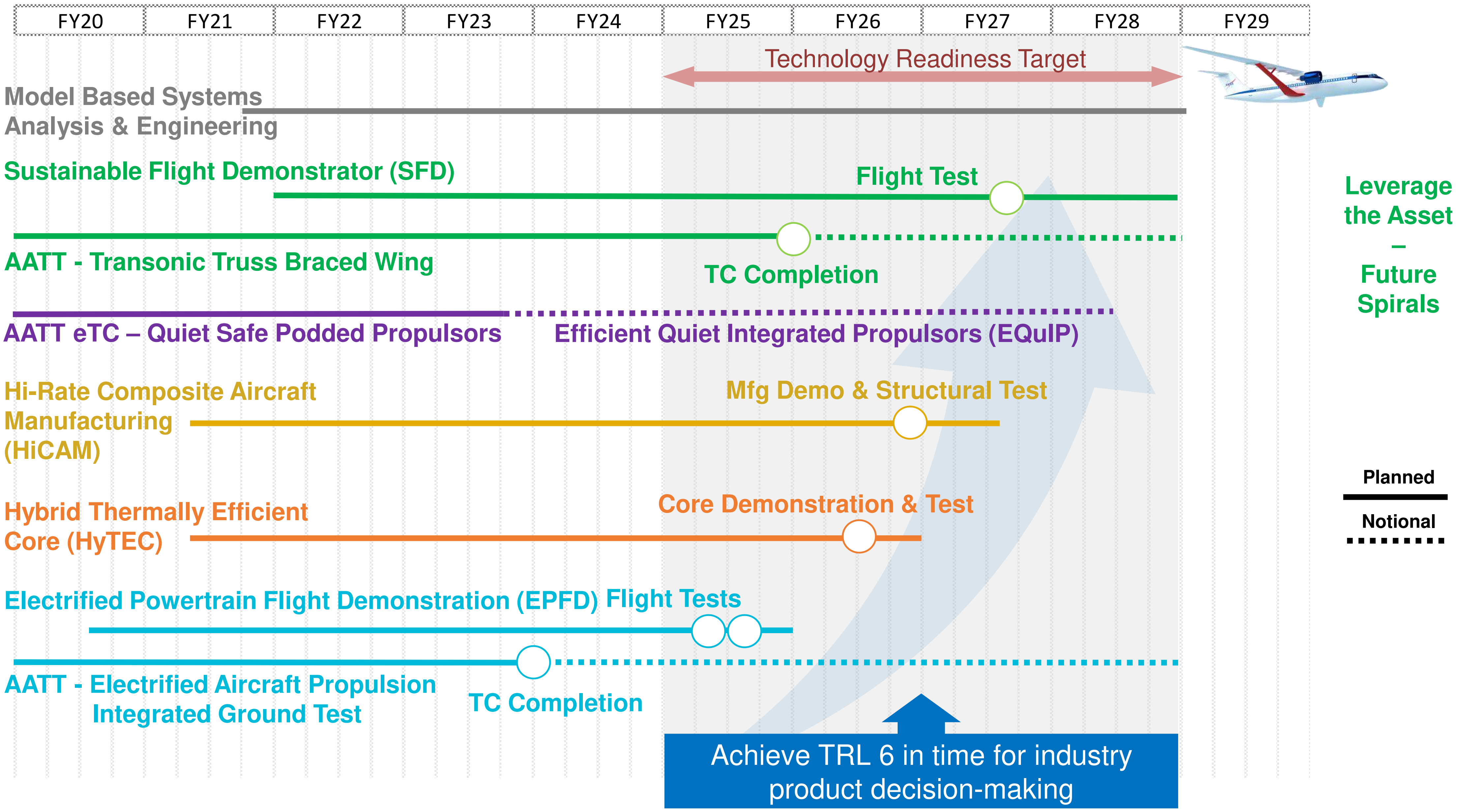
Achieve 25-30% energy efficiency improvements and 10-15 dB noise reduction in next-generation transports*

* U.S. Aviation Climate Action Plan

Subsonic Transports: Integrated Technology Development

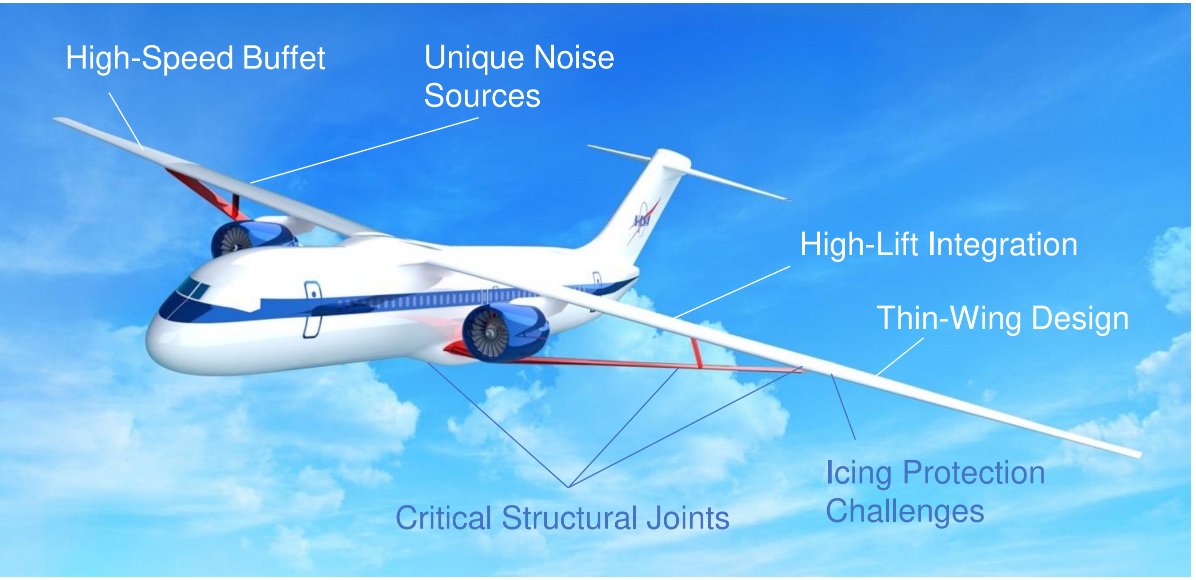






Transonic Truss-Braced Wing Technology Maturation

Increase confidence in technology to be robustly integrated in the aircraft system



Scope

- Mature and reduce risk of Transonic Truss-Braced Wing (TTBW) technology, focused on:
  - Buffet boundary prediction
  - Stall characteristics
  - High-lift system integration
  - Acoustic assessment
  - Icing impact
  - Thin wing structural design
  - Unique structural joints

Benefit

- Achieve 5-10% reduction in fuel burn through reduced drag

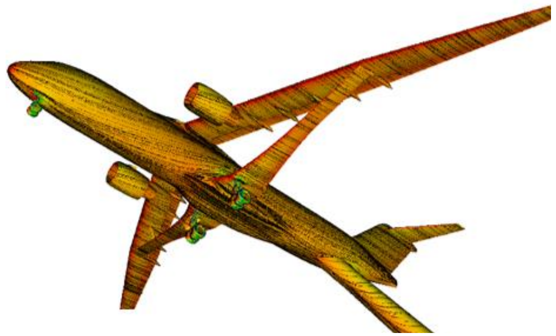
Approach

- Concept studies through scale model testing
- Perform high-fidelity prediction, testing and validation to increase confidence in fuel burn benefit

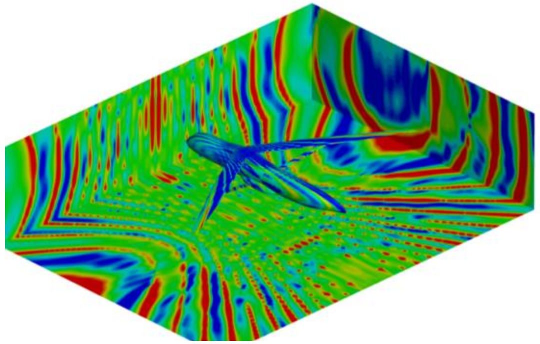
Design/Analysis/CFD studies and wind-tunnel tests are underway

TTBW Acoustic Research, Predictions, and Assessment

- Steady CFD simulations of the TTBW in-progress – results being validated against wind tunnel test data and used for system-noise assessments
- Noise scattering tests on-going in the NASA LaRC Quiet Flow Facility
- High resolution unsteady numerical simulations to predict noise and guide the improvement of system level prediction tools **(NASA/3DS/AVEC)**
- Development of computational tools to predict and assess the effects of scattering by the TTBW airframe **(Old Dominion University)**
- Modeling and testing of Slat Gap Filler (SGF) devices for low-noise leading-edge designs applicable to TTBW **(NASA & Texas A&M)**
- Assess noise contribution of Krueger flap bracket to TTBW system noise via testing in Florida State University's hybrid wind tunnel **(FSU)**.



PowerFlow Unsteady CFD Simulation

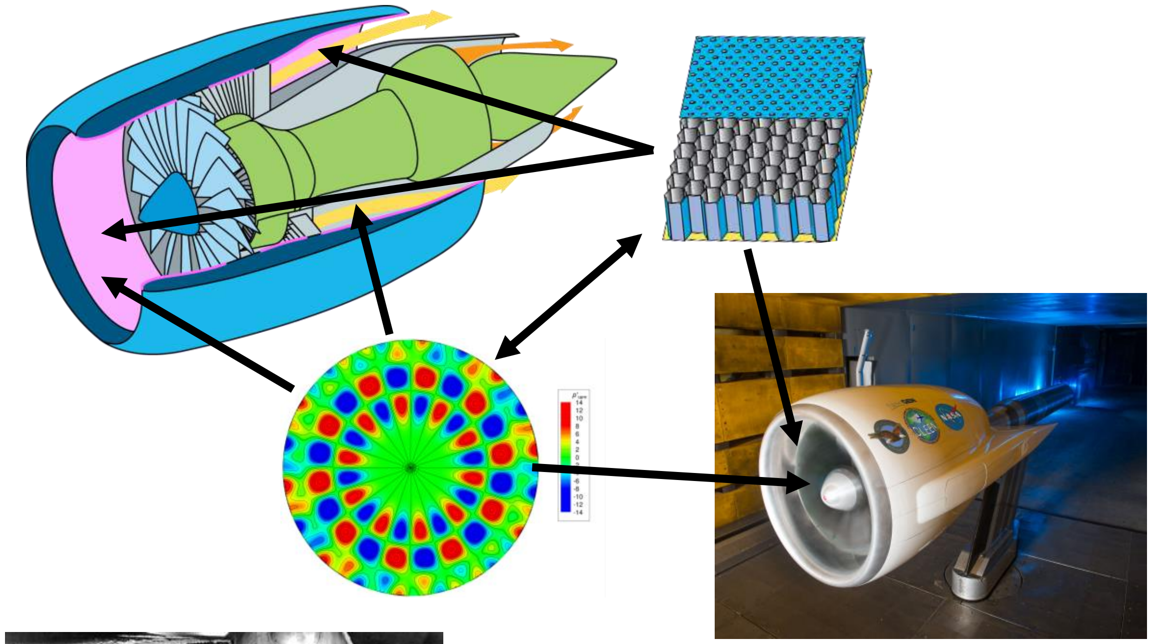


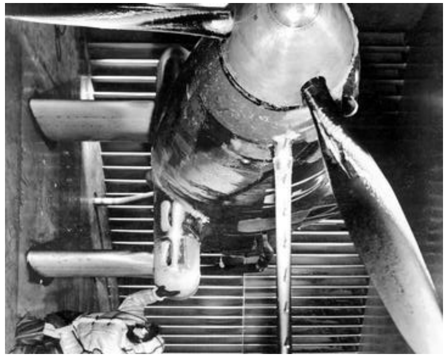
TTBW Noise Scattering Prediction

Computational and experimental work in progress to: support TTBW system noise assessments; reduce uncertainty; and assess potential noise reduction technologies

Quiet Safe Podded Propulsors (QESPP) eTC

Support MBSA&E and industry develop and assess next-generation propulsor technology





Scope

- Assess, model, and predict noise from advanced propulsors, develop source and liner noise mitigation technologies, evaluate aerodynamic performance, and assess icing and aeromechanics risks

Benefit

- Accelerate next-generation propulsor development for 5-10% fuel burn reduction and Chapter 14 noise with margin
- Support MBSA&E efforts with validated models and predictions in relevant time

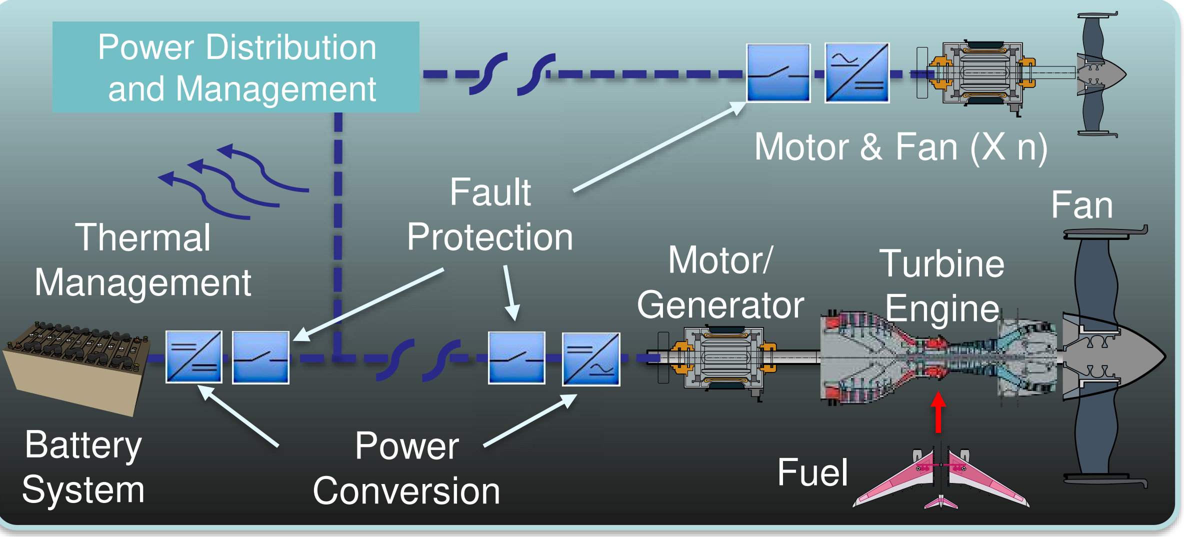
Approach

- Partner with industry and FAA CLEEN to mature and demonstrate promising technologies

Modern high bypass ratio propulsors are a dominant aircraft noise source with potential for significant efficiency gains regardless of power source

Focused Technologies for Electrified Aircraft Propulsion

Retire barrier technical and integration risks for megawatt-class electrified aircraft propulsion systems



Scope

- Address critical challenges for electrified aircraft propulsion by maturing and reducing risk for Electrified Aircraft Propulsion (EAP) technology, focused on:
  - Mass and weight reduction
  - Electrical losses
  - Reliability
  - EMI, power quality, dynamic stability
  - Limits on DC voltage levels
  - System design and integration

Benefit

- Accelerate U.S. industry readiness to transition to EAP-based commercial transport aircraft.
- Reduce key risks for a range of future applications and help enable new standards that are needed for EAP-based aircraft certification

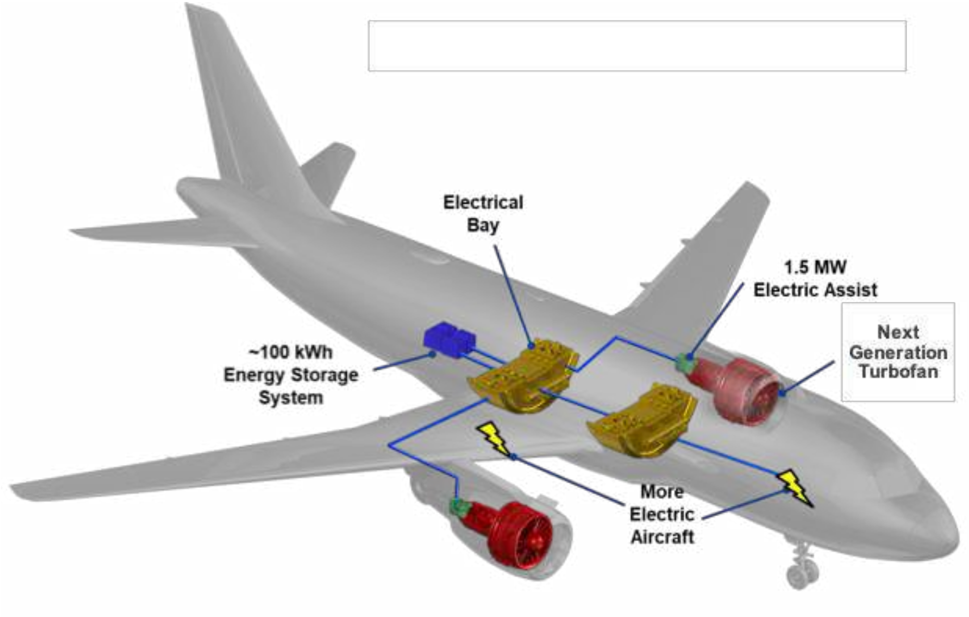
Approach

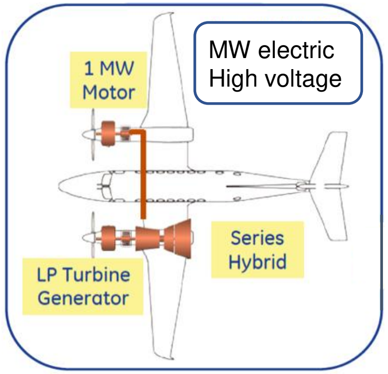
- Conduct technology-focused integrated ground tests
- Partner with industry on testing of electrified propulsion architectures and component technologies
- Leverage prior electric aircraft propulsion advances (TRL ~4)

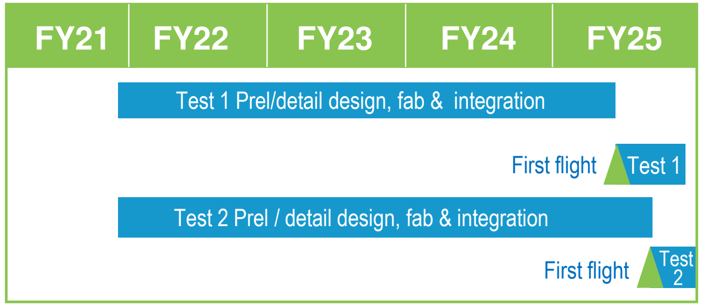
Architecture development and
high-power component tests are underway.

Electrified Powertrain Flight Demonstration

Demonstrate integrated electrified powertrains in flight using industry platforms







Scope

- Demonstrate practical vehicle-level integration of megawatt-class electrified aircraft propulsion systems, leveraging advanced airframe systems to reinvigorate the regional and emerging smaller aircraft markets and strengthen the single aisle aircraft market.
- Assess gaps in regulations/standards to support future Electrified Aircraft Propulsion (EAP) certification requirements.

Benefit

- Accelerate U.S. industry readiness to transition to EAP-based commercial transport aircraft.
- Enable new standards that are needed for EAP-based aircraft certification.

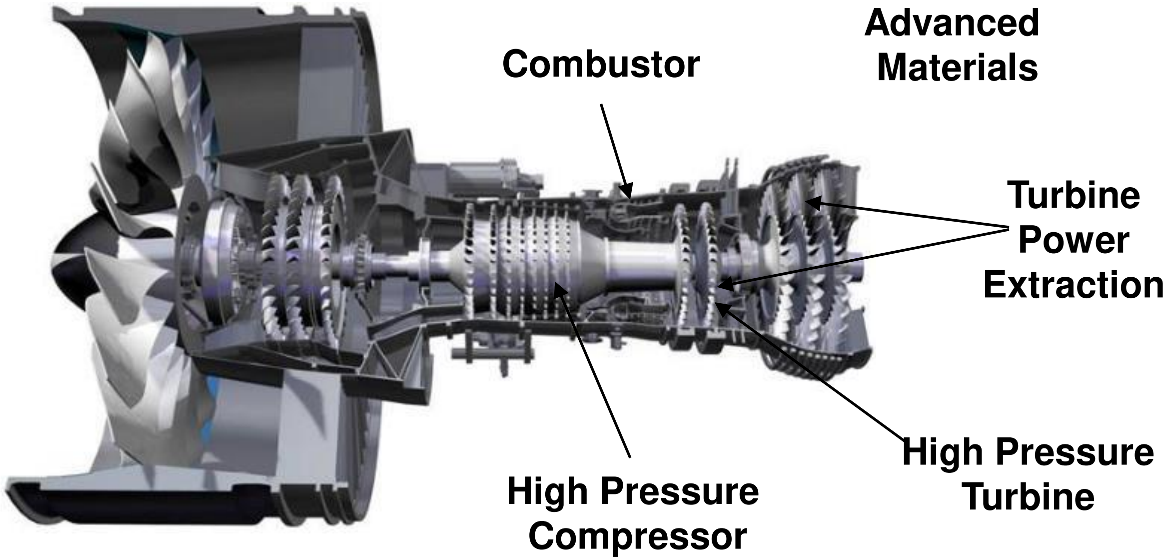
Approach

- Engage with U.S. industry to integrate and demonstrate megawatt-class EAP machines in flight.
- Engage with the FAA, SAE, ASTM, etc. to contribute data that inform EAP standards and regulations.

Two Flight Demonstration Contracts Awarded in September 2021

Hybrid Thermally Efficient Core

Accelerate development and demonstration of advanced turbine engine technologies



HyTEC
Hybrid Thermally Efficient Core

Scope

- Develop and demonstrate in integrated ground tests engine core technologies to Increase thermal efficiency, reduce engine core size and facilitate hybridization

Benefit

- Achieve **5-10% fuel burn reduction** versus 2020 best in class
- Achieve **up to 20% power extraction** (4 times current state of the art) at altitude to optimize propulsion system performance and enable hybridization

Approach

- Partner with industry to mature and demonstrate promising technologies

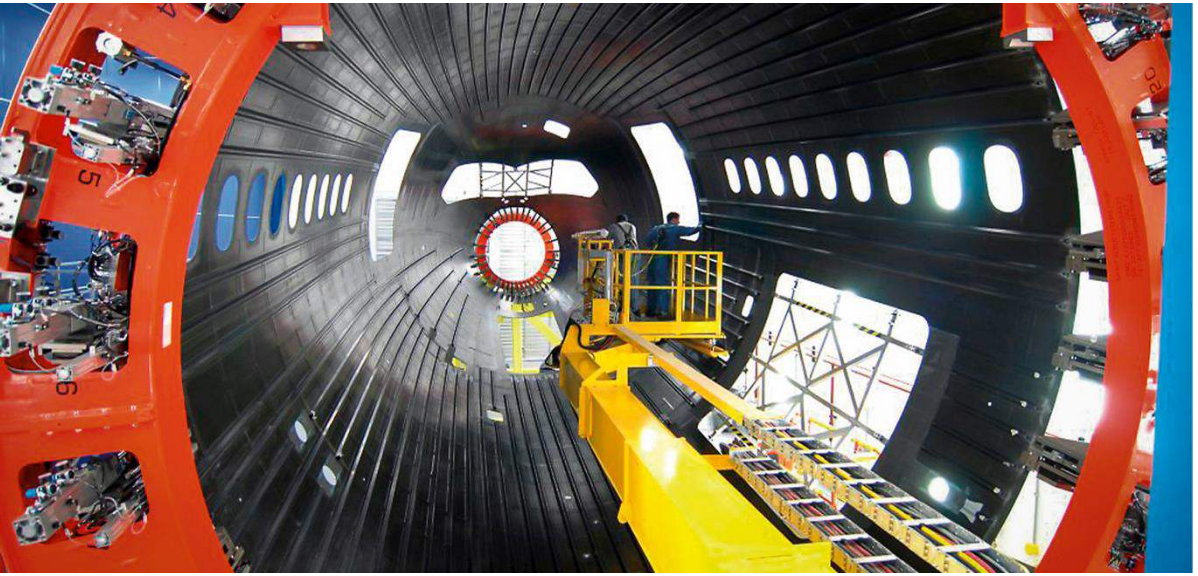
Small-core turbofan technology
contract awards were made in September 2021.

Hi-Rate Composite Aircraft Manufacturing (HiCAM)

4–6x production rate increase without cost or weight penalty

Production Rate per Month

• Metals	SOA:	60
• Composites	SOA:	10-15
	Target:	80-100



Scope

- Explore and advance high-rate composite manufacturing and assembly technologies
  - Evolving State-of-Art (SOA) thermosets, thermoplastics, resin transfer molding
  - Materials, processes, and architectures
  - Develop model-based engineering tools for high-rate manufacturing concepts

Benefit

- Increased manufacturing rates for composite aircraft structures to meet future production requirements and enable market penetration for lightweight composite materials

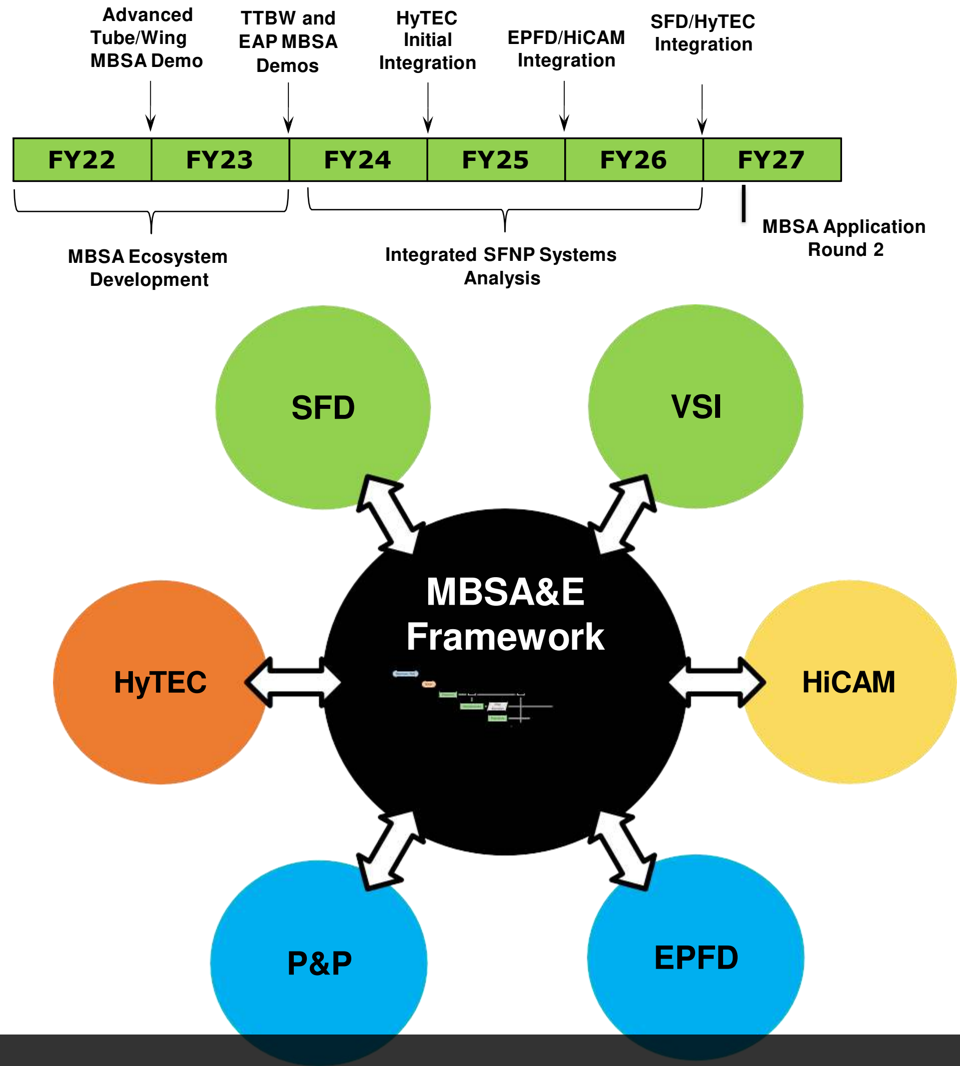
Approach

- Leverage advances in simulation including methods from Advanced Composites project
- Partner with industry for rapid prototype and evaluation of manufacturing concepts
- Demonstrate technologies in large structural ground tests

12 Cooperative Tasks Awarded to Inform HiCAM Plans

Model Based Systems Analysis and Engineering (MBSA&E)

- Objective: Assess system-level benefits over a broad portfolio of sustainable aircraft technologies in relevant time
- Approach: Develop an open cross-program MBSA&E capability for system analysis and benefit assessments
- Anticipated Results:
  - Component-level research and demonstration teams will provide relevant models appropriate for the MBSA&E framework
  - MBSA&E framework will be used to digitally integrate SFNP technologies and vision concepts and assess the collective impacts of broader, component-level research



MBSA&E will provide traceable, integrated, system-level benefit assessments of vision vehicle concepts informed by SME's, demonstrations, and external partnerships

NASA AACES 2050 Studies

Advanced Aircraft Concepts for Environmental Sustainability

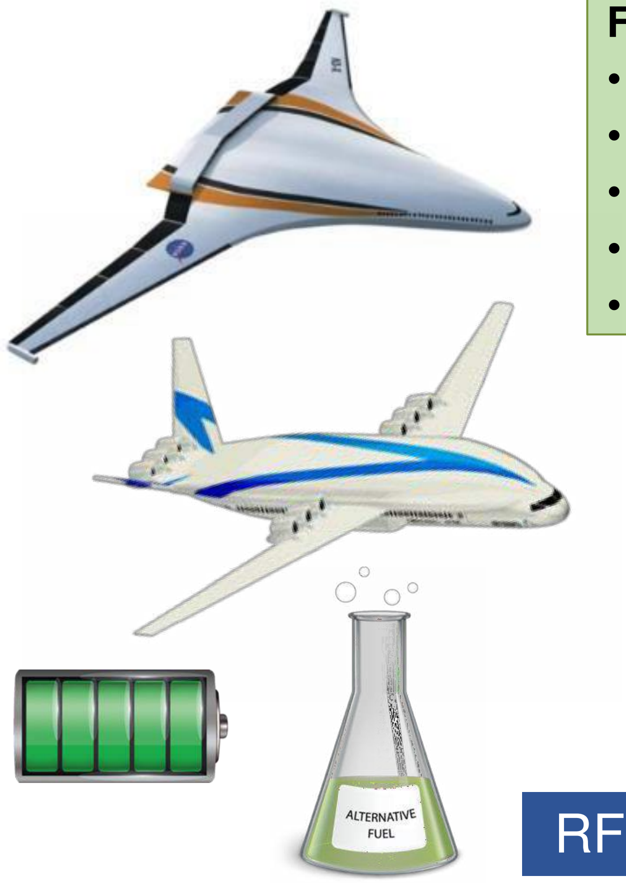
2008-2019 → 2020-2029 → 2030 - 2039 → 2040 - 2050

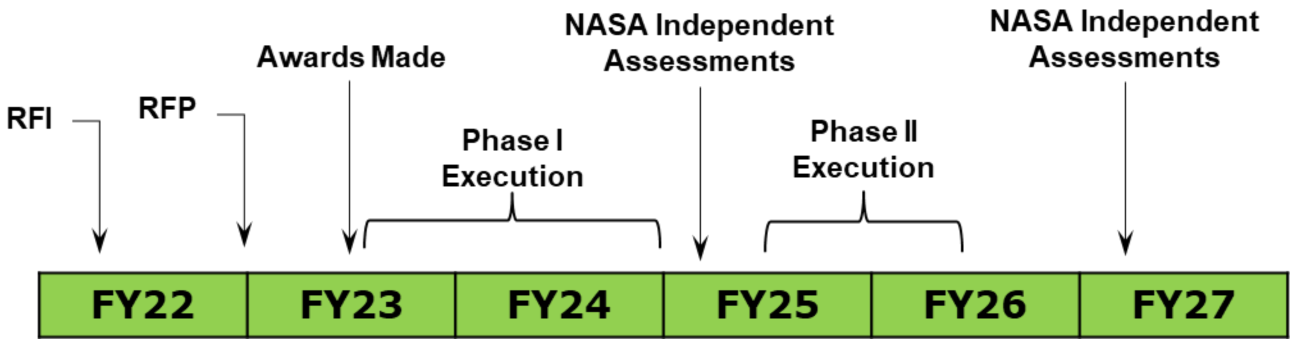
FY10-15 ERA N+2 for the 2020s Impact

FY09 N+3 Adv Concept Studies Target 2030-35 Impact

FY23 "N+4" AACES Studies - Explore 2020s, Demo 2030s, Impact 2040s

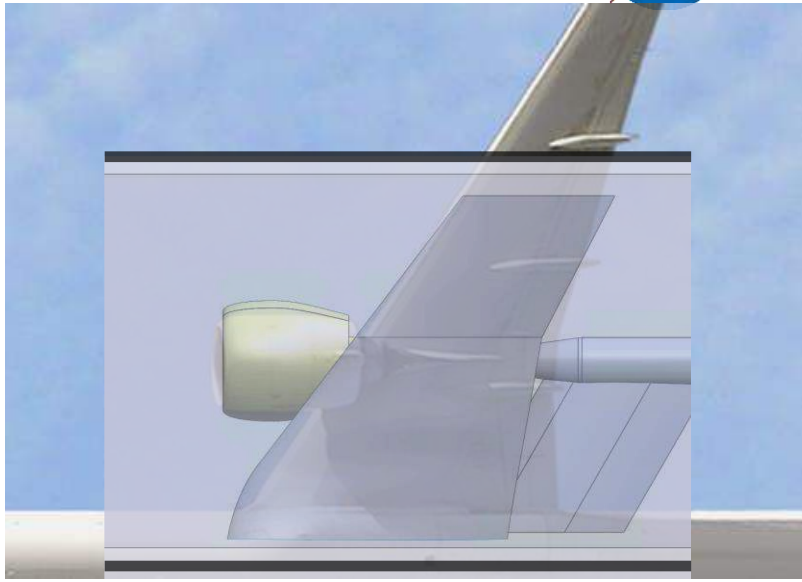
- *2040s Marketplace (payload/range/speed), 2050 Environmental Goals*
- *Alternative Energy Scenarios (LH2, LNG, Increased Electrification, 100% SAF)*
- *Advanced Airframes (clean energy compatible, shielding, adaptive, unconventional structures)*
- *Alternative propulsion (clean energy compatible, BLI, distributed propulsion, hybrid electric)*
- *Tools & Methods for Reduced Lifecycle Cost & Environmental Impact*



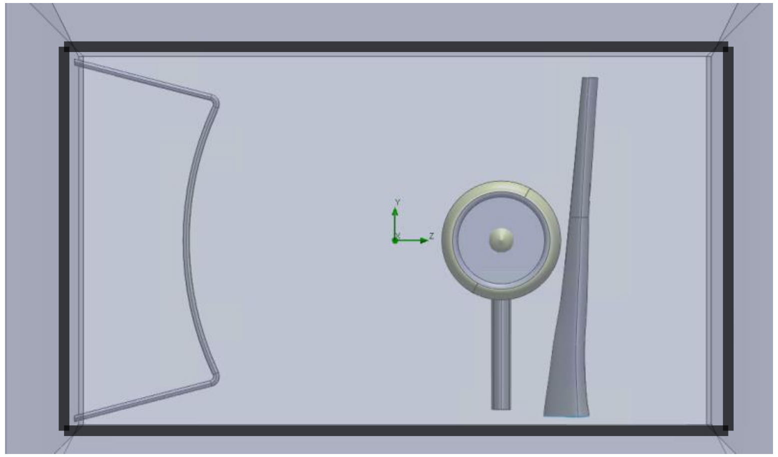


RFI Released 5/19/22, RFP Fall 2022, Awards Early CY23

Efficient Quiet Integrated Propulsors (EQuIP) Proposal



- Objective:
  - Assessment and risk mitigation of integrated propulsors to meet noise and efficiency goals for the next-generation single-aisle aircraft in the 2030's.
  - Provide noise and performance models with integration effects to support MBSA&E and AACES studies
- Approach: Include wing section in NASA's 9x15 Low Speed Wind Tunnel for integrated propulsor testing
- Status:
  - CFD to demonstrate feasibility, provide aerodynamic loading on wing, angle of attack limitations
  - Mechanical design feasibility study



Modern propulsors are closely coupled to the airframe; we must account for the effect of engine-airframe integration on noise and efficiency in our models and assessments

Educational Outreach: NASA Advanced Noise Control Fan

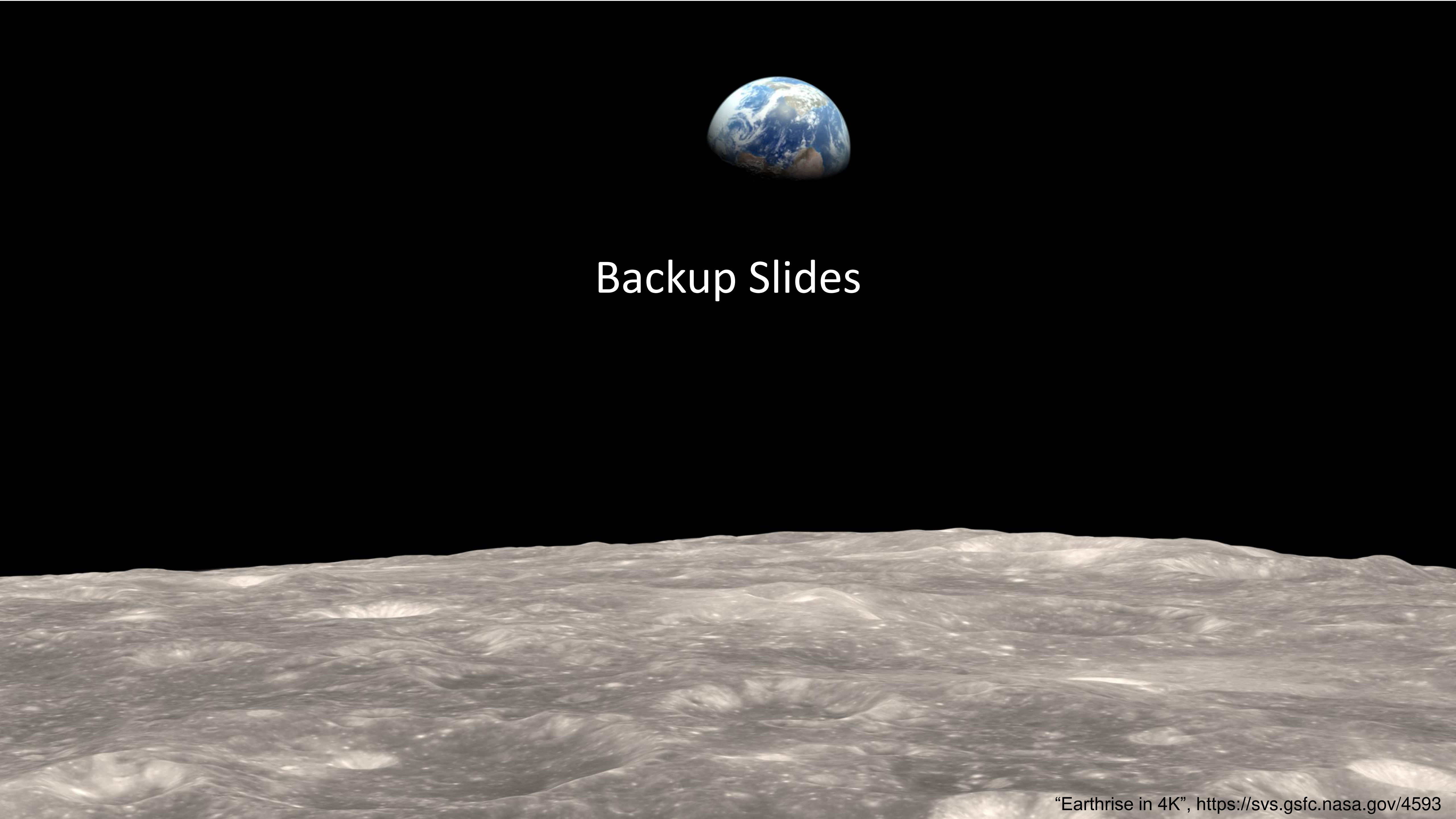
- Objective:
  - Advance noise source reduction and acoustic/thermal management liner technologies
  - Prepare the next generation of engineers
- Approach: Partner with University of Notre Dame to operate the ANCF as a low-TRL, low-cost concept evaluation test rig
- Results (2022):
  - 12 students from 4 universities gained hands-on experience using the ANCF for undergraduate and graduate research
  - Lab and research capabilities improved at UND, WSU, NCAT

Meeting the sustainability challenge requires meeting the needs of society in the present while *preparing the next generation to meet their own needs*

Sustainable development “meets the needs of the present without compromising the ability of future generations to meet their own needs.” Sustainability “does imply limits – not absolute limits but limits imposed by the present state of technology”; but technology can be “improved to make way for a new era of economic growth.”
-- U.N. Commission on Environment and Development, “Our Common Cause”, 1987

“Earthrise in 4K”, https://svs.gsfc.nasa.gov/4593

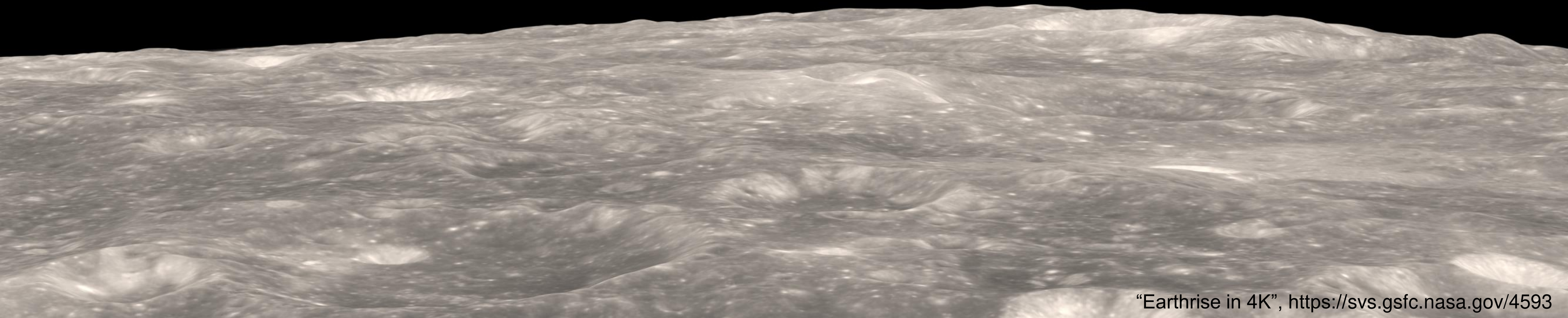
Backup Slides



“Earthrise in 4K”, https://svs.gsfc.nasa.gov/4593

“Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainable development does imply limits – not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities. But technology and social organization can be both managed and improved to make way for a new era of economic growth.”

-- U.N. Commission on Environment and Development, “Our Common Cause”, 1987



“Earthrise in 4K”, https://svs.gsfc.nasa.gov/4593

U.S. Aviation Climate Action Plan (2021) Goals

Net-Zero GHG Emissions* from the U.S. Aviation Sector** by 2050

* Aviation GHG emissions include life cycle carbon dioxide (CO2), nitrous oxide (N2O), and methane (CH4) emissions. Aircraft engines produce negligible amounts of nitrous oxides and methane, so this plan has a focus on aviation combustion CO2 emissions and well-to-tank life cycle GHG emissions (CO2, N2O, and CH4)…

** This U.S. aviation goal encompasses CO2 emissions from (1) domestic aviation…from U.S. and foreign operators, (2) international aviation (i.e., flights between from two different ICAO Member States) from U.S. operators, and (3) airports located in the United States.

Community Co-Benefits through Improved Air Quality and Reduced Noise

In addition to its impacts on climate change, aircraft operations have impacts on human health and welfare via noise pollution and emissions that degrade air quality. These impacts are felt in communities near airports as well as much further away in the communities that surround our metropolitan areas. The actions outlined in this document will not only put us on a course to achieve net-zero GHG emissions by 2050, but they will also reduce the impacts of noise and air quality on airport communities.

Goals: achieve net-zero CO2 aircraft and well-to-tank life cycle GHG emissions and 10-15 dB aircraft noise reduction (re. 2021 best in class) by 2050

NASA Aeronautics – Vision for Aviation in the 21st Century

ARMD continues to evolve and execute the Aeronautics Strategy
https://www.nasa.gov/aeroresearch/strategy

6 Strategic Thrusts

- Safe, Efficient Growth in Global Operations
- Safe, Quiet, and Affordable Vertical Lift Air Vehicles
- Innovation in Commercial Supersonic Aircraft
- In-Time System-Wide Safety Assurance
- Ultra-Efficient Subsonic Transports
- Assured Autonomy for Aviation Transformation

U.S. leadership for a new era of flight

Aviation is Vital to our Nation's Economy

Pre-COVID

- $78 billion positive trade balance; the largest positive trade balance of any U.S. manufacturing sector
- $1.8 trillion total U.S. economic activity
- 10.9 million direct/indirect jobs
- 21.3 billion tons of freight transported by U.S. airlines in 2019

The Aviation Carbon Reduction Challenge

- By 2050, an estimated 10 billion passengers will fly each year a distance of 22 trillion revenue passenger kilometres.
- With today's fleet and operational efficiency, this activity would require over 620 megatonnes (Mt) of fuel and generate close to 2000 Mt of CO_2.
- Imagine enabling the same level of demand while reducing net CO_2 emissions to zero by 2050.

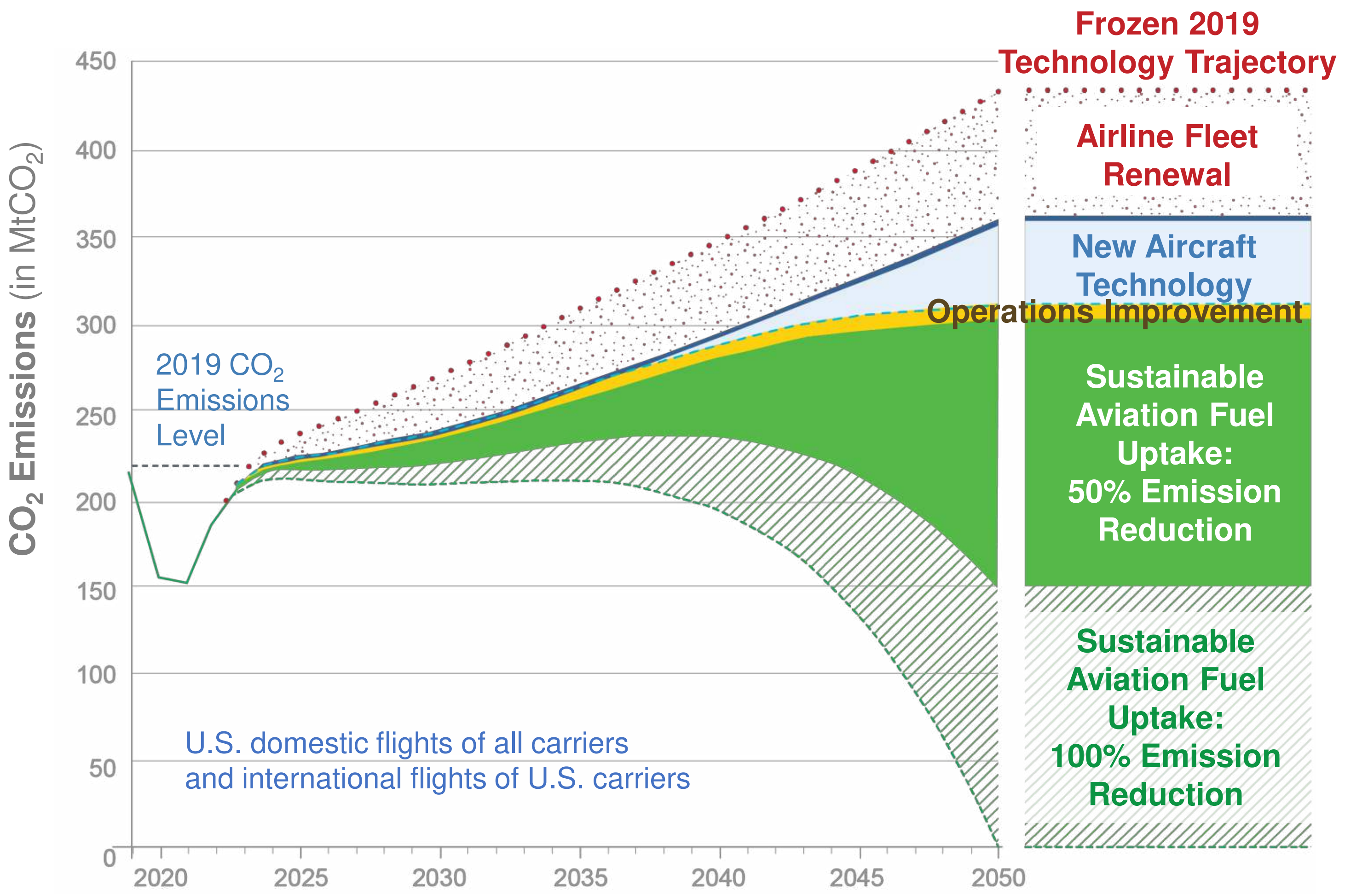
Meeting the challenge is the opportunity for the United States to lead the world in innovation and reductions in CO_2 aviation emissions, and to maintain economic competitiveness in a critical export industry ($6 trillion-plus market over the next 20 years).

U.S. Aviation Climate Action Plan

Global Context for Sustainable Aviation

U.S. aviation goal is to achieve
net-zero greenhouse gas emissions by 2050.

U.S. Aviation Climate Action Plan is aligned with
- U.S. economy-wide goal
- International Civil Aviation Organization
- Air Transport Action Group



The U.S. is working with the global community to achieve net-zero greenhouse gas emissions by 2050 using a common basket of measures.

Sustainable Flight Demonstrator

Demonstrate integrated airframe-focused technologies in flight

Scope

- Develop and fly integrated airframe-focused technology flight demonstrator with U.S. industry to mature technologies that enable the next-generation single-aisle aircraft in the 2030s.

Benefit

- Validate promising technologies, retire technical risks, and mature to TRL 6 key synergistic commercial transport vehicle technologies. Combined, these technologies could support efficiency and environmental performance goals for the 2030s.

Approach

- Request for Information supporting Project Formulation 2020-21
- Project Formulation and Risk Reduction in 2021-22
- Competitive Request for Proposals in 2022

Risk Reduction Contract Awards Made August 2021
Design/Build Contract Award Anticipated Late 2022

Sustainable Aviation Fuels

Enable the use of 100% sustainable aviation fuels (SAF) and reduce climate impact

Scope

- Support adoption of high-blend ratio sustainable aviation jet fuels

Benefits

- Reduced aviation environmental impact
- Reduced uncertainty for climate impact of aviation-induced cloudiness
- Improved efficiency/emissions with drop-in synthetic and biofuels

Approach

- Characterize high-blend sustainable aviation jet fuel emissions on ground and in flight

Future SAF Research Plans in Development

Long-Term Transport Technology and Innovation

Generational studies to inform future technology investments

2008-2019	2020-2029	2030 - 2039	2040 - 2050

Subsonic Fixed Wing

N+2 Studies, ERA for the 2020s Impact

N+3 Advanced Concept Studies SFNP for 2030s Impact

Concept Studies and Technology Development Needed for 2040s Impact

Opportunities to Define
Future Aviation Systems and Concepts

- Advanced Concept Studies for 2040+ EIS
- Net-Zero Emissions Concepts
- Promising Technologies and Architectures
- Support Aviation Community with NASA-unique Contributions

Innovations for 2040s and Beyond

Sustainable Flight National Partnership Benefits

Small Core Gas Turbine for 5%-10% fuel burn benefit

Electrified Aircraft Propulsion for ~5% fuel burn and maintenance benefit

Sustainable Aviation Fuels for reduced lifecycle carbon emissions

Model-based Systems Analysis & Engineering provides digital integration

Transonic Truss-Braced Wing for 5%-10% fuel burn benefit

High-Rate Composites for 4-6x manufacturing rate increase

Integrated Trajectory Optimization for 1%-2% reduction in fuel required and minimization of contrail formation

Sustainable Flight Demonstrator for integrated airframe-focused technology maturation

ADP Fan Commissioning Test in the 9x15 Wind Tunnel

October 18, 2022

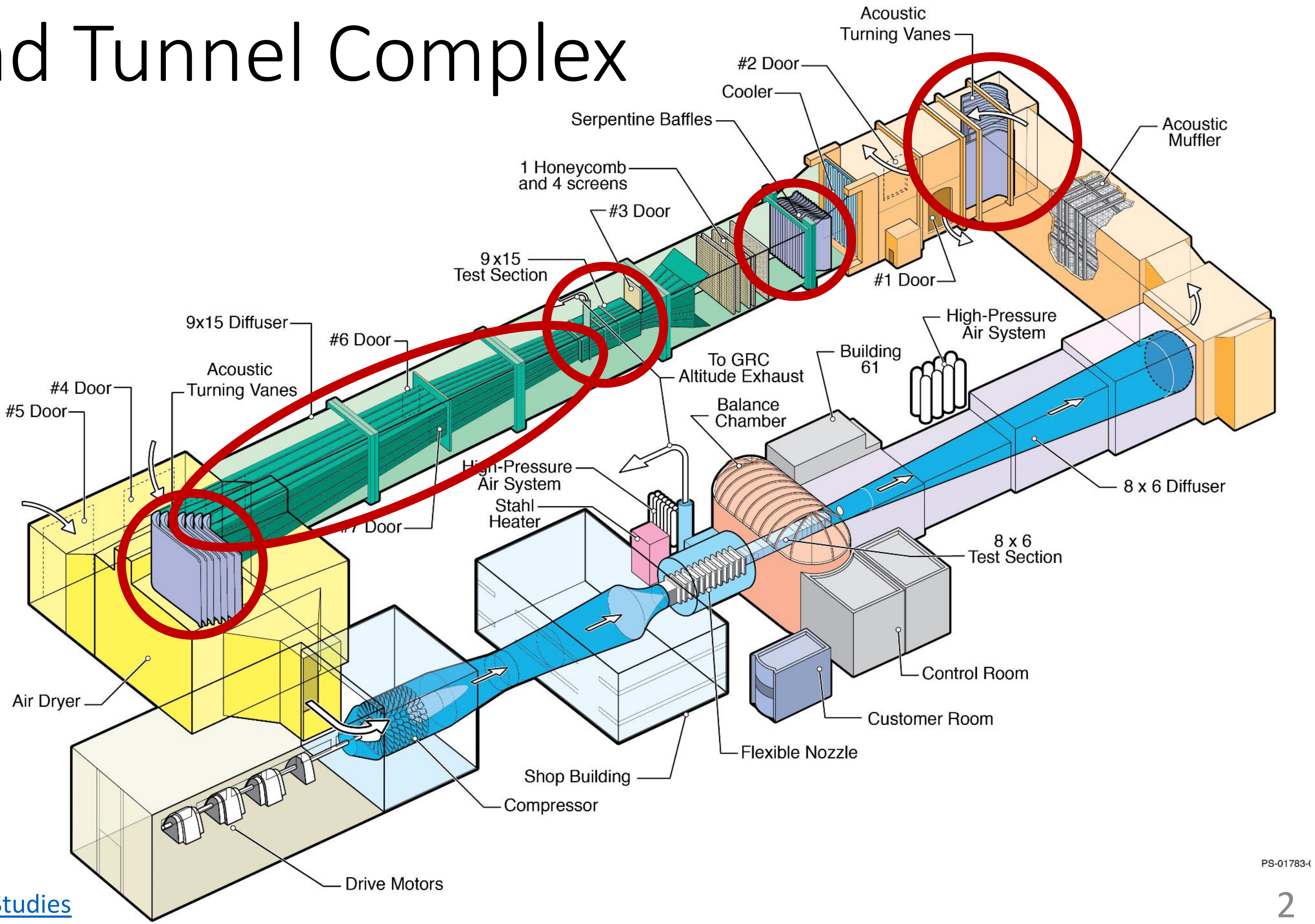
POC: David Stephens (NASA GRC Acoustics Branch)

This work has been funded by the
- NASA Advanced Air Transport Technology Project
- NASA Aeronautics Evaluation and Test Capabilities Project

8x6 / 9x15 Wind Tunnel Complex

9x15 Background Noise Reduction
5 Complementary Improvements

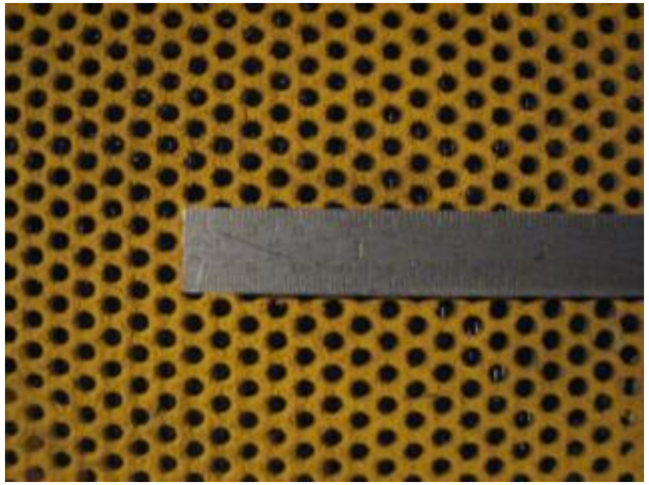
1. Add fairings and acoustic turning vanes to turn 2
2. Add acoustic baffles downstream of doors 1 & 2
3. Replace test section, uniform deep acoustic absorber, new flow surface, remove slots, lengthen by 5 feet
4. Reshape diffuser and add acoustic treatment
5. Add acoustic turning vanes to turn 3

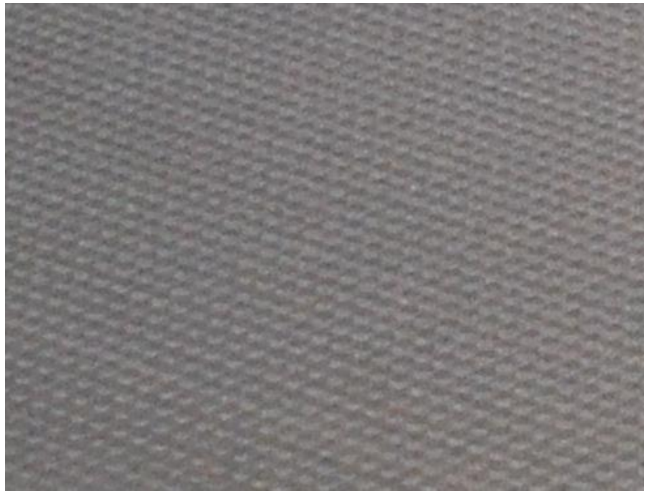


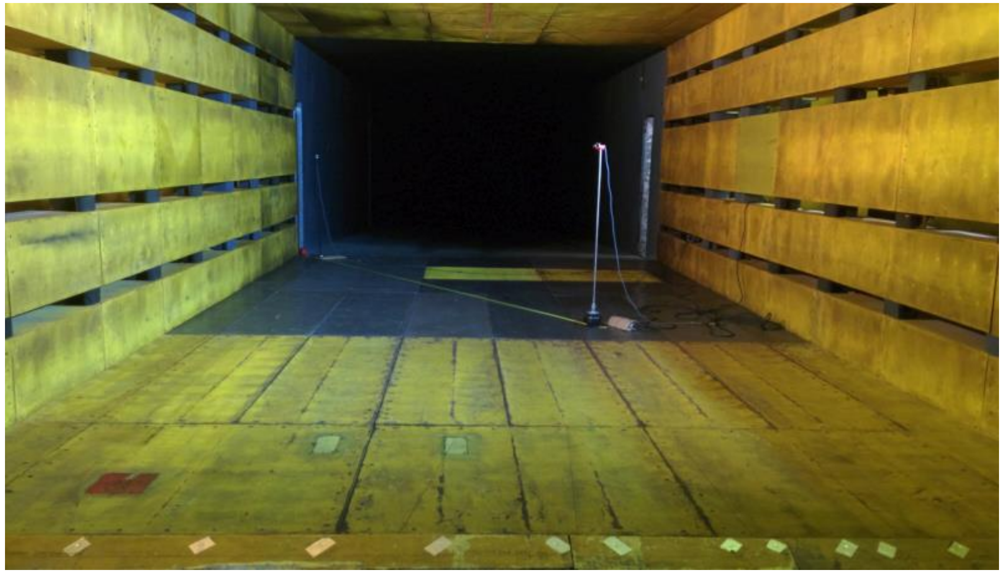
Two TMs published this summer:
[9x15 LSWT Acoustic Upgrade Part 1: Supporting Studies]
[9x15 LSWT Acoustic Upgrade Part 2: Improvement Comparison]

Test Section Flow Surface

- Principal noise reduction due to flow surface roughness reduction
- Bare perforate replaced by diffusion bonded panel: micronic wire cloth over perforate
  - Similar to NFAC 40x80 at NASA ARC







[Noise Produced by Fabric and Wire Mesh Covered Panels in Low-Speed Anechoic Wind Tunnels]()

Commissioning?

Confirming that the wind tunnel and drive rig control, safety and data systems are integrated, tested and operated properly.

1. Rebuild UHB Drive Rig Test Capability
   - 450 psi supply lines, valves, etc.
   - New mic traverse
   - New steady-state data (ESCORT->COBRA)
2. Demonstrate safe operation of tunnel and rig
   - New rig control system monitoring tunnel/rig health with alarms, warnings, rig e-stop
   - Evaluate new procedures for operations
3. Verify data quality improvements
   - Aerodynamic performance with rake installed
   - Acoustic performance in flight configuration


Replace ESCORT with COBRA


Rebuild Drive Rig Infrastructure


ADP Fan in 1995


Building ADP Fan Model in 2005

[Some Acoustic Results From The Pratt And Whitney Advanced Ducted Propulsor: Fan 1]

9x15 Test Section (2006)

9x15 Test Section (2020)

ADP in 9x15 (June 2022)

Test Summary

Schedule

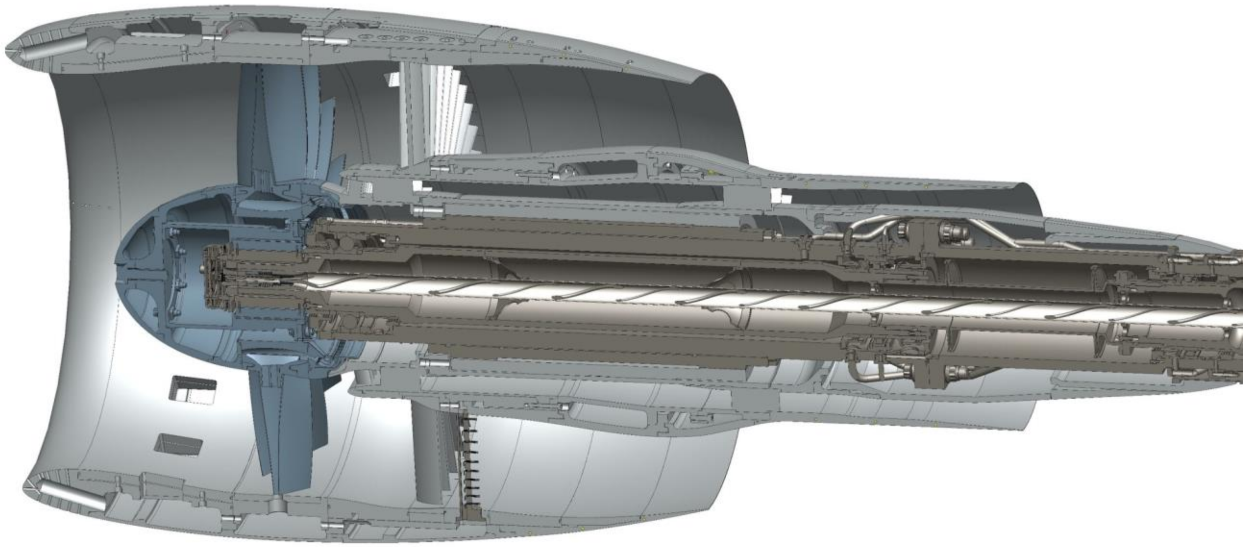
- February 17, 2022 – 8x6 test of X-59 completed, facility shifts to ADP preparation, UHB drive rig installation
- May 27, 2022 – Model buildup completed, first checkout run
- June 13, 2022 – First research run
- June 24, 2022 – Model being removed

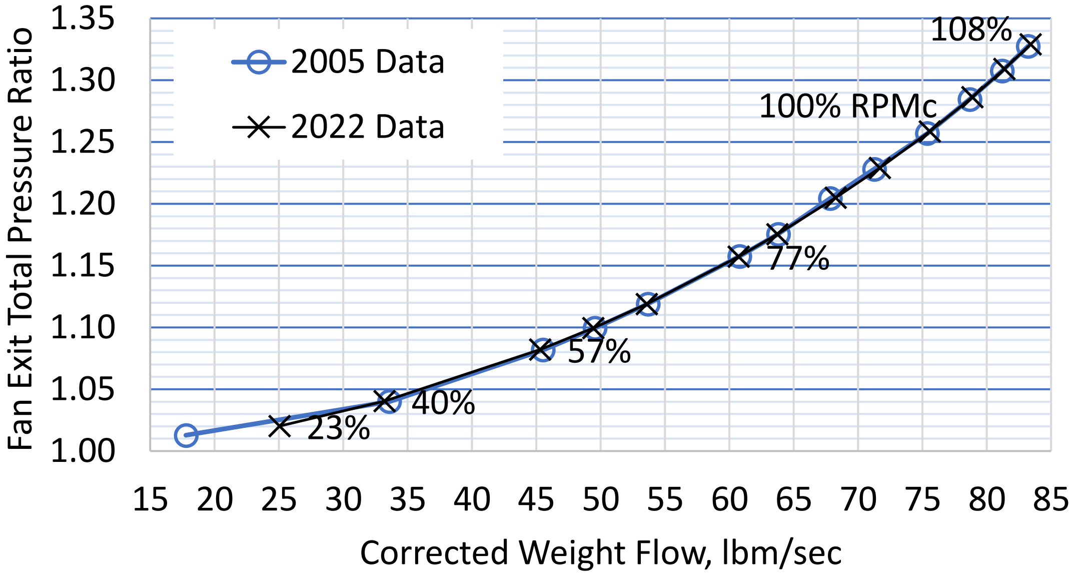
Objectives Met

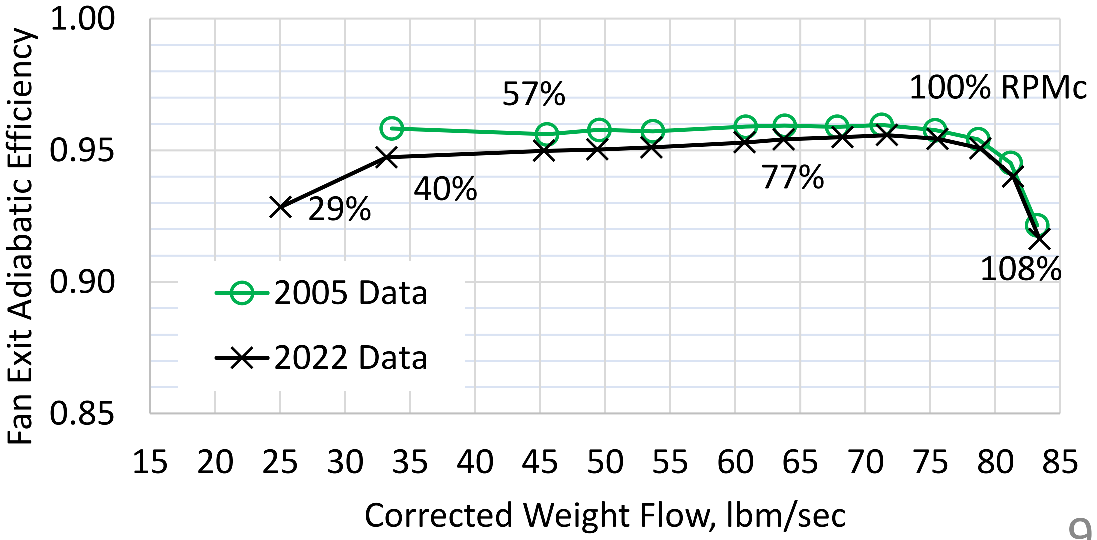
1. Checkout of UHB drive rig controls and safety systems
2. Validation of new COBRA fan program and associated instrumentation
3. Aero and acoustic data acquired at 12 fan speeds and 4 tunnel speeds for a single configuration
    - For comparison with prior data
    - For demonstration of tunnel aero and acoustic performance

Example aero-performance comparison with prior ADP data (preliminary)

- Rebuild the same hardware
- Set tunnel to same flow speed
- Set fan to same RPM
- Performance and acoustics better follow!

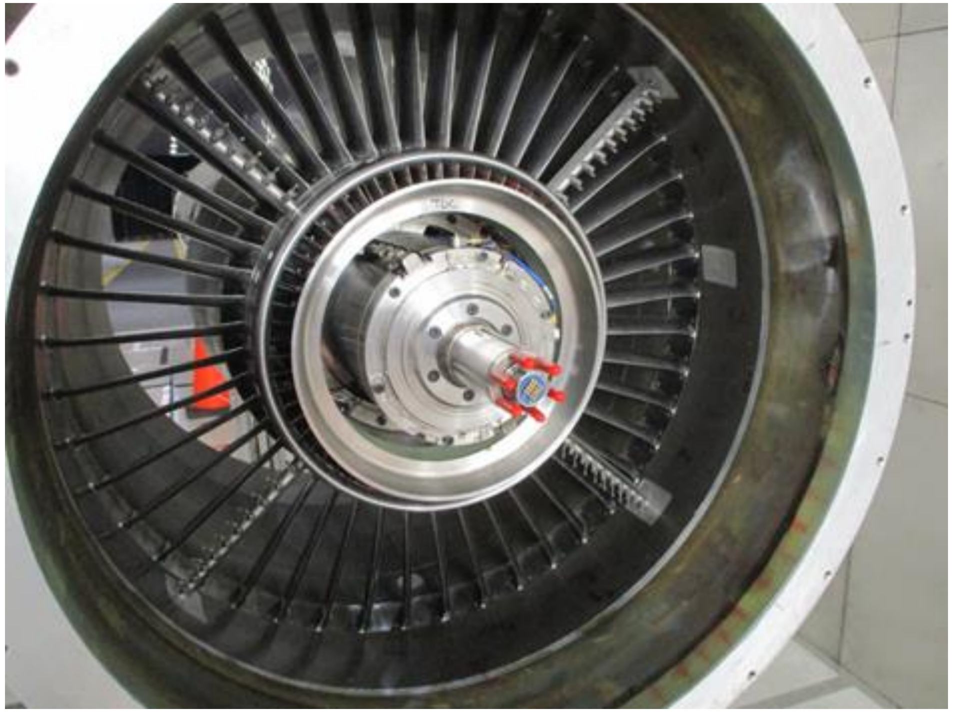


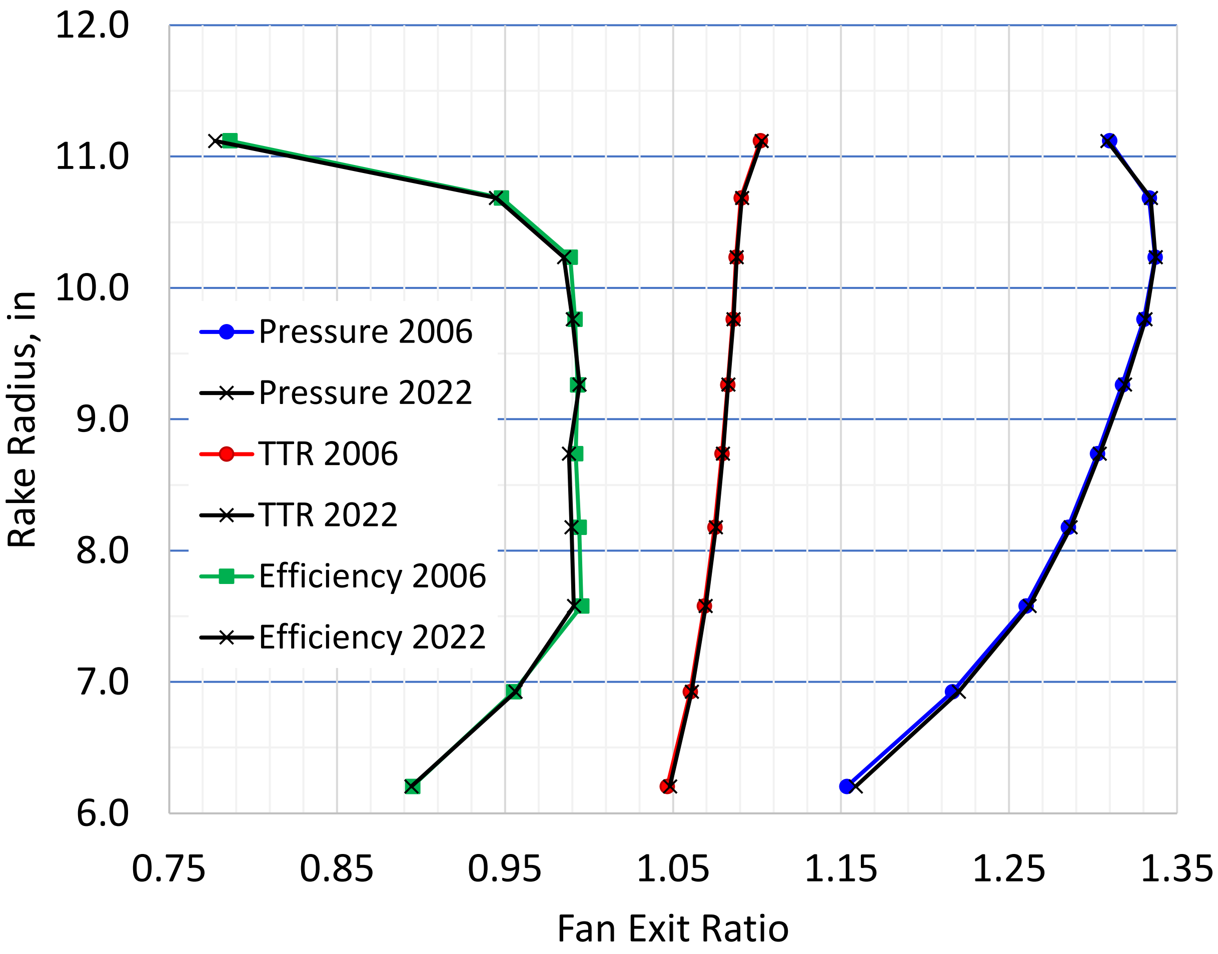




Example aero-performance comparison with prior ADP data (preliminary), cont.

- Station 12.5 rakes
- 100% RPMc, Mach 0.1
- Adiabatic efficiency

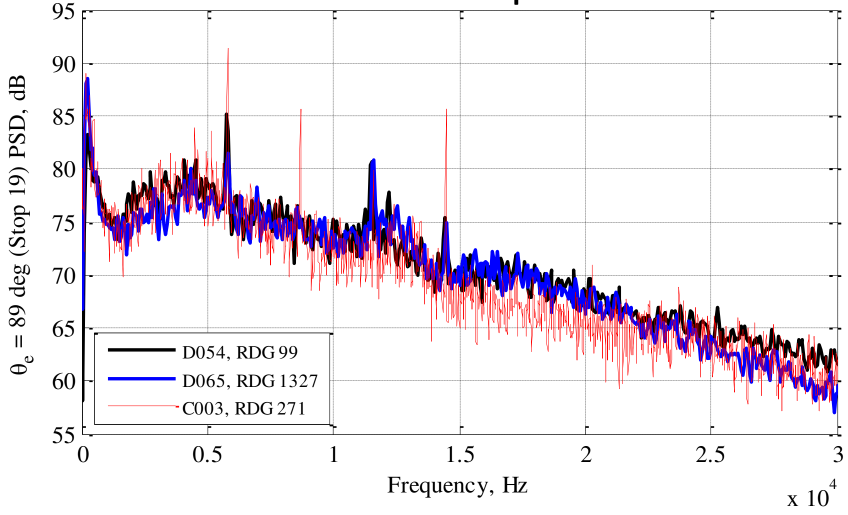




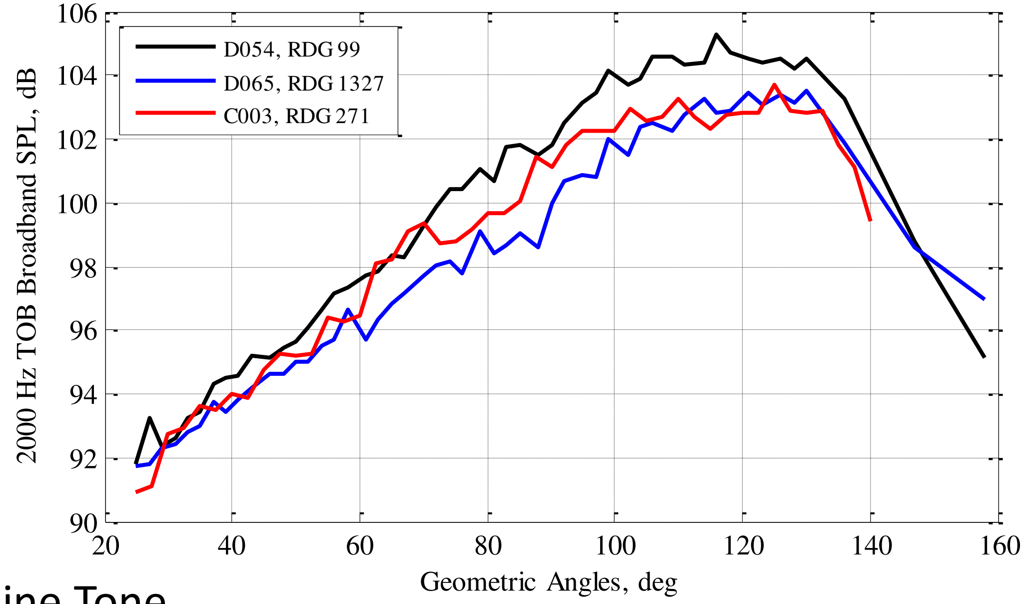
Example acoustic comparison with prior ADP data (preliminary)

Red – 2022
Blue – 2005
Black – 1996

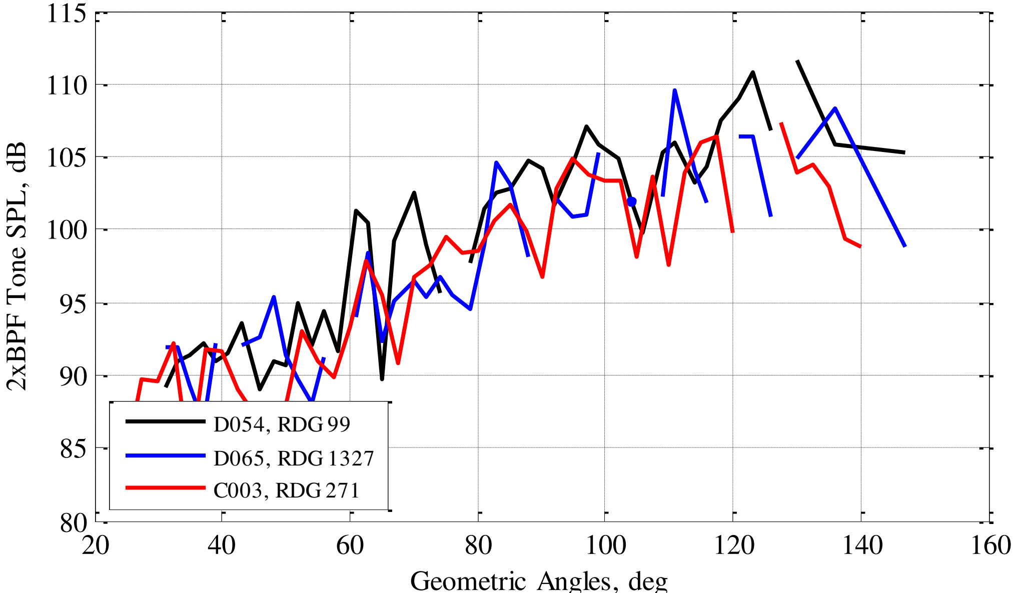
Narrowband spectra



Sideline Broadband



Sideline Tone

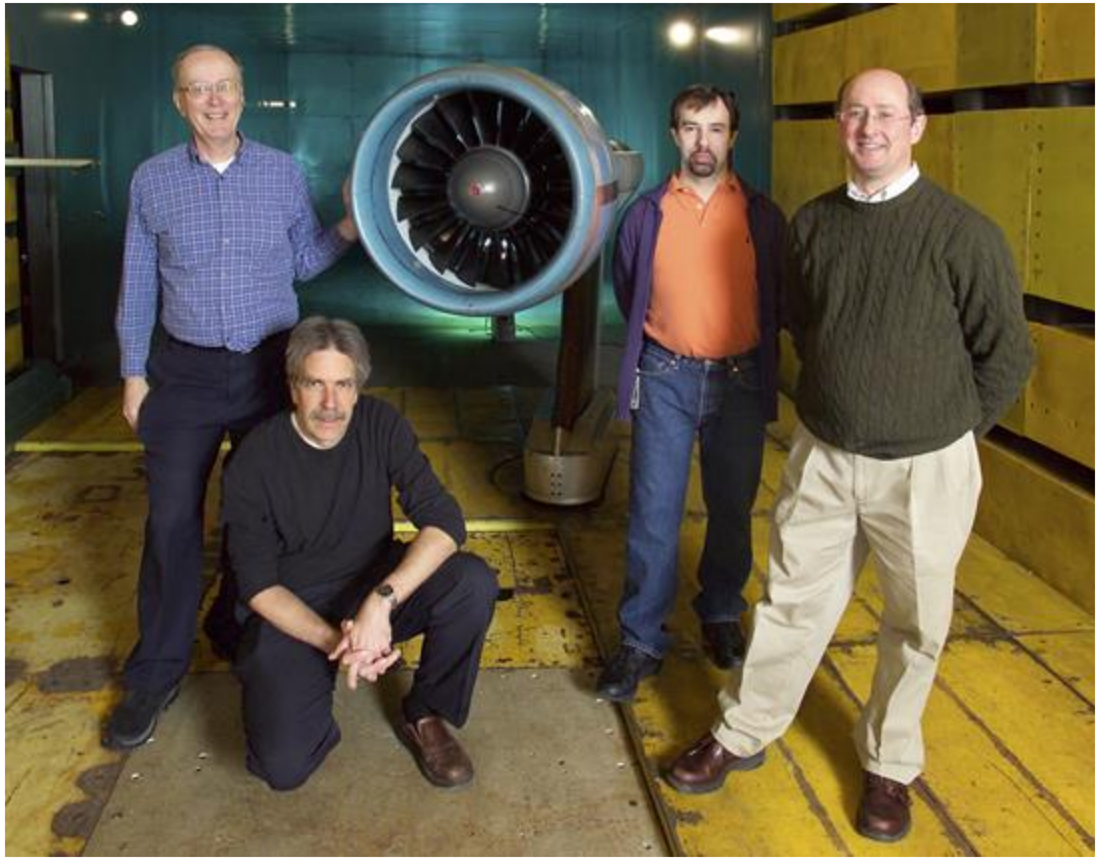


New acoustic data processing developed in Python.

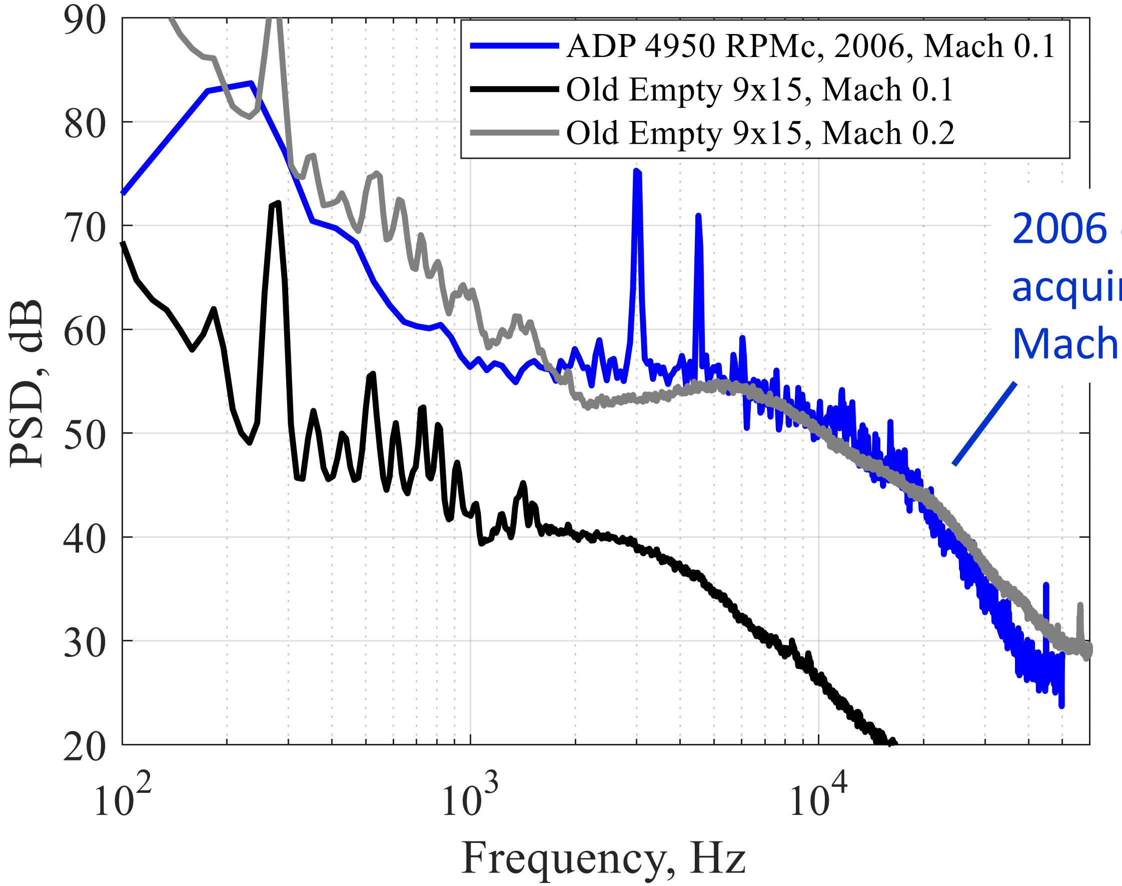
Aero and acoustic data and comparisons to be published as NASA TM

Fan Testing 2006

For the last 30 years, fan testing has been conducted at Mach 0.1 to limit background noise.



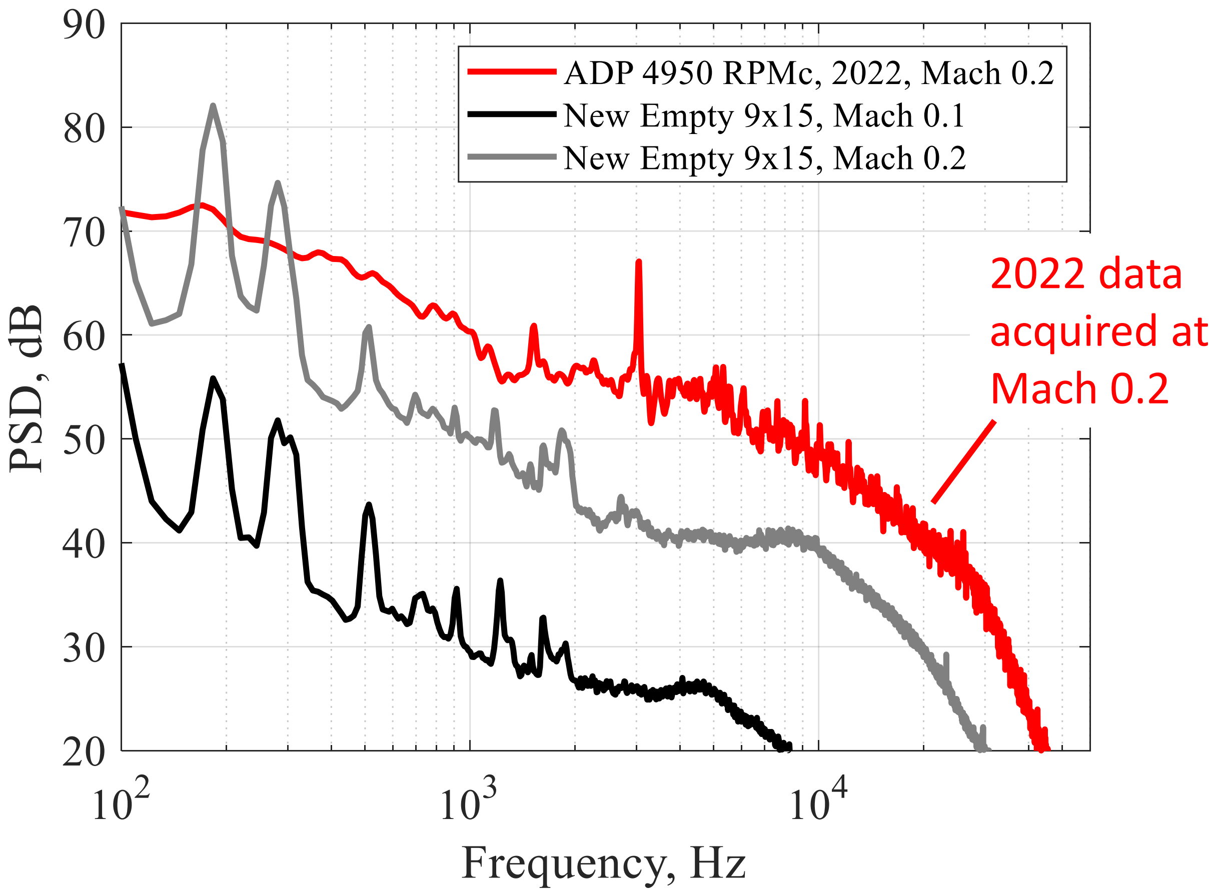
Acoustics branch research engineers (2006)



Fan Testing 2022

Now testing can be conducted at Mach 0.2, which approximates actual takeoff/landing speeds.

Acoustics branch research engineers (2022)



Questions?

Summary

The 9- by 15-Foot Low Speed Wind Tunnel (9x15 LSWT) at NASA Glenn Research Center was built in 1969 in the return leg of the 8- by 6-Foot Supersonic Wind Tunnel (8x6 SWT). A major acoustic improvement upgrade project was conducted, starting with concept studies in 2012 and ending with construction completion in 2019. The systems to operate a fan model were rebuilt and the integrated system was utilized in 2022 during a commissioning test. The present document describes summarizes the work on the facility and the fan test.

Progress Towards a High-Accuracy 4D Prediction Tool

Ray Hixon
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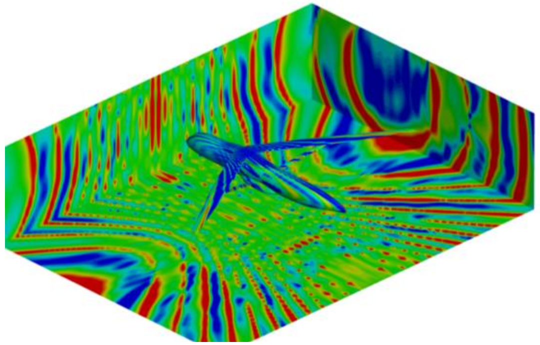
Acoustics Technical Working Group
October 18, 2022

Space-Time Mapping Analysis - Motivation

- Computational Aeroacoustics (CAA) is focused on the time-accurate numerical prediction of unsteady flow and noise
- Traditional CAA uses optimized numerical schemes and time-marching methods to efficiently compute nonlinear unsteady flow solutions
- For unsteady flow problems with rotating machinery and/or wide variance in turbulent scales, time marching is inefficient and introduces inaccuracies
  - We can do these problems but they use a lot of time and computational resources

PowerFlow Unsteady CFD Simulation

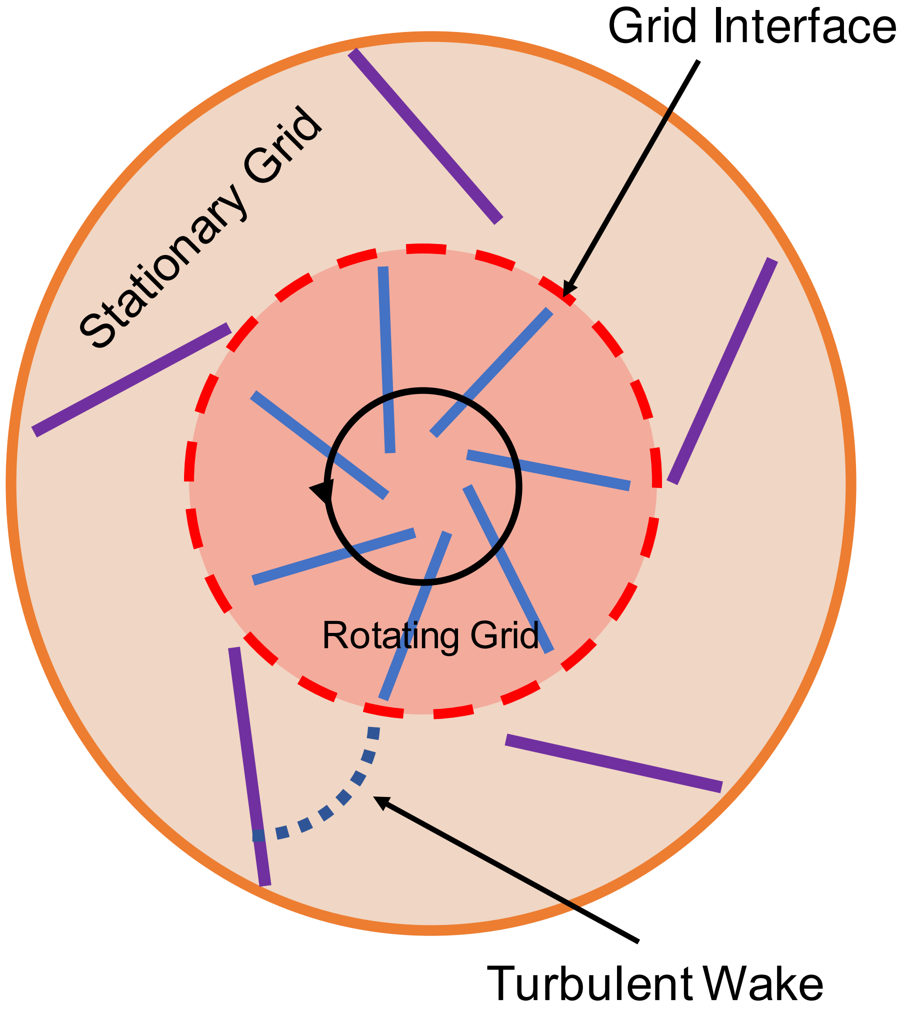


TTBW Noise Scattering Prediction

By treating time as an additional dimension orthogonal to the spatial dimensions, geometry movement falls out and new computational efficiencies become available

Example: Centrifugal Pump in 2D

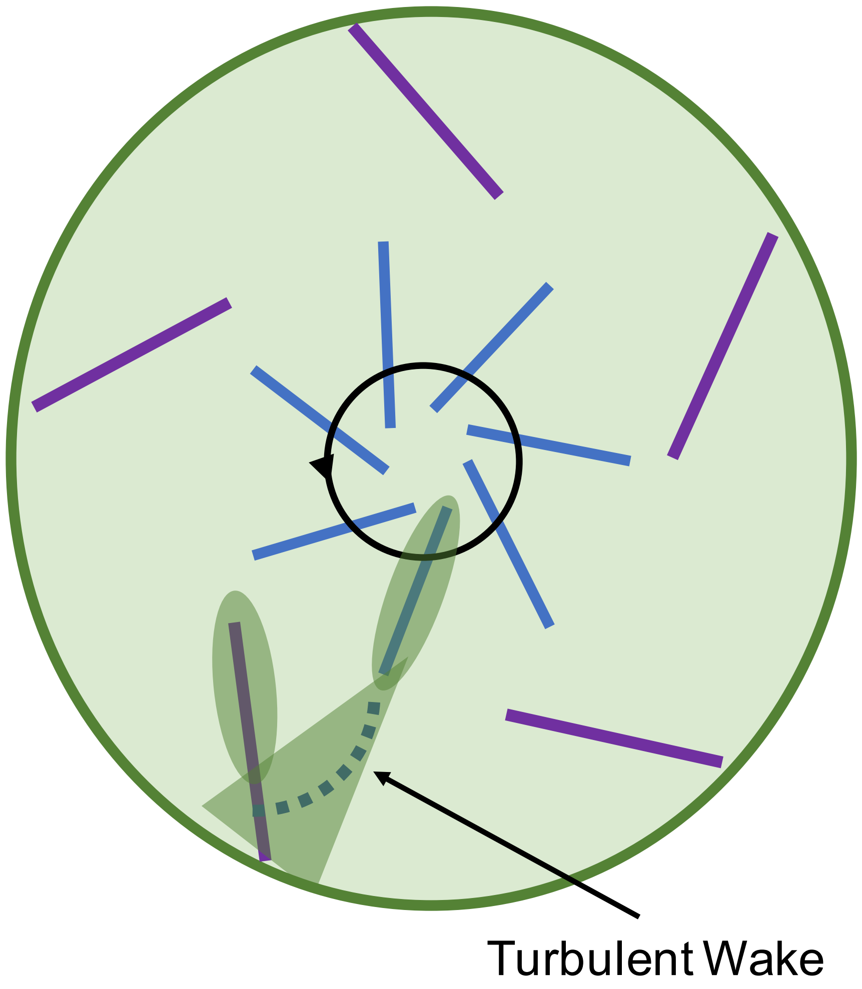
- In time marching CAA:
  - Grid interface must be maintained at every step
  - Stationary grid density must be maintained everywhere for rotor turbulent wakes



Rotating machinery problems are important in aviation and testing is expensive; STMA has potential to give high-accuracy simulations in these cases

Example: Centrifugal Pump in 2D

- In time marching CAA:
  - Grid interface must be maintained at every step
  - Stationary grid density must be maintained everywhere for rotor turbulent wakes
- In STMA:
  - Equations naturally handle grid rotation eliminating the stationary/rotating grid interface
  - Grid density can naturally adapt to places where resolution is needed at a given time



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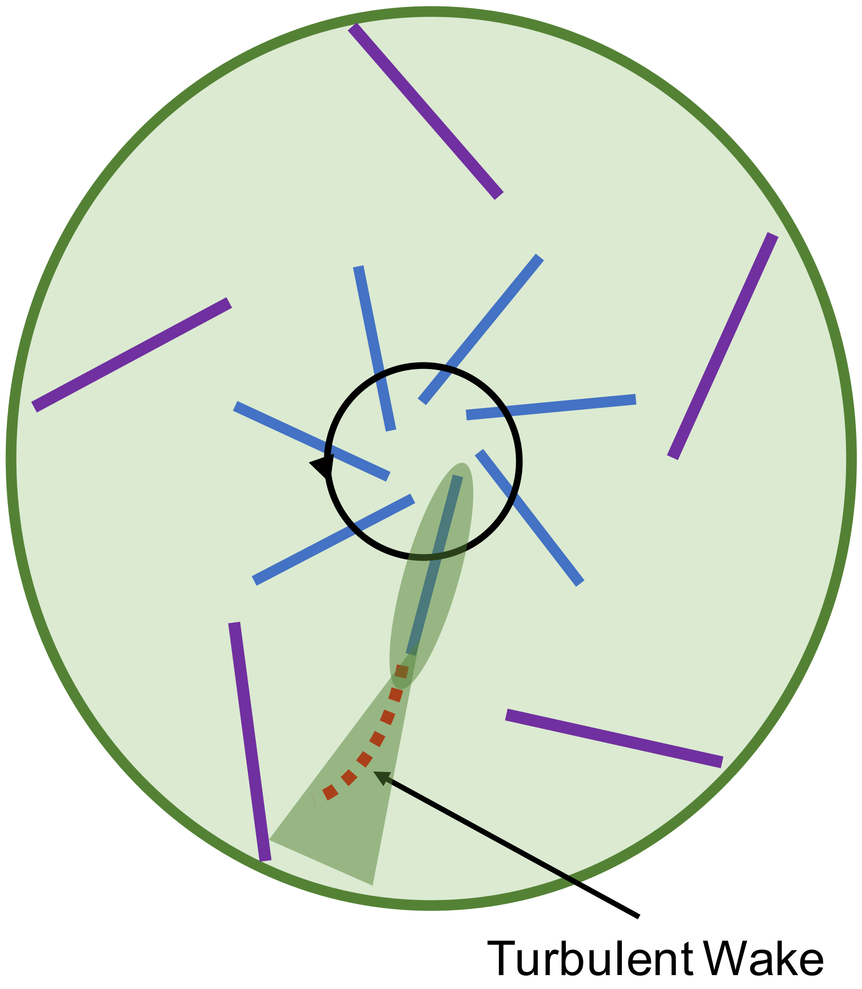
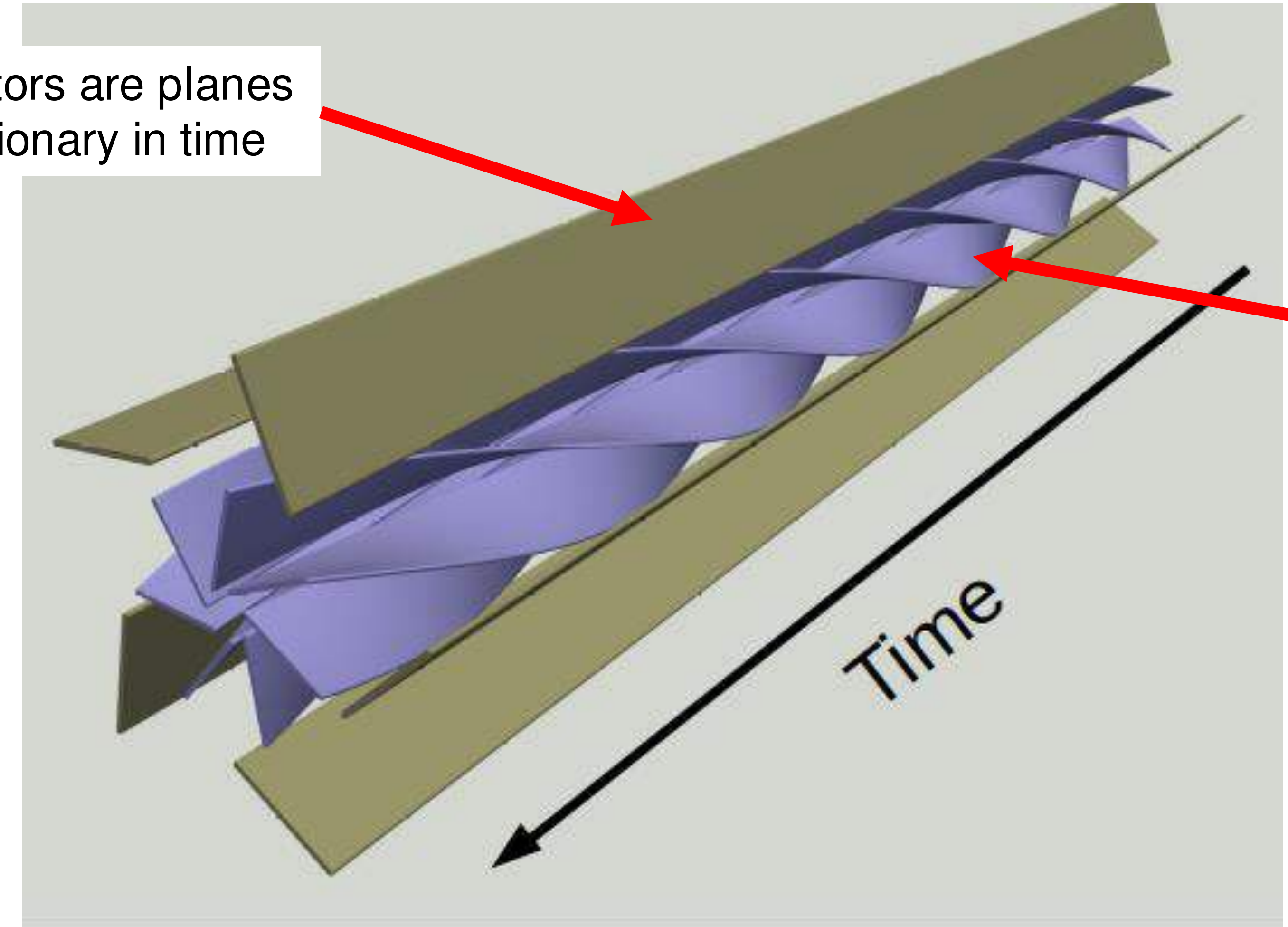


Rotating machinery problems are important in aviation and testing is expensive; STMA has potential to give high-accuracy simulations in these cases

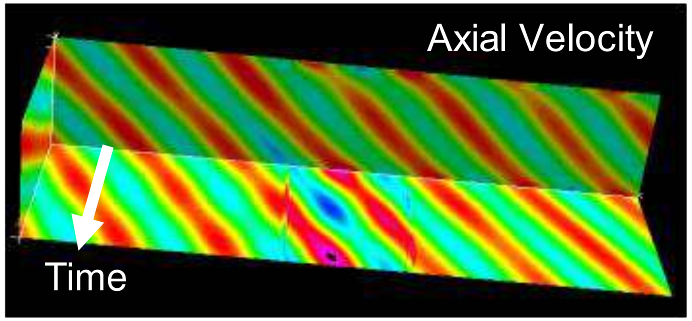
Example: Centrifugal Pump in 2 Space-1 Time Dimensions

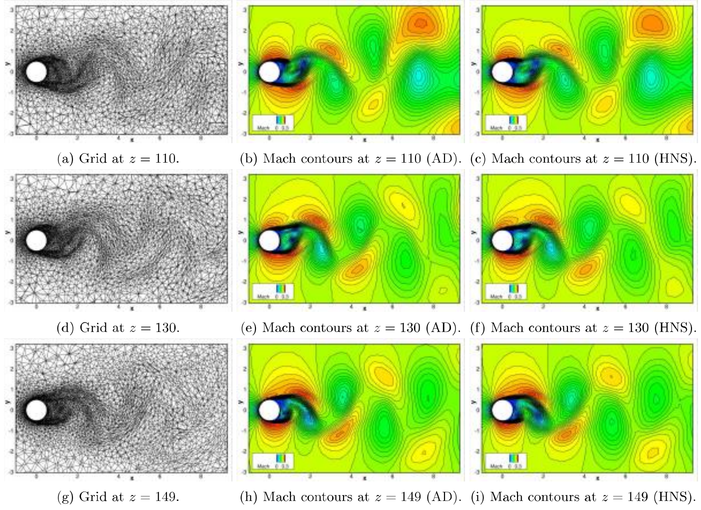


Every grid line is a function of time and space and evolves with rotor movement;
Flow is steady in space-time so grid clusters when and where wakes are present

Space-Time Mapping Analysis – Historical References

- Inviscid 2-Space 1-Time proof of concept in early 2000’s
  - CAA Benchmark: Flat plate vortical wake interaction
  - CAA Benchmark: loaded Source Diagnostics Test (SDT) fan cascade wake interaction
  - CAA Benchmark: Lifting Joukowski airfoil gust interaction
  - Nonlinear Test: Lifting airfoil with high-amplitude gusts and moving shocks
- 2022: Padway and Nishikawa 2-Space 1-Time cylinder vortex shedding simulation (ICCFD11-2022-3001)

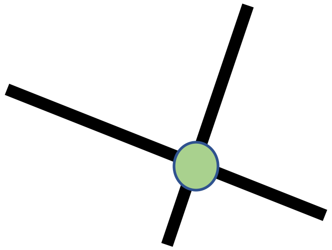




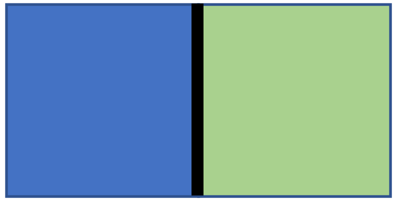
Limited to 2-Space 1-Time dimensions; how do you make a 4-D grid?
How do you solve the Navier-Stokes equations in 4-D?

Getting to 3-Space 1-Time Dimensions

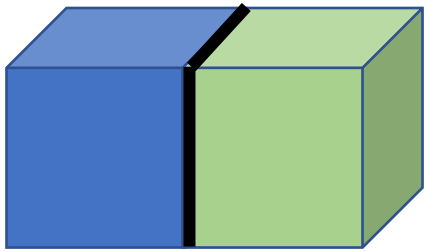
- Two lines meet at a point

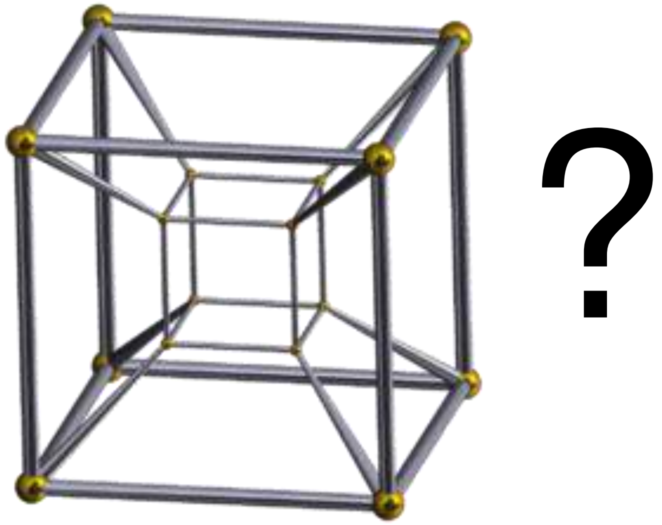


- Two planes meet at a line



- Two cubes meet at a plane





Two tesseracts meet at a cube
(Automated 4-D Grid Generation Required!)

Objects in 1-, 2-, 3-dimensions can be described and visualized;
equations can be extended to 4-dimensions following this pattern

Traditional Governing Equations

$$\left(\frac{Q}{J}\right)_\tau + \left(\frac{\hat{E}}{J}\right)_\xi + \left(\frac{\hat{F}}{J}\right)_\eta + \left(\frac{\hat{G}}{J}\right)_\zeta = 0$$

- Where:
  - $\left(\frac{\hat{E}}{J}\right)_\xi, \left(\frac{\hat{F}}{J}\right)_\eta, \left(\frac{\hat{G}}{J}\right)_\zeta$ are fluxes
  - $\tau = \tau(t)$
  - $\xi = \xi(\mathrm{x,y,z,t})$
  - $\eta = \eta(x,y,z,t)$
  - $\zeta = \zeta(x,y,z,t)$

Spatial variables are functions of time

i

- Time step (generally) set by the highest frequency of interest anywhere in the domain
  - Most flow over-resolved in time
- Solution must be synchronized after every time step introducing scalability constraints
- Relative grid motion must be resolved between time steps to ensure alignment

Nothing happens faster than the time step allows

STMA Governing Equations

$$\left(\frac{Q}{J}\right)_{\hat{\imath}} + \left(\frac{\widehat{D}}{J}\right)_{\tau} + \left(\frac{\hat{E}}{J}\right)_{\xi} + \left(\frac{\hat{F}}{J}\right)_{\eta} + \left(\frac{\hat{G}}{J}\right)_{\zeta} = 0$$

- Where:
  - $\left(\frac{\widehat{D}}{J}\right)_{\xi}, \left(\frac{\hat{E}}{J}\right)_{\xi}, \left(\frac{\hat{F}}{J}\right)_{\eta}, \left(\frac{\hat{G}}{J}\right)_{\zeta}$ are fluxes
  - *$\hat{\imath}$ is an iterative direction orthogonal to the four space-time dimensions*
  - $\tau = \tau(x, y, z, t)$
  - $\xi = \xi(\mathrm{x}, \mathrm{y}, \mathrm{z}, \mathrm{t})$
  - $\eta = \eta(x, y, z, t)$
  - $\zeta = \zeta(x, y, z, t)$

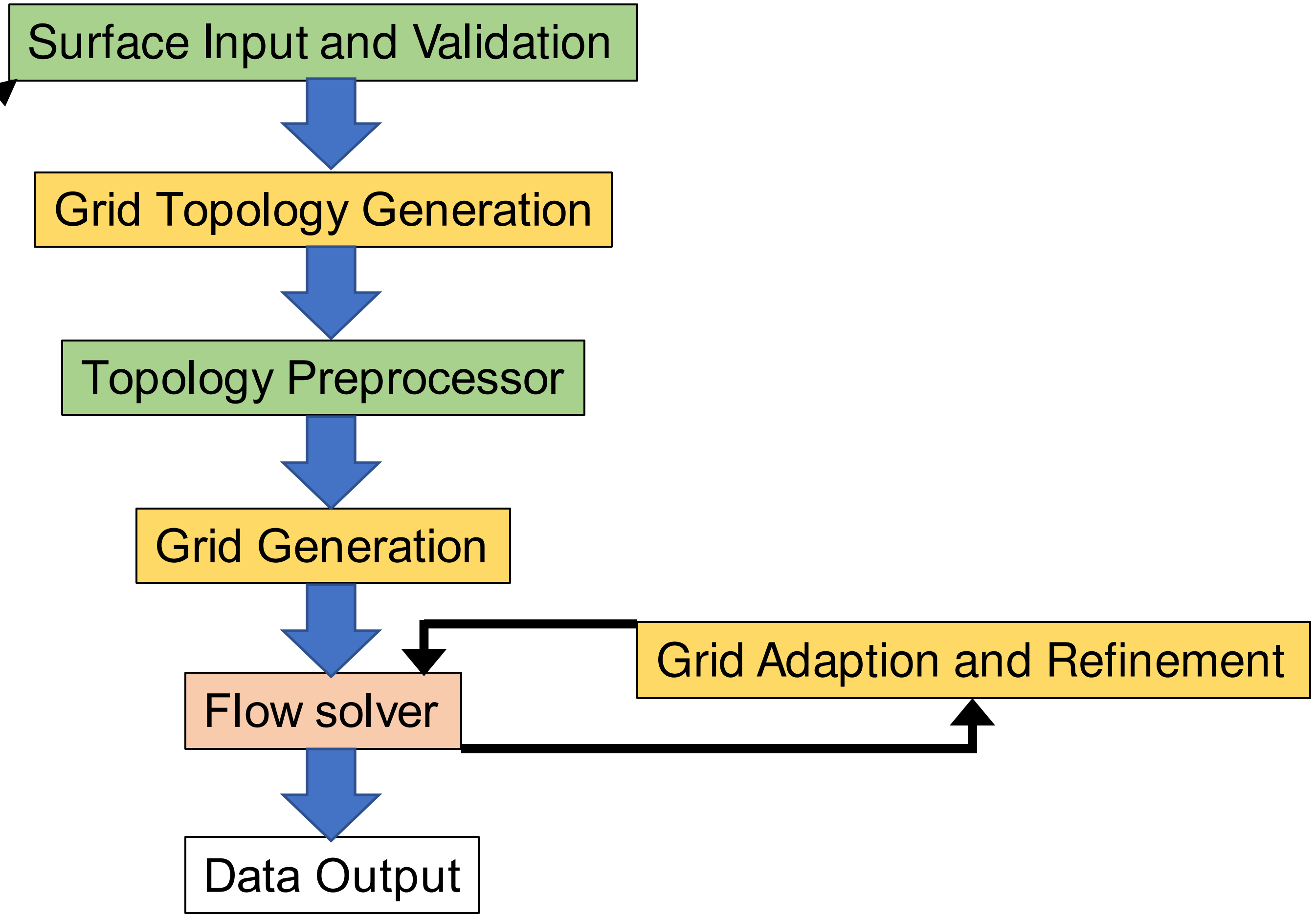
i

- In space-time, unsteady flows are solved by iterating until convergence
- Steady-state CFD methods like local time stepping and grid sequencing can be used to accelerate convergence
- The converged solution will be numerically conservative in space-time

Writing time as a function of space-time, we solve by iterating in $\hat{\imath}$ and unsteady flow problems appear as steady flow to the solver

Current Status – Surface Input and Validation

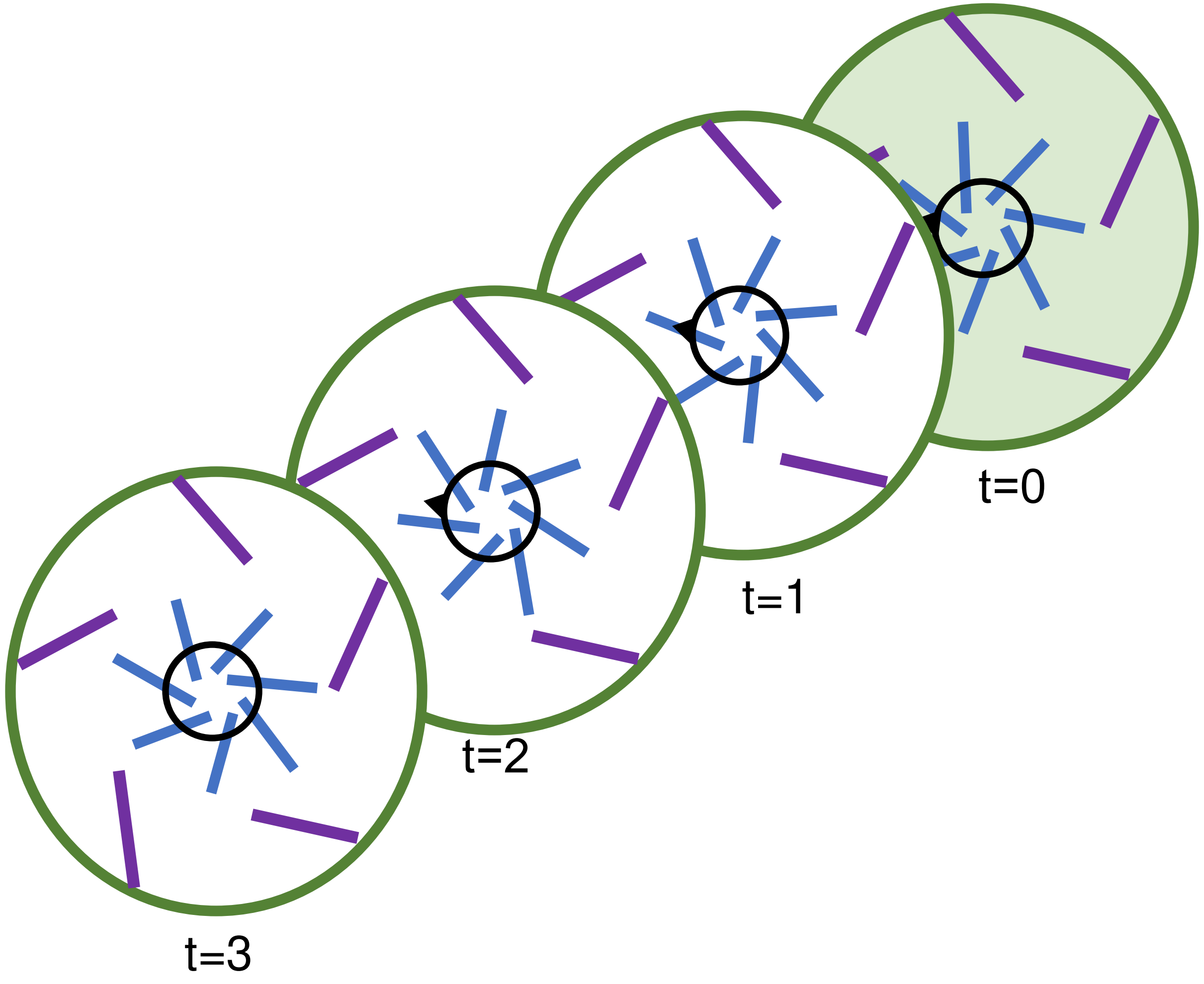
- User provides a watertight domain definition using the 4-D equivalent of an unstructured STL surface geometry
- Preprocessing routines, including connectivity and watertight checks in 3-D and 4-D complete



Step 1: The boundaries of the domain are specified by the user and tested to make sure they're valid.

User 4-D Space-Time Input

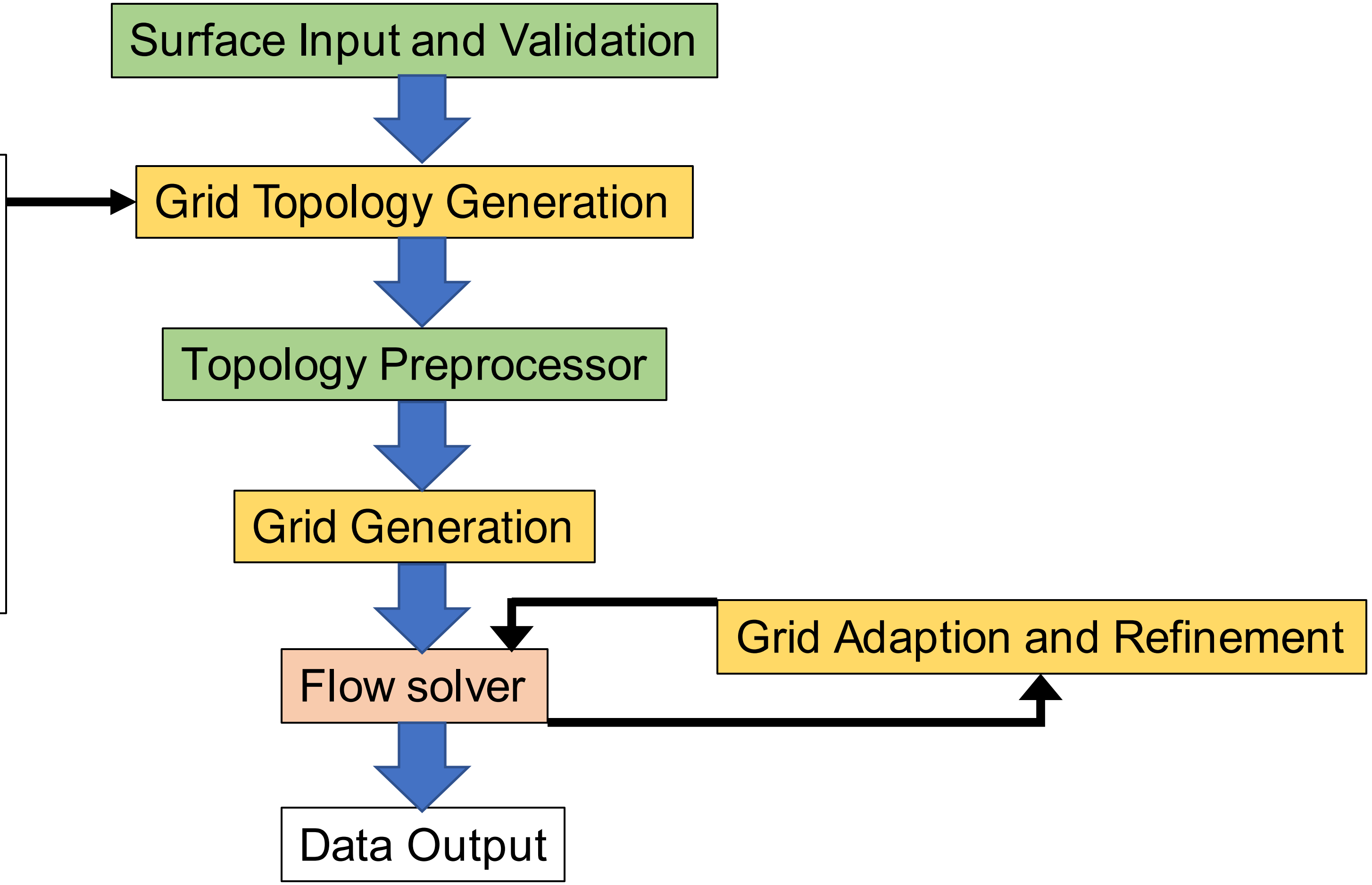
- User starts with unstructured 3D STL at each time level for geometry movement
- 3D STL files are stitched together to make 4D unstructured STL-like geometry
- Current Status:
  - 4D STL are hand generated
  - Plans to create automated geometry stitching tool (after flow solver is running!)



User needs 4D input but only really has access to 3D geometries;
Time can be separated from Space in geometry development

Current Status – Grid Topology Generator

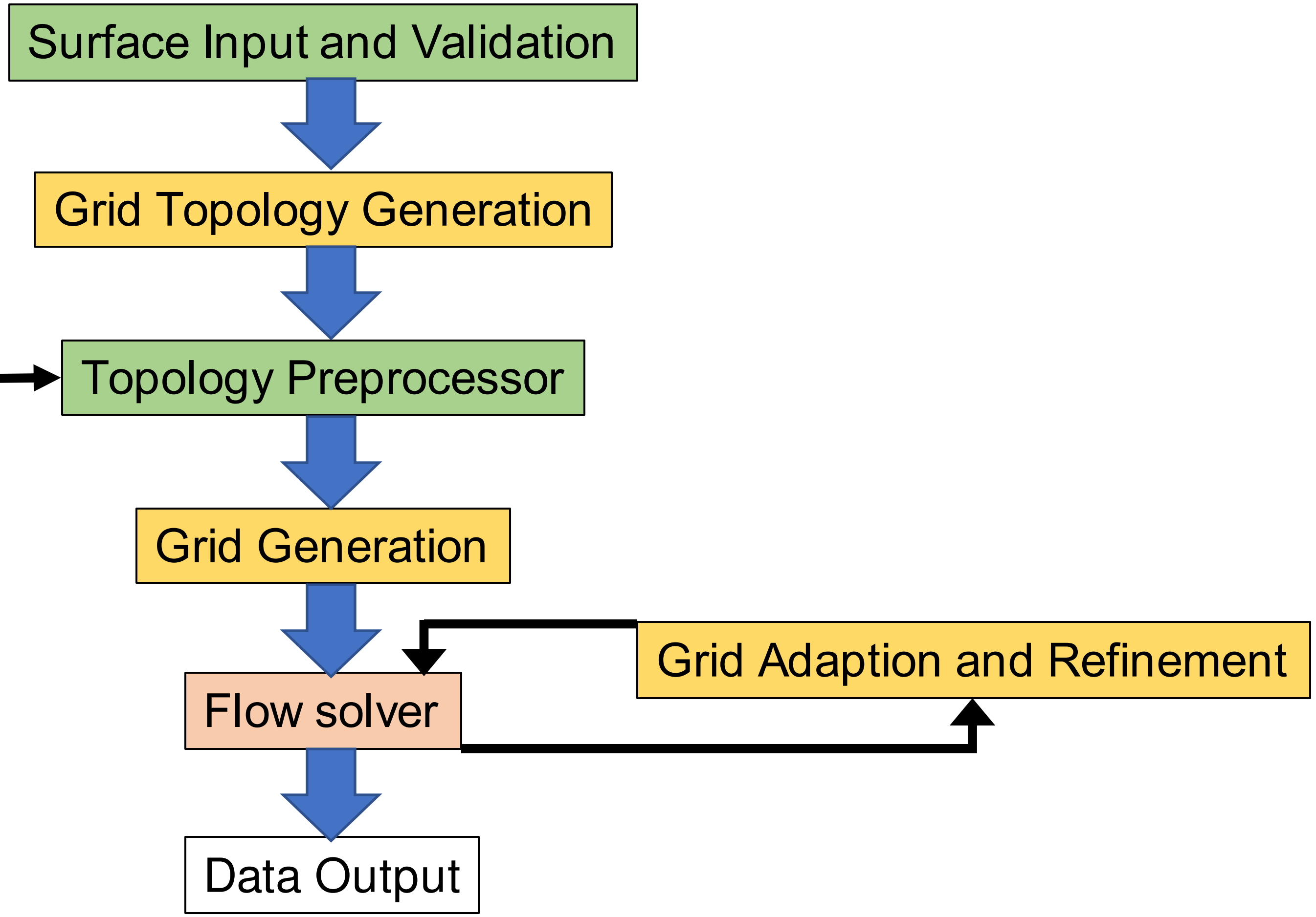
- Refinement methods and templates developed in 2-D, 3-D, 4-D
- Routines to efficiently identify the nearest surface elements are being developed
- Coding for Cartesian grid topology generator in 2-D, 3-D, 4-D underway



Step 2: A body-fitted, full-face-matching initial framework for the grid is determined.

Current Status – Topology Preprocessor

- Given full-face-matching structured multiblock topology:
  - Checks topology is valid
  - Generates block connectivity
  - Finds grid singularities
  - Generates boundary connectivity
- Topology preprocessor is complete and passed initial verification tests in 2-D, 3-D, 4-D

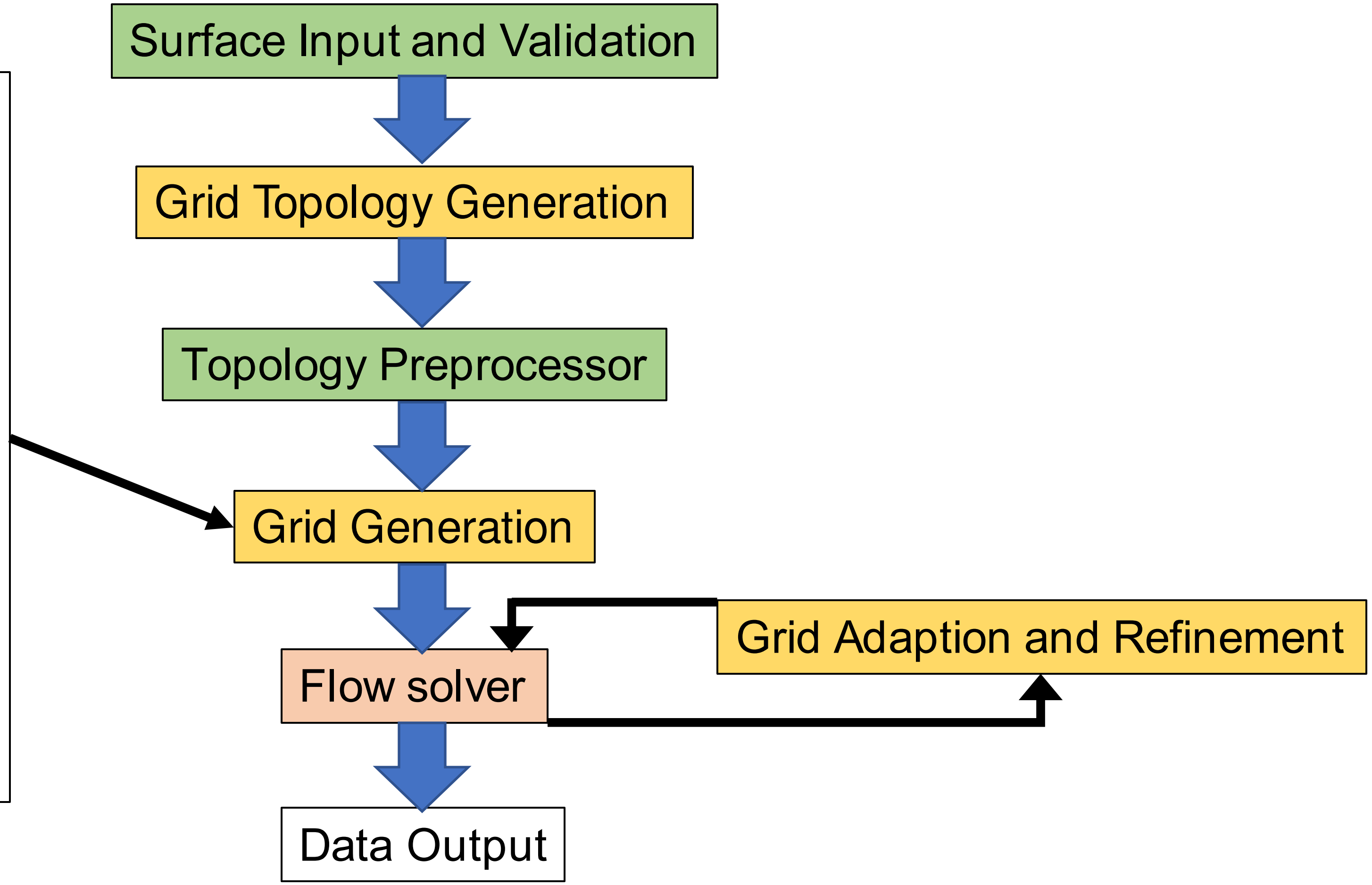


Step 3: The grid topology is checked, and the necessary geometric data for the grid generator and flow solver is determined.

Current Status – Grid Generator

- Takes topology and iteratively generates smooth grid using elliptic equations
- Includes grid refinement and adaptation routines

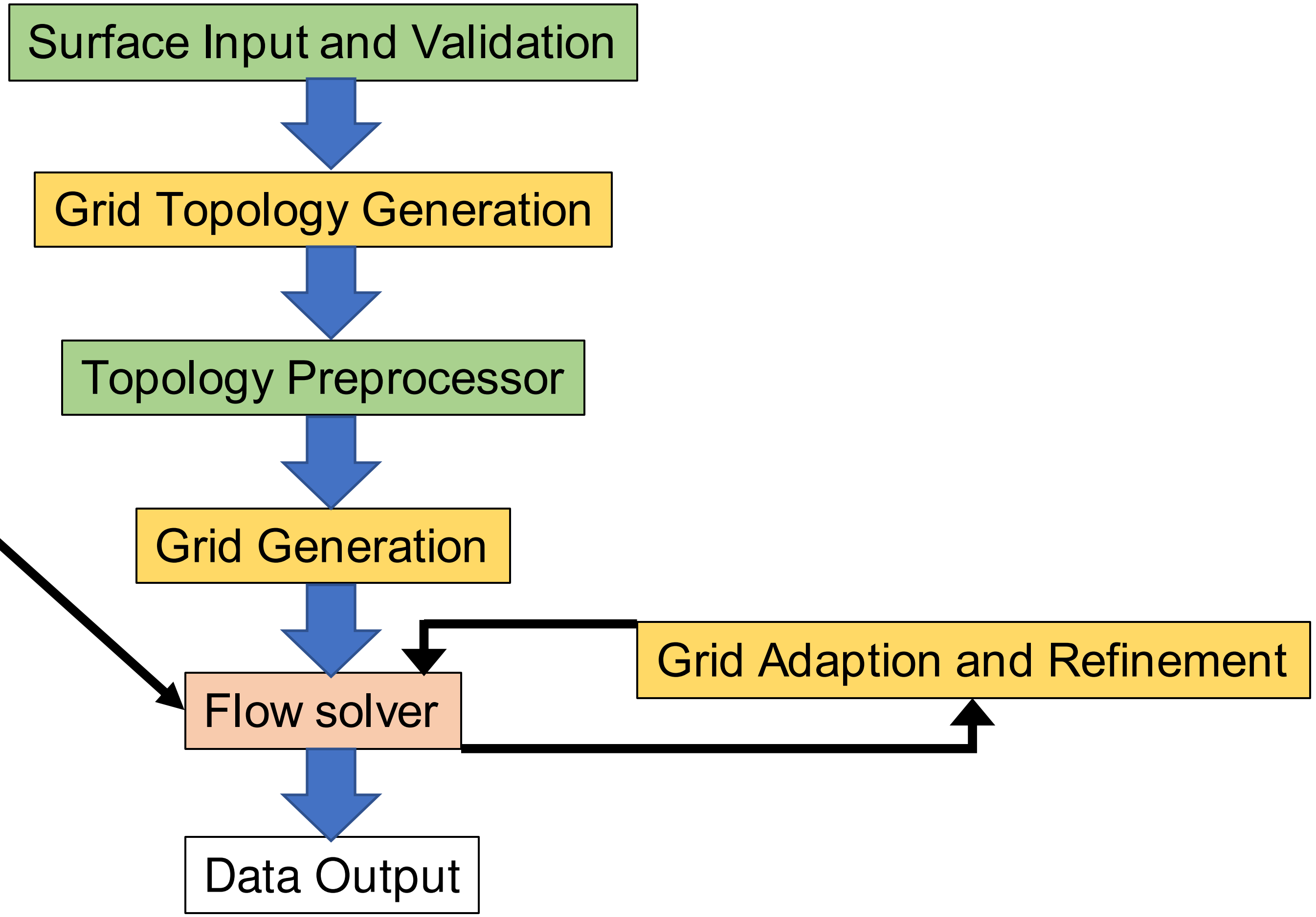
- Current Status:
  - Nonlinear multigrid routines have been coded and tested
  - Block solvers for grid generation equations have been coded and tested (hardwired) in 2-D and 3-D
  - Now being extended to multiblock topologies



Step 4: A smooth body-fitted curvilinear grid is generated, with specified clustering.

Current Status – Flow Solver

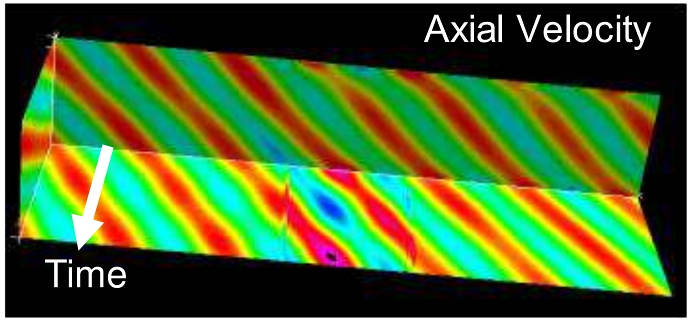
- Unsteady space-time flow solver:
  - Choice of 6th order or optimized 4th order differencing in space and time
  - 4-D implicit solver using grid sequencing and multigrid methods
- Current Status:
  - Implicit solution techniques developed for 4-D (LU-SGS)
  - Implicit solution techniques for 4-D ADI are under investigation
  - Flow solver relies on many of the grid generation routines where development has been focused

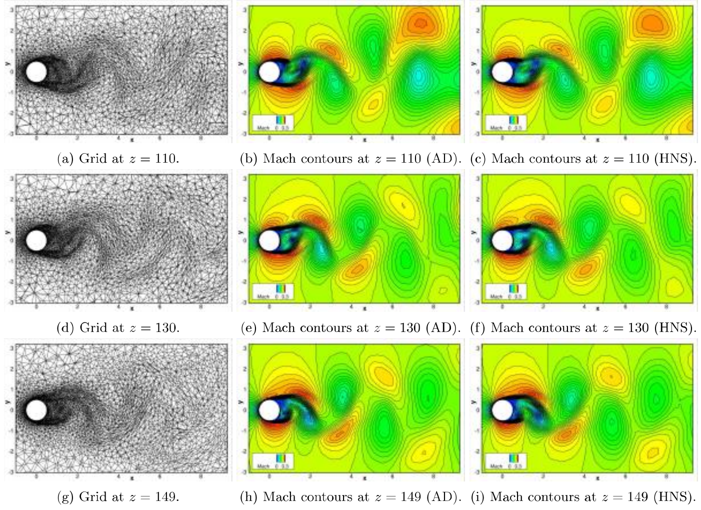


Step 5: The unsteady flow solution is determined, adapting and refining the grid as needed.

Next Steps and Timeline

- Trial grid generator in 4D (January 2023)
  - Hand-built topology for testing Topology Preprocessor and Grid Generator
- Trial flow solver in 4D (April 2023)
  - Uses trial grid without Grid Adaption and Refinement
  - Verify convergence in full 4D simulation
- Topology Generator and Grid Adaption and Refinement to follow starting Summer 2023
- Building toward Low Pressure Ratio (LPR) Fan simulation in 4D





(a) Grid at $z = 110$. (b) Mach contours at $z = 110$ (AD). (c) Mach contours at $z = 110$ (HNS).
(d) Grid at $z = 130$. (e) Mach contours at $z = 130$ (AD). (f) Mach contours at $z = 130$ (HNS).
(g) Grid at $z = 149$. (h) Mach contours at $z = 149$ (AD). (i) Mach contours at $z = 149$ (HNS).

Building a new CAA capability for unsteady flows with high-accuracy in time and space at significantly less computational cost

Progress Toward a New System Noise Liner Prediction Method

Jason June, Doug Nark, Jordan Kreitzman

PAA & ASN and Liner Physics Teams

Fall Acoustic Technical Working Group Meeting

10/18/22

Motivation and Goal

Recent system noise assessments indicate high importance of fan noise (source, liner, & propulsion-airframe aeroacoustics) on overall prediction accuracy

Develop a system-noise-compatible acoustic liner prediction method applicable to current and future aircraft nacelles, improving physical fidelity and accuracy over available methods.

system-noise-compatible
- low-cost model evaluation
- compact feature space
- large design domain

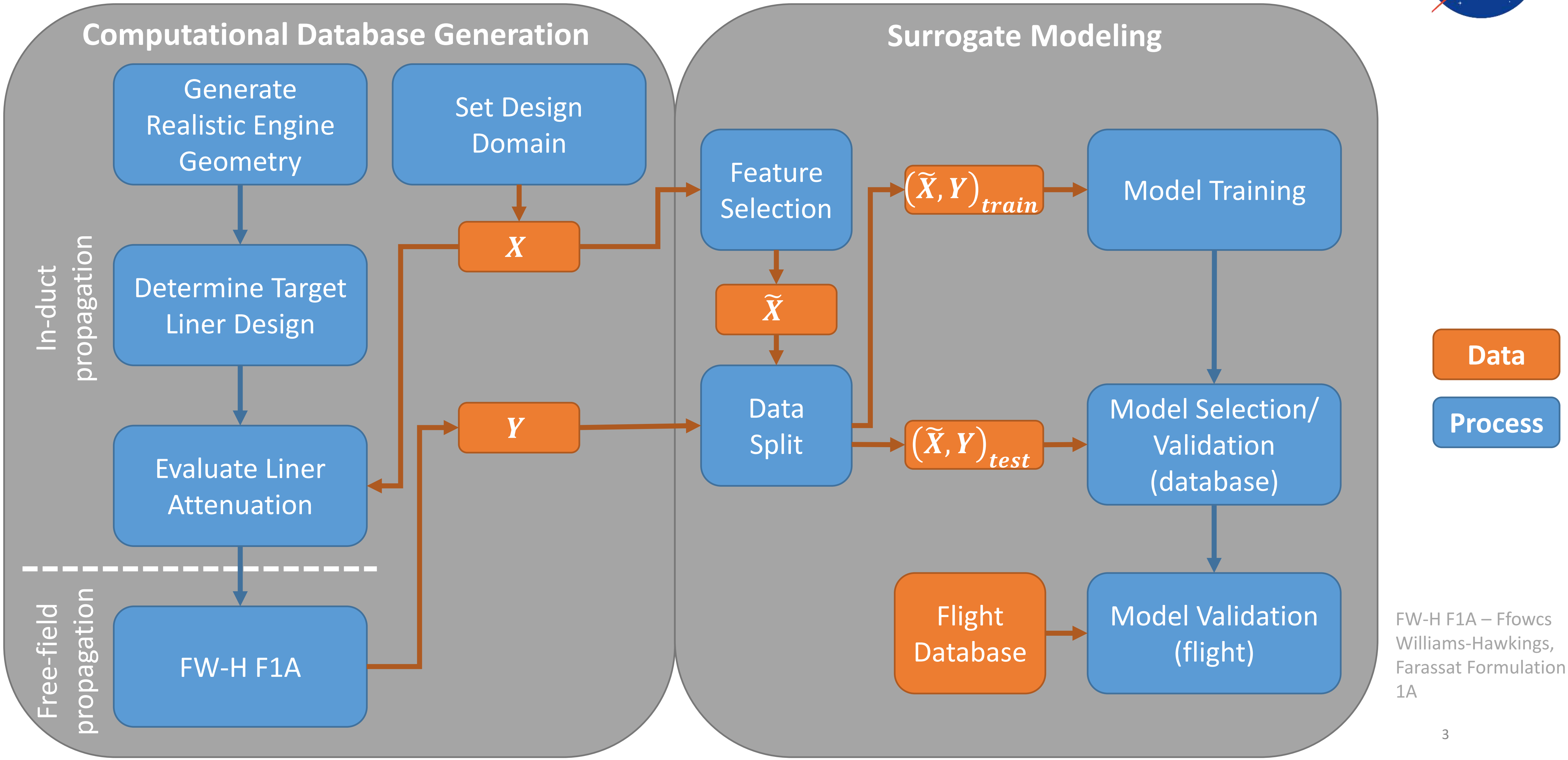
current and future aircraft
- realistic geometry
- liner design flexibility
- constrained to computational approach

improving physical fidelity
- narrowband
- azimuthal dependence
- fan source specific modeling

improving … accuracy
- out-of-sample
- flight validation

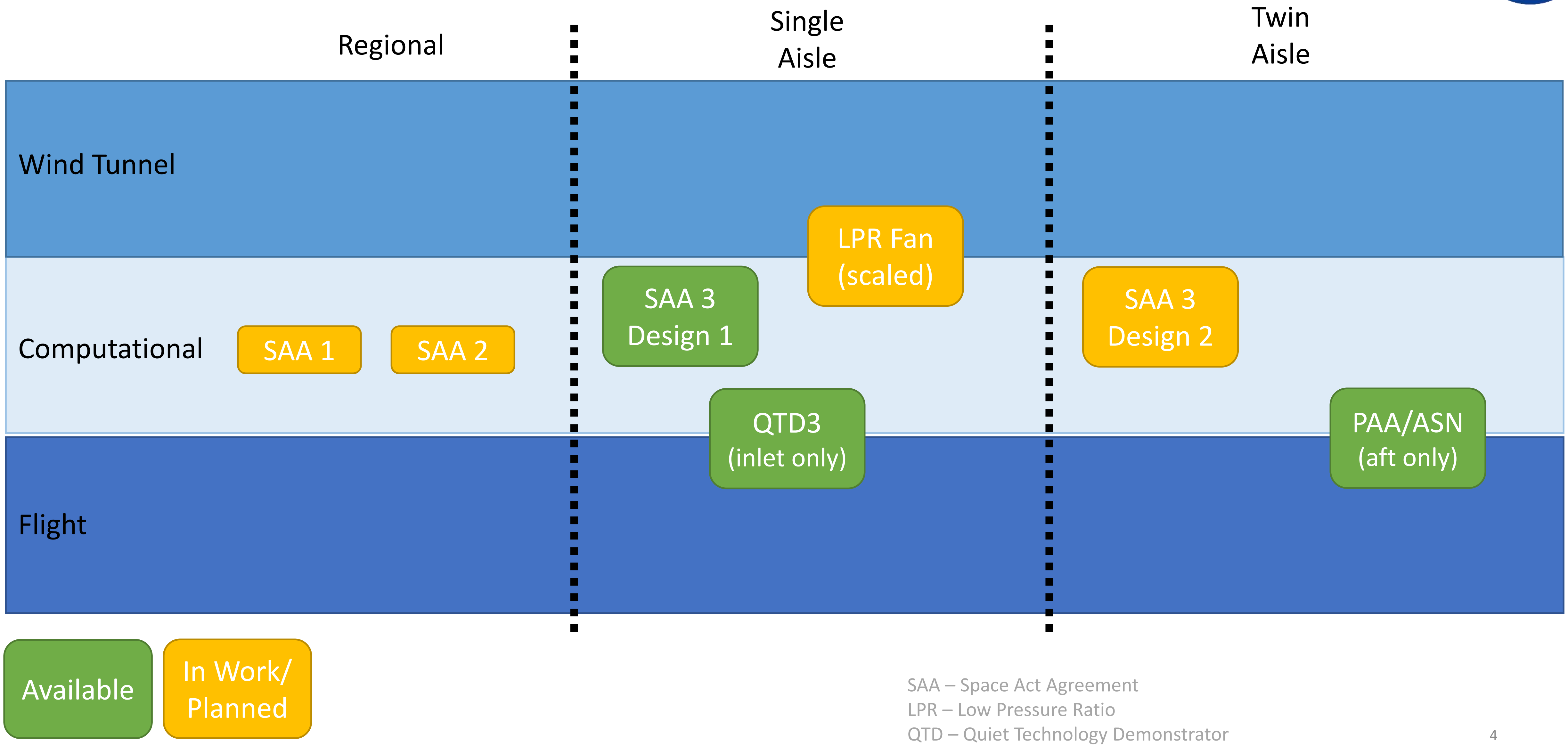
Limit scope to inlet for initial modeling iteration

Proposed Approach



FW-H F1A – Ffowcs Williams-Hawkings, Farassat Formulation 1A

Notional Model Data Sources



SAA – Space Act Agreement
LPR – Low Pressure Ratio
QTD – Quiet Technology Demonstrator
PAA/ASN – Propulsion Airframe Aeroacoustics/Aircraft System Noise

Liner Optimization Procedure

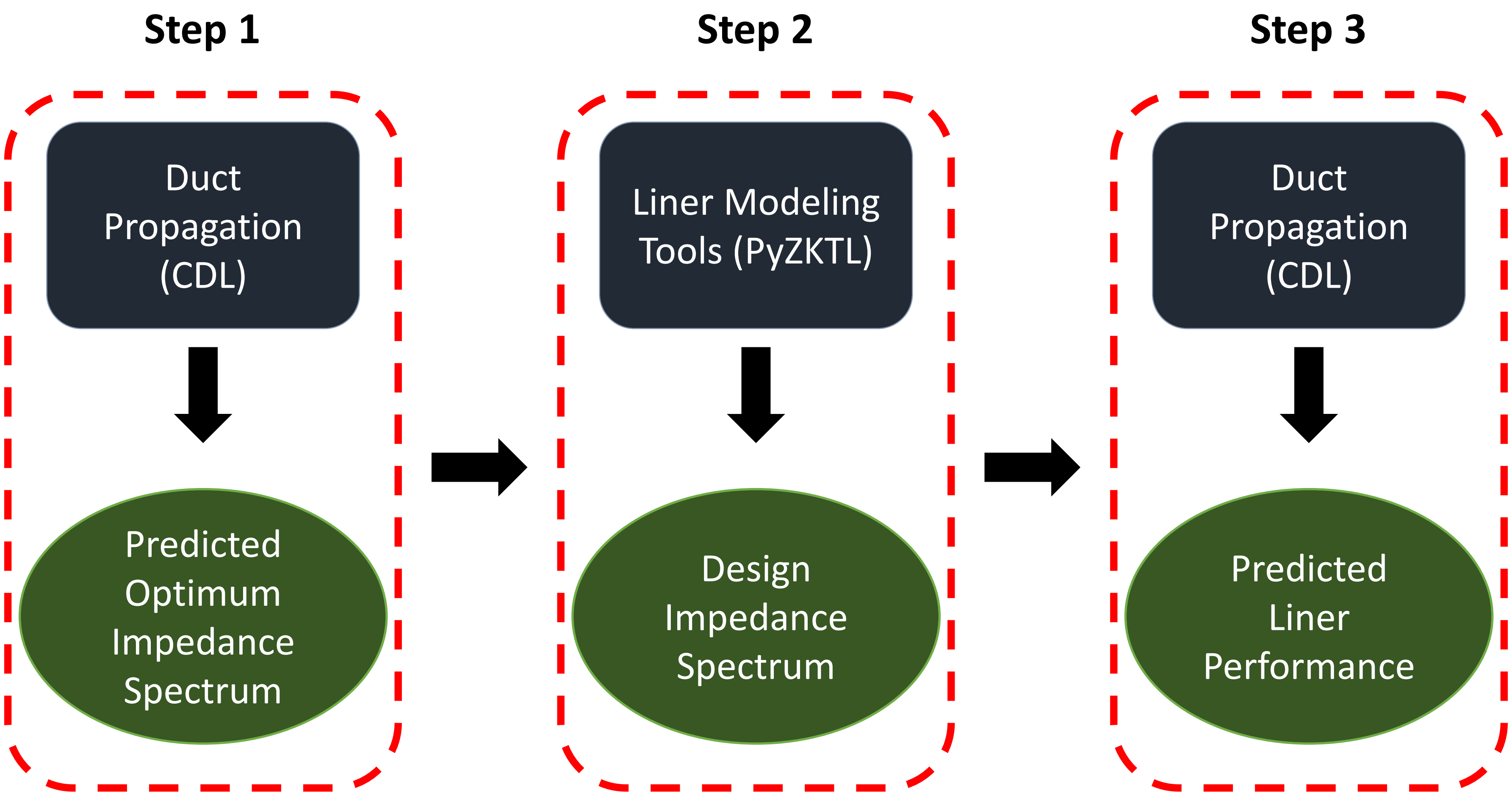


Figure adapted from: Nark & Jones AIAA 2019-2764 presentation

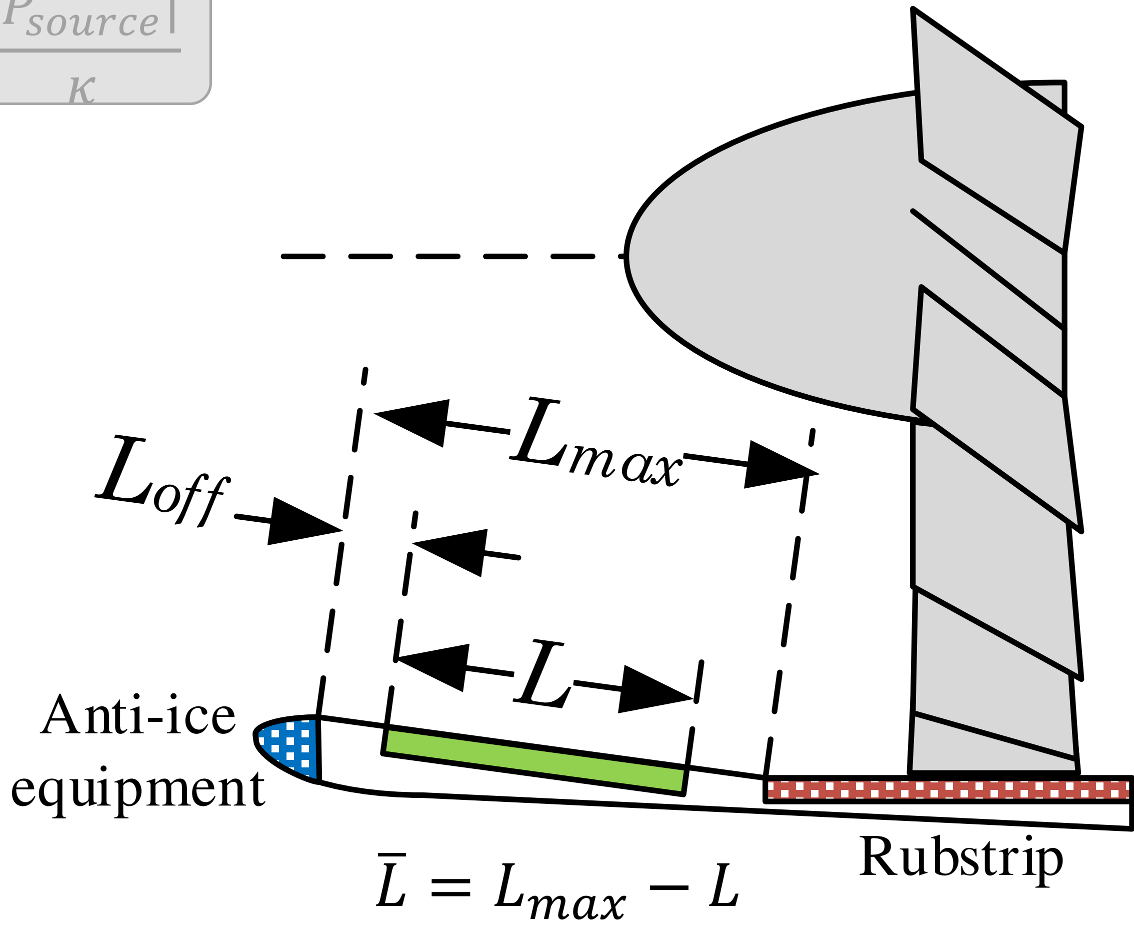
CDL – CDUCT-LaRC
PyZKTL – Python wrapped Zwikker-Kosten Transmission Line

Feature Space – Inlet Dimensional Analysis

- Gather all* scales from governing equations and nondimensionalize

$$\Delta SPL \sim \theta, \frac{L}{D}, He_D, Ma, \phi, \frac{\bar{L}}{D}, \frac{L_{off}}{D}, \zeta, \frac{D_{spinner}}{D}, \frac{|P_{source}|}{\kappa}$$

- For "proof of concept" modeling, start with single:
  - Engine geometry
  - Liner design architecture
  - Source level
- Past ANOPP model dependencies
  - GE TREAT[1]
  - Magliozzi[2]
- Expect minimal role of unlined and offset lengths



*additional spatial scales from realistic geometry not included here

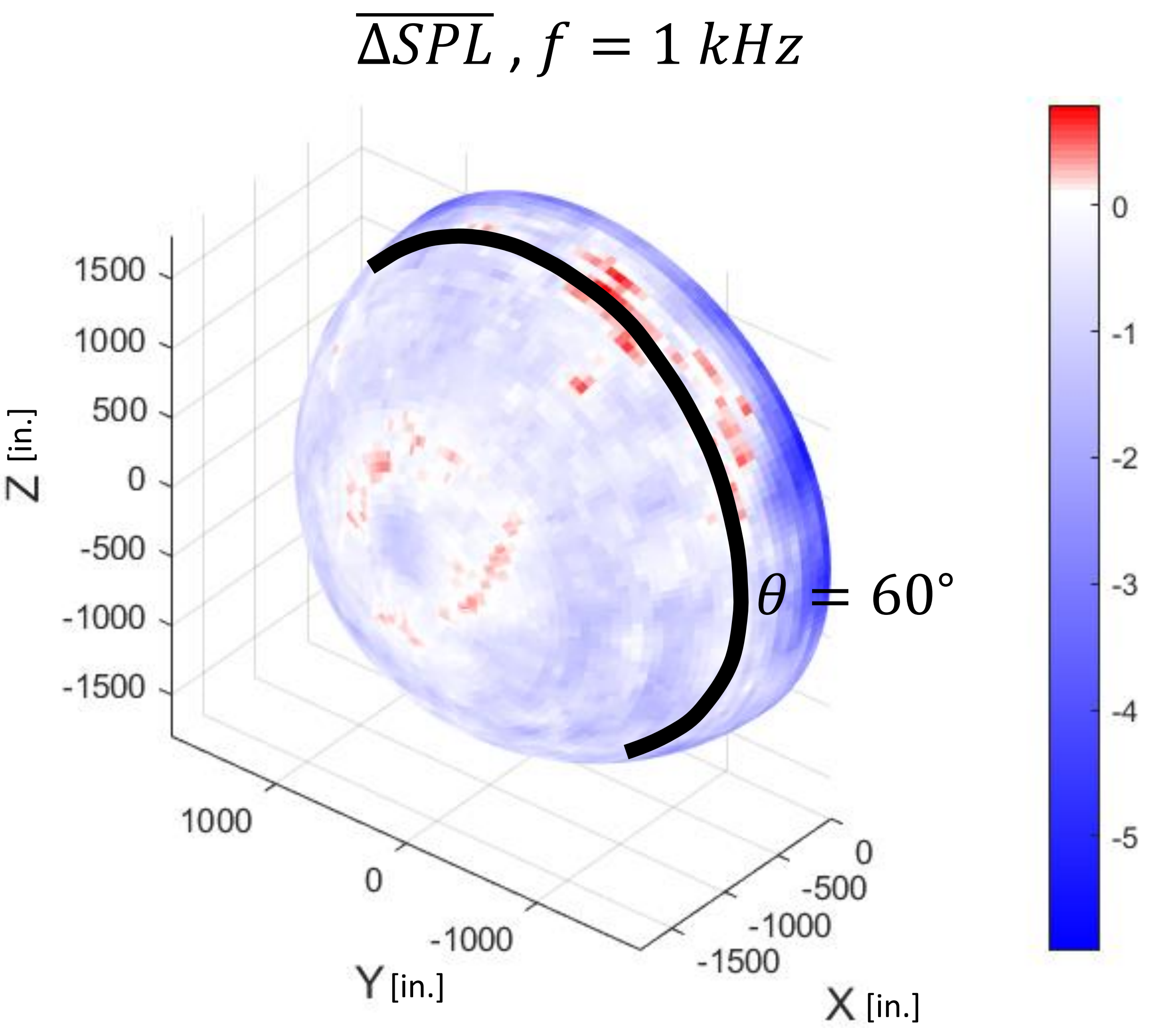
[1] Kontos, K. B., Kraft, R. E., Gliebe, P.R. NASA CR 202309, Vol. 2

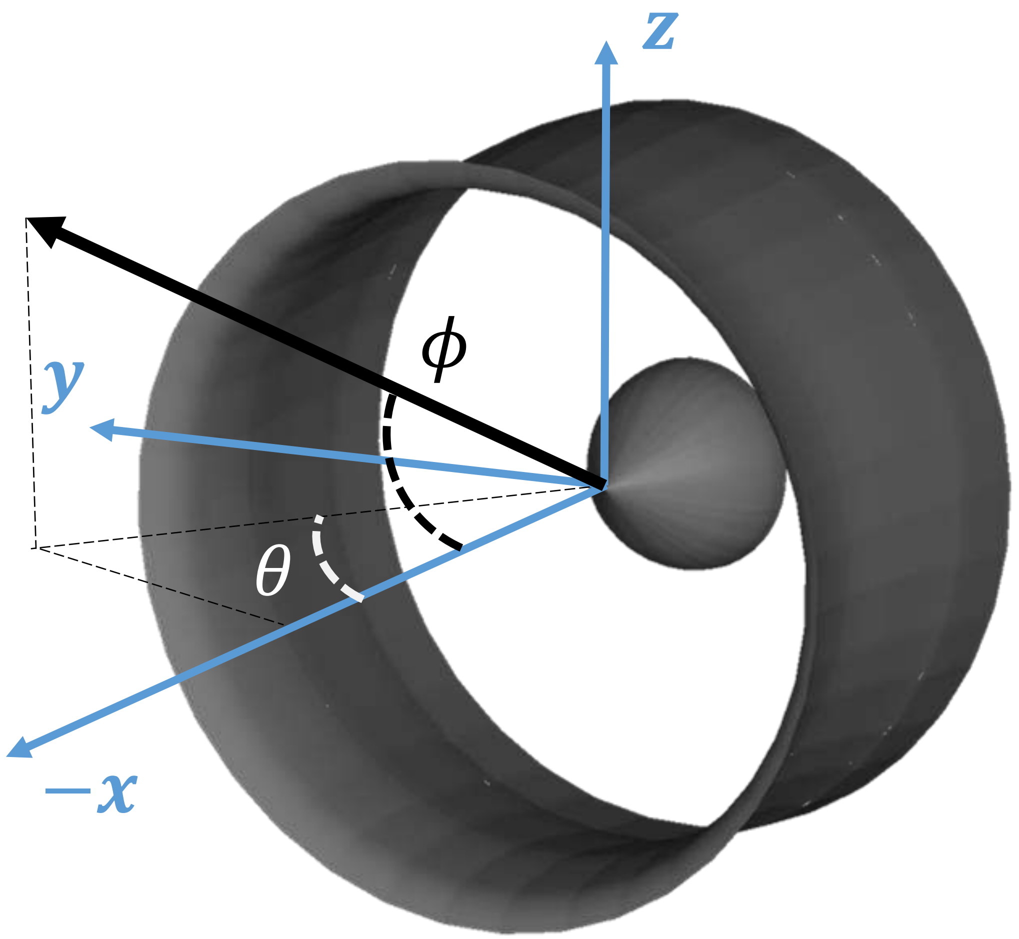
[2] Magliozzi, B. FAA-RD-76-49, Vol. 1-3

Exploratory CDL Database

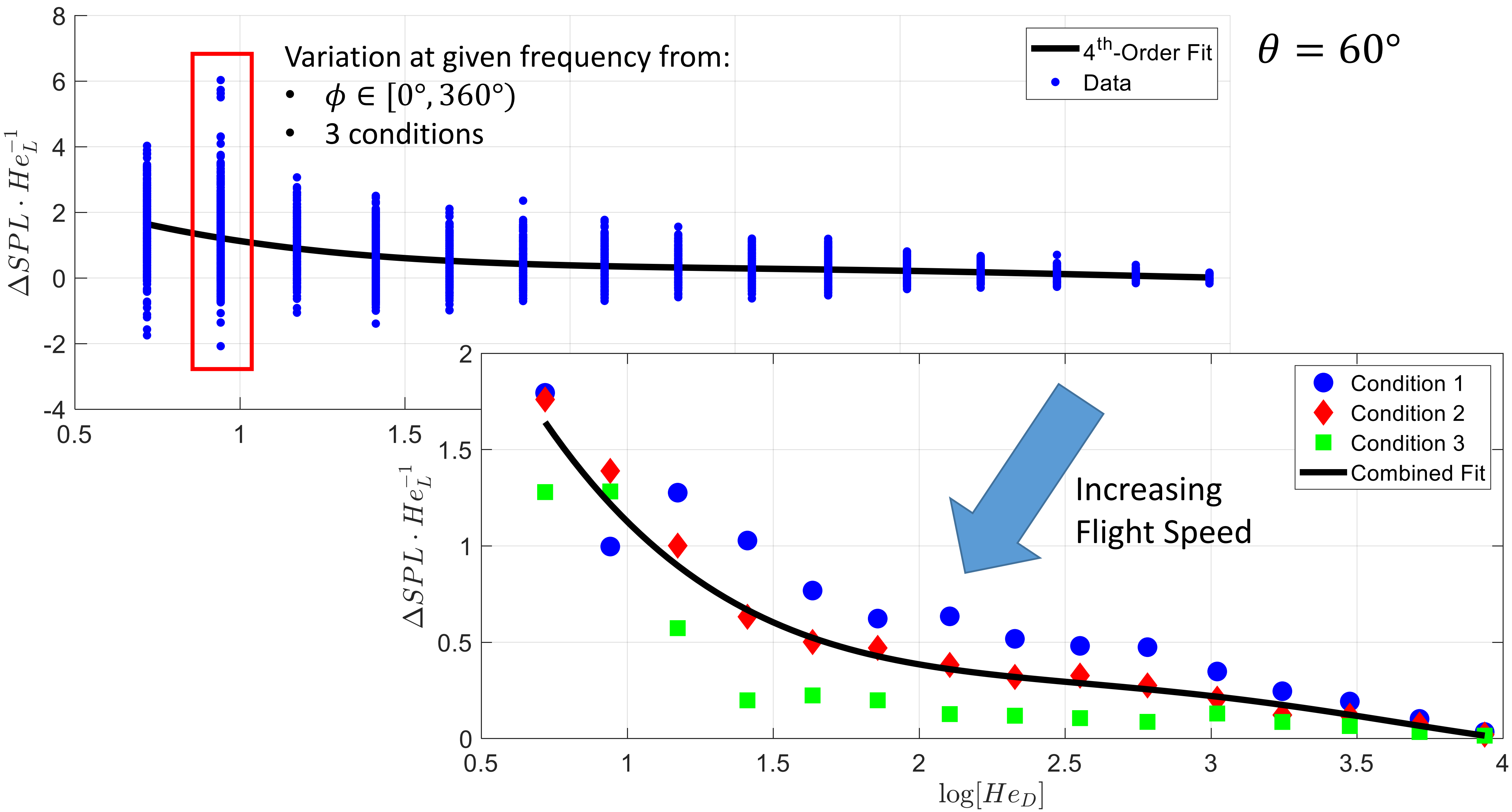
- Optimized 3DOF liner for QTD3 inlet geometry
- Three engine operating points
- Fixed liner length and position
- Center-band frequencies (400 Hz – 10 kHz)
- Inlet observer hemisphere with 2° resolution
- 100 random phase/amplitude combinations of all modes (with cut-on ratio > 1.25)

Representative Attenuation Azimuthal Dependence



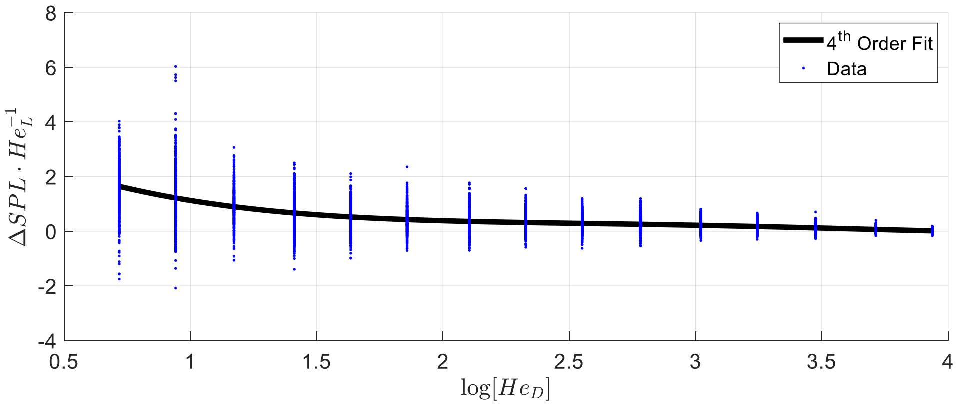


TREAT: Overfitting & Model Bias

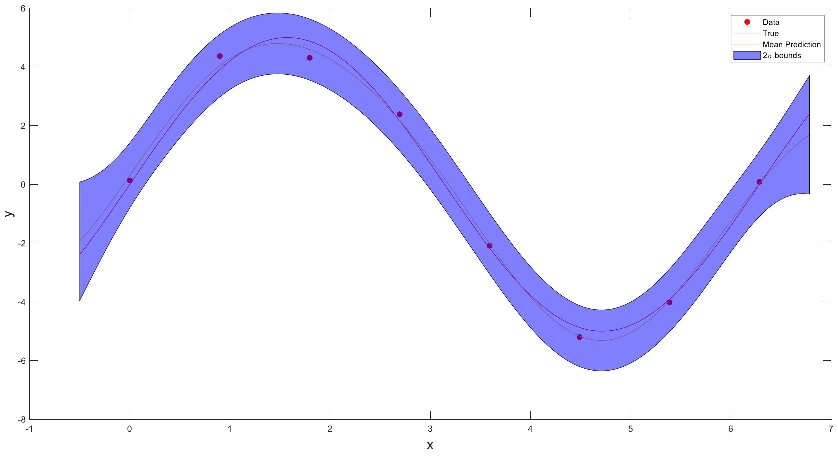


Possible Surrogate Modeling Techniques

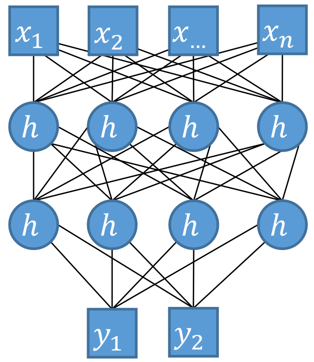
Polynomial Basis Functions



Gaussian Process



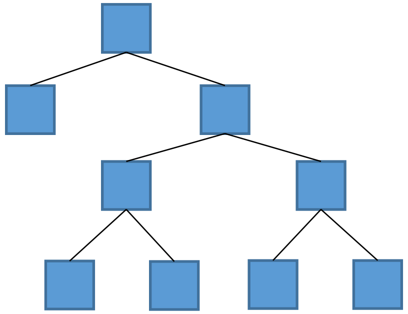
Neural Network



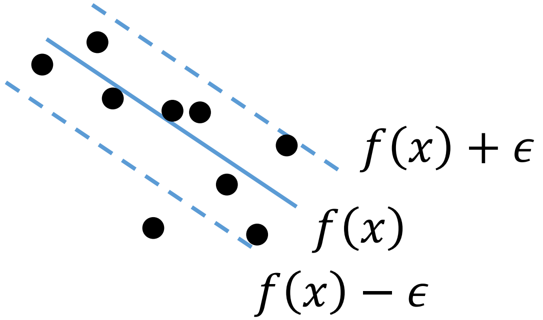
Primary Candidates

Secondary Candidates

Decision Trees

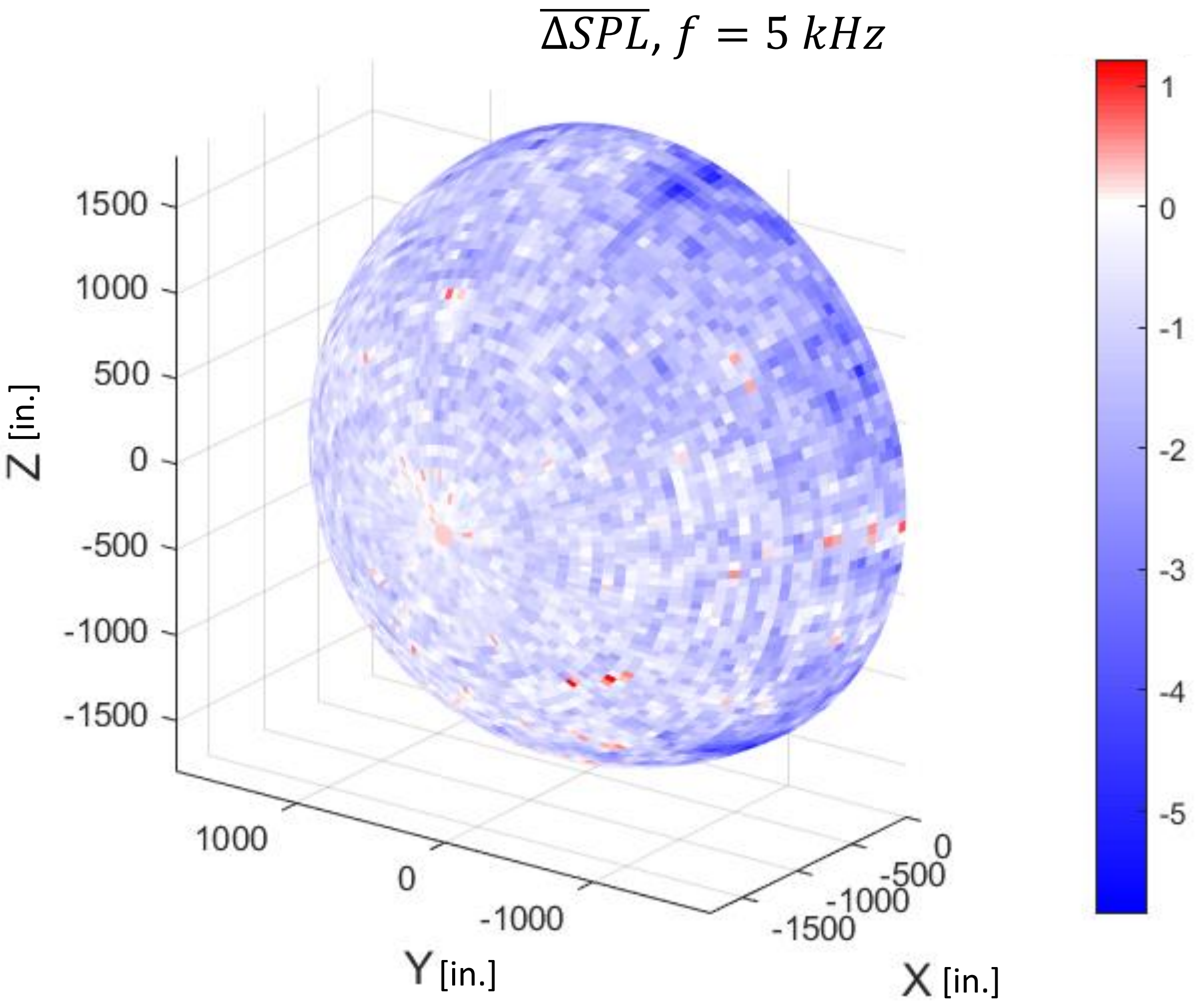


Support Vector Regression



Some Challenges…

- Dimensionality
  - Rich spatial content
  - Far-field statistic convergence of random modal inputs
  - Noise reduction technologies (e.g., inlet scarf)
- Choosing objective function for ‘optimal’ liners
- Generalization to different geometries
- Sparse (in some features) flight test validation data



Summary

- Clear opportunity and need for improved system noise acoustic liner prediction
- General plan in place for database generation
- Seeking feedback/experience on past usage of regression modeling (including ones not mentioned here) on similar applications
- Multistage expansion of design space planned for additional tool capability
    - Full set of available geometries (inlet and aft duct)
    - Different liner design architectures
    - Adaptation for tonal noise attenuation
    - Noise reduction technologies
    - Multifidelity modeling (e.g., ACTRAN)

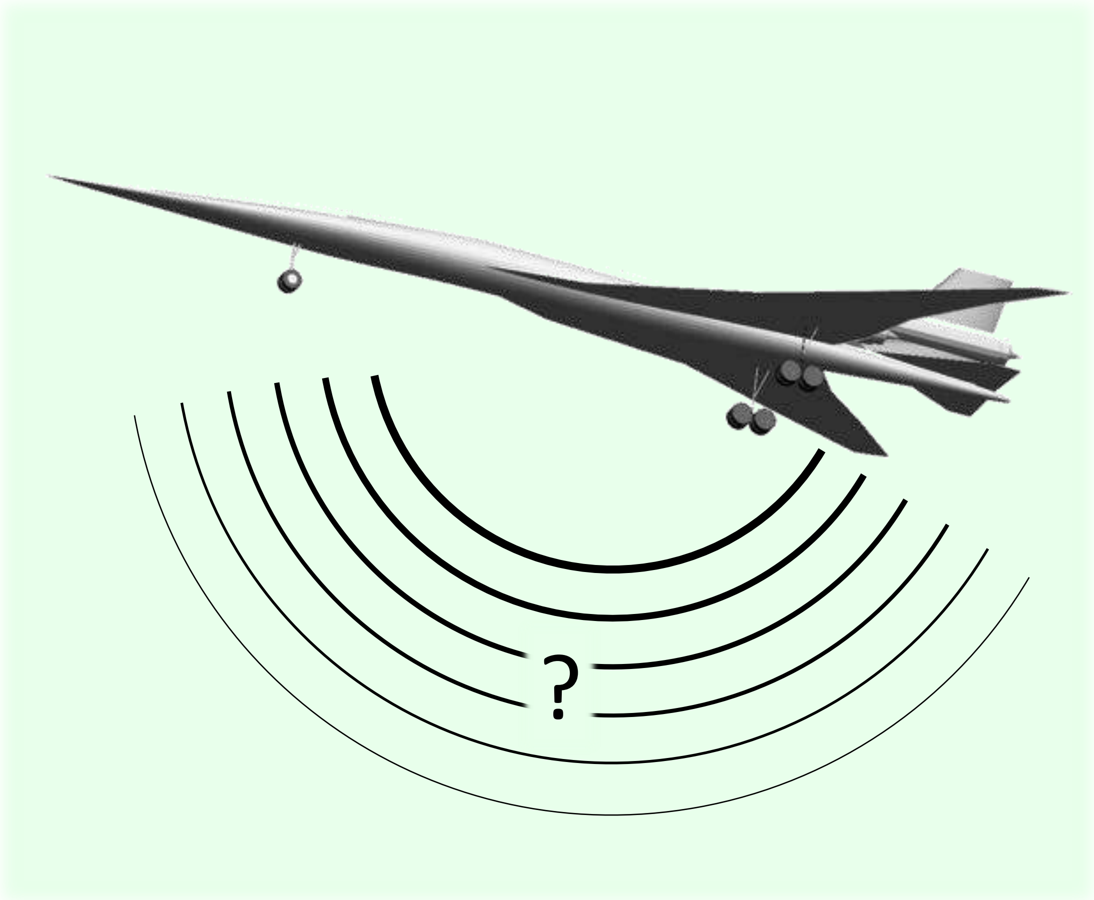
The Advanced Air Transport Technology project is gratefully acknowledged for funding this work.

NASA

Tuesday Afternoon

Update on Prediction Uncertainty Reduction (PUR) Tech Challenge

Commercial Supersonic Technology
NASA Acoustics Technical Working Group Meeting
19 Oct 2022



James Bridges, Airport Noise Tech Lead
NASA Glenn Reseach Center
james.e.bridges@nasa.gov

Major contributors:
NASA Glenn: Alexander Svetgoff, David Stephens, Ed Envia, Brenda Henderson, Lennart Hultgren, Mark Wernet, Patrick Brandt
NASA Ames: Gerrit Stich, Aditya Ghate, Jeffrey Housman, Cetin Kiris

Outline

- PUR goal
- Approach
- Recent progress
  - Fan noise simulations—source+propagation validation on SDT and ADP, source calculations on SuperFan
  - Jet noise simulations—validation review, initial runs of Plug20 configs
  - NATR refurbish completed, Plug20 test completed
  - Learjet test (Henderson, Revesz)
  - Modification of empirical component models
    - Fan (Brandt)
    - Jet
- Next steps

Tech Challenge: Prediction Uncertainty Reduction (PUR)

- Uncertainty in prediction of LTO noise of future supersonic commercial aircraft is a significant risk for market development.
- Uncertainty in prediction of LTO noise is primarily associated with **configuration differences** between conventional and supersonic aircraft.
- Current empirical noise models not based on supersonic configurations.
  - Baseline assessment* shows 5+EPNdB difference in uncertainty predicting noise of Supersonic aircraft relative to Conventional aircraft
- Tech Challenge approach

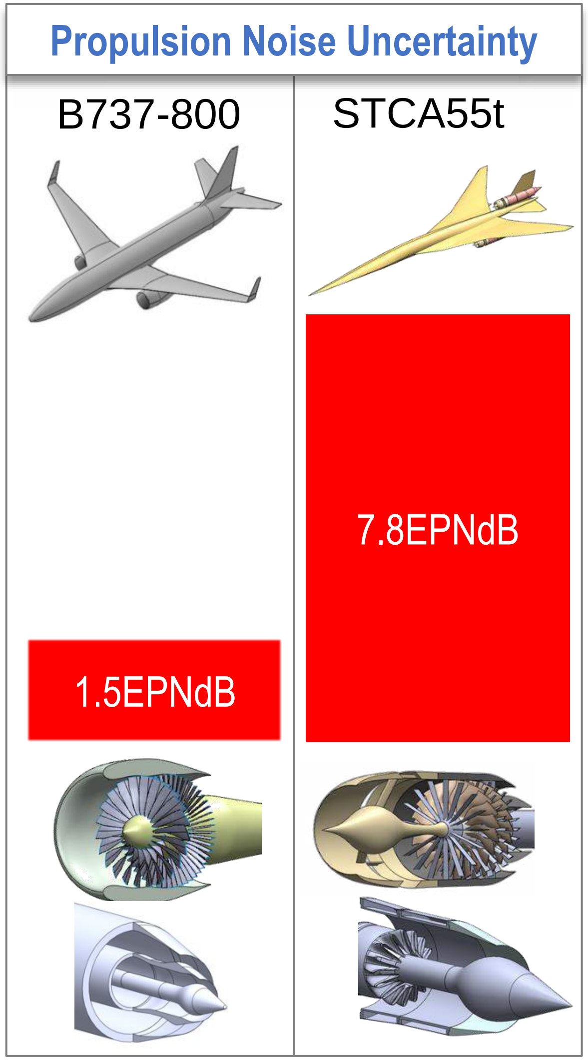
– Obtain relevant inlet, fan, and nozzle designs from OEM input.

– Validate physics-based simulations (PBS) against rig data for conventional configs.

– Use physics-based simulations (PBS) of supersonic configs to produce ‘data’.

– Modify empirical models using PBS data for future studies.

**Bridges, Stephens, and Berton, “Quantifying Uncertainty of Landing and Takeoff Noise for Commercial Supersonic Aircraft,” doi: 10.2514/6.2022-3051.*



Fan PBS validation—SDT & ADP test cases

Ed Envia, David Stephens, Alexander Svetgoff

Objective

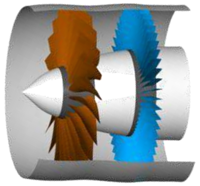
– Predict radiated sound, compare with experimental data.
– Establish expected error for PBS fan noise toolchain.

Approach

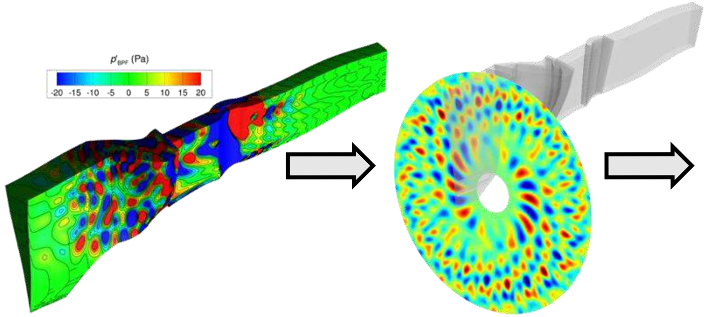
– RANS/URANS/NLH (FINE/Turbo) gives pressure perturbations.
– Actran iTM to extract mode amplitudes.
– Mode amplitudes input to propagation codes (Actran & COMSOL).
– Sideline noise predicted and compared with experiment.

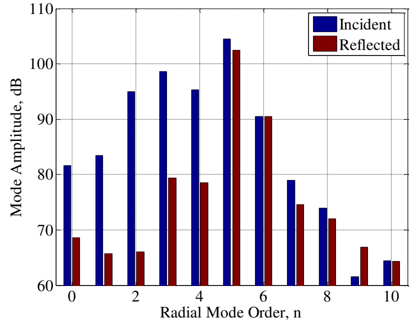
Status

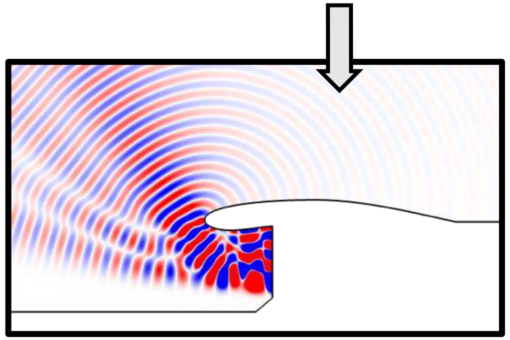
– Workflow established and documented
– Consistent definition of ‘modes’ between codes found.
– Eight speeds, multiple tones simulated for SDT test.
– Liner insertion loss for two liners, 11 speeds for ADP test.
– Statistical results being documented for external review.
– AIAA Aviation paper in works.

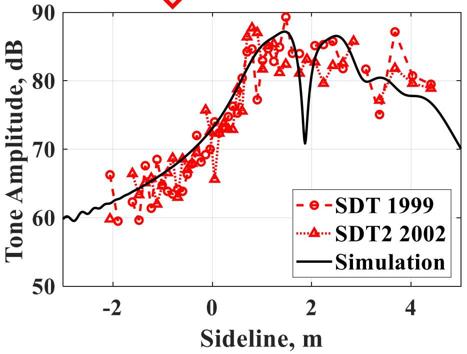


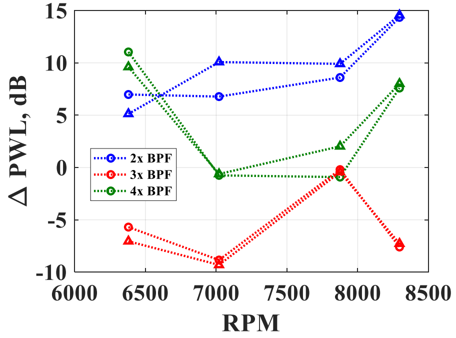
SDT fan











Jet PBS validation

Gerrit-Daniel Stich, Aditya Ghate, Jeffrey Housman, Cetin Kiris

Objective

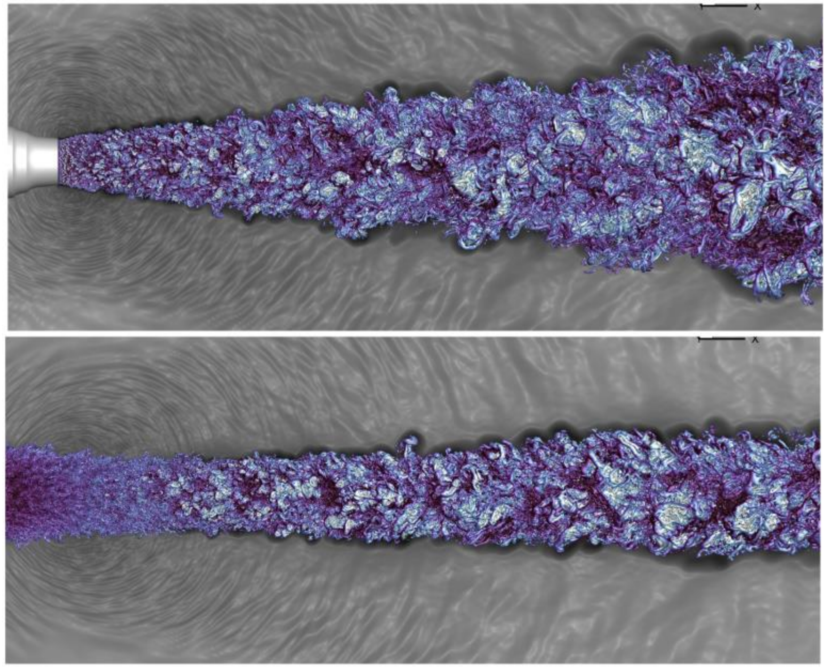
- Predict radiated sound, compare with experimental data.
- Establish expected error for PBS jet noise tools.

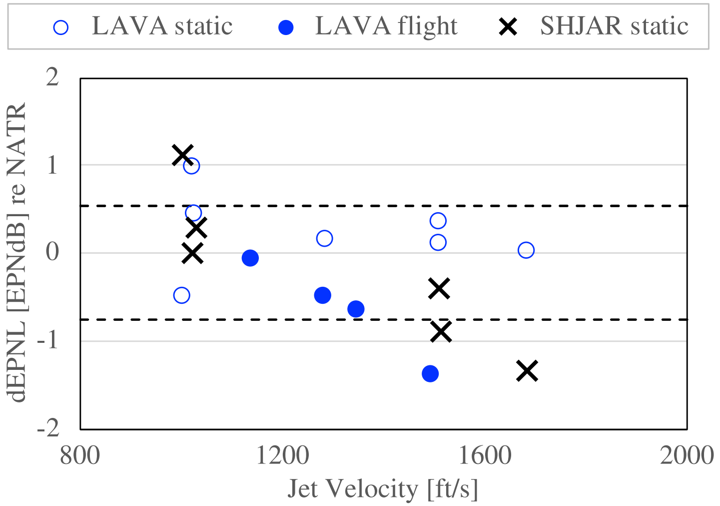
Approach

- Heated single-stream jet flows, static and in flight, from NASA rigs
- LES simulates flow, far-field acoustics
  - LAVA: structured overset grid, wall-modeled LES, FW-H
- Validate flow statistics with PIV, far-field noise

Status

- Completed simulations, created statistics of deviations from rig data.
- Held external review of methods, results
  - ***Deviations of rig-LES were statistically same as rig-rig for static cases***.





Stich, Ghate, Housman, and Kiris, "Wall-Modeled Large-Eddy Simulation of Jet Noise in Flight Conditions," doi: 10.2514/6.2022-3002.

Initial LES of Plug20 Configuration

Gerrit-Daniel Stich, Aditya Ghate, Jeffrey Housman, Cetin Kiris

Objective

– Extend ‘validation’ to existing supersonic configurations—Plug20.

Approach

– Apply LAVA/structured/WMLES to exhaust systems with internal mixers, plugs.

– Validate against PIV and far-field acoustic data.

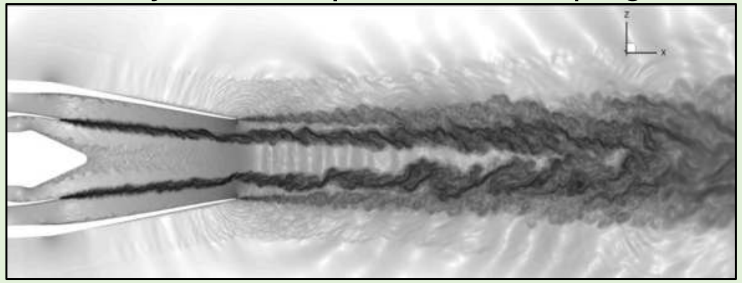
Status

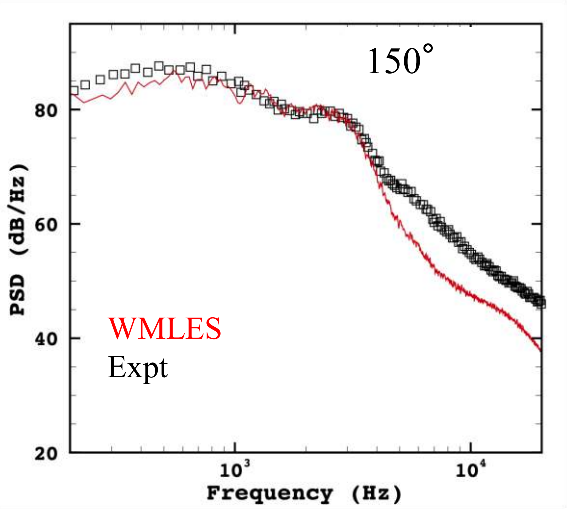
– Acoustic results for axisymmetric cases complete.

– Gridding approach developed for lobed mixers.

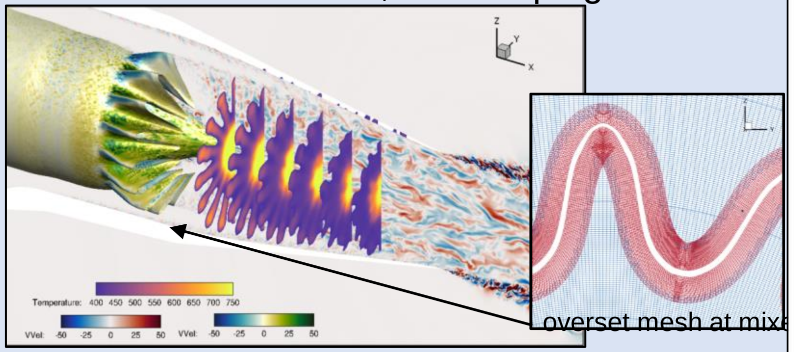
– **Preparing to generate Plug22 noise database.**

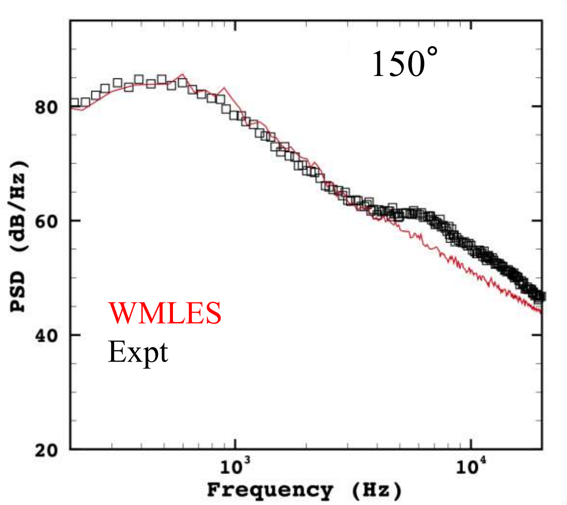
Axisymmetric splitter, internal plug





Lobed mixer, internal plug





Refurbishment of Nozzle Acoustic Test Rig (NATR)

James Bridges, David Stephens

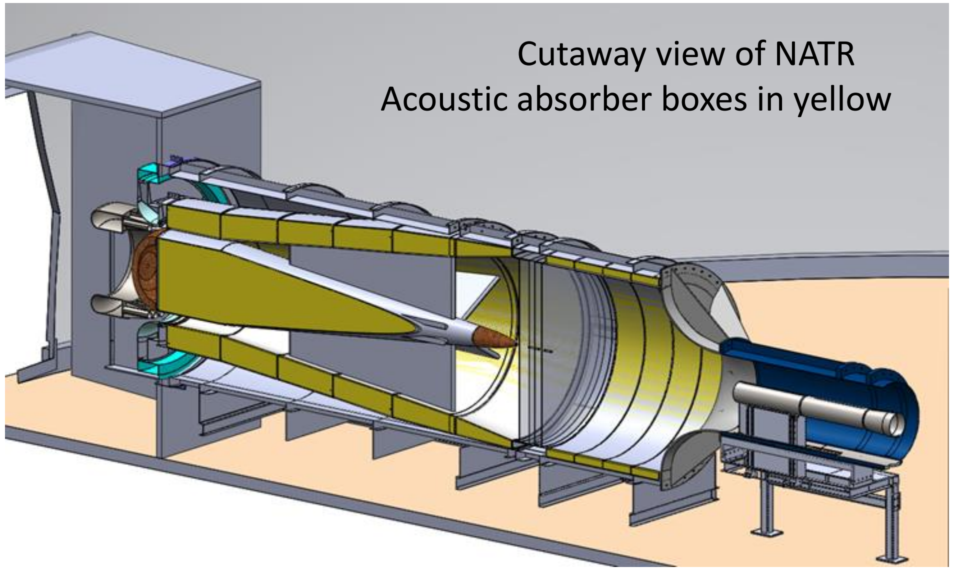
NATR provides the quiet flow of air past the engine rig, simulating the aircraft engine in flight.

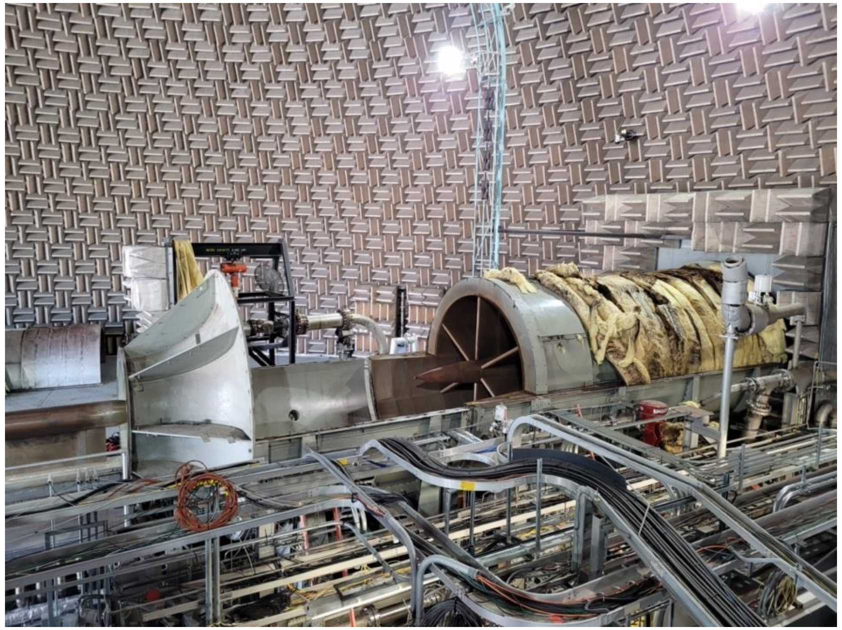
Over time, the chopped Kevlar filament that filled the acoustic absorber boxes had eroded.

– The increase in background noise levels covered the noise of the test article, even for commercial supersonic aircraft.

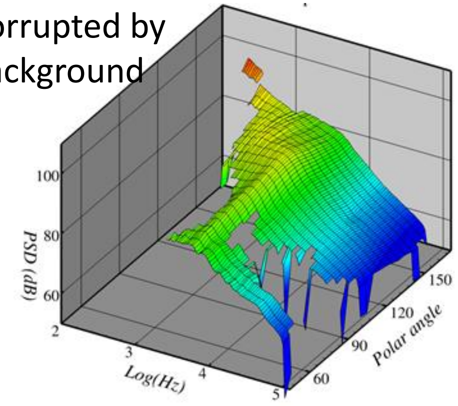
During FY19-20, ARMD funded a refurbishment of NATR, with the objectives of restoring original background noise levels and stopping future degradation.

- Refurbishment was completed in December of 2021.
- Acoustic performance verified in March-May 2022.

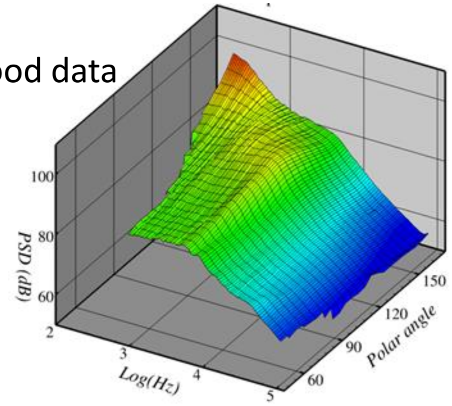

Cutaway view of NATR
Acoustic absorber boxes in yellow



Corrupted by background



Good data



Plug20 test completed

James Bridges, Mark Wernet

Plug20 test designed to produce flow, acoustic data for likely supersonic exhaust system.

Testing halted in March 2020 by COVID shutdown, then NATR refurbishment.

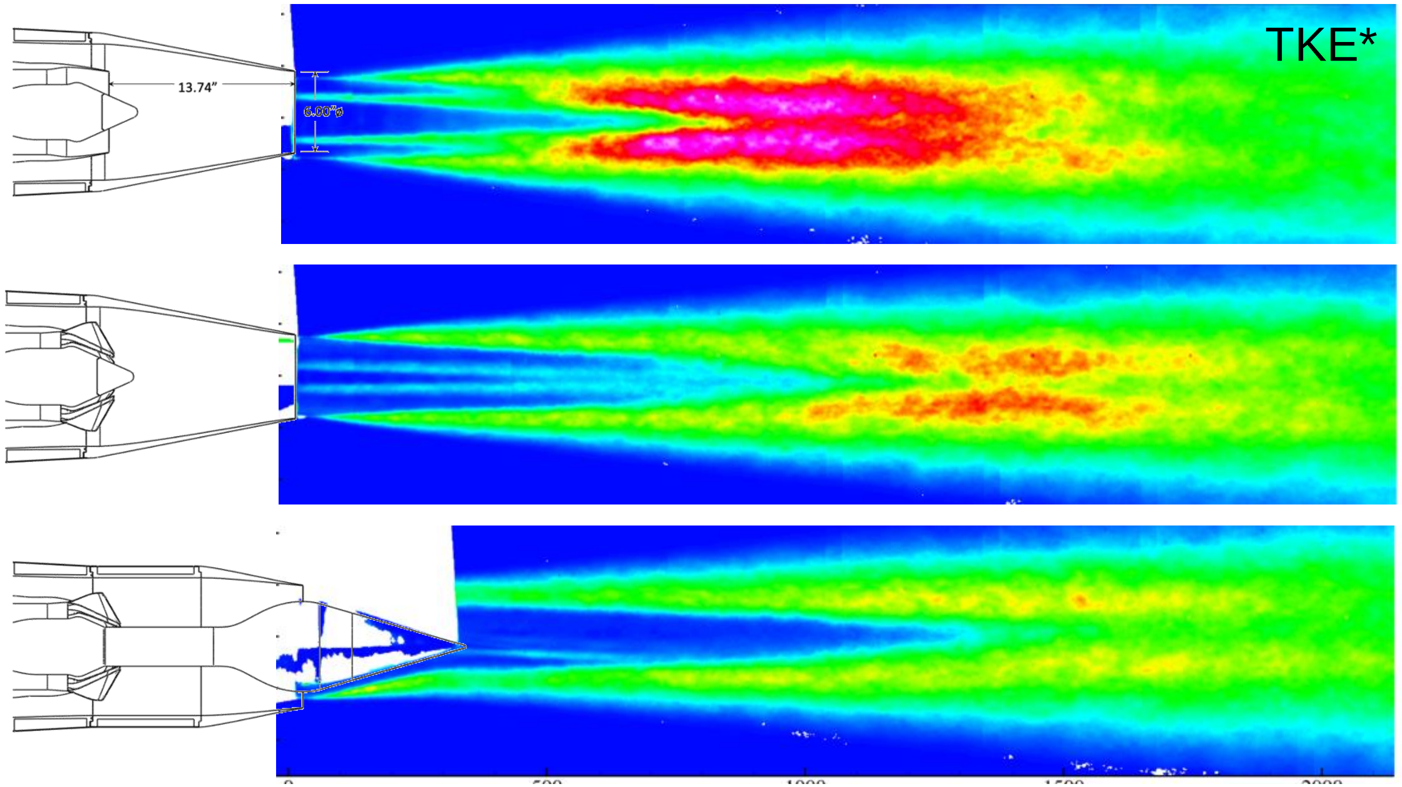
- Limited acoustic, schlieren, phased array published in 2021 NASA TM*.
- Lacked planned PIV data.

Testing resumed in April 2022, repeating key 2020 acoustic results.

PIV acquired in May-June 2022.

NASA TM with new data in process.

2022 PIV—Setpoint 1203



**Bridges and Wernet, "Plug20 Test Report," NASA Technical Memo NASA/TM-2021-10291*.

Learjet Airport Noise Flight Tests Completed

Brenda Henderson, Lennart Hultgren

Objective:

- Connect jet noise prediction models to flight via jet rig tests.

Approach:

- Acquire far-field noise from jet-noise dominated aircraft and repeat in model scale at NATR with similar uncertainties in test variables.

Status:

- See Henderson talk!

Significance:

- Have data to validate/correct data corrections for rig test data.

NASA photos

Fan Noise Method HDNFAN2S Created

Objective

– Develop a new version Heidmann fan noise model (HDNFAN) for two-stage fan inlet noise

– Demonstrate workflow for using data to generate model coefficients

Approach

– Review 2002 data from two-stage QSP fan model

- Now approved for release and dissemination

– Compare against existing HDNFAN methods, identify deficiencies

– Update coefficients and replace functional forms as needed

– Demonstrate improved model fit against other QSP data sets

Status

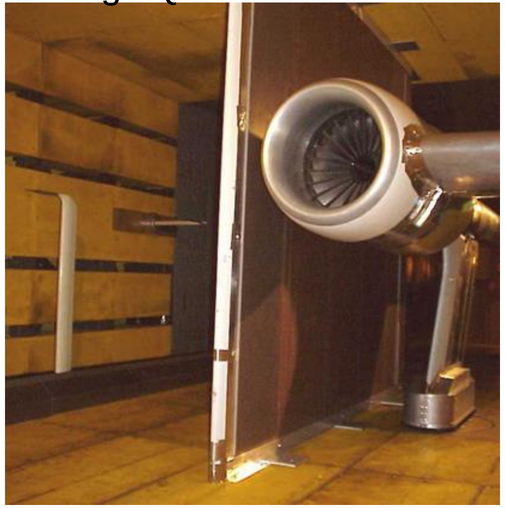
– See Brandt talk!

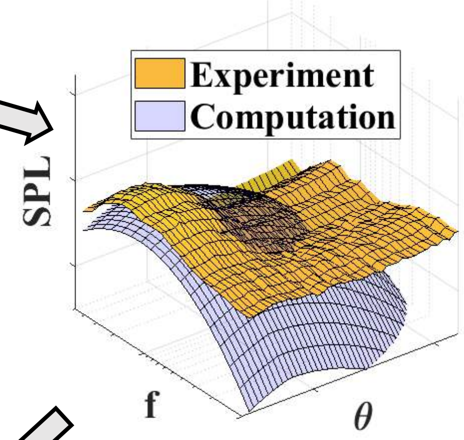
Significance

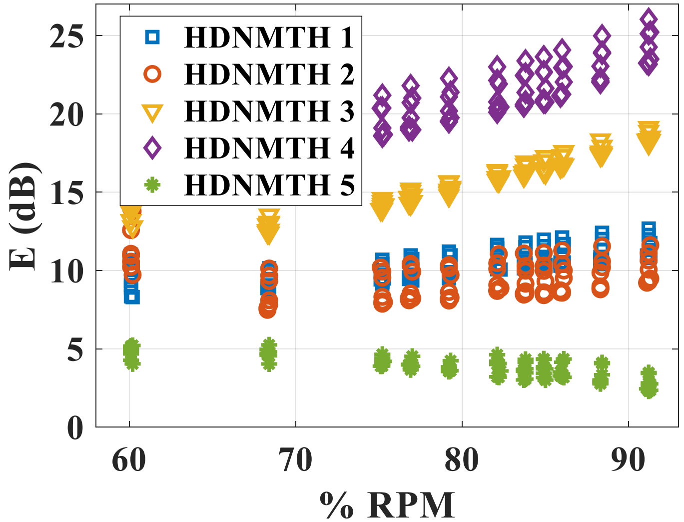
– Significantly reduces uncertainty in fan model for multi-stage fans

Patrick Brandt & David Stephens

Two-Stage QSP Fan Model 2002







Existing Methods

New Method

Jet Noise Method PINTv1 Created

Objective

– Develop an empirical model to predict jet noise from Plugged Internally mixed, external Nozzles (PINT).

– Modular construction to allow future updates.

Approach

– Based on proven model for single-stream jet noise, ***sJet***.

sJet(Um, Tm, Djet) + ***ΔM***(BPR, Uc/Ub, mixer geo, plug geo, flight)

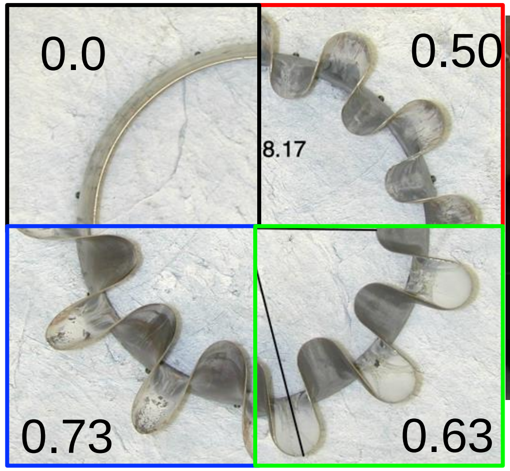
– Create model for **ΔM** by fitting to non-CST rig data.

– Future updates will use PBS data.

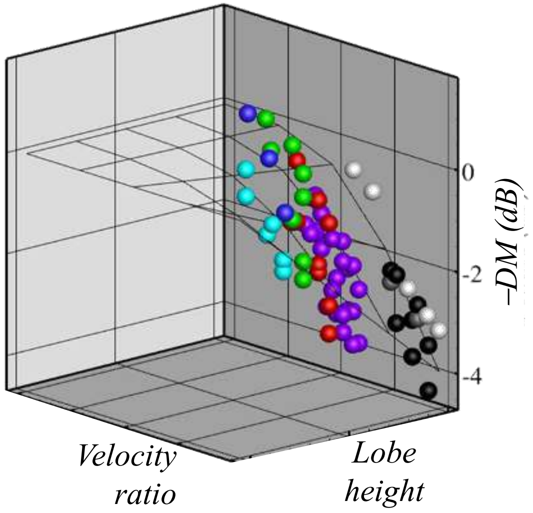
Status

– Effect of internal mixer and external plug now in noise model.

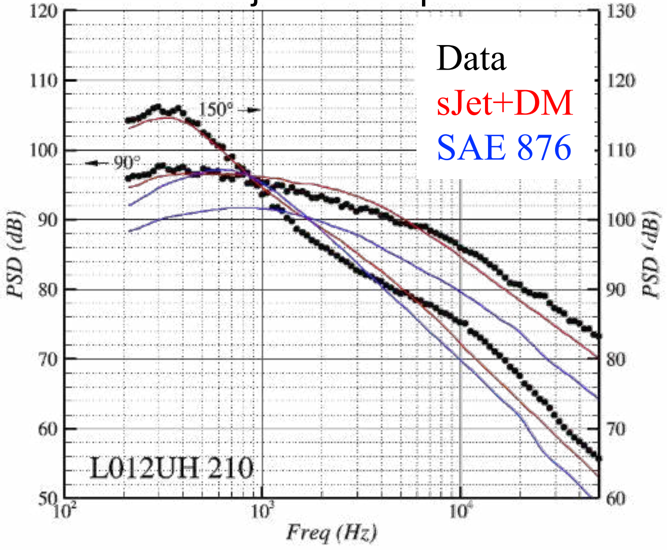
Mixer lobe heights



James Bridges



Far-field jet noise spectra

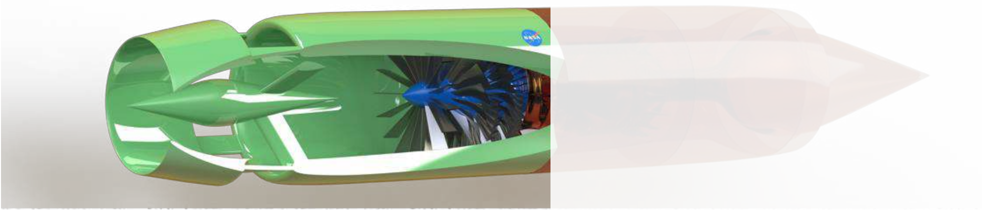


Khavaran & Bridges, "Development of Jet Noise Power Spectral Laws Using SHJAR Data," AIAA 2009-3378. doi: [10.2514/6.2009-3378](https://doi.org/10.2514/6.2009-3378).

Next Steps

Fan noise:

- Complete external review of fan noise validation exercise.
- Complete baseline SuperFan noise simulations for far-field noise.
- Interrogate simulations to address common assumptions of multistage fan noise.



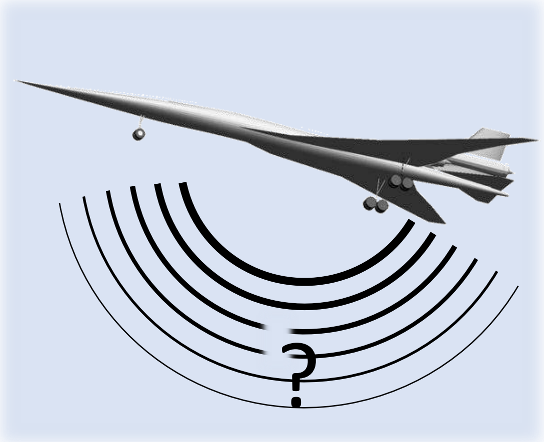
Jet noise:

- Complete LES of Plug20 configurations.
- Produce next-gen exhaust system for LES analysis.
- Reconcile flight and rig data from Learjet tests.

System

- Finish interim uncertainty assessment of new fan, jet empirical models for FY22.

DONE



Recent progress in community survey plans for NASA's Quesst mission

Aaron B. Vaughn, William J. Doebler, Kathryn M. Ballard, and Jonathan Rathsam

NASA Langley Research Center

October 18-19, 2022

Acoustics Technical Working Group Meeting at Glenn Research Center

New Mission Brand - Quesst

- New mission brand announced in Spring 2022
  - Quesst mission name replaces Low Boom Flight Demonstration (LBFD) mission name
  - LBFD project remains unchanged
  - Aircraft will be called X-59 instead of X-59 QueSST (Quiet Supersonic Technology)
- Logo
  - X-59 aircraft
  - Shock waves do not merge, enabling X-59 to produce a quieter sound
  - Houses represent the communities to be overflown
  - Land crescent denotes supersonic flight over land
  - Blue and green symbolize the Earth
- Website
  - nasa.gov/Quesst/

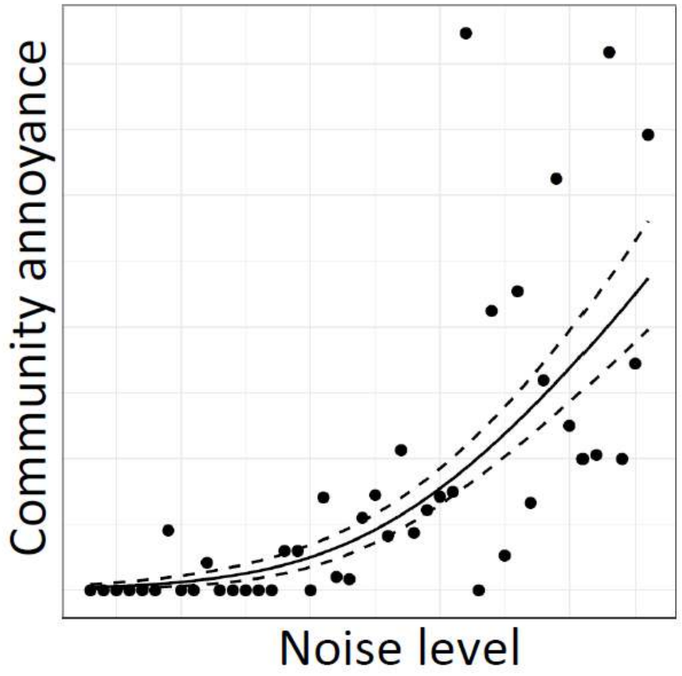
Overview

➢ **NASA Survey Team Objective:**

- Ensure that survey preparation and execution result in a quality community response dataset understood and accepted by the international community

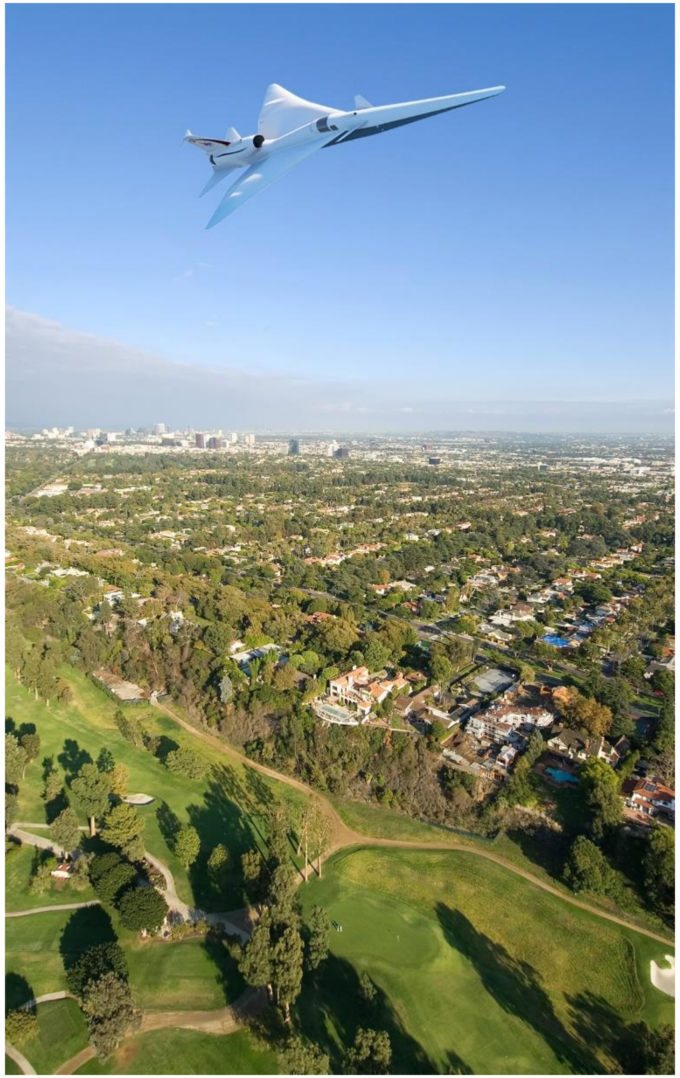
➢ **Recent Questions Investigated*:**

- **Carryover effect:** Do previous responses or noise doses impact participants' current response to the current noise dose?
- **Dose uncertainty:** How to deal with noise dose error in dose-response modeling?



*More details provided in POMA articles from 2021 Seattle ASA Conference

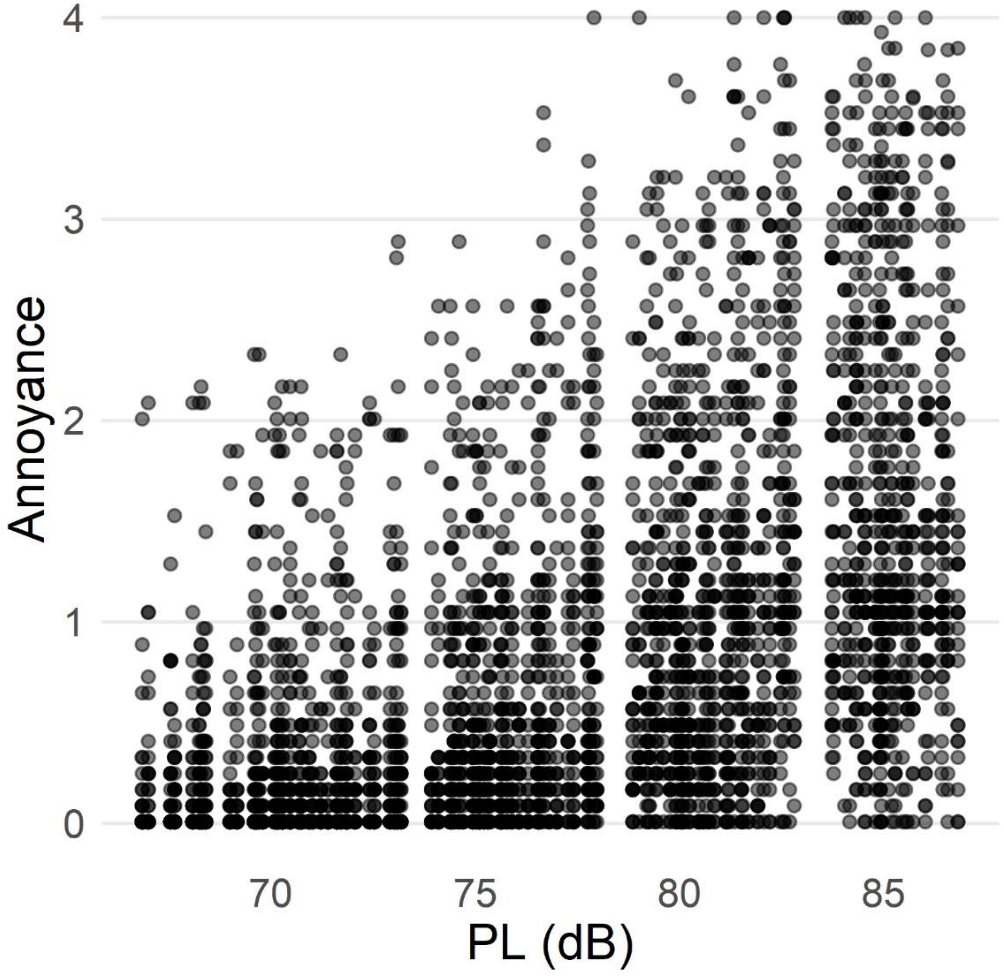
Carryover Effect Analysis: Overview



- **Research Question:**
  - Is there evidence of carryover effects in previous low-boom data?
    - **Carryover effect**: previous stimuli affect the response to the current stimulus
- **Motivation:**
  - Dose-response model assumes no carryover effects
  - Participants respond to <u>multiple</u> surveys in a longitudinal (panel) study
  - X-59 will make multiple overflights during the flight campaign
  - Data can have dependence in measurements from the same person
    - Examples of carryover effect in dose-response data::
      - Previous dose level affecting current response (order effect)
      - Previous annoyance affecting current response (decisional carryover)
      - Becoming acclimated to the low-booms over time (habituation)
      - Becoming more annoyed by the low-booms over time (contrast effect)
  - Influence design to minimize carryover effect
- **Approach:**
  - Analyze low-boom laboratory listener data via graphical and regression analyses

Carryover Effect Analysis: Laboratory Test Data

- Lab study conducted at the NASA Langley Research Center indoor sonic boom simulator in 2013 (Loubeau 2015)
  - 30 subjects
  - 140 simulated booms (doses)
    - 67–87 Perceived Level (PL) dB
      - Similar range as field studies
  - Rated annoyance on a dial:
    - 0 (“*not at all*”) to 4 (“*extremely*”)
- Not directly comparable to field tests
  - Test length (few hours vs few weeks)
  - Environment (lab vs home/work/life)
- Why analyze this dataset?
  - Similar stimuli (low-boom noise doses)
  - No missing responses

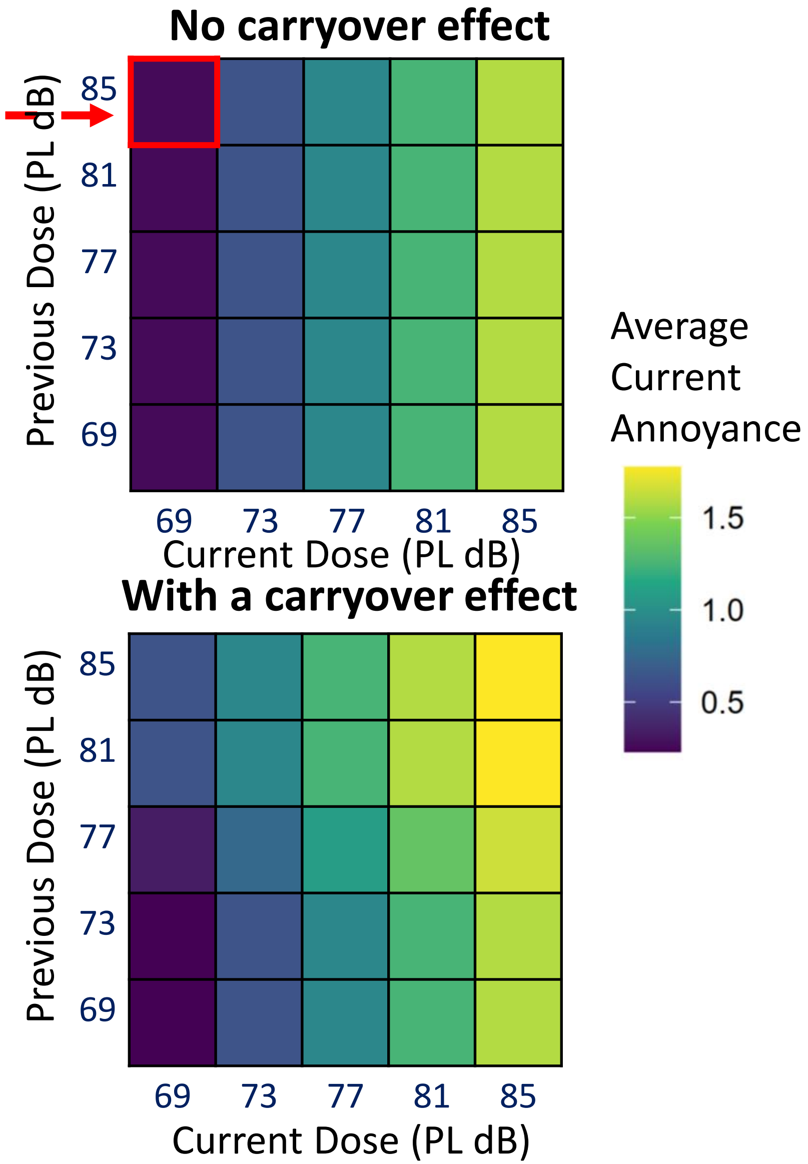


Carryover Effect Analysis: Graphical Methodology

- Each square consists of the average current annoyance to the current noise dose and a previous stimuli
  - $(\mathrm{PL}_t,\ \mathrm{PL}_{t-1},\ \mathrm{Annoyance}_t)$

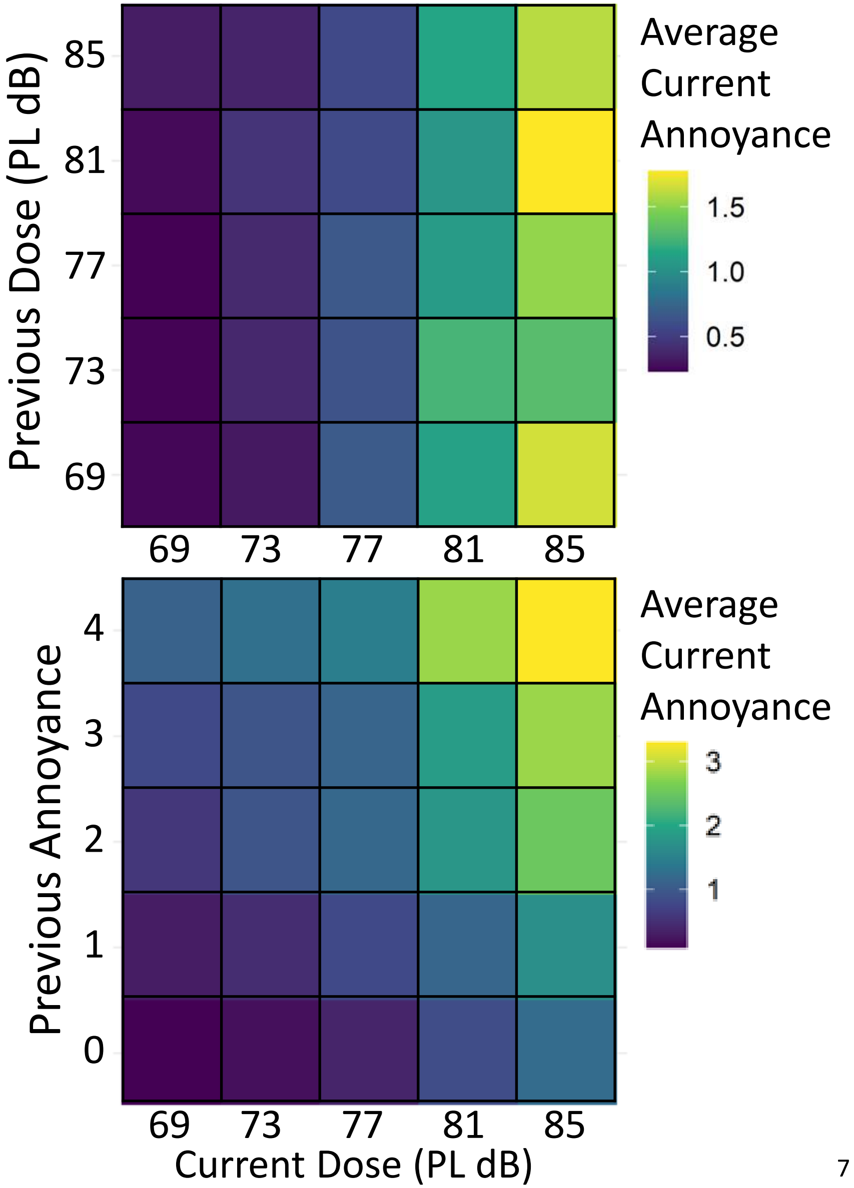
Participant	Boom Number	Dose	Annoyance
8	11 (previous)	**85**	1.288
	12 (current)	**69**	**0.088**

  - (69, 85, 0.088)
- Qualitative interpretation of tile plot:
  - Horizontal trend denotes direct effect (dose-response relationship)
  - Vertical trend indicates presence of carryover effect
- Limited to first-order effects



Carryover Effect Analysis: Graphical Results

- **Previous Dose:**
  - Annoyance increases with current dose (horizontal trend)
    - Expected direct effect
  - Previous dose **does not** appear to affect the current annoyance (vertical trend)
    - No carryover effect
- **Previous Annoyance:**
  - Similarly, previous annoyance ratings can be used in place of previous dose
  - Annoyance increases with current dose (horizontal trend)
    - Expected direct effect
  - Previous annoyance **does** appear to affect the current annoyance (vertical trend)
    - Decisional carryover



Carryover Effect Analysis: Regression Methodology

- Looking beyond first order effects with regression modeling

$$\boldsymbol{Annoyance_{it} \sim BoomNumber_t + PL_{it} + PL_{it-1} + PL_{it-2} + PL_{it-3} + Annoyance_{it-1} + Annoyance_{it-2} + Annoyance_{it-3} + (1|Participant_i)}$$

For time t and participant i

- Mixed-effects model captures person-to-person differences $(1|Participant_i)$
  - Generalized Linear Mixed Model (GLMM)
- Test significance of terms and remove until a suitable model is reached:
  - Boom number $(BoomNumber_t)$
  - Current noise dose (PL_{it})
  - Previous noise doses $(PL_{it-1}, PL_{it-2}, PL_{it-3})$
  - Previous annoyance responses $(Annoyance_{it-1}, Annoyance_{it-2}, Annoyance_{it-3})$

Carryover Effect Analysis: Regression Results

- Qualitative results:
  - Current noise dose has **large positive effect** on current annoyance
  - Up to 3 previous noise doses have a **small negative effect** on current annoyance
  - Up to 3 previous annoyance responses have a **large positive effect** on current annoyance
  - As the study progressed, there was a **very small increase** in annoyance
- Takeaways:
  - There is evidence of carryover effects in previous low-boom data
    - Previous response has a large positive effect on current annoyance
    - How relevant or impactful are these results to X-59 tests?
  - Experimental design consideration for X-59 community tests:
    - Cannot randomize order of noise doses for each subject
    - Capture various orders of noise doses to enable graphical and regression carryover effect analyses

Dose Uncertainty Modeling: Overview

Research Questions:

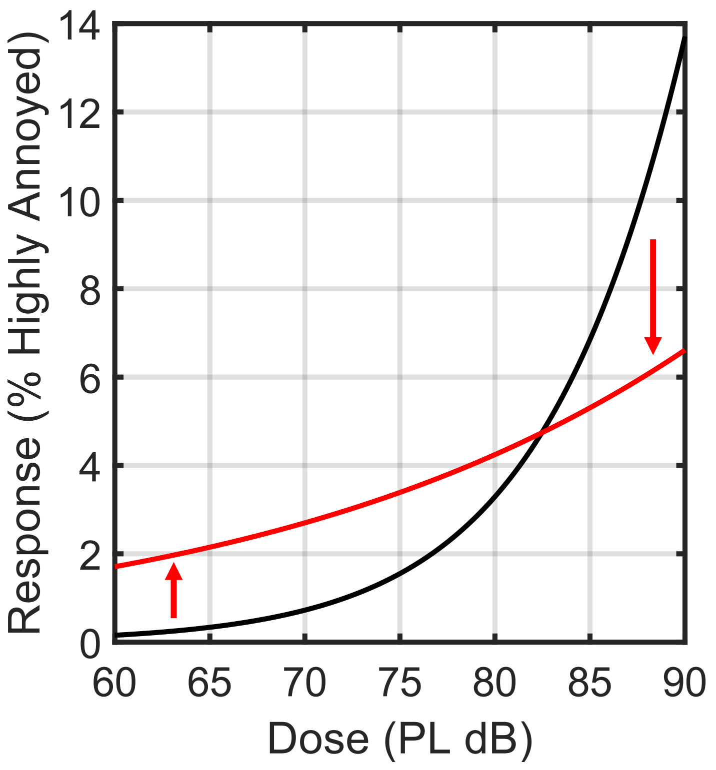
- How do we deal with noise dose error in dose-response modeling?
- Can an extra term be added to a modeling method to correct the effect of dose uncertainty?

Motivation:

- Dose is assumed to be known exactly in dose-response modeling
- Measured dose is contains uncertainty
- Uncertainty in dose flattens dose-response curve
- Flattened curve impacts ultimate deliverable of dose-response curve

Approach:

- Add a dose uncertainty term to a Bayesian model and fit to simulated and previous NASA field data



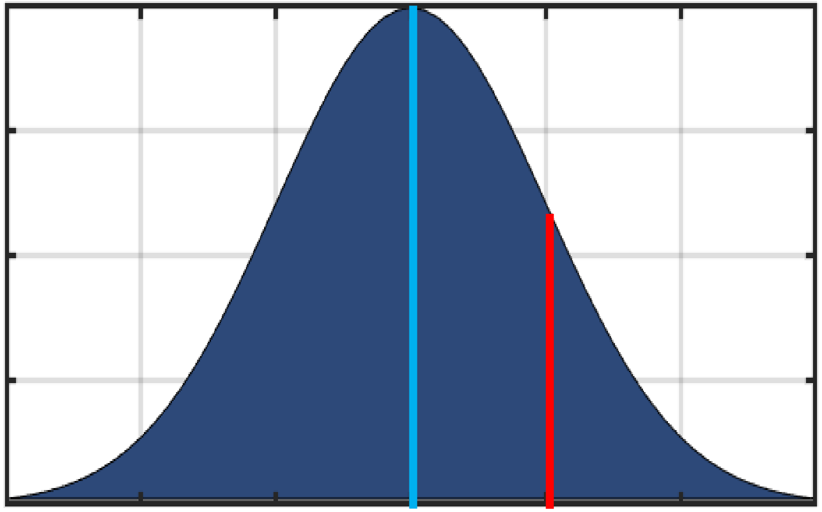
Dose Uncertainty Modeling: Including Uncertainty Term in Model

True dose

- Dose experienced by participant
- Classically treated as fixed value

Measured dose

- Value assigned to participant
- Classically treated as random perturbation of true dose



No Dose Uncertainty

$H_{ij} \sim Bernoulli(p_{ij})$

$p_{ij} = logit^{-1}(\beta_{0i} + \beta_1 PL_{ij}^{estimated})$

$\beta_{0i} \sim N(\beta_0, \sigma^2)$

$\beta_0 \sim N(0,100)$

$\beta_1 \sim N(0,100)$

$\sigma^2 \sim InverseGamma(0.01,0.01)$

Classical Dose Uncertainty

$H_{ij} \sim Bernoulli(p_{ij})$

$p_{ij} = logit^{-1}(\beta_{0i} + \beta_1 PL_{ij}^{true})$

$PL_{ij}^{true} \sim Unif(-100,200)$

$PL_{ij}^{measured} \sim N(PL_{ij}^{true}, \sigma_{dose\ uncertainty}^2)$

$\beta_{0i} \sim N(\beta_0, \sigma^2)$

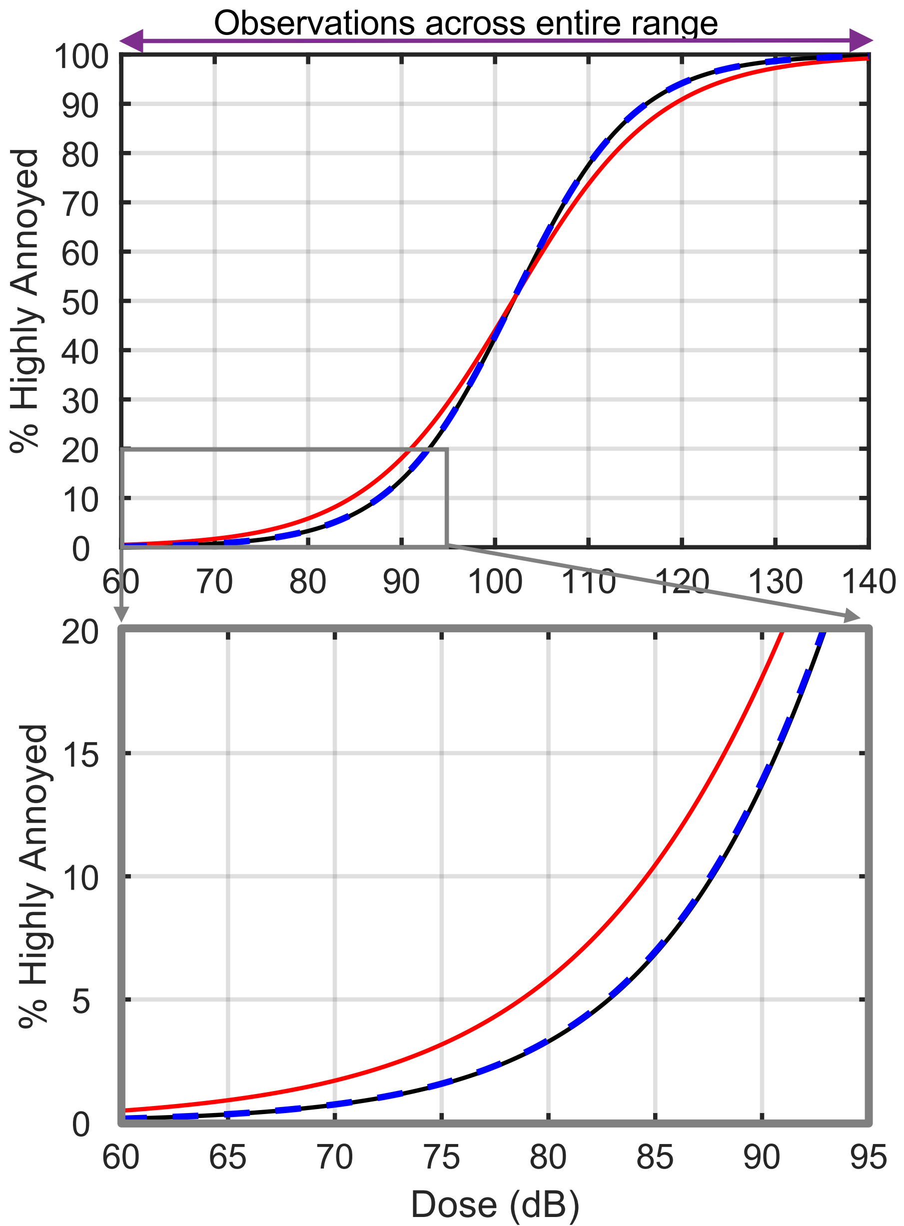
$\beta_0 \sim N(0,100)$

$\beta_1 \sim N(0,100)$

$\sigma^2 \sim InverseGamma(0.01,0.01)$

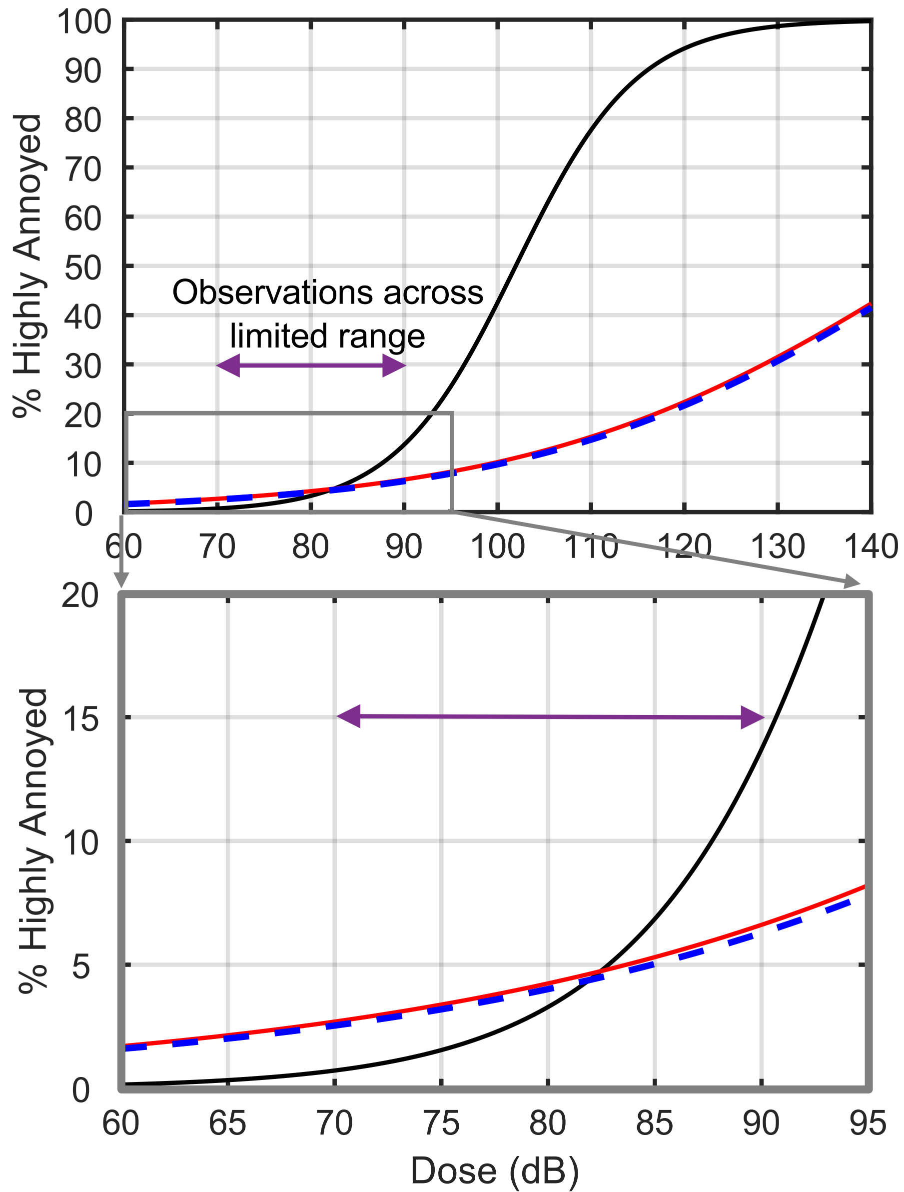
$\sigma_{dose\ uncertainty} = known\ value(s)\ in\ dB$

Dose Uncertainty Modeling: Simulation 1 – Full Sample



- **Sampling Parameters**
  - 200 dB dose range
  - 1 dB dose spacing
  - 1000 binary observations at each dose
  - Perturb each dose by a draw from $N(0, \sigma_{dose\ uncertainty})$
- The **model with the uncertainty term** **can** correct **the flattened slope** when the dose response curve is **fully sampled**

Dose Uncertainty Modeling: Simulation 2 – Sparse Sample



- Model w Unperturbed Dose Data
- Model w Perturbed Dose Data
- Model w Perturbed Dose Data & Dose Uncertainty Term

- **Sampling Parameters**
  - 20 dB dose range (70 to 90 dB)
  - 0.1 dB dose spacing
  - 1000 binary observations at each dose
  - Perturb each dose by a draw from $N(0, \sigma_{dose\ uncertainty})$
- The **model with the uncertainty term** **<u>cannot</u>** correct **the flattened slope** when the dose response curve is **sparsely sampled**
- **Previous community data resemble Simulation 2**

Dose Uncertainty Modeling: NASA Community Studies

WSPR2011

- **Noise source: N-wave sonic booms**
  - 110 booms delivered
  - PL Range: 63 to 106 dB
- **~1 square mile (2.6 km^2) survey area**
- **12 noise monitors**
- **49 participants**
- **1,981 survey responses**
- **Dose estimated by 2D spatial interpolation of measurements to participant locations**

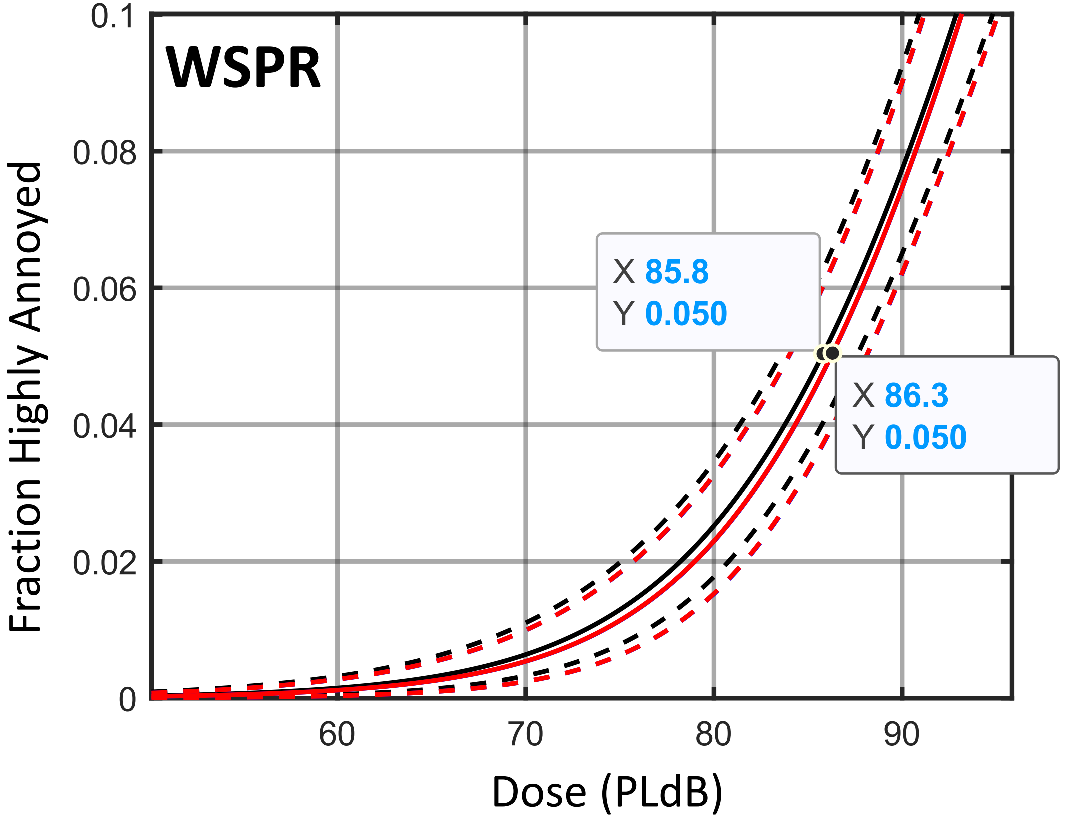
QSF18

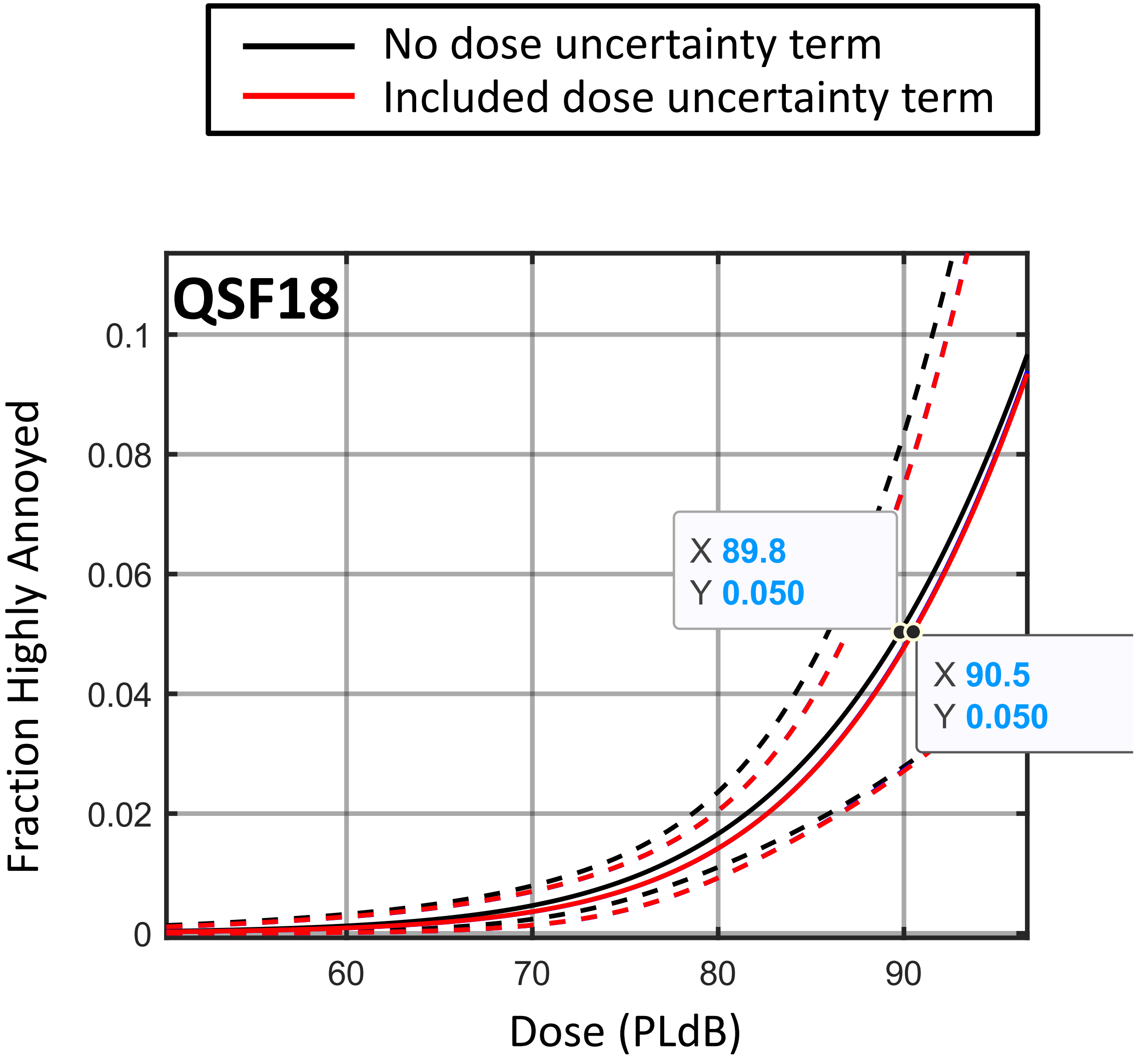
- **Noise source: N-wave sonic booms**
  - 52 booms delivered
  - PL Range: 56 to 90 dB
- **~60 square mile (155 km^2) area**
- **12 noise monitors**
- **371 participants**
- **4,998 survey responses**
- **Dose estimated by combination of measurements and predictions at participant locations**

Previous analyses of these pilot studies assumed the noise dose was known without uncertainty

Dose Uncertainty Modeling: Population Summary Curves

- **This resembles Simulation 2**
  - 95% Credible Intervals overlap
  - Difference at 5% HA:
    - WSPR: 0.5 PLdB
    - QSF18: 0.7 PLdB





Dose Uncertainty Modeling: Summary

- Simulations demonstrated the effectiveness of dose uncertainty term in correcting the curve
  - Simulation 1: Fully sampled curve **able** to correct for dose uncertainty
  - Simulation 2: Sparsely sampled curve **unable** to correct for dose uncertainty
- Previous and future community studies resemble Simulation 2
- How to address dose uncertainty moving forward:
  - Not ideal to expand upper dose range to achieve 100% HA
  - Minimize measured dose uncertainty and capture uncertainty per dose
  - Investigate what dose-response data are sufficient for this method to work effectively
  - Further explore modeling techniques to account for dose uncertainty

References

- Ballard et al. (2022), "Analysis of carryover effects in a low boom laboratory listener study" *Proceedings of Meetings on Acoustics*, Vol. 45, No. 1, 040002 https://doi.org/10.1121/2.0001566
- Doebler et al. (2022), "Simulation and application of Bayesian dose uncertainty modeling for low-boom community noise surveys" *Proceedings of Meetings on Acoustics*, Vol. 45, No. 1, 040004 https://doi.org/10.1121/2.0001592
- Vaughn et al. (2022), "Comparison of two statistical models for low boom dose-response relationships with correlated responses" *Proceedings of Meetings on Acoustics*, Vol. 45, No. 1, 040001 https://doi.org/10.1121/2.0001541


Work supported by the NASA Commercial Supersonic Technology (CST) Project
NASA
QUESST

Learjet Test Update

Commercial Supersonic Technology Project
Advanced Air Vehicles Program

Brenda Henderson (NASA Glenn Research Center), Lennart Hultgren (NASA Glenn Research Center), Devin Boyle (NASA Glenn Research Center)

NASA Acoustics Technical Working Group
Oct 18 – 19, 2022

Team

NASA Glenn: Acoustics, LiDAR (on loan from Langley), GPS Aircraft Positioning

Brenda Henderson (PI)
Lennart Hultgren (co-PI)
Devin Boyle
Jordan Cluts
Alexander Svetgoff

NASA Glenn: Airworthiness, GPS Trial Flights

Jeff Polack
Matt Fakler
Kurt Blankenship
Mark Russel
Stephen Plaskon

NASA Langley: Drone Weather Measurements

Jacob Revesz
Jennifer Fowler
Mark Motter
Mark Frye
Scott Sims

Objectives

- Acquire jet-noise flight data from a Learjet 25
  - Compare results from AAPL to flight data
  - Develop flight correction model if required
- Learjet 25 selected to ensure a jet-noise dominated source
  - Uses CJ610 engine (civil derivative of the J85)

Desired outcome is to improve our ability to predict takeoff noise for future supersonic commercial aircraft

Schedule

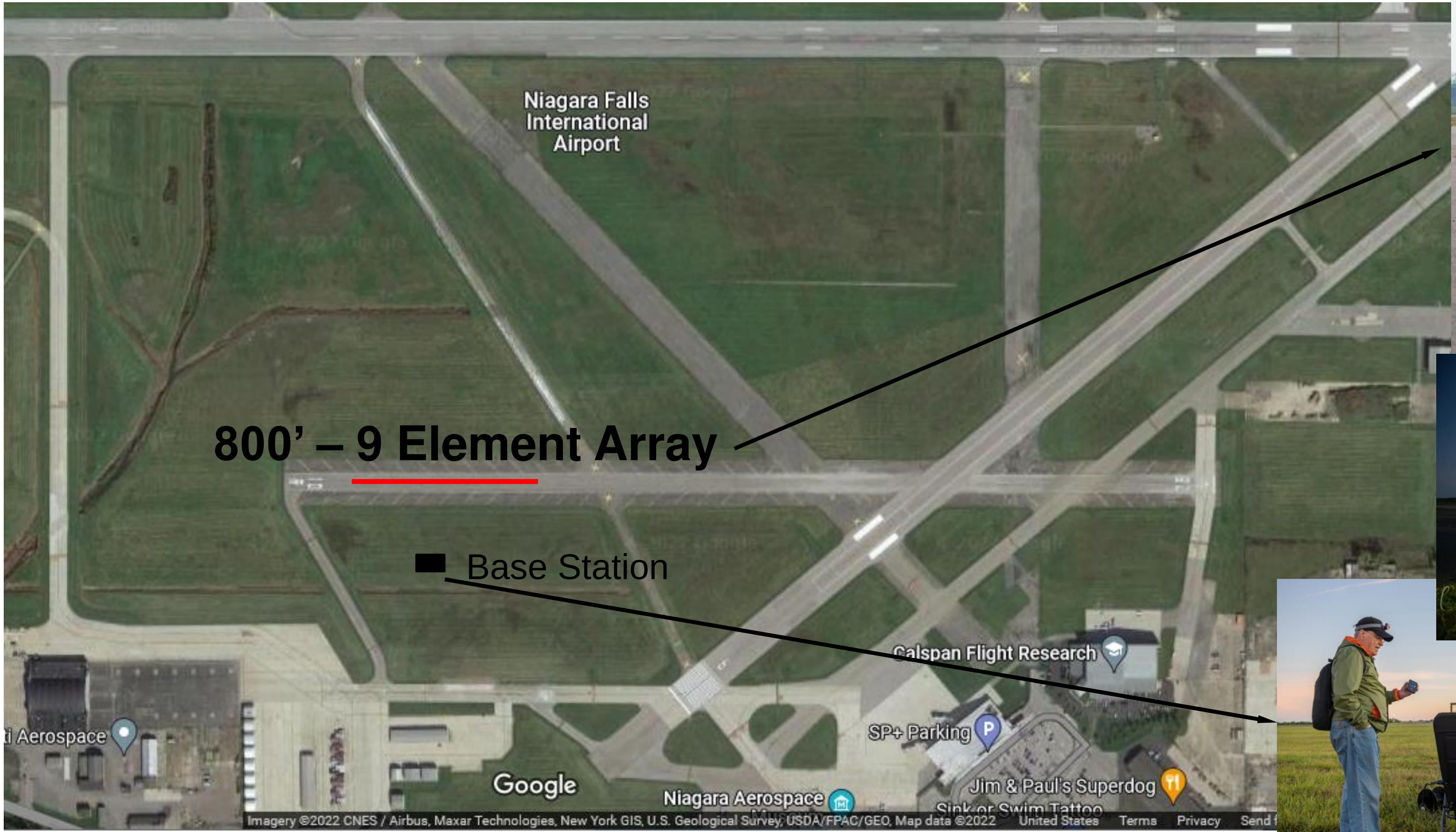
Contract Award	September 2021
GPS Development Flights	May – July 2022
Trial Flight	August 10, 2022
Flight Test	August 29 – September 8, 2022
AAPL Scale Model Tests	September 12 – October 7, 2022

Aircraft was flown and instrumented by Calspan Corp.

GPS Development Flights

- NASA responsible for aircraft precise positioning
- Originally planned to use unit and services from NASA Ames
    - Ames program ended in October 2021
- Purchased VectorNAV VN210 – used by other programs at NASA Glenn
- Developed acquisition software
- Processed GPS
- Acquisition software tested in T-34C flights in Cleveland area and with flights between Cleveland and Niagara Falls International Airport

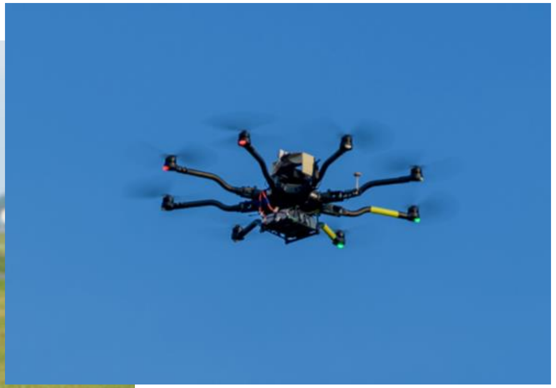
Flight Test Location – Niagara Falls International Airport



Instrumentation

- Data acquired by Calspan Corp.
  - Engine Pressure Ratio (EPR), Exhaust Gas Temperature (EGT), and engine RPM recorded continuously
- Data acquired by NASA
  - Aircraft position (and IMU output)
  - Acoustics from 9 element array
  - Wind speed from the LiDAR system
  - Temperature, pressure, and humidity as a function of altitude from the NASA Langley drone

All data were acquired with GPS timestamps



Flight Operations

- Trial Flights were used to determine
  - Aircraft state (no flaps or landing gear were required)
  - Aircraft trajectories
  - Flight speeds
  - Background noise levels relative to Learjet
    - ✓ Treated surrounding area with pesticide (for crickets)
- Flight Tests
  - 4 sorties over 2 days, 17 – 20 flyovers per sortie
    - ✓ Total of 73 flyovers
  - One engine at idle
  - Typical go-around time – 5 to 6 minutes
  - Drone deployment time ~ 9 minutes
  - Drone was deployment 3 times per sortie – beginning middle, and end
  - Sortie time ~ 2 hours

Data Acquired

Nominal EPR	NPR	NTR	Flight Mach#
1.5	1.57	2.63	0.26
1.6	1.69	2.70	0.27
1.7	1.80	2.79	0.26
1.8	1.91	2.87	0.27
1.9	2.00	2.96	0.27
2.0	2.12	3.04	0.27

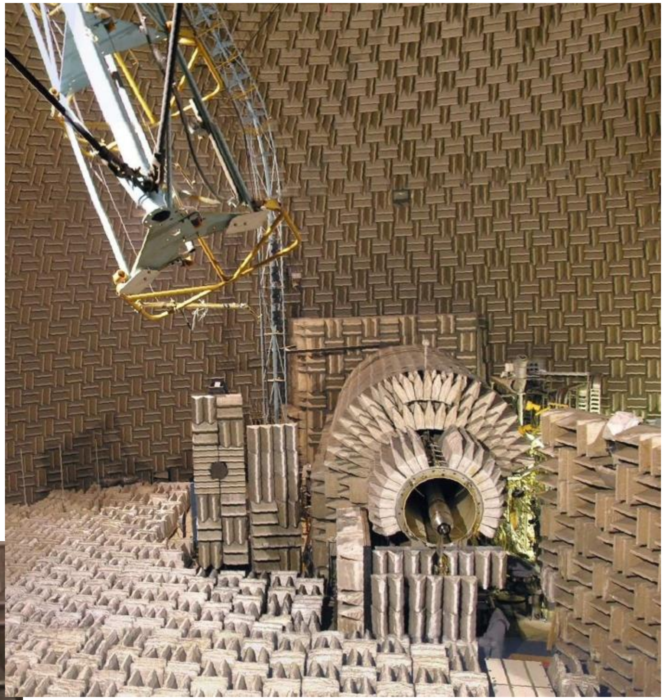
Required flight Mach numbers below 0.3 for follow-on scale-model testing

- EPR – engine pressure ratio - P_{oj}/P_{oa}
- NPR – nozzle pressure ratio (used in tunnel measurements) - P_{oj}/P_a
- NTR – nozzle temperature ratio (used in tunnel measurements) - T_{oj}/T_a

Previous Learjet flight test results indicated no significant shock associated noise for supersonic exhaust conditions used in this flight test

Follow-On Scale Model Testing

- Aero-Acoustic Propulsion Laboratory
- Nozzles
  - ➢ Learjet scale model
  - ➢ 2 conical single stream nozzles
- Repeated Learjet flight test conditions
- Acquired additional data for modeling efforts (model presented at previous ATWGs)



SUMMARY

- Flyover noise acquired from a jet-noise dominated aircraft – Learjet 25/CJ610
- 9-microphone linear array on ground
- Drone for atmospheric measurements (a first)
- LIDAR for wind measurements
- Research instrumentation on aircraft for position and engine conditions
- Complementary rig data obtained – AAPL/NATR

Objective: a well documented reference/validation case of flyover acoustic data ✓

In Progress: comparison of facility and flight data – develop flight correction model

Significance: expected improvement in noise-prediction methods for system studies of future commercial supersonic aircraft


N30
INFLIGHT SI

Event Q&A

Any conflicts with the KC-135's flying there at Niagara?

The conflicts with the KC-135s were minimal. They do not fly continuously and only impacted a couple of the flyovers.

When do you expect to complete the data analysis?

We expect to complete the data analysis by the end of calendar year 2023.

Was the flyover level flight or climb?

The flyovers included level flight and climb. The majority of the data were acquired for climb.

Was GPS data processed/corrected in real-time or post-processed?

The GPS data was post-processed.

National Aeronautics and
Space Administration

Weather Observation Methods Using UAS in Support of Acoustic Testing

Jacob Revesz

National Institute of Aerospace

NASA Langley UAS Operations Office

Oct 18, 2022

(252)-773-2161

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Langley UASOO Overview

- Provides strategic and tactical assistance to projects requesting UAS flight operations
- Strategic:
  - Risk assessment including hazards identification and mitigations
  - CONOPS development
  - Airworthiness oversight
  - Operations review
- Tactical:
  - Range Safety Oversight
  - FAA interface for COAs, waivers, etc.
  - Range agreements
  - Ground Support Equipment
  - Pilot, Ground Control Station Operator and Observer Certification

BlackSwift S2

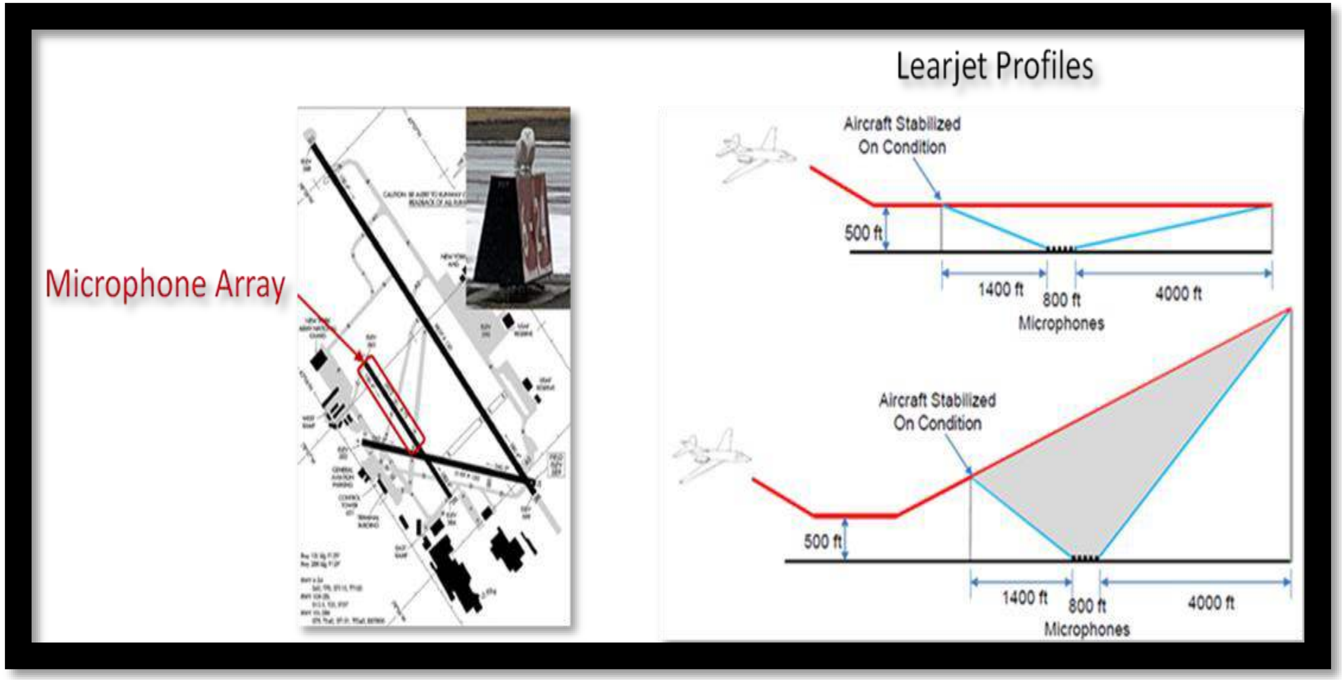
Freefly Astro

Using a LARC Multirotor to collect Wx Data

- UAS provide repeatability, because the atmospheric sensors are recovered and reused.
- Operate under NASA COA, MOA or Part 107
- UAS altitude is selectable and can support dynamic changes during flight
- UAS can maneuver around obstacles
- Programable ascent and descent rates
- Can acquire data beyond visual line of sight
- Minimal training needed by research team, because LARC provides UAS pilots and equipment
- Mobile and easy to adjust the flight path to get higher resolution data temporally and spatially
- Flight path is not dependent on winds
- With appropriate NASA/FAA approvals operations over people, at night, and in high-density air space are possible.

UAS Weather Measurements (KIAG) - Overview

- NASA Glenn Research Center, NASA Langley Research Center, and associated contractor, Calspan, worked with Niagara Falls International Airport (IAG) to conduct a series of acoustic flight test missions. To fully characterize the acoustic response, atmospheric profiles were collected by a small Unmanned Aircraft System (sUAS) owned and operated by LaRC between Learjet passes over microphone array.



Calspan Learjet

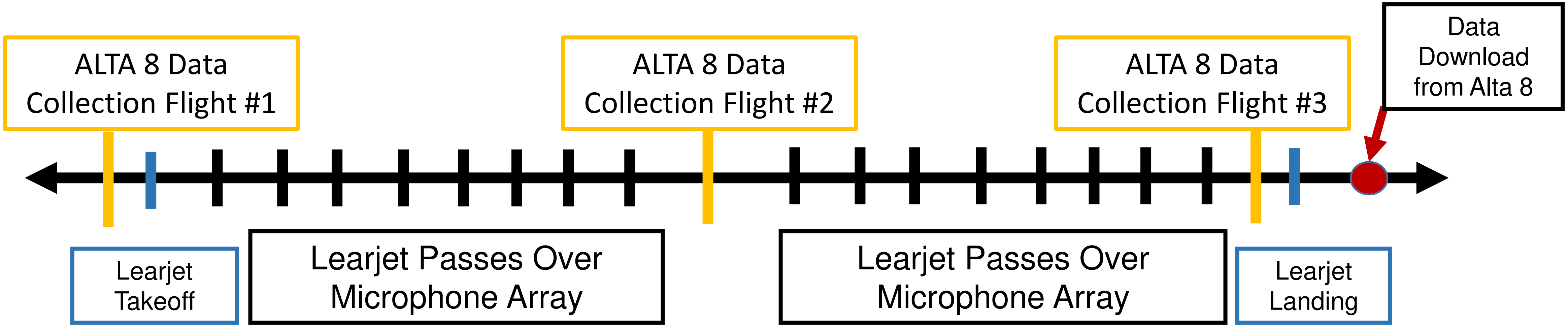
UAS Weather Measurements (KIAG) - Overview

Why Temperature, Pressure, and Relative Humidity Data was Collected for KIAG Acoustics Testing :

1. Atmospheric correction for the sound propagating from source to observer (speed and attenuation)
2. The propagation of sound depends on atmospheric conditions
3. Tracking the changing location and ambient conditions throughout flight ops
4. Identify atmospheric parameters every 5 m from surface to 304m (1000ft)
5. Large vertical gradients in atmospheric parameters can have significant influence on the direction of sound propagation

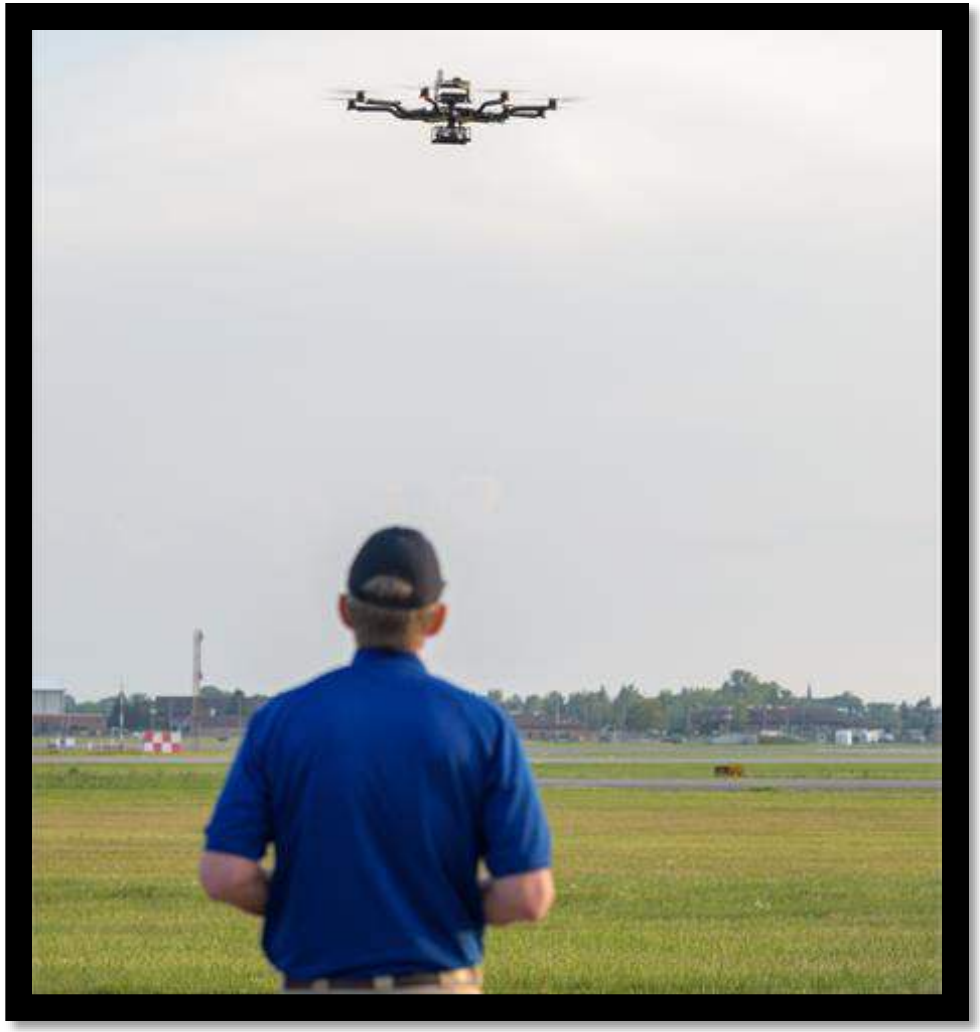
UAS Weather Measurements (KIAG) – Nominal Event Timeline

- Alta 8 collected atmospheric data before the Learjet takes off, at the midpoint of the mission, then after the Learjet completes its final pass over the microphone array.
- Once each sortie was completed, we would debrief and process all flight data (i.e., iMet, Alta flight data, and PPK GPS Data) then package up data and send to the project within 24hrs.
- Each nominal sortie consisted of one Learjet takeoff, one Learjet landing, three Alta takeoffs and three Alta landings. There were multiple sorties flown to collect all acoustics data over multiple days.

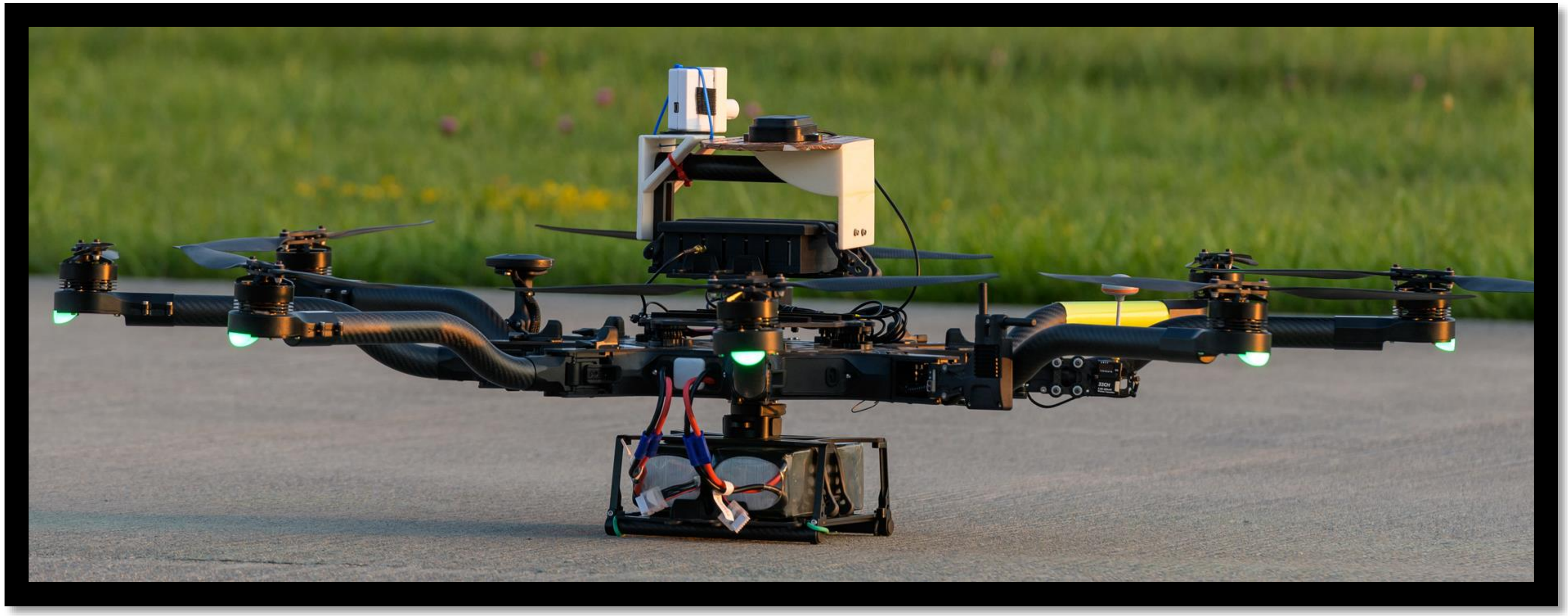


UAS Weather Measurements (KIAG) – Operations Overview

- Requires three crew members to operate this system. Range Safety Officer (RSO), Remote Pilot (RP), Ground Control Station Operator (GCSO).
- Initial System set up time ~25min
- Follow on flight preparation time ~10-15 min



UAS Weather Measurements (KIAG) - ALTA 8 PR0 (N563NU)



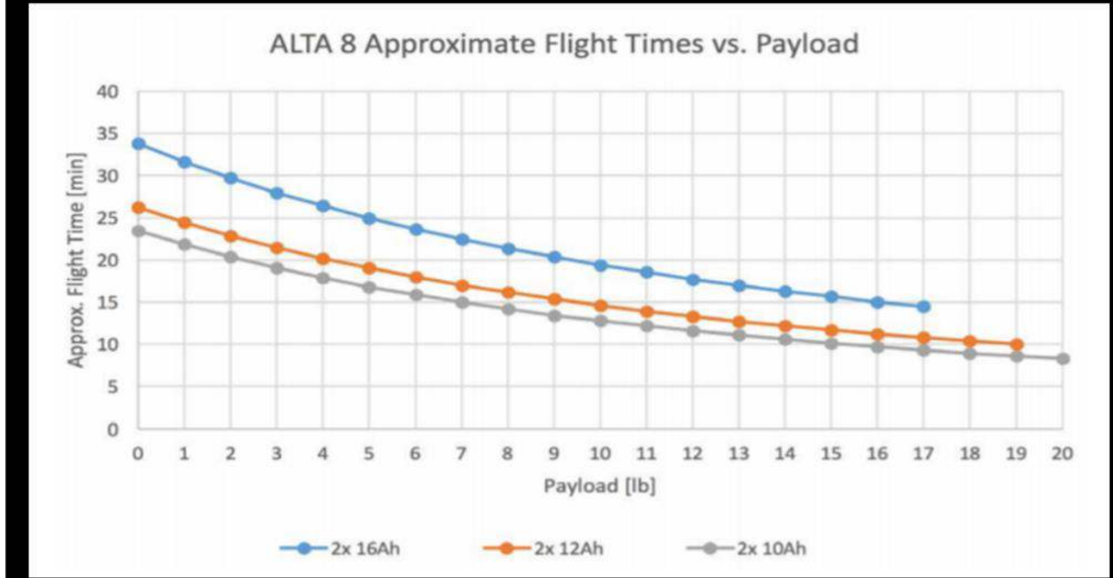
Unfolded Diameter (does not include Props)	1325 mm (52.2 In)
Folded Diameter (does not include Props)	660 mm (25.9 In)
Height to base of Toad In The Hole (TITH)	263 mm (10.3 In)
Maximum Gross for Takeoff	18.1 kg (40.0 lbs.)
Maximum Payload.	9.1 kg (20.0 lbs.)
Typical Standard Empty Weight	6.2 kg (13.6 lbs.)

ALTA 8 PR0 (N563NU) - Performance

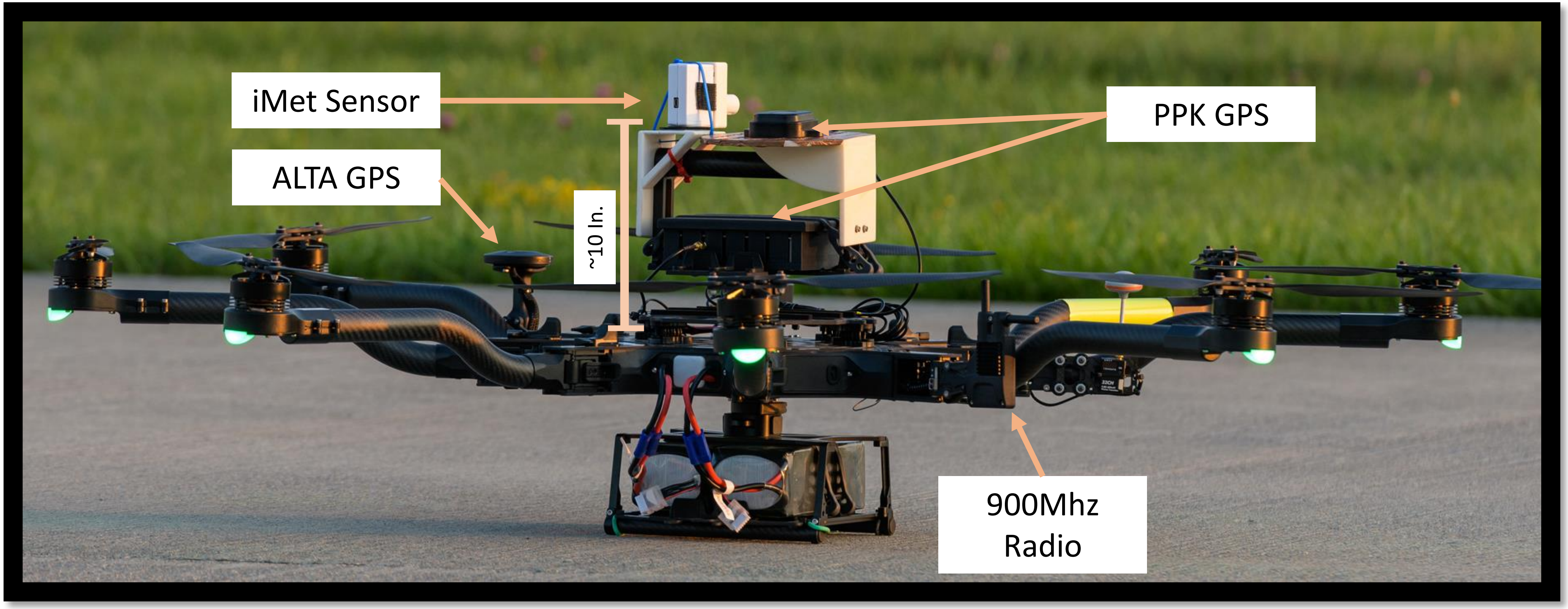
Performance Envelope: motor, thrust, speed, max altitude and speed

- Motor : Freefly F35 Direct Drive 3-Phase PMAC Outrunner (8) with 18“ × 6 Folding propeller
- Thrust : 1.85 : 1
- Max Altitude : 10,000ft MSL
- Range : 13.8mi (22.2 km)
- Max Speed (Horizontal): 0 – 30 kts (0-15.4m/s)
- Endurance : 10-35 min (payload dependent)

Press Alt Ft	0ºC		10ºC		20ºC		30ºC		40ºC	
	Maximum Gross Weight (lb)	Maximum Gross Weight (kg)	Maximum Gross Weight (lb)	Maximum Gross Weight (kg)	Maximum Gross Weight (lb)	Maximum Gross Weight (kg)	Maximum Gross Weight (lb)	Maximum Gross Weight (kg)	Maximum Gross Weight (lb)	Maximum Gross Weight (kg)
S.L.	40.0	18.1	40.0	18.1	39.3	17.8	38.0	17.2	36.8	16.7
1000	40.0	18.1	39.3	17.8	37.9	17.2	36.7	16.6	35.5	16.1
2000	39.2	17.8	37.8	17.2	36.6	16.6	35.4	16.0	34.2	15.5
3000	37.8	17.2	36.5	16.5	35.2	16.0	34.1	15.5	33.0	15.0
4000	36.4	16.5	35.2	15.9	34.0	15.4	32.8	14.9	31.8	14.4
5000	35.1	15.9	33.9	15.4	32.7	14.8	31.6	14.3	30.6	13.9
6000	33.8	15.3	32.6	14.8	31.5	14.3	30.5	13.8	29.5	13.4
7000	32.6	14.8	31.4	14.2	30.3	13.8	29.3	13.3	28.4	12.9
8000	31.3	14.2	30.2	13.7	29.2	13.2	28.2	12.8	27.3	12.4
9000	30.2	13.7	29.1	13.2	28.1	12.7	27.2	12.3	26.3	11.9
10000	29.0	13.2	28.0	12.7	27.0	12.3	26.1	11.9	25.3	11.5



UAS Weather Measurements (KIAG) - ALTA 8 PR0 (N563NU)



iMet Sensor
- Temp is +/- .3 deg C accuracy
- RH is +/- 5% accuracy
- Pressure is +/- 1.5 mbar accuracy
- Altitude accuracy: +/- 12m
- Data collection 1Hz

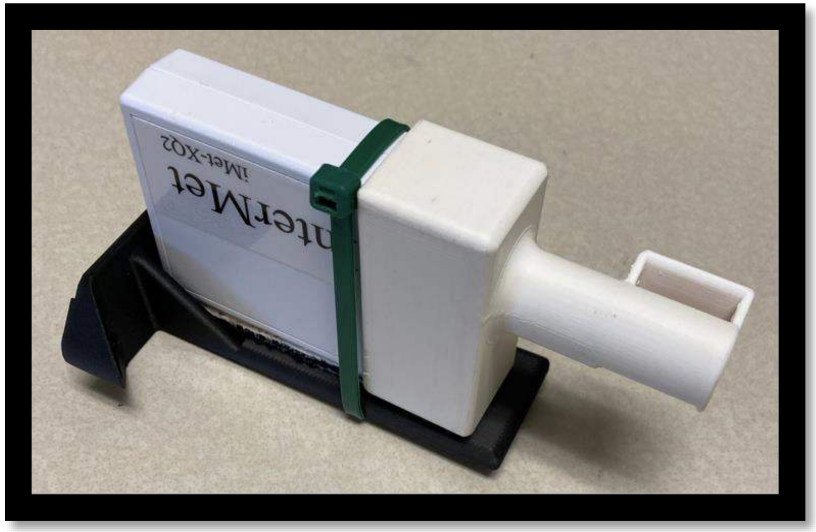
PPK GPS
- Altitude accuracy: +/- 0.5m
- PPK processing with CORS stations and RTKLIB software
- Data collection: 5Hz

ALTA 8 GPS (Here2)
- Position accuracy: +/- 2.5m
- Position function: 3D FIX SBAS
- Positioning Chip: UbloxM8N
- Gyro + Accelerometer and Barometer
- Data Collection : 5Hz

UAS Weather Measurements (KIAG) - Sensors

High Precision GNSS Module

Temperature, Pressure, and Relative Humidity Sensor



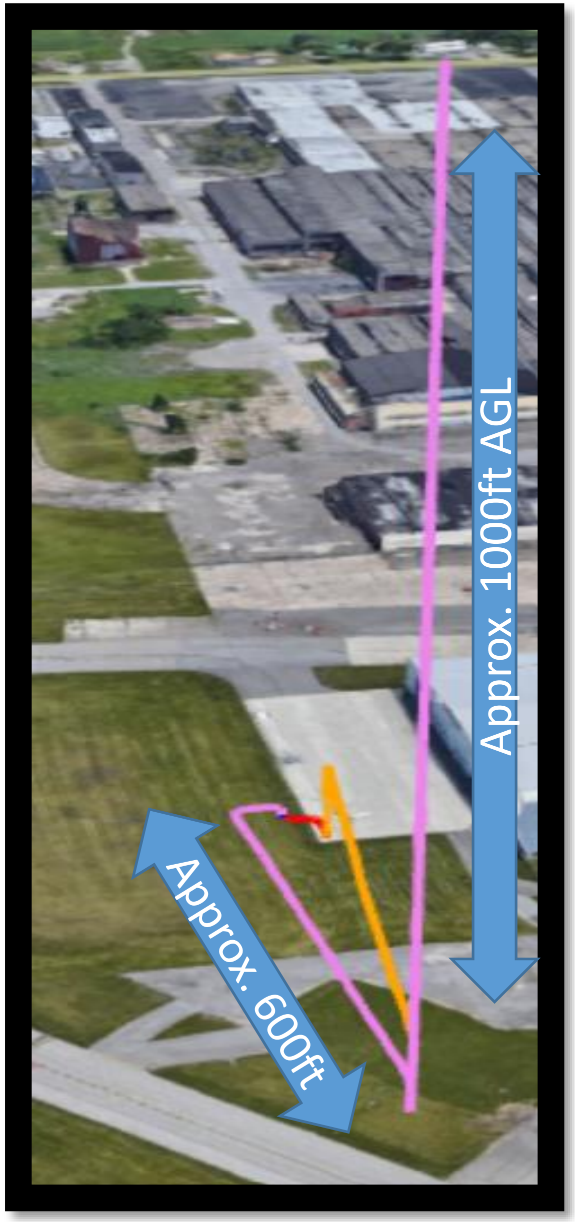
Cover required to account for solar heating affects while maintaining proper ventilation of sensors.

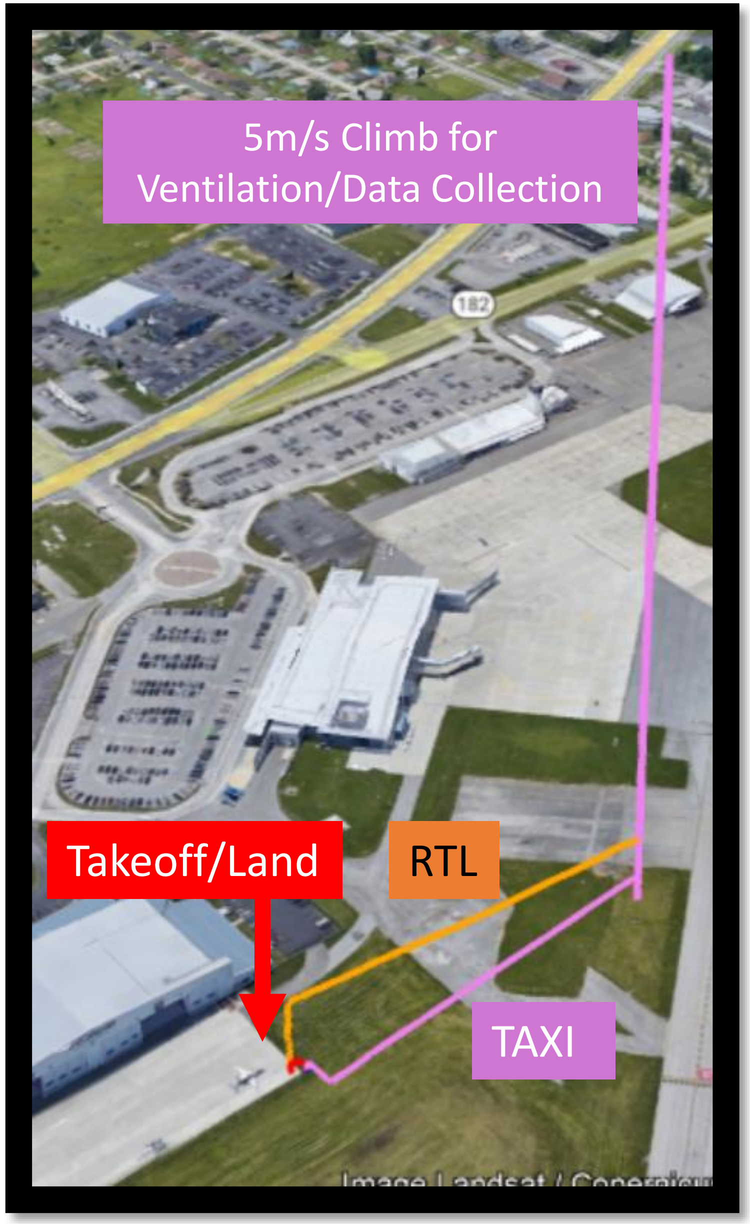
Output Data = F9P Post-Processed GPS latitude, longitude, and time + iMet Temperature, Pressure, and Relative Humidity Profile

UAS Weather Measurements (KIAG) - ALTA 8 PR0 (N563NU) – Flight Data

Nominal Flight Profile

- Manual Takeoff 50ft AGL
- Taxi at 50ft AGL
- Descend to 10ft AGL
- Climb to 1000ft AGL
- Descend to 10ft AGL
- Climb to 1000ft AGL
- Descend to 100ft AGL
- Autonomous RTL & Land

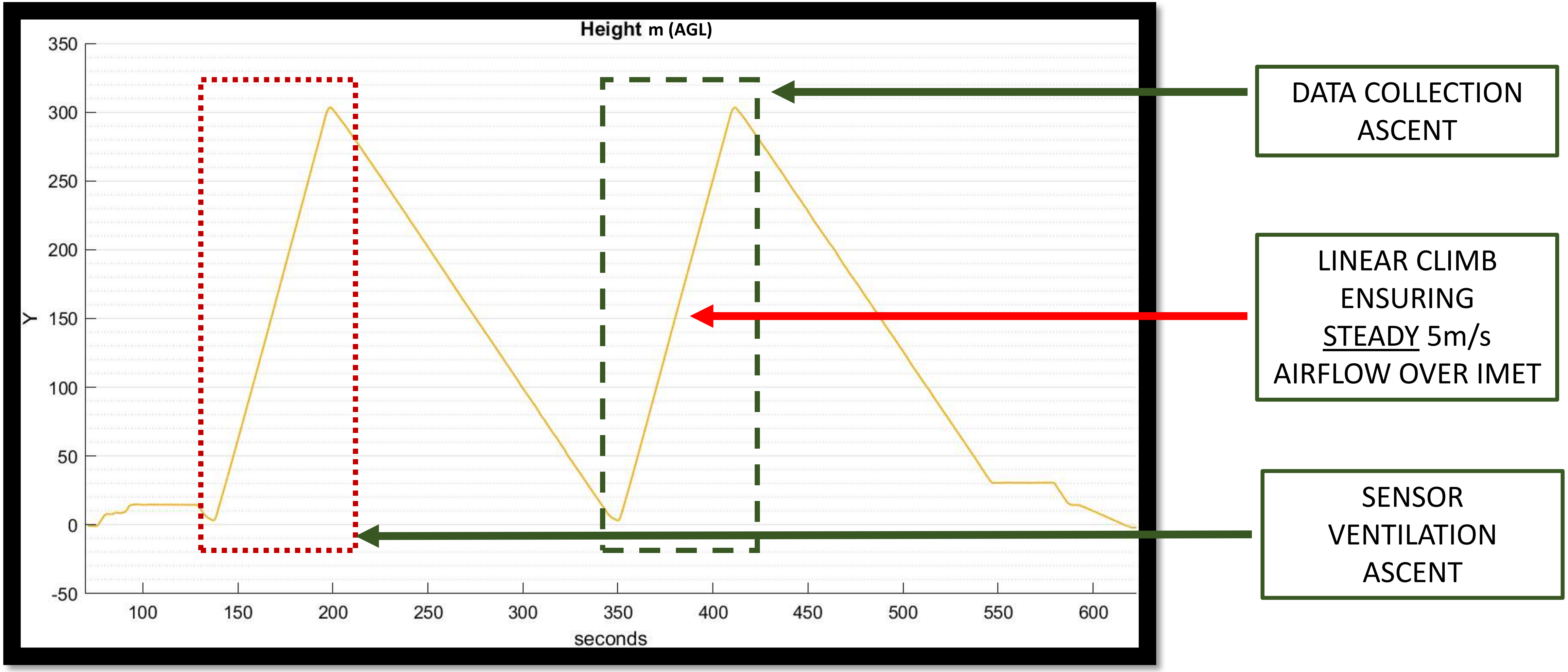




KIAG Field Elev: 592.3ft /180.5m MSL

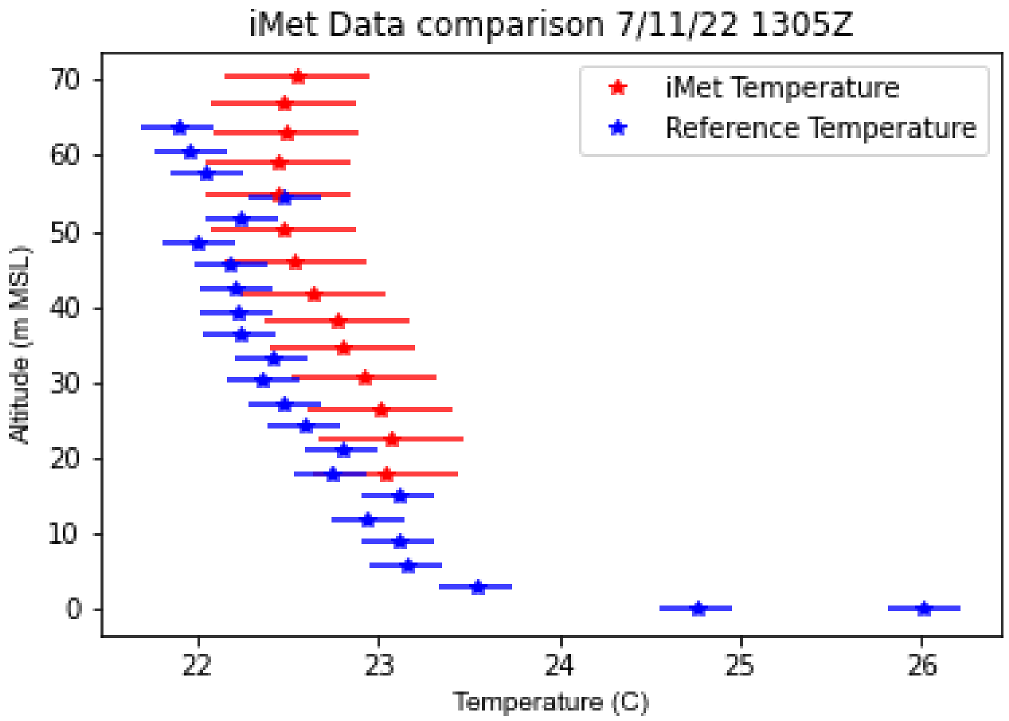
UAS Weather Measurements (KIAG) - ALTA 8 PR0 (N563NU)- Flight Data

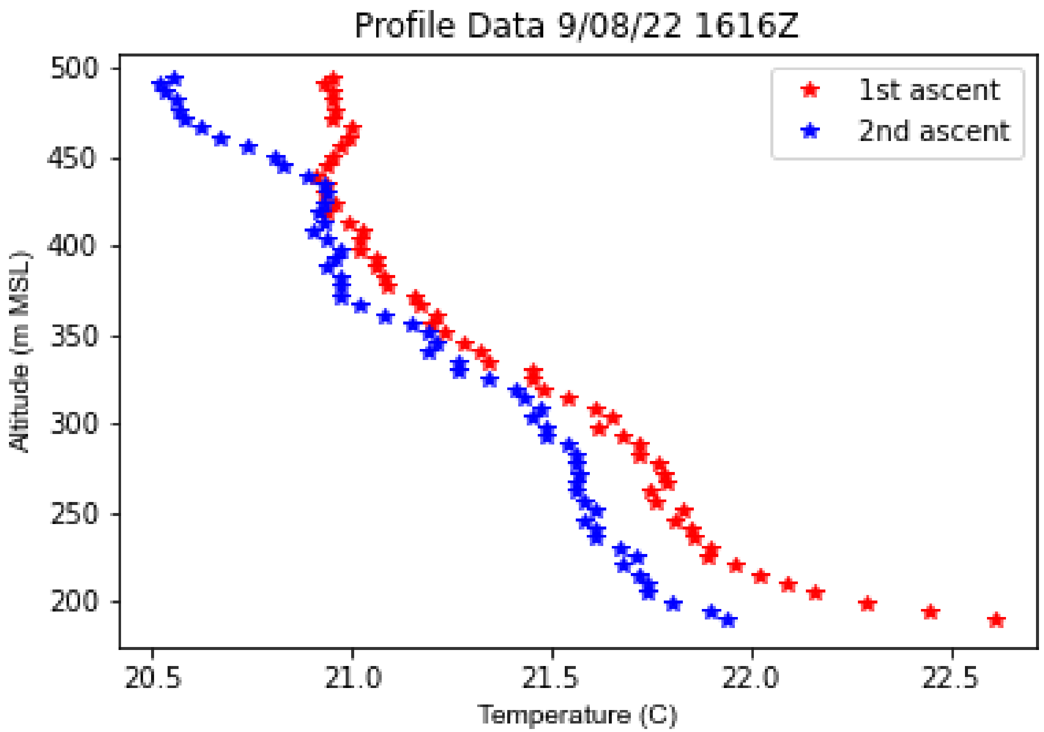
- Ventilation was required because of ambient solar/ground heat warming the iMet while sitting on the ground preparing for flight.



KIAG Field Elev: 592.3ft /180.5m MSL

UAS Weather Measurements (KIAG) - Data





Reference data is from a string of thermocouples suspended from top of LaRC Gantry.
iMet sensor mounted on Skydio X2D not Alta 8.
Altitude data is MSL from iMet (+/- 12m), <u>not PPK GPS.</u>

This is first flight of the day on 9/8/22. Altitude is from PPK GPS (+/- < 2m) in MSL.

KIAG Field Elev: 592.3ft /180.5m MSL

UAS Weather Measurements (KIAG) - Data QC

Limit and Outlier Check
(based on response ranges of the given sensors)

https://ncar.github.io/aspendocs/algo_limitcheck.html

Relative Humidity Thresholding and Limiting
(Do RH values outside 0-100% range still contain valid data?)

https://ncar.github.io/aspendocs/man_qc.html

Rate of Change Limits
(Are there abrupt changes in the data that represent sensor anomalies?)

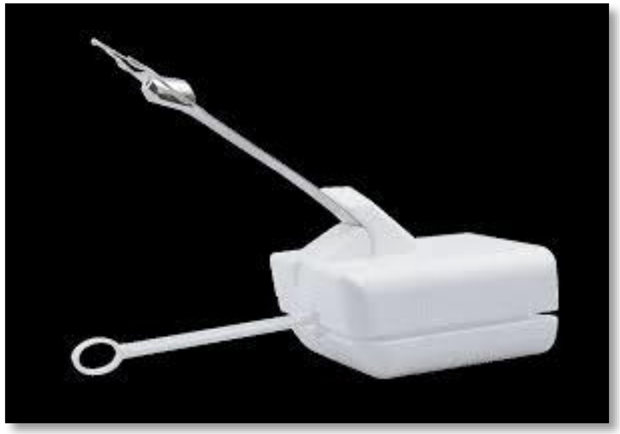
(Formulas outlined in Meeks and Hatfield, 1993)

Data Continuity Check
(Is there a continual no-observed-change in time limit)

(Formulas outlined in Meeks and Hatfield, 1993)

UAS Weather Measurements – System Improvements

Better Sensors



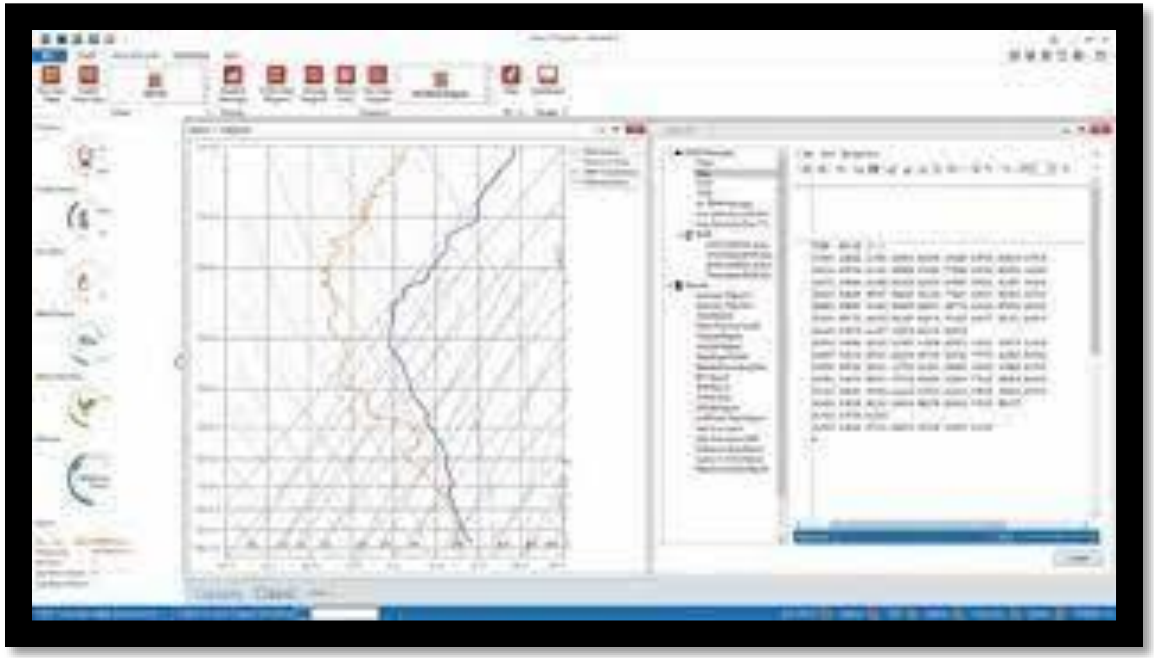
Replacing iMet with Graw DFM-17 radiosonde that has been evaluated by the WMO and is the current balloon- borne sonde for NWS daily soundings.

Graw temp is < .2 deg C accuracy
Graw RH is < 4% accuracy
Graw pressure is < 1 mbar accuracy
Graw geopotential height uncertainty < 8m

Additional Measurements

Adding Anemoment TriSonica Wind Flux Sensor measures u (east-west),v (north-south), and w (vertical).

Correlated, Real-Time Data



Output is in real-time with available skew-t plots. Wind data is sent through XData to radiosonde transmission stream to be included in a single data set.

UAS System Improvements

- Endurance: 40-60min
- Max Ground speed 31mph
- Max ascent speed 13ft/s
- Max descent speed 9ft/s
- Precipitation: IP-54 Rated/MIL-STD-810G
- Wind 40mph sustained, 56mph gusting
- Payload Capacity: 7.7lb.
- Radio Range: Up to 5 miles
- Cost: ~$80k

- Endurance: 10-55min
- Max Ground speed: ~20m/s (Configurable)
- Ascent/Descent Speed: 1-10m/s(Configurable)
- Precipitation: IP-43
- Payload Capacity: 40lbs
- Radio Range: ELOS
- Cost: ~$20k

Acknowledgements

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Questions?

Commercial Supersonic Fan Noise Modeling

Patrick Brandt

Aerospace Engineering Graduate Student

The Ohio State University

Mentor: David Stephens

LERCIP Internship, Summer 2022

Supported by Commercial Supersonic Technology Project

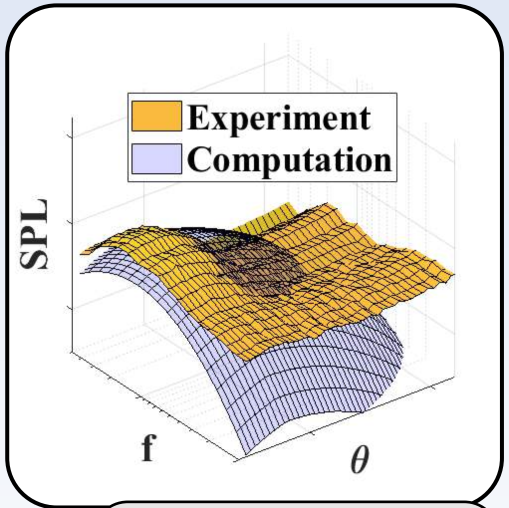
Problem Outline

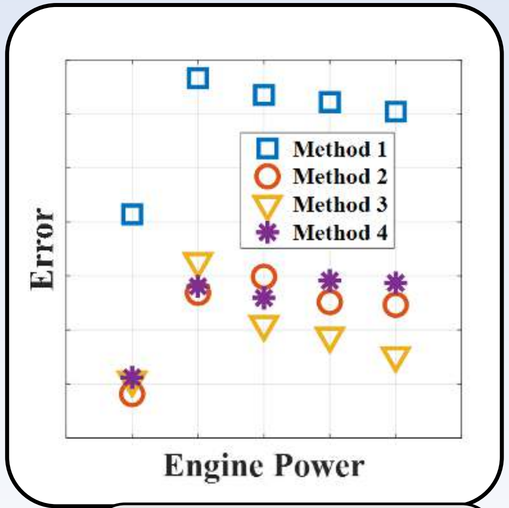
Fan acoustics modeling for supersonic design engine

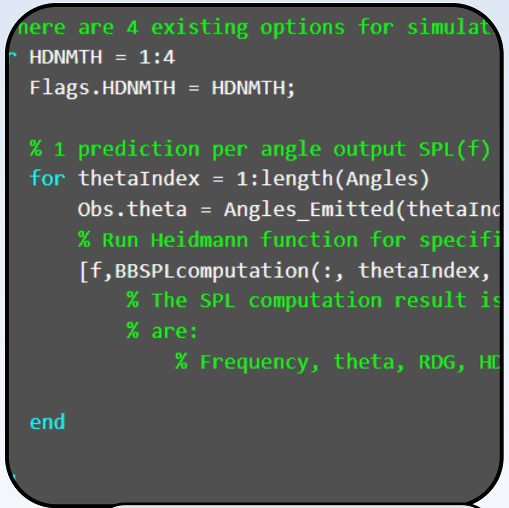
- Existing empirical models based on subsonic engine designs

- Using data from acoustic experiment:
  1. Determine usefulness of existing models
  2. Develop an empirical model for supersonic type turbofan noise

Approach







Experiment

- (2002) NASA GRC 9x15 wind tunnel
- Interpret data

Computation

- Model experiment with existing models

Compare

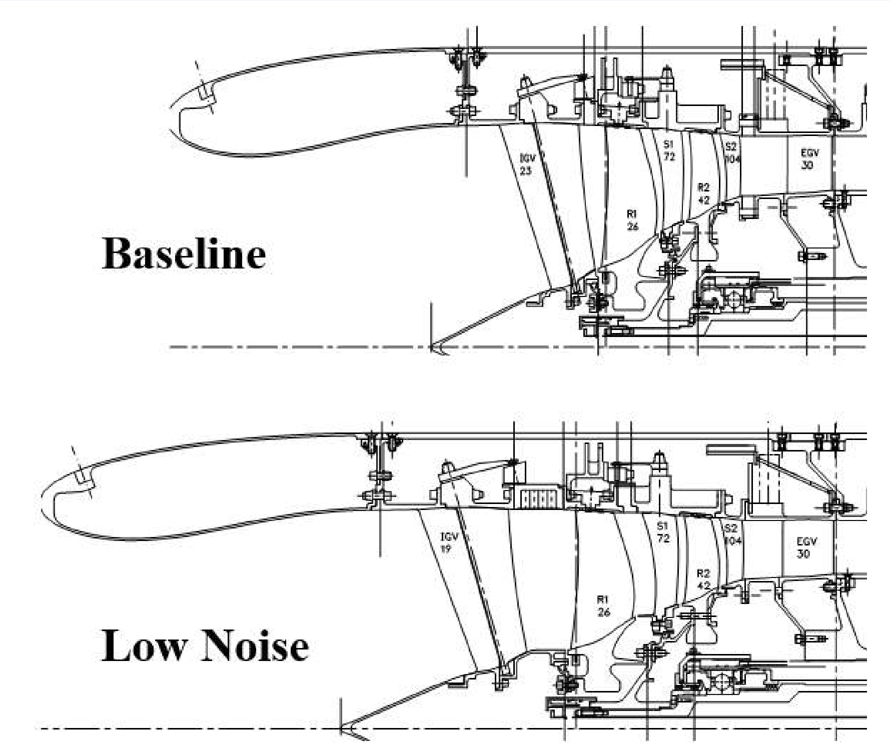
- Determine needs for new model

Program

- Update model
- Evaluate and iterate

Experiment

- Quiet Supersonic Propulsor (QSP)
  - Tested in the 9 x 15
  - $M_\infty = 0.15$

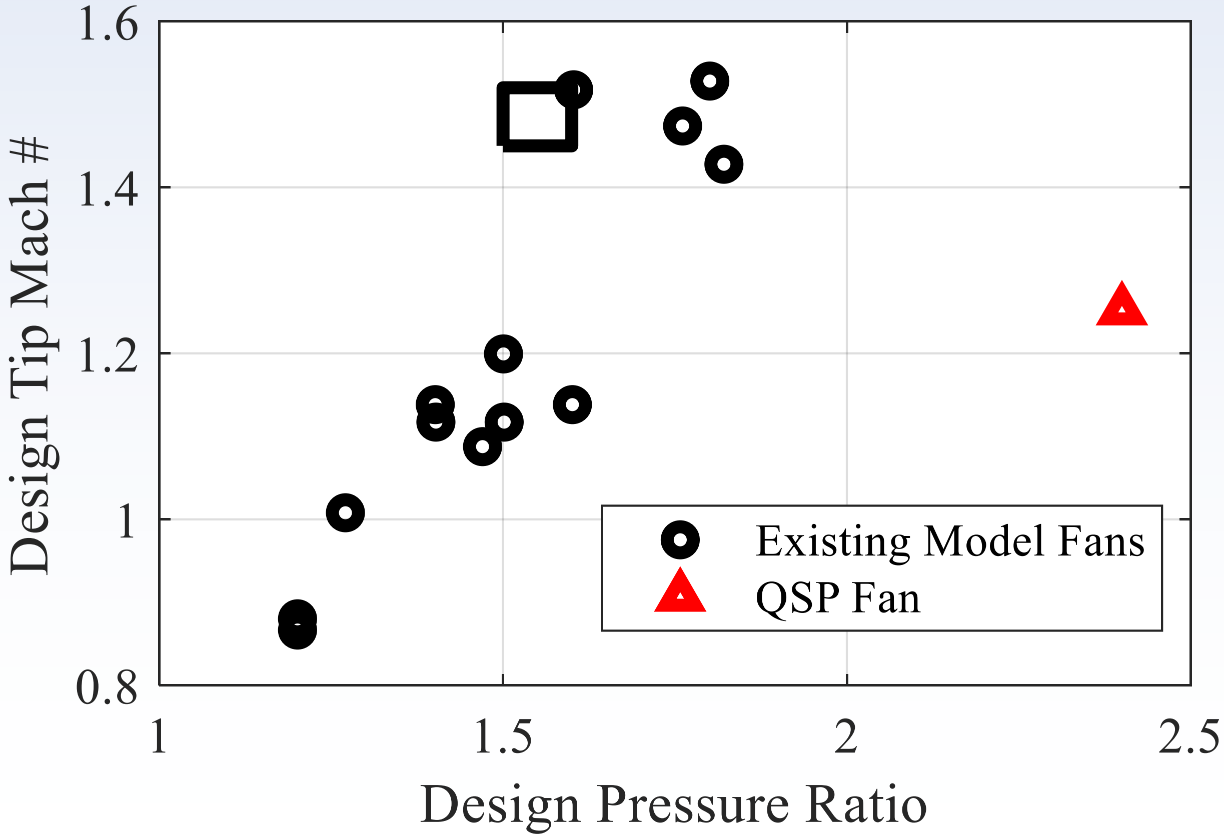


Config. #	IGV Count	IGV/R1 Spacing	IGV/R1 Spacer Treatment	R1/S1 Spacing	S1 Angle (deg.)	Acoustic Barrier Wall
1A	23	Nom.	N/A	Nom.	4.1	Orig.
2	23	Open	Hard Wall	Nom.	4.1	Orig.
3	23	Open	Treated	Nom.	4.1	Orig.
4	19	Open	Treated	Nom.	4.1	Orig.
5	19	Open	Hard Wall	Nom.	4.1	Orig.
9A	19	Open	Treated	Open	4.1	Extended
9S	19	Open	Treated	Open	- 3.0	Extended
11W	23	Nom.	N/A	Open	4.1	Extended

Computational Model

$$SPL(f,\theta) = 20\log_{10}\left(\frac{\Delta T^*}{\Delta T^*_{ref}}\right) + 10\log_{10}\left(\frac{\dot{m}^*}{\dot{m}^*_{ref}}\right) + F_1(M_d, M_r) + F_2(s^*) + D(\theta) + S(f)$$

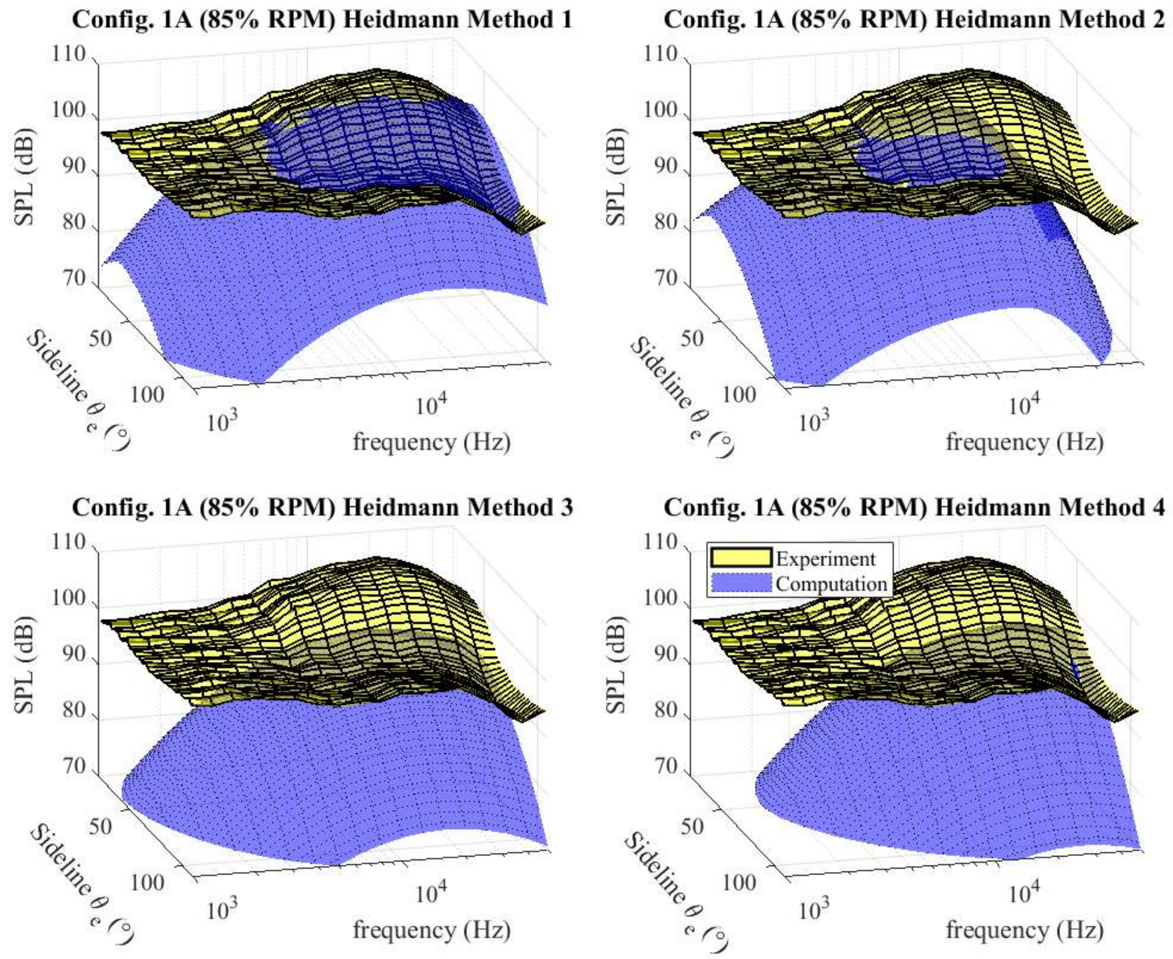
- Normalized by:
  - engine power ($\Delta T \cdot \dot{m}$)
  - specific work (ΔT)
- Source terms for operating conditions
- 5 fan noise components
- Based on experimental data for low-pressure-ratio turbofans



Existing Models

4 "Heidmann Methods"

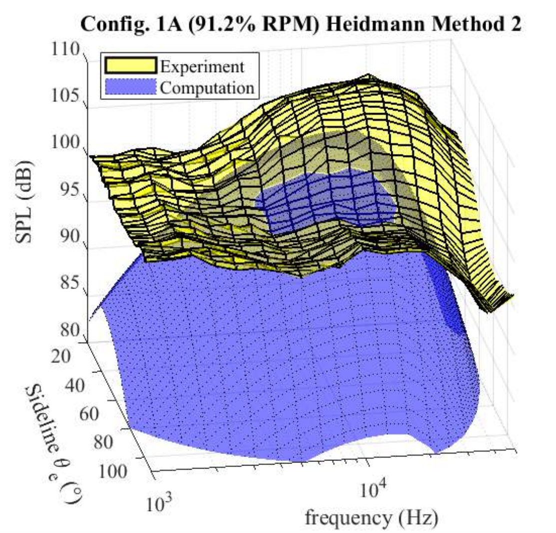
1. Original – NASA
   - No inlet flow conditioners
2. Small fans – Allied Signal
3. Large fans – GE Aviation
4. R4 fans – Diversitech

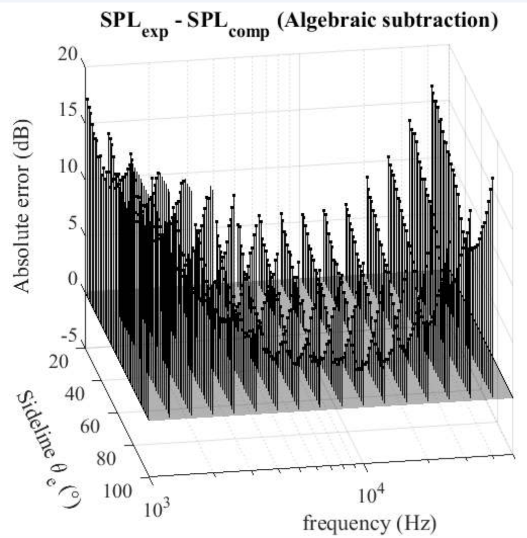


(Broadband noise only)

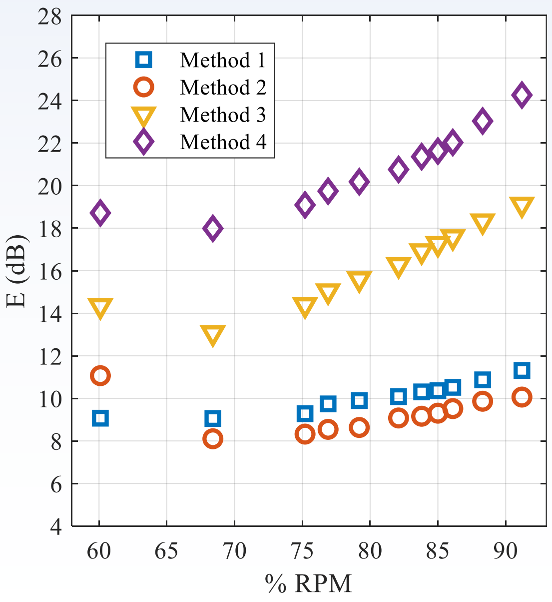
Error Metrics

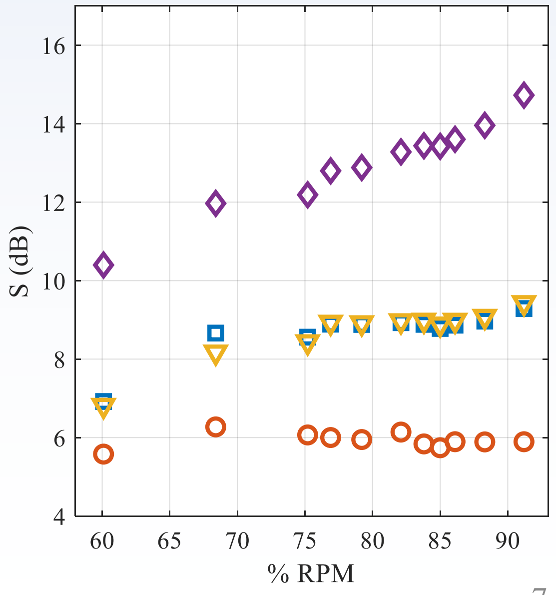
$E = \sqrt{\frac{1}{nf \cdot n\theta} \sum_{f,\theta} \left(SPL_{\{exp,f,\theta\}} - SPL_{\{comp,f,\theta\}}\right)^2}$	$S = std_{\{f,\theta\ domain\}}(SPL_{exp} - SPL_{comp})$
Magnitude of error	Deviation of error
How close are the levels	How close are the shapes





(Configuration 1A)





Goal: Develop a model that better estimates the data

Criterion: The new model should have reduced error metrics

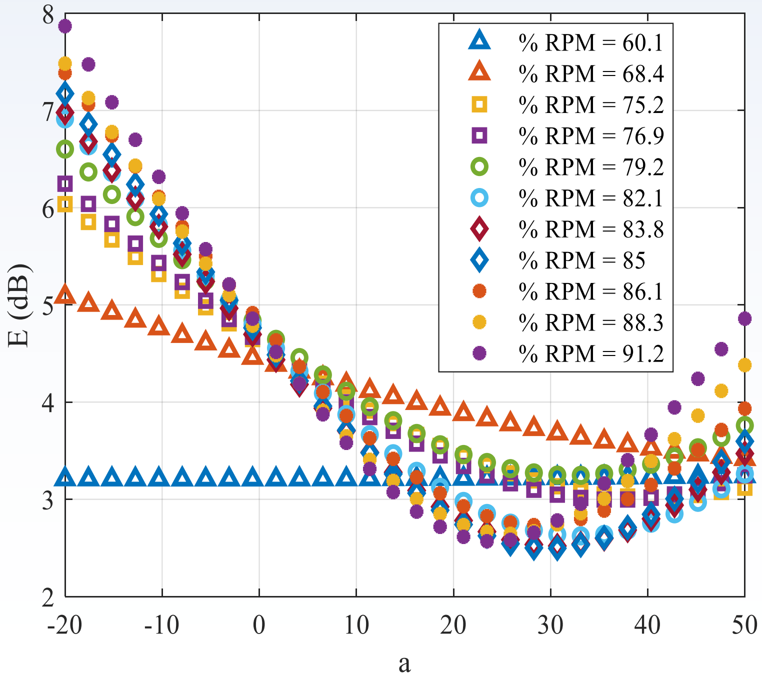
Method: Wrote an algorithm to systematically minimize E

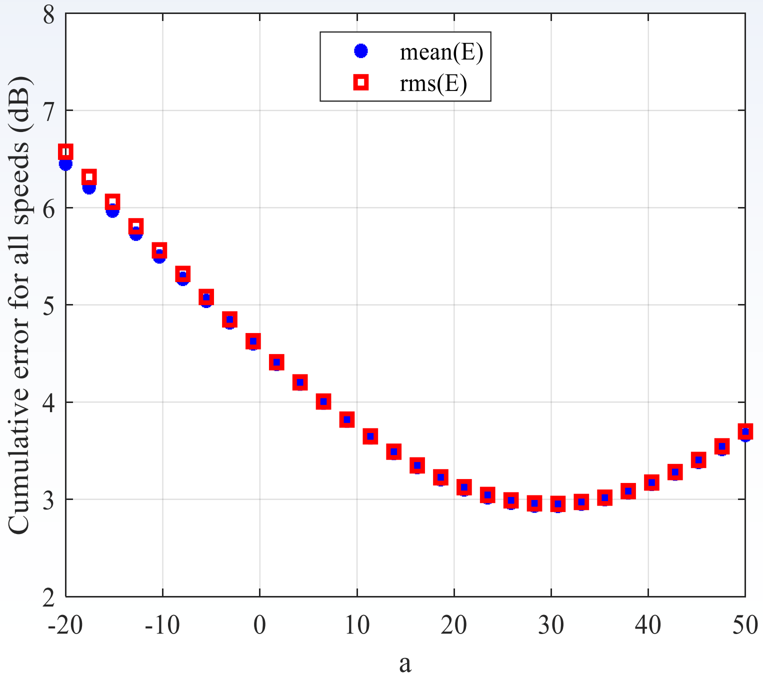
Method

$$SPL(f,\theta) = 20\log_{10}\left(\frac{\Delta T^*}{\Delta T^*_{ref}}\right) + 10\log_{10}\left(\frac{\dot{m}^*}{\dot{m}^*_{ref}}\right) + F_1(M_d, M_r) + F_2(s^*) + D(\theta) + S(f)$$

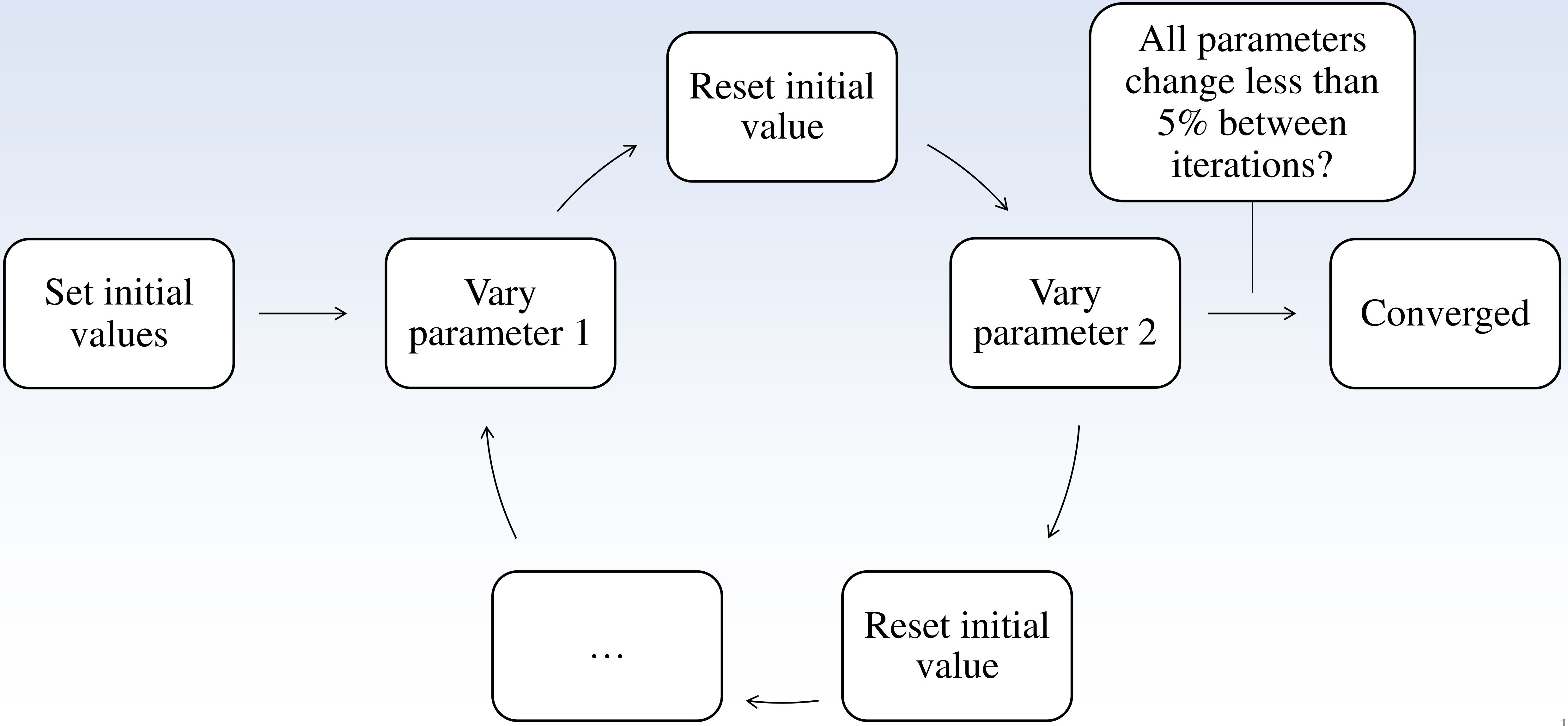
$$F_1(M_d, M_r) = 69 + 20\cdot\log_{10}(M_d) - \boldsymbol{a}\cdot\log_{10}\left(\frac{M_r}{0.83}\right)$$

- Configuration 1A



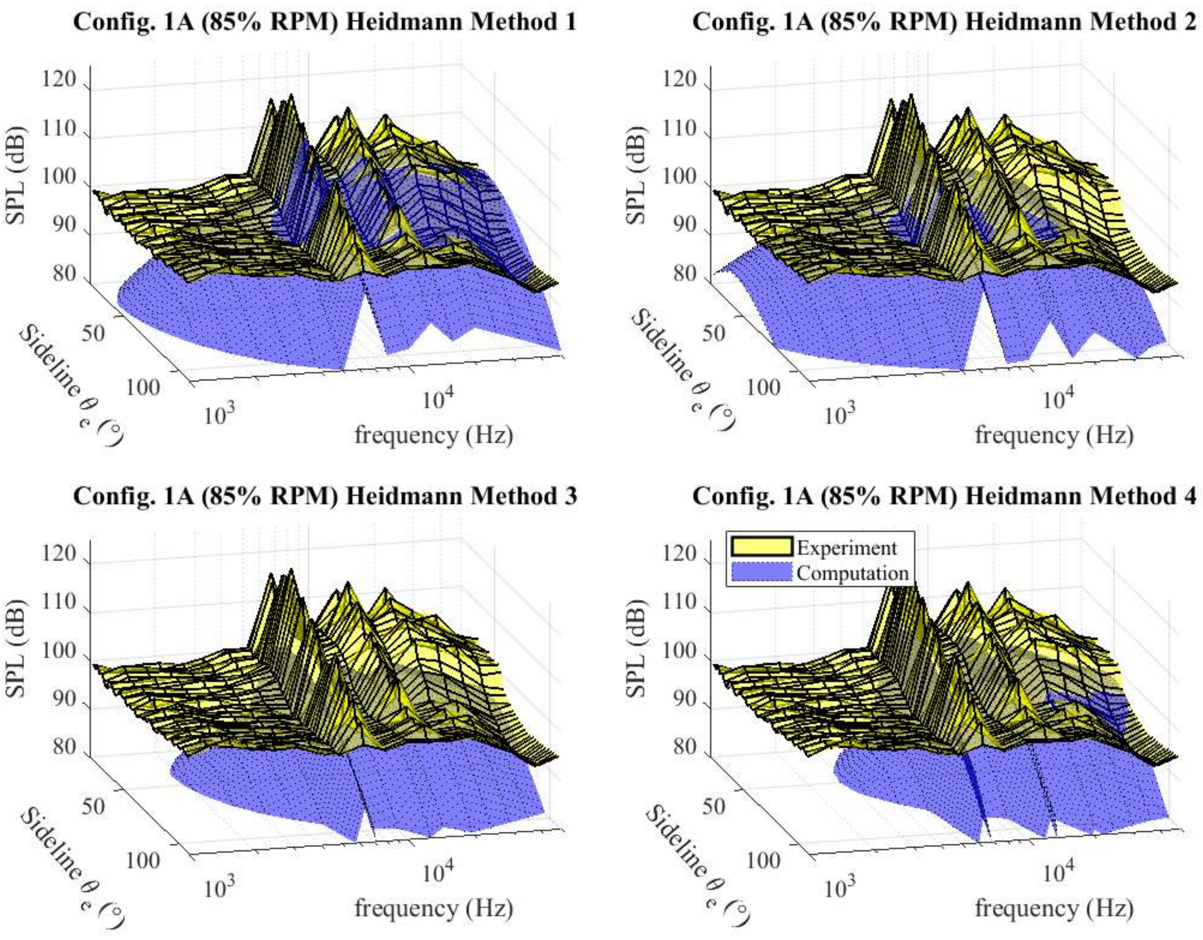


Method

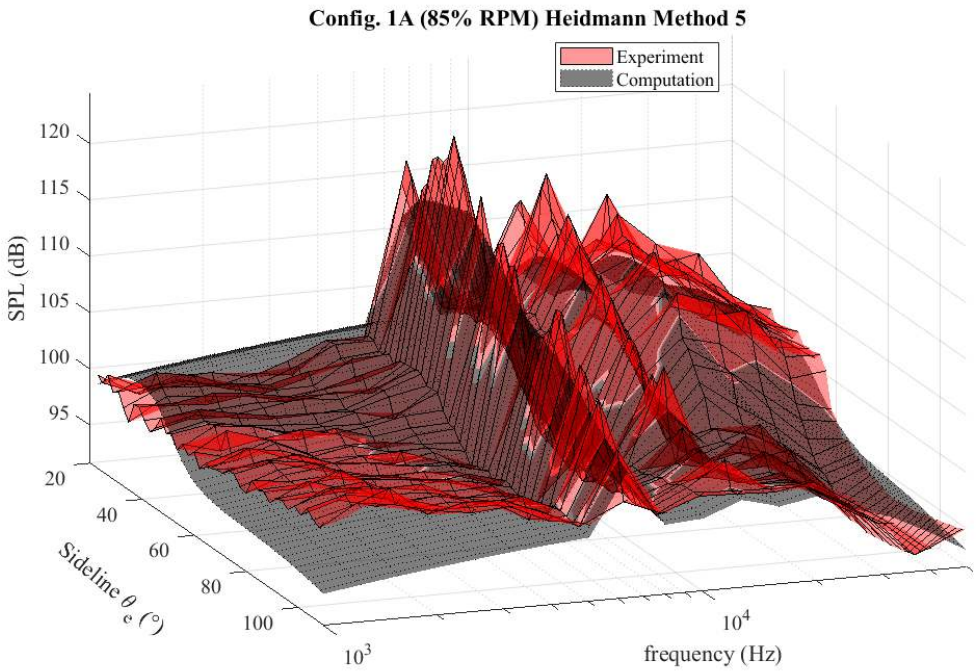


Reset initial value
All parameters change less than 5% between iterations?
Set initial values
Vary parameter 1
Vary parameter 2
Converged
…
Reset initial value

Results

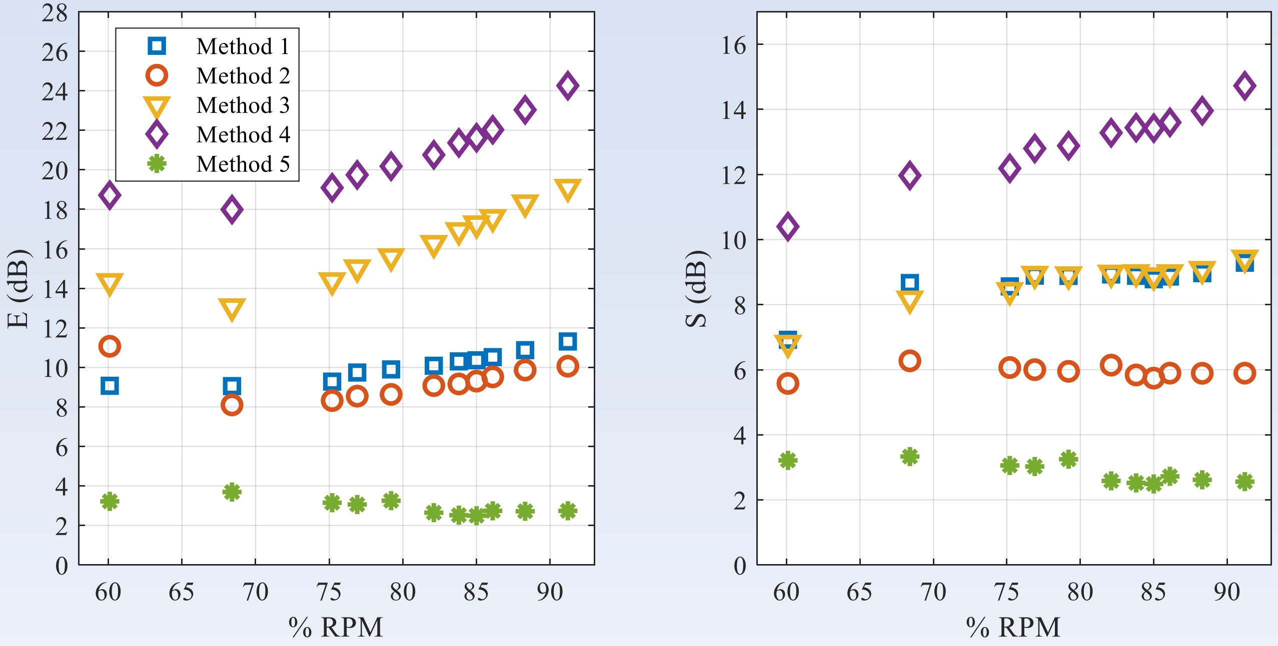


Config. 1A (85% RPM) Heidmann Method 1
Config. 1A (85% RPM) Heidmann Method 2
Config. 1A (85% RPM) Heidmann Method 3
Config. 1A (85% RPM) Heidmann Method 4
Experiment
Computation
SPL (dB)
Sideline θ_e (°)
frequency (Hz)

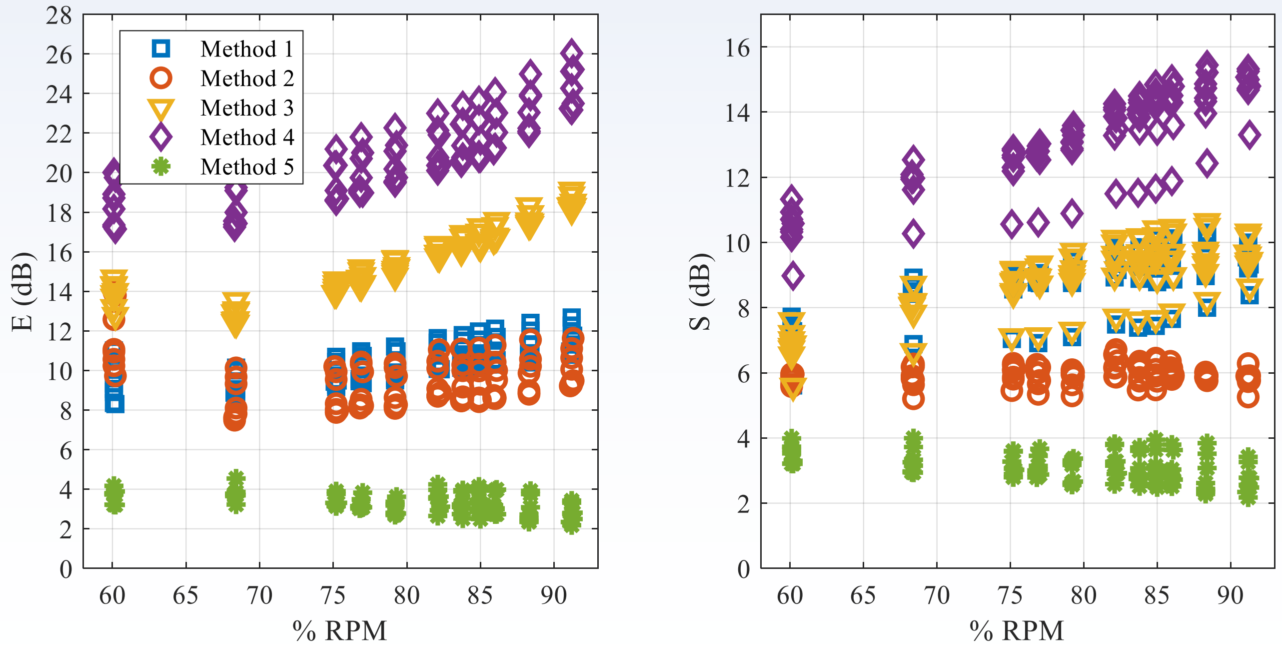


Config. 1A (85% RPM) Heidmann Method 5
Experiment
Computation
SPL (dB)
Sideline θ_e (°)
frequency (Hz)

Configuration 1A



All Configurations



Conclusions

Actions: Developed an empirical fan noise model based on QSP data

- Compared existing models against data
- Defined quantitative error metrics
- Reduced error metrics with new model

Significance: Beneficial to early design noise estimation

- Fast estimations more reliable for supersonic vehicle design
- Documented the procedure for future work

Thank you!

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Summary

This presentation describes the development of an empirical noise model for a two-stage fan designed for a supersonic commercial aircraft. The existing fan noise models are reviewed and compared with noise data from a wind tunnel experiment where a model scale two-stage fan was tested. An error metric was developed to quantify how well the measurements and empirical model match. This error metric was then used to determine new coefficients and parameters for a version of the fan model that is a good match for the experimental data.

Toward Development of an Improved Perforate Impedance Model

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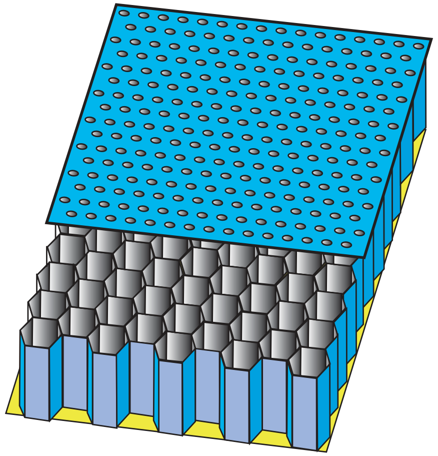
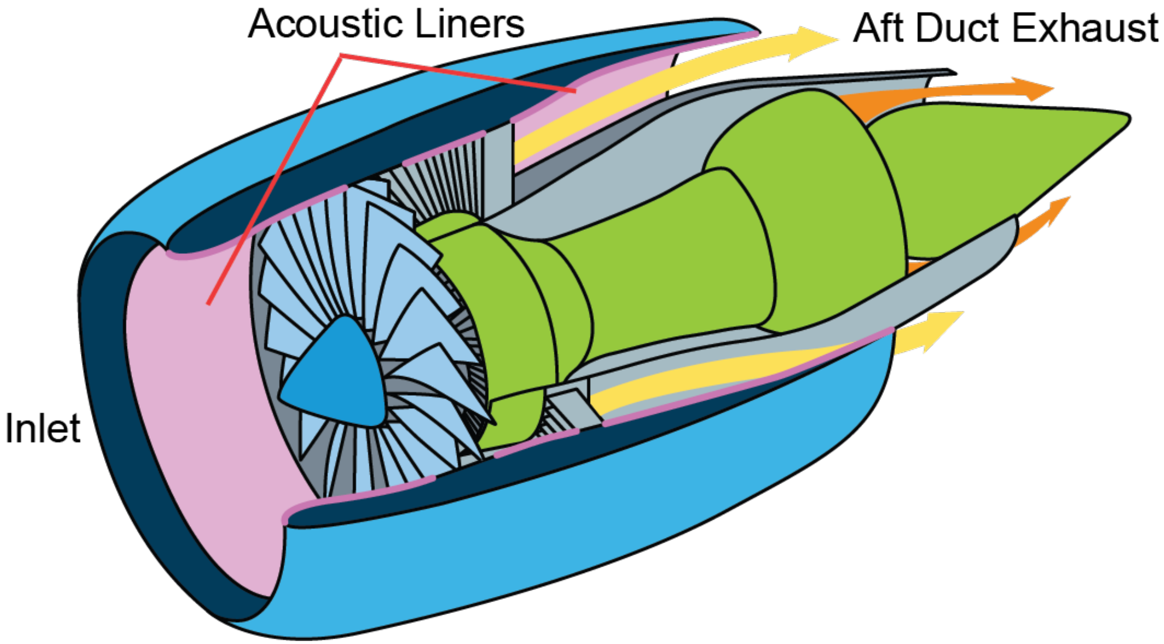
Outline

- Motivation
- List of Perforate Models Included in Investigation
- Analysis: 2-Factorial
- Experimental Setup
- Analysis: L_2 Norm
- Next Steps

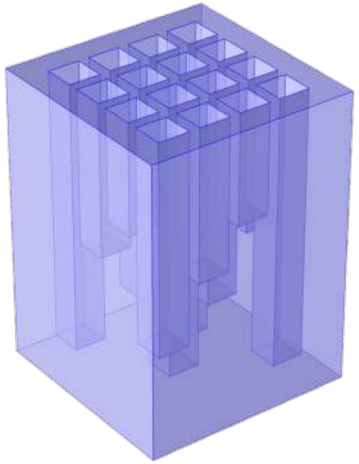
Motivation

Conventional SDOF

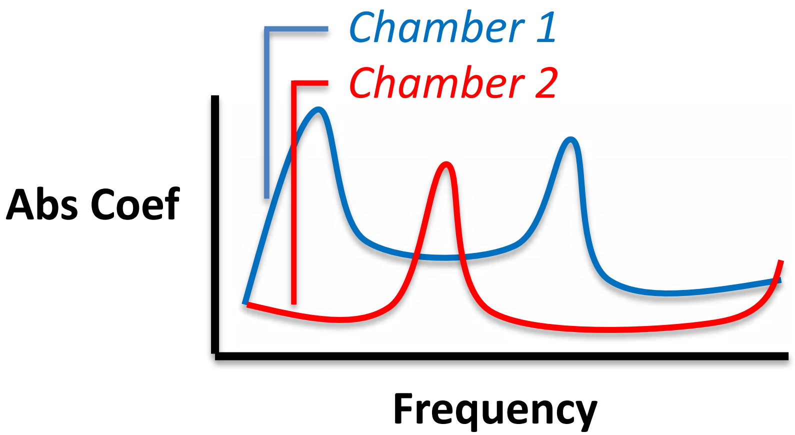




Variable Depth



- Nacelles becoming shorter with larger diameter
- Increased emphasis on optimized liners
- One option: variable depth liners
- Increasing importance for off-resonance effects



List of Models

Model	Authors	Reference
1	Guess	JSV (40), 1975
2	Kooi and Sarin	AIAA 81-1998, October 1981
3	Motsinger, Kraft	NASA RP-1258, August 1991
4	Parrott 'correction' to Model 3	-
5	Kirby and Cummings	JSV (217), 1998
6	Maa (with grazing flow effect added)	JASA (104) 1998
7	Crandall (per Betts)	Betts PhD, 2000
8	Elnady, Boden	AIAA 2003-3304, May 2003
9	Parrott, Jones – 2006	AIAA 2006-2402, May 2006
10	Yu, Ruiz, Kwan	AIAA 2008-2930, May 2008
11	Parrott – 2008	TWG, September 2008
12	Schultz, Liu, Cattafesta, Sheplak, Jones	AIAA 2009-3301, May 2009
13	Jones, Howerton, Ayle	AIAA 2012-2194, June 2012
14	Kabral, Boden, Elnady	AIAA 2003-3304, June 2014

Other methods were not included
- limited application
- difficult measurement requirements
- inefficient computations
- insufficient time

Recent studies
- Murray, Di Giulio: AIAA 2022-2929
- Eversman, Drouin: AIAA 2022-2966

Many are based on models developed by Crandall or Guess

4 years (and counting) study

Analysis: 2-Factorial

- Analysis is conducted over restricted parameter range (**assumed** to represent conventional usage)

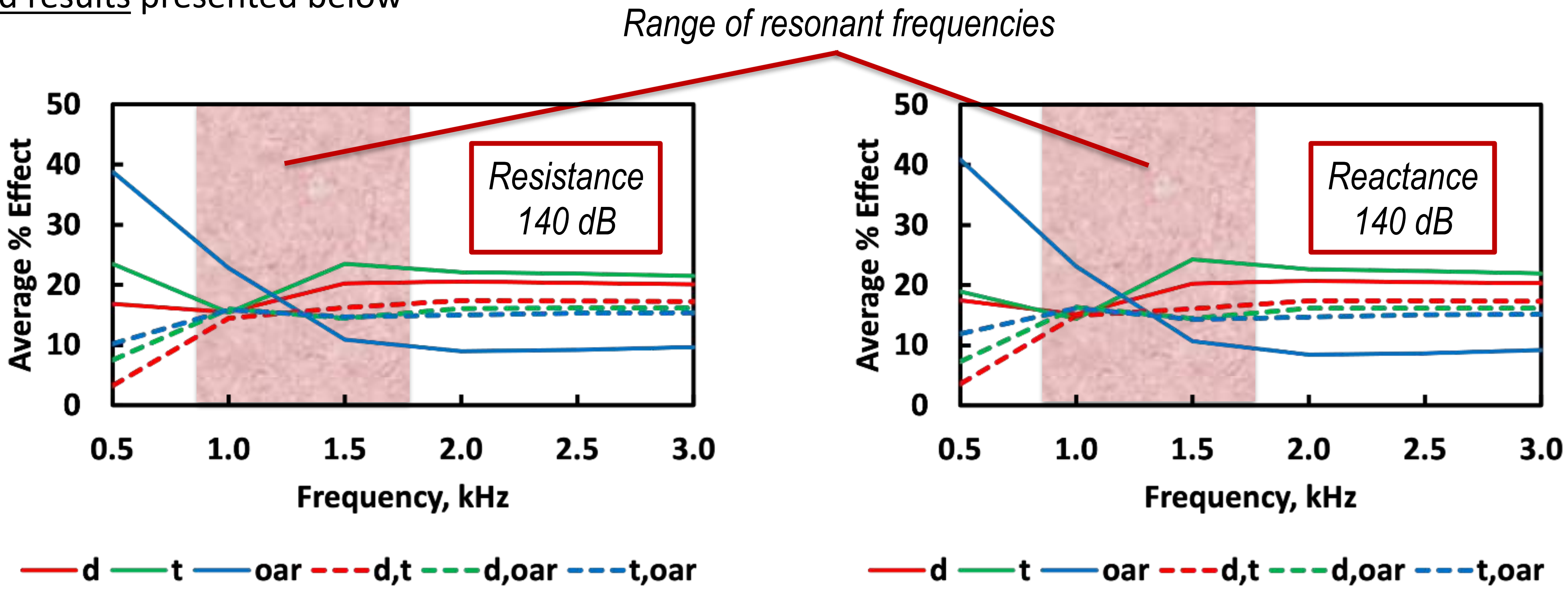
Hole diameter	$0.020'' \leq d \leq 0.090''$
Sheet thickness	$0.020'' \leq t \leq 0.060''$
Open area ratio	$0.03 \leq \sigma \leq 0.16$
Core height	$h = 1.5''$
Mach #	$M = 0.0$
Sound pressure level	$100 \leq \mathrm{SPL} \leq 140\ \mathrm{dB}$

- Use each model to predict the impedance at each corner and the midpoint of the parameter space
- Use Moffat's version of the 2-factorial method* with these predictions to determine the relative importance of
  - geometric parameters (d, t, σ)
  - combinations of parameters ($d\ \&\ t, d\ \&\ \sigma, t\ \&\ \sigma$)

*Moffat, R. J., "Planning Experimental Programs - Lecture Notes," Moffat Thermosciences, Inc., Palo Alto, CA, 1990

Analysis: 2-Factorial

- Each model demonstrates similar trends regarding effects of the different parameters
- <u>Averaged results</u> presented below



- Clear <u>frequency regime dependence</u> (below/above resonance), similar for resistance and reactance components
- Note the importance of <u>interaction effects</u>; will consider this as part of model refinement
- If h or M are included in the 2-factorial analysis, M dominates resistance and h dominates reactance

Experimental Setup

Design

- NIT facesheets

  $0.020" \leq d \leq 0.090"$ (hole diameter) $0.025" \leq t \leq 0.090"$ (sheet thickness)

  $0.03 \leq \sigma \leq 0.16$ (open area ratio) $h = 1.500"$ (core height)

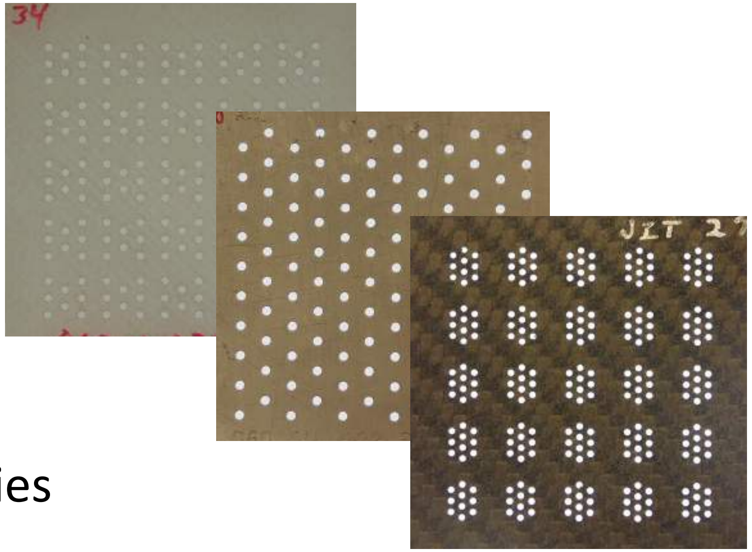
- GFIT facesheets

  $0.025" \leq d \leq 0.080"$ (hole diameter) $0.025" \leq t \leq 0.045"$ (sheet thickness)

  $0.03 \leq \sigma \leq 0.16$ (open area ratio) $h = 1.500"$ (core height)

Fabricate

- Three materials and corresponding fabrication techniques
- Accura (Protolabs) – 33 NIT panels, 9 GFIT panels
- Aluminum (Ferguson) – 18 NIT panels
- Carbon fiber composite (Ikonics) – 24 NIT panels
- Accura and carbon fiber panels designed to support multiple studies
- *Total – 75 NIT panels, 9 GFIT panels*



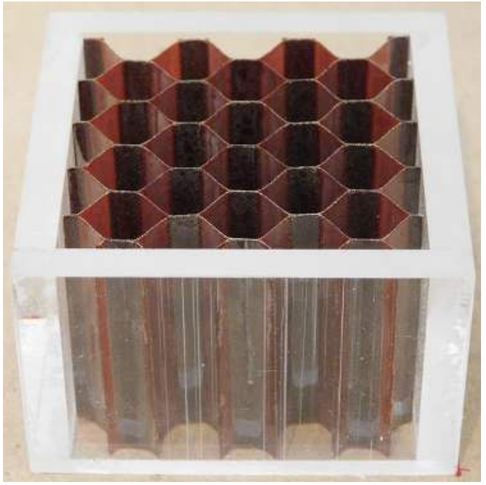
Experimental Setup

Normal Incidence Tube (NIT)

- 2” x 2” waveguide
- Two-Microphone Method
- Freq: 0.4 to 3.0 kHz
- Source Type: Swept Sine
- Source SPL: 100, 120, 140 dB

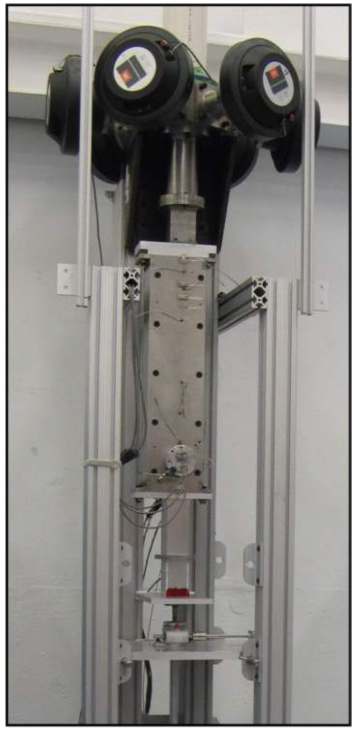
Grazing Flow Impedance Tube (GFIT)

- 2” x 2.5” waveguide
- Prony Method
- Freq: 0.4 to 3.0 kHz
- Source Type: Swept Sine
- Source SPL: 120, 140 dB



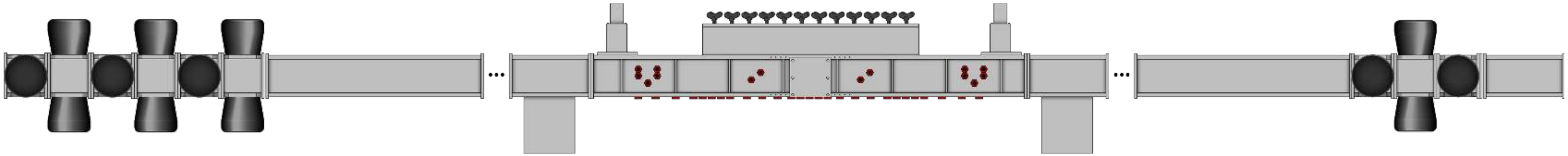
Phenolic Core

NIT



GFIT results to be included in Phase 2

GFIT



Analysis: L_2 Norm

- Phase 1: **NIT, $\boldsymbol{M = 0.0}$, $\boldsymbol{h = 1.5}$"**
- Compared measured and predicted impedances (14 models)

$$\mathrm{L_2\ norm} = \sqrt{\sum_{n=1}^{\mathrm{N}} \left[\left(\zeta_{pred,n} - \zeta_{meas,n}\right)\left(\zeta_{pred,n} - \zeta_{meas,n}\right)^{*} \right]}$$

- 158 test conditions ($N = 158$)

  One test condition consists of one liner geometry at one source SPL (512 frequencies)
- Three models provide best comparisons (in rank order)

1. Model 7 (Betts)
2. Model 13 (Jones, Howerton, Ayle)
3. Model 3 (Motsinger and Kraft) - we proceed with Model 3 for this phase of the study because
   – Convenience: Model 3 has been our standard and is already coded.
   – Simplicity: Model 7 is similar and is slightly more complicated to implement.
   – Nonlinearity: Model 13 does not (in this implementation) account for nonlinear effects

Model 3: Further Study

- Start with 'corrections' for t, d, σ
  - Replace t, d, and σ with αt, βd, and $\gamma\sigma$ in the model
  - Initial estimates: $\alpha = 0.73$, $\beta = 0.90$, $\gamma = 0.98$
  - Consider interaction effects (d & t, d & σ, t & σ)

Motsinger and Kraft

$$\zeta = \frac{a\mu t}{2\rho c(\sigma C_D)d^2} + \frac{\kappa_i + \kappa_e}{2c(\sigma C_D)} v_{rms} + \frac{M_{C/L}}{\sigma\{2 + 1.256(\delta_1/d)\}} + i\left\{\frac{k(t + \epsilon d)}{\sigma} - \cot(kh)\right\}$$

Modified Motsinger and Kraft

$$\zeta = \frac{a\mu\{\alpha t\}}{2\rho c(\{\gamma\sigma\}C_D)\{\beta d\}^2} + \frac{\kappa_i + \kappa_e}{2c(\{\gamma\sigma\}C_D)} v_{rms} + \frac{M_{C/L}}{\{\gamma\sigma\}\{2 + 1.256(\delta_1/\{\beta d\})\}} + i\left\{\frac{k(\{\alpha t\} + \epsilon\{\beta d\})}{\{\gamma\sigma\}} - \cot(kh)\right\}$$

Next Steps

- Use SciPy optimizers (and possibly machine learning) to determine correction factors
- Consider different metrics (weighting factors)
  - Res vs Rea
  - Frequency or SPL range
- **Add GFIT data ($M \geq 0.0$, Phase 2) and redo entire process**
  - Tests complete, analysis in progress
  - Will be included at AIAA Aeroacoustics 2023
- All NIT and GFIT data will be made available to the public; targeting mid-2023
- Investigate effects of other liner features
  - Variable impedance (e.g., variable porosity, variable depth)
  - Partition thickness
- Insert your suggestions here!

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Summary of Research in 2022 using the Advanced Noise Control Fan (ANCF) facility

NDTL Overview

- 55 full-time employees and graduate students
- 12-15 undergraduate internships per year

- 1-10 MW compressor and turbine testing
- Propulsion, power systems, thermal management, and acoustics.

- 8 individual test cells and facilities, including the ANCF.

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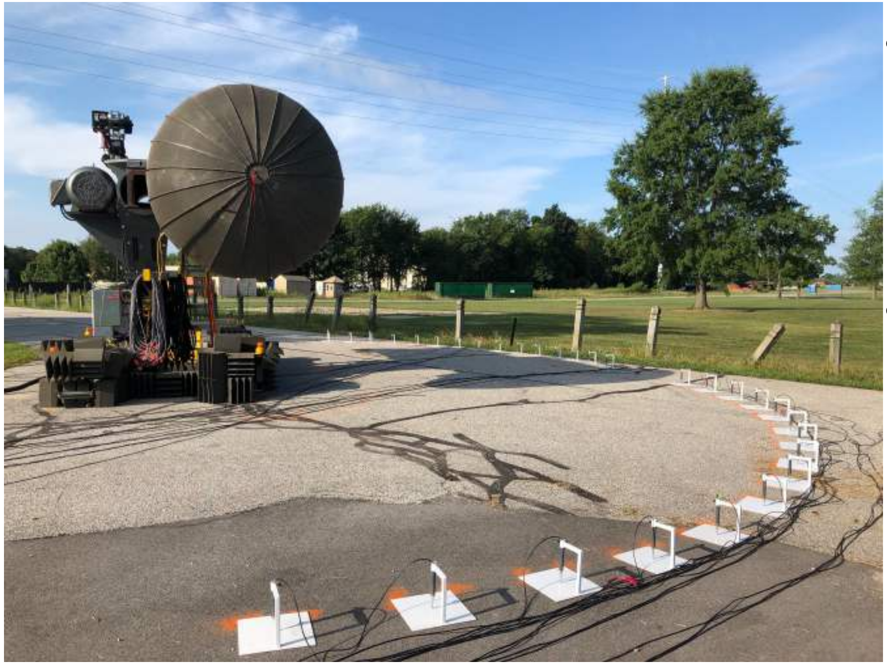
NASA's Advanced Noise Control Fan (ANCF) Facility



- ANCF is well suited for low-mid TRL technology development.
  - **balance between measurement fidelity, realistic geometry, and cost.**
- Significant opportunities for student involvement and workforce development
  - **UG interns, MS projects, PhD topics**

Operated by the Notre Dame Turbomachinery Laboratory (SAA3-1688).

2022 Summary

- 2 Ph.D Students supported
- Multiple (>5) undergraduate internships
- Navair FOD program
- Liner Testing
- Open Rotor Concept

Inlet Debris Monitoring System using RF sensors

- Flush mounted RD antenna used to detect FOD events.
- Uses a novel polarimetry method for high sensitivity.
- ANCF served as a perfect test bed for mid-TRL development.

- New aluminum rotor manufactured to accept FOD objects without damage.

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Movie of “shot fired”

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Gradient Metal Foam Liners

- **Bhisham Sharma**
- Department of Aerospace Engineering
- Wichita State University, Wichita, KS

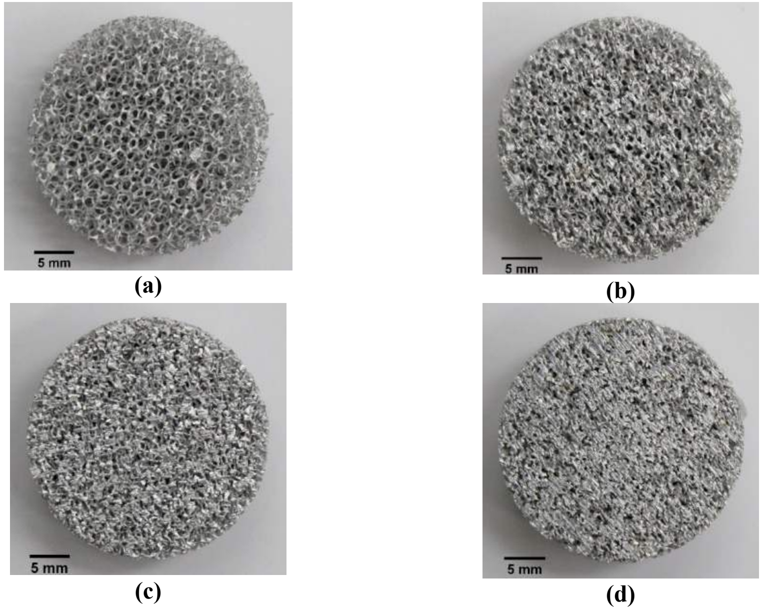


Fig. 1. Representative examples of the **(a)** uncompressed and **(b)**, **(c)**, **(d)** compressed foams with compression ratio of 2, 3, and 4, respectively.

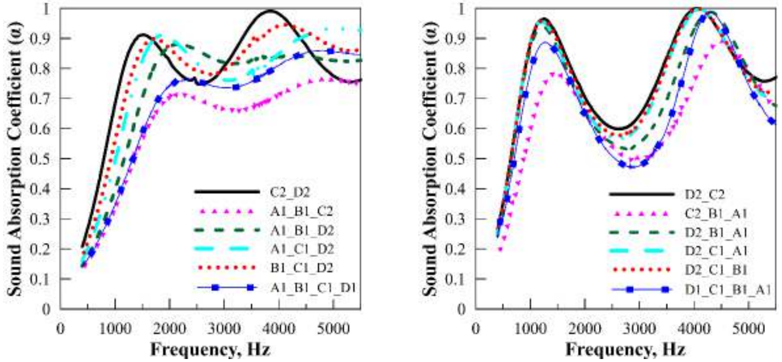


Fig 2. Normal Incidence Experimental Results

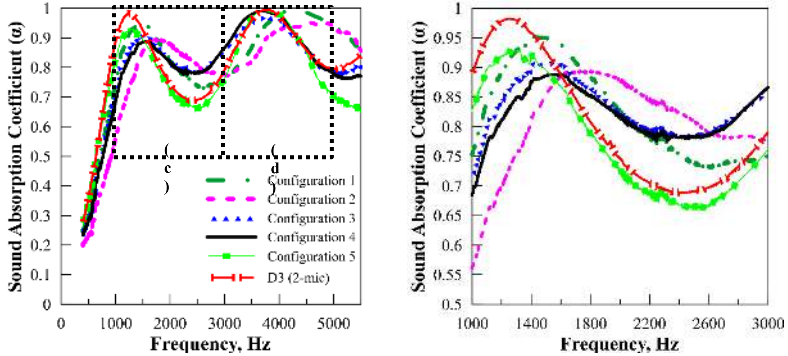


Fig 3. Transfer Matrix Based "Optimization"

Based on results obtained under normal incidence and grazing flow conditions, a metal foam liner configuration will be created in collaboration with ERG Aerospace for UND tests.

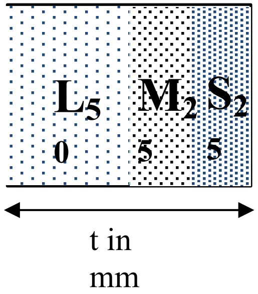
Granular Porous Materials for Acoustic Mitigation Applications

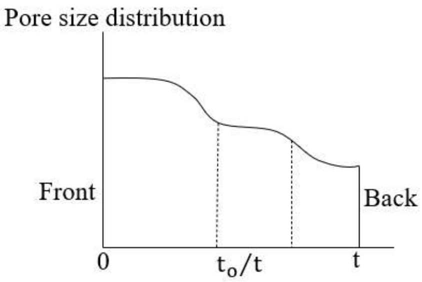
Hollow Microbubbles

- Low density and rough surface

Solid beads: **Smooth Surface** → Hollow Microbubbles: **Rough Surface** → **Surface causes more energy loss from friction (heat)**

Multilayer with Graded Distribution

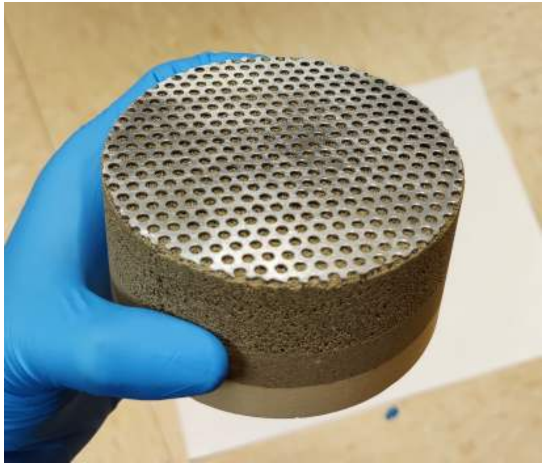




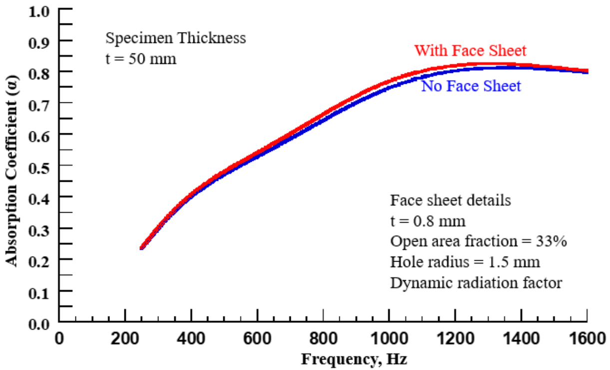
L – Large, M – Medium, S – Small
Subscripts represent % of each layer thickness

8

Granular Porous Materials for Acoustic Mitigation Applications

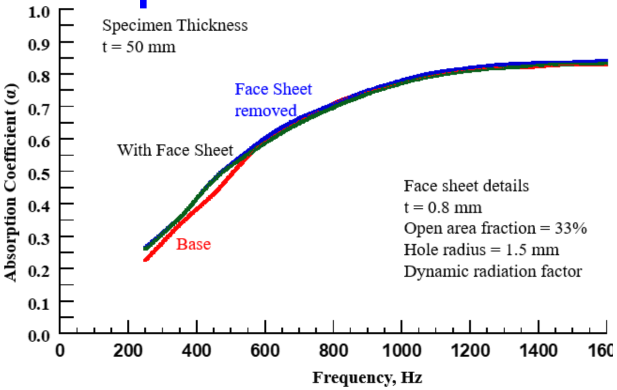


Face sheet glued onto the material surface



MATELYS Predictions

Experimental Validation



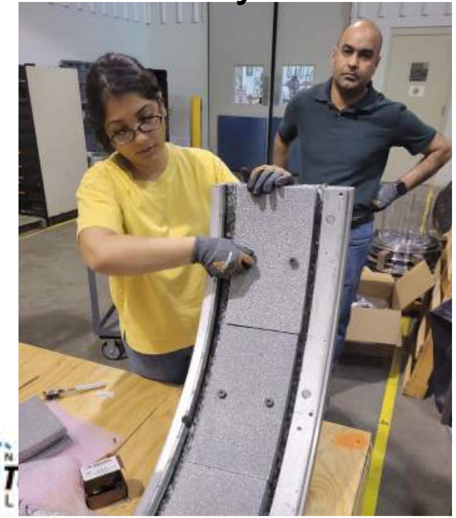
1. Validation of MATELYS by textbook example.

2&3. Effect of face sheet open area fraction / thickness on absorption coefficient.

Proposed face sheet details: Open area fraction = 33% / Thickness = 0.8 mm / Hole Radius, R_h = 1.5 mm

4. MATELYS prediction with and without face sheet.
    - a. Large / b. Medium / c. Small size hollow microbubbles
5. Multilayer system
    - a. Prediction – with and without face sheet / b. Experimental validation

WSU Assembly Team



NCAT Assembly Team

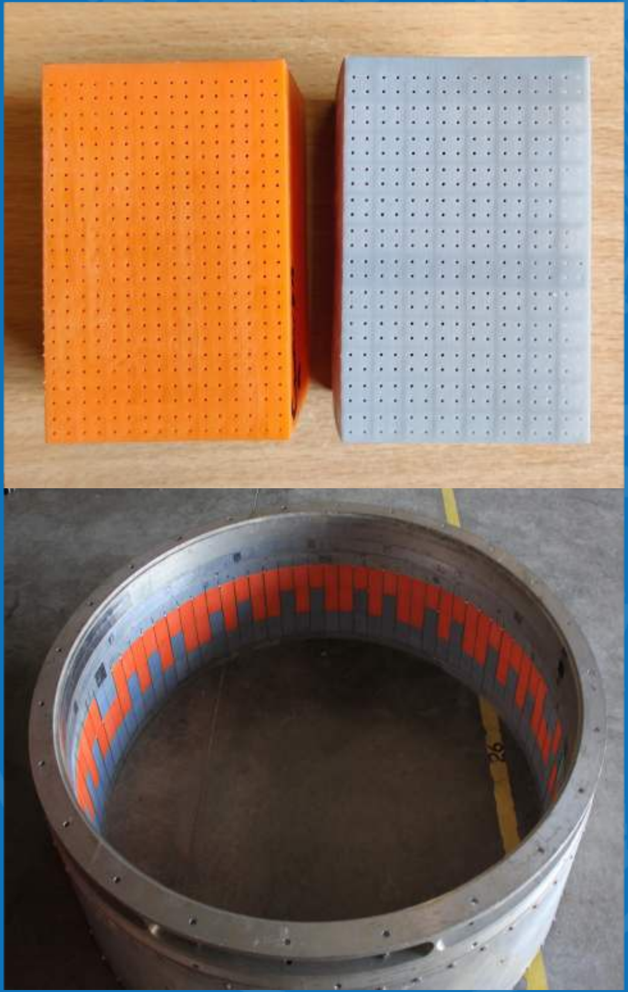
Liner Installed

Collins Aerospace Liner Testing

"testing of novel liners and zoned liner technology to mature design methodology for nacelle acoustic systems developed under FAA CLEEN II program."

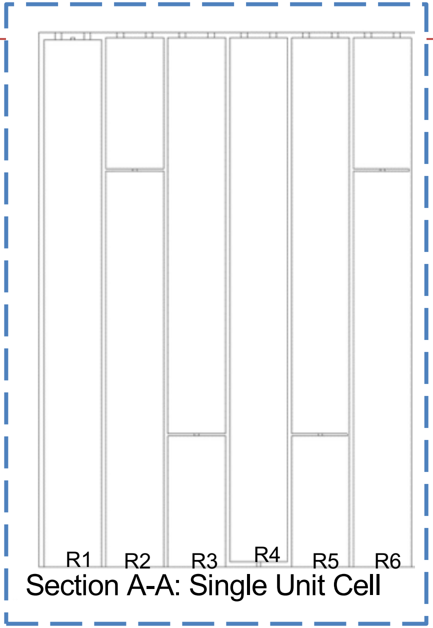
Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

Hybrid Acoustic Metamaterial

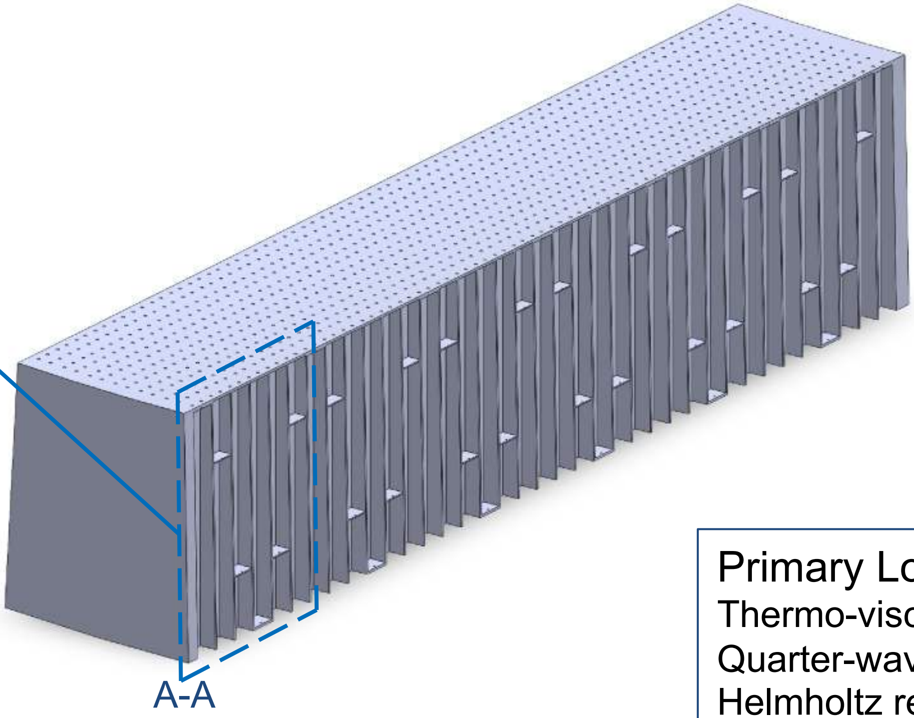


Eoghan Ross, Prof. Gareth J. Bennett
Kelvin Figueroa-Ibrahim, Prof. Scott Morris

Hybrid Acoustic Metamaterial

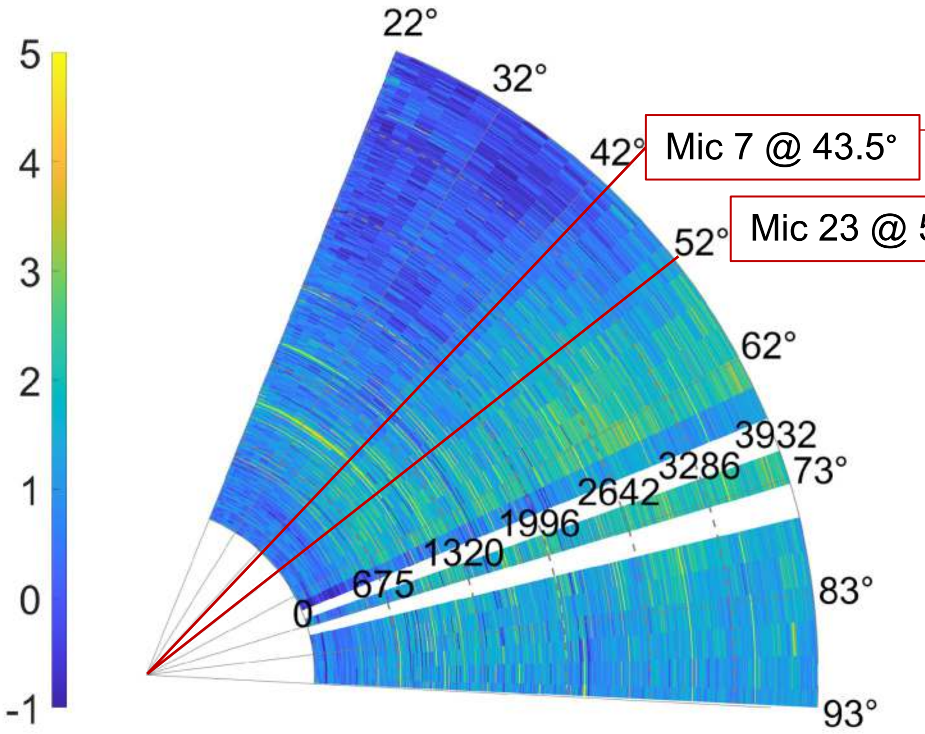


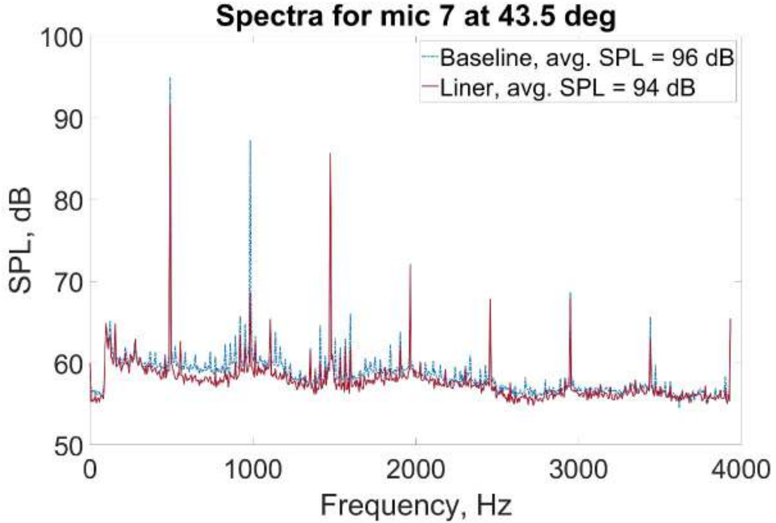
Total #sample = 237
Resin cost = €2000
Print time = 480 hrs

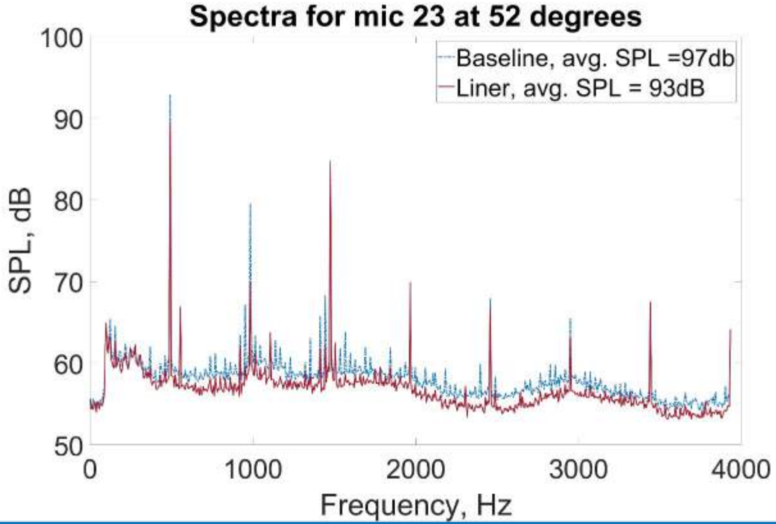


Primary Loss Mechanism:
Thermo-viscous losses
Quarter-wavelength resonance
Helmholtz resonance

Full Liner Reduction @ 1800 RPM

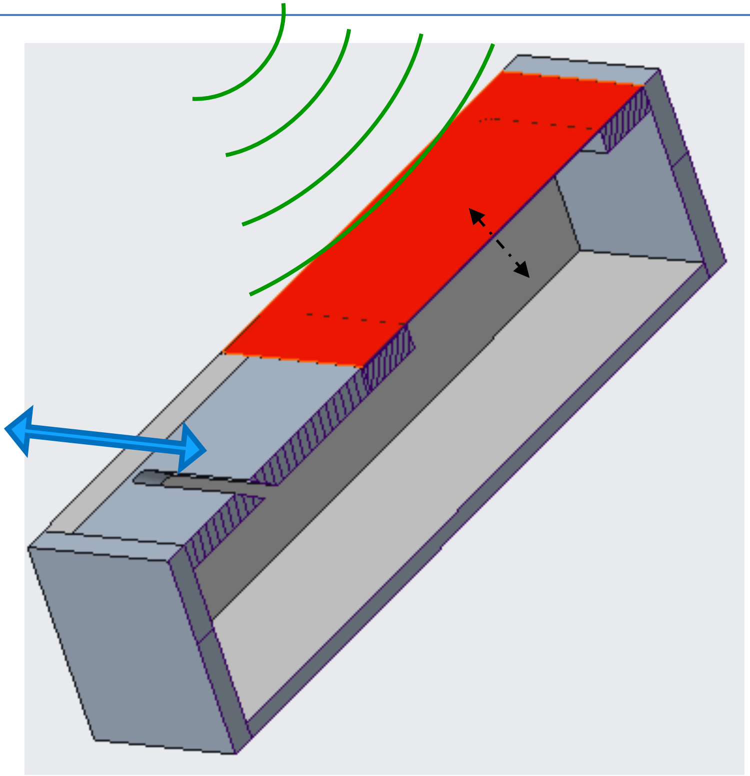






Fundamental mode reduced by 3.5 dB
1st Harmonic reduction by up to 18.6 dB
Avg. SPL reduction by 2.6 dB

Acoustic to Kinetic Energy Conversion Concept

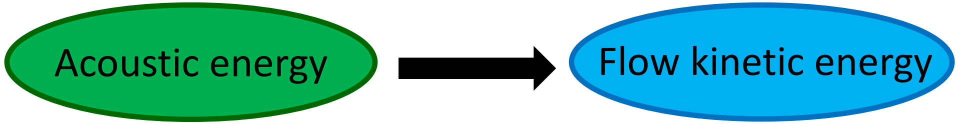


Components

Thin rubber membrane

Cavity

Pitched orifice



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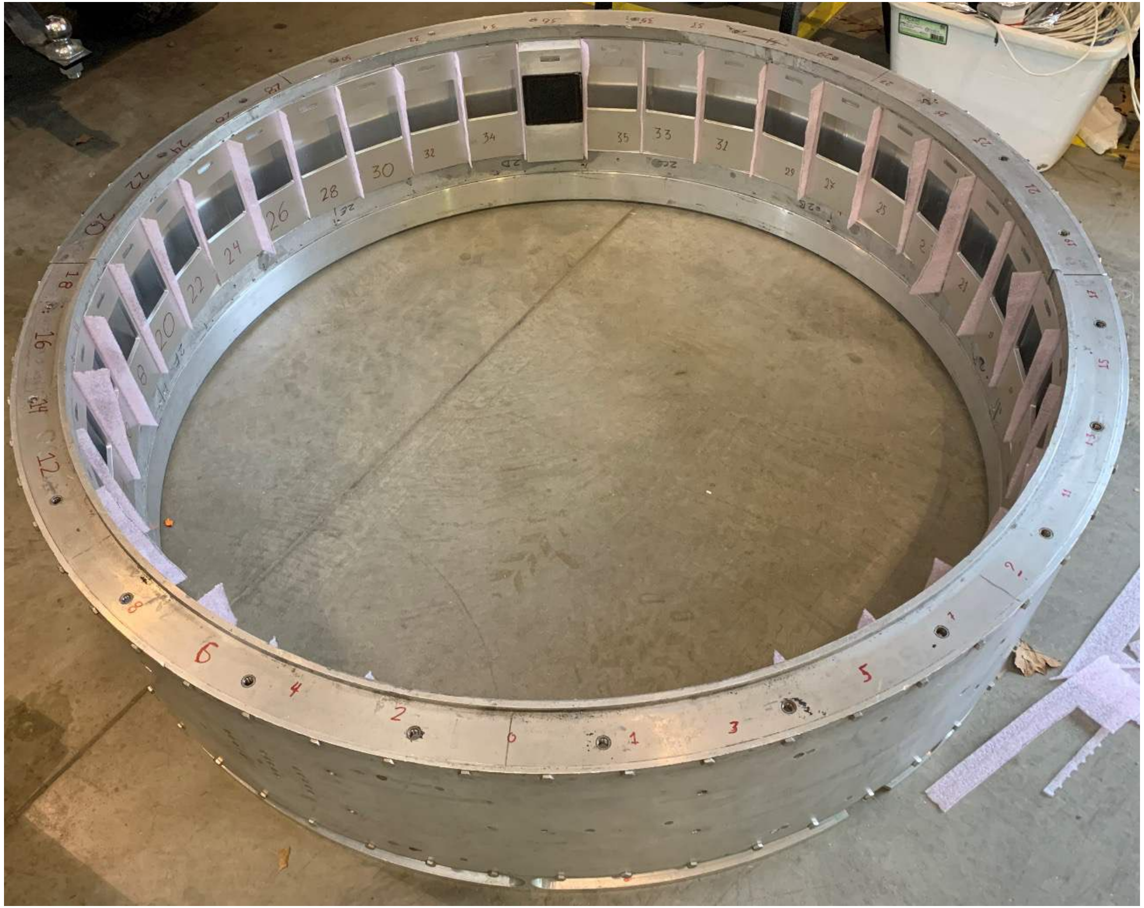
Liner samples in casing



NOTRE DAME TURBOMACHINERY LABORATORY

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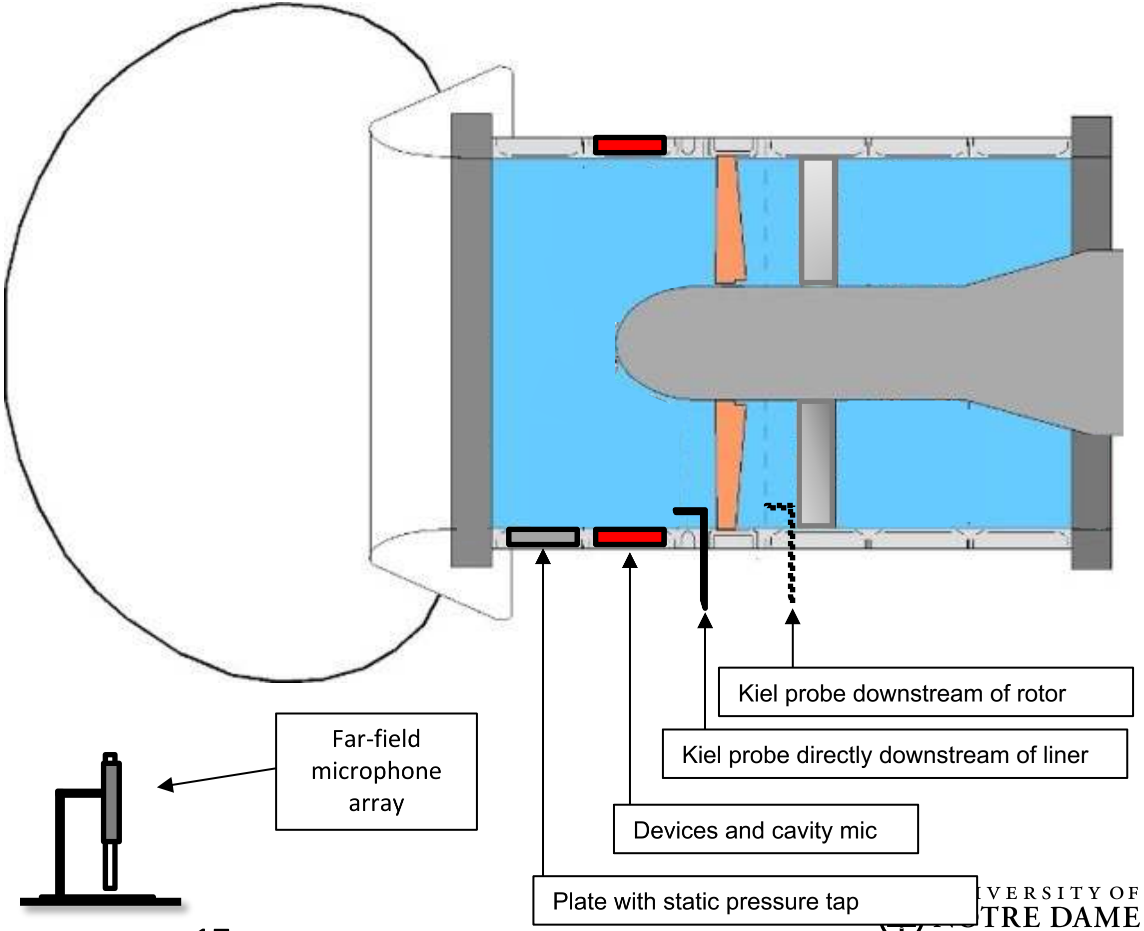
Research questions

- How is the far-field sound pressure level affected by the vibrating membranes and oscillating jets?
- How is the cavity pressure of the devices affected by the acoustic excitation of the ANCF?
- How is the internal flow of the ANCF affected by the oscillating jets?
- How is the fan performance affected by the oscillating jets?



Summary

- Extensive (and busy) research and testing activities in 2022
- Significant educational opportunities for both graduate and undergraduate students


TURBOMACHINERY
LABORATORY

Wednesday Morning

U.S. AIR FORCE

USSF

AFRL

Rocket Noise Models for USDOD

ALAN T. WALL, PH.D.
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REESE D. RASBAND – BALL AEROSPACE, INC.

NASA ACOUSTICS TECHNICAL WORKING GROUP, 18-19 OCT 2022

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Disclaimer

The views expressed are those of the authors and do not reflect the official guidance or position of the United States Government, the Department of Defense or of the United States Air Force.

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Overview

- USAF Aeroacoustics Overview
- Rocket Noise Relevance, Requirements, Impact
- Rocket Noise Background & Current State of Models
- Rocket Noise Model Gaps & Research Needed
- Rocket Noise Roadmap

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USAF Aeroacoustics Overview

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Environmental Impact

- Advanced Acoustic Model (AAM)
  - Simulation model with basis in NASA Rotorcraft Noise Model (RNM) and DoD NOISEMAP.
  - Under review for official adoption by Office of the Secretary of Defense for noise impact studies.
- Jet Noise Crackle Perception Research
  - Completion of a Phase II Small Business Innovative Research project by Blue Ridge Research and Consulting, LLC, presented to Defense Noise Working Group
  - Provided quantifiable metric for crackle intensity
  - Preliminary (laboratory) studies of human annoyance vs. crackle metric

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Jet Noise Reduction

- F404 Engine Acoustic Imaging and Engine Performance
  - Brigham Young University, Office of Naval Research, and Air Force Research Laboratory
  - 3-D Acoustic Imaging of installed F404 engine noise
  - Simultaneous noise levels vs. actual jet/nozzle parameters

Photo Credit: AFRL/711 HPW/RHWS

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Jet Noise in Enclosed Spaces

- F-35 Engine Operations in Hardened Aircraft Shelters
  - Assessments against exposure criteria to certify aircraft as safe to operate after it has run engine inside each HAS
  - All safety factors considered together to enable broadest range of CONOPS
    - Airframe acoustics - cracking and structural failure
    - Personnel noise exposure
    - Personnel chemical (gas & particulate) emissions exposure
    - Foreign Object Debris (FOD)

Photo Credit: AFRL/711 HPW/RHWS

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Rocket Noise Relevance, Requirements, & Impact of Rocket Noise

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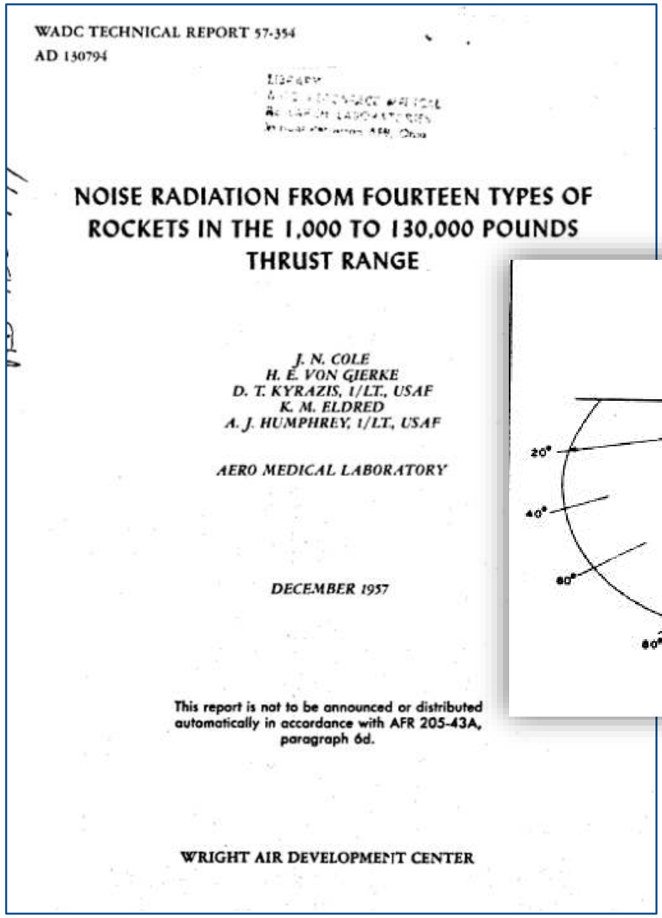
Background

- NASA during Apollo Era (1960s - 1971)
  - Joint approach to jet noise and rocket noise research
  - Based on 1957 measurements of small-to-mid-sized rockets
  - Ended with moon landing
  - NASA SP-8072 model adopted for rocket noise predictions
- No program supporting further research
- Current state-of-the-art rocket models for environmental impact rely on minor modifications to NASA SP-8072
  - Known errors in models still exist
  - Uncertainty in predictions not yet quantified
  - No definitive model validation


WADC TECHNICAL REPORT 57-354
AD 130794

NOISE RADIATION FROM FOURTEEN TYPES OF ROCKETS IN THE 1,000 TO 130,000 POUNDS THRUST RANGE

J. N. COLE
H. E. VON GIERKE
D. T. KYRAZIS, 1/LT., USAF
K. M. ELDRED
A. J. HUMPHREY, 1/LT., USAF

AERO MEDICAL LABORATORY

DECEMBER 1957

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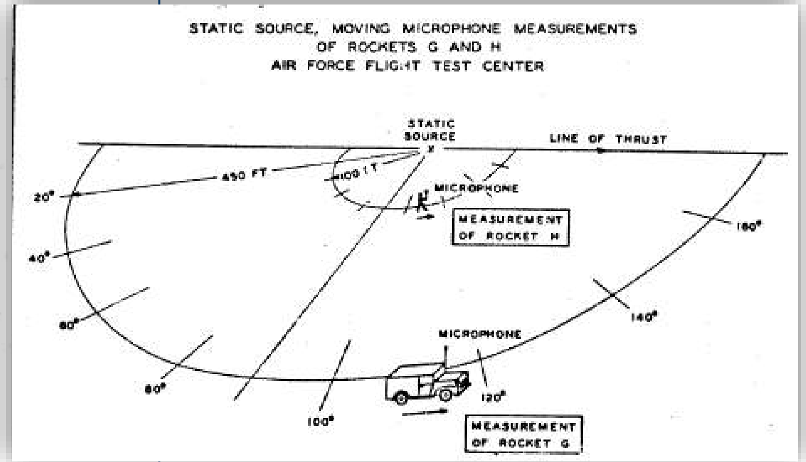
WRIGHT AIR DEVELOPMENT CENTER



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The Future of Space 2060

- In 2060, **space will be major engine of national political, economic, and military power**
- The U.S. faces **growing competition** in the exploration and use of space
- **China continues to execute a long-term strategy** to develop the cis lunar domain with the explicit aim of **displacing the U.S.** as the leading space power
- The U.S. must ***invest in science and technology*** to drive the rapidly changing global space environment

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Rocket Noise Environmental Impacts

SIMILARITIES WITH AIRCRAFT

- DoD requirements governed by NEPA Law
- National Historical Preservation Act
- Community noise
- Wildlife
- Structural damage from sonic booms

DIFFERENCES FROM AIRCRAFT

- Typically higher noise levels
- Less frequent, 10s per year
- Lower frequency, 10-100 Hz peak
- Lower public opposition, but may grow with increased operations tempos

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Primary DoD Organizations

- United States Space Force/S4: Directorate of Logistics, Engineering, and Force Protection
  - Coordinates for infrastructure from the Air Force Installations and Mission Support Center

USSF

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Primary DoD Organizations

- Vandenberg Space Force Base, Space Launch Delta 30, CA
  - Military, civil, and commercial launches
  - ~680 orbital launches since 1959
    - Cadence in last 20 years has been 5-6/yr
  - Forecast increase up to 100 launches/yr
    - Potential construction of new launch complexes
  - Sonic boom impacts
    - Launch: Channel Island wildlife significant concern
    - Landing: Around VSFB
  - Relatively remote from population centers
    - 12 – 20 km to Lompoc, depending on launch pad

SpaceX Falcon 9 booster, containing 50 Starlink satellites, launched into low-Earth orbit from Vandenberg's Space Launch Complex-4E, Friday, Feb. 25, 2022 at 9:12 a.m. Pacific Standard Time. (U.S. Space Force photo by Airman 1st Class Rocio Romo) https://www.vandenberg.spaceforce.mil/News/Photos/igphoto/2002945627/

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Primary DoD Organizations

- Cape Canaveral Space Force Station & Patrick Space Force Base, Space Launch Delta 45, FL
  - 19 launches in 2021
  - Launch pads on loan to several commercial launch providers, new construction

An Atlas V Advanced Extremely High Frequency vehicle number 6 rocket successfully launches from Space Launch Complex-41 at Cape Canaveral Air Force Station, Fla., March 26, 2020. The AEHF-6 launch, a sophisticated communications relay satellite, is the first Department of Defense payload launched for the United States Space Force. (U.S. Air Force photo by Joshua Conti) https://www.spaceforce.mil/Multimedia/Photos

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Primary DoD Organizations

- United States Air Force
  - Headquarters Air Force
  - Air Force Civil Engineering Center
  - Air Force Research Laboratory
- **Defense Noise Working Group**

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Rocket Cargo Vanguard Program (AFRL)

- Objective: Deliver up to 100 tons of cargo anywhere on planet in ~1 hour.
- UASF’s 4th Vanguard program, anticipated USSF program of record
- SpaceX Starship Heavy is most mature candidate vehicle
- AFRL Rocket Cargo Vanguard requirement to assess personnel noise exposures on ground at launch/landing sites for hearing conservation

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DoD & FAA Roles & Requirements

FAA Office of Commercial Space Transportation (AST)

- Commercial and private space operations
- Mainly responsible for commercial/private launches from DoD sites
- RUMBLE and PCBoom are candidate tools for adoption for regulatory use.* Existing models in use by FAA are approved on a case-by-case basis. Further validation required.
- FAA acknowledges that "given the infrequent number of launch events per year at a particular site, the **DNL metric may not fully describe the noise experienced during a commercial space launch**. Hence, supplemental noise metrics in conjunction with DNL should be used to describe and assess noise effects for commercial space operations."**

**National Academies of Sciences, Engineering, and Medicine 2018. User Guides for Noise Modeling of Commercial Space Operations RUMBLE and PCBoom. Washington, DC: The National Academies Press. https://doi.org/10.17226/25099.*

*** FAA Order 1050.1F Desk Reference Version 2, 2020*

DOD

- DoD may be required to support environmental work for commercial/private launches from DoD sites as a cooperating agency
- Subject to NEPA Law for environmental impact
- Not yet adopted official modeling tools
- Similar needs as FAA to validate and accredit models

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Background & Current State of Rocket Noise Models

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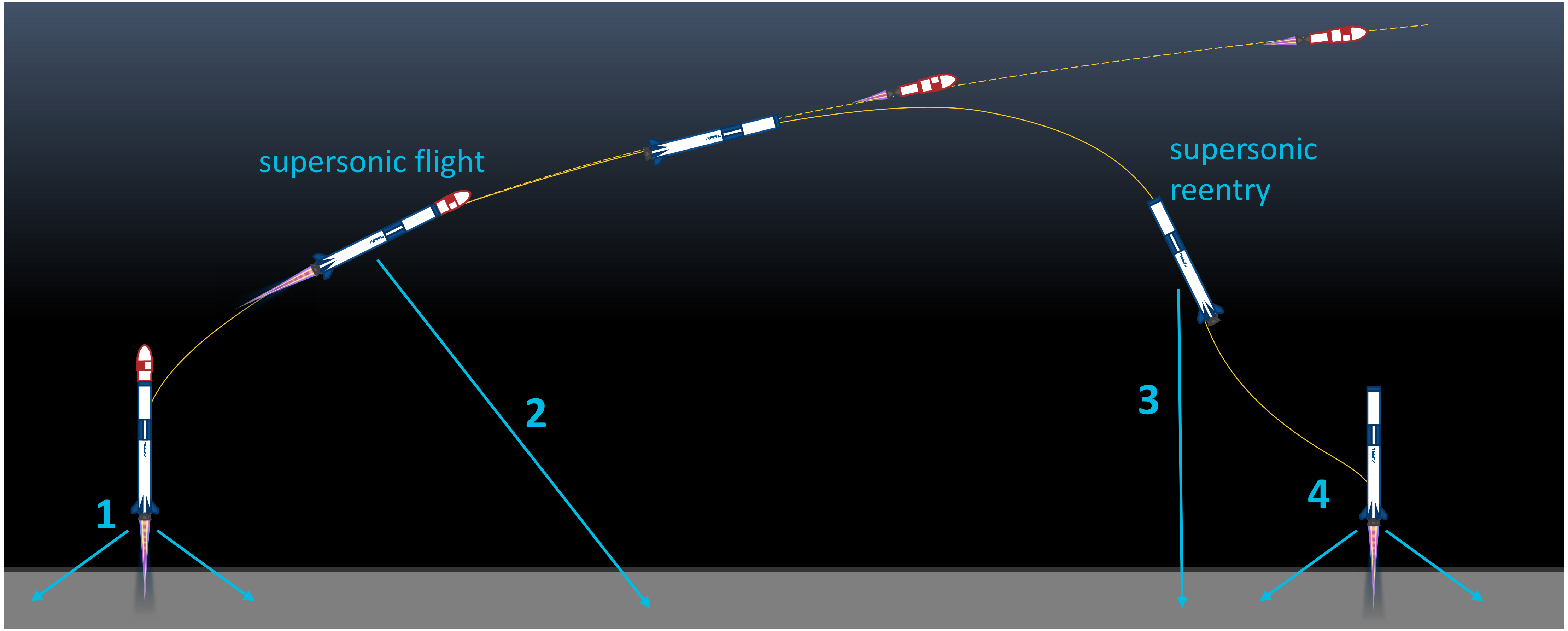
Rocket Noise Overview

- Phase 1: Ignition, plume deflection, liftoff, launch
- Phase 2: (Ascent) sonic boom during launch
- Phase 3: (Descent) sonic boom during reentry
- Phase 4: Landing noise



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Launch & Landing Noise Models

- Most (or all) models in use based on NASA SP-8072*
  - BRRC's RUMBLE
  - KBR's RNOISE
  - Inputs:
    - Vehicle trajectory
    - Mechanical power
    - Acoustic directivity
    - Pad impingement surfaces
    - Atmospheric profiles
  - Outputs:
    - Overall and spectral time histories on the ground
    - LMAX, LAMAX
    - SELA
    - DNL/CNEL

**NASA, "Acoustic Loads Generated by the Propulsion System," SP-8072.*

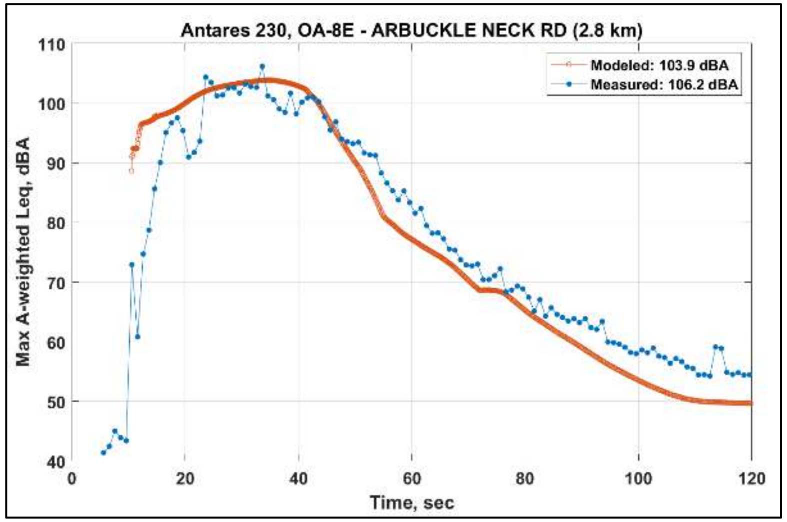
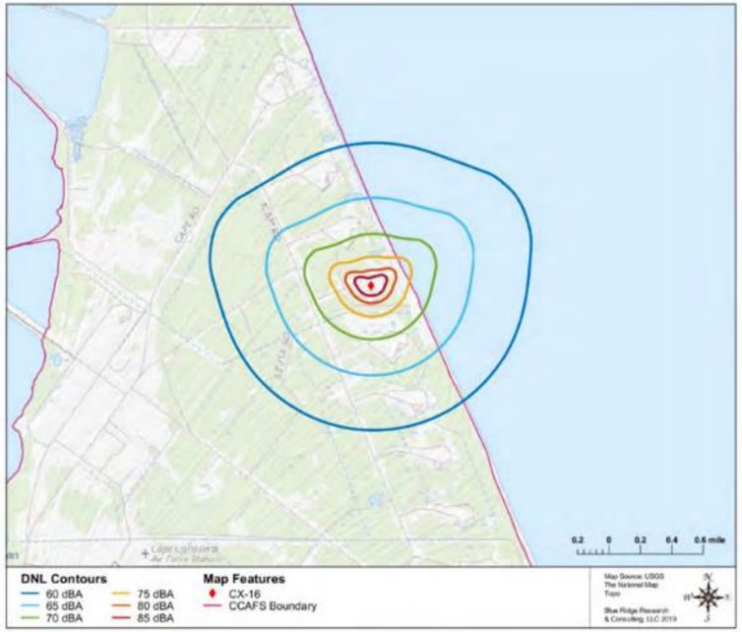


Figure 15. DNL Contours for Terran 1 Launch and Static Operations



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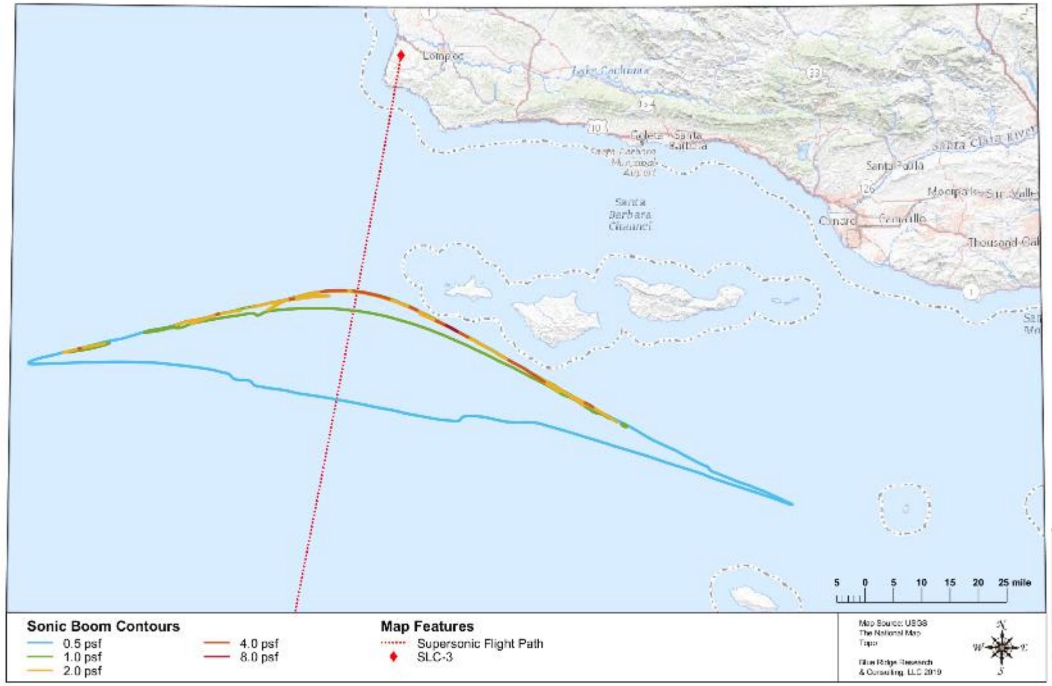
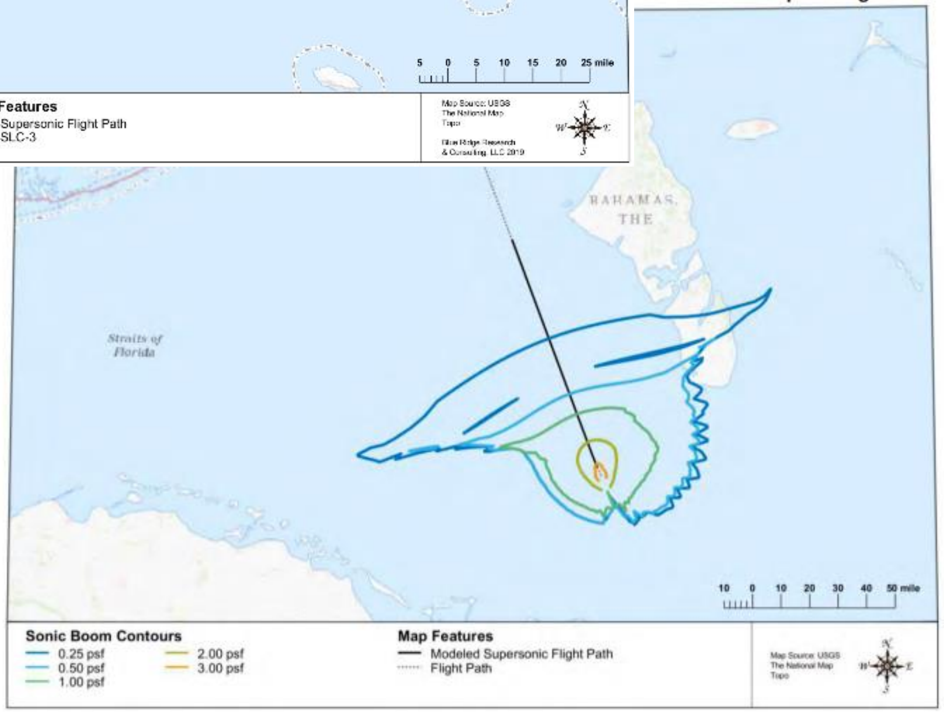
Sonic Boom Models

- Reentry overpressures
  - PCBoom
  - NASA-1122
- Perception/human response
  - NASA Armstrong Flight Research Center
- Trajectory optimization
  - NASA's CLEOPATRA
- Glass breakage
  - Many govt and commercial models





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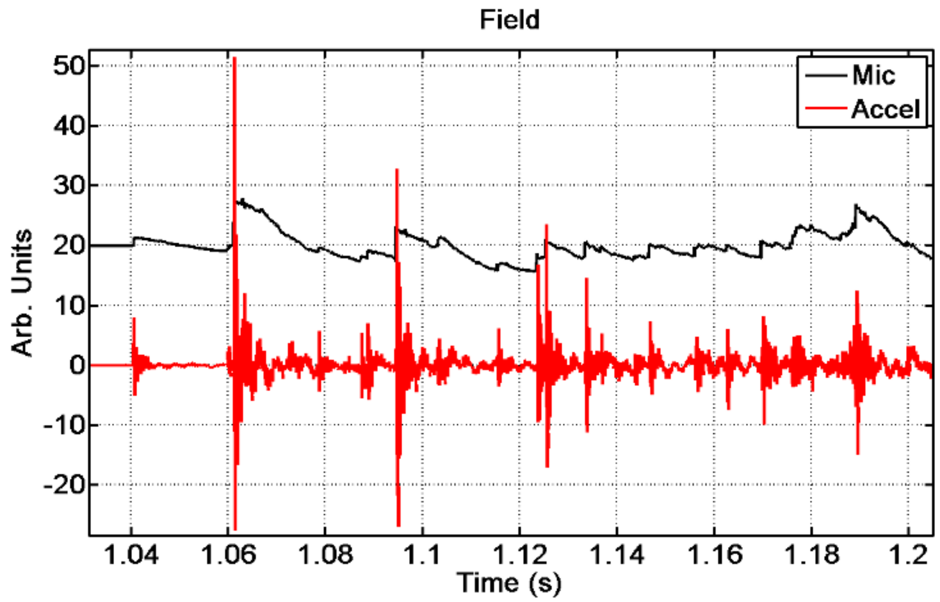
Shocks and Acoustic Loading

- Acoustic shocks (black) lead to large mechanical accelerations (red) of physical structures.
- Mechanical accelerations can cause glass breakage, other structural damage. Also can cause “rattle.”



Co-located acoustic microphones and accelerometers during ATK 5-segment solid booster test.

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Rocket Noise Model Gaps & Research Needed

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Model Gaps & Research Needed

- Known errors in NASA SP-8072. Unknown impact of errors on rocket noise predictions
- Discrepancies identified in sonic boom model comparisons
- Dozens of glass-breakage models. Which to use?
- Limited dataset availability
- Limited validation studies
- Multi-engine plume interactions at full scale not quantified
- Appropriateness of DNL or ASEL as measure of impact?

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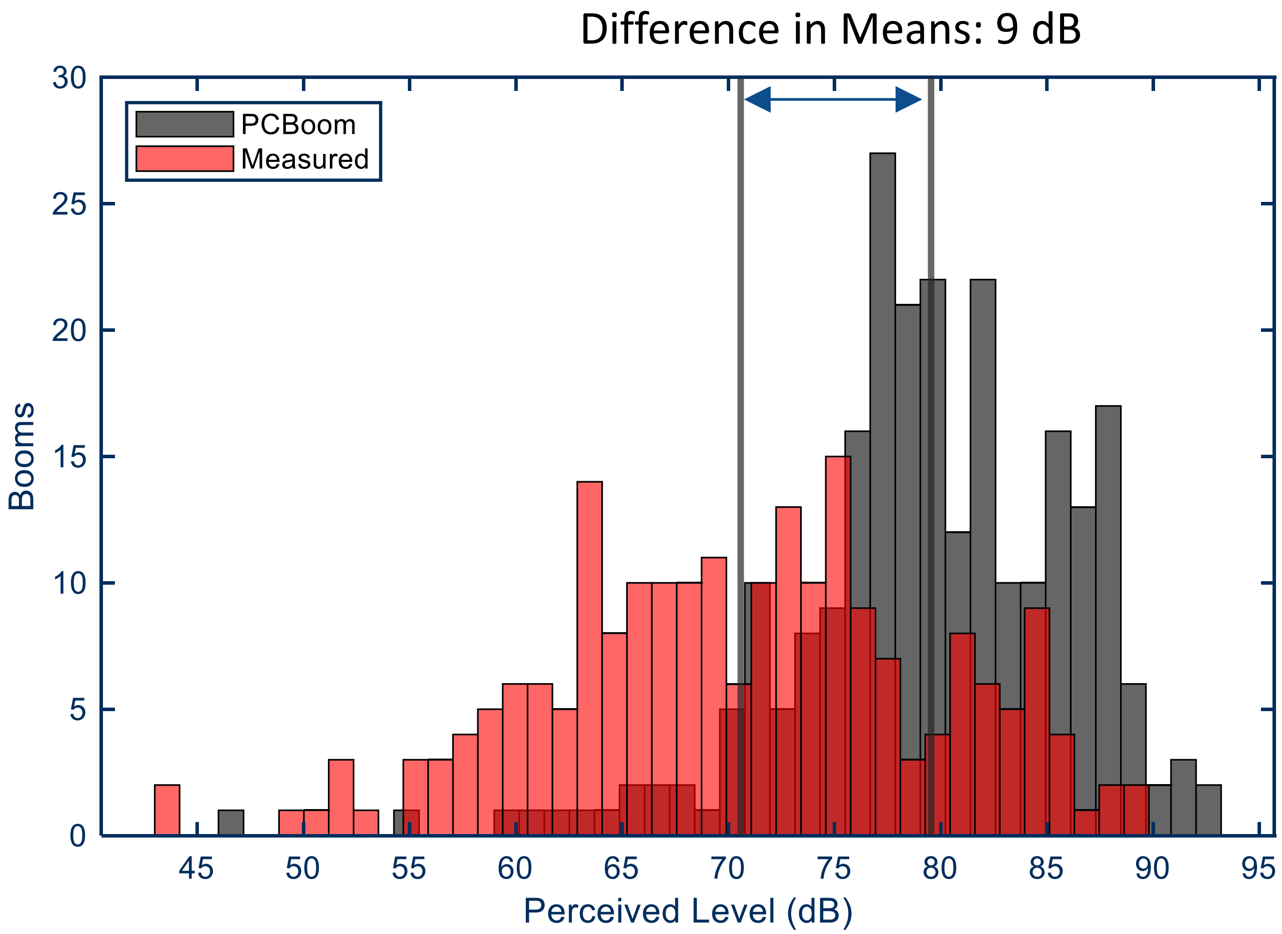
PCBoom Errors for NASA Low-Boom Dive Maneuver

- PCBoom often overestimates measured levels of metrics important to perception
- From NASA QSF18 tests (Galveston, TX), data processed at BYU
- RSME for PL (prediction vs measurement) is 10-13 dB, depending on boom SNR selection criterion



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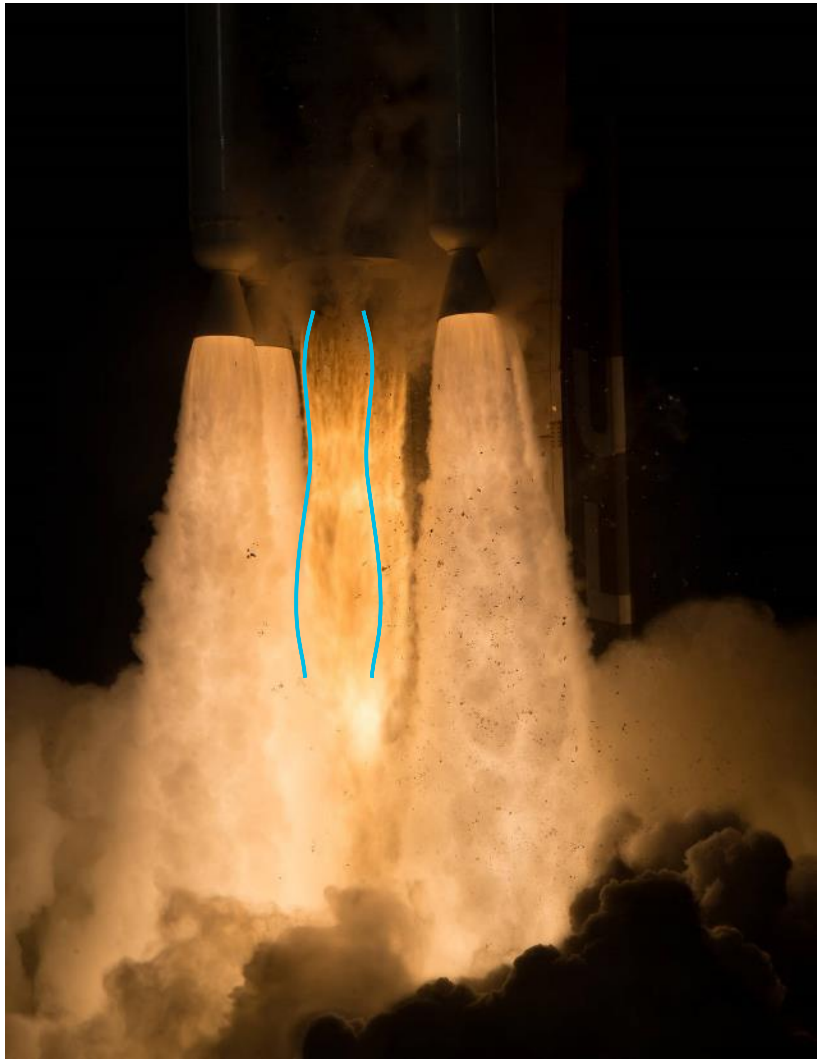
Rocket Engine & Motor Noise Sources

- Difference between solid rocket motors and liquid-fueled engine noise generation mechanisms unknown
- Launches optimized for performance (operating over much wider altitude range than military aircraft), exhaust is **highly non-ideally expanded** near ground
- Canonical BBSAN spectra common in military jets at non-ideally expanded conditions, but not evident in rocket noise measurements
- Noise source region more extended and peaks farther downstream than military jet aircraft exhaust.



The engines fire as a United Launch Alliance Atlas V rocket with NASA's Mars Perseverance rover onboard launches from Space Launch Complex 41, Thursday, July 30, 2020, at Cape Canaveral Air Force Station in Florida. Image Credit: NASA/Joel Kowsky https://www.nasa.gov/image-feature/a-different-view-of-the-mars-perseverance-launch

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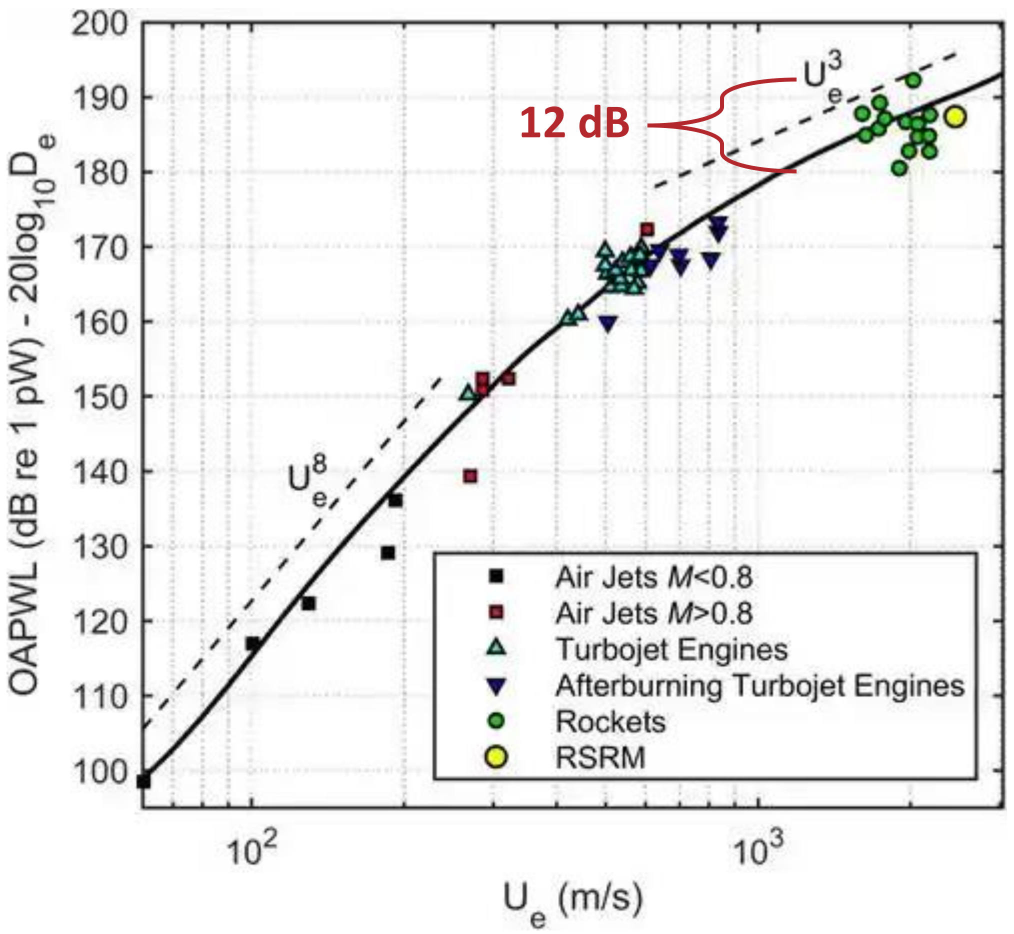
Large Data Spread

- Limited historical data show 12+ dB spread around fitted curve, and mechanisms for spread not understood
- New comprehensive datasets not collected since late 1950s, except for single-point opportunistic measurements for specific customers.



Lubert *et al.* (JASA, 2022), adapted from from Chobotov and Powell, Rama-Wooldridge Corp. Rept. E.M.-7–7 (1957) and Ffowcs Williams, Philos. Trans. R. Soc., A **255**(1061), 469–503 (1963).

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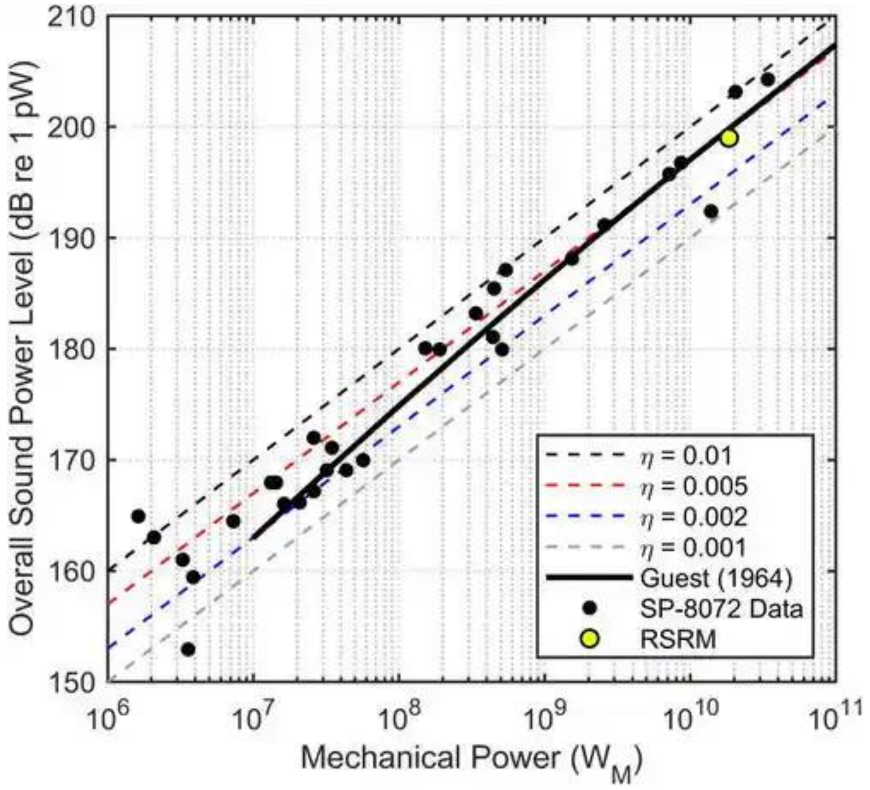
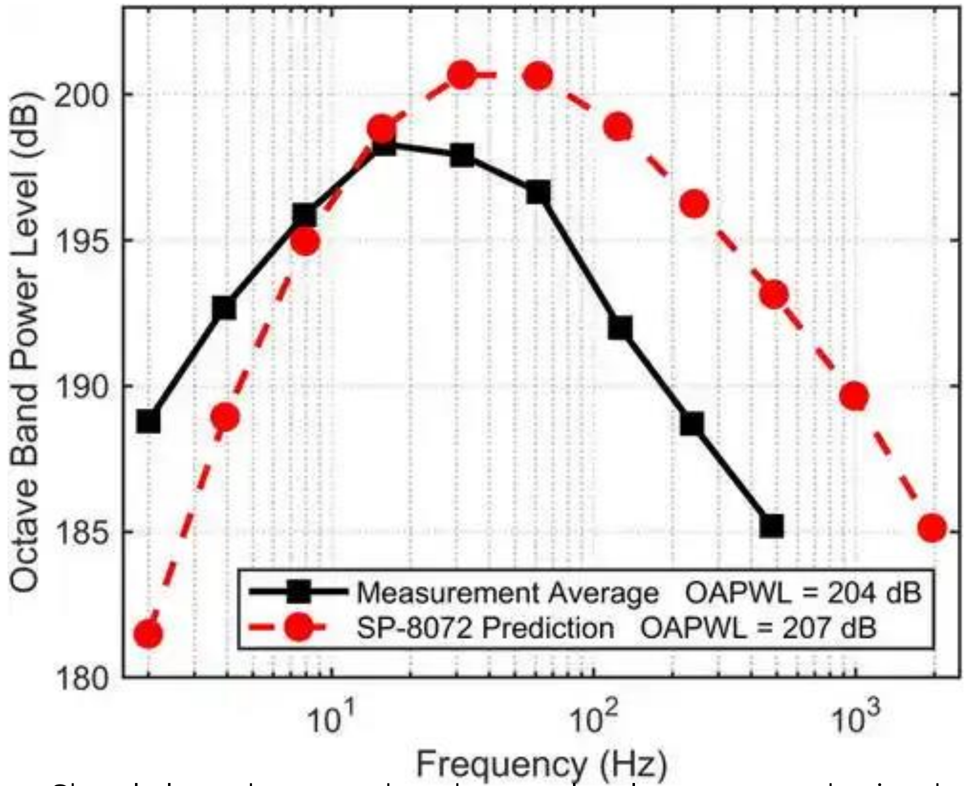
NASA SP-8072



Lubert *et al.* (JASA, 2022) OAPWL versus mechanical power, adapted from Fig. 3 of NASA SP-8072.

Space Transportation System (Shuttle) Sound Power Level Spectra



Shuttle launch octave-band power level spectra, as obtained from Fig. 15 of McInerny Noise Control Eng. J. 38(1), 5–16, 1992). The measurement average is the mean of the three power level spectra in McInerny's figure.

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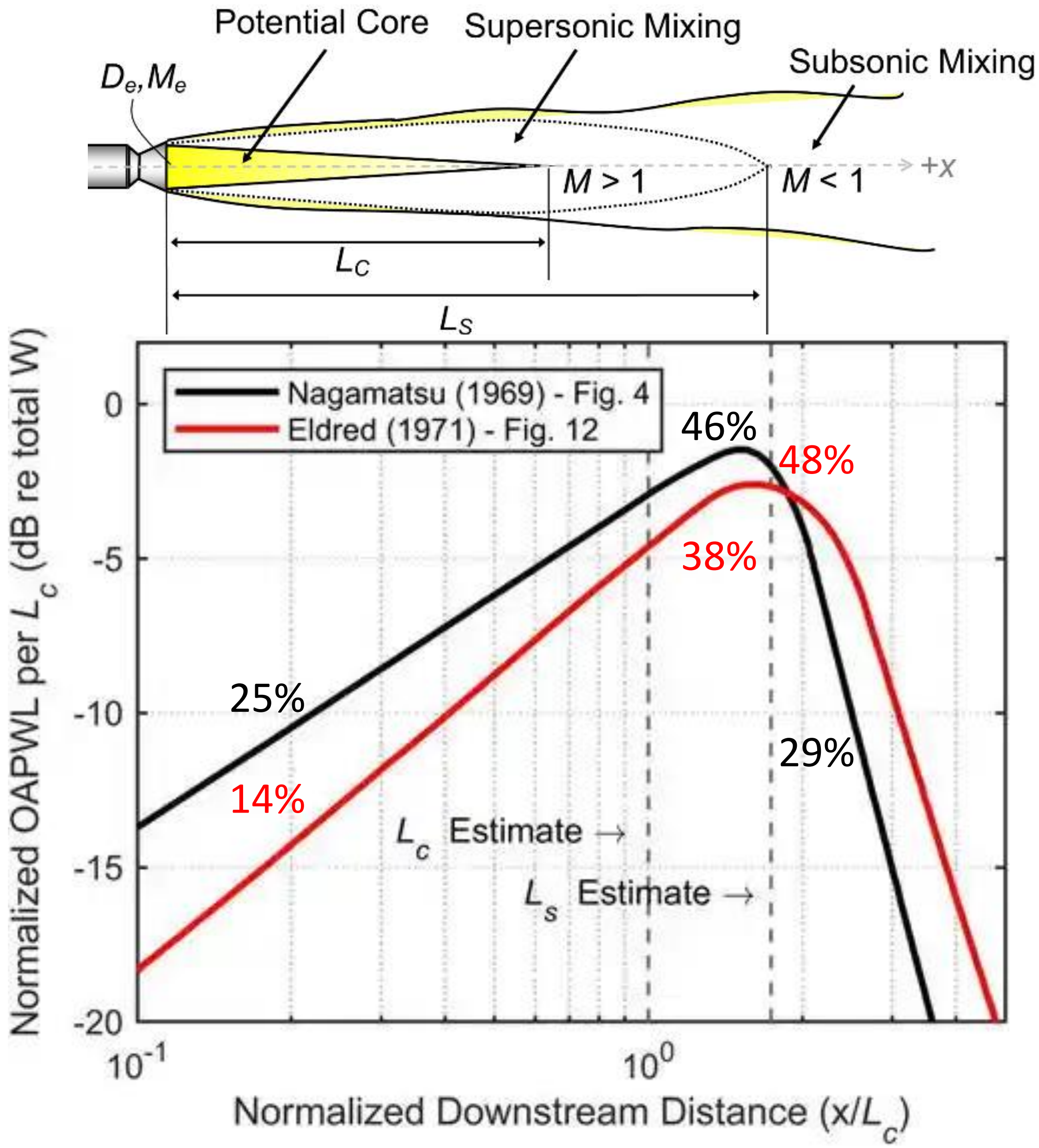
Source Description Error

- NASA SP-8072 (Eldred, 1971) source description contains a plotting error propagated from Potter (1968) report
- Dominant sound power origin downstream of the supersonic core is physically implausible
- The correct curve (Nagamatsu, 1969) is based on a laboratory-scale, unheated, ideally expanded nitrogen jet.
  - Unknown locations for L_c and L_s for a rocket (see James, JSASS, 2017)
  - Unknown similarity between rockets and jets



K. L. Gee, "A tale of two curves and their influence on rocket and supersonic jet noise research," The Journal of the Acoustical Society of America 149, 2159 (2021); https://doi.org/10.1121/10.0003938

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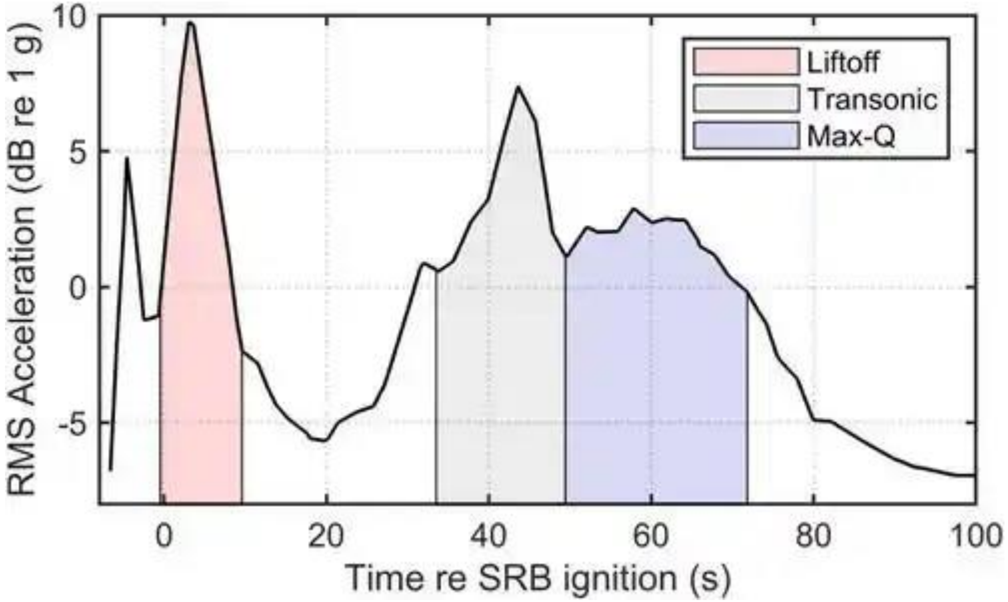
Impact on Pads, Vehicles, and Payloads

- Large acoustic levels on near-field structures (incl. vehicle and payloads) lead to risk for damage during liftoff
- Likely that vehicles over-designed to ensure payload not damaged
- Over-design leads to weight increase and higher thrust, i.e. higher noise impact on environment



Space Shuttle vibration data from Fig. 7.6 of Himelblau et al. ("NASA handbook 7005: Dynamics environmental criteria," NASA-HDBK7005, Washington, DC., 2001) relative to the SRB ignition.

Proposed Roadmap

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Model Accuracy and Validation

What constitutes **sufficient** model accuracy?

What are quantifiable **impacts** of model errors?

More to come…

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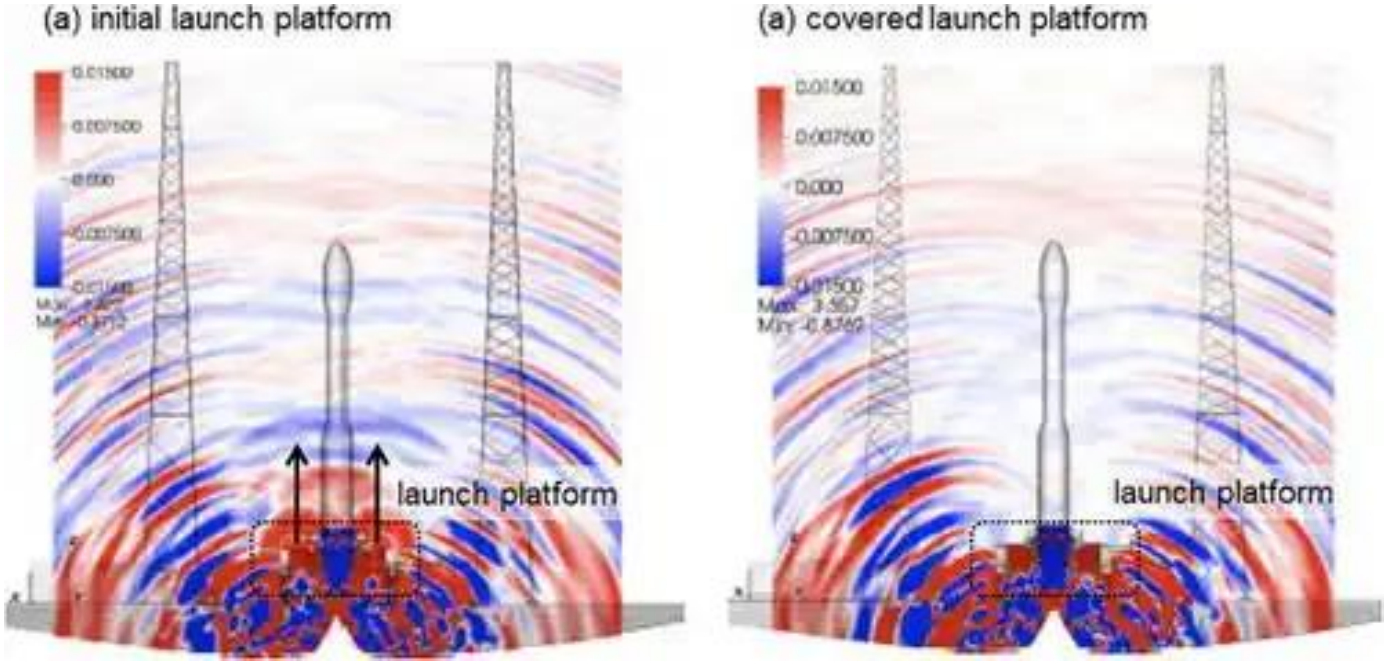
Noise Reduction Strategies

- It is possible to alter acoustics in intended directions by altering launch pad design



The numerical results from the VEGA launch vehicle CFD (Palmieri, D., Nicolini, D., Neri, A., Barbagallo, D., Spina, S., Roviera, P. M., Barad, M. F., Kiris, C., Vu, B., and Chesnutt, D. (2017). " Design and validation of VEGA launch pad modifications to reduce payload acoustic environment at lift-off," in Proceedings of the International Astronautical Congress (IAC), September, Vol. 15, pp. 9771–9776).

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Summary

- Rocket noise modeling critical to support growing space defense programs
- Model errors and deficiencies have unknown impact

Proposed Roadmap

- Rocket noise modeling requirements and regulation similar to aircraft noise*
- Seek program-level support for:
  - Model improvements
  - Software validation and accreditation**
  - Source data collection
  - Data collection standards
- Coordinate with NASA, FAA, and other USG programs

**DoD Instruction 4715.15, "DoD Operational Noise Program," Office of the Under Secretary of Defense for Acquisition and Sustainment, January 28, 2020.*

***Defense Acquisition Guidebook, Chapter 4 – Systems Engineering, Section 4.4.16. Software.*

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Event Q&A

How does one get copies of the models you mentioned?

PCBoom and RUMBLE are available by request from the NASA Technology Transfer Program at "https://software.nasa.gov/".

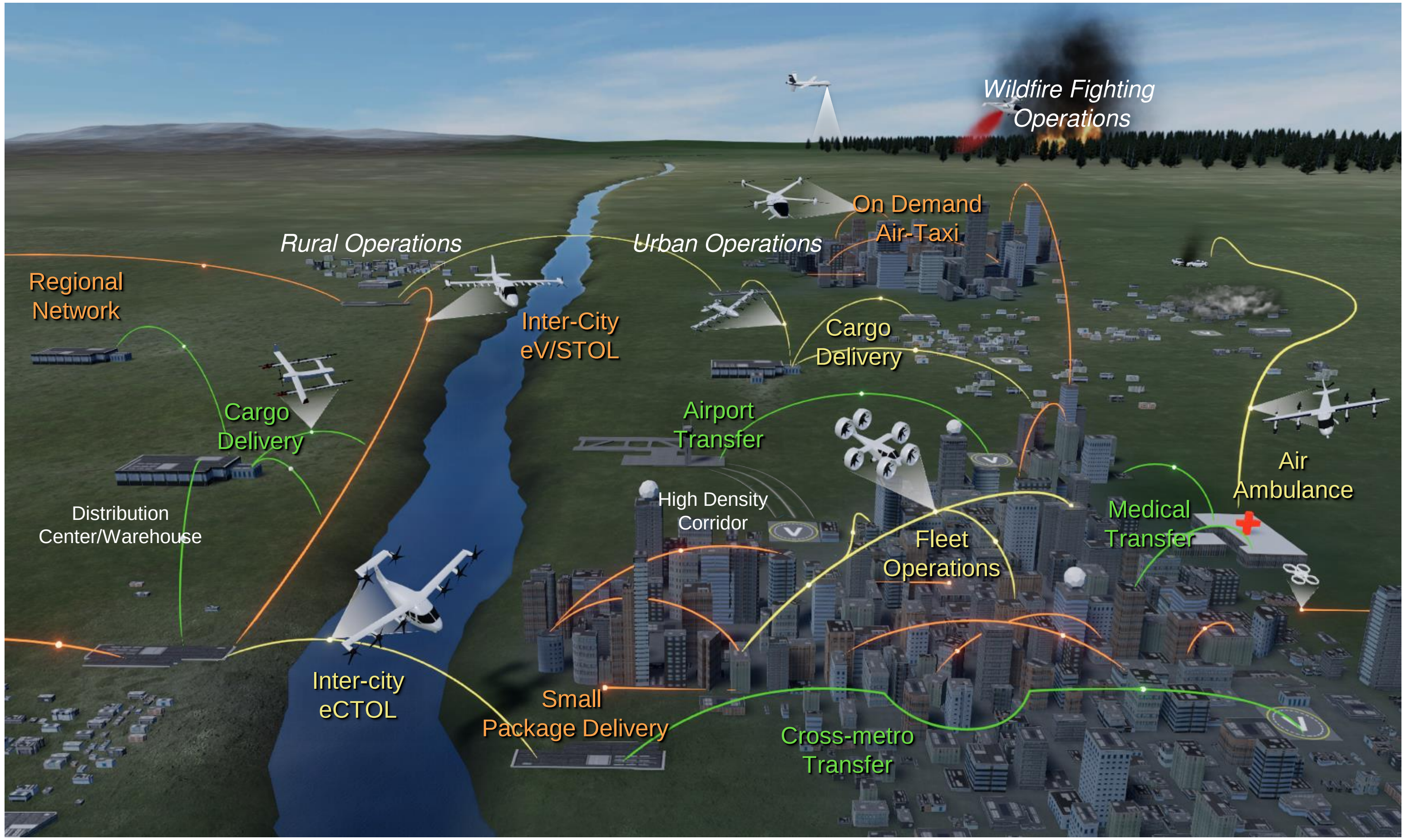
Revolutionary Vertical Lift Technology Project

Focused on Urban Air Mobility (UAM) vehicle tools and technologies for noise, safety, environment, and efficiency

Develop and validate tools, technologies, and concepts to overcome key barriers for vertical lift vehicles

Advanced Air Mobility (AAM) and Urban Air Mobility (UAM)

- AAM missions characterized by < 300-500 nm range
- Vehicles require increased automation and are likely electric or hybrid-electric
- Rural and urban operations are included
- Missions can be public transportation, cargo delivery, air taxi, or emergency response
- Urban Air Mobility (UAM) is a subset of AAM and is a segment that is projected to have high economic benefit and be the most difficult to develop
  - UAM requires an airspace system to handle high-density operations
  - UAM requires an advanced urban-capable vehicle
  - UAM vehicle variants can target other missions



RVLT is one of the seven projects that support the AAM Mission

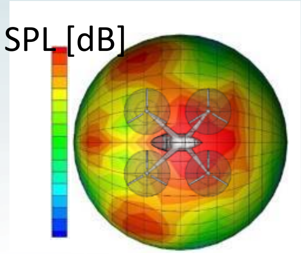
NASA's RVLT Project Provides Tools and Design Practices for AAM eVTOL Vehicles

Focus on Barriers of Noise and Safety to Enable New Markets

Noise Research

Human Response to AAM Noise

AAM Acoustic Impacts

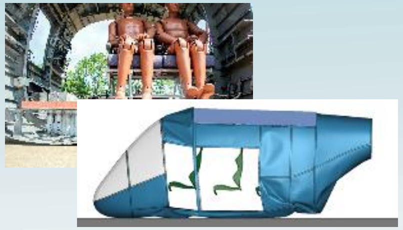


Predictive Tools for AAM Noise

Safety Research

Electric Powertrain Reliability

Handling Qualities



Crashworthiness & Occupant Protection

Share technical insights and lessons learned

FEDERAL AVIATION ADMINISTRATION

INDUSTRY

ACADEMIA

SDOs

Inform eVTOL Systems Standards and Certification

NASA AAM Noise Research Approach Overview

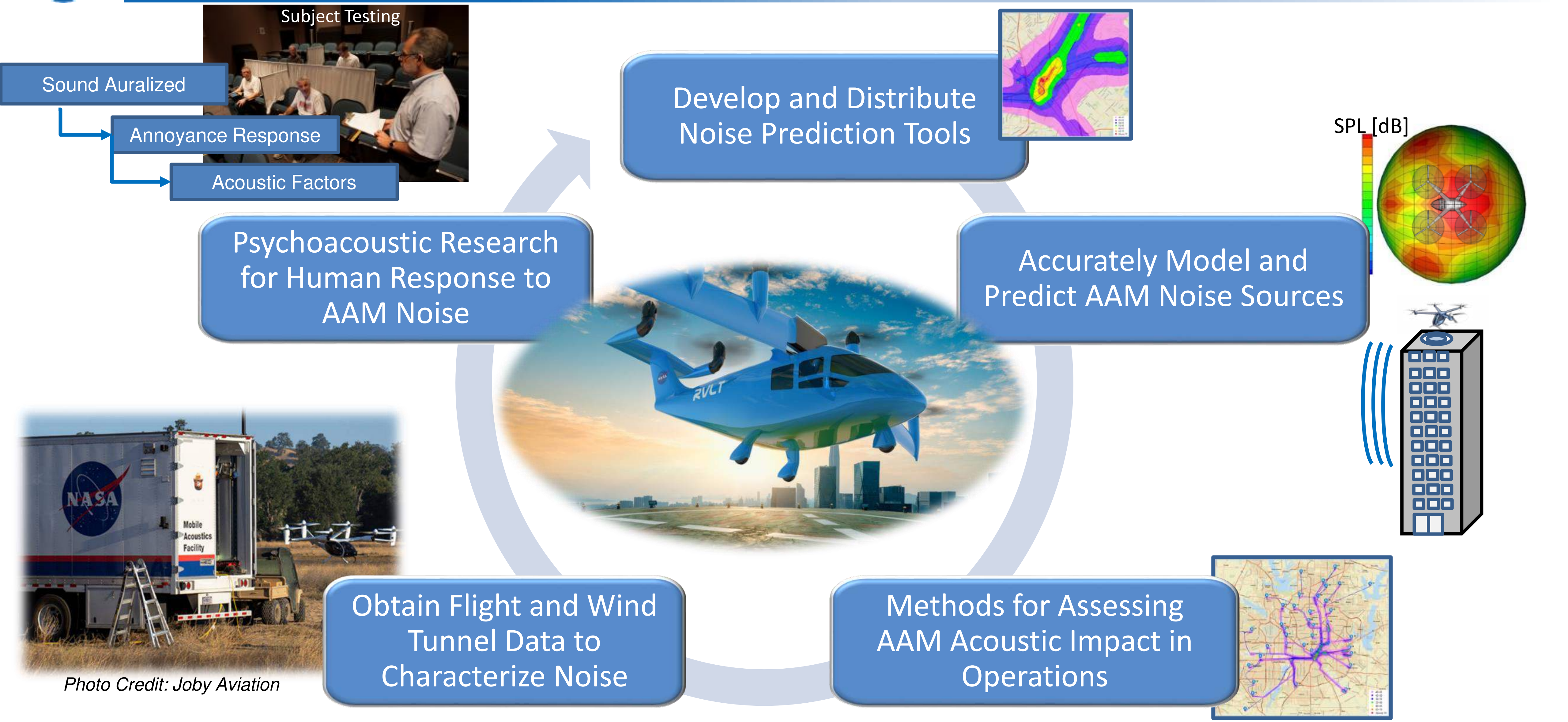


Photo Credit: Joby Aviation

Provide Design Tools and Guidelines for Low Noise Design and Operations

NASA AAM Safety Research Approach Overview

Develop Assessment Tools and Guidelines for AAM Modeling

Use Unique Facilities to Generate Data and Assess New Concepts

Transfer Tools and Data to Regulators, Standards Development Organizations, and User Community

Propulsion: reliability of motors, fault-tolerance, electrical system standards

Magnetic Gear Motor Prototype

Handling and Ride Qualities: vehicle response, control system authority, passenger response to motion

Evaluation of Seats, Subfloor, and Occupant Loads during Impact

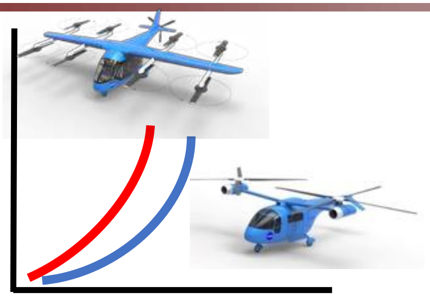
Crashworthiness: occupant protection, safety after impact

Simulated Operation for Handling Quality Evaluation

Provide Design Tools and Guidelines for Safe, Reliable Operations and Standards

RVLT Research Focus – Vehicle Noise and Safety

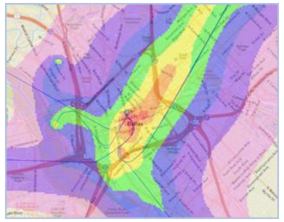
Noise and Performance



Tools to Explore the Noise & Performance of Multi-Rotor UAM Vehicles

- Plan and conduct validation experiments
- Improve efficiency & accuracy of conceptual design tools
- Improve community transition & training for analysis tools

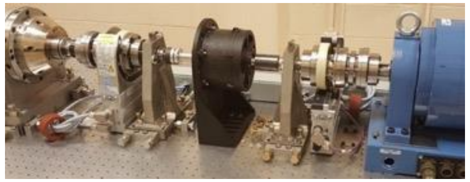
UAM Fleet Noise



UAM Operational Fleet Noise Assessment

- Generate Noise Power Distance (NPD) database for several UAM ref. configurations & trajectories
- Develop method to assess acoustic impact of UAM fleet operations
- Conduct psychoacoustic testing to assess human response to UAM vehicles

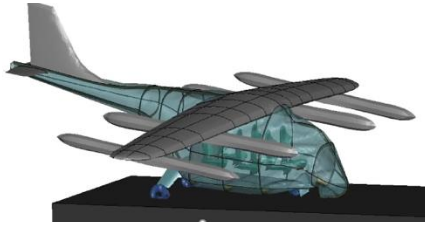
Vehicle Propulsion Reliability



Reliable & Efficient Propulsion Components for UAM

- Reconfigure labs for electric propulsion testing
- Develop tools to assess electric motor reliability & explore new design concepts
- Develop design and test guidelines for eVTOL propulsion & thermal components

Occupant Safety



UAM Crashworthiness and Occupant Protection

- Conduct full-scale and component level tests
- Develop test guidelines, modeling best practices, and vehicle technologies for crash mitigation
- Deliver crash and impact data to consensus standards organizations

Handling & Ride Qualities

Acceptable Handling and Ride Qualities for UAM

- Conduct human subject testing to assess handling and ride qualities
- Establish handling and ride qualities guidelines for UAM vehicles
- Develop flight dynamics and control modeling tools for conceptual design

NASA RVLT Project Research Areas

Ames Research Center

- Aeromechanics
- System Analysis
- Computational Methods
- Experimental Capability
- Flt Dyn & Ctrl
- Acoustics

Armstrong Flight Research Center

- UAM Handling and Ride Qualities
- UAM Electric System and Flight Control Integration

Glenn Research Center

- Hybrid/ Electric Systems
- Electro-Mech Powertrains
- Icing
- System Analysis
- Impact Dynamics
- Acoustics

Langley Research Center

- Acoustics
- Computational Methods
- Aeromechanics
- Experimental Capability
- Impact Dynamics
- System Analysis

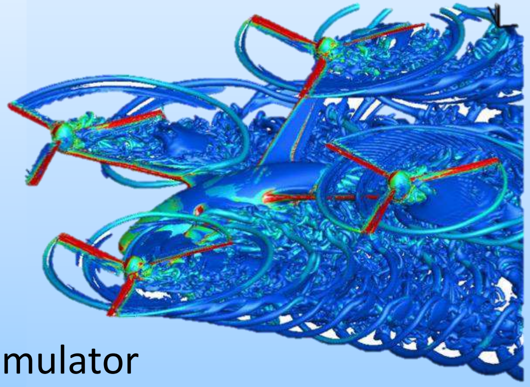
Resources and Facilities

FY22/23 RVLT Summary

~113/113* Civil Service Workforce
~ $34M/38*M per year (includes salary)

Ames Research Center

- National Full-Scale Aerodynamics Complex (NFAC)
- Supercomputing Complex (NAS)
- Vertical Motion Simulator



Armstrong Flight Research Center

- Simulators
- Test Hardware

Glenn Research Center

- Power, Motor and Transmission Test Facilities (ERB)
- Icing Research Tunnel

Langley Research Center

- 14- by 22-Foot Subsonic Tunnel
- Transonic Dynamics Tunnel
- Landing and Impact Research
- Mobile Acoustic Facility
- Low-Speed Aero-acoustic Wind Tunnel

- Exterior Effects Synthesis & Sim Lab

Expected levels based on FY23 President's Budget

RVLT FY22-23 Project Structure

PROJECT

Project Manager: Susan Gorton
Deputy PM: John Koudelka
Associate PM for Technical Challenge Integration: Noah Schiller
Associate PM for Partnerships: Carl Russell

Senior Technical Advisor
Gloria Yamauchi

Project Liaison Interface to Centers
AFRC: Robert Navarro
ARC: Gina Willink
GRC: TBD
LaRC: Benny Lunsford

Business unit
Lead Analyst: Angela Williams
Center Analysts: Eric Lee, Maddie Duncan, Alee Pacheco
Scheduler: Joyce Moran

SIP/ RVLT RESEARCH THEME

- Clean and Efficient Propulsion
- ModSim and Test Capability
- Efficient and Quiet Vehicles
- Safety, Comfort, Accessibility

SUB-PROJECT

eVTOL Propulsion Subproject
SPM: TBD
SPTL Tim Krantz, Mark Valco, Linda Taylor

Design, Simulation and Validation Subproject
SPM: Gina Willink
SPTL Chris Silva, Brian Allan, Norm Schaeffler, Tom Norman

eVTOL Noise, Safety and Comfort Subproject
SPM: Benny Lunsford
SPTL Doug Boyd, Noah Schiller, Justin Littell, Carlos Malpica

ELEMENT

eVTOL Propulsion Subproject:
- Electrical Power Systems
- Electro-Mech Powertrain Systems
- Thermal Management and Materials

Design, Simulation and Validation Subproject:
- Conceptual Design
- High-fidelity Modeling
- Validation Test Campaigns

eVTOL Noise, Safety and Comfort Subproject:
- Source Noise and Community Response
- National Campaign Acoustics
- Safety and Environment
- Ride Quality

TECH CH

- TC.UAM.ELECTRIC.1 Reliable and Efficient Propulsion Components for UAM
- TC.UAM.NOISE.1 Urban Air Mobility (UAM) Operational Fleet Noise Assessment
- TC.UAM.HQRQ.1 Acceptable Handling and Ride Qualities for Urban Air Mobility (UAM) Vehicles
- TC.UAM.NOISE.2 Tools to Explore the Noise and Performance of Multi-Rotor UAM Vehicles
- TC.UAM.SAFETY.1 UAM Crashworthiness and Occupant Protection

Summary

NASA RVLT is focused on

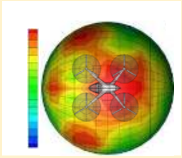
- Vertical lift supporting Urban Air Mobility
- Completing acoustic measurement commitment to NASA National Campaign #1
- Technical Challenges
  - Electric propulsion reliability and performance
  - Tools to compute vehicle source noise and performance
  - Fleet noise
  - Ride quality and passenger acceptance
  - Crash safety and occupant protection

Our vision is to create a future where VTOL configurations operate quietly, safely, efficiently, affordably and routinely as an integral part of everyday life.

Backup

RVLT Contributions to AAM Industry—Deliverables and Impact

Noise Research



Predictive Tools for AAM Noise

AAM Acoustic Impacts

Safety Research

Electric Powertrain Reliability

Handling & Ride Qualities

Crashworthiness & Occupant Protection

Deliverables

- Vehicle Conceptual Design Tool Chain, New Noise Analysis Methods, Experimental Databases
- Vehicle Noise Database and Footprint Assessment, Modeling Best Practices, Annoyance Testing Results
- Validated Drivetrain Models, Motor Reliability/Performance Data, Design & Test Guidelines
- UAM Handling & Ride Qualities Guidelines, Updated Prediction Tools, Expanded Test Capabilities
- Vehicle and Occupant Crash Loads Data, Validated Structural Models, Best Practices for Testing and Analysis

Stakeholder Benefits

FAA / Regulators / Standards Orgs.

Data and tools will support means-of-compliance decisions and recommendations

U.S. Industry

Improved toolsets and databases will accelerate vehicle design, analysis, and development timelines

Academia

Improved toolsets and databases support fundamental research in vehicle modeling and development

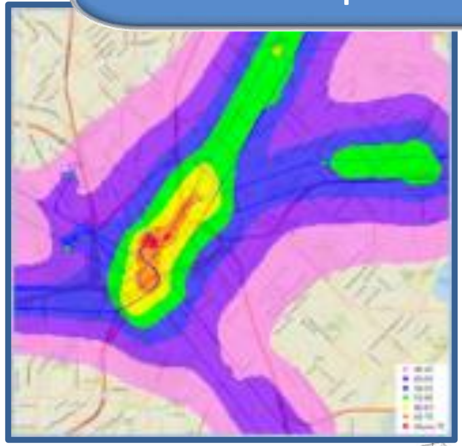
Other NASA Projects

Vehicle and sub-system performance data and models inform airspace, automation, and AAM system-level modeling and testing

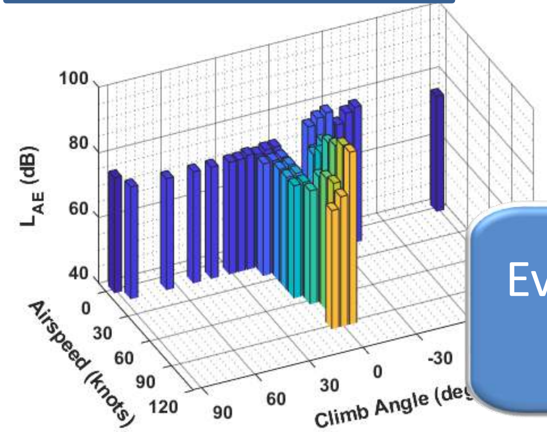
NASA AAM Operational Fleet Noise Assessment Approach

Use AEDT to evaluate ground noise, combining all the vehicles and operational states

Choose to target FAA's Aviation Environmental Design Tool (AEDT) because it is required for any actions subject to National Environmental Policy Act (NEPA)

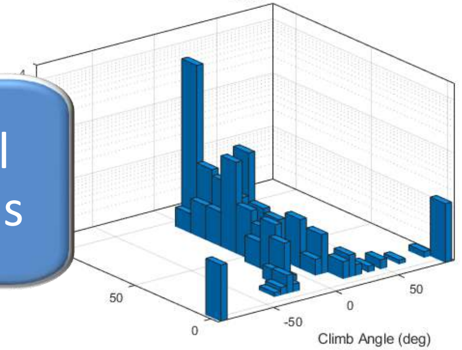


Identify routes, trajectories, and aircraft flight conditions



Evaluate source noise at all the operational states

Establish aircraft operational states for the flight conditions



Rizzi 2022 AIAA SciTech

Provide Guidelines for Using AEDT to Model AAM Noise in Operations

AAM Mission Research Swimlanes

Automation, Airspace, and Safety (i.e., Automation Architecture Prototype)

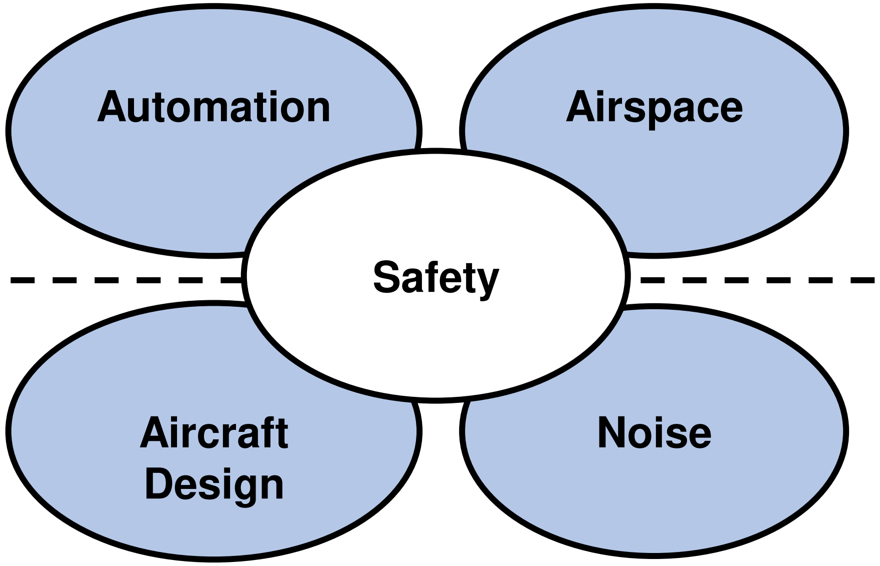
All automation domains are critical to develop an integrated automation architecture for the AAM Critical Commitment and enabling automated flight for AAM

Primarily supported by **SWS, ATM-X, and AAM**

Aircraft Design, Noise, and Safety

Aircraft safety and noise are not tightly integrated with the elements of NASA's AAM Mission Automation CC for 2026. However, research and deliverables in these areas inform the AAM MBSE modeling in support of the AAM Mission CC for 2030.

Primarily supported by **RVLT**



NOTE: Community Integration pillar not an emphasis of NASA portfolio

UAM Vehicles Provide Variants for Public Good Missions

UAM Vehicle Design
- 4-6 pax (~1200 lb payload)
- 75-100 mi range
- ~115-140 mph speed

UAM Air Taxi

Disaster Relief
- Evacuations
- Supplies
- Search and Rescue

Aerial Firefighting
- Responder transport
- Fire retardant delivery

Medical Transport
- Intracity patient transport
- Clinic staff transport
- Organ/supply transport

Environment
- Agriculture
- Environmental surveys
- Wildlife management

Moog SureFly® Hover Test Update

Revolutionary Vertical Lift Technology Project
Advanced Air Vehicles Program

Brenda Henderson (NASA Glenn Research Center)
Jordan Cluts (NASA Glenn Research Center)
Devin Boyle (NASA Glenn Research Center)
Alexander Svetgoff (NASA Glenn Research Center)
Chris Miller (NASA Glenn Research Center)
Justin Jantzen (Moog)

NASA Acoustics Technical Working Group
Oct 18 – 19, 2022

Objectives

Objectives

- Determine location of far-field
- Measure sound pressure levels for vehicle in hover
- Acquire data to use in electric motor efforts
- Acquire dataset for future predictive tool validation

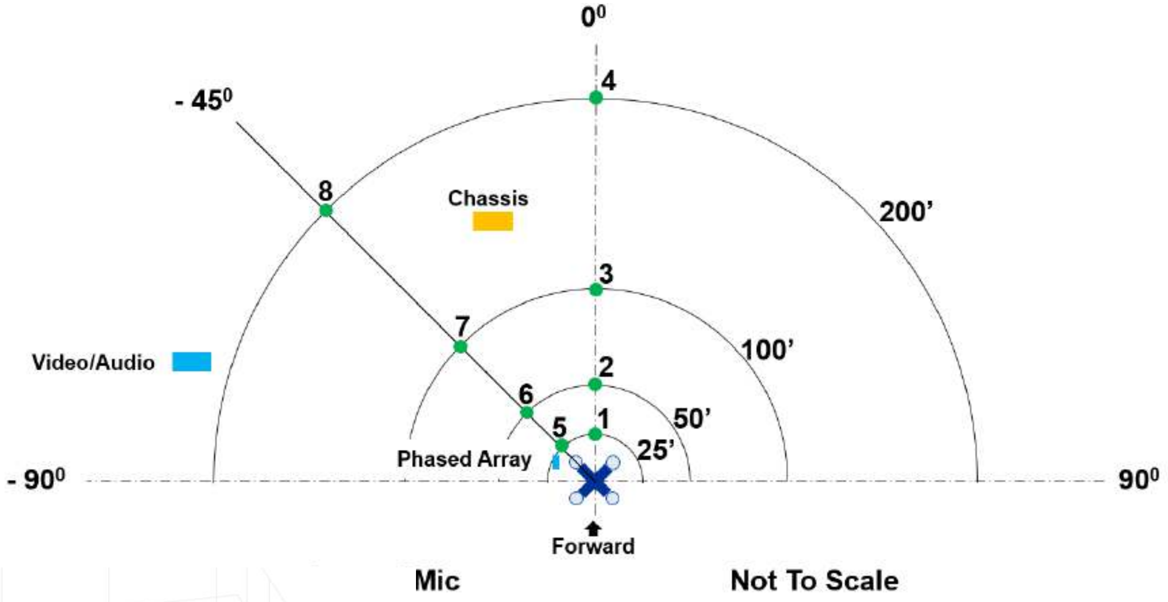
Test Constraints

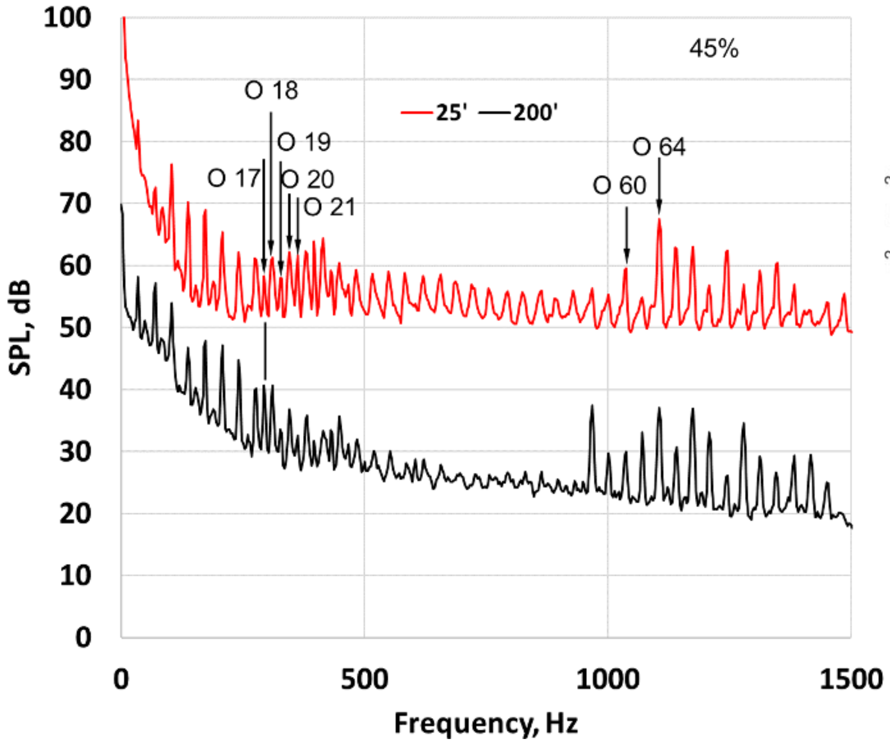
- Lunken Field
  - 15’ maximum hover
  - Limited testing area
  - Fog!
- ~10 minutes flight time
- Altitude (z coordinate) part of control loop, x and y coordinates maintained visually by pilot
  - x and y box was approximately equivalent to that expected from the control system
- Needed to post process GPS data for accuracy

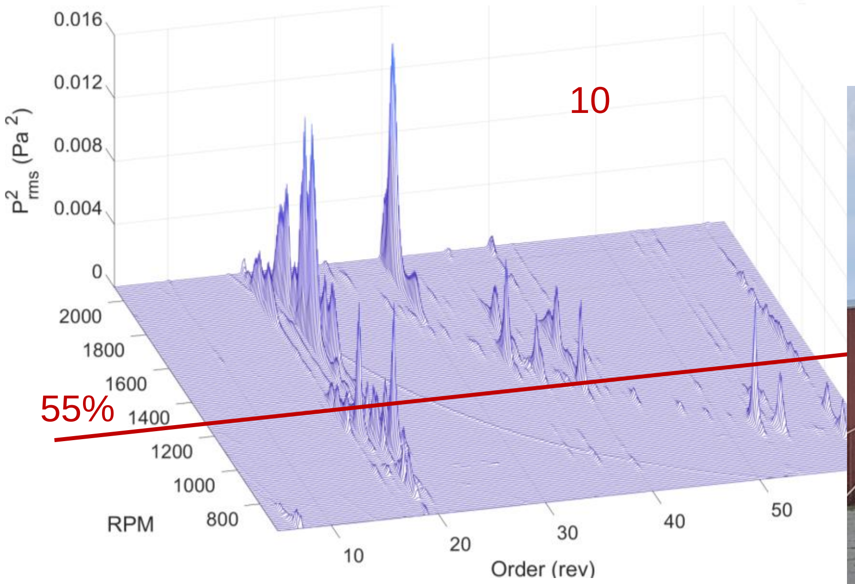
Test Date – 6/29/2022

Previous Results

- Ground Runups in November 2019 with sparse microphone array (NASA/TM-20210015042) and constrained to 55% throttle
- Electric motor noise measurements in August 2021 (NASA ATWG Spring 2022)
- RotCFD calculations 2022 in preparation for hover test

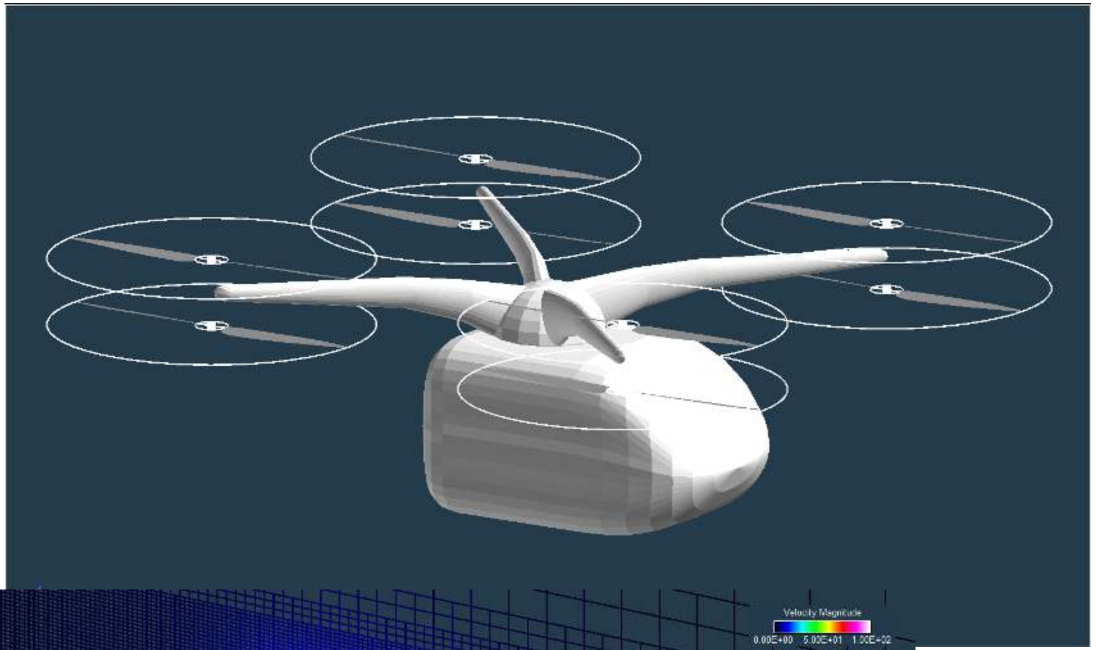


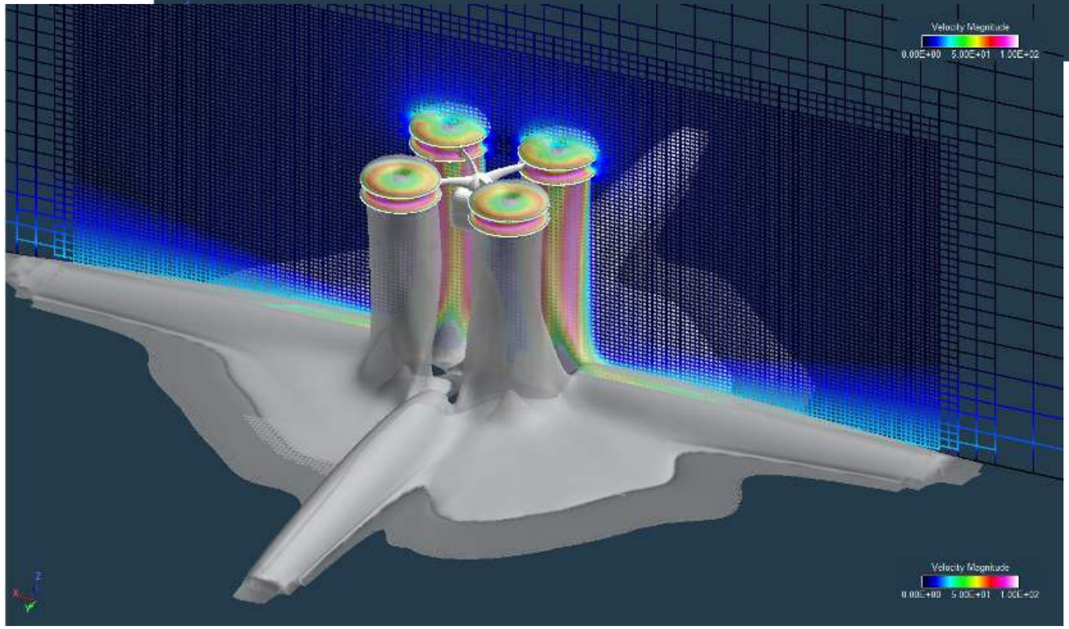




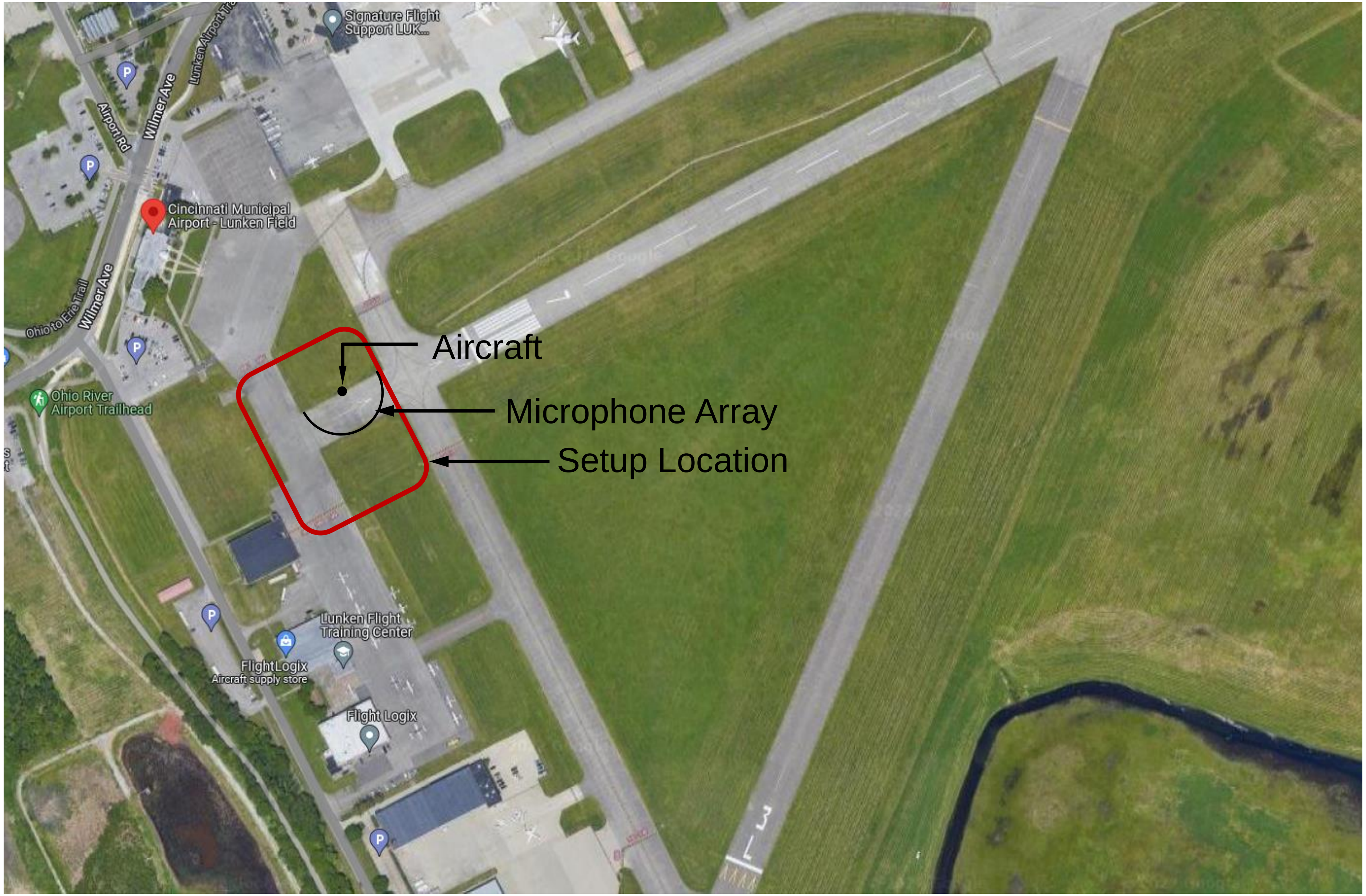
Moog SureFly – RotCFD

- GOAL
  - ➢ Preliminary analysis to protect ground plate microphones and assess hover test results
- APPROACH
  - ➢ Hover In Ground Effect (HIGE)
  - ➢ Actuator disk rotors
  - ➢ At estimated power and uniform RPM
- RESULTS
  - ➢ Strong ground plumes avoided for some angles
  - ➢ Minimum time on condition estimated
- FUTURE
  - ➢ Use actual rotor power and RPM
  - ➢ Predict rotor tones



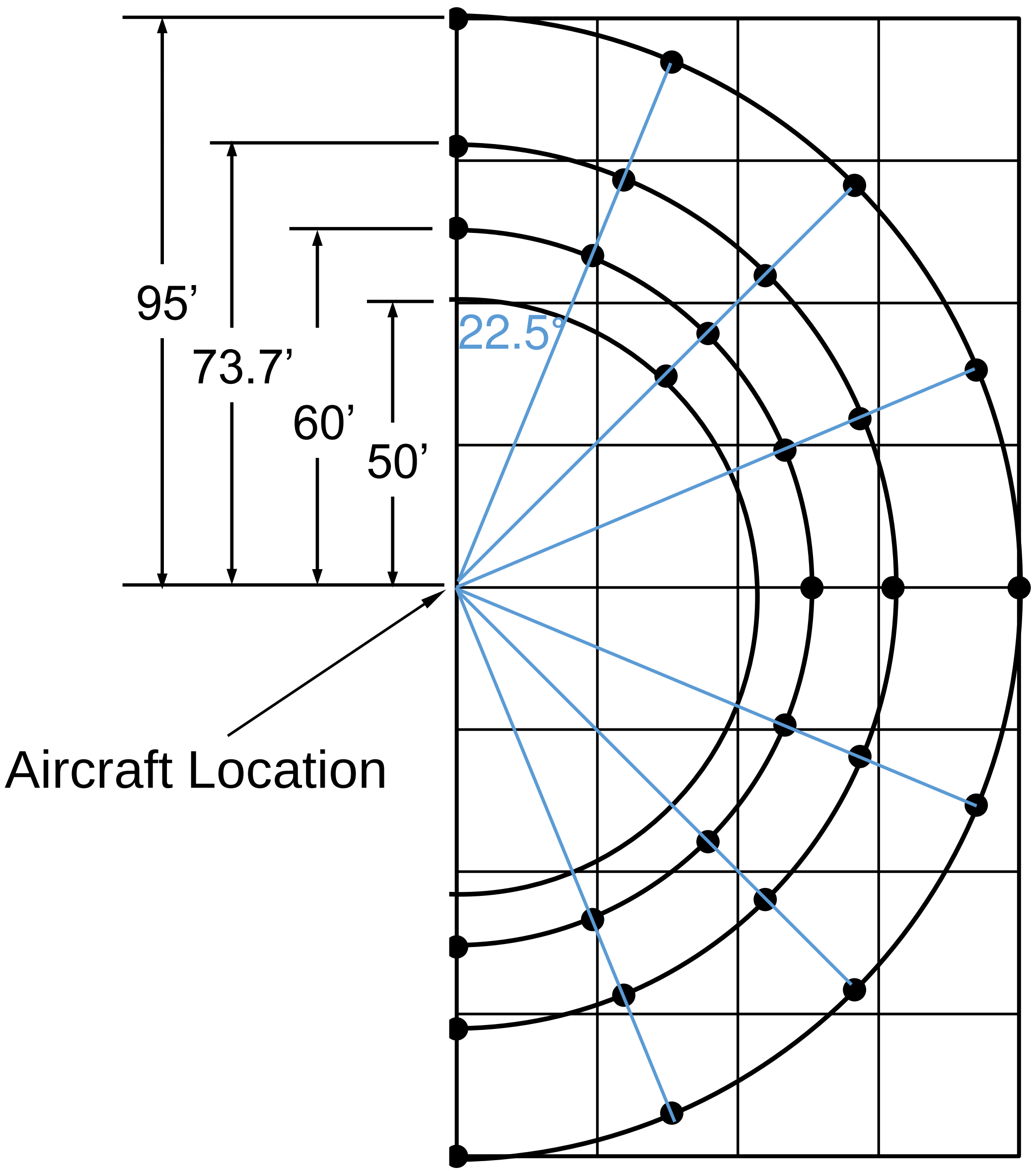


Test Location - Lunken Field in Cincinnati



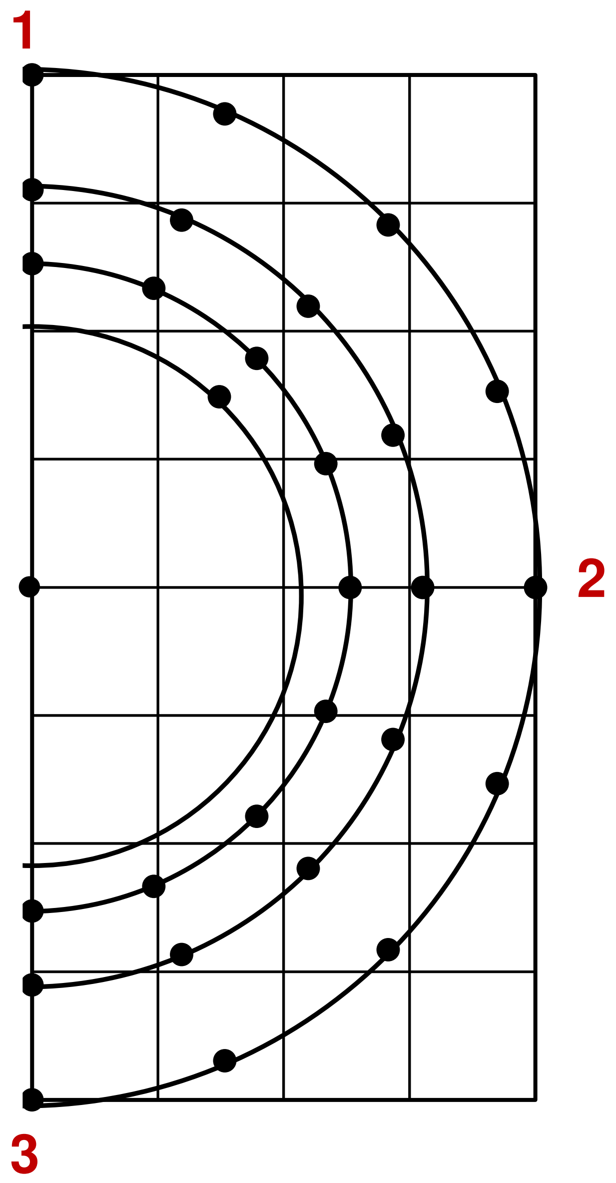
Array Layout

- 28 Ground plate microphones
- Maximum distance from the aircraft in the test location was 95' (100' to aircraft at 15')
- Array allowed for determination of directivity and distance to the far field



Test Procedure

- Align with microphone 1 and hold for 20 sec
- Rotate to microphone 2 and hold for 20 sec
- Rotate to microphone 3 and hold for 20 sec
- Repeat in opposite rotational direction
- Land, liftoff, repeat procedure



- Acoustic data was acquired continuously to record steady hover and yaw conditions
- Humidity, temperature, pressure, wind speed were recorded at roughly 10' above ground

Requested Vehicle Data

- GPS for vehicle position
    - L1 Capable
    - Distance to nearest base station - 14.7 km
- Vehicle attitude from inertial measurement unit (pitch, yaw, roll)
- Motor speeds
- Electric motor input (at least one leg)
- Shaft power
- Weight
- Center of gravity
- Rotor blade angle settings

Summary

- Preliminary RotCFD complete. Final analysis will be completed once vehicle data is incorporated
- In the process of obtaining RINEX files needed for GPS post processing – needed for far-field determination
- Electric motor noise assessment planned for Spring ATWG
- Exercise acoustic predictive tools in Spring
- Hover test at higher altitude is planned for Springfield-Beckley Municipal Airport airport in Spring


N8 W

Event Q&A

Is the assumption that the electric motor noise with an unloaded motor is representative of what you would hear with a rotor a verified one?

We anticipate the levels for the loaded motor to exceed those of the unloaded motor.

Did you perform any tests with different RPM or different pitch? If yes, what were the obsevered trends?

The pitch of the rotors is constant. The RPM was that required for the hover procedure discussed in the presentation. No attempt was made to intentionally change the RPM

PVT+AUDIO. Online psychoacoustic testing iOS app for evaluating AAM/UAM noise response.

Fall 2022 ATWG

Durand R. Begault Ph.D.

durand.r.begault@nasa.gov

Human Systems Integration Division (TH)

NASA-ARC

Moffett Field CA

Work supported by NASA RVLT

Outline

- Implementation of a remote version of a UAM noise study
  - **PVT+** background and extension to **PVT+AUDIO**
  - Overview of current laboratory experiment
  - Implementation of audio within a **PVT+** app architecture
  - Response paradigm
  - App page sequence; subject engagement considerations
  - Signal processing for spatial audio, binaural, headphone compensation
  - Calibration conisderations
  - Example instructions
  - Anonymizer for maintining subject privacy

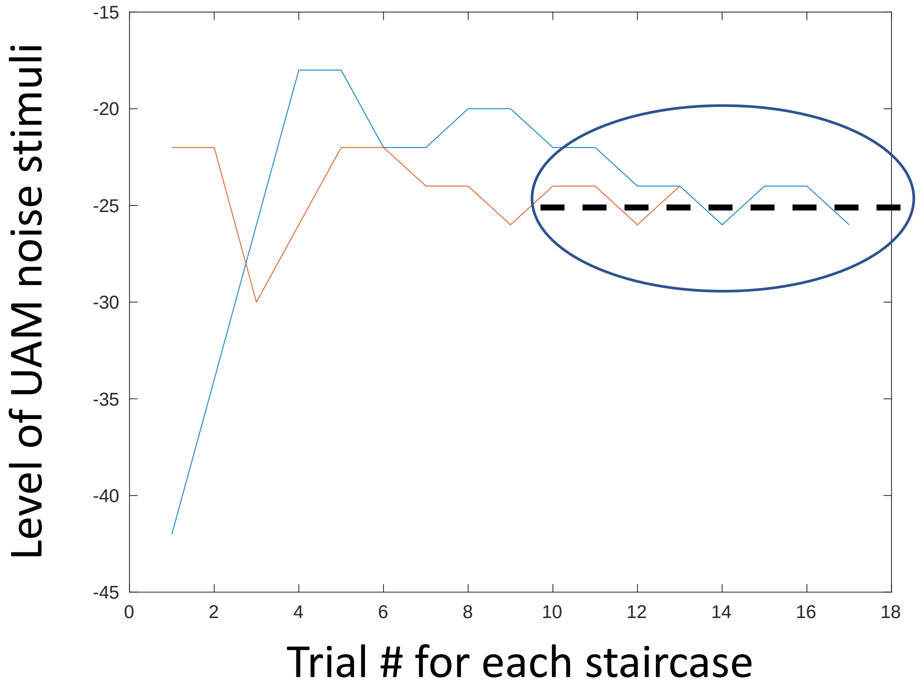
PVT+AUDIO. Online psychoacoustic testing iOS app for evaluating AAM/UAM noise response

- The **PVT+** (**P**sychomoter **V**igilance **T**ask) app was developed 6 years ago for NASA-ARC's **Fatigue Countermeaures Laboratory** (Dr. Erin Flynn-Evans, director; Kenji H. Kato, developer).
- Currently used to evaluate **commercial airline pilot fatigue** and neurobehavioral changes in vigilant attention, e.g., via reaction time.
- The app is **NASA-approved** & has been available since 2020 on the Apple App Store, for download to **iOS devices**.
- The architecture of the app allows it to be extended to **separate audio and vision psychophysics** studies (+AUDIO, +VISION…)
- First execution of **PVT+AUDIO** underway for UAM noise studies based on in-house development

PVT+AUDIO. Online psychoacoustic testing iOS app for evaluating AAM/UAM noise response

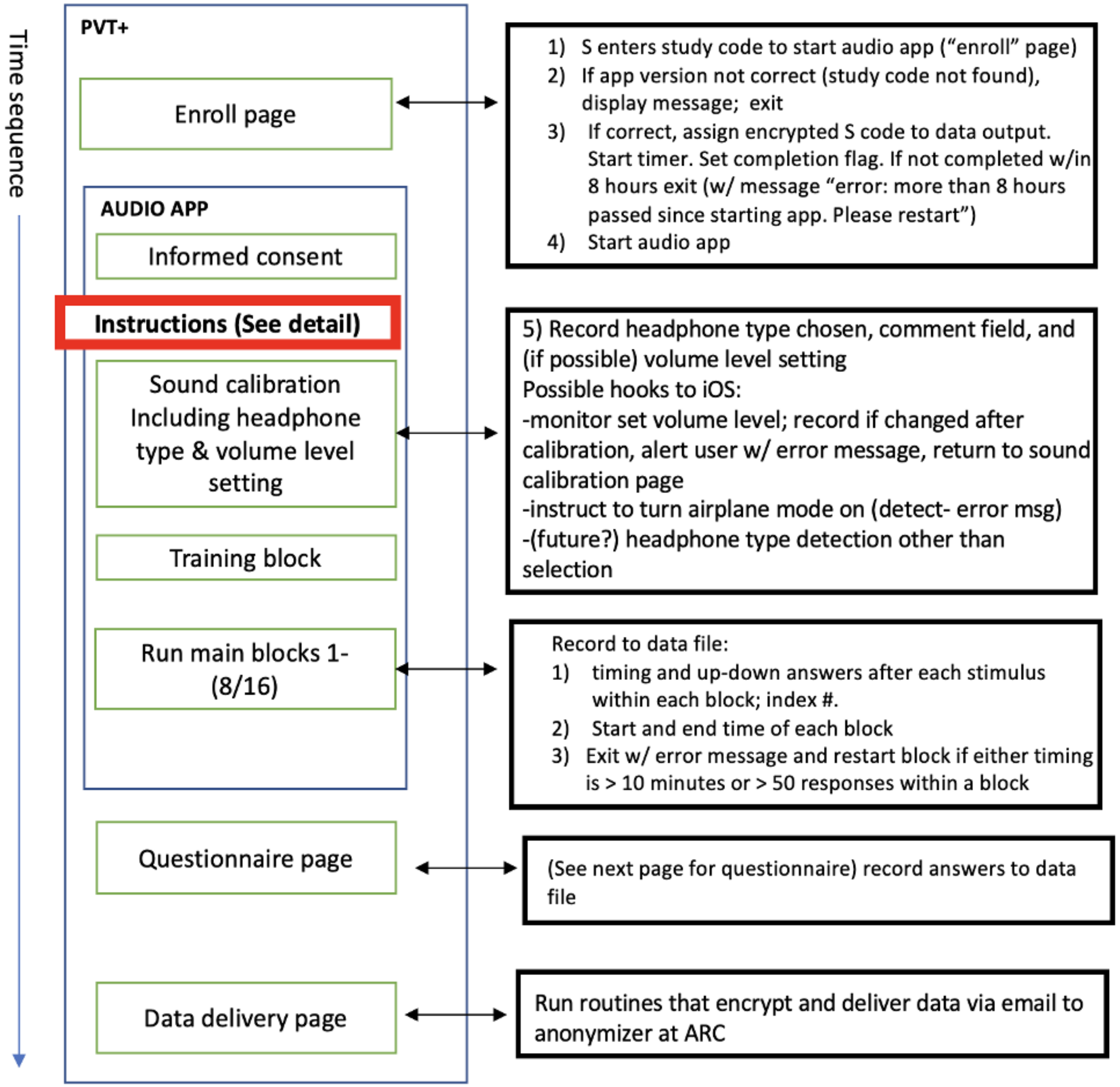
Remote version of current laboratory study

- COVID motivated a **remote version** of an ongoing lab study investigating **subjective response to UAM sound level**, as experienced in **different ambient environments** (“PARK” &“STREET”)
- The study contrasts UAM sound level **thresholds** obtained using two different **subjective criteria**:
  - **annoyance** (“very” or “extremely” annoyed)
  - **acceptance** (based on “**blend**” with the ambient)
- Thresholds are established via the “method of limits” (**interleaved adaptive staircase**): two-alternative forced choice (up or down) to adjust UAM noise level
- Trade-off between # of subjects and variance to be evaluated by comparing lab versus remote data



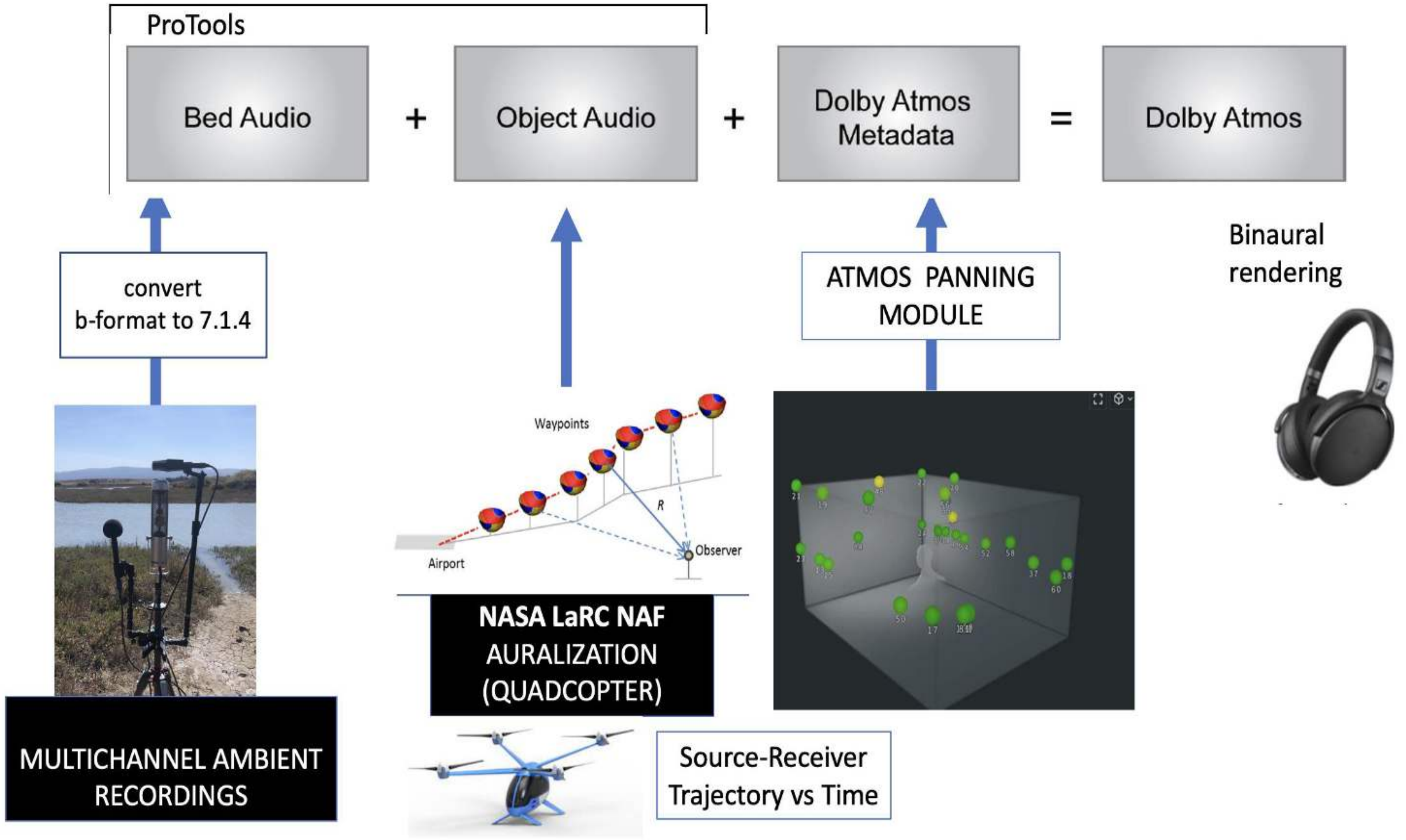
PVT+AUDIO. Online psychoacoustic testing iOS app for evaluating AAM/UAM noise response

- App design to maintain subject engagement requires minimum time, clear instructions
- Use of a between subjects design halves number of trials and eliminates cross-over effects (but more subjects required)
- Succession of app pages:
  - Enrollment code entry
  - Informed consent
  - **Instruction movie** 4 min.
  - Sound calibration (level, headphones) 3 min.
  - Training block, **Main blocks (8)** 4-5 min.
  - Questionnaire
  - Data delivery



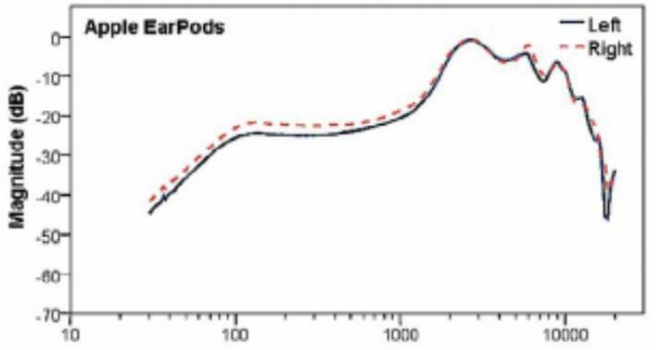
PVT+AUDIO. Online psychoacoustic testing iOS app for evaluating AAM/UAM noise response

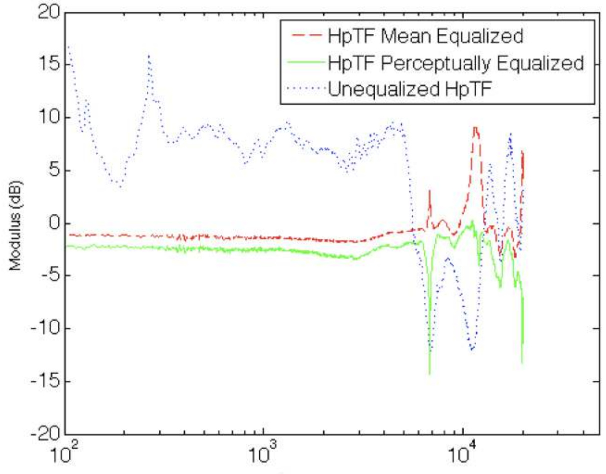
- **PVT+AUDIO** uses binaural rendering to simulate the 7.1.4 Dolby Atmos simulation used in the laboratory
- Fly-over trajectory is rendered as an Atmos “object”; ambient is rendered as an Amos “bed”
- All playback media are downloaded within the **PVT+AUDIO** app



PVT+AUDIO. Online psychoacoustic testing iOS app for evaluating AAM/UAM noise response

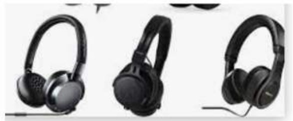
Design of compensatory filters for different types of headphones





SOUND CALIBRATION PAGE 1

Select the type of headphones used:

- Circumaural: Surrounds the ear 
- Supra-aural: sits on the ear 
- Wired earbuds 
- Wireless earbuds (e.g., apple airpods) 

* Other/ don't know ?

If you know either the brand or model or both, please type here:

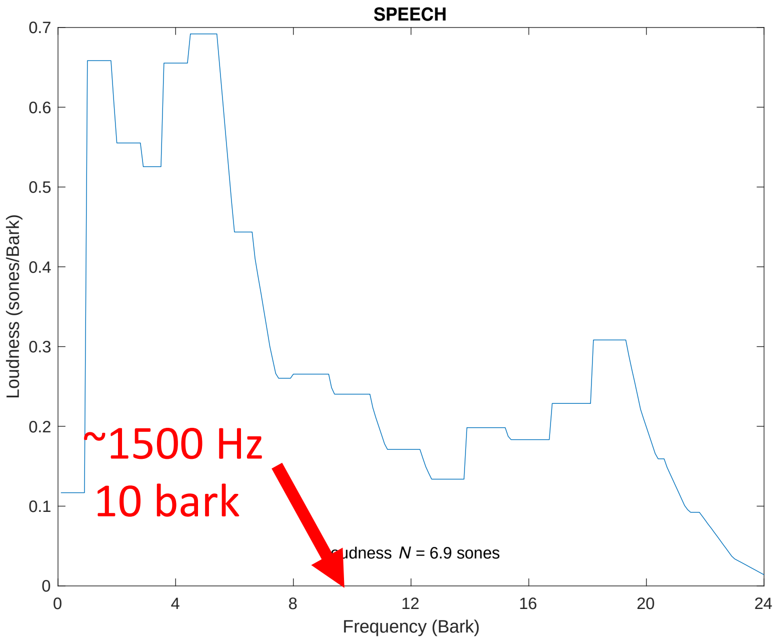
Box for text entry

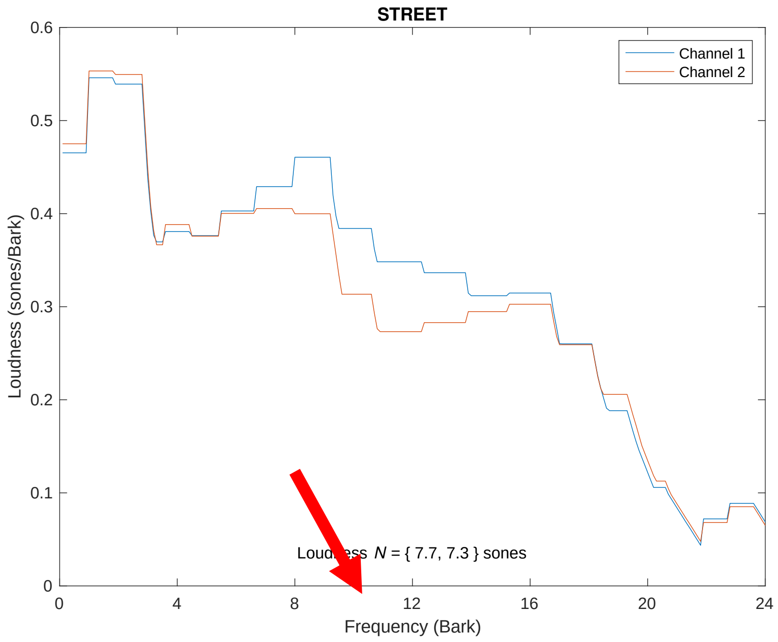
Click to proceed

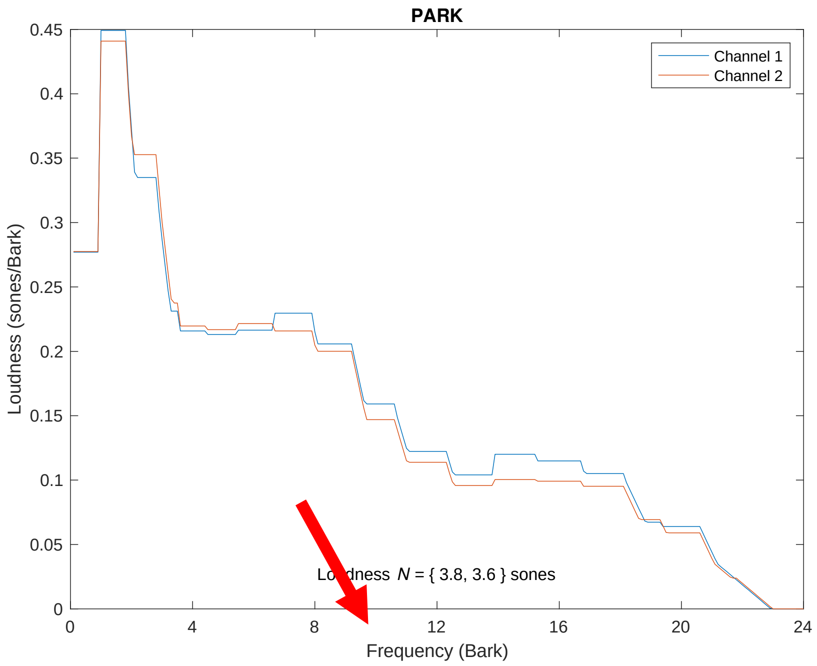
PVT+AUDIO. Online psychoacoustic testing iOS app for evaluating AAM/UAM noise response

- Calibration of playback level to face-face speech at 3 feet
- More realistic matching dBC speech & ambient levels than dBA
- Room tone with “virtual” ambient mic unsuccessful;

  “FM DJ” close mic judged easier to subjectively calibrate

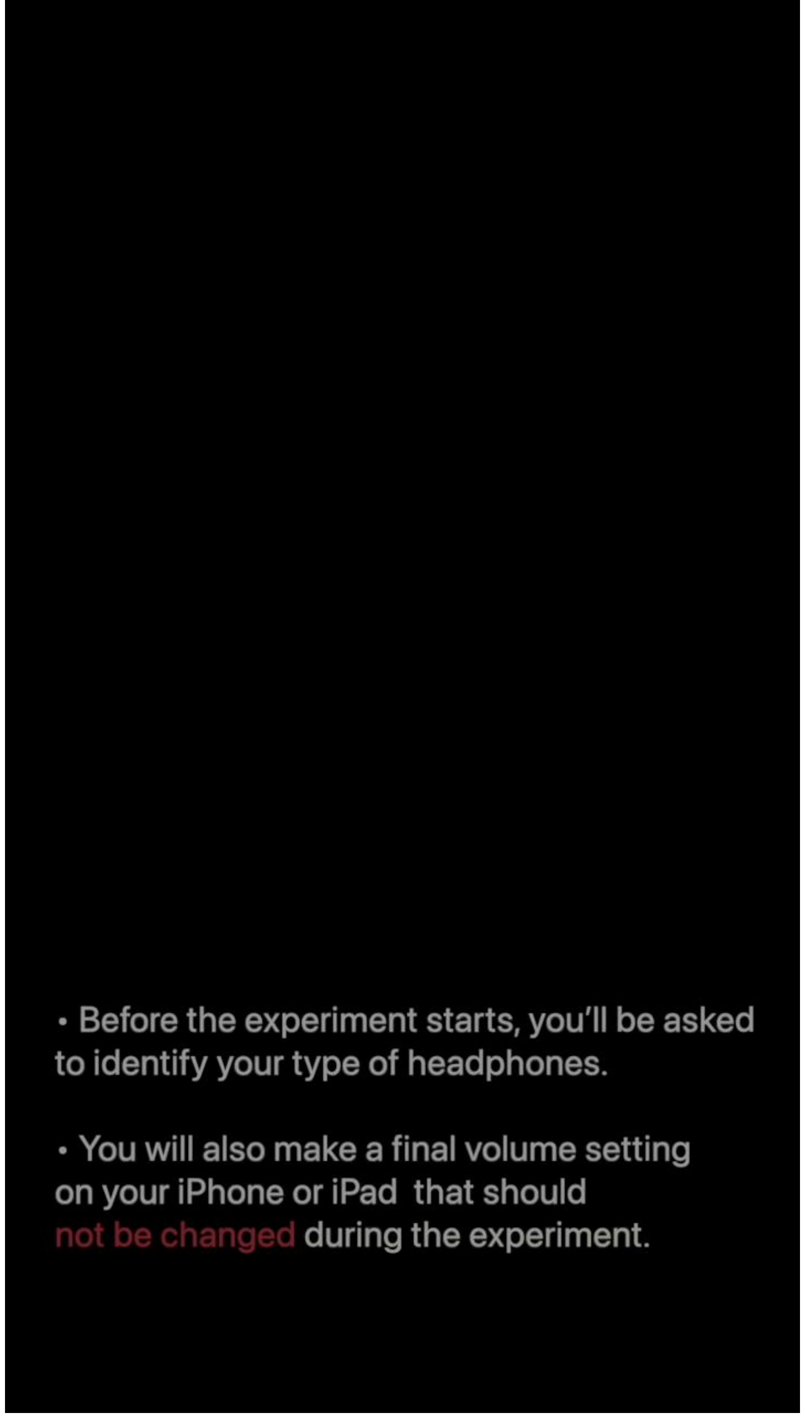






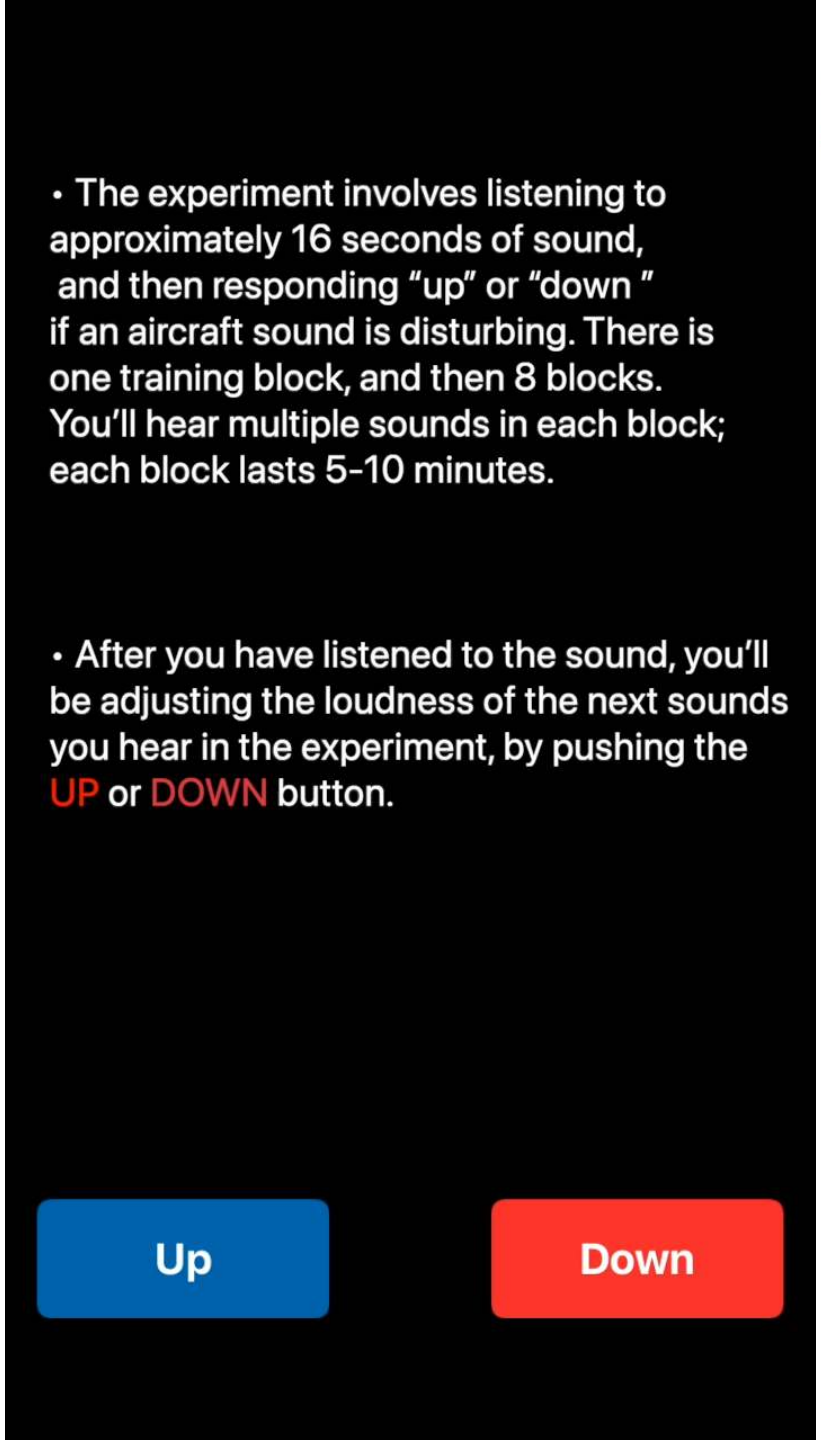
PVT+AUDIO. Online psychoacoustic testing iOS app for evaluating AAM/UAM noise response

Training for “blend” blocks



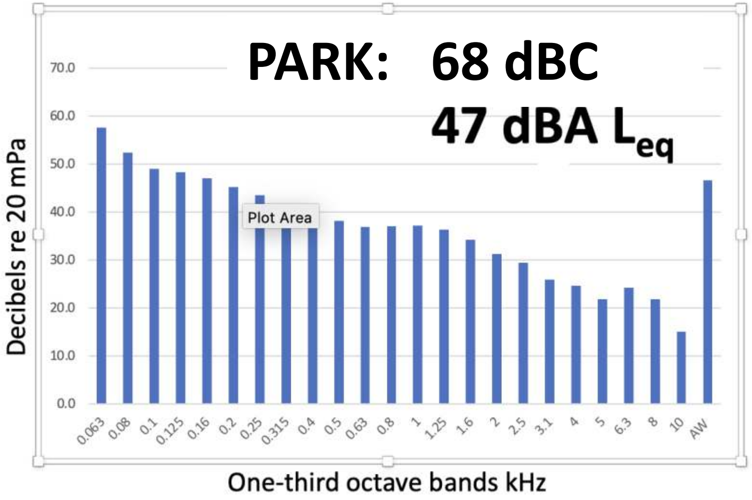
PVT+AUDIO. Online psychoacoustic testing iOS app for evaluating AAM/UAM noise response

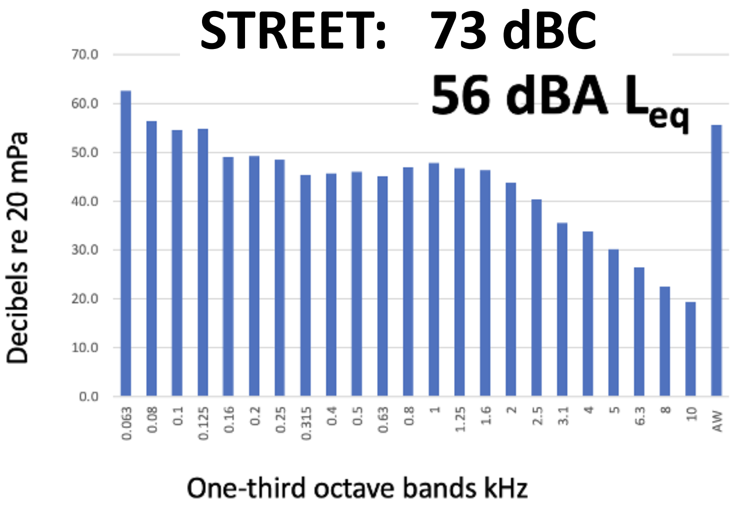
Training for annoyance blocks



PVT+AUDIO. Online psychoacoustic testing iOS app for evaluating AAM/UAM noise response

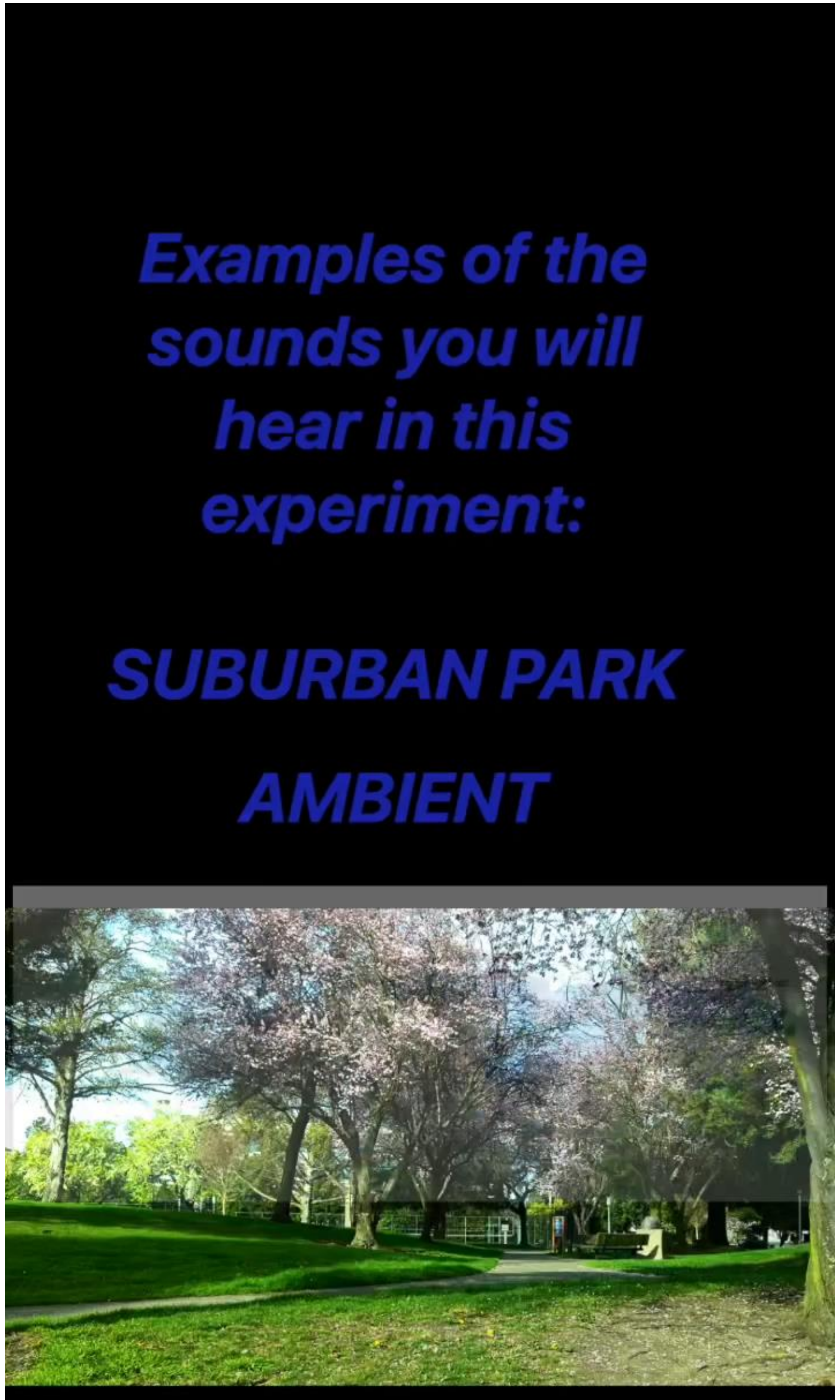
- **Sound examples.** The ambient remains fixed: subject adjusts the level of the eVTOL per **annoyance** or **blend** criteria)





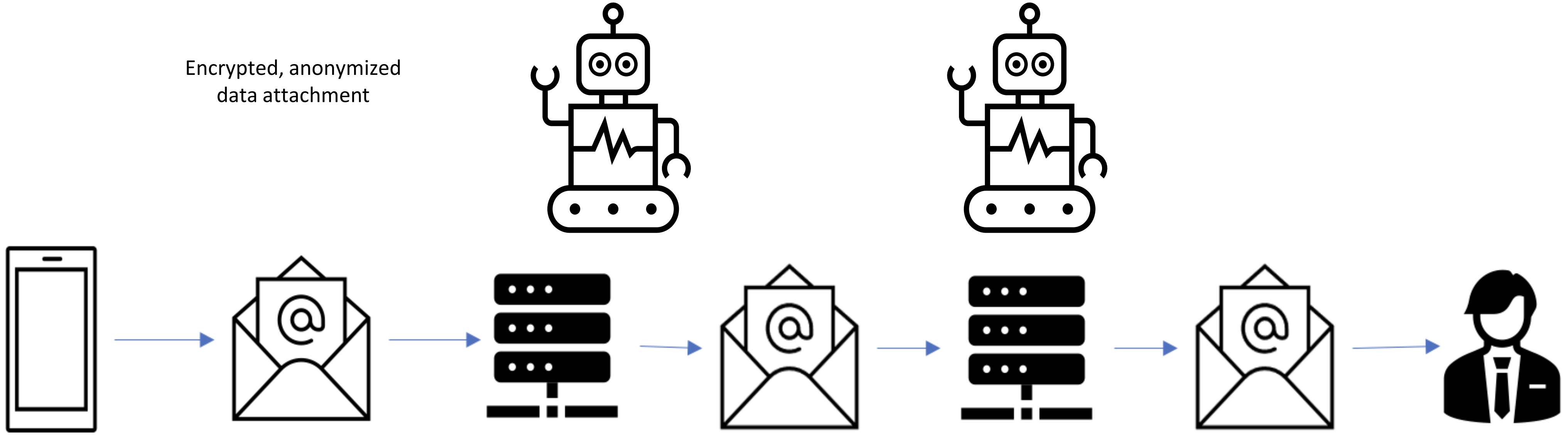
-22.5 -15 -22.5 -15

-7.5 0 -7.5 0



PVT+AUDIO. Online psychoacoustic testing iOS app for evaluating AAM/UAM noise response

"anonymizer" removes identity of subject



Subject completes study on their own device

PVT application emails the results to ARC-CodeTH@nasa.gov

ARC-Codeth@NASA.gov forwards the email to PVT-CodeTH@eos.arc.nasa.gov

PVT-Codeth@eos.arc.nasa.gov receives the forward and takes the attachment and sends it to a researcher via email

Researcher picks up the email with just the file attachments, no subject email is included in the email forward from eos

Graphic: Julie Matsuda

Summary

- **PVT+AUDIO** app ideal for pilot studies, initial investigations, use of larger subject group than possible in laboratory
- "Rapid prototyping", conceptual testing; in-house modification easy
- Optimization of binaural sound simulation with auralization & ambient recording
- First experiment to be run within 2-4 months after testing
- Study results will determine significance of acceptance vs. annoyance criteria, as a function of different ambient backgrounds
- Eventual comparison to laboratory-based version of the study with fewer subjects

PVT+AUDIO. Online psychoacoustic testing iOS app for evaluating AAM/UAM noise response.

Fall 2022 ATWG

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Work supported by NASA RVLT

Acknowledgments:

DEVELOPERS:

Kenji H. Kato
Mark R. Anderson
(NASA ARC-TH; ASRC Systems)

Many thanks also to:

RVLT DNA Team
Steve Rizzi
Andrew Christian
Menachem Rafaelof
Matthew Boucher
Siddhartha Krishnamurthy
Kevin Shepherd

ARC Code TH Colleagues
Bernard Adelstein
Brent Beutter
Julie Matsuda

Initial Results from a Psychoacoustic Test for UAM Sound Quality

Andrew Christian[1], Matthew Boucher[1], Durand Begault[2]
Menachem Rafaelof[3], Stephen Rizzi[1], Siddhartha Krishnamurthy[1]
[1]NASA Langley Research Center, [2]Ames Research Center, [3]National Institute of Aerospace

Acoustics Technical Working Group Meeting
October 18th-20th, 2022

Urban Air Mobility

- Over the past few years, NASA has become interested in what's called "Urban Air Mobility" (UAM).

- This concept involves passenger air vehicles operating between, for instance, a "vertiport" in an urban center, and a nearby airport.

Psychoacoustic Testing for UAM

- There has been a lot of pontification on the role that noise will play in the rollout of UAM concepts.
- NASA maintains several psychoacoustics labs across the country that may be used to investigate the human response to the noise of UAM, even before recordings of vehicles are available.

Exterior Effects Room (EER) at NASA Langley

Psychoacoustic Testing for UAM

NASA has been executing a series of lab psychoacoustic tests for UAM-like sounds (via the EER as well as other facilities).

The questions we are interested in investigating include:

1. What are the qualitative attributes of UAM sound that lead to annoyance? Do things like the presence of tones from motors, sharpness arising from broadband, or amplitude and frequency fluctuation in the sound lead to more annoyance?
2. What way should we be integrating annoyance over time? How does annoyance build up over the course of a single event? How does it build up over the course of multiple events?
3. What role does background sound play in the annoyance of UAM? How does a preexisting (e.g., urban) soundscape impact the perception of UAM vehicles?

These tests are meant to produce data that will be used in building models of annoyance that are inclusive of these effects.

Psychoacoustic Testing for UAM

What are the qualitative attributes of UAM sound that lead to annoyance? Do things like the presence of tones from motors, sharpness arising from broadband, or amplitude and frequency fluctuation in the sound lead to more annoyance?

- We can investigate the efficacy of existing methods of evaluating SQ:

$$PA = N \times \left(1 + \sqrt{w_{FR}^2 + w_S^2}\right)$$

  - Often attributed to Fastl/Zwicker, though seems to be from Widmann in the early '90s
  - More 2011: Addition of tonality for aircraft noise
  - Di et al. 2019: Extension to more types of noise
  - Torija et al. 2022: Fit to UAV noise specifically

→ We want to look into this for UAM noise in particular. Ultimately, we'd like to incorporate other effects as well (integration, masking, etc.).

Investigating Sound Quality: TUSQ

- To generate data for this, an EER psychoacoustic test was executed
  - Test of UAM Sound Quality (TUSQ)
  - 40 subjects over a week of testing in June/July 2022

- The rest of this presentation will go over details of the test and some initial exploratory data analysis.
  - Models do not have to be restricted to that form, but will probably be roughly:

$$Annoyance = Loudness + f(T, S, R, FS, I, \dots)$$

→ We need data that determine the function, but also data that determine the parity between the function and loudness.

Initial Results from a Psychoacoustic Test for UAM Sound Quality

Andrew Christian[1], Matthew Boucher[1], Durand Begault[2]
Menachem Rafaelof[3], Stephen Rizzi[1], Siddhartha Krishnamurthy[1]
[1]NASA Langley Research Center, [2]Ames Research Center, [3]National Institute of Aerospace

Acoustics Technical Working Group Meeting
October 18th-20th, 2022

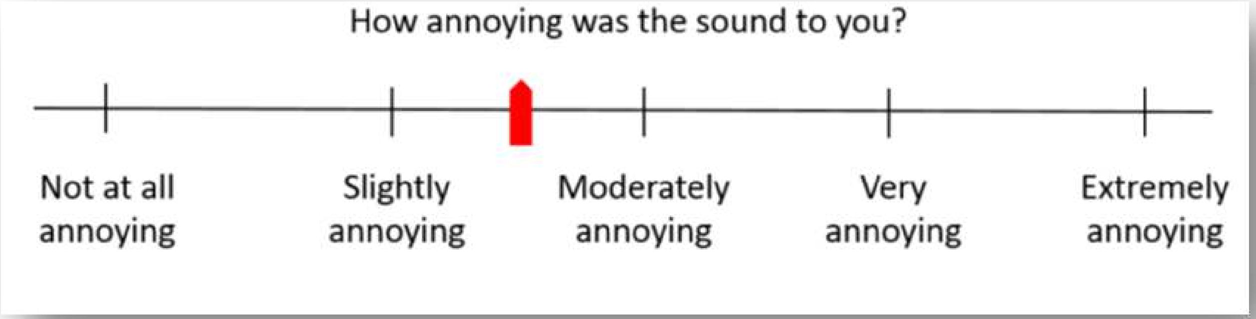
Test of UAM Sound Quality

- Motivation
- Two test questions: Loudness and other SQ
- Start with simulations
- Post-process to get stimuli
  - Change in BPF
  - Factorial test design
- How noise parameters influence sound quality

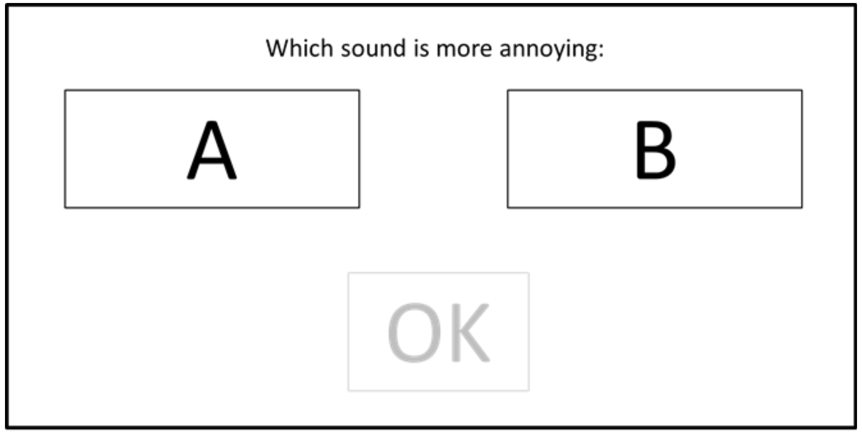
Two test questions: Loudness and other SQ

$$Annoyance = Loudness + f(T, S, R, FS, I, \ldots)$$

- How does annoyance change if loudness is constant?
  - Annoyance ratings
  - 136 sound of various sound quality
  - Constant loudness



- How does annoyance change with loudness?
  - Paired comparisons
  - 26 sounds selected from above
  - Vary loudness of reference sound

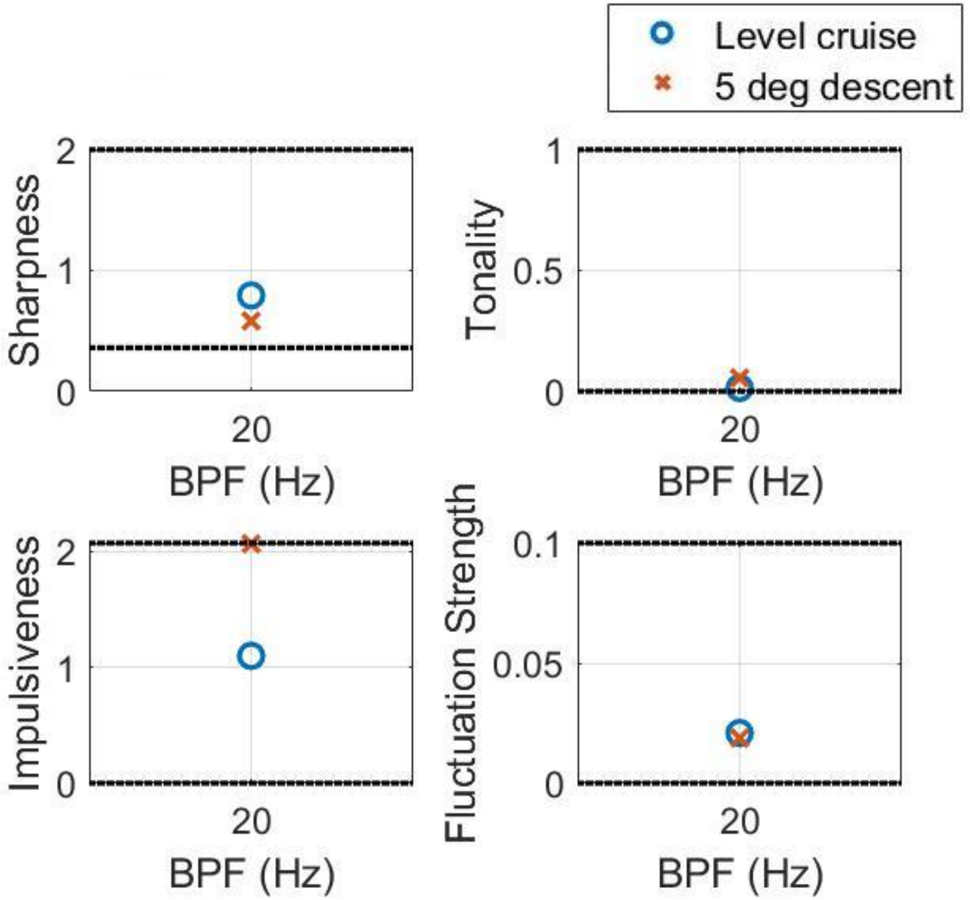


Start with simulations

Blade passage Frequency (Hz)	Level cruise	5 degree descent
20		

Auralizations

- F1A from Aircraft Noise Prediction Program (ANOPP2)
- Broadband synthesis developed for rotorcraft
- Auralize using NASA Auralization Framework

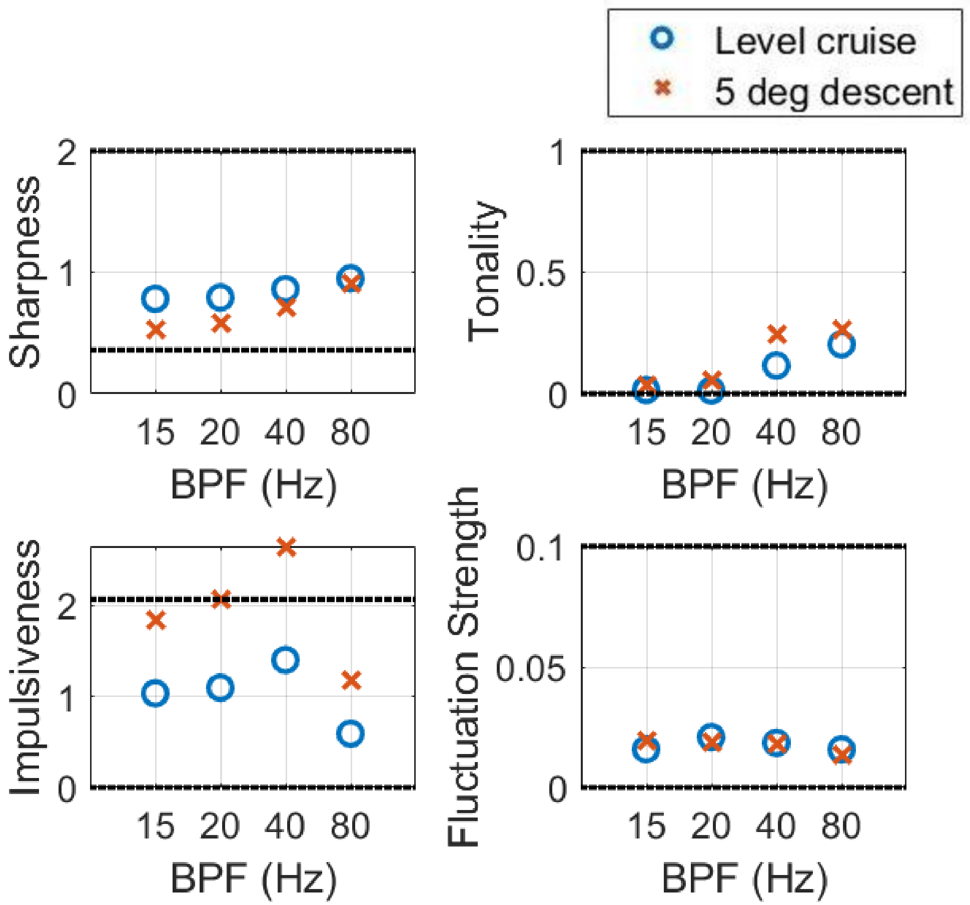


Christian, Boucher, and Begault, F

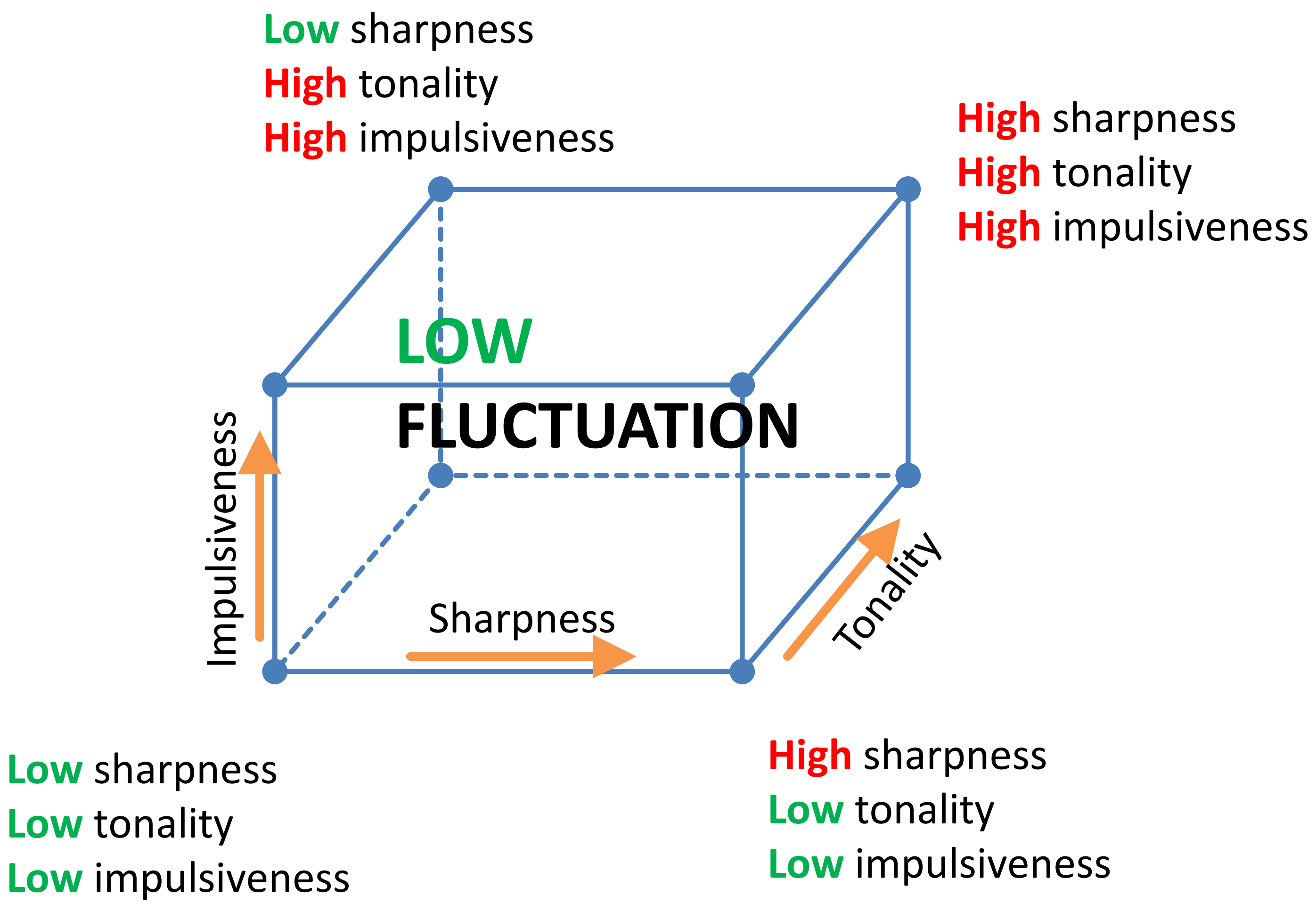
Post-process to get stimuli: change in BPF

- Relate design parameters to changes in sound quality
- How did we generate the 8 baselines?

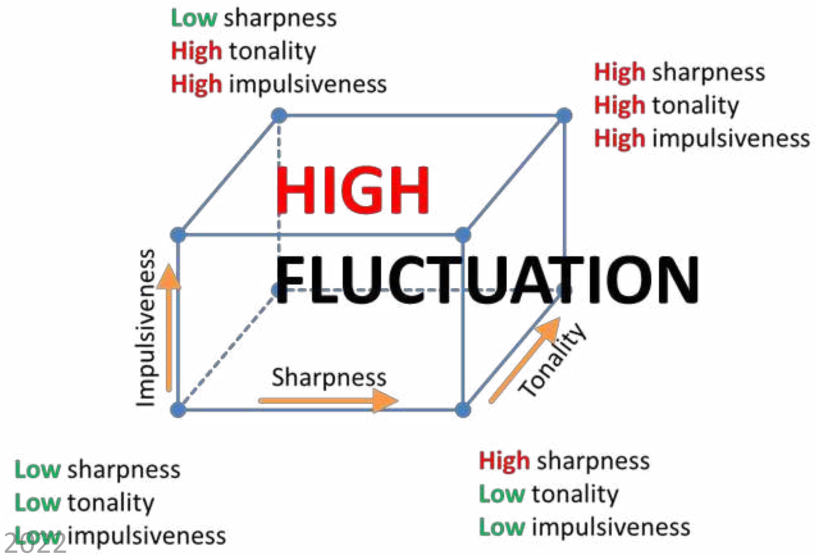
Blade passage Frequency (Hz)	Level cruise	5 degree descent
15		
20		
40		
80		



Post-process to get stimuli: factorial test design



- For fixed BPF and flight condition
- Cube depicts 3-factor,
  - 2-level design
- 4th factor is another cube for high fluctuation strength



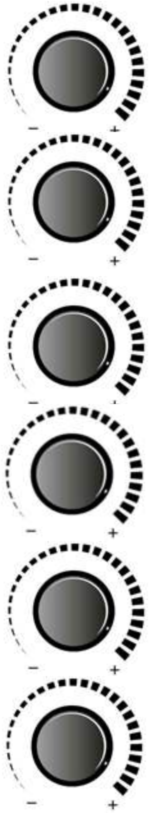
How noise parameters influence sound quality

- Baseline: 5-degree descent with 20Hz blade passage frequency
- Broadband gain to change sharpness
- Tone amplitude to change tonality
- Moving average on loading and thickness noise to change impulsiveness
- Modulation amplitude to change fluctuation strength

Low sharpness, tonality, impulsiveness and fluctuation	High	High sharpness, tonality, impulsiveness and fluctuation
	Sharpness	
	Tonality	
	Impulsiveness	
	Fluctuation Strength	

What factors are important for annoyance?

Synthesis parameters



- Flight condition
- Blade passage frequency
- Self-noise (broadband) level
- Tone amplitude
- Crispness of loading & thickness noise (mov. avg.)
- Modulation amplitude

→

Sound quality

- Loudness
- Sharpness
- Tonality
- Roughness
- Impulsiveness
- Fluctuation Strength

→ **Annoyance**

Initial Results from a Psychoacoustic Test for UAM Sound Quality

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Acoustics Technical Working Group Meeting
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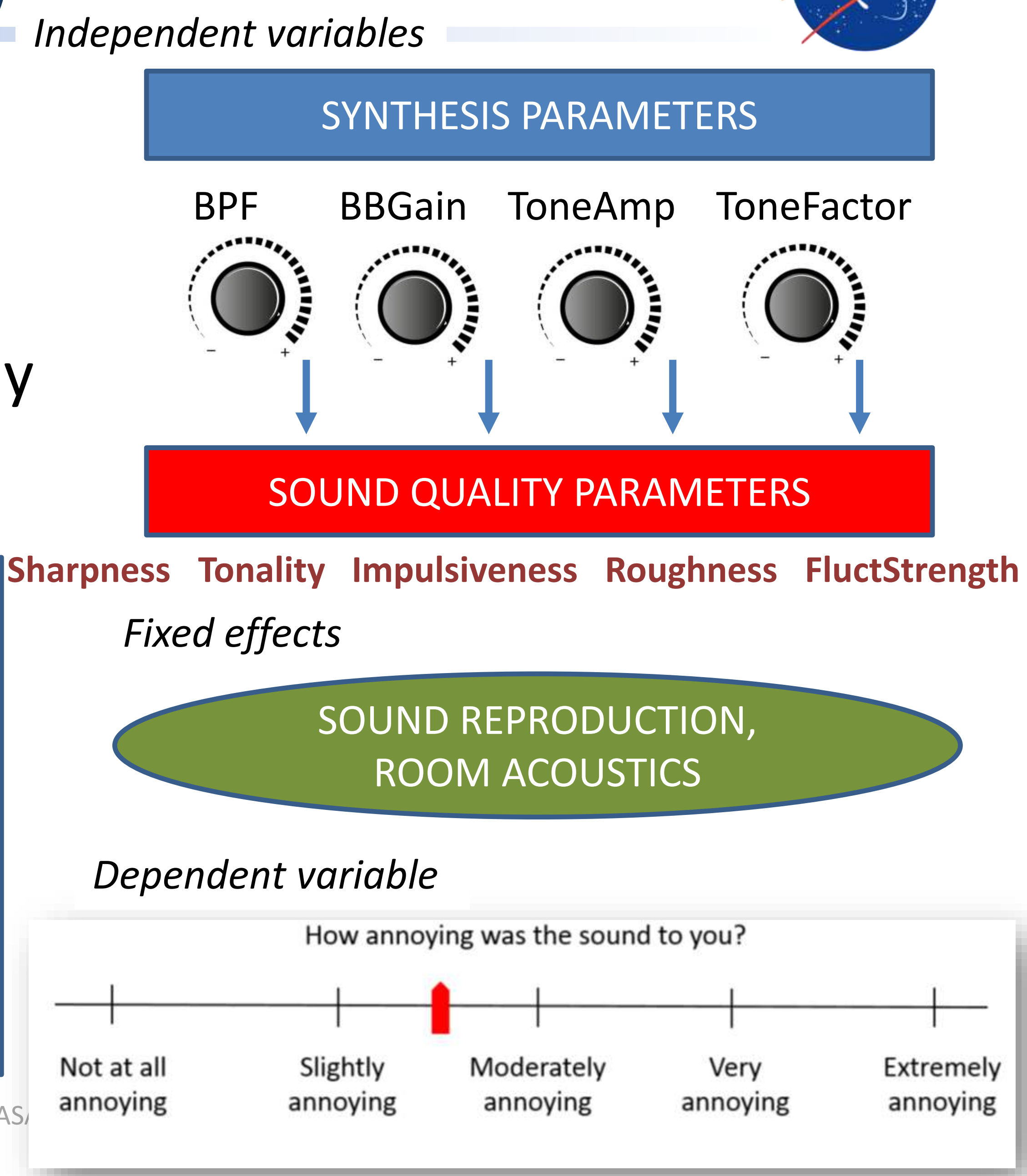
Initial data results (a "first cut")

- Subject's annoyance responses to vehicle design ("**synthesis**") and objective **Sound Quality** (**SQ**) parameters were evaluated **separately**, and for the "flyover" stimuli only *(n =2560)*



- Do **either** synthesis or SQ parameters **predict annoyance** in a linear fashion? What is the **effect size**?
- How **consistent** are inter- and intrasubject annoyance judgements?

Initial data results: linear regression, ANCOVA

SOUND QUALITY PARAMETERS				
Sharpness	Tonality	Impulsiveness	Roughness	FluctStrength

SOUND QUALITY PARAMETER ANALYSIS:

- Regression R^2 indicated that only **6% of the variability** in overall subjective responses explained by **sound quality** factors.
- ANCOVA (Analysis of Covariance) analysis includes subjects as an independent variable. The R^2 indicated **44% of the variability** due to both sound quality factors **and** subjects, with **subjects** being the most influential parameter.
- What is the source of **subject variability**?

Initial data results: linear regression, ANCOVA

SYNTHESIS PARAMETERS		
BPF	BBGain	ToneAmp

SYNTHESIS PARAMETER ANALYSIS:

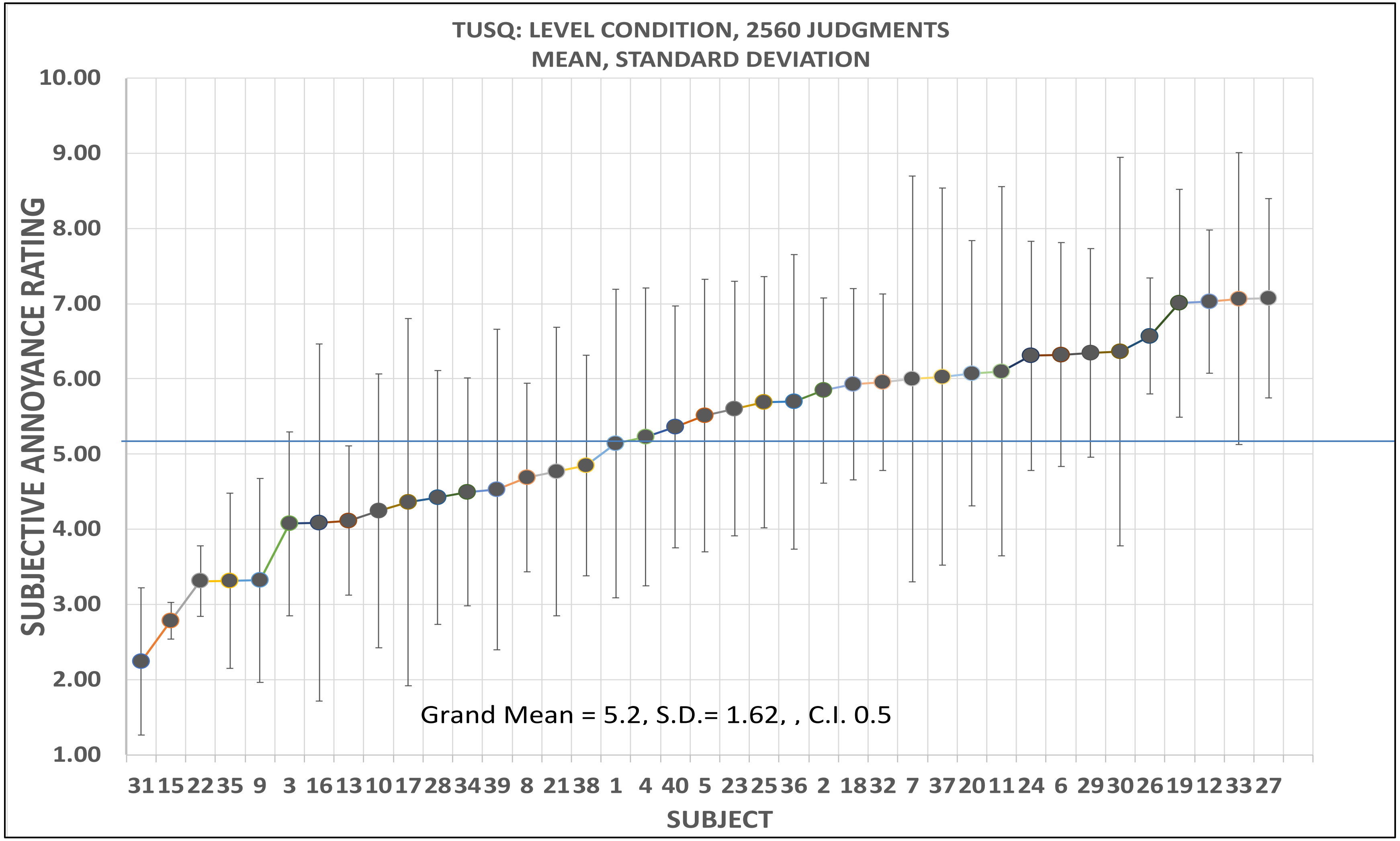
- Regression R2 indicated that only 10% of the variability in overall subjective responses explained by sound synthesis parameters. (31 out of 40 subjects are significantly affected by at least one parameter.)
- ANCOVA analysis includes subjects as an independent variable.

The R^2 indicated **47% of the variability** due to both sound quality parameters **and** subjects, with **subjects** being the most influential parameter.

- Again, what is the source of **subject variability**?

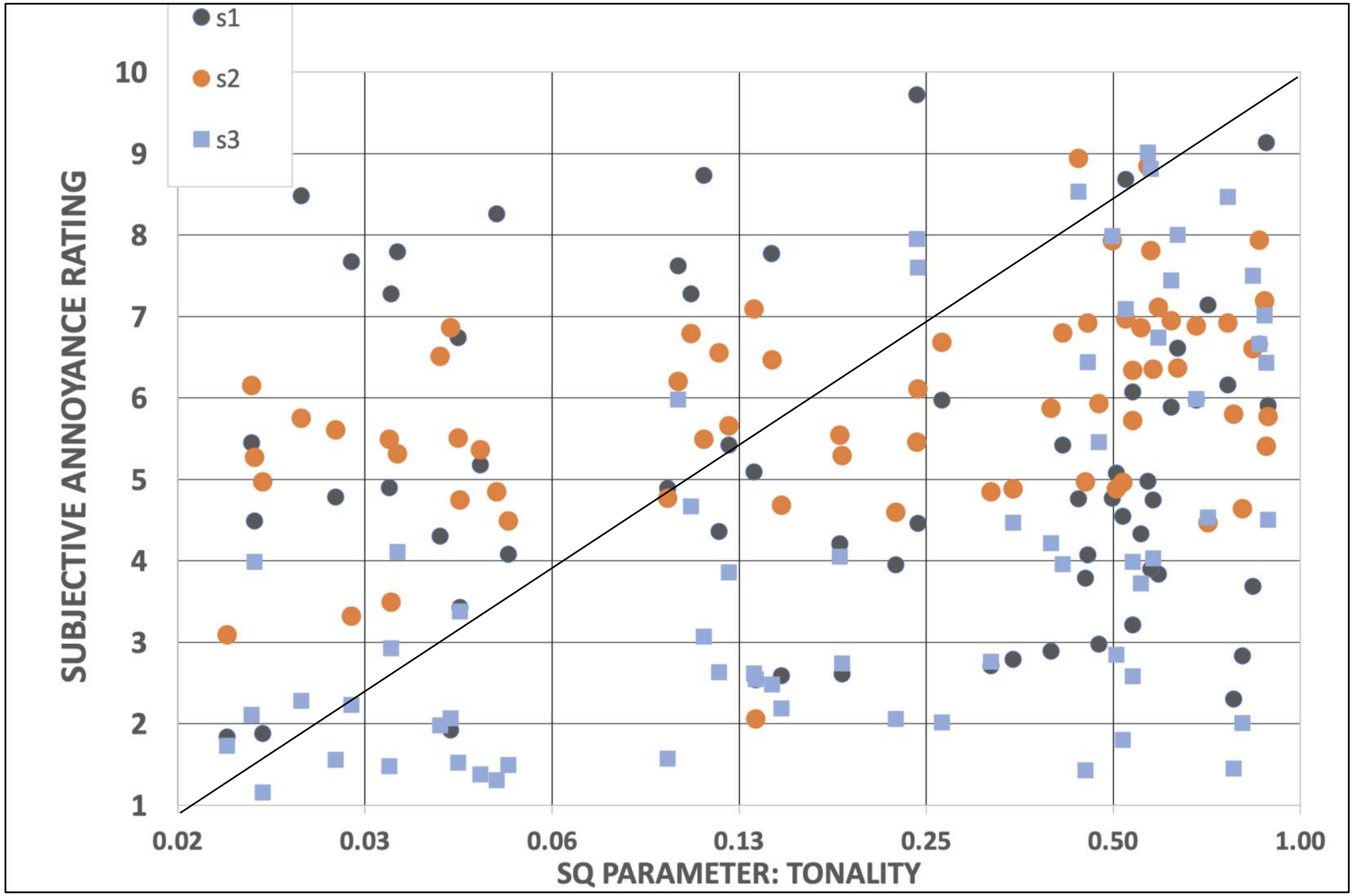
Initial data results: raw data

- Subjects sorted by mean annoyance judgments shows intersubject differences, different use of annoyance scale



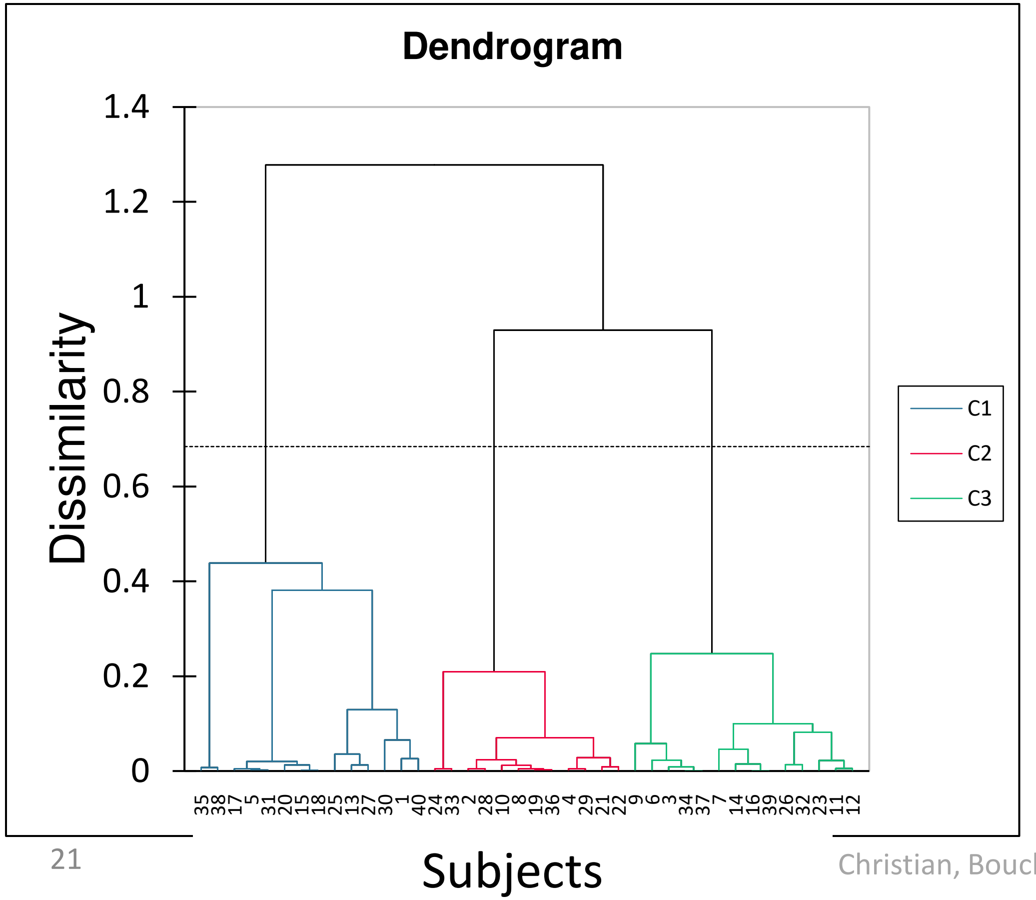
Initial data results: raw data

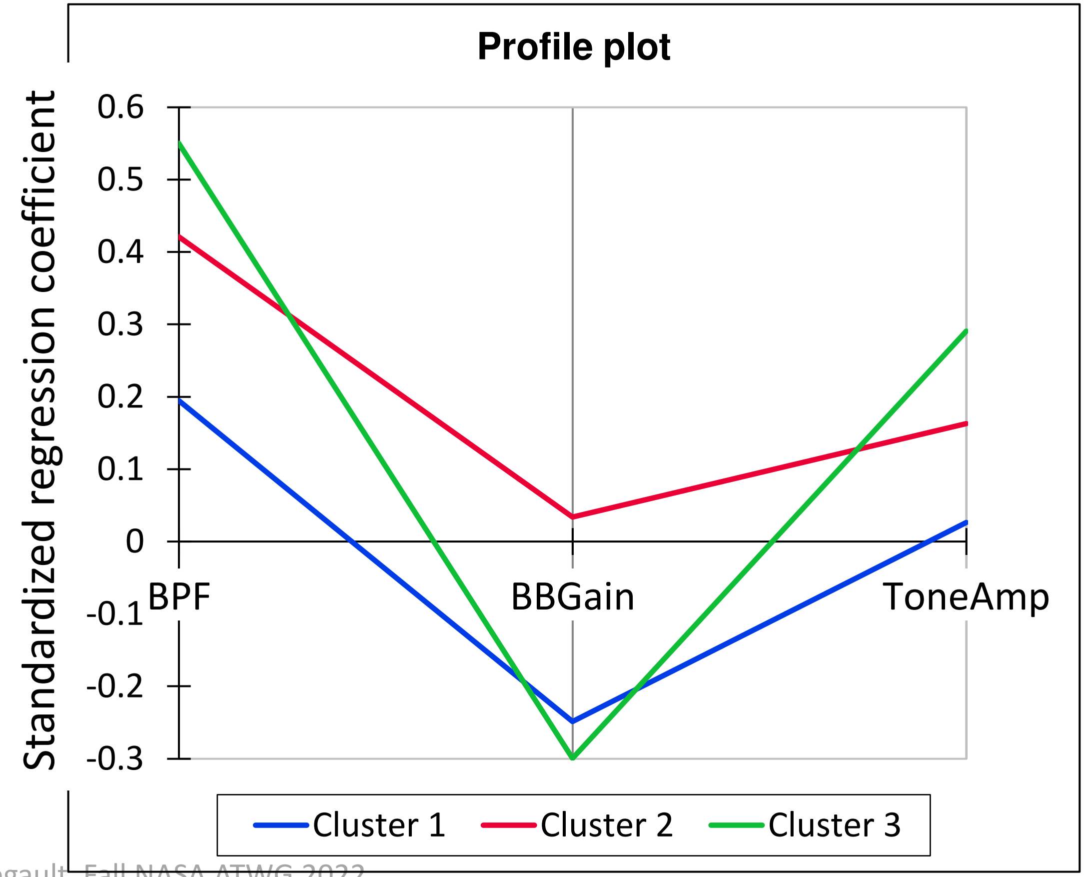
- **Example showing 3 out of 40 subjects who do not respond to changes in the SQ parameter *tonality* consistently** (due to other **covariates;** criteria shift; and/or scale use).



Agglomerative hierarchical clustering (AHC)

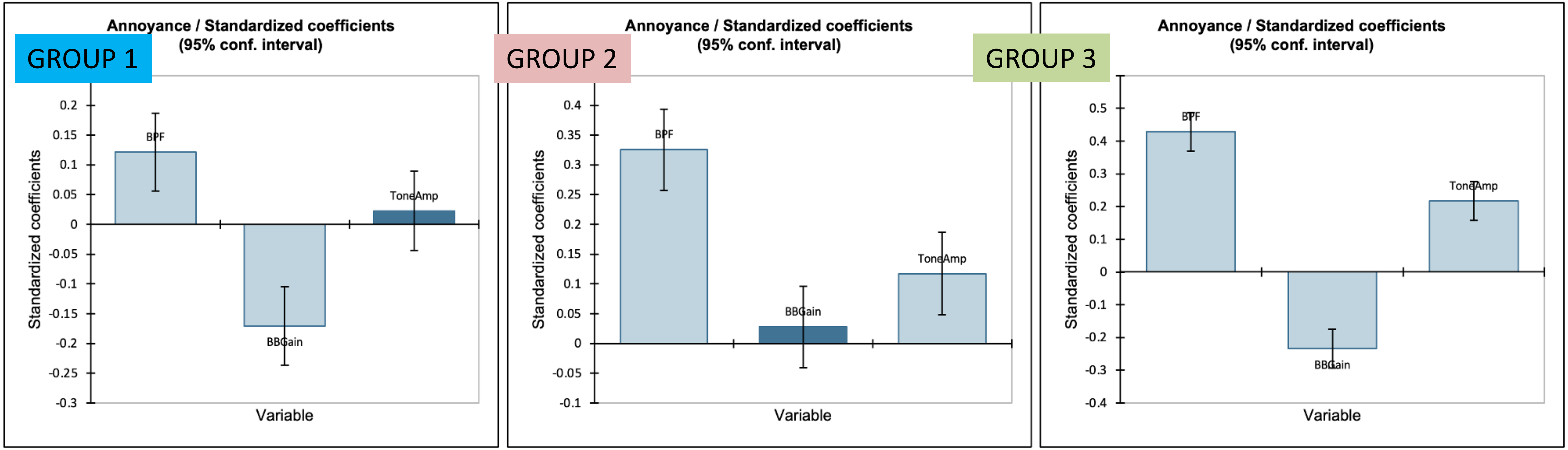
- **Synthesis data** (normalized coefficients) for BPF, Bbgain and ToneAmp fits a model with 40 subjects divided into **3 clusters** (subject groups) of 14, 12 and 14 members



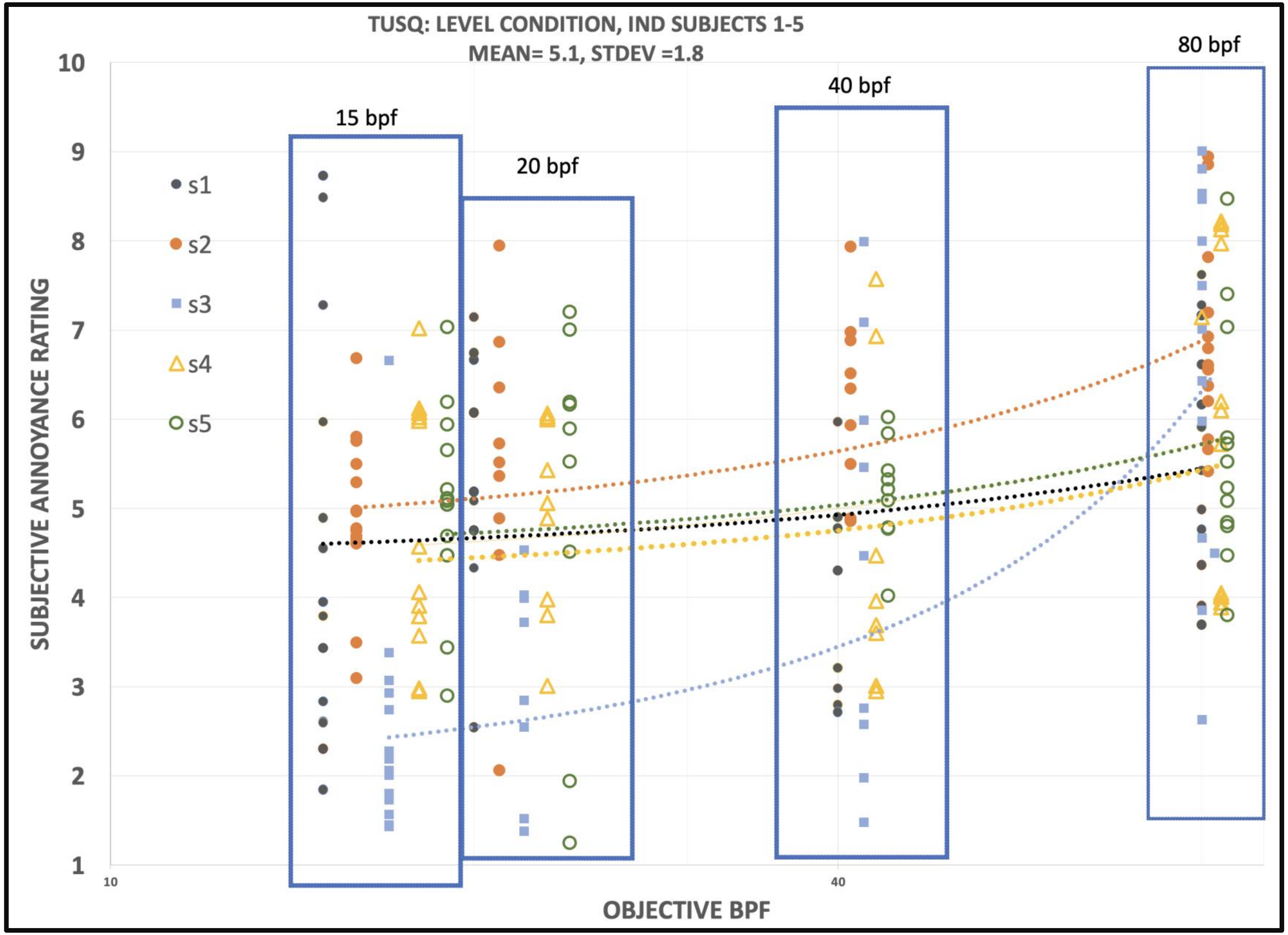


Initial data results: linear regression by cluster

- **Synthesis parameters**: normalized coefs., subject group 1 vs 2 vs 3
- All groups **significantly affected** by increase in BPF; **and….**
  - Group 1 also *inversely* sensitive to BBgain, but not to ToneAmp
  - Group 2 also sensitive to ToneAmp, but not BBgain
  - Group 3 also *inversely* sensitive to BBgain **and** sensitive to ToneAmp



Initial data results: need to determine effect size



- **5 of 40 subjects' data for BPF. While significant, the average effect size varies between subjects.**

- Large effect size for s2, s3
- Small effect size for s1, s4, s5

Disclaimers

- These results are a **PRELIMINARY** look at a subset of the total data (level flyover); no final conclusions should be drawn.
- Note that the subset of data for simulation of a 5-degree descent have a different sound characteristic, and likely a different subjective response.

Ongoing Work

- Further analyses are planned for these data:
  - Determination of the relative importance of the sound quality parameters.
  - Fitting models of psychoacoustic annoyance to the data.
  - Comparison of results with tests from other authors.
- Combination with datasets from other tests (both results of similar SQ tests, and results of other types of tests from this series).
- Further presentation and dissemination of the data.

Acknowledgements

Credit is due to many others for their support of this work:

- Kevin Shepherd, for guidance and expert opinion
- Erin Thomas, for human subject recruitment
- Aric Aumann, for support of the EER software
- Brian Tuttle, for support of the signal generation process
- LaRC Safety, Industrial Hygiene, Health Services, and others who helped guide this (in-person) test in the wake of COVID-19

This work is funded through the Revolutionary Vertical Lift Technology project at NASA. Thanks to Susan Gorton, Benny Lunsford, Noah Schiller, and others for the opportunity to pursue these questions.

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Tonality Perception Modeling Lessons Learned

Presented to Acoustics Technical Working Group

NASA Glenn Research Center

October 19, 2022

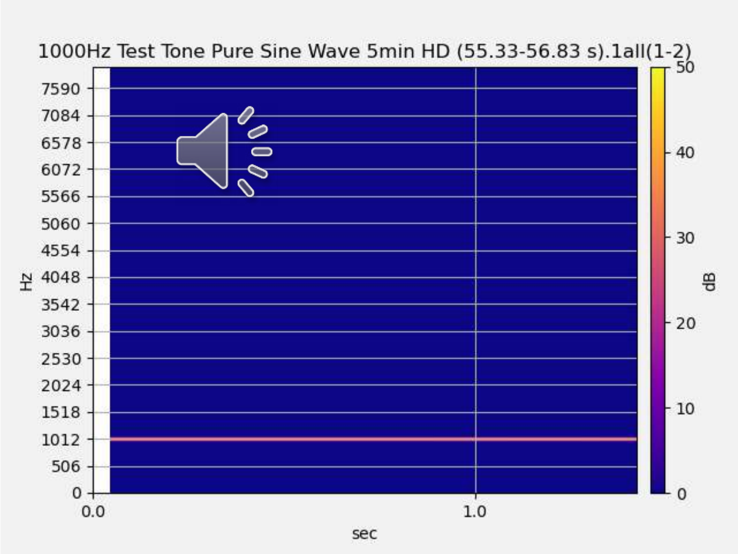
Charles Oppenheimer, PhD, PE
Oppenheimer Consulting, LLC

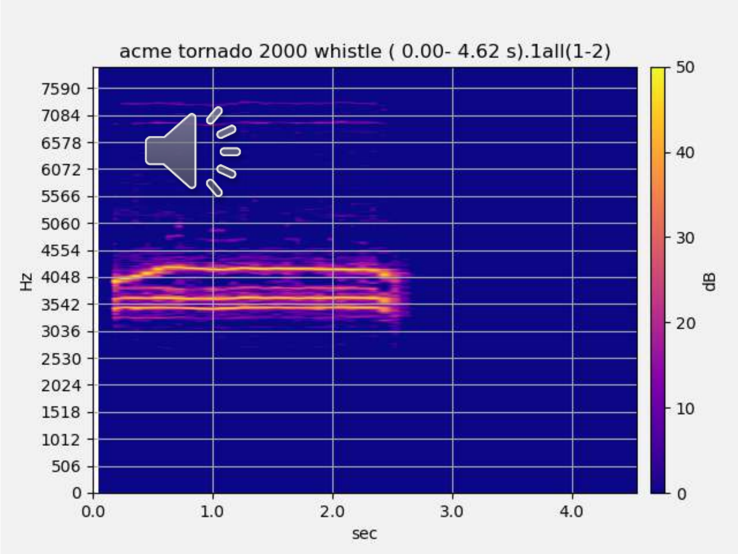
Oppenheimer Consulting, LLC

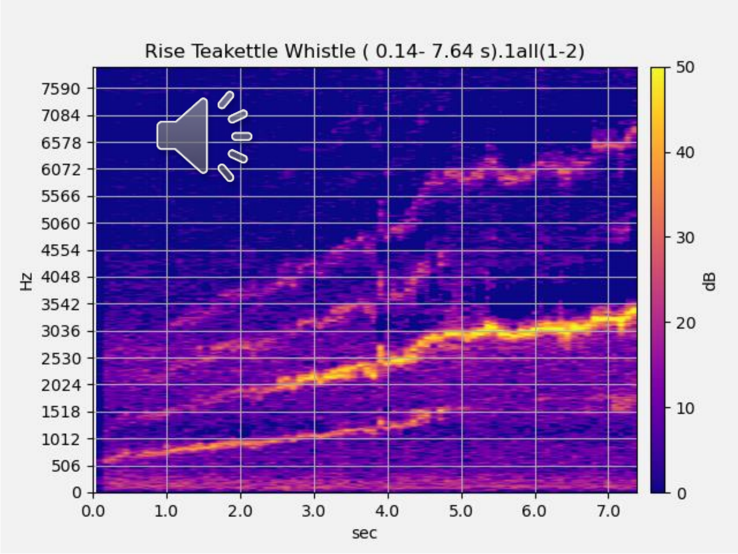
Tonality

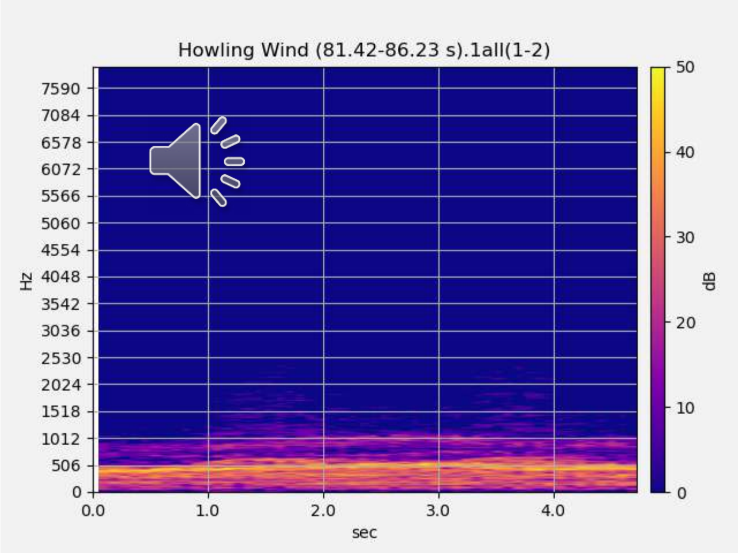
- Definition: a sound to which pitch may be associated
  - Hummable, musical
  - Not noise
- Causes
  - Pure and modulated tone(s)
  - Band limited noise…can be surprisingly broad
- Noticeable!
  - Alarms, beepers, sirens, etc.
- On-going investigation

Tonality Examples



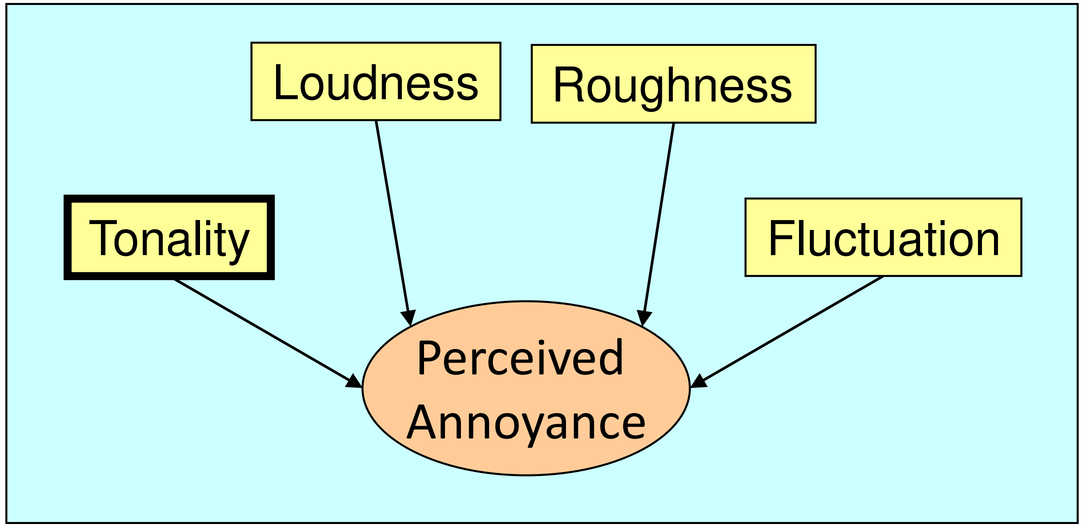






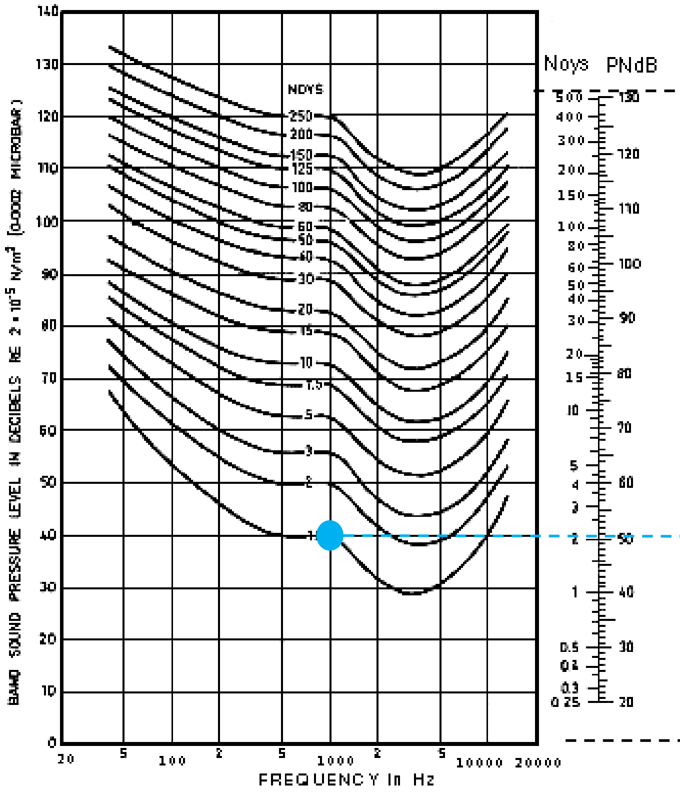
Program

- Several metrics
- Flyover and IT equipment sounds
- Validation
- Psychoacoustics

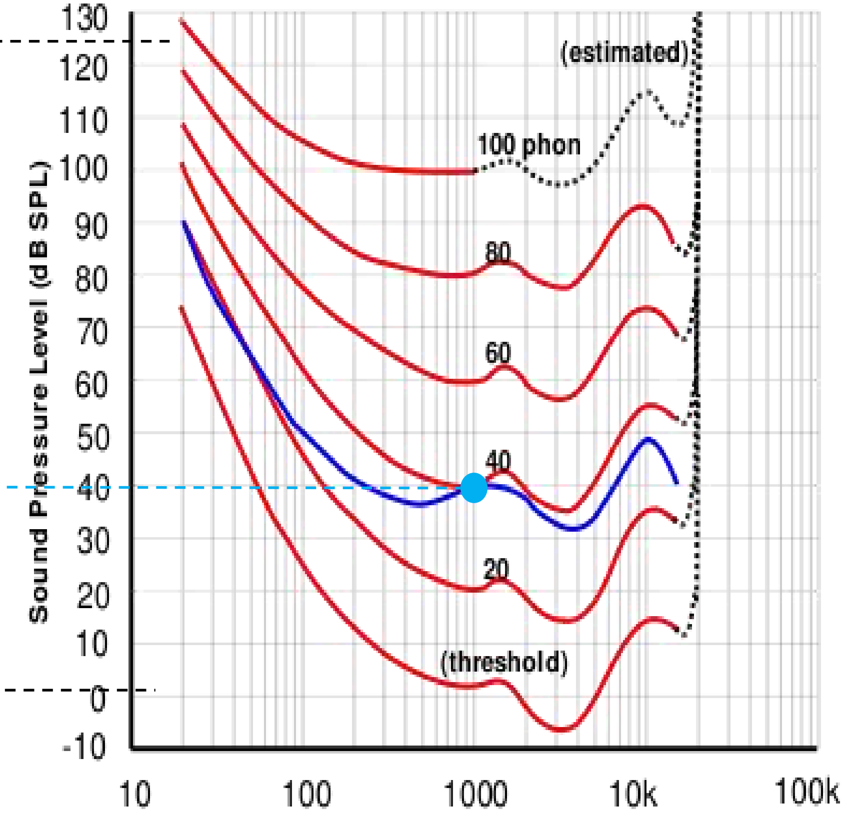


Perceived Noise Level
by 1/3 Octave Band spectrum

Equal Noys Contours



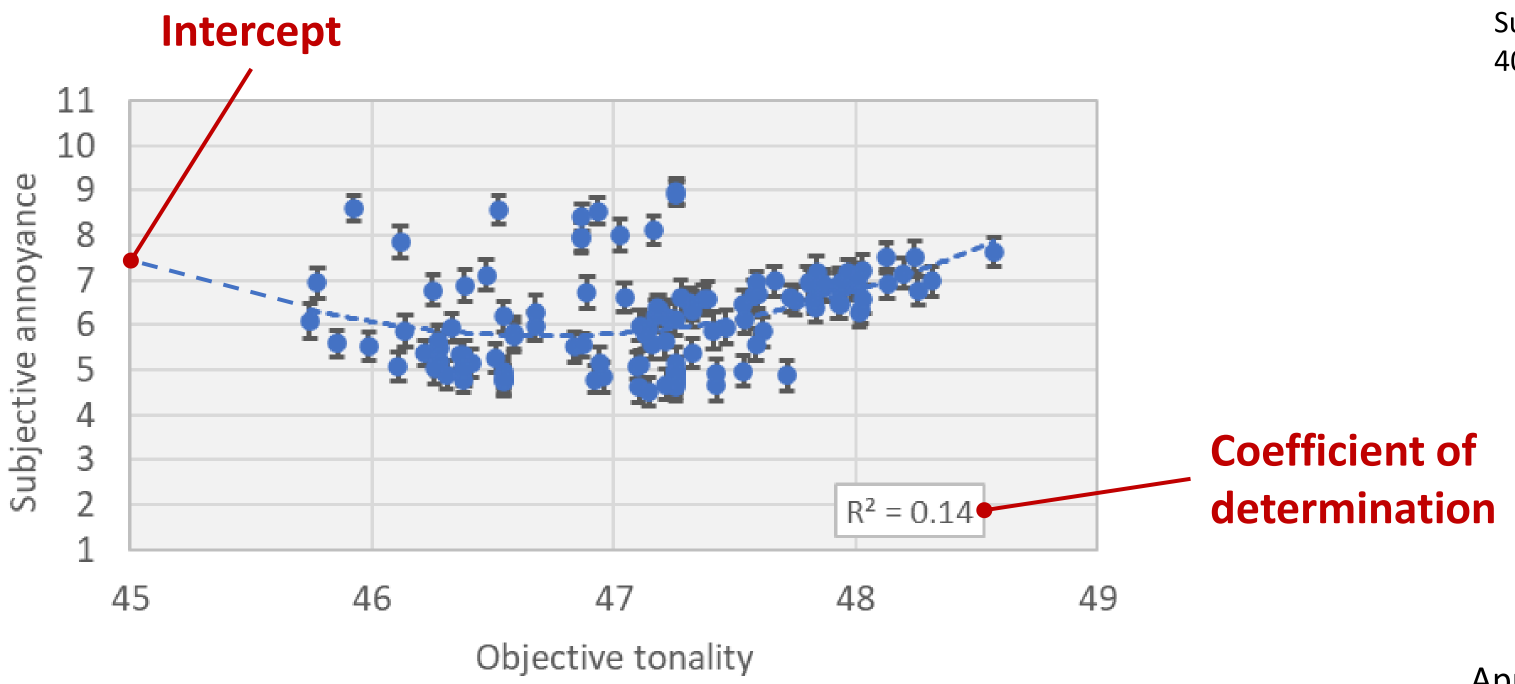
Equal Loudness Contours



Equal-loudness contours (red) (from ISO 226:2003 revision)
Original ISO standard shown (blue) for 40-phons

Subjective Annoyance vs. Approximate Perceived Noise Level

ROQM-1 data



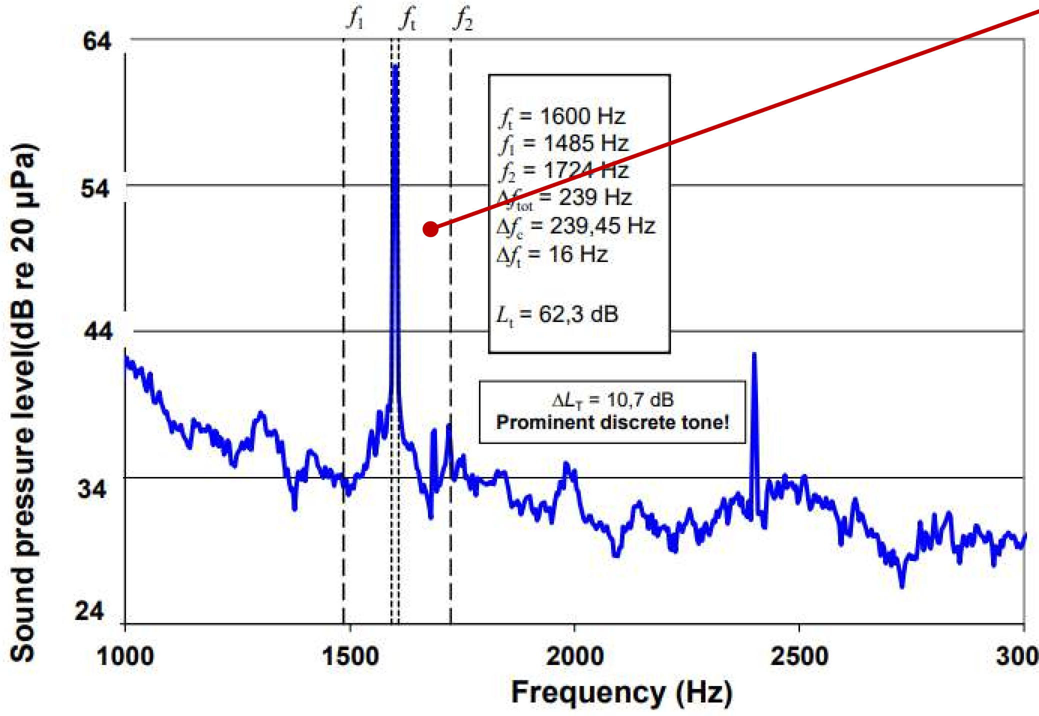
Subjective annoyance rated by 40 subjects on 1-11 scale

Approximation:
Loudness in lieu of Noys

- Room for improvement

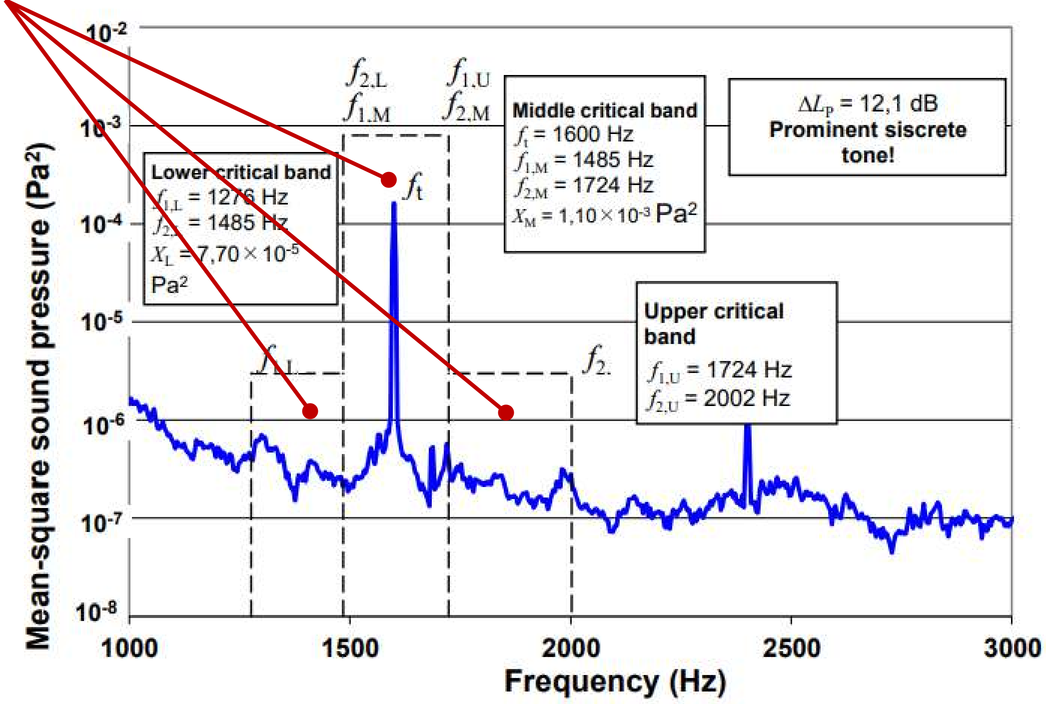
ECMA-418-1 TNR and PR

Tone-to-Noise Ratio (TNR)



Critical bands

Prominence Ratio (PR)



(Tone energy) / (Noise energy)

(Critical band energy) / (Mean adjacent CB Energy)

- Psychoacoustic critical bands applied to narrow band FFT spectra

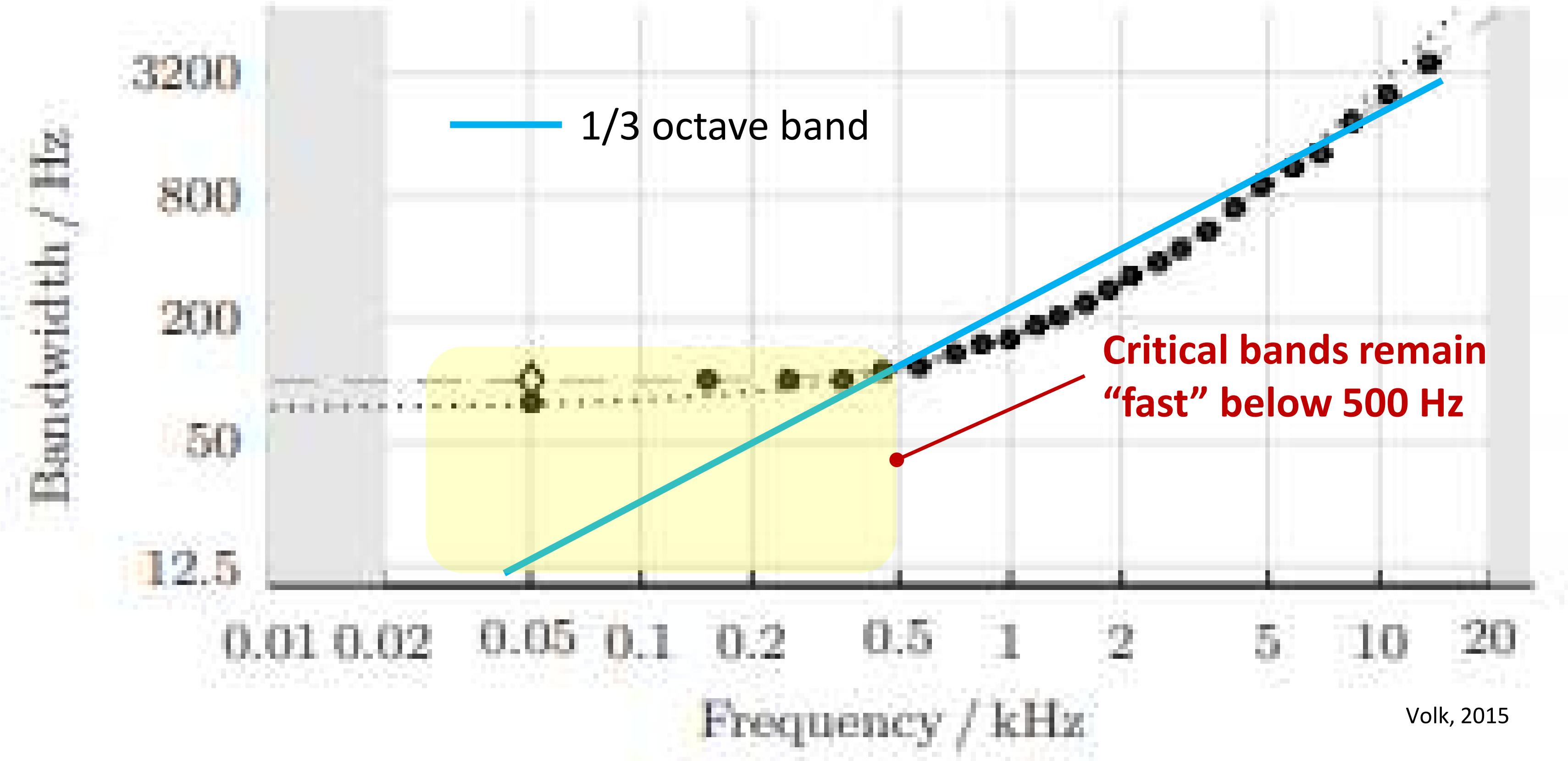
DIN 45681 Tonal Components

Table 1 — Tonal adjustment K_T as a function of ΔL

Difference ΔL dB	Tonal adjustment K_T dB
$\Delta L \leq 0$	0
$0 < \Delta L \leq 2$	1
$2 < \Delta L \leq 4$	2
$4 < \Delta L \leq 6$	3
$6 < \Delta L \leq 9$	4
$9 < \Delta L \leq 12$	5
$12 < \Delta L$	6

- Like ECMA-418-1 TNR with additional tonal adjustment

Critical Bandwidth



Volk, 2015

- Zwicker and Terhardt (1980, dashed gray contour)
- Traunmüller (1990, dotted black contour)
- Black dots: originally tabulated (Zwicker 1961)
- Unfilled diamond: update, Zwicker and Terhardt (1980)

Audiometric experiment

Tone as loud as Two Tones

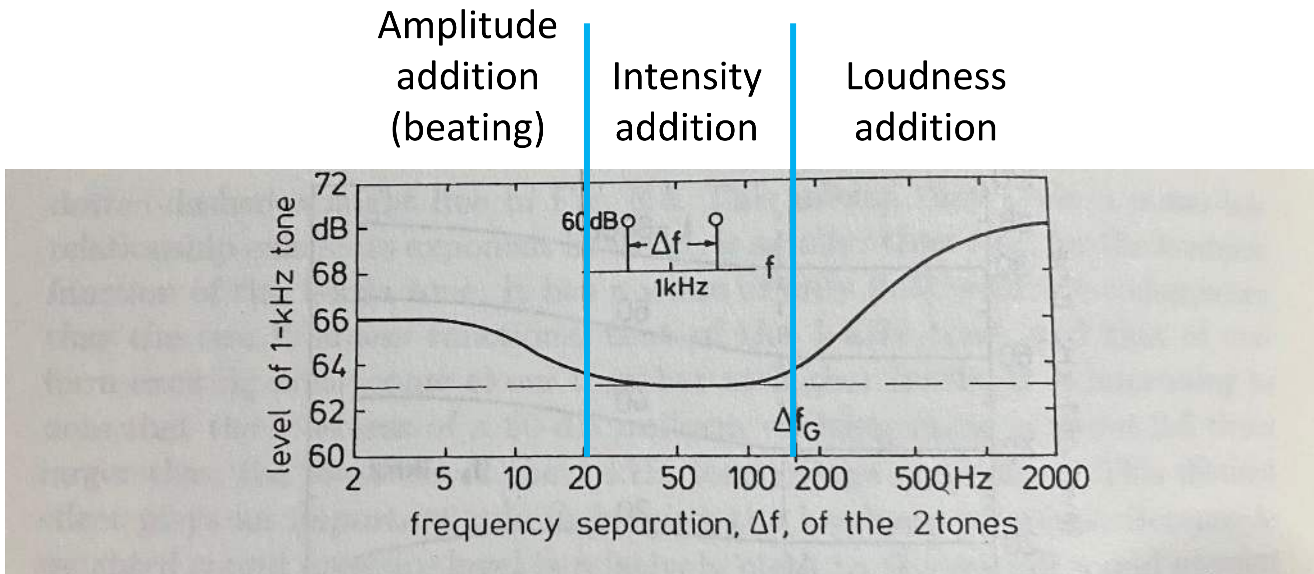
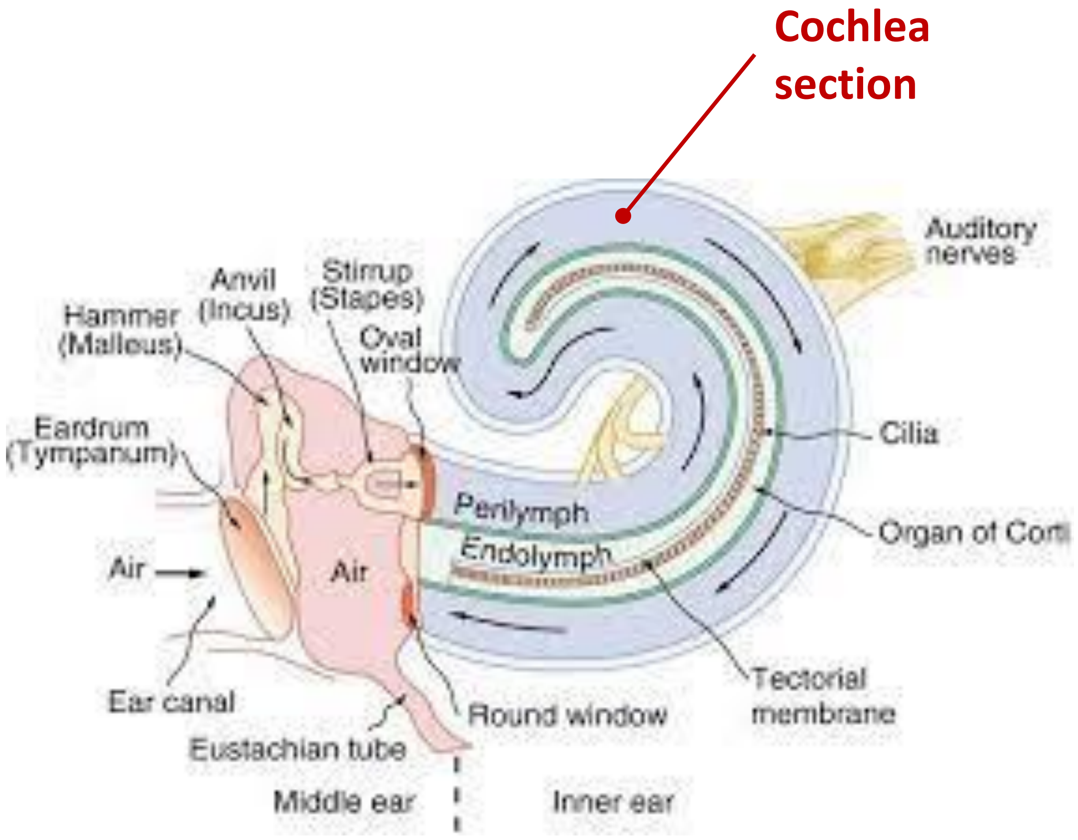


Fig. 8.8. Level of a 1-kHz tone judged as loud as a two-tone complex, each tone with 60 dB SPL and centred at 1 kHz, as a function of the frequency separation Δf of the two tones. The *broken line* indicates the overall level of the two tones

Psychoacoustics, Fastl and Zwicker



- Cochlea “filters in place”

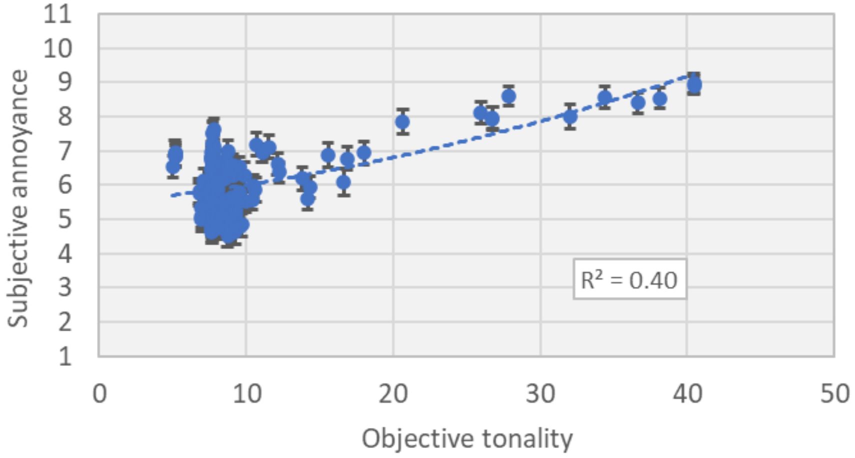
- Sound is perceived in Critical Bands

Subjective Annoyance vs. Tonal Predictions

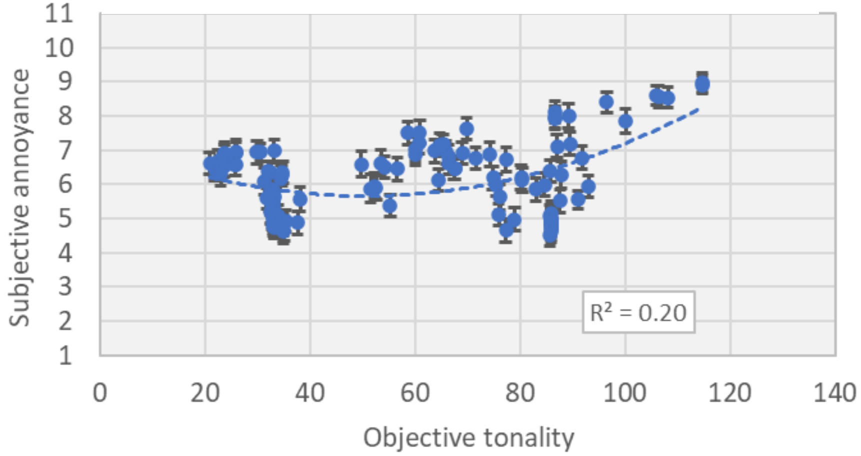
ROQM-1 data

Subjective annoyance rated by 40 subjects on 1-11 scale

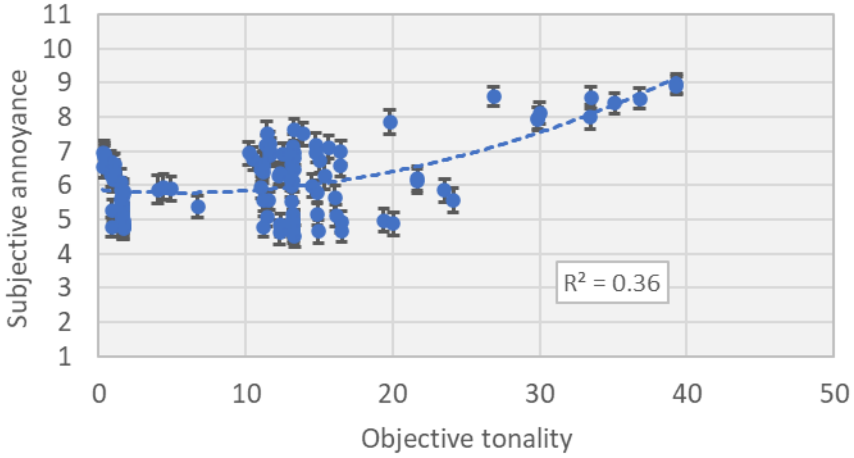
Prominence Ratio (ECMA-418-1)



Tonal Components (DIN 45681)

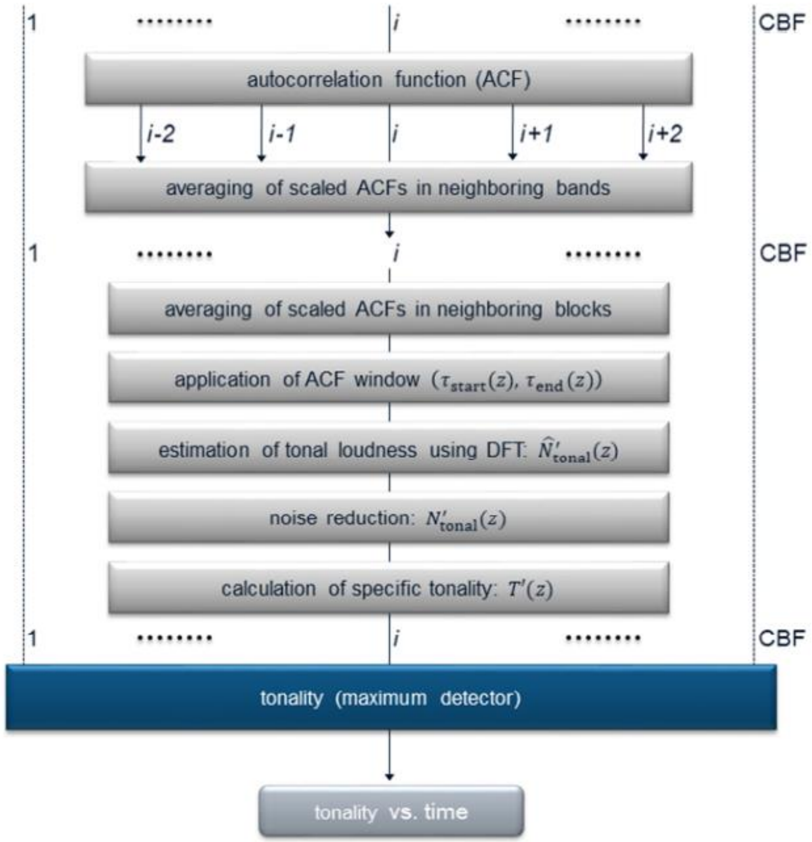


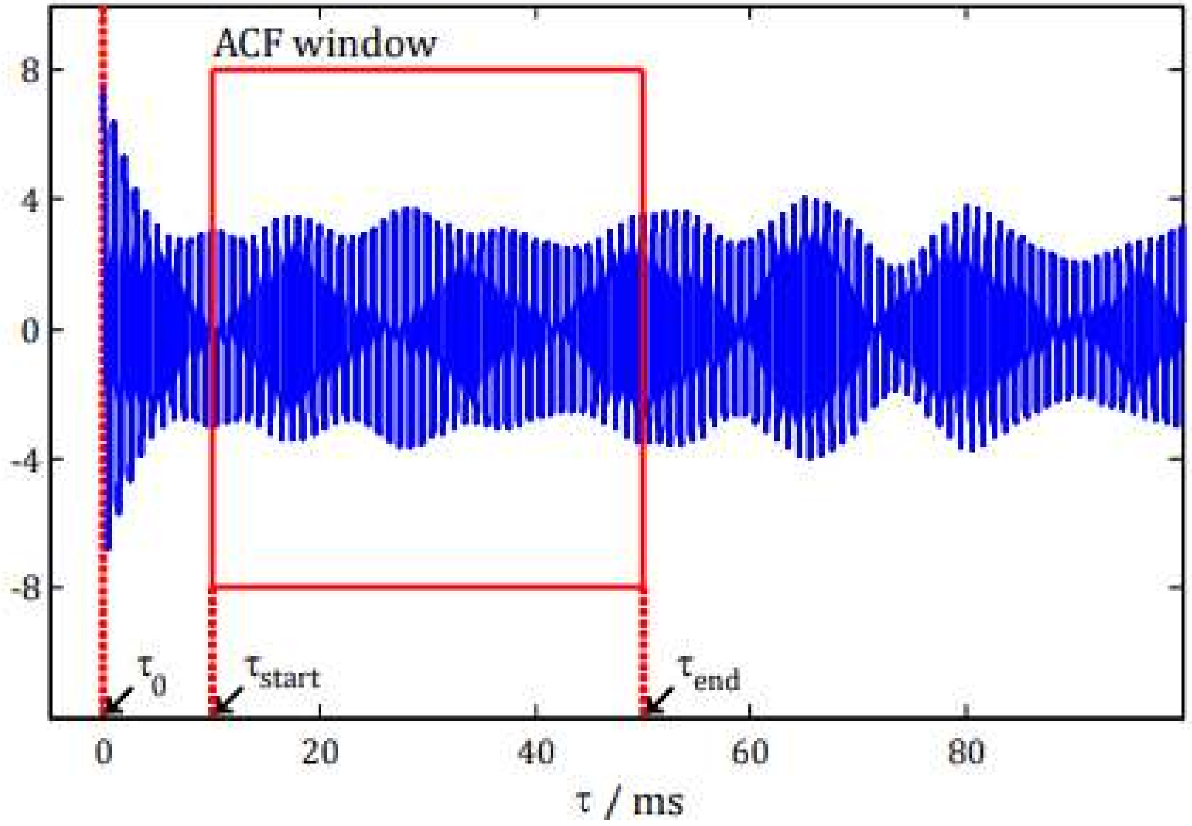
Tone-to-Noise Ratio (ECMA-418-1)



- Tonal predictions explain small portion of subjective annoyance
- Non-zero intercept points to other factors like roughness

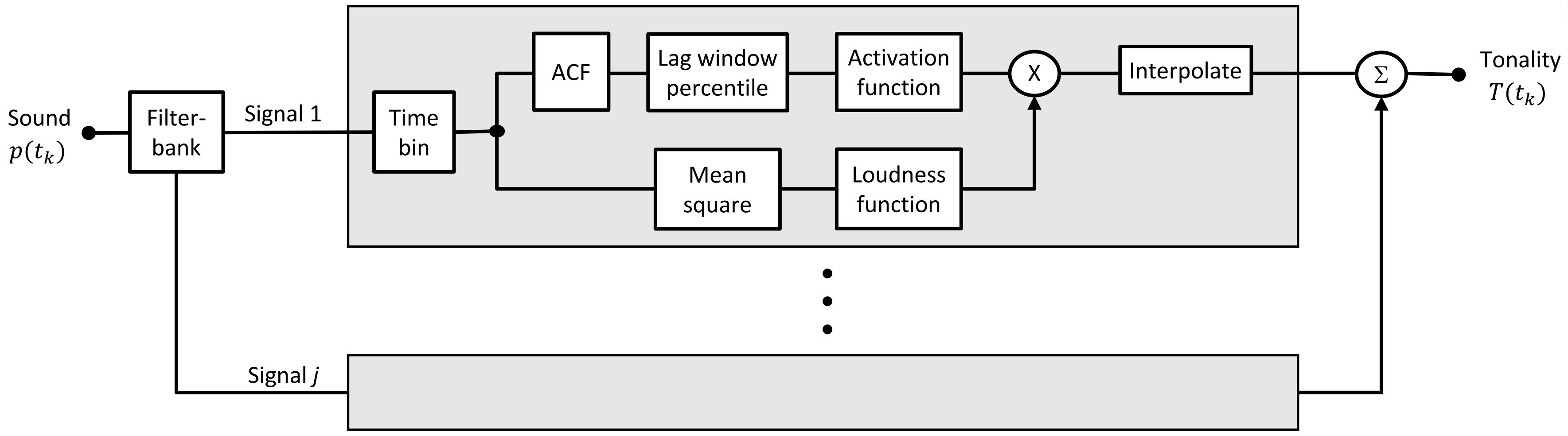
ECMA-74 / ECMA-418-2 Tonality

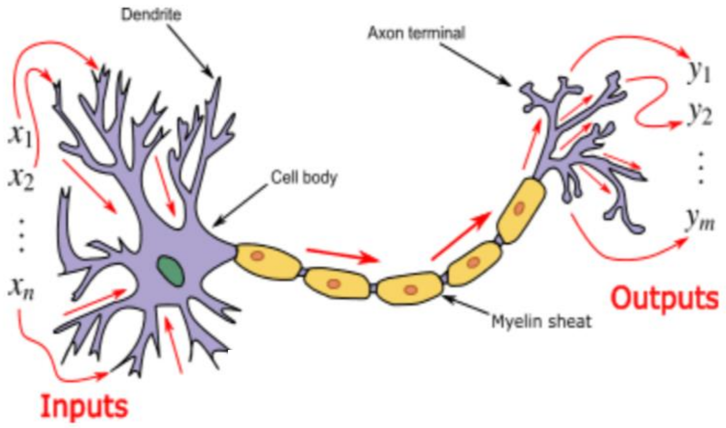


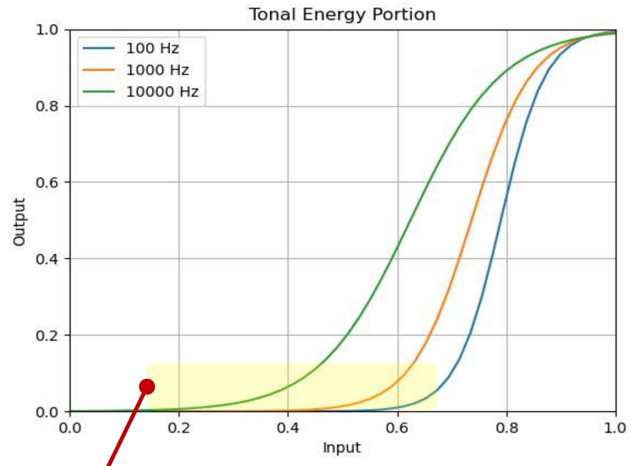


- Uses auto-correlation function (ACF)
- Window extracts tonal component

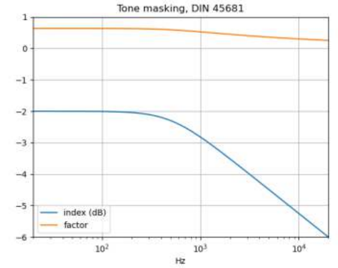
Unpublished Tonality







Sensitive to tone masking



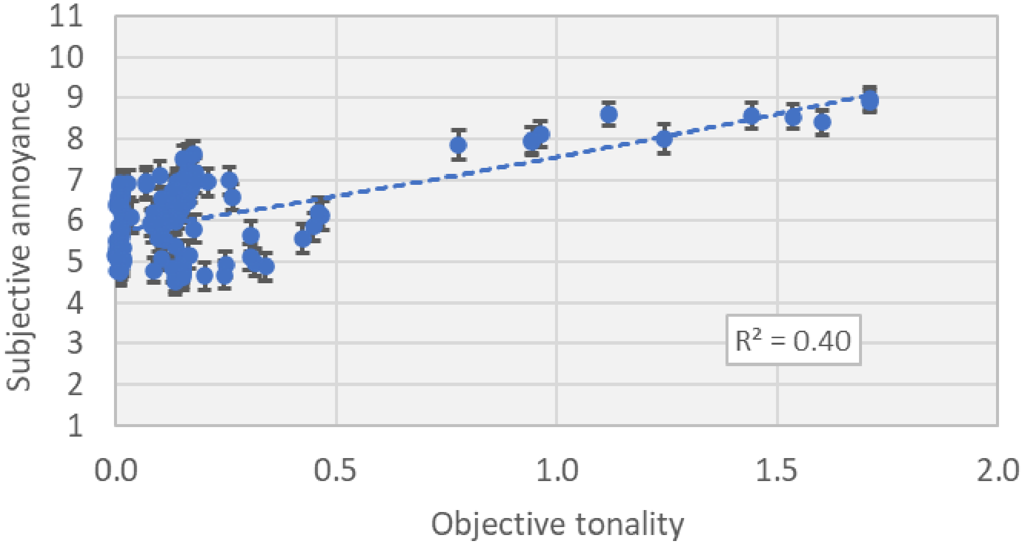
- Auto-correlation, activation, loudness
- Developed for IT equipment

Subjective Annoyance vs. Perceived Noise

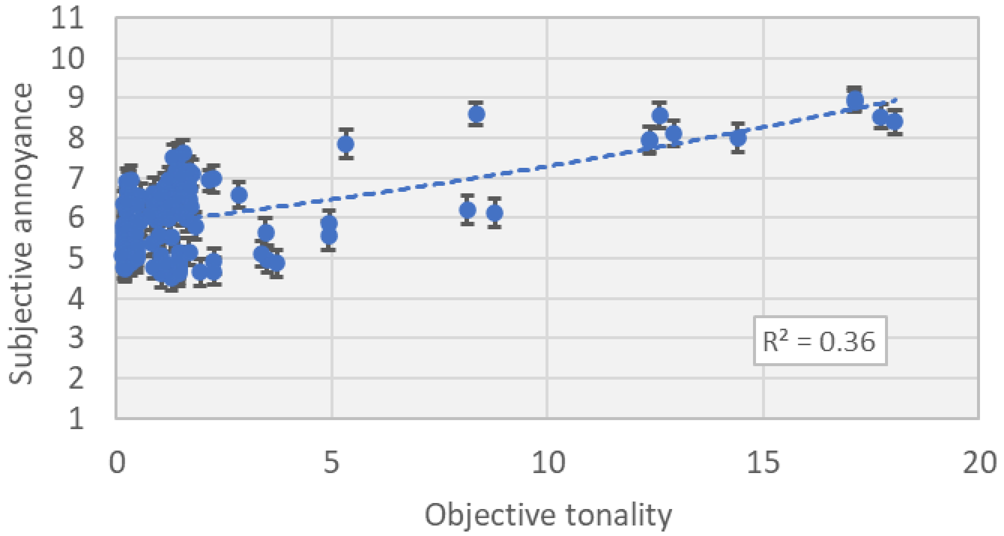
ROQM-1 data

Subjective annoyance rated by 40 subjects on 1-11 scale

Tonality (ECMA-74 & ECMA-418-2)



Tonality (unpublished)



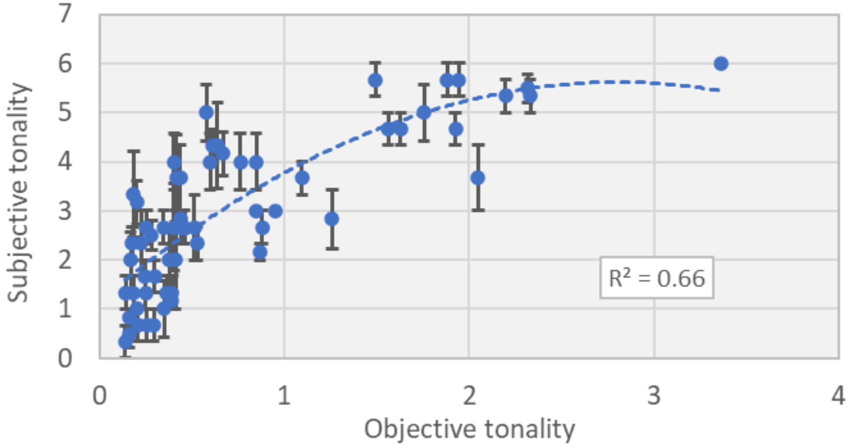
- About as good as Prominence Ratio (tonality predictions explain ~40% of subjective annoyance)
- Non-zero intercept points to other factors like roughness and fluctuation
- Subjective scores span less than half of the scoring range

Score	Meaning
0	none
1	very low
2	low
3	medium
4	high
5	very high
6	extreme

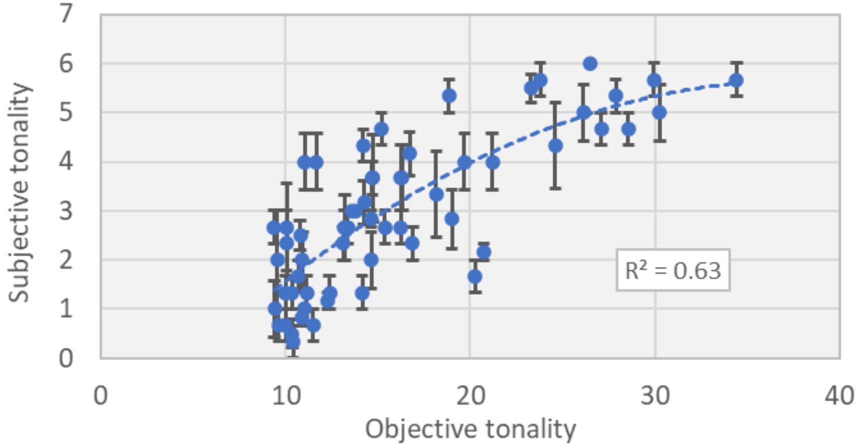
Subjective vs. Objective Tonality

IT Equipment data

Tonality (ECMA-74 & ECMA-418-2)

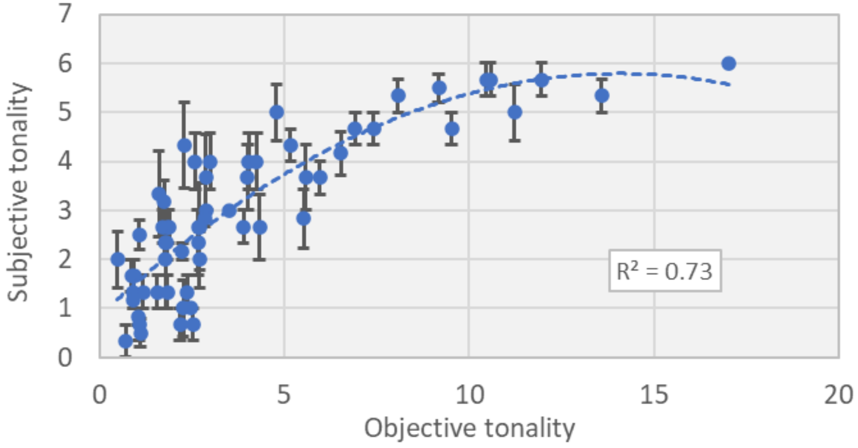


Prominence Ratio (ECMA-418-1)

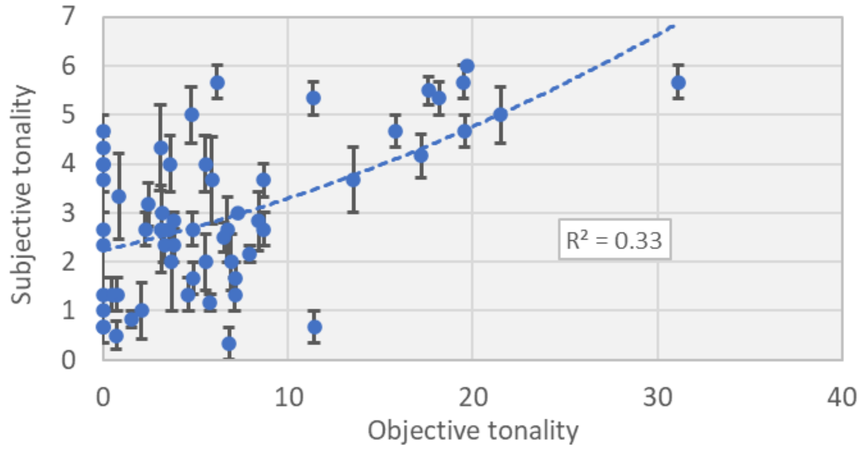


ACF based tonality metrics outperform FFT based metrics

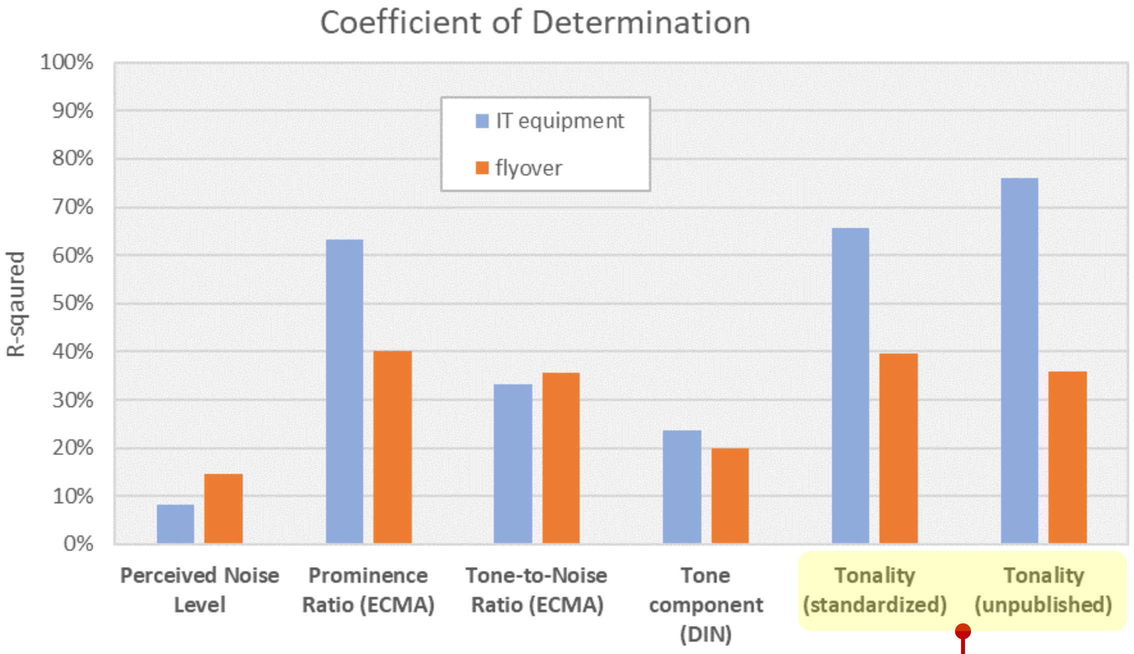
Tonality (unpublished)

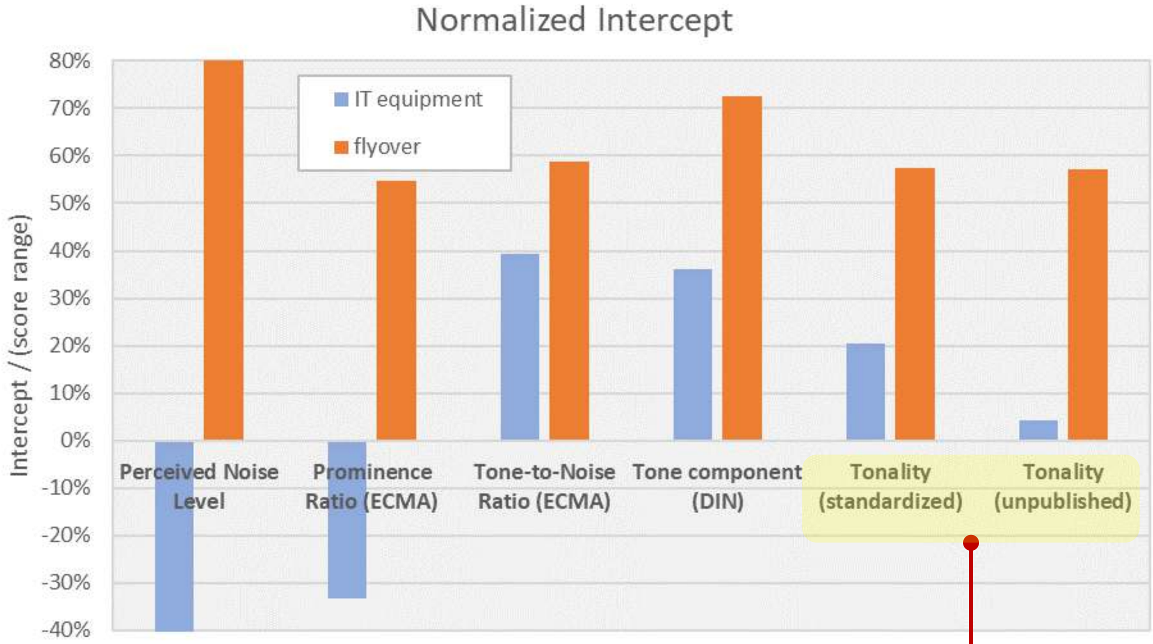


Tone-to-Noise Ratio (ECMA-418-1)



Tonality Model Performance Summary





Best performers

- Why do ACF based metrics outperform FFT based metrics?

Auditory Nerve(s) as Autocorrelator

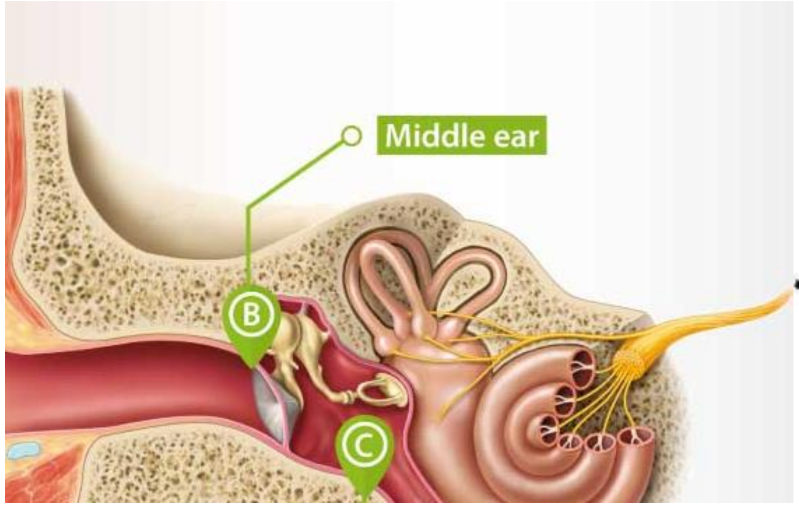
N_{ij} : contribution of j^{th} neuron of group i (quiescent 0, or firing 1)

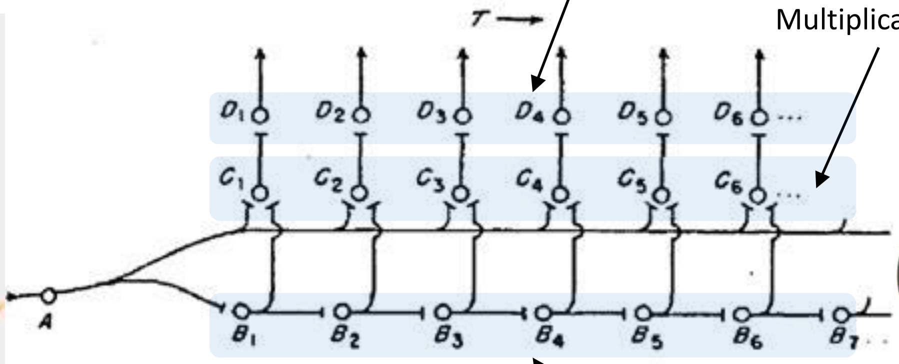
τ : synaptic delay

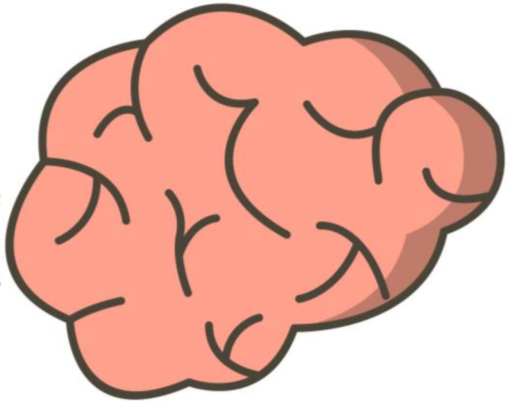
$$\varphi_{ij}(t, \tau) = \overline{N_{ij}(t)\, N_{ij}\,(t - \tau)}$$

Time integration/averaging

Multiplication



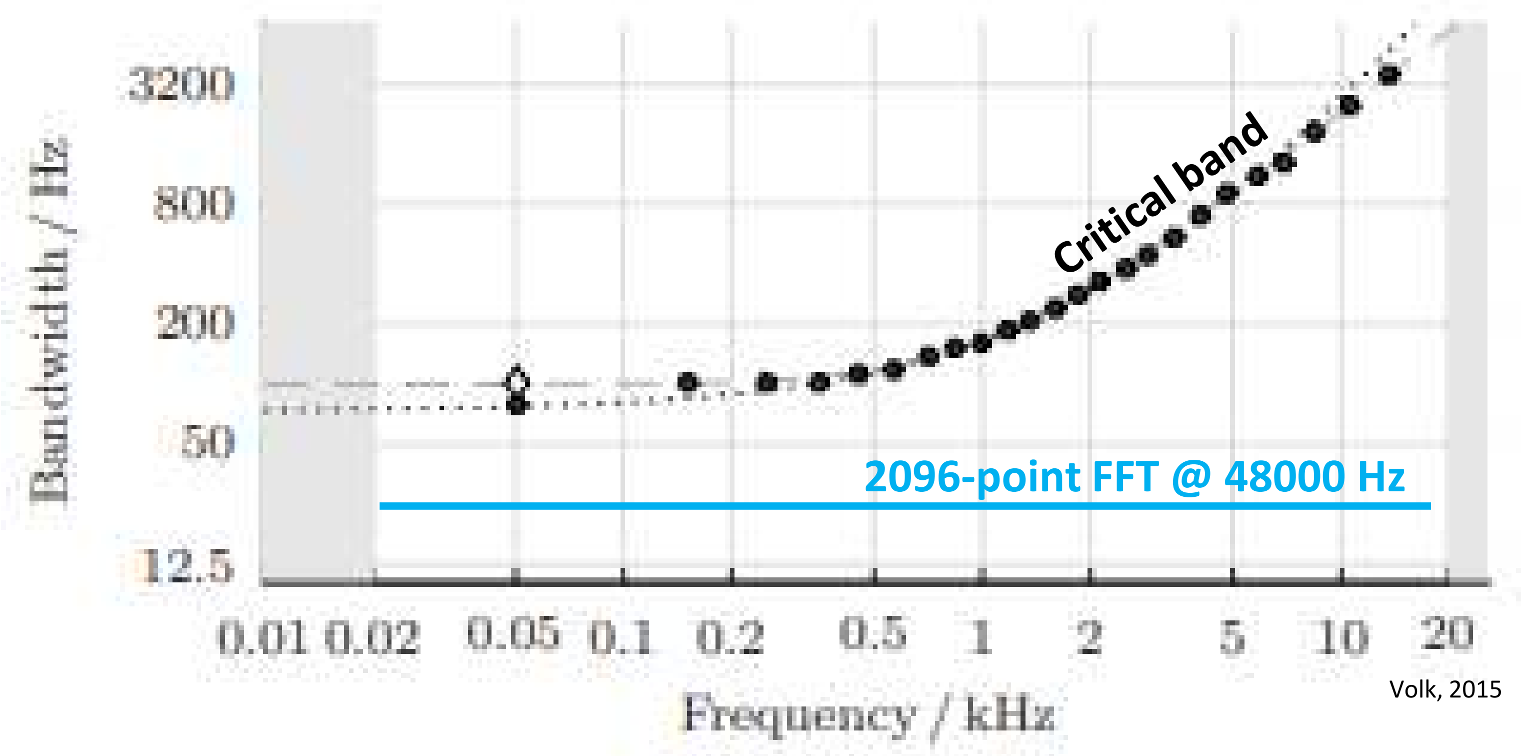




Delay

"A Duplex Theory of Pitch Perception" Licklider 1951

Filter Bandwidth

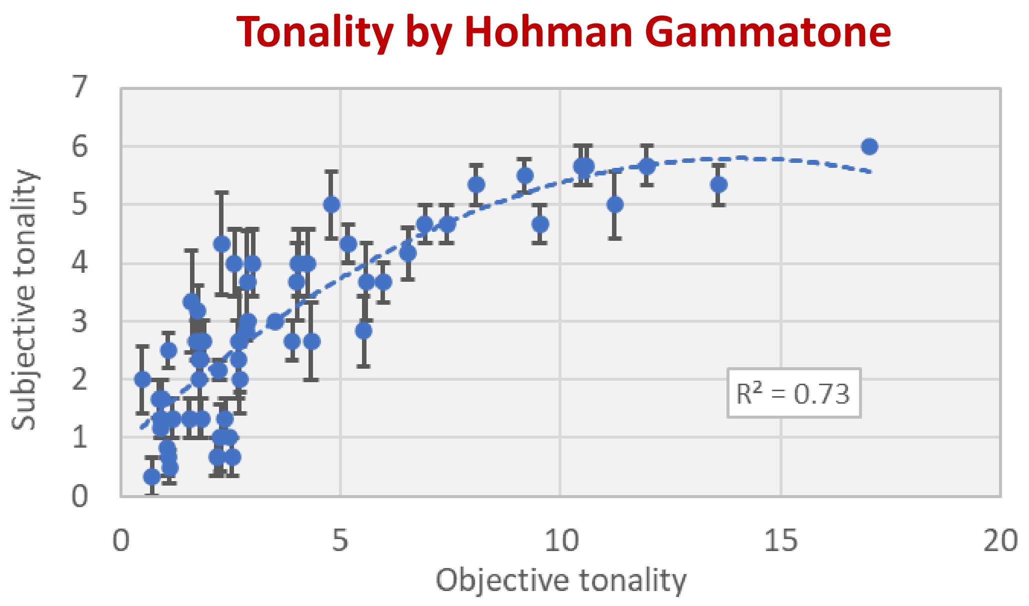


- FFT bandwidth poorly represents perceptual sound aggregation and responsiveness

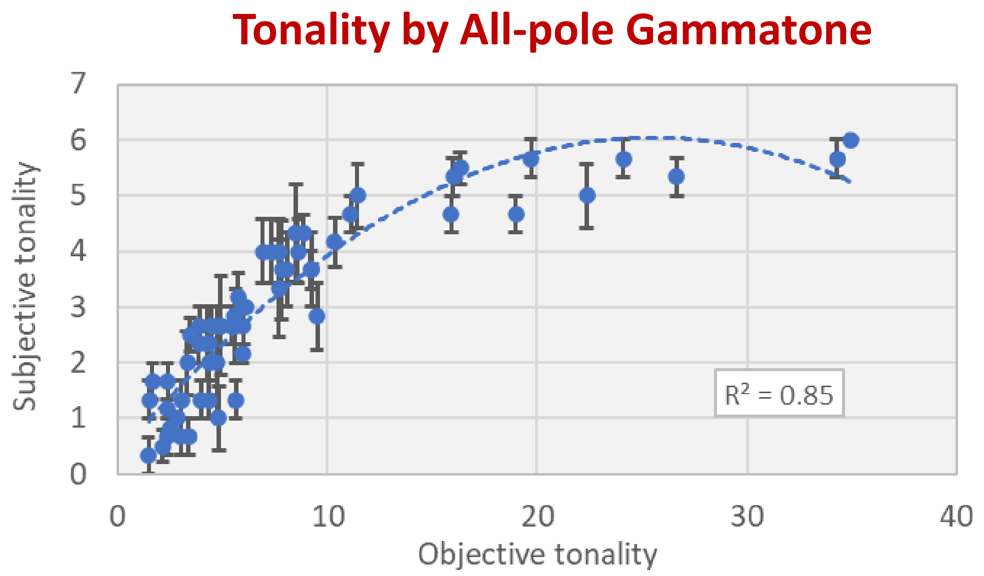
Subjective vs. Objective Tonality

IT Equipment data

Score	Meaning
0	none
1	very low
2	low
3	medium
4	high
5	very high
6	extreme



V. Hohmann, Frequency analysis and synthesis using a Gammatone filterbank, May 2002, Acta Acustica 88(3):433-442

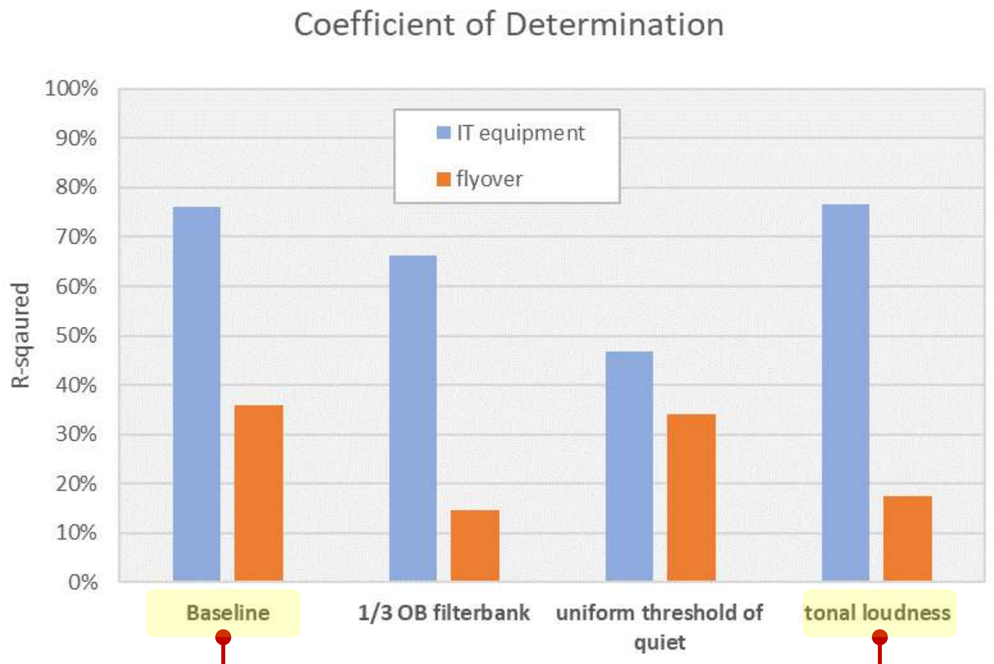


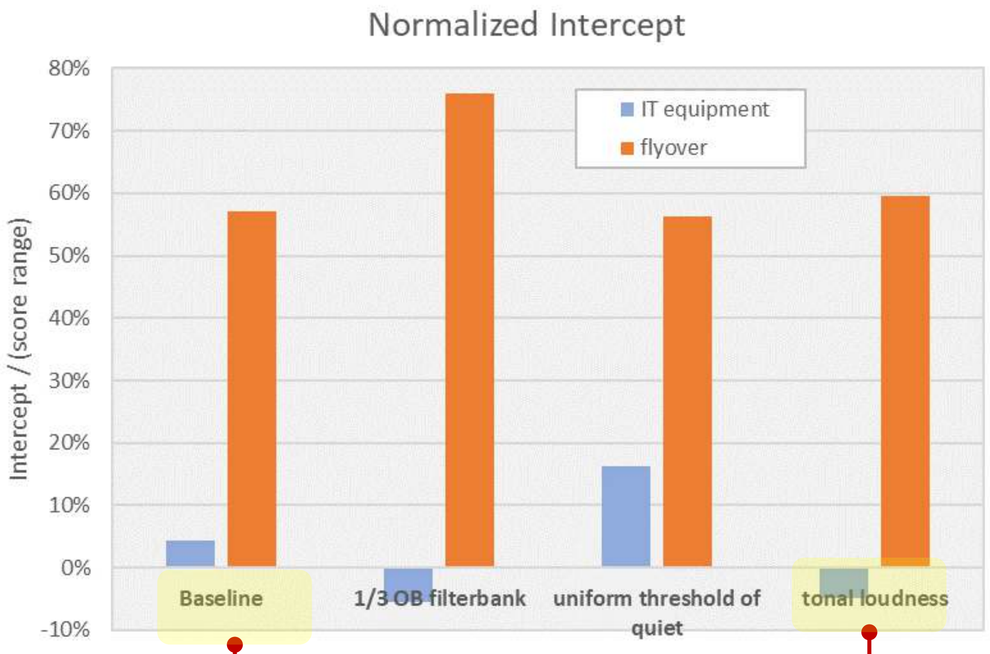
R. F. Lyon, A. G. Katsiamis, and E. M. Drakakis, History and future of auditory filter models, Proc Intl Symp Circuits and Systems, 3809-3812, 2010

- Filter details matter

What matters?

Feature	Baseline	Alternate
Filterbank	Gammatone	1/3 octave band
Threshold of quiet	ISO 226 (frequency dependent)	Uniform, 1 dB SPL
Metric	Loudness-weighted tonal energy portion	Tonal loudness





Top contenders

Tonality Perception Modeling Lessons learned

- Tonality influences, does not control, perceived flyover noise annoyance (confirms previous findings)
- ROQM-1 mean SQ scores span half the scoring range
- ACF-based tonality metrics outperform Perceived Noise Level and standardized FFT-based metrics
- Physiological emulation matters: filterbank bandwidth & shape, ACF, threshold of quiet
- Loudness-weighted tonal energy portion and tonal loudness perform comparably

Recommendations

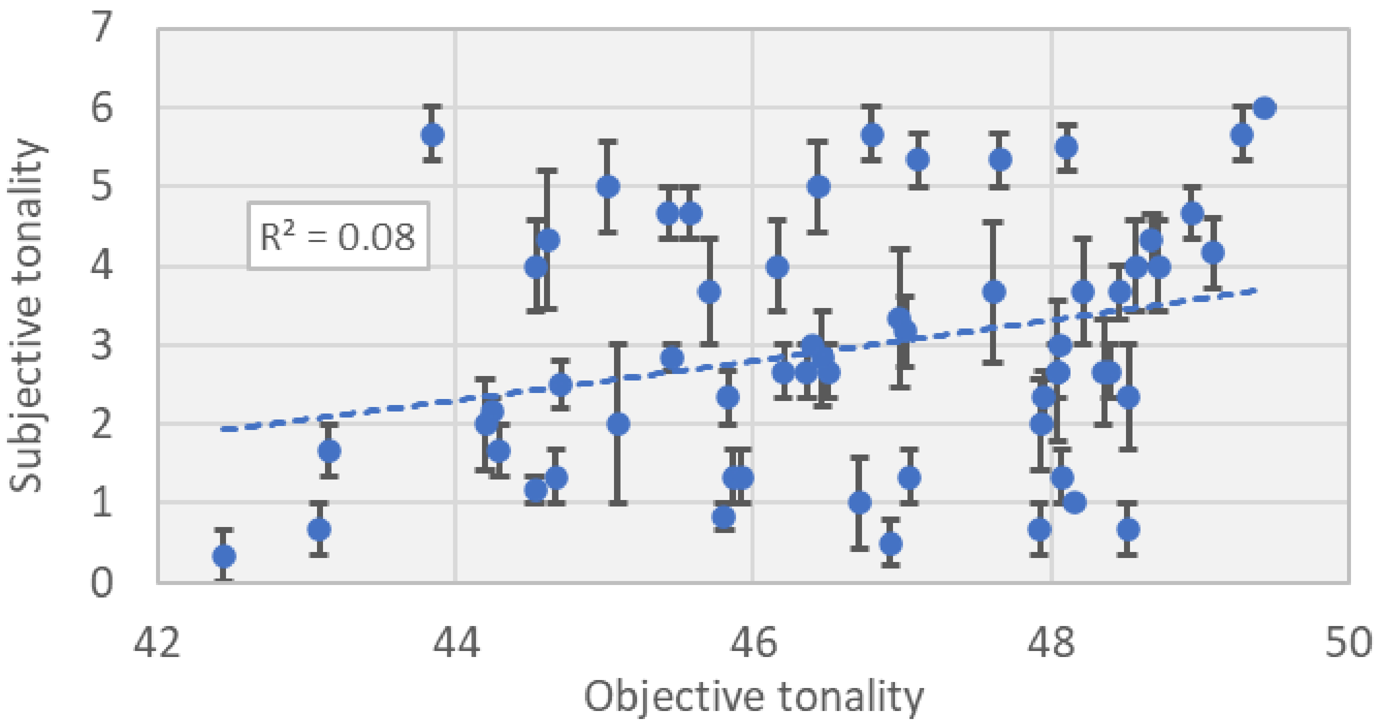
- Sharpen SQ trials
  - Select sounds to span full scoring range
  - Re-visit scoring scale
  - Expand scope to include roughness (especially) and fluctuation as well as perceived annoyance
- Continue metric development
  - Both individual (tonality, roughness, fluctuation) and aggregate (perceived annoyance)
  - Refine auditory filterbank
  - Involve additional flyover sounds
  - Resolve: weighted tonal energy vs. tonal loudness…implications for perceived annoyance
  - Analogous investigation of roughness, fluctuation

Extras

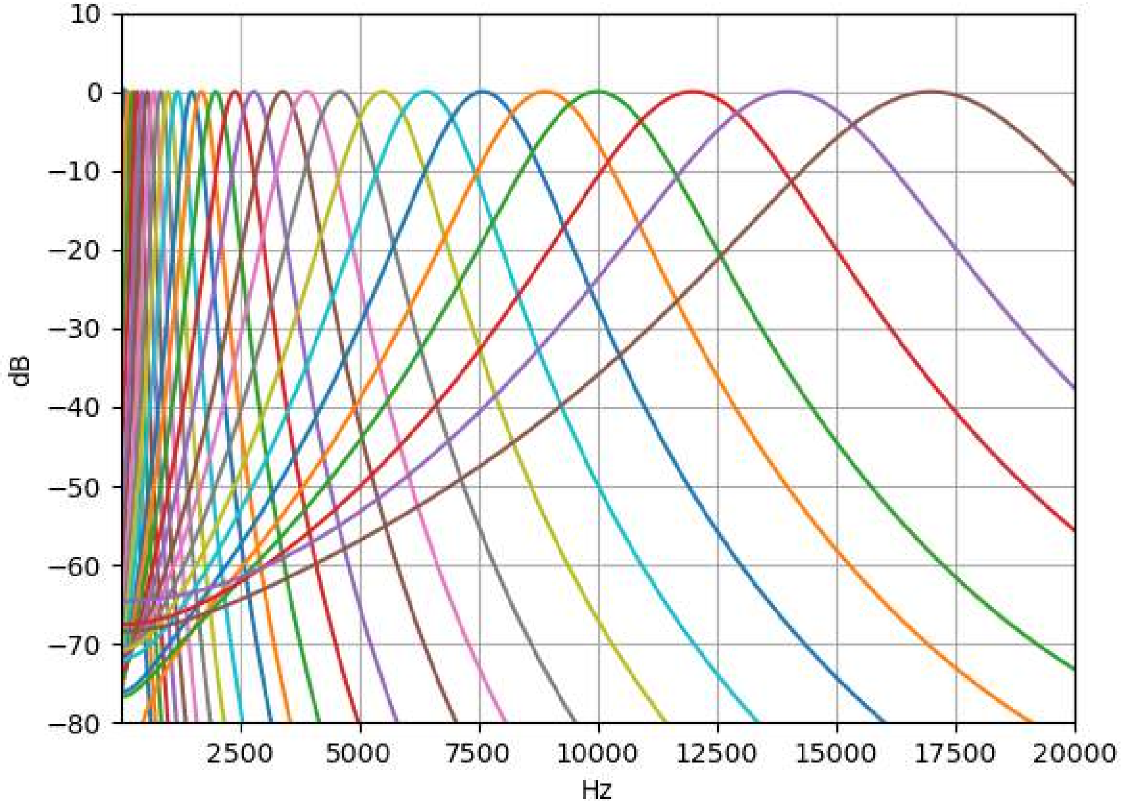
Subjective vs. Objective Tonality

IT Equipment data

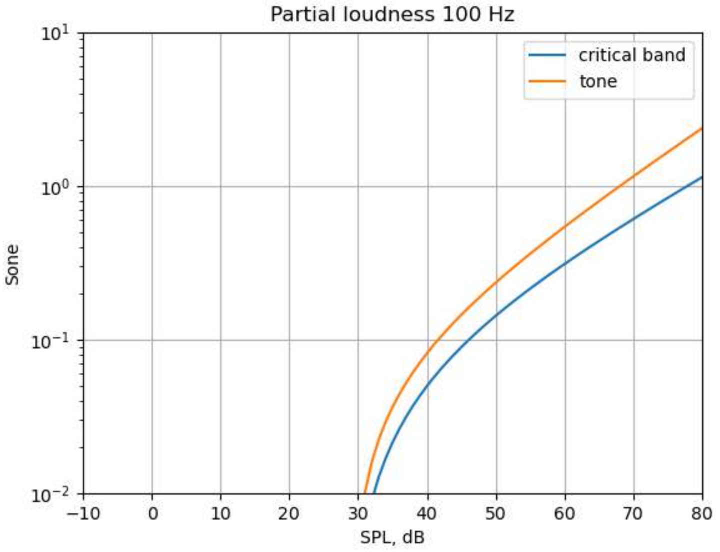
Score	Meaning
0	none
1	very low
2	low
3	medium
4	high
5	very high
6	extreme

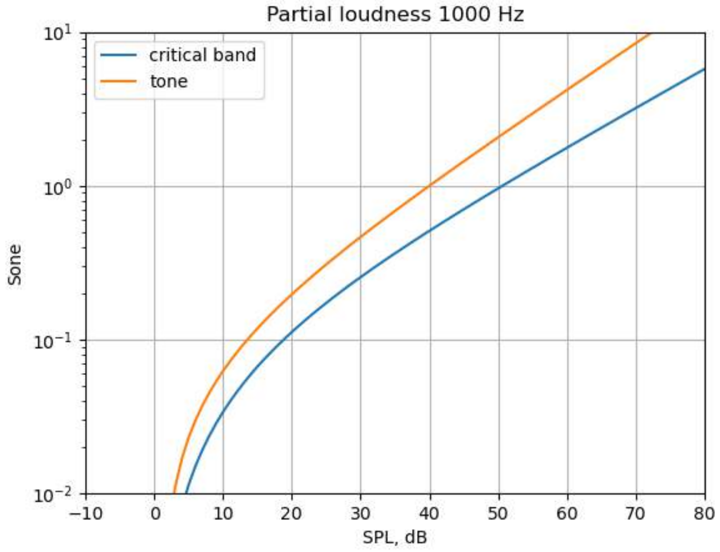


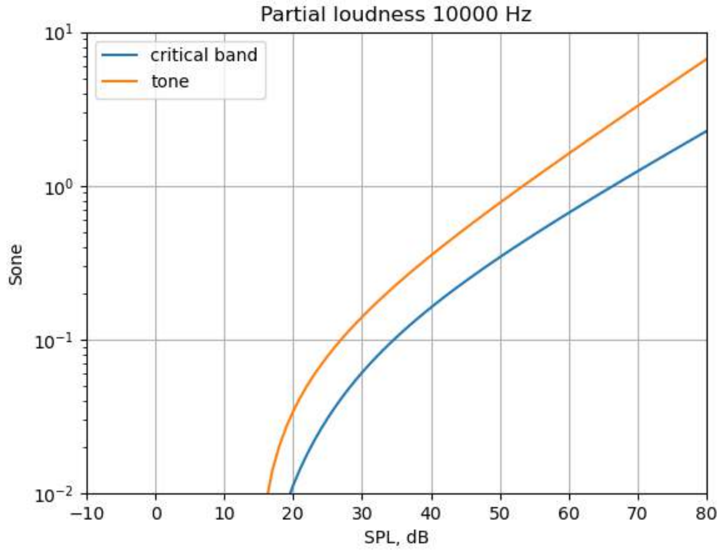
Gammatone Filterbank



Tone and Critical Band Loudness







- More sensitivity to tones than noise

Wednesday Afternoon

Status of UAM Proprotor Design Validation Campaign: Available Data and Computational Tools

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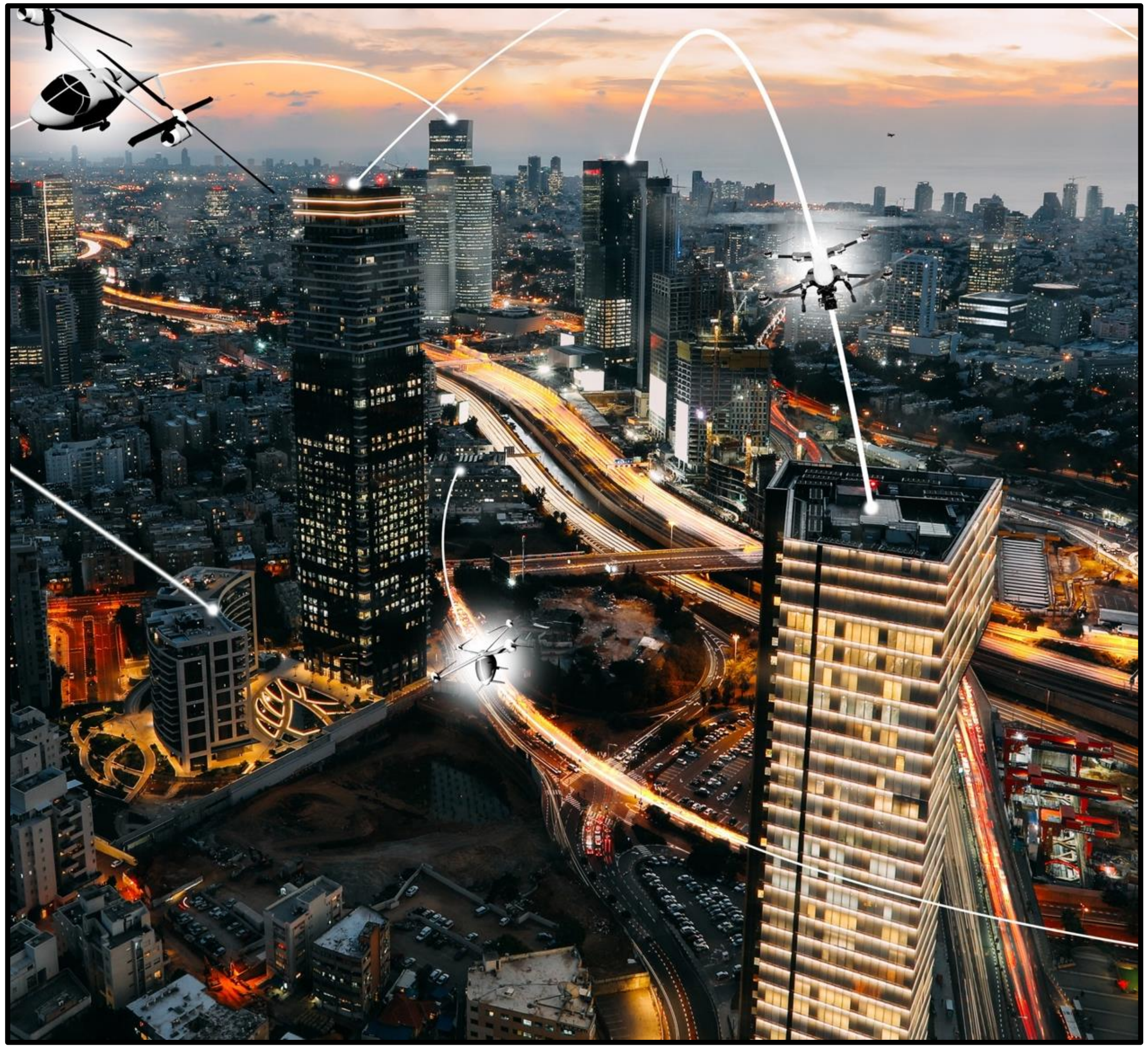
Acknowledgments:
Transformational Tools and Technologies (TTT) project

Advanced Air Mobility (AAM) Challenge

- Opportunities of AAM vehicles are numerous
  - Large-sized vehicles for intraregional transportation
  - Medium-sized vehicles for urban and rural applications (UAM)
  - Small-sized vehicles for package deliveries and surveillance (sUAS)
- AAM challenges aeronautics community with unique challenges in performance and community impact
  - Safety
  - Reliability
  - Automation
  - Community impact (noise)



AAM Challenge

- Traditional large transport vehicles limit design opportunities
  - Tube and wing
  - Not the case with hybrid wing or TTBW designs
- Large helicopters and multirotor vehicles do have design opportunities but are limited also
  - Traditional main/tail configurations
  - X-rotors, tandem, etc.
- AAM vehicles offer significantly more design opportunities
  - Rotor count, placement, blade count, rotation direction
  - Wing design and placement, installation effects
  - Blade shape and rotor sizing
- AAM vehicles also have significantly different flight mission requirements
- Offers opportunity to design from the ground up

➢ **What can our design tools predict?**

➢ **What do our design tools miss?**
  - Does validation data exist?
  - What about scale? Full vehicle vs component?

- Silva, C. and Johnson, W., "Practical Conceptual Design of Quieter Urban VTOL Aircraft," Vertical Flight Society's 77th Annual Forum & Technology Display, Vertical Flight Society, Fairfax, VA, USA, 2021

Outline

- **Validation of design optimization for AAM proprotors**
  - **Experimental validation process**
  - **Multidisciplinary design optimization procedure**
- **Update on available tools**

➢ **Isolated proprotor campaign**

➢ **Installed proprotor campaign**

- **Update on available UNWG SG1 Datasets**
  - **Previously 1, now 2, soon to be 4**
- **Conclusions**

Image credit: RVLT

Experimental Design Validation Campaign

Measured
Background
Predictions

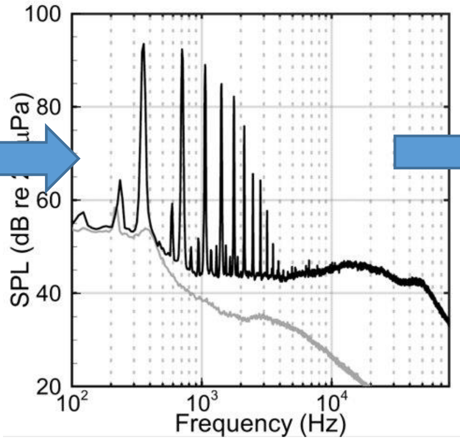
Baseline Geometry

$$\phi = \mathrm{TAN}^{-1}\left(\frac{P}{\pi D}\frac{R}{r}\right)$$

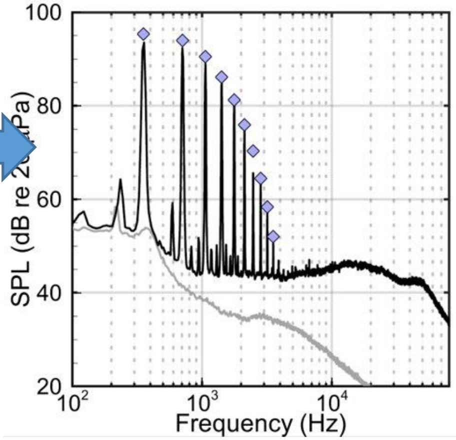
Parameter	Value
c, in. (mm)	1.5 (38.1)
P, in. (mm)	16.0 (406.4)
D_p, in. (mm)	24.0 (609.6)

Baseline Tunnel Entry

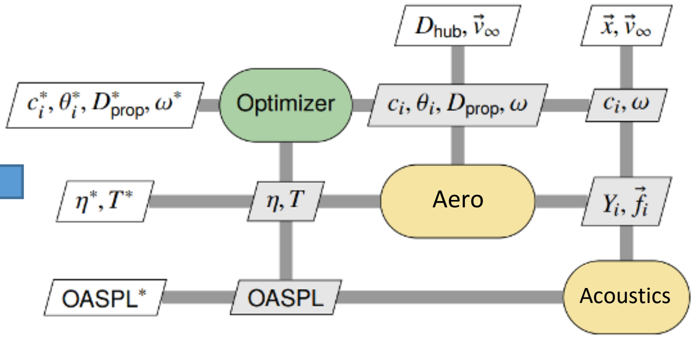
Baseline Data



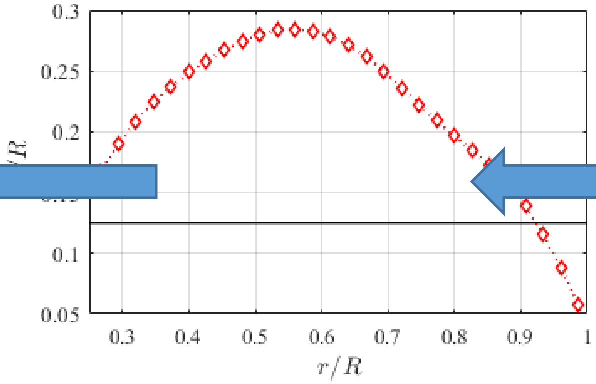
Analysis Using Optimization Tools



Design Optimization

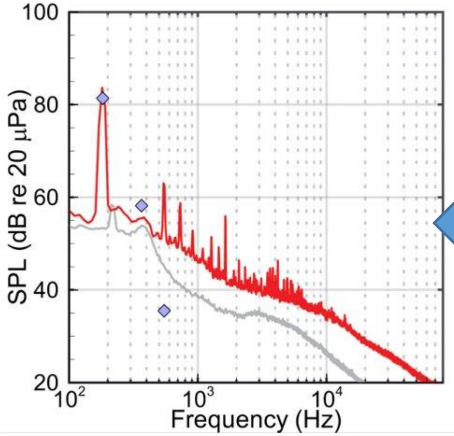


Optimized Geometry



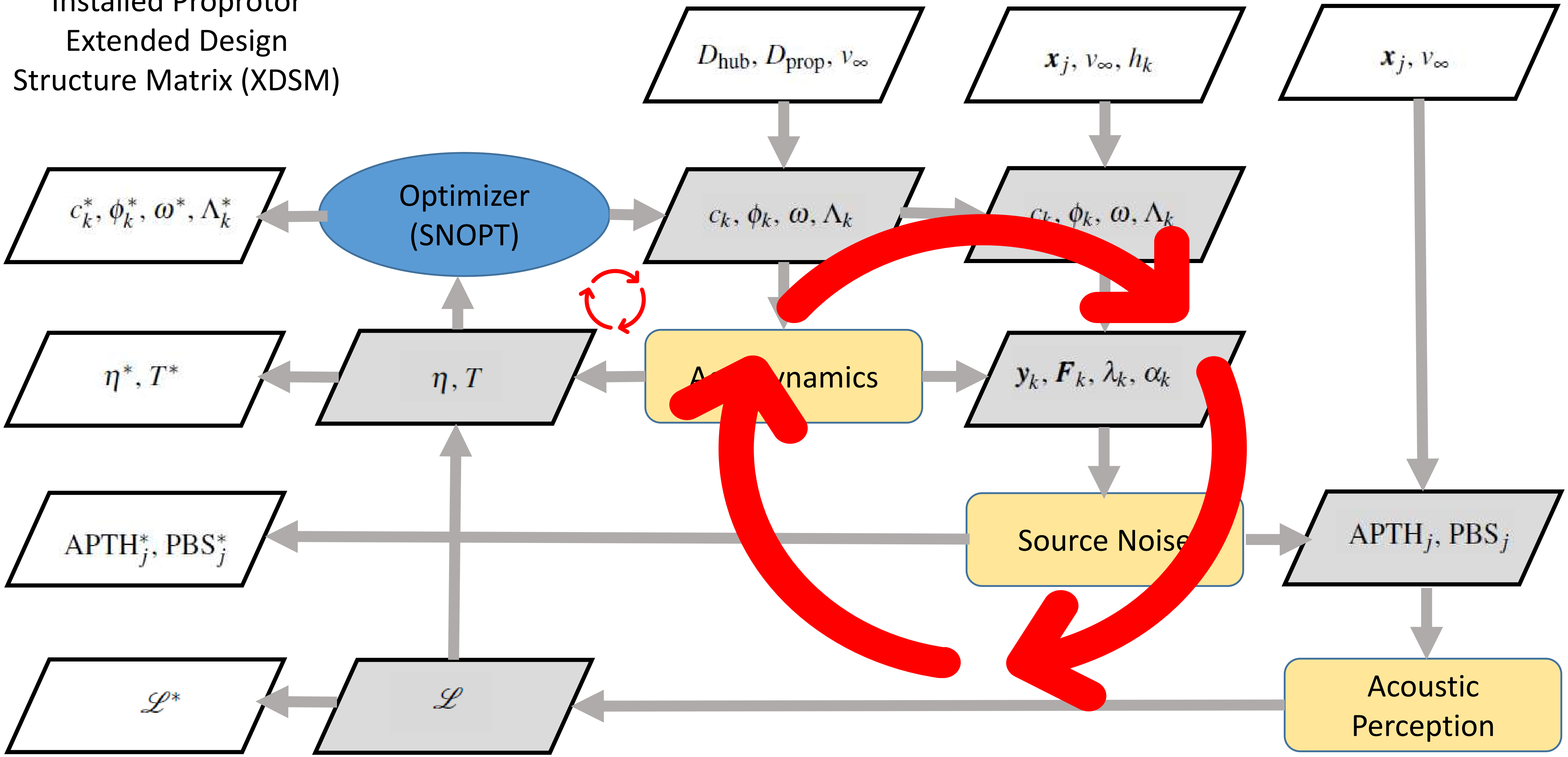
Optimization Tunnel Entry

Validation Data



Multidisciplinary Design Optimization

Installed Proprotor
Extended Design
Structure Matrix (XDSM)

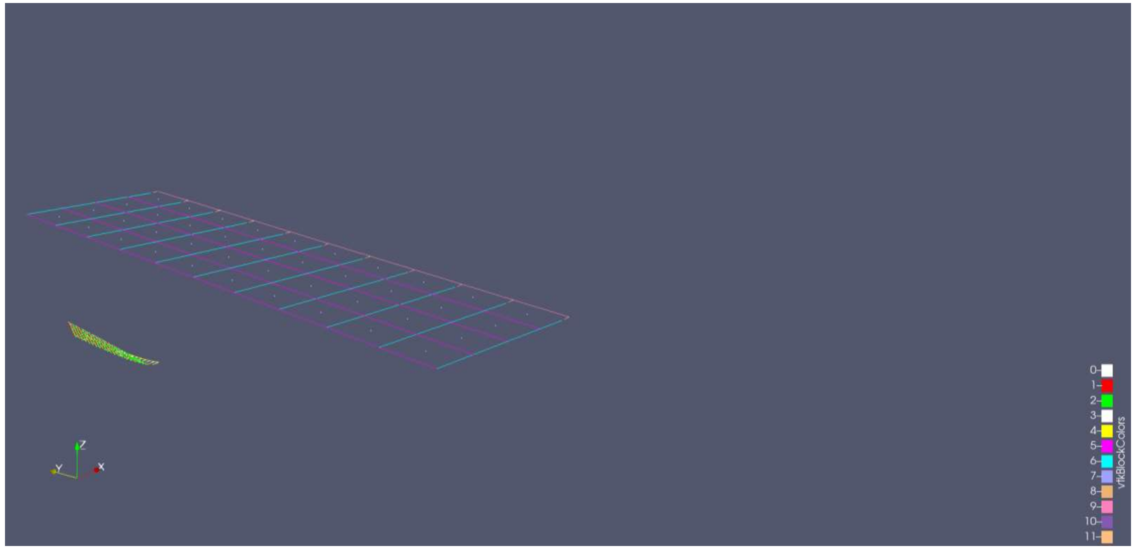


Aerodynamics

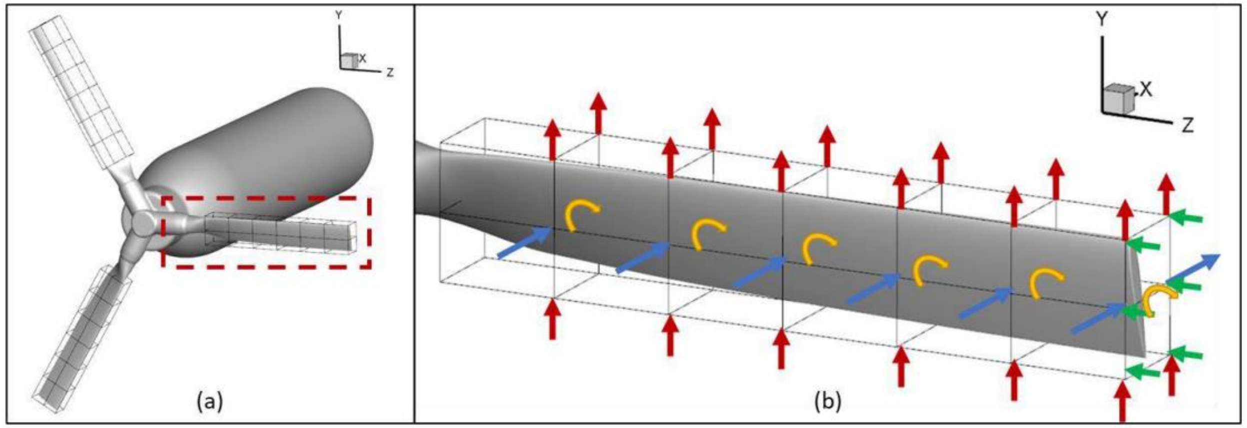
Available codes highlighted in red

Increasing Fidelity

- Blade element momentum theory (BEMT)
  - Implementation:
    - CCBlade.jl from A. Ning, BYU.
  - Advantages:
    - Robust (important for multi-disciplinary optimization)
    - Accurate (for simple configurations single rotor, on-axis flow)
    - Derivatives available via automatic differentiation (AD)
    - Very easy to use
  - Disadvantages:
    - Can't do multiple rotors, installation effects
- Unsteady Vortex Lattice Method (UVLM)
  - Implementations:
    - VortexLattice.jl from T. McDonnell, A. Ning, BYU
    - VSPAERO, part of OpenVSP, D. Kinney, NASA ARC
  - Advantages:
    - Naturally incorporate more complex configurations
    - Reasonably computationally efficient
      - Slower than BEMT, but much faster than CFD
      - Much easier workflow than CFD
  - Disadvantages:
    - Stability of derivatives may be a problem (but there's hope).
- Unsteady Reynolds-averaged Navier-Stokes (URANS)
  - Implementations:
    - Open-source multi-physics suite SU2 from Stanford University
  - Advantages:
    - Blade shape deformations
    - Frequency weighting
    - Multiple observer positions
  - Disadvantage
    - Could not reduce tip chord length significantly
    - Difficult to converge
    - Slow



- Ingraham, D. J., "Low-Noise Propeller Design with the Vortex Lattice Method," April 2022, NASA Acoustics Technical Working Group



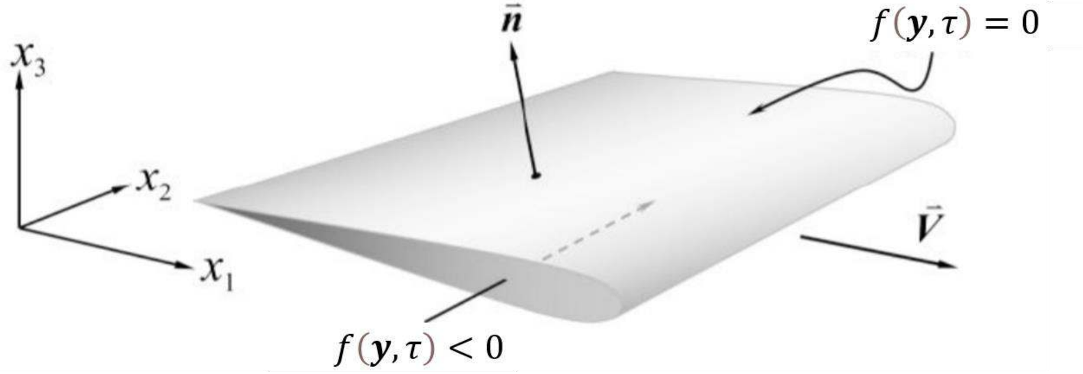
- Icke, R. O., Baysal, O., Lopes, L. V., Diskin, B., "Optimizing Proprotor Blades Using Coupled Aeroacoustic and Aerodynamic Sensitivities," August 2–6 2021, AIAA Paper No. 2021-3037, presented at AIAA AVIATION 2021 Forum. doi:10.2514/6.2021-3037

Source Noise

Available codes highlighted in red

Tonal Noise

- **AcousticAnalogies.jl**
- **ANOPP2 Formulation 1A IFM (AF1AIFM):**



Farassat's Formulation 1A (F1A): Compact and Nondeforming Blade

$$\frac{4\pi}{\rho_\infty} p'_m(\boldsymbol{x},t) = \int\limits_{F=0} \left[\Psi \mathscr{C}_{1A} K\right]_{\text{ret}} \mathrm{d}u$$

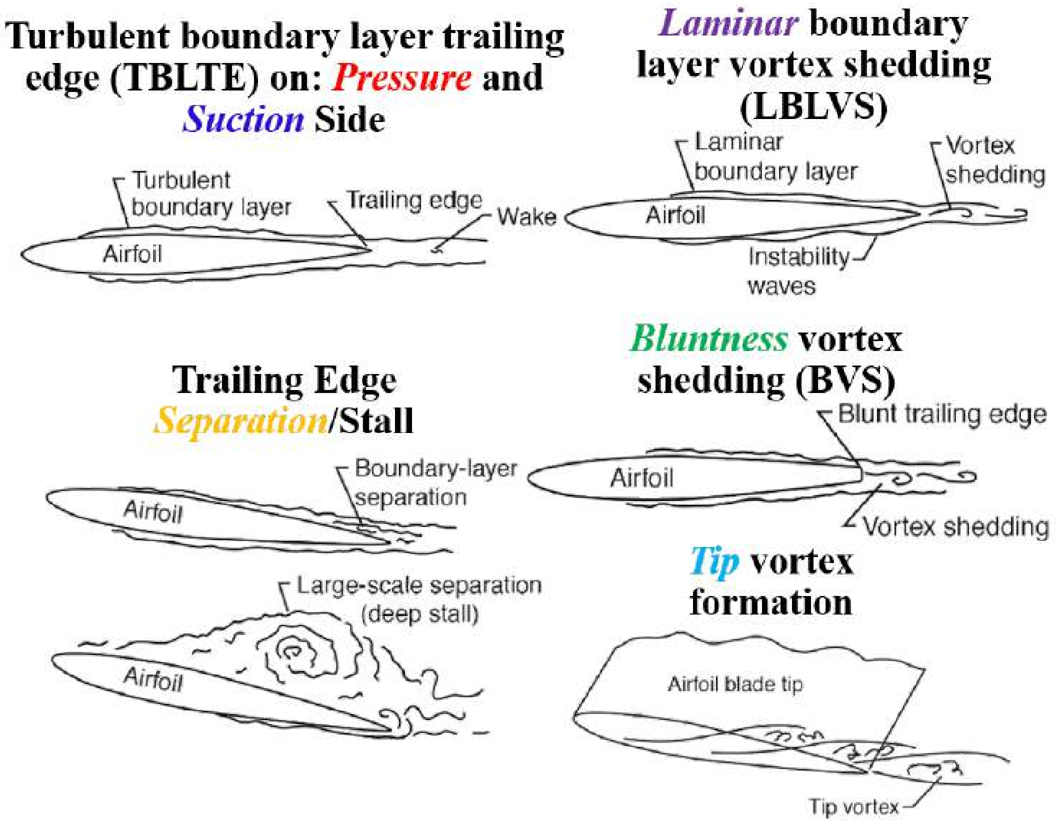
$$4\pi c_\infty p'_d(\boldsymbol{x},t) = \int\limits_{F=0} \left[\dot{\boldsymbol{F}} \mathscr{D}_{1A} K\right]_{\text{ret}} \mathrm{d}u + \int\limits_{F=0} \left[\boldsymbol{F} \mathscr{E}_{1A} K\right]_{\text{ret}} \mathrm{d}u$$

Where $\mathscr{C}_{1A}$, $\mathscr{D}_{1A}$, and $\mathscr{E}_{1A}$ are functions of $\hat{\boldsymbol{r}}_j$ and $\boldsymbol{M}_i$ and their source time derivatives

- Lopes, L. V., "ANOPP2 Farassat Formulations Internal Functional Modules (AFFIFMs) Reference Manual," NASA TM 2021-0021111, National Aeronautics and Space Administration, December 2021.
- Lopes, L. V., "Compact Assumption Applied to the Monopole Term of Farassat's Formulations," Journal of Aircraft, Vol. 54, No. 5, September 2017, pp. 1649–1663, doi:10.2514/1.C034048.

Broadband Self Noise

- **ANOPP2 Self Noise IFM (ASNIFM):**



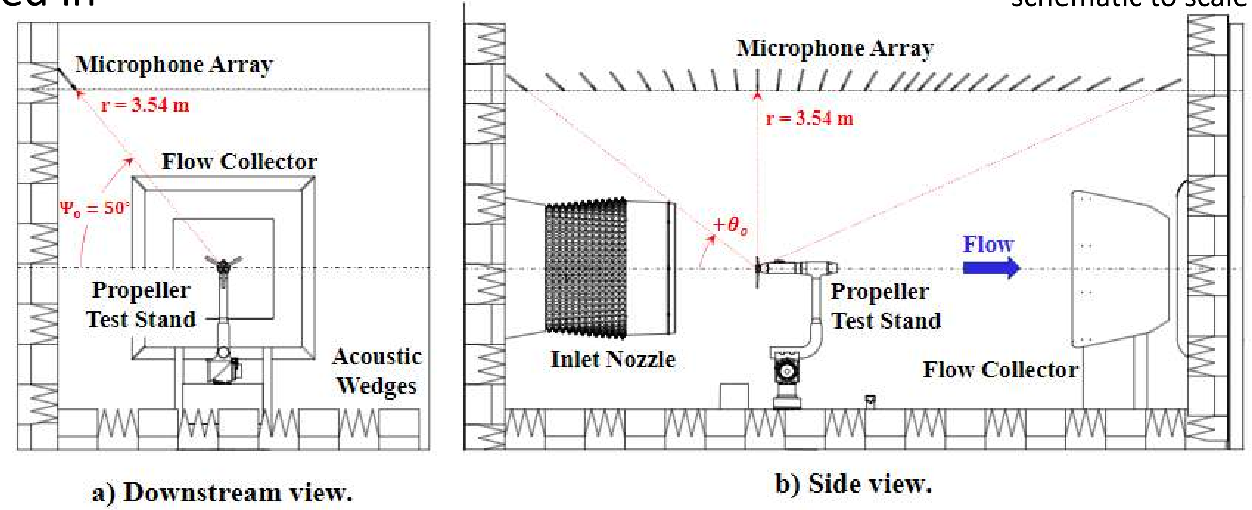
- Brooks, T. F., Pope, S. D., and Marcolini, M. A., "Airfoil Self-Noise and Prediction," NASA RP 1218, National Aeronautics and Space Administration, July 1989.
- Pettingill, N. A., Zawodny, N. S., Thurman, C. S., and Lopes, L. V., "Acoustic and Performance Characteristics of an Ideally Twisted Rotor in Hover," January 11–12 & 19–21 2021, AIAA Paper No. 2021-1928, presented at AIAA Scitech 2021 Forum. doi:10.2514/6.2021-1928.

Acoustic Perception

Available codes highlighted in red

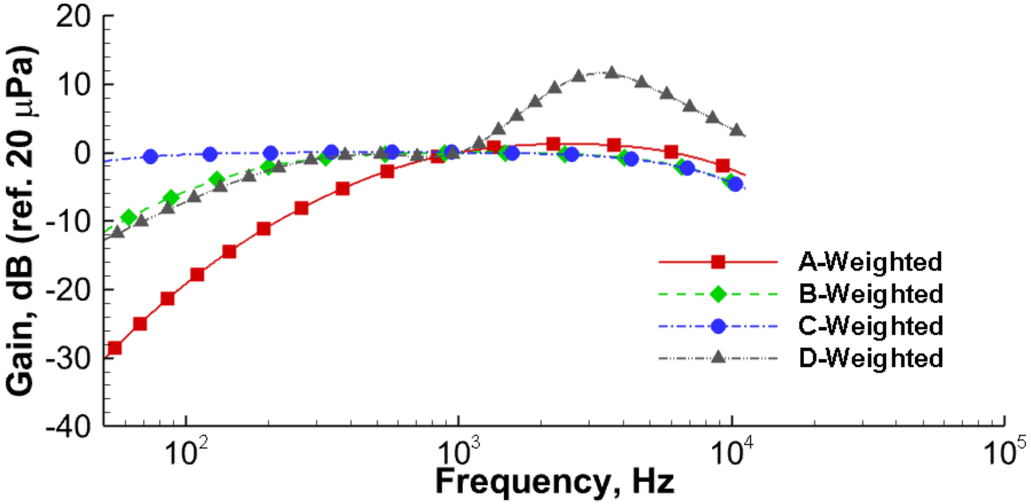
- Several different acoustic constraints that can be utilized in this approach
- Current campaign
  - Tonal noise only
  - Low-fidelity
    - Inplane observer
    - One forward flight condition
    - Unweighted OASPL
  - High-fidelity
    - Spatially integrated acoustic power
    - Hover and one forward flight condition
    - A-weighted OASPL
- Future campaigns will expand capabilities
  - With and without broadband self noise
  - Single microphone vs spatially integrated acoustic power
  - Hover and/or one or more forward flight condition
  - Several different weighing metrics
- ANOPP2 Acoustic Analysis Utility (AAAU)

schematic to scale



a) Downstream view. b) Side view.

- Litherland, B. L., Borer, N. K., and Zawodny, N. S., "X-57 'Maxwell' High-Lift Propeller Testing and Model Development," August 2-6 2021, AIAA Paper No. 2021-3193, presented at AIAA AVIATION 2021 Forum. doi:10.2514/6.2021-3193



- Lopes, L. V. and Burley, C. L., "ANOPP2's User's Manual," NASA TM 2016-219342, National Aeronautics and Space Administration, October 2016.

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    - Experimental validation process
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➢ **Isolated proprotor campaign**

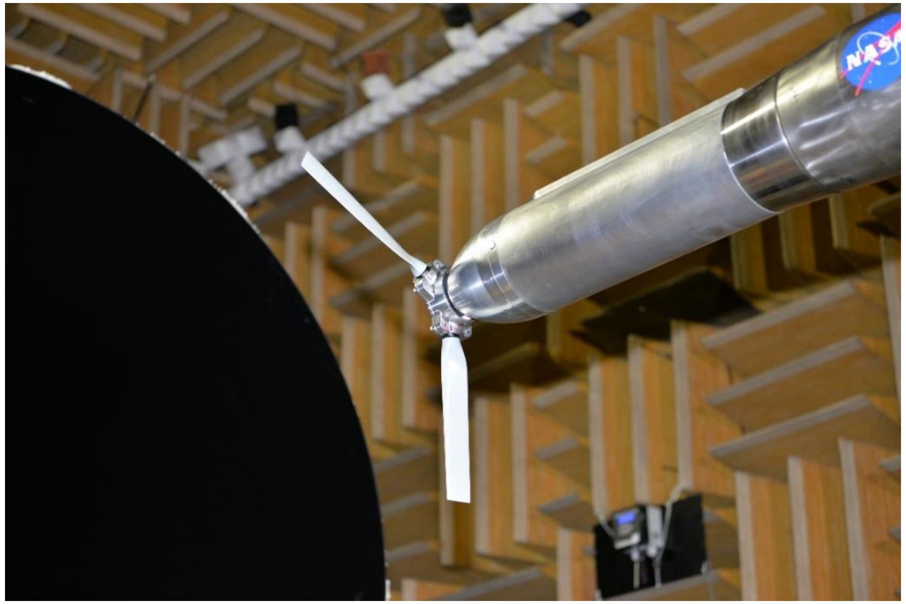
➢ **Installed proprotor campaign**

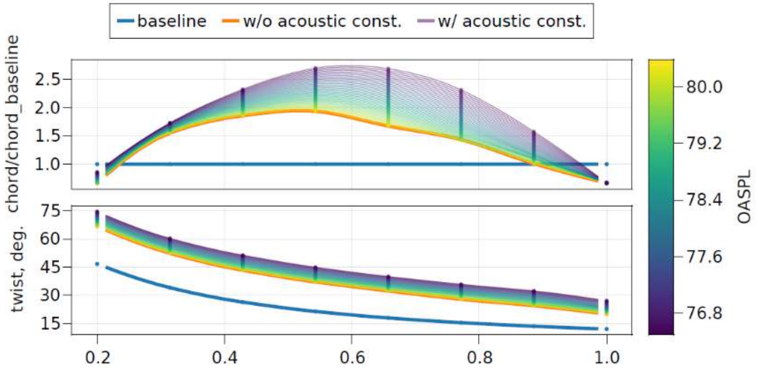
- **Update on available UNWG SG1 Datasets**
    - ➢ **Previously 1, now 2, soon to be 4**
- **Conclusions**

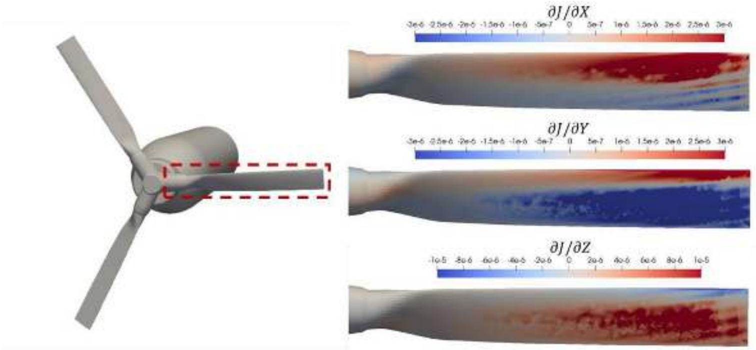
Image credit: RVLT

Isolated Proprotor Design Optimization Campaign

- Helically Twisted Rotor (HTR) aka C24ND
  - Used for checkout of Propeller Test Stand (PTS)
  - $\phi\left(\frac{r}{R}\right) = \text{atan}\frac{P}{\pi D * \frac{r}{R}}$
  - D = 24” (propeller diameter)
  - P = 16” (propeller pitch)
  - C = 1.5” (constant chord length)
  - NACA 0012 airfoils
  - Measurement data for multiple flight conditions
- This is a very noisy rotor
- Two optimization efforts
  - ccblade.jl: BEMT, OASPL at single in plane observer, no frequency weighting, one forward flight condition
  - SU2: URANS, multiple observer positions, a-weighted integrated OASPL, one forward flight and one hover condition





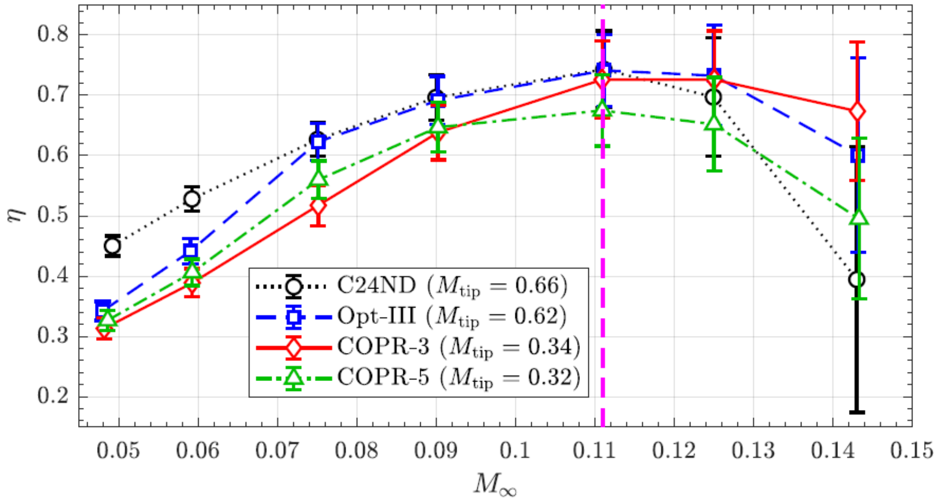


- Ingraham, D. J., Gray, J. S., and Lopes, L. V., “Gradient- Based Propeller Optimization with Acoustic Constraints,” January 8–12 2019, AIAA Paper No. 2019-1219, presented at AIAA Scitech 2019 Forum. doi:10.2514/6.2019-1219
- Icke, R. O., Baysal, O., Lopes, L. V., Diskin, B., “Optimizing Proprotor Blades Using Coupled Aeroacoustic and Aerodynamic Sensitivities,” August 2–6 2021, AIAA Paper No. 2021-3037, presented at AIAA AVIATION 2021 Forum. doi:10.2514/6.2021-3037

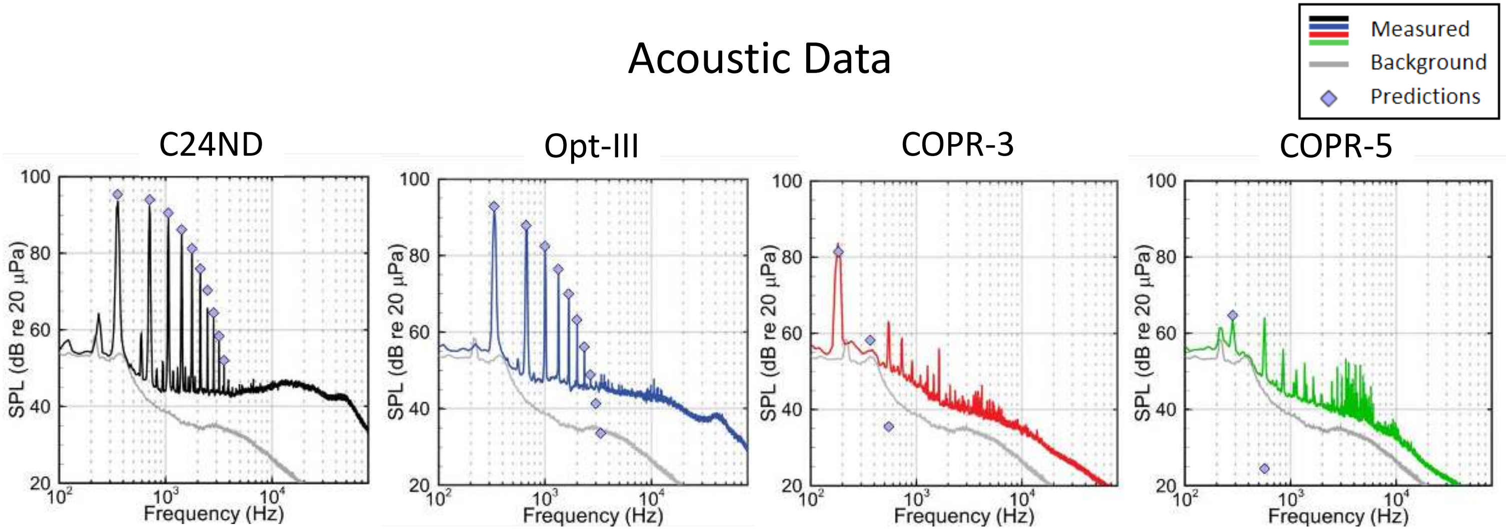
Isolated Proprotor Design Optimization Campaign

Baseline	SU2	ccblade.jl	ccblade.jl blade design x5

Performance Data



Acoustic Data

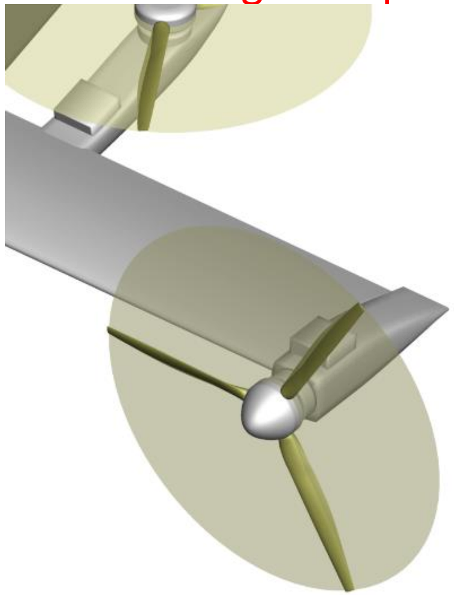


Preliminary predictions using ANOPP-PAS, will use AF1AIFM in future

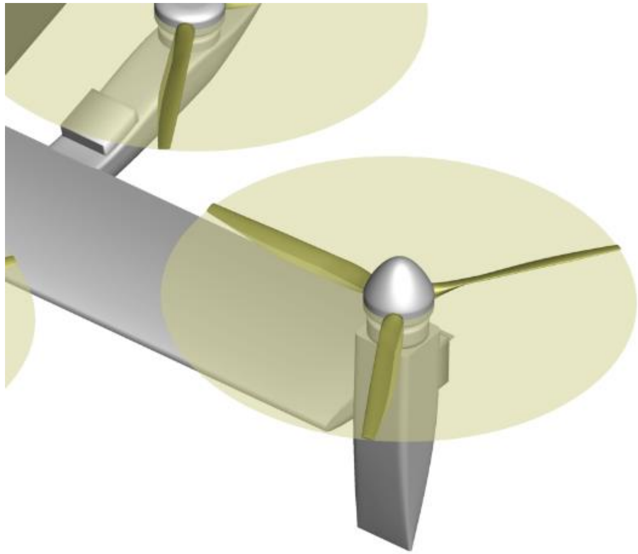
Installed Proprotor Design Optimization Campaign

- Focus on low-fidelity aerodynamics for quicker turnaround time (also more capability)
- Tackle new physics in the optimization cycle
  - Broadband noise via ASNIFM
  - Aerodynamic installation effects via VortexLattice.jl and/or VSPAERO (tiltprop)
  - Add more dynamic and community-representative acoustic constraints
- Baseline geometry will be COPR-3 (optimized isolated proprotor)
- Computational effort for installed proprotor will wrap up in early spring
- Tunnel entry in late spring or summer conditional on LSAWT upgrades

Forward Flight Proprotor



Hover Proprotor



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- ➢ Installed proprotor campaign
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  - ➢ **Previously 1, now 2, soon to be 4**
- **Conclusions**

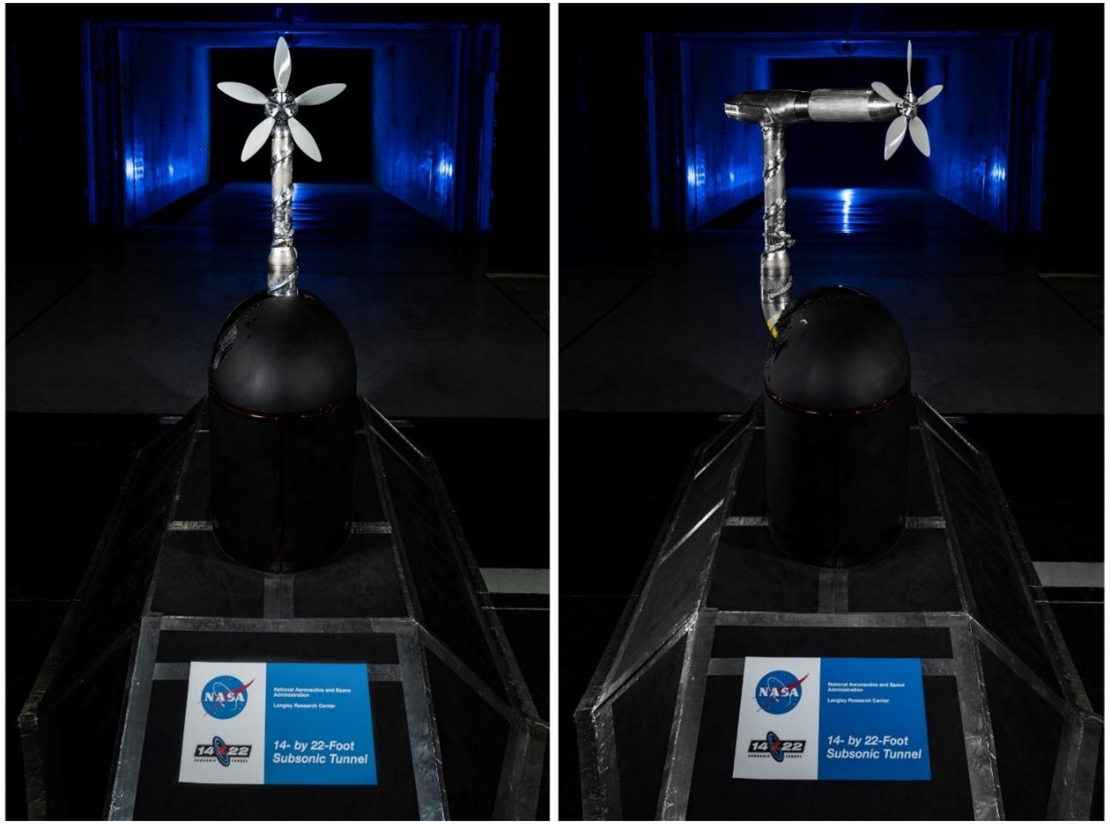
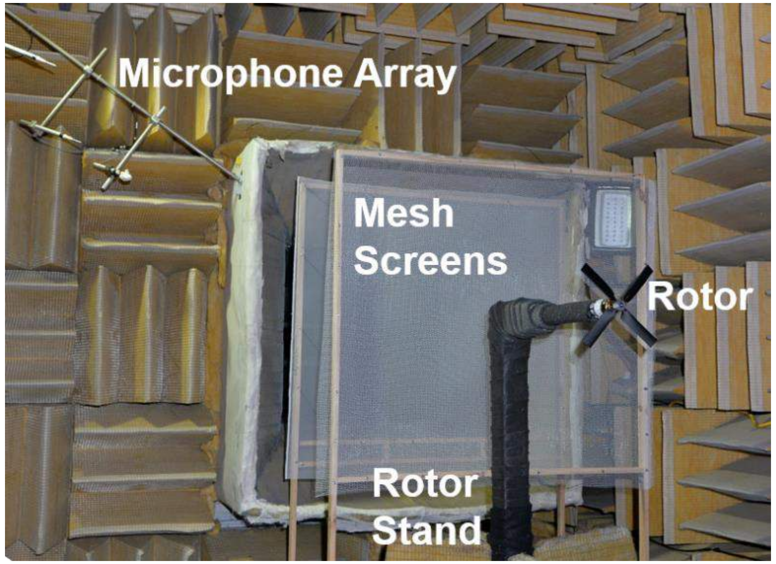


Image credit: RVLT

1) Ideally Twisted Rotor Dataset (2021)

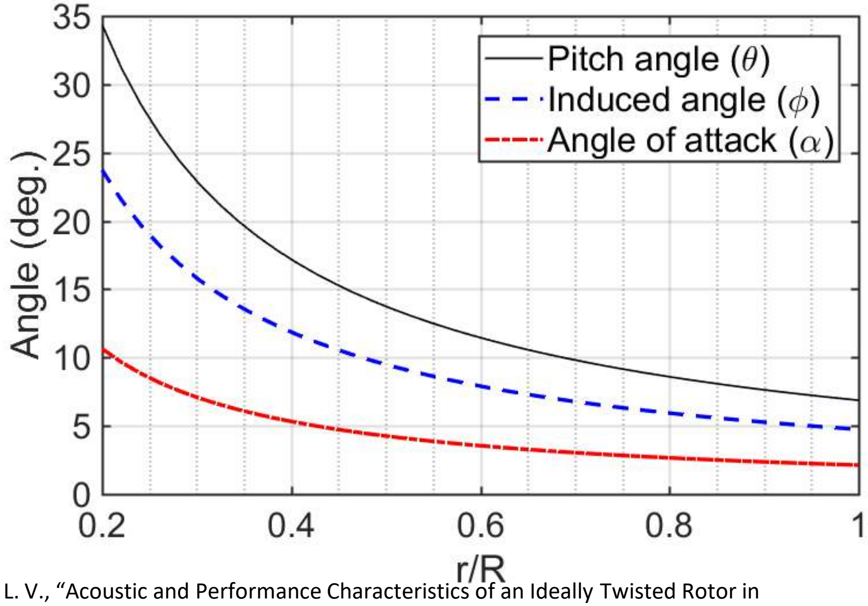
- Ideally, radially constant induced inflow to minimize induced power.
- From blade element momentum theory (BEMT) in hover:

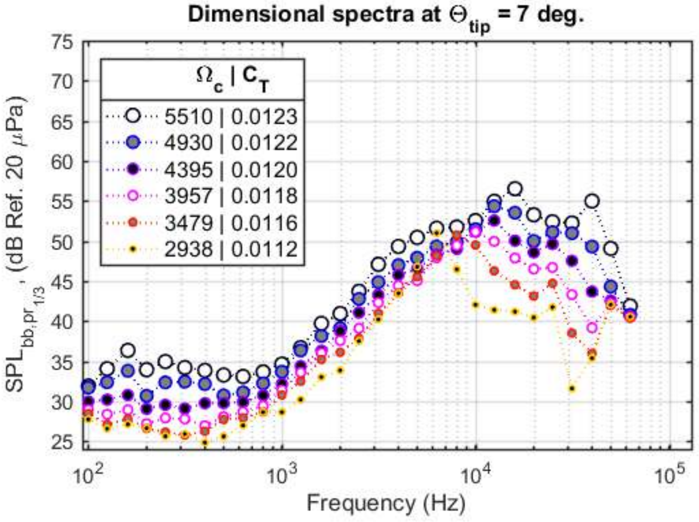
$$\lambda(r) = \frac{\sigma C_{l_\alpha}}{16}\left(\left(1 + \frac{32}{\sigma C_{l_\alpha}}\theta r\right)^{1/2} - 1\right) \qquad \theta = \frac{Constant}{r}$$



- Small Hover Anechoic Chamber (SHAC)
- Hover condition only
- Multiple surface materials (influence of roughness on broadband noise)

	Parameter	Value
Geometry	R (m)	0.1588
	c/R	0.20
	Θ_{tip} (°)	6.9
	N_b	4
	σ	0.255
Operating Condition	C_T	0.0137
	M_{tip}	0.27
	Ω_c (RPM)	5500

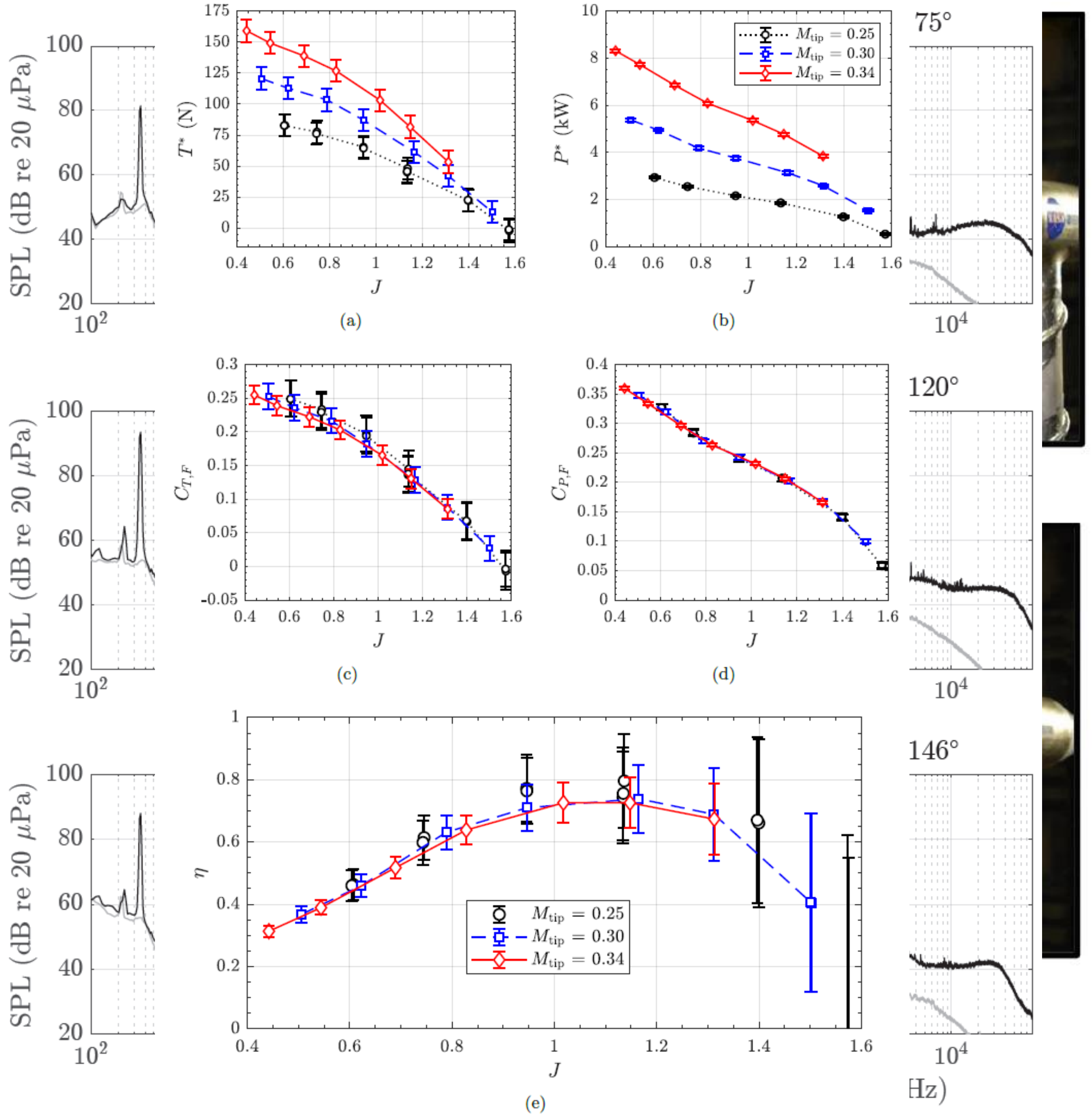




- Pettingill, N. A., Zawodny, N. S., Thurman, C. S., and Lopes, L. V., "Acoustic and Performance Characteristics of an Ideally Twisted Rotor in Hover," January 11–12 & 19–21 2021, AIAA Paper No. 2021-1928, presented at AIAA Scitech 2021 Forum. doi:10.2514/6.2021-1928.

2) Helically Twisted Rotor Design Optimization (2022)

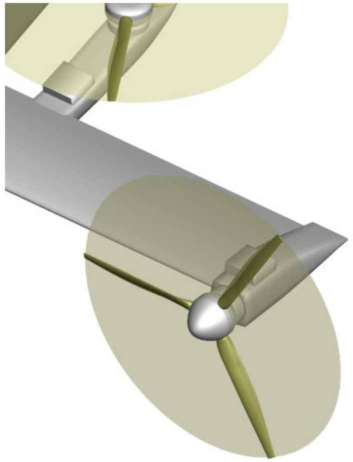
- Started with very noisy helically twisted rotor (a.k.a. C24ND)
- Low-fidelity and high-fidelity optimization efforts resulted in Opt-III and COPR-3 and COPR-5 designs
- Low Speed Aeroacoustic Wind Tunnel (LSAWT)
- A first TM (NASA/TM-20220015637) is near publication documenting tunnel entry and measurement data
  - Performance data
  - Acoustic data
- A second TM early next year comparing predictions to measurements and will draw conclusions on acoustic trends



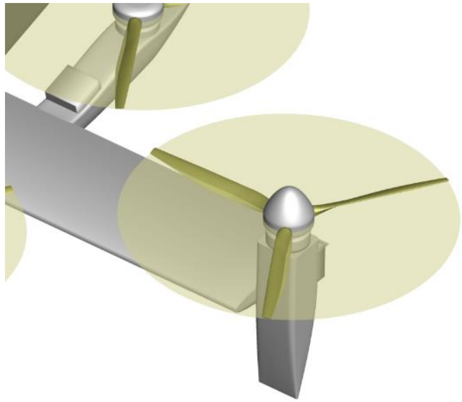
3) Installed COPR-3 Proprotor (Available Late 2023)

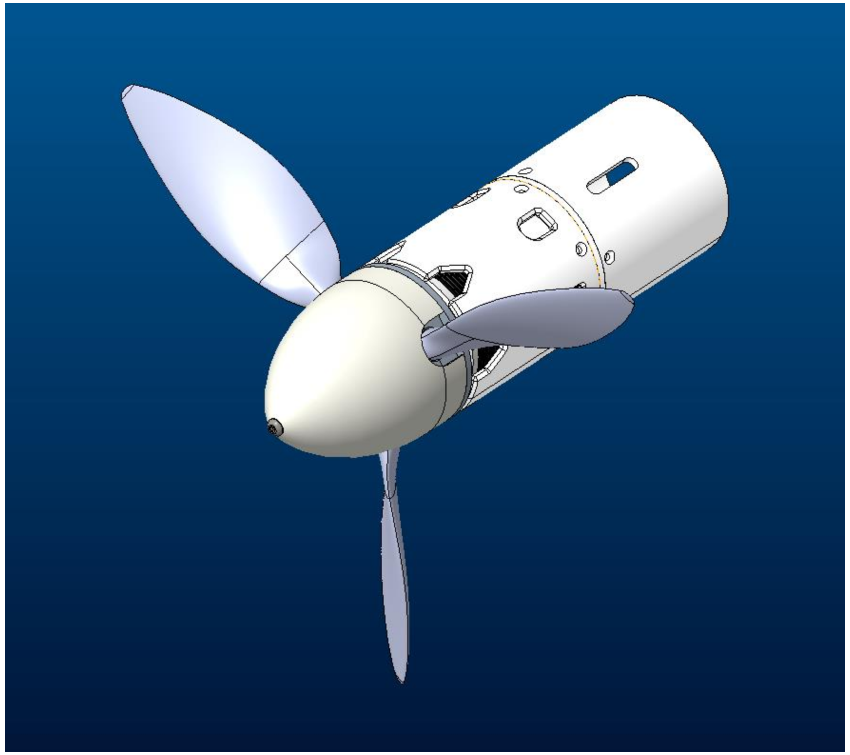
- Installed proprotor test data will be made available via UNWG SG1
- Will include geometry of baseline, wing, and multiple optimized geometries
  - Different aerodynamic, source noise, and perception constraints lead to different designs
- Wing/prop configurations based on concept vehicle
  - Ratio of wing to proprotor radius ~ 1
  - Due to tunnel limitations, proprotor will have 1 ft diameter
    - COPR-3 has 2 ft diameter, allows for proprotor scaling study

Forward Flight Proprotor



Hover Proprotor





4) Optimum Hovering Rotor (Available Early 2023)

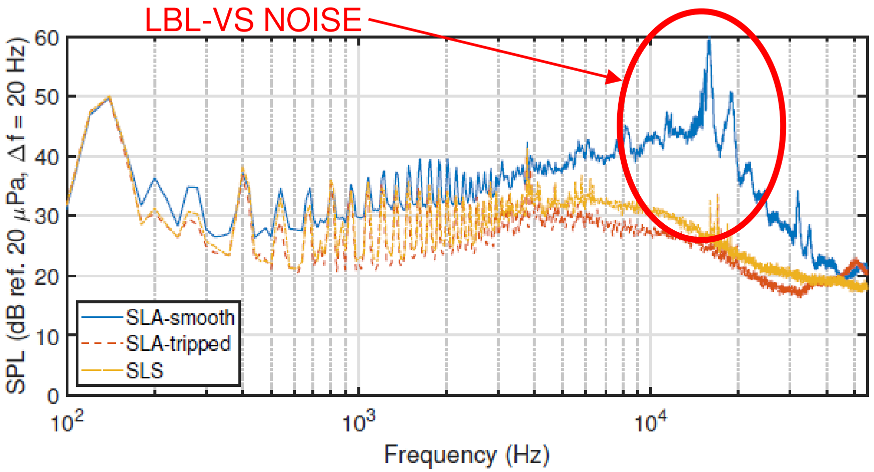
- Minimum induced power requirement
- Minimum profile power requirement

$$\theta_{tw}(r) = \frac{1}{r}\left(\frac{4C_{T_{design}}}{5.73\sigma(r)} + \sqrt{\frac{C_{T_{design}}}{2}}\right) - \alpha_0$$

- Focusing on LBL-VS noise and how to mitigate
  - Dependent on surface materials

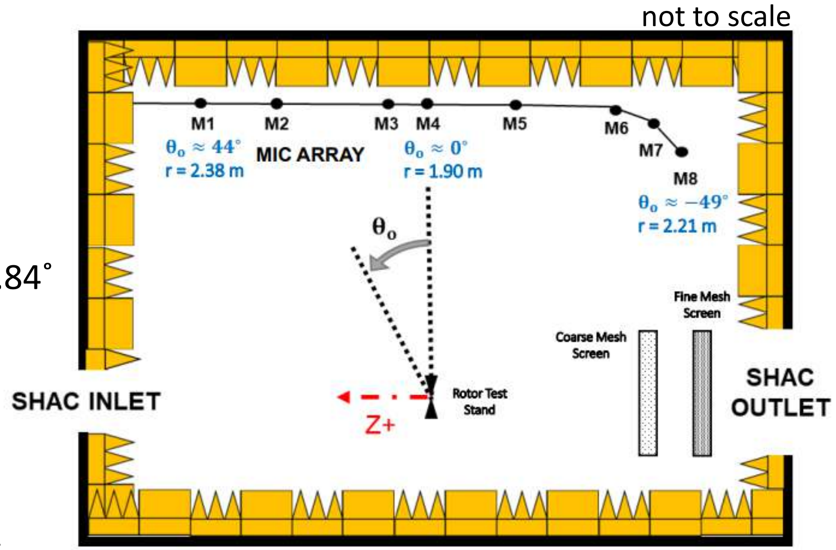
> ➢ SLA-smooth (Protolabs – Accura Xtreme)
> ➢ SLA-tripped (Protolabs – Accura Xtreme with boundary layer trip)
> ➢ SLS (Protolabs – PA12 Mineral-filled)

- Planned dataset release spring UNWG meeting



Design conditions

- $R = 7.5$ in
- $\Omega = 2500 - 5000$ RPM
- $T_{design} = 1.875$ lb
- $c_{tip} = 0.75$ in
- TE bluntness = 0.03c(r)
- NACA 5408 airfoil: $\alpha_0 = -4.84^{\circ}$
- Taper = 2.25 to 1



- Thurman, C. S., Zawodny, N. S., Pettingill, N. A., "The Effect of Boundary Layer Character on Stochastic Rotor Blade Vortex Shedding Noise," May 10–12 2021, presented at Vertical Flight Society's 78th Annual Forum & Technology Display. doi:10.4050/F-0078-2022-17428
- Pettingill, N. A., Zawodny, N.S., Thurman, C.S., "Aeroacoustic Testing of UAS-Scale Rotors for a Quadcopter in Hover and Forward Flight," June 14–17 2022, AIAA Paper No. 2022-3110, presented at AIAA Aeroacoustics Conference. doi:10.2514/6.2022-3110.

Conclusions

1. Presented two campaigns on the validation of tools used in proprotor design optimization including an acoustic constraint
2. Presented the aerodynamic and acoustic tools being used in those campaigns, all of which are available outside NASA
3. Presented four experimental datasets that are or will be shortly available to the community via UNWG SG1

National Aeronautics and
Space Administration

Improved sUAS Broadband Noise Calculations using Enhanced Very Large Eddy Simulation Paradigm

Christopher Thurman

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Aeroacoustics Branch, NASA Langley Research Center

NASA Acoustics Technical Working Group

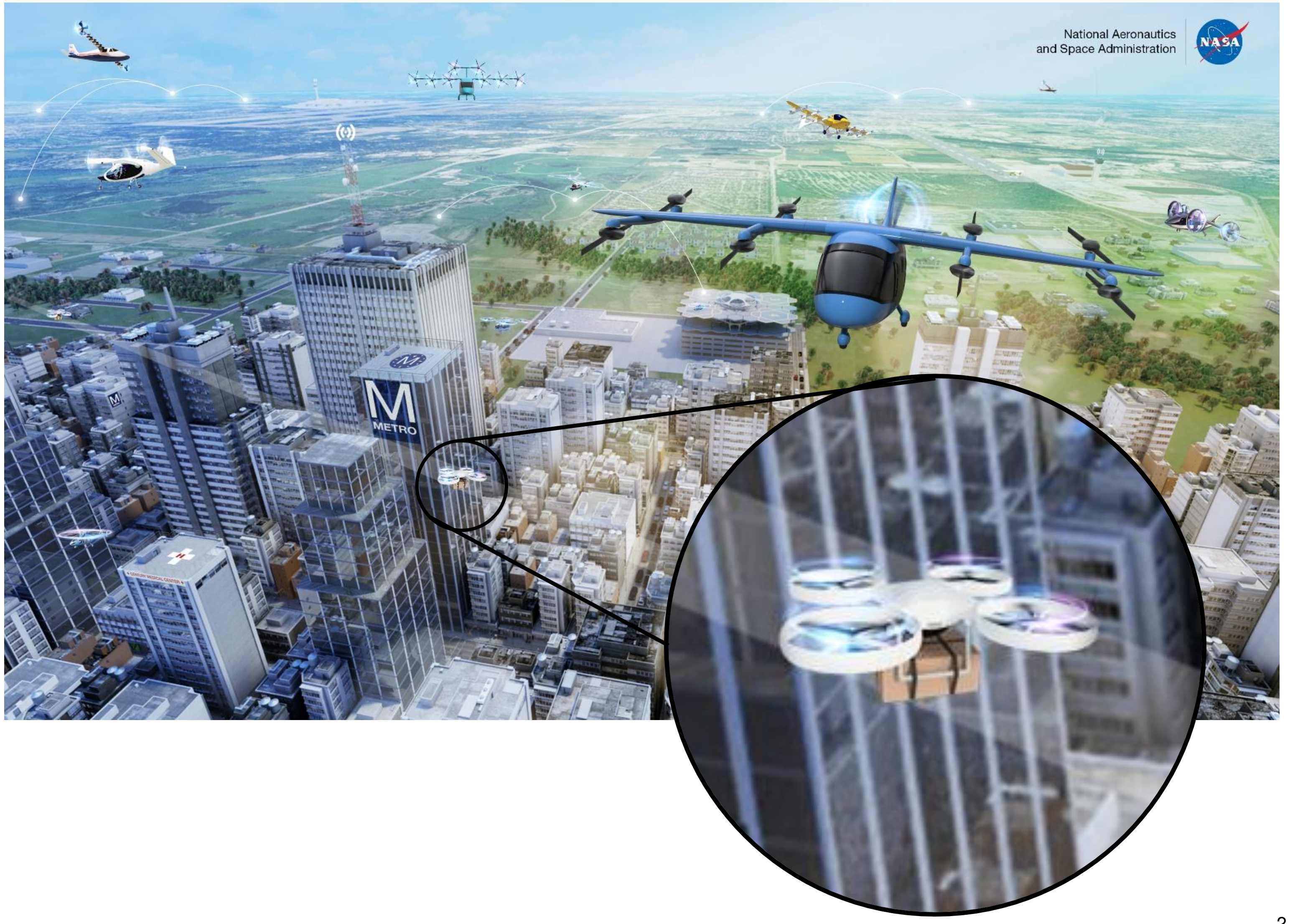
October 19, 2022

Background: Advanced Air Mobility (AAM)

- **Advanced Air Mobility (AAM)** is working to create safe, sustainable, accessible, and affordable aviation to move people and packages.

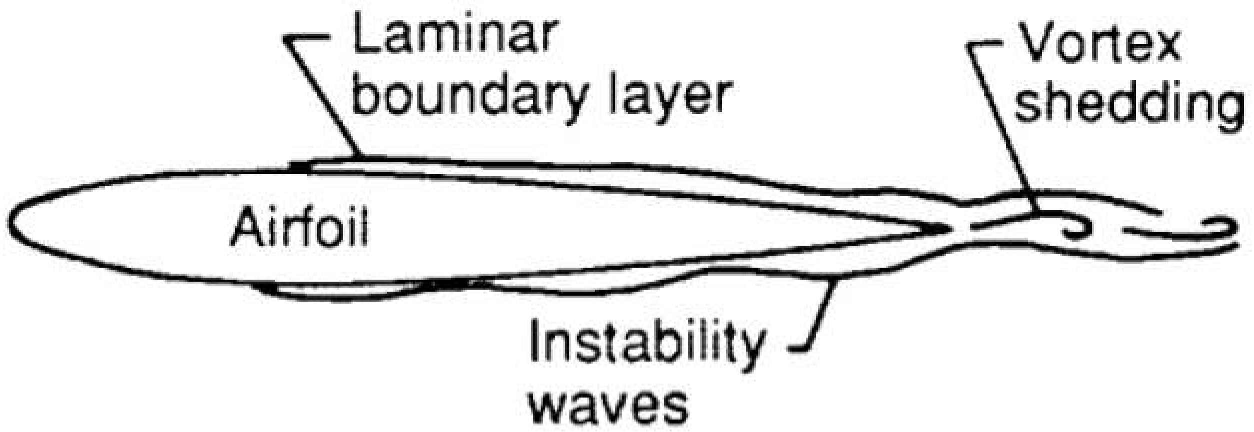
- Noise may be a large inhibitor to aviation growth. Increased demand in AAM has motivated research toward identifying and characterizing the noise sources produced by vehicles such as quadcopters.

- Broadband noise has been shown to be a dominant noise source for AAM vehicles, unlike for conventional helicopters. Very little work has been done toward its study, and it is still not highly understood.



Background: Rotorcraft Noise Sources

- **Deterministic (tonal)**
  - ➢ Thickness noise
  - ➢ Loading noise

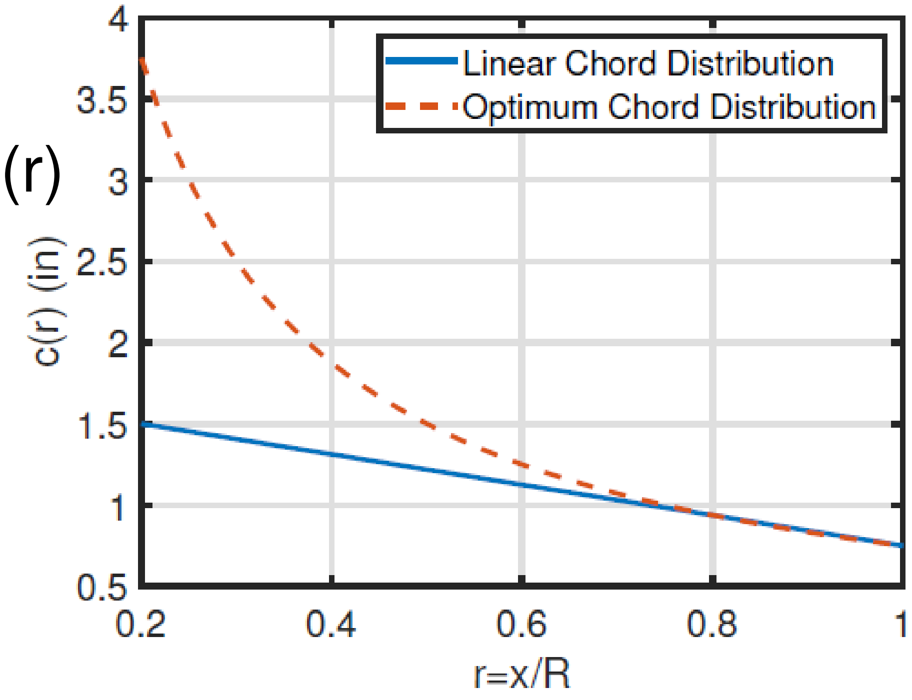


Brooks, T. F., Pope, D. S., and Marcolini, M. A., "Airfoil Self-noise and Prediction," NASA RP 1218, 1989.

- **Stochastic (broadband)**
  - ➢ Turbulence Ingestion Noise (TIN)
  - ➢ Blade-wake Interaction (BWI) noise
  - ➢ Blade Self-noise
    - Laminar boundary layer vortex shedding (LBL-VS noise)
      - $5x10^4 \leq Re \leq 2x10^6$

Technical Approach: Geometry

- **Design conditions**
  - R = 7.5 in
  - Ω = 3950 RPM
  - T_{design} = 1.875 lb
  - c_{tip}= 0.75 in
  - TE bluntnesss = 0.03c(r)
  - NACA 5408 airfoil: $\alpha_0 = -4.84°$
  - Taper = 2.25 to 1

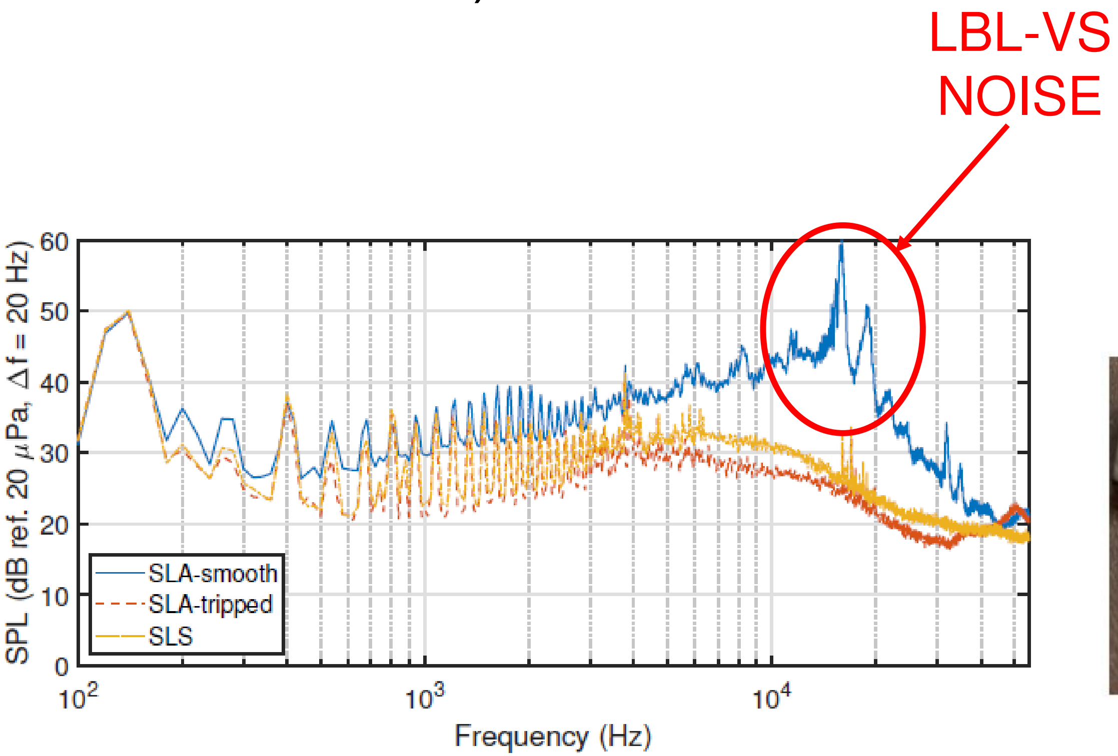


Technical Approach: Experimental Setup

- **Blade materials**
  - SLA-smooth (Protolabs – Accura Xtreme)
  - SLA-tripped (Protolabs – Accura Xtreme with BL trip)
  - SLS (Protolabs – PA12 Mineral-filled)

SLA-tripped

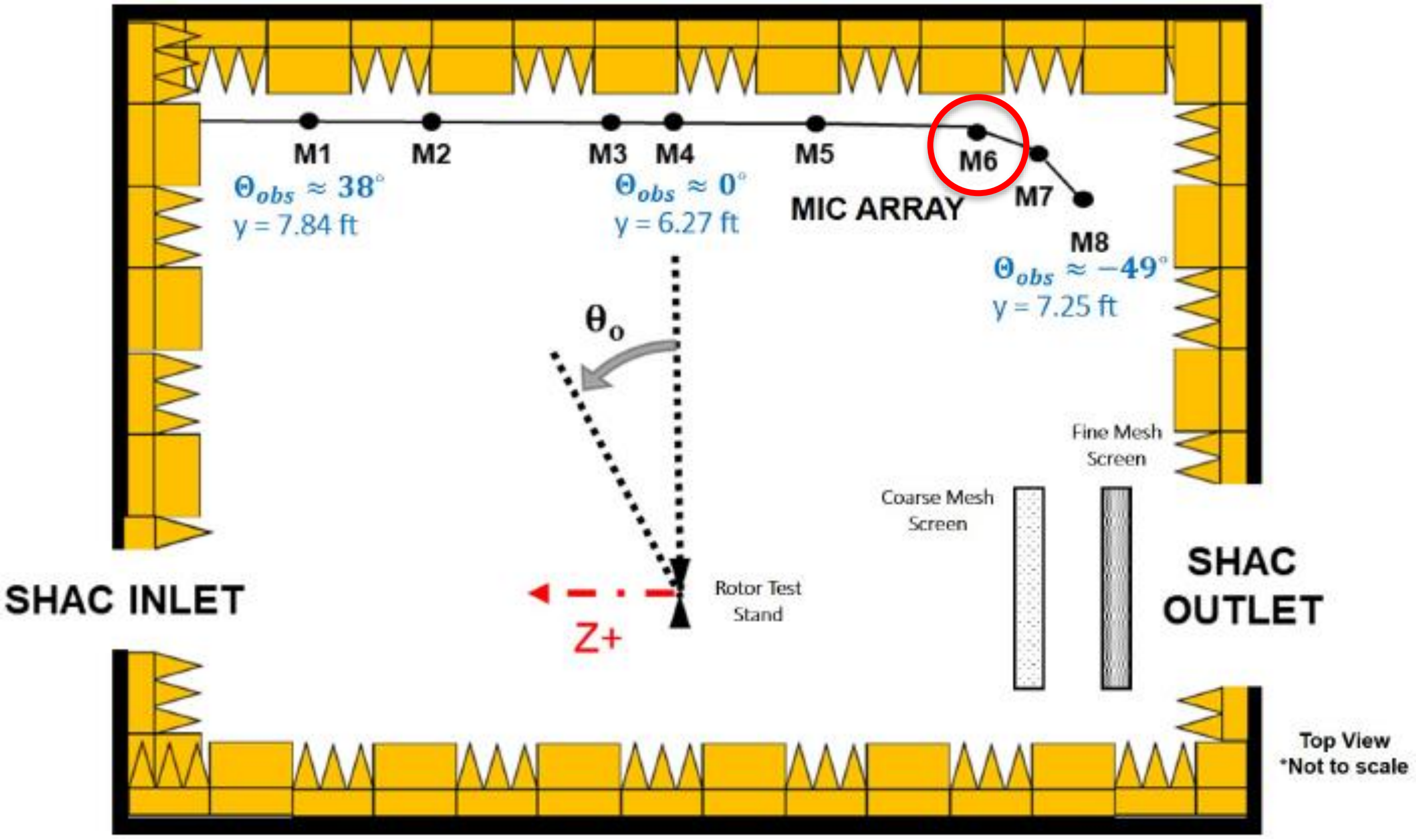
SLS



Thurman, C. S., Zawodny, N. S., and Pettingill, N. A., "The Effect of Boundary Layer Character on Stochastic Rotor Blade Vortex Shedding Noise," *VFS International 78th Forum & Technology Display, Fort Worth, TX*, May 2022.

Technical Approach: Experimental Setup

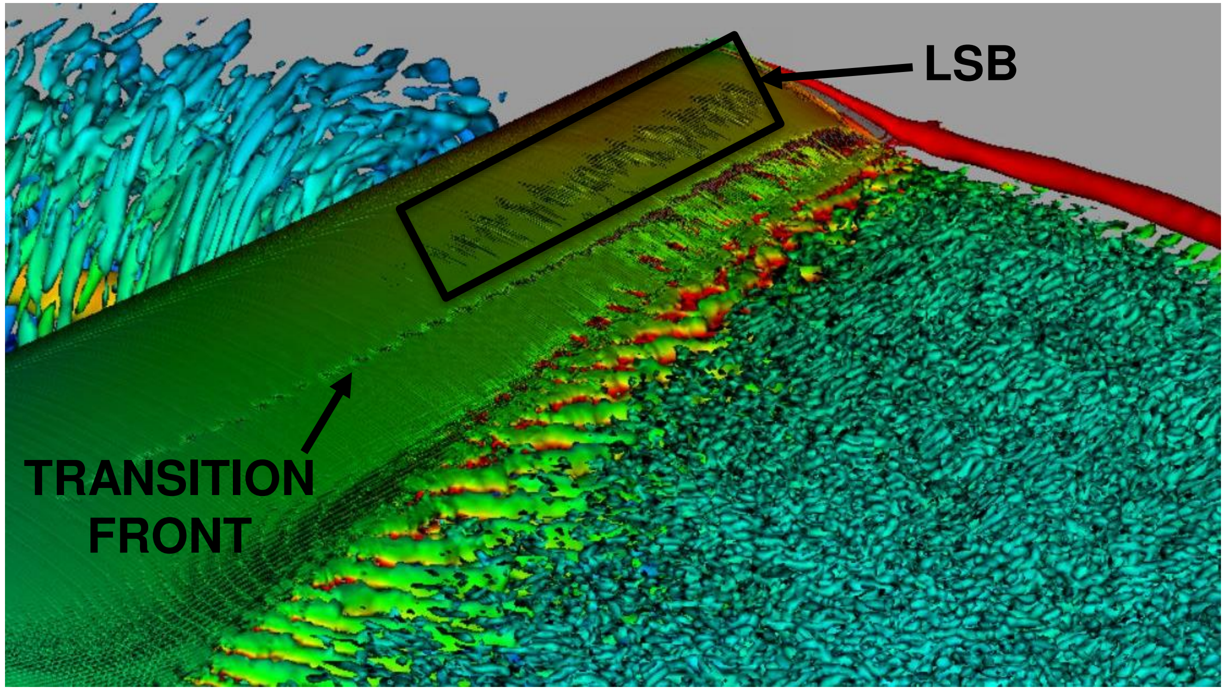
- **Experiment conducted in the Small Hover Anechoic Chamber (SHAC) facility at NASA LaRC**
  - All measured and predicted results correspond to Microphone 6
    - $\Theta_{obs} = -35°, y = 7.5$ ft

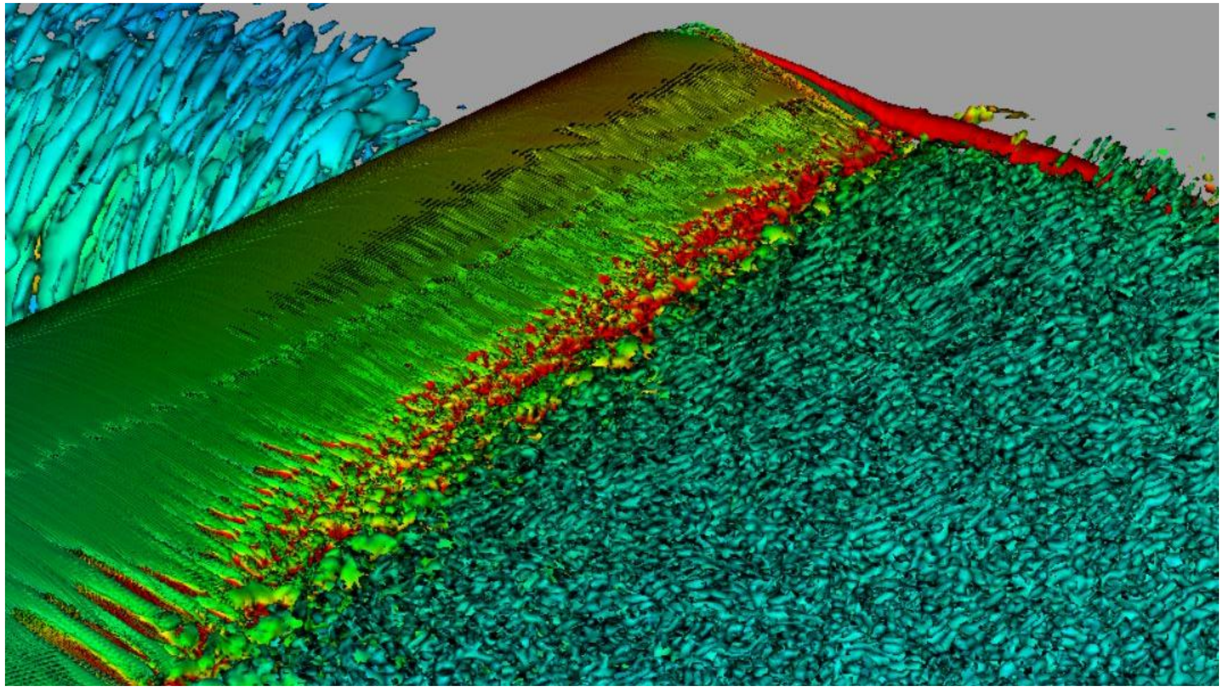


Technical Approach: Computational Approach

- **High-fidelity tools**
  - PowerFLOW simulations using two versions: VLES and improved VLES (VLES-I)

VLES **VLES-I**





Instantaneous isosurfaces of $\lambda_2 = -1x10^5 1/s^2$

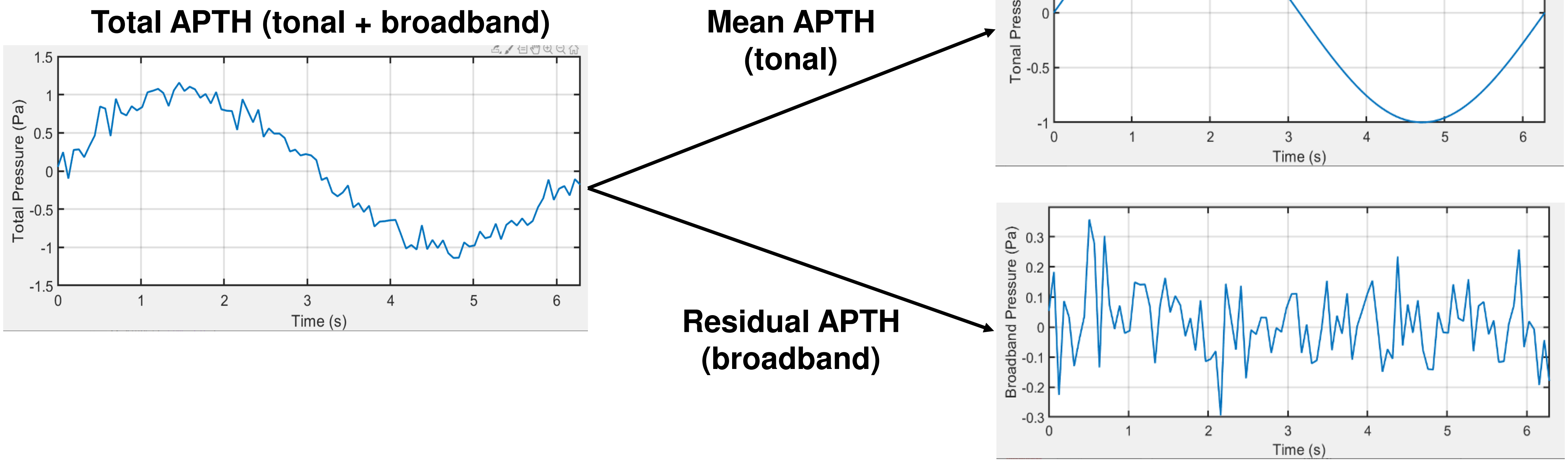
Technical Approach: Computational Approach

- **High-fidelity tools continued**
  - PowerFLOW simulations using two versions: VLES and improved VLES (VLES-I)
  - Two grid resolutions (cVLES and fVLES) with VLES
  - Only fine grid resolution for VLES-I
  - 'Automatic' transitional wall-functions used for all simulations
  - Acoustic propagation using F1A in PowerACOUSTICS (10 revs of acoustic pressure time history (APTH))

Case	Finest Voxel Size	y+ at R
cVLES	0.0025"	17.13
fVLES	0.001875"	12.8
Extrapolated VLES	NA	NA
VLES-I	0.001875"	12.8

Technical Approach: Computational Approach

- **High-fidelity tools continued**
  - ➢ Acoustic propagation using F1A in PowerACOUSTICS (10 revs of APTH)



Technical Approach: Computational Approach

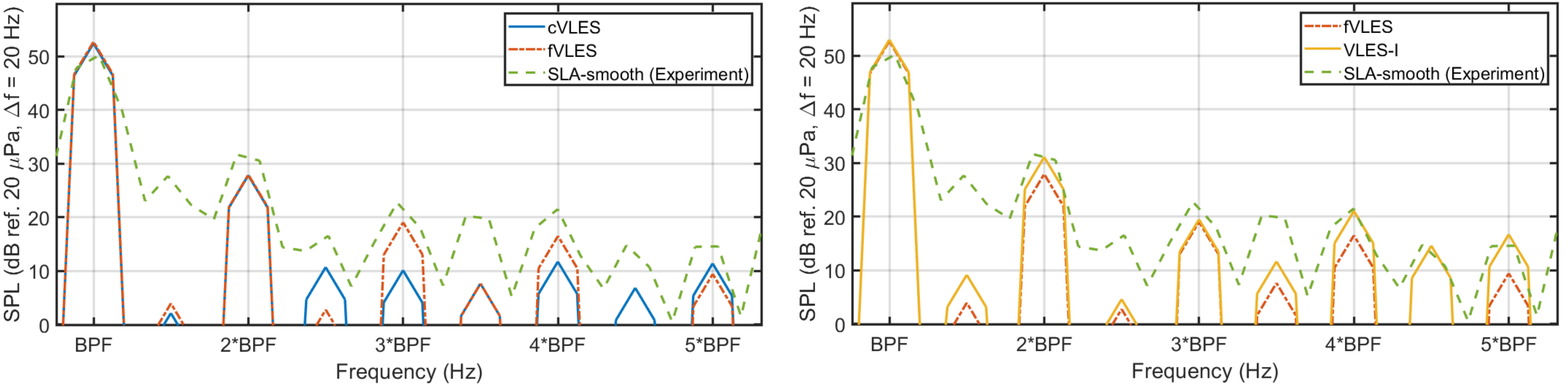
- **Richardson Extrapolation**

$$f_\infty = f_{fine} + \frac{f_{fine} - f_{coarse}}{\left(\frac{\Delta s_{coarse}}{\Delta s_{fine}}\right)^2 - 1}$$

Case	Measured thrust (lb)	Predicted Thrust (lb)	Relative Error (%)
cVLES	1.86 ± 0.1125	1.58	15.1
fVLES		1.60	14.0
Extrapolated VLES		1.63	12.4
VLES-I		1.61	13.4

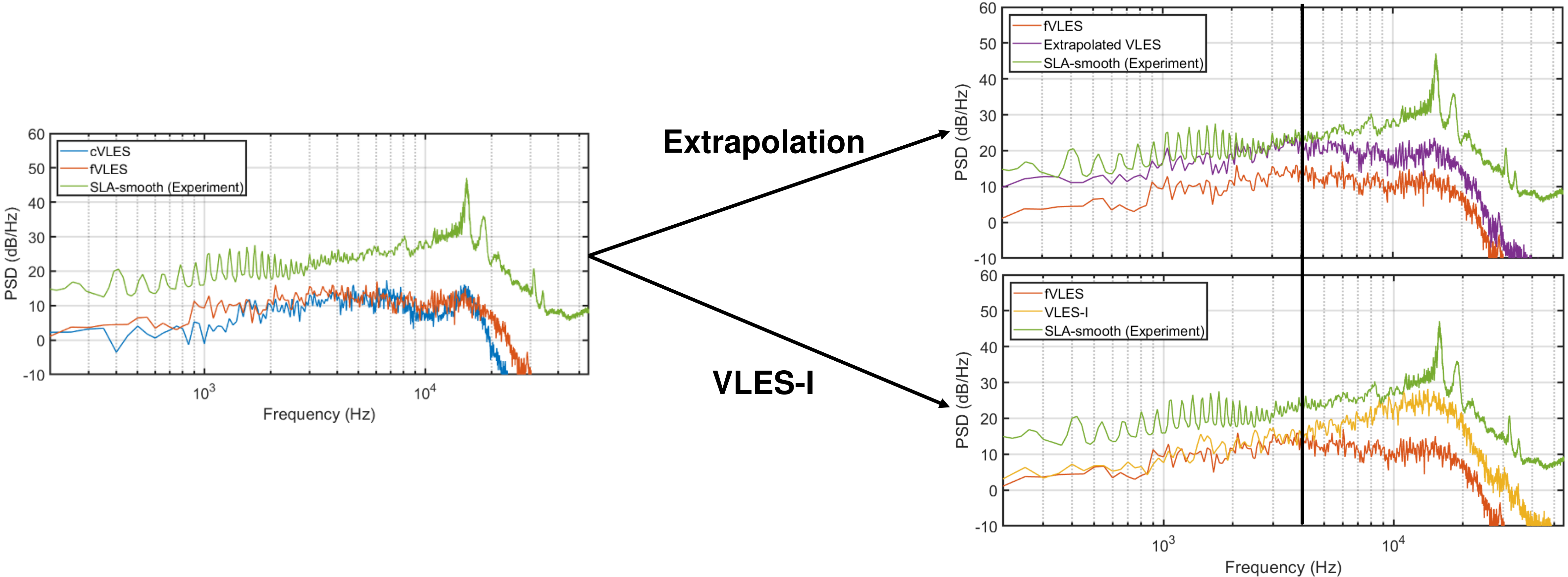
Results: Computational Aeroacoustics

- ➢Increasing grid resolution increases tonal noise accuracy
- ➢Beta-VLES solver can accurately resolve higher-frequency loading (4*BPF and 5*BPF)



Results: Computational Aeroacoustics

- ➢Extrapolated VLES can only account for grid-dependent misprediction (below 4kHz)
- ➢VLES-I can resolve BL turbulence and subsequent broadband noise (above 4kHz)



Summary

- LBL-VS noise is highly dependent on boundary layer character
- Turbulent boundary layers (i.e., caused by trip or surface roughness) can decrease broadband noise by ~30 dB at frequency of maximum emission
- VLES-I can better resolve energetic boundary layer turbulence associated with broadband noise generation when compared to VLES
- Extrapolation can elucidate regions of misprediction caused by inadequate spatial resolution
- Further study is necessary to determine grid-dependence of broadband noise using Beta-VLES solver

Acknowledgments

- Nikolas Zawodny and Nicole Pettingill of the Aeroacoustics Branch at the NASA Langley Research Center

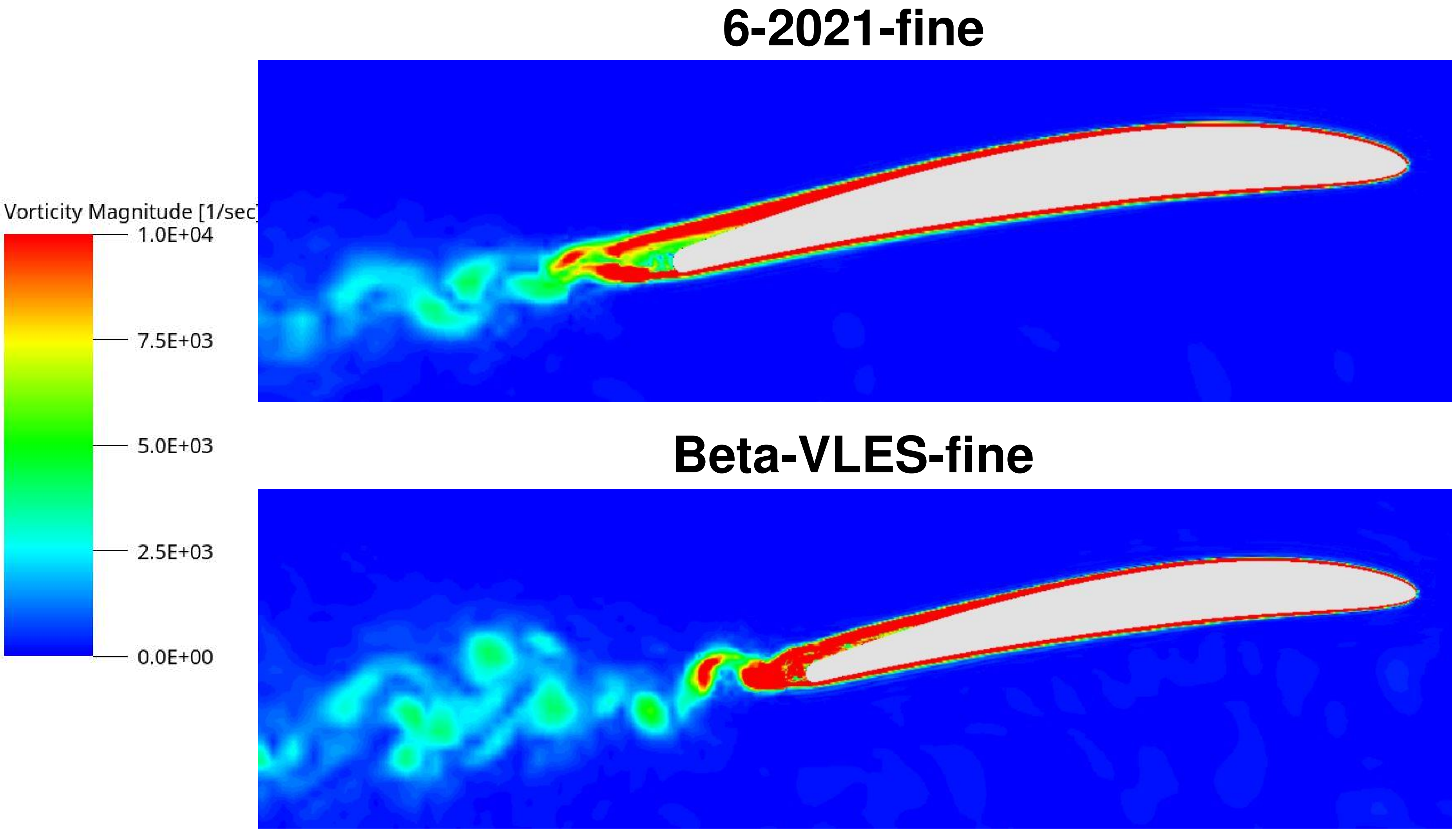
- Damiano Casalino at Dassault Systèmes

- Revolutionary Vertical Lift Technology (RVLT) Project funding

- Computer resources provided by NASA Advanced Supercomputing (NAS) facility and the Midrange HPC K-Cluster at the Langley Research Center

Questions?

Extra Slide



Instantaneous off-body vorticity magnitude at 0.85R

Evaluation of Aerodynamic Tools for Predicting UAM Vehicle Acoustics: Best Practices to Date

Natasha Schatzman, Lauren Weist, Dorsa Shirazi

Fall 2022 Acoustics Technical Working Group

October 19, 2022

Aeromechanics Branch - NASA Ames Research Center

Team introduction

Dr. Natasha Schatzman

- Georgia Institute of Technology (BS, MS, and PhD)
- NASA Ames Research Center Aeromechanics Branch
- Experimental and computational aerodynamics and aeroacoustics

Lauren Weist

- University of Maryland (BS) and Pennsylvania State University (MS)
- NASA Ames Research Center Aeromechanics Branch
- Experimental and computational aeroacoustics

Dorsa Shirazi

- University of California Irvine (BS, MS)
- NASA Ames Research Center Aeromechanics Branch
- Experimental and computational aerodynamics

Outline

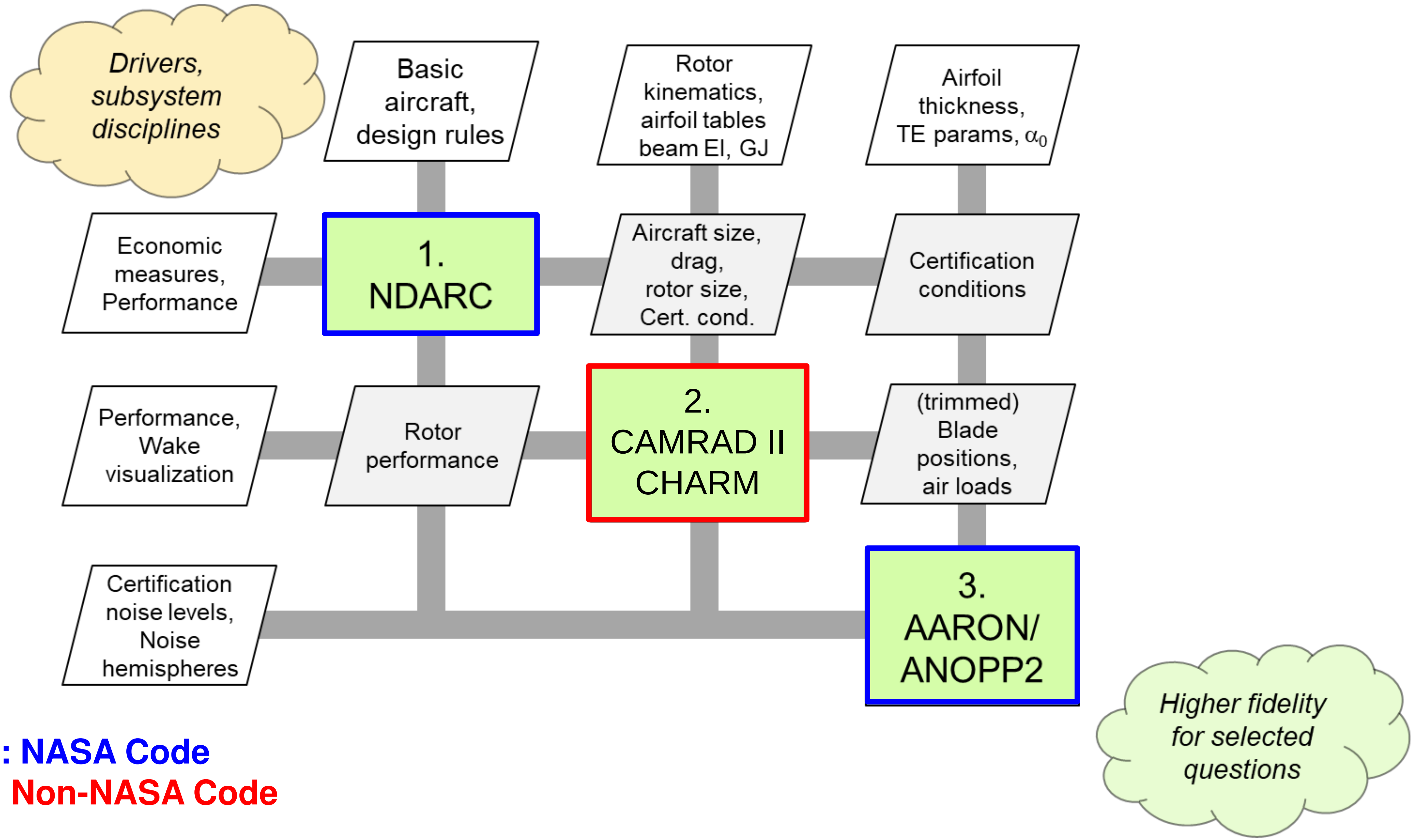
- Objectives
- Toolchain overview
- Tools used
- Selected cases
- Best practices to date
  - Data precision
  - Wake fidelity
  - Number of panels
  - Azimuthal resolution
  - Broadband inputs
- Status and conclusions
- Next steps
- Acknowledgements

Objective

Provide best practices for computing UAM vehicle acoustics with the NASA aerodynamic and acoustic prediction tool chain

- Identified prediction tools to compare:
  - Aerodynamics (provides blade loading)
    - **CAMRAD II:** Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics
    - **CHARM:** Comprehensive Hierarchical Aeromechanics Rotorcraft Model
  - Acoustics
    - **ANOPP2:** Aircraft NOise Prediction Program 2
    - **AARON:** ANOPP2's Aeroacoustic ROtor Noise tool
  - Coupling
    - **RCOTools:** Rotorcraft Optimization Tools
    - pyaaron
- Identify CAMRAD II and CHARM capabilities and limitations with regards to acoustics

NASA RVLT conceptual design toolchain



Blue color: NASA Code
Red color: Non-NASA Code

Aerodynamic tools

Non-NASA codes

CAMRAD II

- Acronym: **C**omprehensive* **A**nalytical **M**odel of **R**otorcraft **A**erodynamics and **D**ynamics[1]
- Comprehensive analysis code that simultaneously solves the rotor dynamics and aerodynamics for trimmed or transient flight conditions
- Developed by Johnson Aeronautics
- Lifting line with a wake model
- Mid-fidelity

CAMRAD II

CHARM

- Acronym: **C**omprehensive* **H**ierarchical **A**eromechanics **R**otorcraft **M**odel[2]
- Comprehensive Vertical Take Off and Landing (VTOL) aircraft analysis tool
- Developed by Continuum Dynamics, Inc. (CDI)
- Lifting line and lifting surface
- Mid-fidelity

CDI Continuum Dynamics, Inc

*** Comprehensive: Multi-disciplinary analysis using similar fidelity tools (aerodynamics, structures)**

1. Johnson, W., "Technology Drivers in the Development of CAMRAD II," American Helicopter Society Aeromechanics Specialist Meeting, San Francisco, CA, January 1994.
2.Quackenbush, T. R., et al., "Computation of Rotor Aerodynamic Loads in Forward Flight Using a Full-Span Free Wake Analysis," AIAA Paper 91-3229 and NASA CR 177611, September 1991 and October 1993.

Acoustic tools

NASA codes

- **ANOPP2**[1]: **A**ircraft **NO**ise **P**rediction **P**rogram **2**
  - Frameworks, tools, and functional modules for the acoustic calculation of thickness, loading, and broadband noise
- **AARON**: **A**NOPP2's **A**eroacoustic **RO**tor **N**oise tool
  - Fortran interface tool for rotorcraft noise calculation with ANOPP2
- Uses Farassat's Formulations: 1, 1A, G1A, G0, G1, V1, V1A, 2B
  - Capable of compact loading, compact thickness, impermeable surface, or permeable surface inputs
- Brooks/Pope/Marcolini[2] (BPM) semiempirical model for broadband noise

1. *L. Lopes and C. Burley. ANOPP2 user manual. NASA TM-2016-219342, 2016.*
2. *Brooks, T.F., Pope, D.S. and Marcolini, M.A. Airfoil Self-Noise and Prediction. NASA RP 1218, July 1989.*

Coupling tools

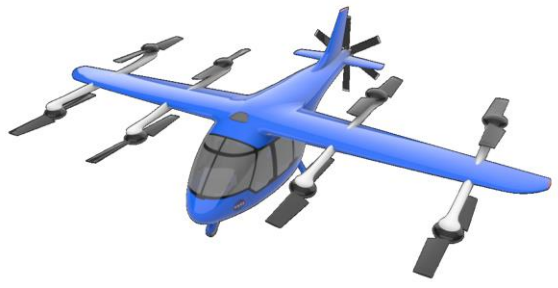
NASA codes

- RCOTools
  - Set of python utilities and wrappers for several rotorcraft design tools
  - Capable of reading, modifying, and writing files
  - Facilitates data transfer between tools
- pyaaron
  - Python based code for the automation of running noise prediction tools coupled with comprehensive analysis
  - Utilizes RCOTools for parsing and execution of comprehensive codes
  - Capable of both CAMRAD II + AARON and CHARM + AARON jobs
  - Adds additional capabilities to AARON

Selected cases

- **Lopes rotor**[1]
  - Simple geometry rotor used as initial validation case with available published predictions
- **NASA UAM conceptual design vehicles**[2]
  - QSMR, Side-by-Side, Quadrotor, Lift+Cruise, etc.
  - Start with QSMR



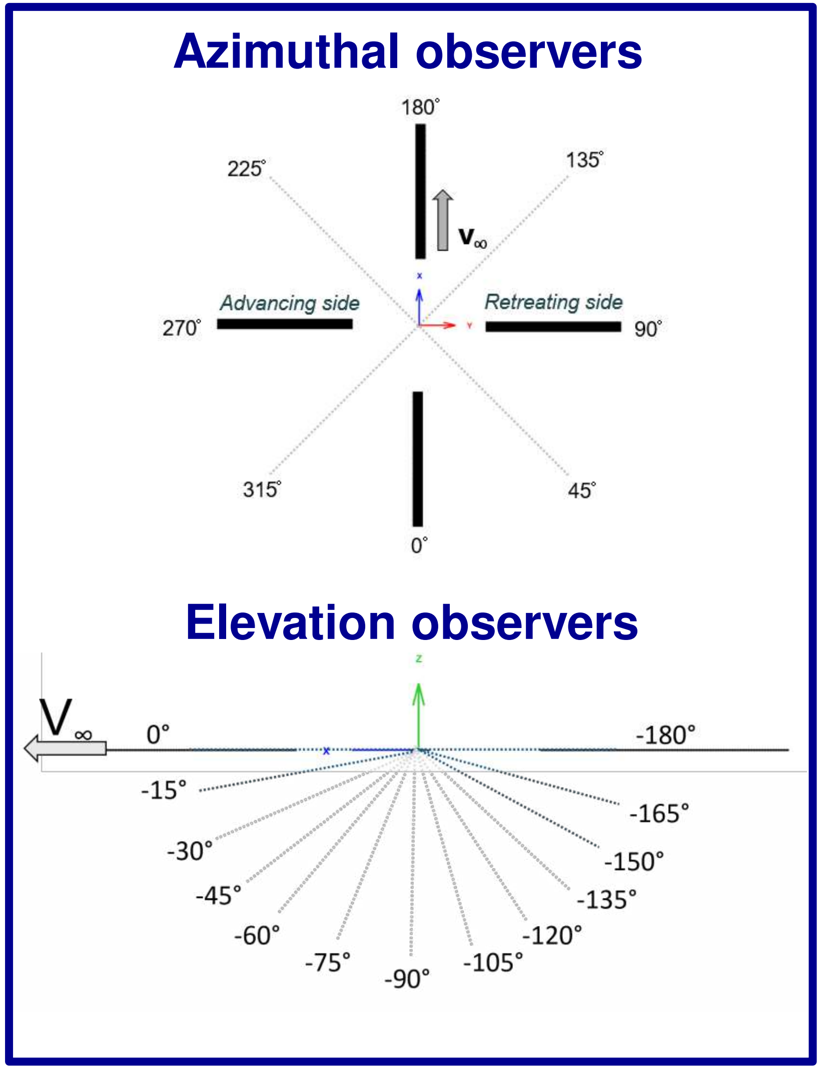



1. *Lopes, L. V., "Compact Assumption Applied to Monopole Term of Farassat's Formulations," Journal of Aircraft, Vol. 54, No. 5, 2017, p. 1649–1663.*
2. *Silva, C. and Johnson, W. Practical Conceptual Design of Quieter Urban VTOL Aircraft. Vertical Flight Society 77th Annual Forum, May 2021.*

Simple Lopes rotor

- Lopes[1] rotor is a simple, rigid, four-bladed isolated rotor, constant chord and airfoil section, no twist
- Published predictions (far-field, in-plane, thickness noise only reported by Lopes):
  - Low-speed: $\mu = 0.1$, $M_{AT} = 0.76$
  - High-speed: $\mu = 0.3$, $M_{AT} = 0.90$
- Observer locations:
  - 100 m from center of hub
  - Sweep of elevation and azimuthal angles

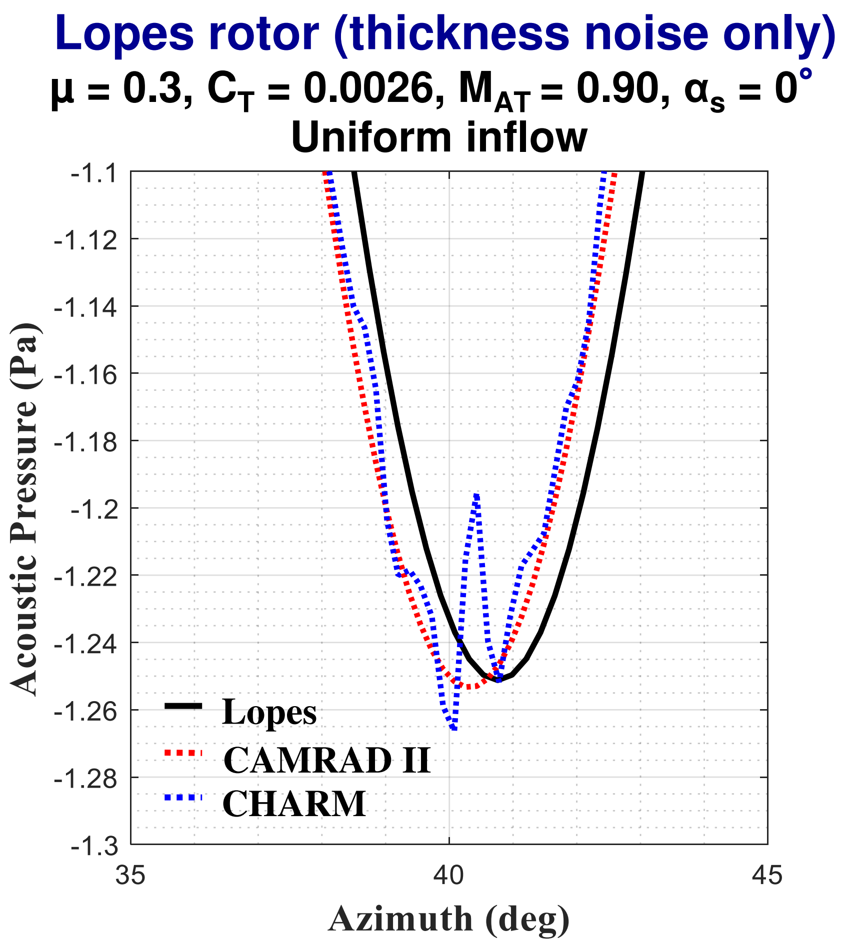
Parameter	Value
Number of blades	4
Radius [m]	10
Chord [m] (constant)	0.5
Linear twist rate [deg/span]	0
Airfoil (constant)	NACA 0012



1. Lopes, L. V., "Compact Assumption Applied to Monopole Term of Farassat's Formulations," *Journal of Aircraft*, Vol. 54, No. 5, 2017, p. 1649–1663.

Best practice #1: Precision

- Precision: the number of stored digits for a variable (# of digits = $2^{\#\text{ of bits}}$)
- CAMRAD II can be compiled with single or double precision (64 bits) and CHARM is compiled with single precision (32 bits)
- Derivatives magnify precision errors
  - Thickness noise requires a 2^{nd} order central difference, 3^{rd} source-time derivative (jerk)
  - Loading noise requires a 2^{nd} order central difference, 1^{st} source-time derivative (velocity)
- CHARM has plans to implement a double precision version



For precise acoustic predictions, using double precision calculations is recommended for input to AARON.

Best practice #2: Wake fidelity

- Wake setting has increasing complexity and accuracy from simple wake to free wake

Simple wake	→	Rigid wake	→	Free wake
• Blade Element Momentum Theory • Simple variation over the blade	→	• Models the wake as a skewed helix • No wake contractions or vortex distortions	→	• Position of wake elements determined due to induced velocities • Full wake contractions and vortex distortions

- For more precise acoustic predictions, a free wake should be used to capture noise sources such as BVI
  - A simple wake should be used when troubleshooting initial comprehensive cases
  - When debugging a free wake case, use rigid wake calculations to reduce computation time

For best practice, start with a simple wake case to ensure convergence, then increase complexity to rigid wake, then to free wake.

Best practice #3: Panels

- Panels are used to separate the blade into spanwise sections
  - In CAMRAD II, panels define the aerodynamic sections and wake sections (wake trailers)
  - In CHARM, wing aerodynamic panels and wake trailers are separately defined
- The number of panels in CAMRAD II should be considered to avoid convergence issues
  - Calculation errors occur in CAMRAD II if wake trailers are too close together in areas of complex flow (example: reverse flow region)

For best practice, 15-25 panels in CAMRAD II is sufficient for *most* rotors to capture wake detail without causing convergence issues, while 50 panels in CHARM is sufficient.

Best practice #4: Azimuthal resolution

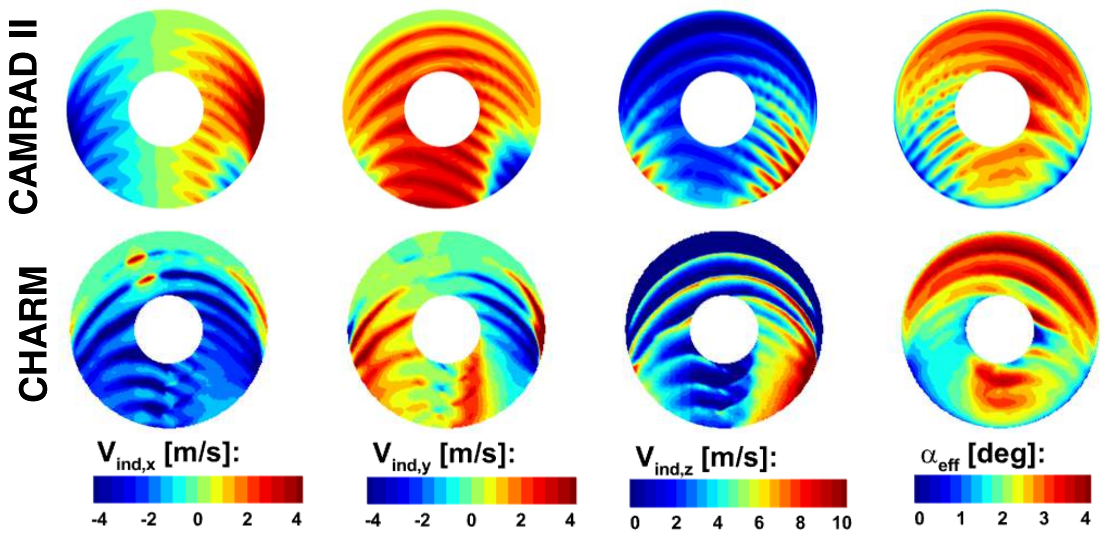
- For acoustic predictions, high azimuthal resolution is required to capture all frequency content, but initial runs should be done with lower resolution
- CHARM should not be run with more than 120 azimuthal steps
  - Too many azimuthal stations causes algorithm failure
  - Initial calculations are done at a low resolution, then reconstruction back-calculates the resolution needed for acoustics

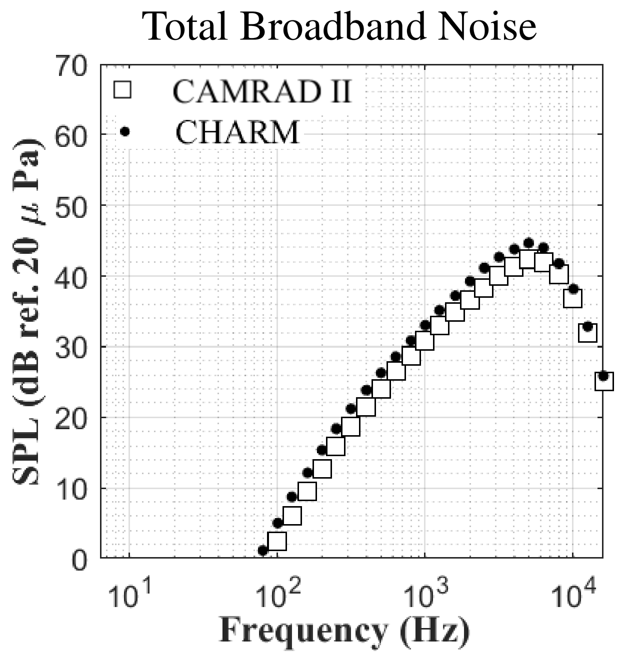
– CAMRAD II computes initial trim with a lower resolution, then can calculate post-trim with higher resolution
  - Post-trim calculates one revolution with high resolution but frozen motion and trim
  - This is similar to the reconstruction process in CHARM

For best practice, run initially with 24 azimuthal steps, then use reconstruction (CHARM) or post-trim (CAMRAD II) with 240 steps.

Best practice #5: Broadband inputs

- The BPM model used by AARON predicts broadband noise due to turbulence, separation, vortex formation, and vortex shedding
- CHARM or CAMRAD II provides **effective angle of attack** and **x, y, and z induced velocity** (all other inputs are geometric and are user specified)





Lopes rotor, free wake, μ = 0.142, M_{AT} = 0.79, α_s = 5°

For best practice, prior to predicting broadband noise, induced velocity and effective angle of attack over the rotor disk should be analyzed.

Status and conclusions

- Completed analysis of the Lopes rotor
  - Analyzed thickness, loading, and broadband noise for various flight conditions
  - Documented missteps from an initial exercise of the tool chain
- Identified five major best practices for the acoustics toolchain to date (October 2022):
  1. For precision calculations, use a double precision precursor to AARON
  2. Start with a simple wake troubleshooting, then use a free wake for accurate loading noise predictions
  3. Number of spanwise aerodynamic panels must be consistent with analysis method and accuracy required
  4. High azimuthal resolution required for accurate loading noise calculations, but CHARM requires the use of reconstruction
  5. Both comprehensive analysis codes provide effective angle of attack and induced velocity for broadband noise, in addition to geometric parameters required

Next steps

- Ensure realistic flight conditions are used with the Lopes rotor
  - Present the best representative case
  - Thrust values, collective values, 0 hub moments, etc.
- Move to the NASA UAM conceptual design vehicles
  - Higher detail CAMRAD II and CHARM models
  - Test current best practices with these vehicles
  - Explore hub modeling impacts for acoustics
- Begin collecting all best practices into a comprehensive document

Acknowledgements

- William Warmbrodt (ARC)
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- Doug Boyd (LaRC)
- Leonard Lopes (LaRC)
- Dan Wachspress (CDI)
- Christopher Silva (ARC)
- Ethan Romander (ARC)
- Larry Meyn (ARC)
- Gloria Yamauchi (ARC)
- Carlos Malpica (ARC)

Thank you!

Questions?

Small Business Innovation Research (SBIR) &
Small Business Technology Transfer (STTR) Program

Phase I Proposal #A1.02-1269
Phase II Order #80NSSC19C0088

Reduced-Order Acoustic Prediction Tool for Ducted Fan Noise Sources Including Inflow Distortion and Turbulence Ingestion

NASA Glenn Fall ATWG

Oct 19, 2022

Techsburg/AVEC Team

Dr. Jon Fleming, Matt Langford, Will Walton, Jacob Gold (Techsburg)
Dr. Ricardo Burdisso, Kyle Schwartz, David Wisda, Bennett Witcher, Dr. Patricio Ravetta (AVEC)
Cory Combs, Brice Nzeukou, Susan Ying (Ampaire)
Dr. William Devenport, Dr. Nathan Alexander (Virginia Tech)

NASA Technical Monitor
Dr. David Stephens
Acoustics Branch
NASA Glenn

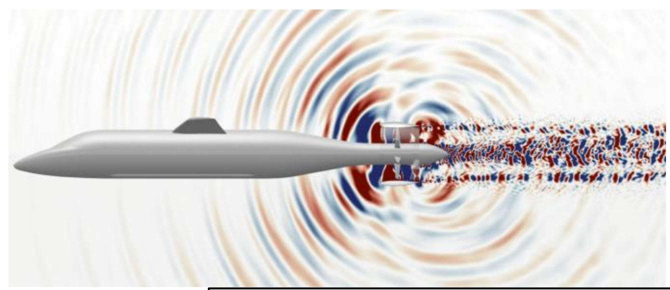
SBIR Project Summary

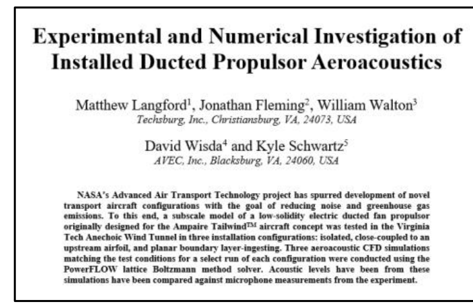
- Objective: Support early design cycle acoustic analysis for ducted fan propulsors
  - Deliverable: "Installed Ducted Fan Noise Model" software
  - Include installed effects to analyze pusher and boundary layer ingesting (BLI) configurations
  - Supported Ampaire Tailwind propulsor design during Phase I (electric 9-passenger regional transport)
    - Used for basis of wind tunnel testing and PowerFLOW analysis during Phase II

- Special thanks to Dr. David Stephens of NASA Glenn for his work as Technical Monitor for Phases I and II

- Project work also to be presented in upcoming paper at the AIAA SciTech Conference (Jan 2023)


Ampaire Tailwind



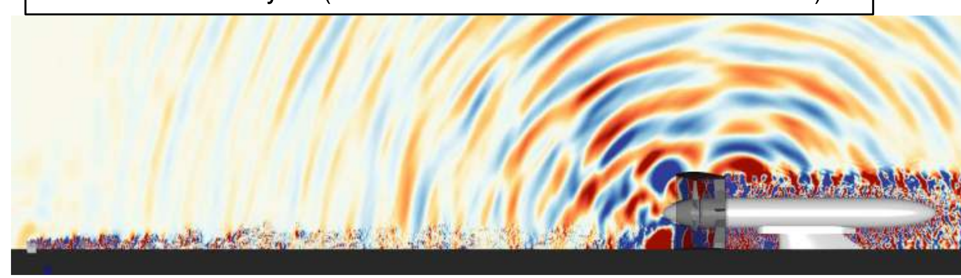

Experimental and Numerical Investigation of Installed Ducted Propulsor Aeroacoustics

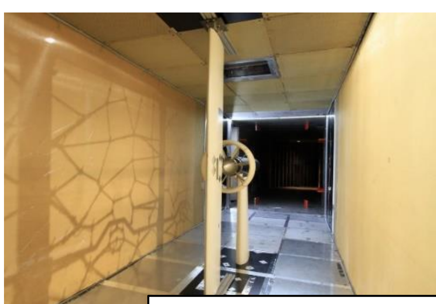
Matthew Langford[1], Jonathan Fleming[2], William Walton[3]
Techsburg, Inc., Christiansburg, VA, 24073, USA

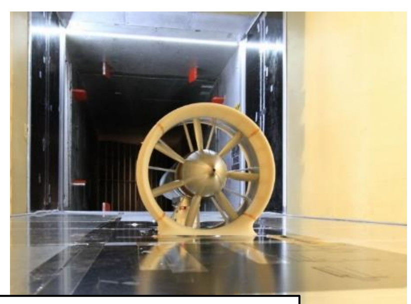
David Wisda[4] and Kyle Schwartz[5]
AVEC, Inc., Blacksburg, VA, 24060, USA

NASA's Advanced Air Transport Technology project has spurred development of novel transport aircraft configurations with the goal of reducing noise and greenhouse gas emissions. To this end, a subscale model of a low-solidity electric ducted fan propulsor originally designed for the Ampaire Tailwind™ aircraft concept was tested in the Virginia Tech Anechoic Wind Tunnel in three installation configurations: isolated, close-coupled to an upstream airfoil, and planar boundary layer-ingesting. Three aeroacoustic CFD simulations matching the test conditions for a select run of each configuration were conducted using the PowerFLOW lattice Boltzmann method solver. Acoustic levels have been from these simulations have been compared against microphone measurements from the experiment.

PowerFLOW analysis (full aircraft and wind tunnel simulations)






Virginia Tech Anechoic Wind Tunnel Testing

NASA SBIR Phase II – Team Contact Info

Reduced-Order Acoustic Prediction Tool for Ducted Fan Noise Sources Including Inflow Distortion and Turbulence Ingestion

Phase I Proposal No. A1.02-1269, Phase II NASA Order No. 80NSSC19C0088

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Other subcontract: Virginia Tech Anechoic Wind Tunnel – wind tunnel use

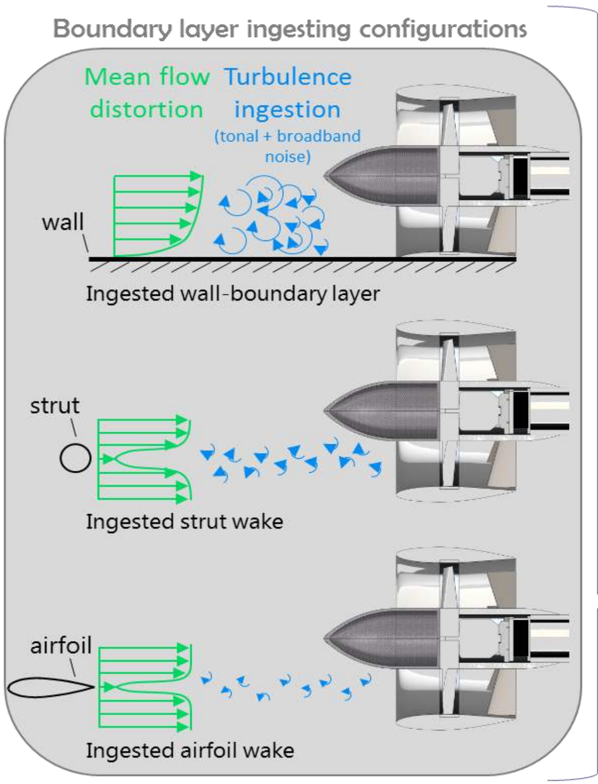
Outline

- Software Overview
  - Identification of need
  - Phase II task summary
  - IDFNM code summary and status
- Noise Source Modeling
  - Turbulence ingestion noise (“TIN”) modeling
  - Validation data comparisons
- Summary and Future Work

Techsburg, AVEC, and Ampaire | NASA Order No. 80NSSC19C0088

Identification of Need

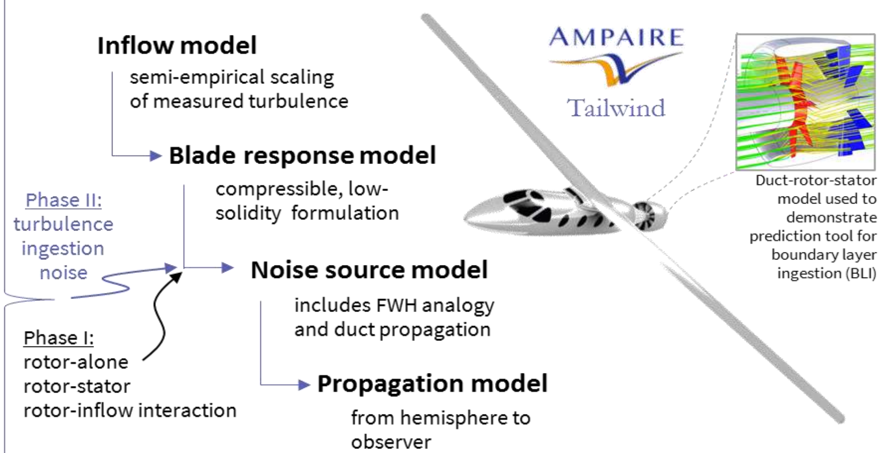
- SBIR work focused on aeroacoustics of installed effects for ducted fans
  - Phase I: address mean inflow distortion sources (i.e., pusher propulsor wake ingestion)
  - Phase II: address turbulence ingestion source (i.e., BLI) ⇦ (***Key technology need***)
    - No current generalized reduced order modeling tool available to address TIN source
    - Turbulence ingestion leads to increases in tonal + broadband acoustic energy



Primary Phase II tasks:

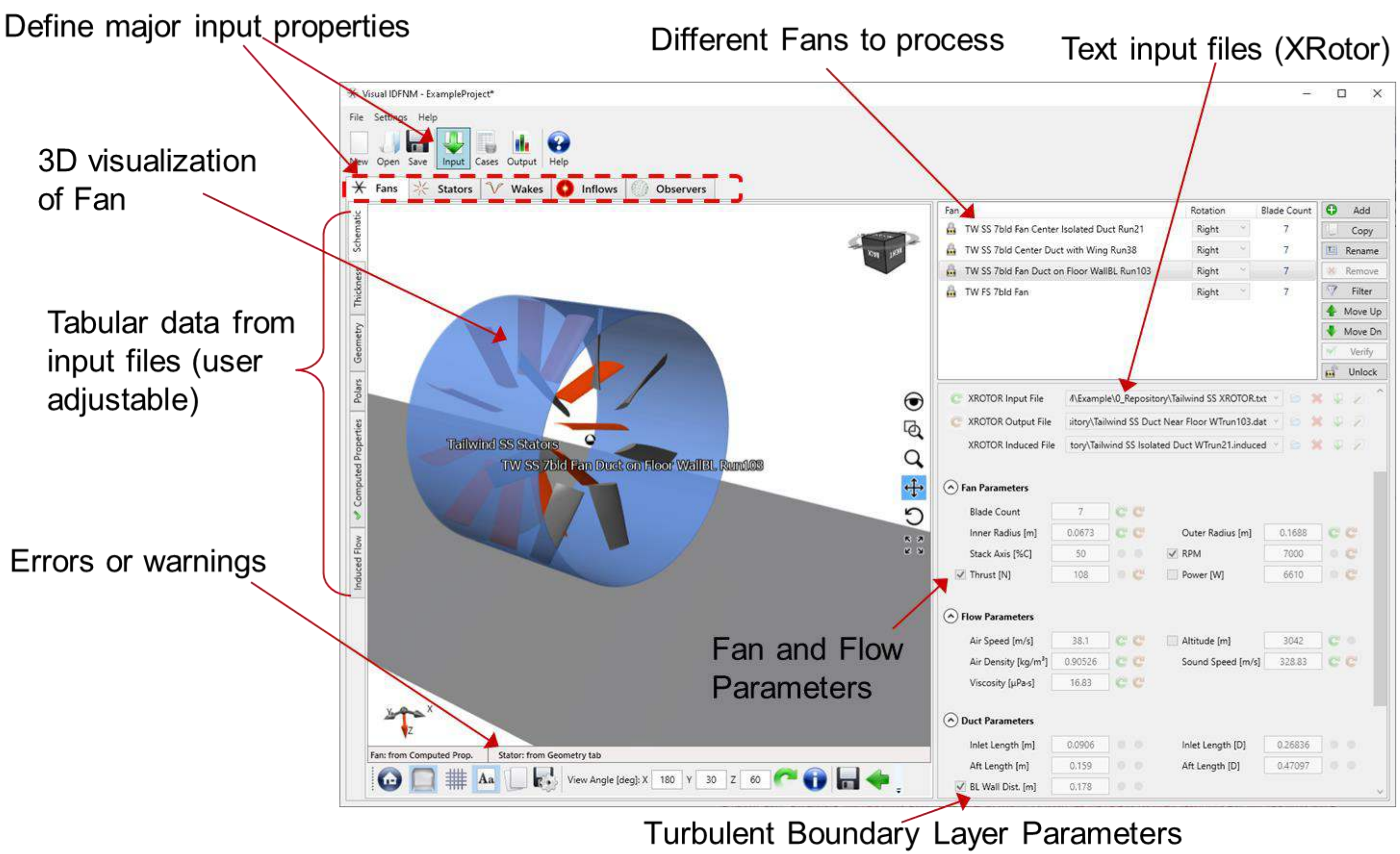
- Task 1: Code development
  - "IDFNM" – compiled MATLAB; Fortran; VB .NET
- Task 2: Noise model development
  - Turbulence-rotor ingestion noise model development
- Task 3a: Anechoic wind tunnel testing (at Virginia Tech)
- Task 3b: PowerFLOW simulations
  - Techsburg's PowerFLOW computing cluster / 128 cores

Turbulence ingestion noise ("TIN")



IDFNM Software Description and Status

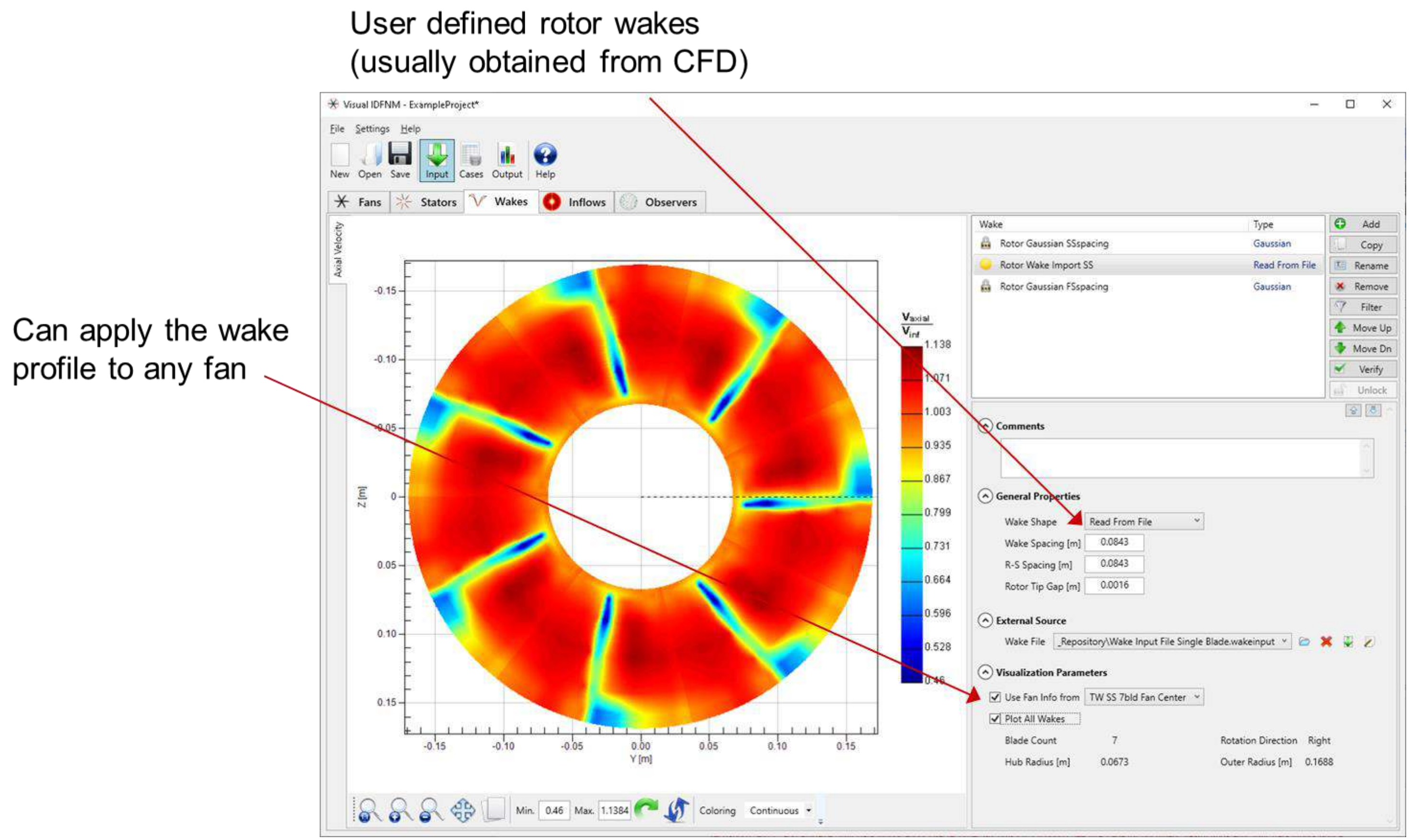
- IDFNM software predicts 3 different noise sources for ducted fans:



Future work: Incorporate other sources such as broadband rotor self-noise, stator broadband, etc.

IDFNM Software Description and Status

- IDFNM software predicts 3 different noise sources for ducted fans:
  - **Tonal**: Rotor-stator interaction source. Tool used is V072 (NASA). Accepts user defined wakes (CFD).



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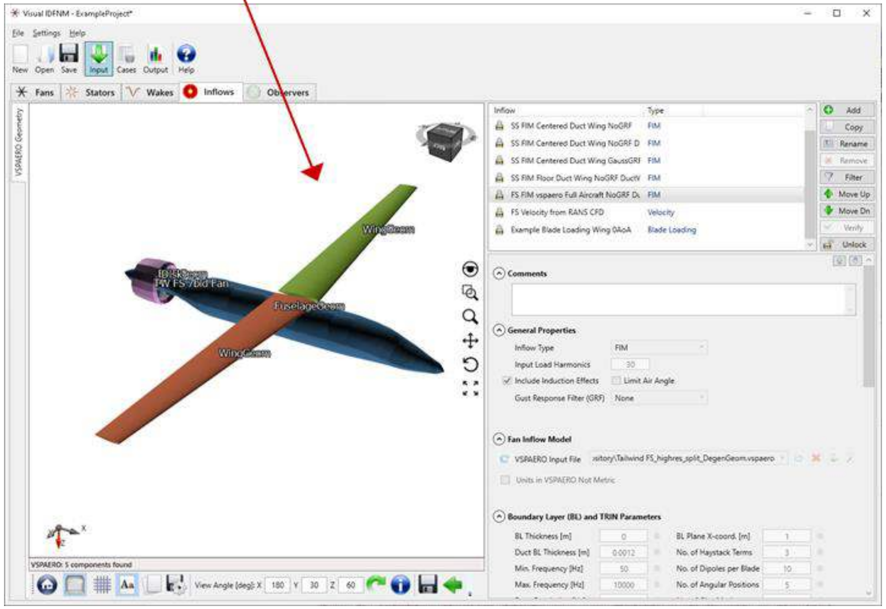
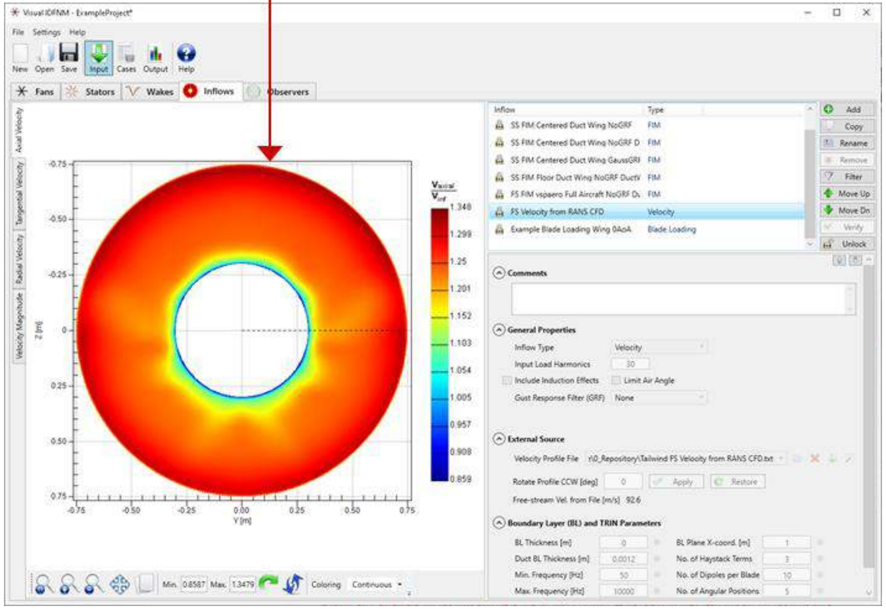
- IDFNM software predicts 3 different noise sources for ducted fans:
  - **Tonal**: Rotor-stator interaction source. Tool used is V072 (NASA). Accepts user defined wakes (CFD).
  - **Tonal**: Rotor Alone (steady loading) and Rotor Inflow Interaction (unsteady loading). Inflow interaction can be input from VSPaero, CFD velocity, or blade Loading directly.

FIM (VSPaero) defines the aircraft geometry and flow settings in a *.csv and *.vspaero text file

Velocity at fan face can also be input (bypassing FIM) and the code will calculate loading on blades.





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IDFNM Software Description and Status

- IDFNM software predicts 3 different noise sources for ducted fans:
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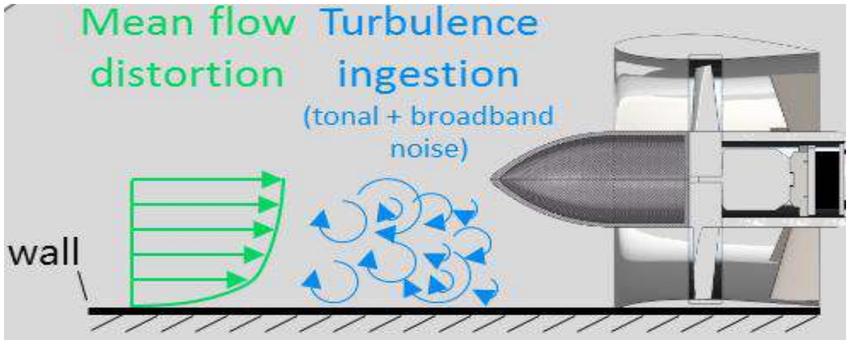
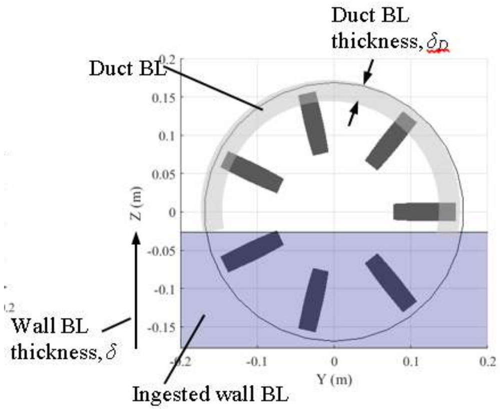
  - **Tonal**: Rotor Alone (steady loading) and Rotor Inflow Interaction (unsteady loading). Inflow interaction can be input from VSPaero, CFD velocity, or blade Loading directly.
  - **Broadband**: Turbulence-rotor interaction noise source (← ***development of this tool was one of the key goals of the Phase II effort***)

    Two sources modelled

    A) ingested wall boundary layer, and

    B) duct wall boundary layer.



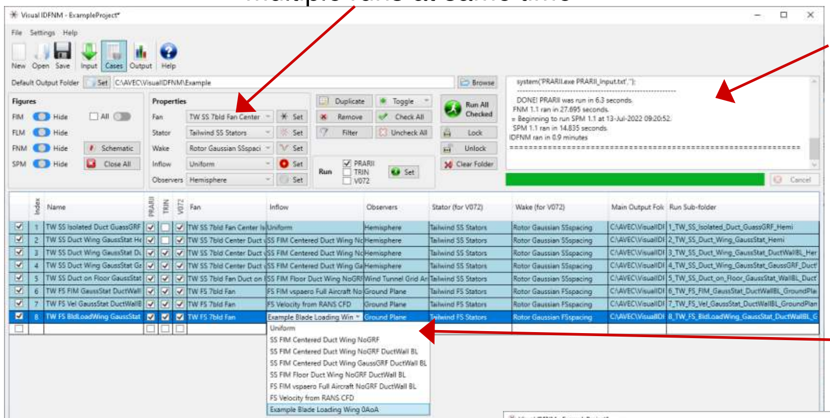


IDFNM Software Description and Status

- IDFNM software GUI also allows:
  A. To run multiple configurations in batch mode
  B. To present results in graphical and tabular forms

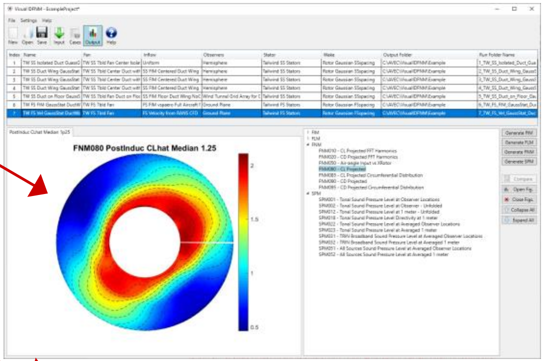
Set fan/stator/inflow/etc for multiple runs at same time

Processing status (~1 minute runtime for this case)

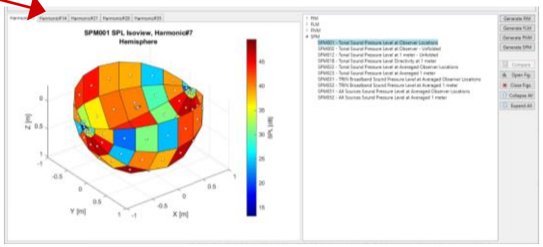


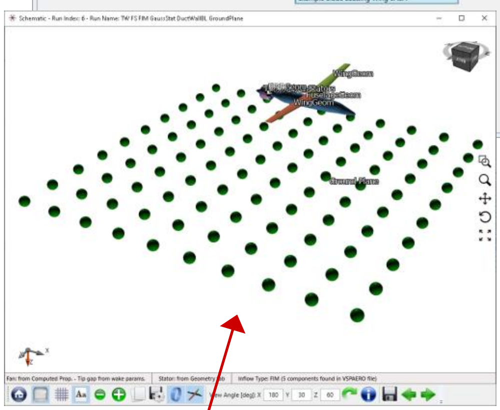
Select fan/ inflow/ observer/ stator/ wake for a given run

All figures that have been generated can be easily shown

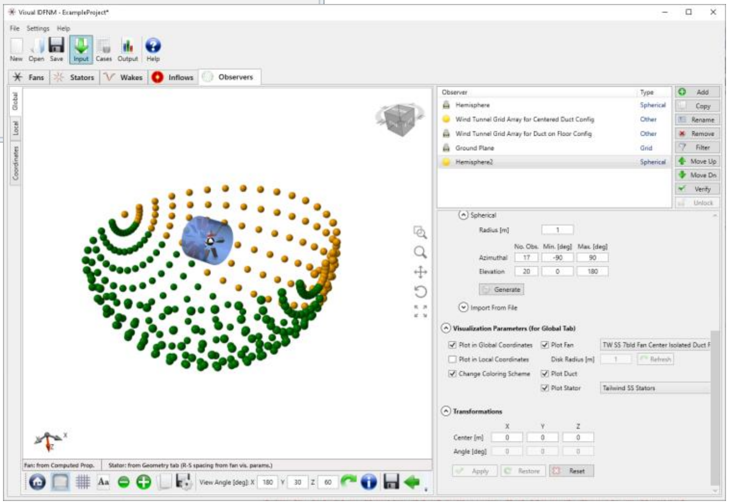


Noise results for each BPF are shown in sub-tabs

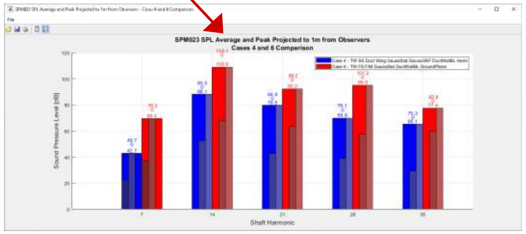




Schematic shows entire system to be predicted



Comparison of noise results between runs is available



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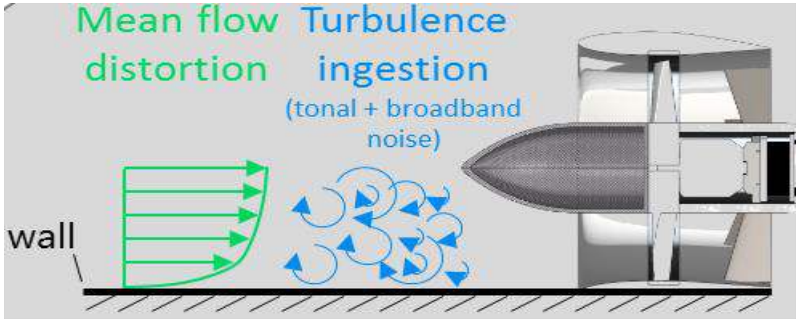
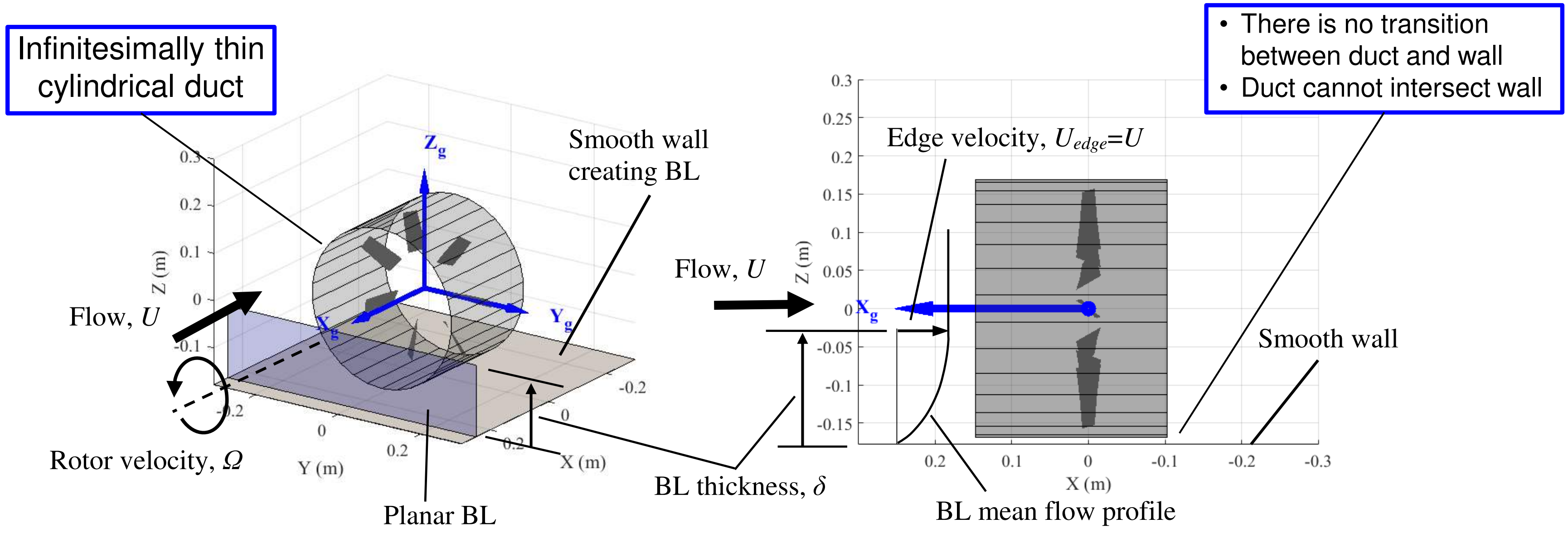
Overview of Turbulence Ingestion Noise Modeling (1)

Actual Problem



Assumptions in TIN Formulation



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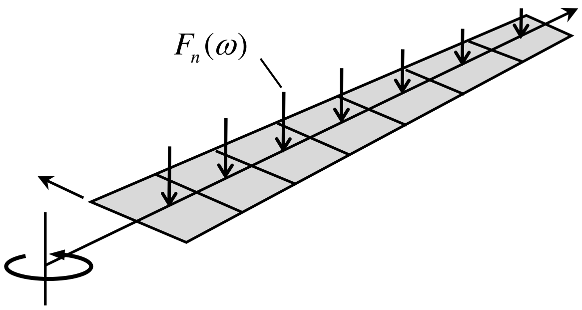
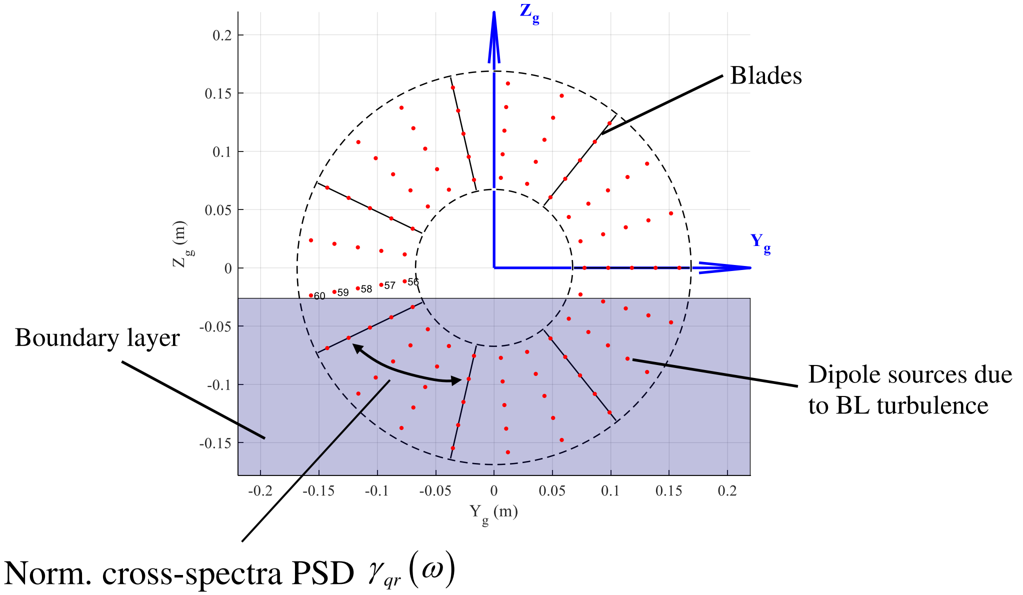
Modeling of Dipole Sources due to Turbulence

- Unsteady pressure due to turbulence over blades approximated by a set of discrete forces (dipoles) evenly spaced, $F_n(\omega)$ (compact formulation).
- Discrete forces are then used to compute the radiated acoustic pressure at the virtual microphones.



- Problem is not axisymmetric and thus the blade section forces will vary with azimuth position.
- Rotor rotation over the inter-blade angle simulated assuming a set of evenly spaced azimuth positions.
- Cross-correlation between blade forces accounted for using normalized cross-spectra PSD $\gamma_{qr}(\omega)$ computed from BL turbulence properties



NOTES:
- BL transversal turbulence properties used to compute dipole strength.
- BL streamwise turbulence properties used to compute hay-stacking effect in spectrum.

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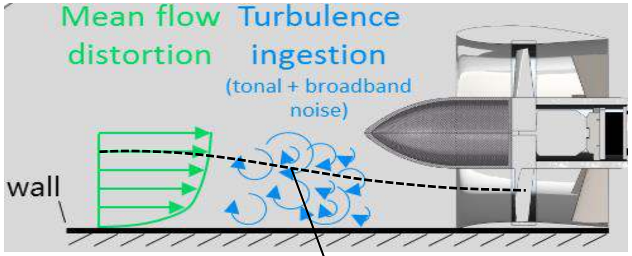
Overview Turbulence Ingestion Noise Modeling (3)

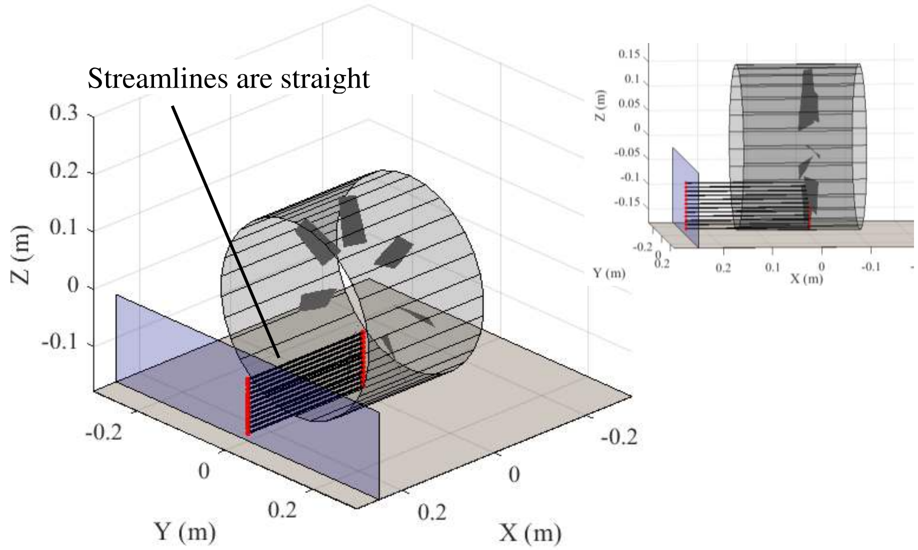
Streamlines From BL to Rotor

- TIN code requires to relate the **known** boundary layer turbulence properties upstream of the duct with the **unknown** turbulence on the rotor.
- A flow solver is required to find streamlines relating points on BL upstream to points on the rotor (Not implemented).
- In TIN, the streamlines from the boundary layer plane to the rotor are simply straight lines.



Streamline from BL upstream to rotor plane

Streamline in TIN Model



- TIN code also requires knowing the relative flow velocity over the rotor (again not axisymmetric).
- TIN uses XROTOR to compute flow at rotor plane.

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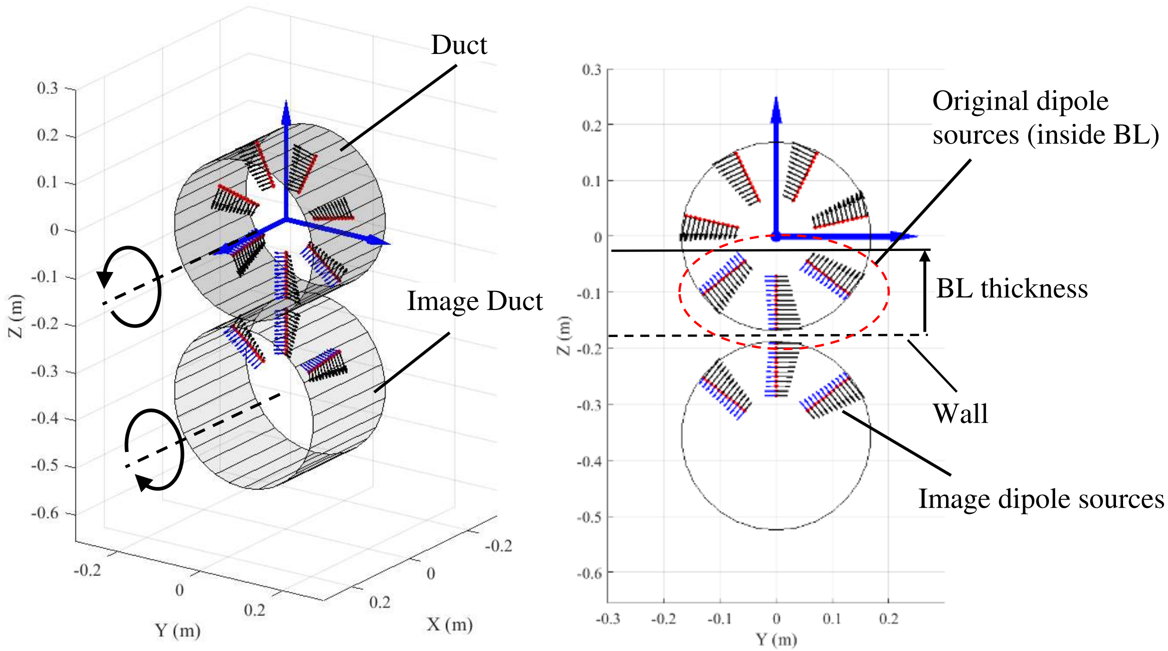
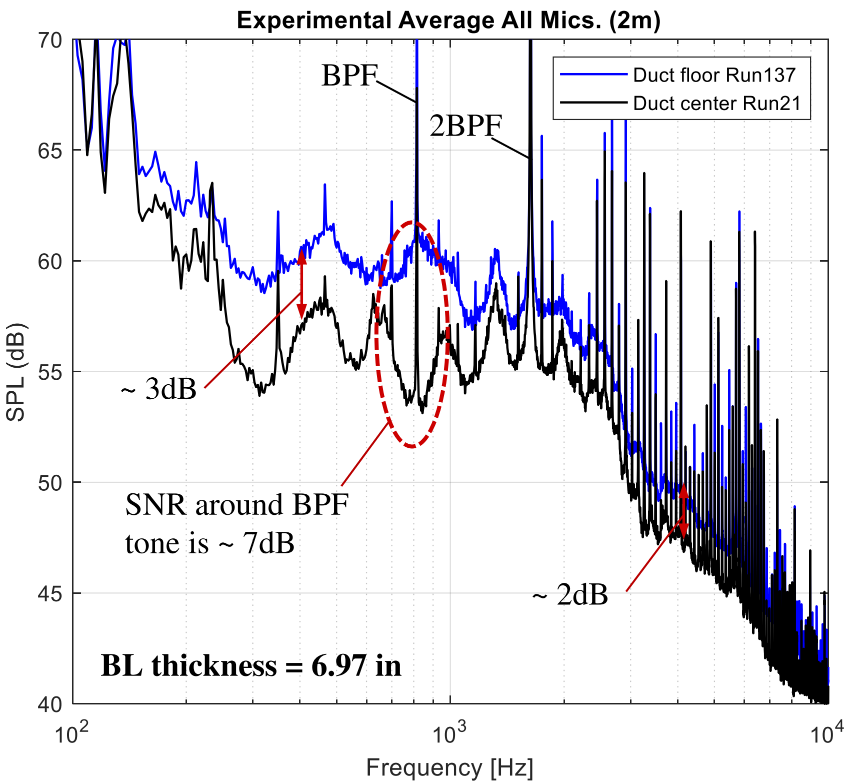
Radiation to Virtual Microphones

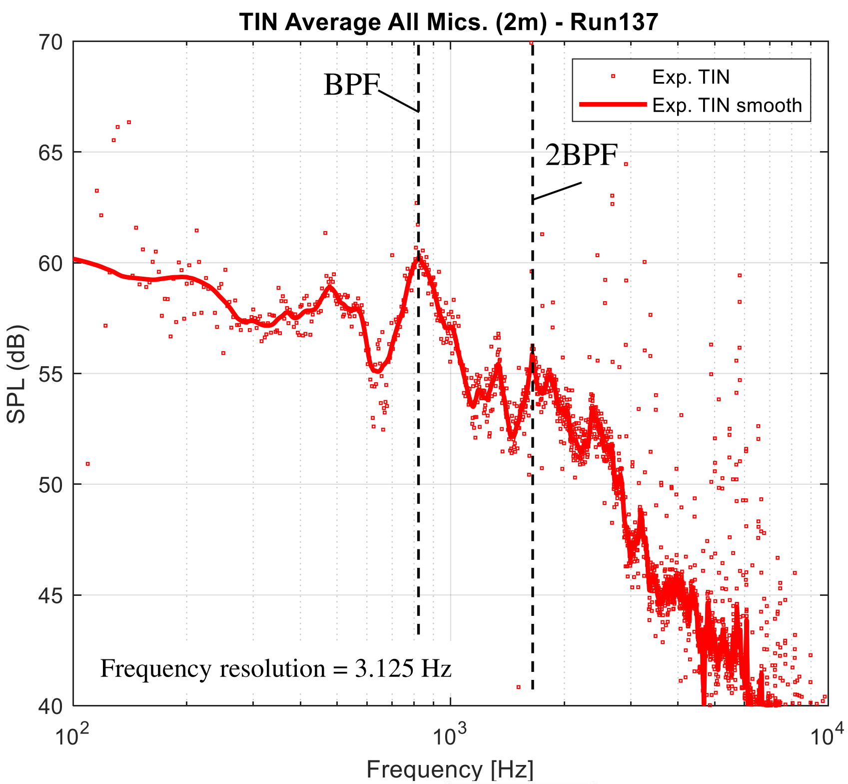
- The final step in the modeling is the computation of the pressure at the virtual microphone location knowing the dipole strengths (PSD) and their cross-correlation.
- The boundary integral equation method (TBIEM3D) developed by Dunn, Tweed and Farassat (1996, 1997, 1998) was implemented.
- TBIEM3D has primarily 2 source model options (spinning and stationary dipole ← implemented).
- TBIEM3D does not account for the reflection from the wall. To include the wall reflection, the image method was implemented (source and image pressure at observers added coherently).



Overview Turbulence Ingestion Noise Modeling
Validation Using WT Test Data (1)

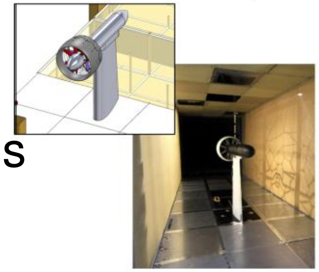
Estimated TIN noise for the "average" of 60 microphones





- TIN estimated from difference between duct floor and duct center wind tunnel (WT) test levels:

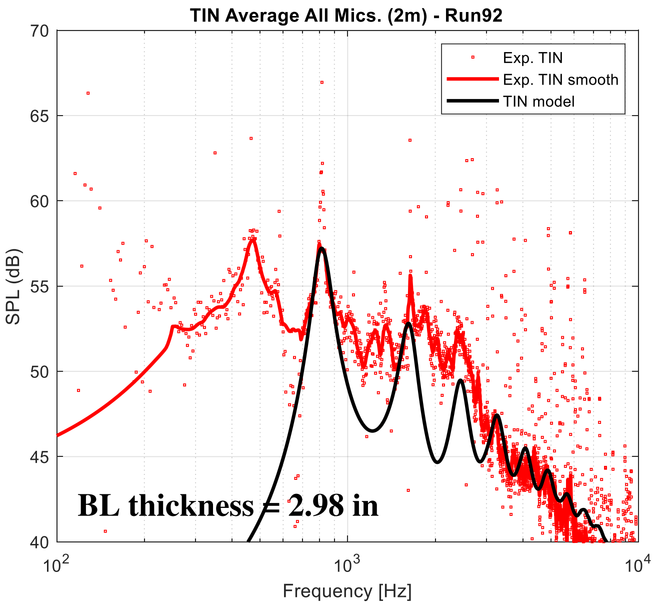
minus

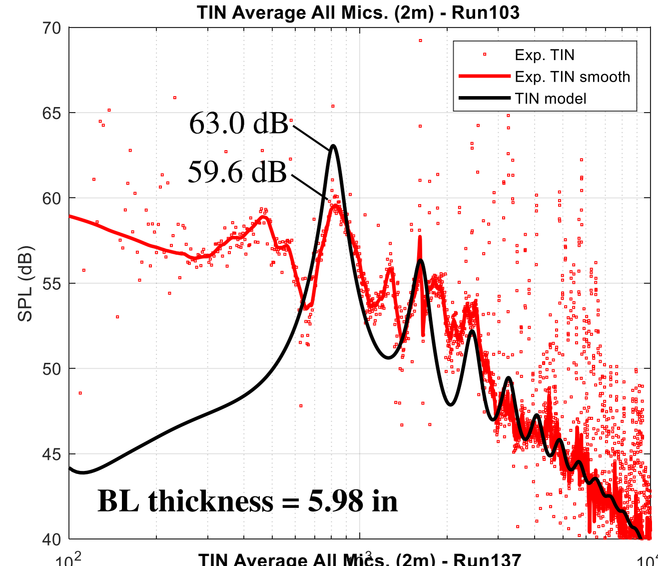


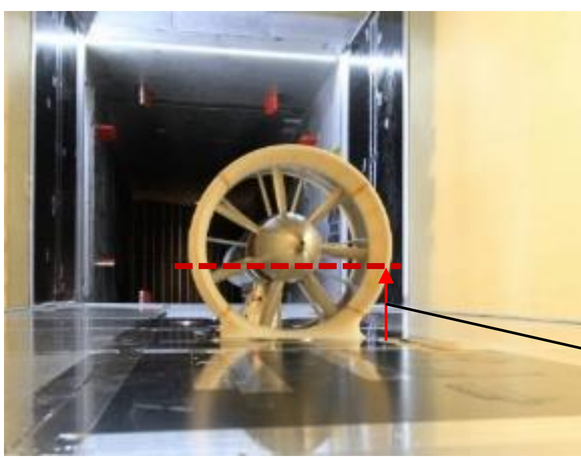
Overview Turbulence Ingestion Noise Modeling

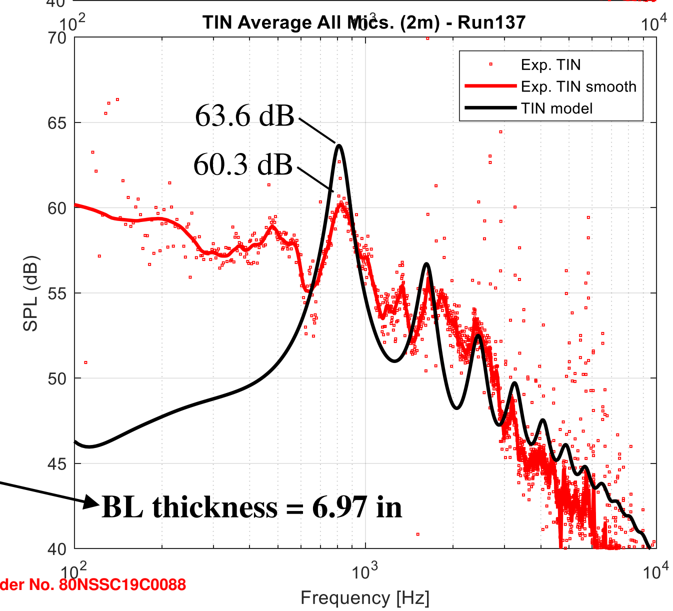
Validation Using WT Test Data (2)

Measured vs Predicted TIN noise









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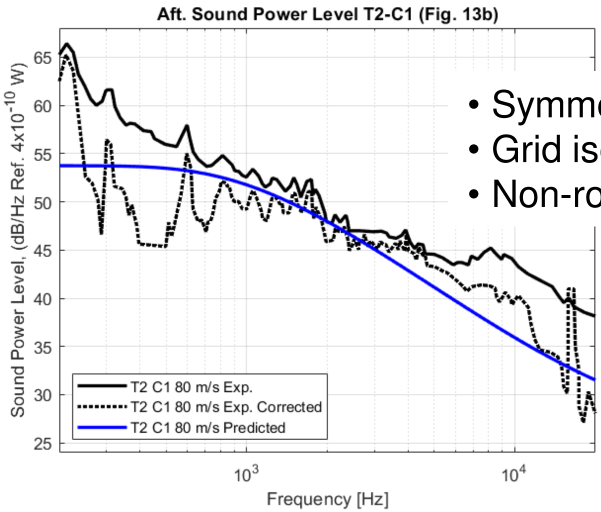
Overview Turbulence Ingestion Noise Modeling
Validation Using Open Literature Data for TIN Noise

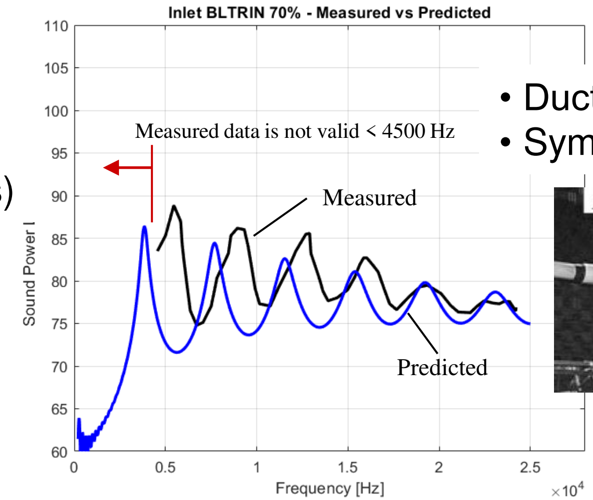
Posson and Roger, 2011 (ducted case):



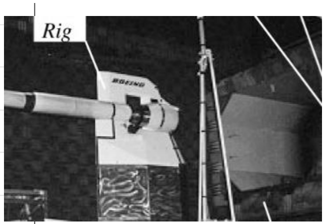
- Symmetric problem
- Grid isotropic turbulence
- Non-rotating blades (stators)

Fig. 1 Downstream view of the experimental setup.

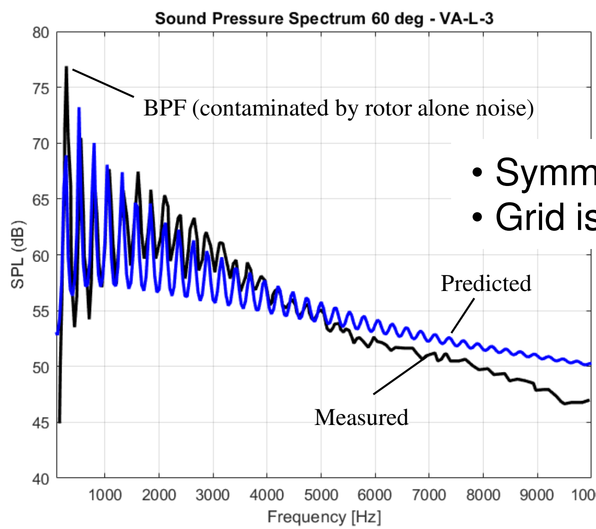
Ganz et al., 1998 (ducted case)



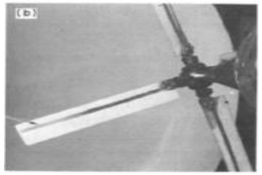
- Duct's BL ingestion
- Symmetric problem



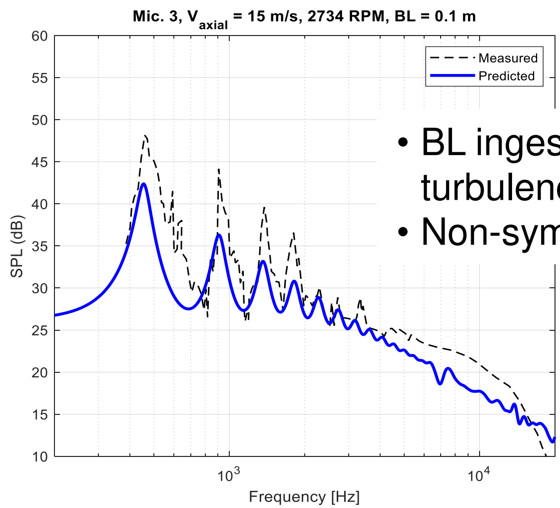
Paterson and Amiet, 1982 (propeller)



- Symmetric problem
- Grid isotropic turbulence



Alexander et al., 2014 (propeller)



- BL ingestion (anisotropic turbulence)
- Non-symmetric problem

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- Summary and Future Work

Summary and Future Work

- Summary
  - The “Installed Ducted Fan Noise Model” (IDFNM) first generation software tool is available
    - Will be supported with ongoing development
  - Validation data sources include wind tunnel data and PowerFLOW analysis (wind tunnel and full aircraft)

- Future Work
  - IDFNM
    - Use radiation code TBIEM3D for all sources (requires changes/improvements to TBIEM3D, near future)
    - Incorporate additional noise sources (rotor self-noise, stator broadband, etc. on-going)
      - Example future inflow distortion sources: tilted/edgewise flight ducted fan inflow; fan-in-wing inflow distortion, etc.
  - Reduced-order modeling of rotor/prop-rotor turbulence ingestion
    - UAM vehicle applications
    - Have compared current model against outdoor rotor hover acoustic data
  - Reduced-order acoustic models using machine learning
    - Use PowerFLOW for model training
    - Current NASA Phase II for modeling of truss-braced wing geometry aeroacoustics

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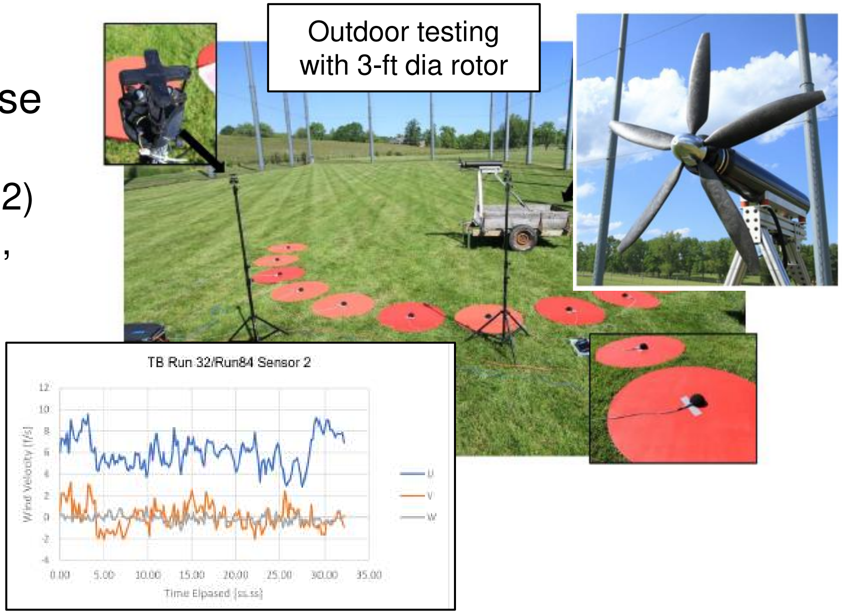
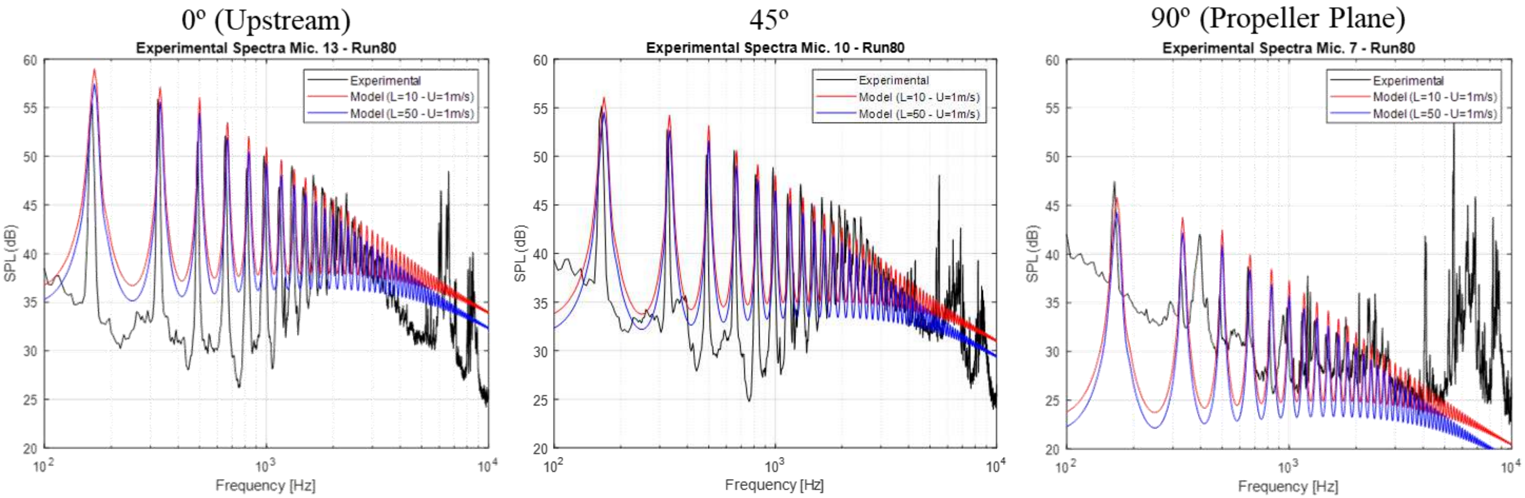
Rotor Atmospheric Turbulence Ingestion

- In-house developed model that predicts narrowband atmospheric turbulence ingestion noise
- Formulation is at its core the same except:
  - atmospheric turbulence model by Højstrup et al. (1982) and Olesen et al. (1984) used (inputs are wind speed, height, and atmopheric stability condition)
  - No duct radiation



Preliminary Comparison vs. Exp. Data

(using two different values for parameter "L")



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Current NASA Phase II: Reduced Order Models Using Machine Learning

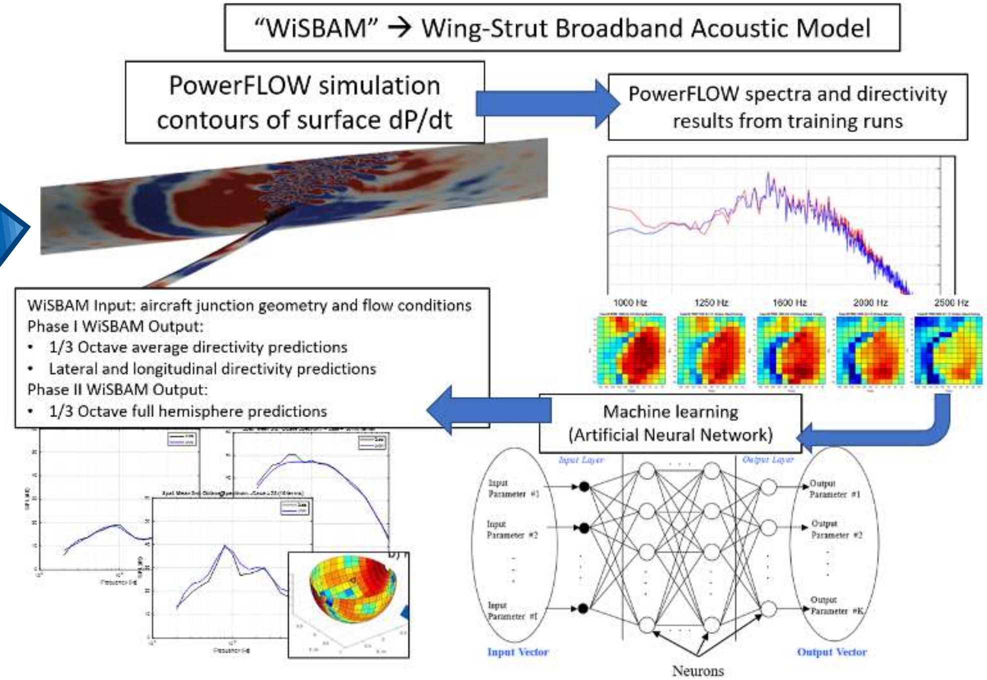
Small Business Innovation Research (SBIR) & Small Business Technology Transfer (STTR) Program

"Design Cycle Prediction Software for Wing-Strut Junction Flow Noise"

- Phase I Proposal No. 2021-I-A1.02-2819 (TPOC: Mehdi Khorrami)
- Phase II Order No. 80NSSC22CA110 (TPOC: David Lockard)
  - Period of performance: May 2022-May 2024

Transonic Truss-Braced Wing concept aircraft (NASA/Boeing)

Boeing Image



PHASE I: Feasibility study for developing reduced-order acoustic model of TTBW junction

PHASE II: Expand modeling input parameters and implement in Wing-Strut Broadband Acoustic Model ("WiSBAM")

This approach provides a general blueprint to address complex aeroacoustic problems characteristic of real vehicles operating in the environment.

Event Q&A

Can you explain how you included the scattering effects of the duct?

The computation of the pressure at an observer requires the transfer function between the dipole forces on the blade sections and the acoustic pressure at the observers. In the formulation, this transfer function is computed using a modified version of the TBIEM3D code (Dunn, 1997). The ducted fan noise prediction code TBIEM3D is based on a Boundary Integral Equation Method developed by Dunn, Tweed and Farassat.

TBIEM3D predicts the acoustic pressure scattered by an infinitesimally thin, finite length cylindrical duct due to known internal sound sources. Thus, the total sound field is given as the linear superposition of a known incident (without the presence of the duct) and unknown scattered component (due to the duct) computed by TBIEM3D. Computing the incident sound field is the key to use this code to model radiation from different noise sources. There are two types of dipole sources modeled in TBIEM3D. The first one is a circumferential array of spinning dipoles used to predict fan loading noise at the BPF and harmonics. The second one is a single stationary dipole align with the duct axis with arbitrary harmonic strength. This source was used in the formulation. However, this source have some limitations: i) the dipole source is aligned along the duct axis and, thus, the dipole direction related to the blade twist cannot be accounted for and ii) the dipole source is not spinning. Thus, there is need to further develop this code.

References:

Dunn, M. H. (1997). TBIEM3D – A computer program for predicting ducted fan engine noise, version 1.1. NASA/CR-97-206232, September 1997.

Dunn, M. H. and Farassat (1998). Liner optimization studies using the ducted fan noise prediction code TBIEM3D. AIAA/CEAS Paper no. 2310, June 1998.

Dunn, M. H., J. Tweed, and F. Farassat (1999). The application of a Boundary Integral Equation Method to the prediction of ducted fan engine noise. Journal of Sound and Vibration (1999) 227(5), 1019}1048.

UAM Noise Working Group Meeting
Welcome, Agenda, and Updates

20 October 2022

Hybrid Meeting

Group Leads:

Brenda Henderson and Stephen Rizzi

Update on Spring 2022 UNWG Meeting

- Prior to the Spring 2022 meeting, subgroups expressed concern over the scope of UNWG as it appears in the white paper and charter
- During the Spring 2022 meeting, subgroup breakout session were held to discuss potential modifications to the UNWG scope
- Original (and current) UNWG scope

The UNWG shall focus its efforts on noise issues of UAM vehicles and operations with representative attributes including†

- *electric vertical takeoff and landing (eVTOL) vehicles that can accommodate up to 6 passengers (or equivalent cargo),*
- *possible autonomy,*
- *missions of up to 100 nautical miles at altitudes up to 3000 ft. above ground level,*
- *flight speeds up to 200 knots, and*
- *payloads between 800 and 8000 pounds*

Update on Spring 2022 UNWG Meeting (con't)

- Summary of breakout sessions
  - Subgroup 2: Ground & Flight Testing
    - ✓ Replace electric with electrified
    - ✓ Specify max takeoff weight, not passenger count. Suggest 8000lbs as max TOGW
  - Subgroup 3: Human Response and Metrics
    - ✓ Range (discussions - no final consensus)
      - – Local missions should be defined as 50 miles in urban/suburban areas. This is consistent with NASA's Advanced Air Mobility (AAM) definitions. The urban center should be defined by other sources such as city administrations
      - – Missions of up to 100 nautical miles and altitudes up to 3000 ft above ground level
    - ✓ UAM Vehicles – include all electrified aircraft including fuel-cell powered
    - ✓ Flight Speed (discussions – no final consensus)
      - – All subsonic speeds
      - – All subsonic speeds < Mach 0.7
      - – Flight speeds up to 200 knots
    - ✓ Passenger count (5 – 6) or equivalent cargo

Update on Spring 2022 UNWG Meeting (con't)

- Summary of breakout sessions (con't)
  - Subgroup 4: Regulation and Policy (discussion – no consensus)
    - ✓ eVTOL
      - There is concern that eVTOL will exclude many designs and manufacturers. May want to remove "e"
      - Need confirmation that hydrogen power is a hybrid aircraft – generates electricity and has electric motors
    - ✓ Range
      - Limiting missions to 100 nautical miles will exclude some manufacturers
    - ✓ Weight and payload
      - Current payload will exclude some startups
      - Don't want to be too restrictive on weight
- Areas that will likely need to be addressed in the future
  - eVTOL, and definition of electric/hybrid
  - Range
  - Payload/weight
- Input on scope was sent to David Josephson for coordination

Agenda

0900	Welcome – Brenda Henderson
0905	UNWG Scope Update – Brenda Henderson
0910	Subgroup 1 (Tools and Technologies) Briefing – Len Lopes
0920	Subgroup 2 (Ground & Flight Testing) Briefing – Kyle Pascioni
0930	Subgroup 3 (Human Response and Metrics) Briefing – Sidd Krishnamurthy
0940	Subgroup 4 (Regulation and Policy) Briefing – Bill He
0950	Overview of Breakout Group Activity – Steve Rizzi
1000	Break
1020 – 1215	Breakout Groups
1215 – 1400	Lunch
1400 – 1530	Breakout Group Report-Outs
1530	Adjourn

Breakout Sessions

- Address selected topics from white paper that are not currently being addressed by the four UNWG subgroups
  - Each subgroup submitted two topics
- Two topics will be assigned to each breakout room
  - The topics are not be from the same subgroup
- Participants in each room will include members from the four subgroups
- Afternoon report outs will include one of the two topics submitted by each subgroup

Breakout Session Topics

Ref: UNWG White Paper [WP] https://ntrs.nasa.gov/citations/20205007433

(1) A dedicated technology maturation effort be performed on the most promising noise mitigation technologies and that opportunities be sought to evaluate their efficacy in flight. **[WP Gap §2.3.1.2, WP Rec §2.4]**

(2) Manufacturers work with appropriate organizations to develop low noise guidance for piloted operations and automated low-noise procedures for autonomous operations that are specific to their products. **[WP Gap §2.3.2.2, WP Rec §2.4]**

(3) Additional work is recommended to define appropriate methods to evaluate acoustic dependence and variability with respect to the vehicle state. [WP Gap §3.3.7, WP Rec §3.4]

(4) Need adequate measurement and analysis methods for evaluating unsteady acoustic emissions in a stochastic manner that yields repeatable quantifiable results and uncertainties. **[WP Gap *New*, WP Rec *New*]**

(5) Comprehensive evaluation of metrics that supplement the day-night average sound level be performed for communicating community noise impact of UAM vehicle noise. **[WP Gap §4.3.2.2, WP Rec §4.4]**

(6) Until early entrants are fielded, and community noise studies can be performed, laboratory studies be performed to help inform how different the annoyance to short-term exposure of UAM vehicle noise is from that of existing aircraft noise sources. Assessments can then be made to determine the sensitivity of noise exposure estimates to changes in the metric or to its level. [WP Gap §4.3.2.1, WP Rec §4.4]

(7) That regulators and policy makers work to clarify the boundaries of responsibilities in managing UAM noise, and support development of guidance for vertiport planning regarding both location identification and environmental assessment at the proposed locations. **[WP Gap §5.3.2, WP Rec §5.4]**

(8) To develop a strategy and framework for community engagement before UAM noise concerns arise. Being prepared to address local community noise concerns early in the process will be critical to success for this market. Initial flight operations should not come as a surprise to the affected community. Modern tools such as virtual reality with auralization could provide effective ways to inform and engage the public. [WP Gap §5.3.3, WP Rec §5.4]

Template (Sample)

Recommendation: A dedicated technology maturation effort be performed on the most promising noise mitigation technologies and that opportunities be sought to evaluate their efficacy in flight.

Current status (inside or outside UNWG):

Why is this not being addressed by UNWG:

What approach should be taken to address the topic:

What resources (skills, schedule, ROM funding) are required:

Other:

Breakout Session Topics

(1) A dedicated technology maturation effort be performed on the most promising noise mitigation technologies and that opportunities be sought to evaluate their efficacy in flight.

(2) Manufacturers work with appropriate organizations to develop low noise guidance for piloted operations and automated low-noise procedures for autonomous operations that are specific to their products.

(3) Additional work is recommended to define appropriate methods to evaluate acoustic dependence and variability with respect to the vehicle state.

(4) Need adequate measurement and analysis methods for evaluating unsteady acoustic emissions in a stochastic manner that yields repeatable quantifiable results and uncertainties.

(5) Comprehensive evaluation of metrics that supplement the day-night average sound level be performed for communicating community noise impact of UAM vehicle noise.

(6) Until early entrants are fielded, and community noise studies can be performed, laboratory studies be performed to help inform how different the annoyance to short-term exposure of UAM vehicle noise is from that of existing aircraft noise sources. Assessments can then be made to determine the sensitivity of noise exposure estimates to changes in the metric or to its level.

(7) That regulators and policy makers work to clarify the boundaries of responsibilities in managing UAM noise, and support development of guidance for vertiport planning regarding both location identification and environmental assessment at the proposed locations.

(8) To develop a strategy and framework for community engagement before UAM noise concerns arise. Being prepared to address local community noise concerns early in the process will be critical to success for this market. Initial flight operations should not come as a surprise to the affected community. Modern tools such as virtual reality with auralization could provide effective ways to inform and engage the public.

Topic I

Recommendation: A dedicated technology maturation effort be performed on the most promising noise mitigation technologies and that opportunities be sought to evaluate their efficacy in flight.

- Current status (inside or outside UNWG):
  - Current focus is bringing vehicle to market.
  - What is the requirement?
  - Some efforts including
    - Operations (e.g., Eric Greenwood),
    - Rotor spacing for edgewise multirotor (Zawodny & Pettingill),
    - Quiet rotor (cruise),
    - Design, phase control (source noise directivity or overall reduction
    - NASA and industry
    - Blade design for broadband noise reduction
    - Reduce disk loading (more blades, more rotors, higher RPM -> absorption vs lower tip speed -> lower performance).
    - Unclear what is being done in design beyond cert.
    - Unclear relative importance of airframe noise (in conventional sense),
    - Other rotor-wake interactions (installation noise)
- Why is this not being addressed by UNWG:
  - Quiet rotor in vertical mode,
  - TLO noise (e.g., unsteady operation due to gusts),
  - Transition, off-nominal design
  - Low noise flight control (some work by Dan Weitzman @ PSU)
  - Cabin noise
  - Active twist
  - Blade shape control
  - Need for validation data (flyover, in particular),
  - Lower order/fidelity tools for low-noise design,
  - Characterization of noise at the ground receiver and/or cabin noise

Topic I

Recommendation: A dedicated technology maturation effort be performed on the most promising noise mitigation technologies and that opportunities be sought to evaluate their efficacy in flight.

- What approach should be taken to address the topic:
  - Technology maturation before flight (TRL 4-5)
  - Low-cost flight test platforms (issues with scaling)
  - Wind tunnel investigations on-going to inform scaling
  - Testing in controlled environment (anechoic + quiet tunnel) vs outdoor
  - Some challenges due to circulation,
  - Use of prior generation development (prototype) vehicles as research/demonstration testbeds at an affordable rate (a surrogate testbed)
  - Search for prior OEMs now out of business
  - Rotor test stand for industry use
  - Private-public partnerships for flight demos
  - Larger scale acoustic ground test facilities lacking
- What resources (skills, schedule, ROM funding) are required:
  - Rapid prototyping
  - Design experience
  - Familiarity with both fixed-wing and rotorcraft
  - Industry can put testbeds together quickly, as short as 8 weeks
  - Novel flight test data acquisition & validation
- Other:
  - Barriers associated with proprietary data
  - Need for low-cost ways to build database

Breakout Session Topics

(1) A dedicated technology maturation effort be performed on the most promising noise mitigation technologies and that opportunities be sought to evaluate their efficacy in flight.

(2) Manufacturers work with appropriate organizations to develop low noise guidance for piloted operations and automated low-noise procedures for autonomous operations that are specific to their products.

(3) Additional work is recommended to define appropriate methods to evaluate acoustic dependence and variability with respect to the vehicle state.

(4) Need adequate measurement and analysis methods for evaluating unsteady acoustic emissions in a stochastic manner that yields repeatable quantifiable results and uncertainties.

(5) Comprehensive evaluation of metrics that supplement the day-night average sound level be performed for communicating community noise impact of UAM vehicle noise.

(6) Until early entrants are fielded, and community noise studies can be performed, laboratory studies be performed to help inform how different the annoyance to short-term exposure of UAM vehicle noise is from that of existing aircraft noise sources. Assessments can then be made to determine the sensitivity of noise exposure estimates to changes in the metric or to its level.

(7) That regulators and policy makers work to clarify the boundaries of responsibilities in managing UAM noise, and support development of guidance for vertiport planning regarding both location identification and environmental assessment at the proposed locations.

(8) To develop a strategy and framework for community engagement before UAM noise concerns arise. Being prepared to address local community noise concerns early in the process will be critical to success for this market. Initial flight operations should not come as a surprise to the affected community. Modern tools such as virtual reality with auralization could provide effective ways to inform and engage the public.

Topic 5

Recommendation: Comprehensive evaluation of metrics that supplement the day-night average sound level be performed for communicating community noise impact of UAM vehicle noise.

➢ Current status (inside or outside UNWG):

- NASA psychoacoustic tests on role of sound quality on annoyance
- Duration and number of events on annoyance
- How audibility and noticeability affects annoyance in different ambient environments
- Use of annoyance as the subjective response metric and evaluation of alternative response metrics including noticeability
- Acceptance/blend
- Annoyance models for sUAS

➢ Why is this not being addressed by UNWG:

- Laboratory studies may not reflect real world conditions, so there is an unknown relationship between lab results and real-world experience
- Relationship between short-term and long-term response vis-à-vis L_{Aeq} based metrics unknown
- Loudness-based supplemental metrics
- Evaluation of performance-based navigation on community response
- Focus has not been on level above and time above
- How are different metrics best utilized for different operating environments, e.g., flyover vs vertiport?
- UAM vehicles not currently in service, so we can't go out and perform a community noise test at this time
- How does response to UAM aircraft noise differ from response to existing aircraft (large commercial transports, helicopters, etc.) and across different UAM vehicles and their operations

➢ What approach should be taken to address the topic:

- Lessons learned from introduction of other emerging technology aircraft (e.g., package delivery drones)
- Development of loudness and location-based supplemental metrics
- Preliminary studies to determine magnitude of various effects, (size, scale)
- Partnerships to identify what is needed

➢ What resources (skills, schedule, ROM funding) are required:

- Real-world acoustic signatures and auralization
- Remote testing capabilities and validation
- Greater opportunities for individual experiences, acoustical engineering, psycho-acousticians
- Physical and virtual simulation
- Immersive (multisensory) testing environments
- Identification of test sites for various test objectives

➢ Other:

Breakout Session Topics

(1) A dedicated technology maturation effort be performed on the most promising noise mitigation technologies and that opportunities be sought to evaluate their efficacy in flight. Deliverables: Template, Report–Out (Rooms 127, 130)

(2) Manufacturers work with appropriate organizations to develop low noise guidance for piloted operations and automated low-noise procedures for autonomous operations that are specific to their products. **Deliverable: Template**

(3) Additional work is recommended to define appropriate methods to evaluate acoustic dependence and variability with respect to the vehicle state. Deliverables: Template, Report–Out (Rooms 127, 128)

(4) Need adequate measurement and analysis methods for evaluating unsteady acoustic emissions in a stochastic manner that yields repeatable quantifiable results and uncertainties. **Deliverable: Template**

(5) Comprehensive evaluation of metrics that supplement the day-night average sound level be performed for communicating community noise impact of UAM vehicle noise. Deliverable: Template

(6) Until early entrants are fielded, and community noise studies can be performed, laboratory studies be performed to help inform how different the annoyance to short-term exposure of UAM vehicle noise is from that of existing aircraft noise sources. Assessments can then be made to determine the sensitivity of noise exposure estimates to changes in the metric or to its level. Deliverables: Template, Report–Out (Rooms 128, 209)

(7) That regulators and policy makers work to clarify the boundaries of responsibilities in managing UAM noise, and support development of guidance for vertiport planning regarding both location identification and environmental assessment at the proposed locations. Deliverable: Template

(8) To develop a strategy and framework for community engagement before UAM noise concerns arise. Being prepared to address local community noise concerns early in the process will be critical to success for this market. Initial flight operations should not come as a surprise to the affected comm

unity. Modern tools such as virtual reality with auralization could provide effective ways to inform and engage the public.
Deliverables: Template, Report-Out (Rooms 209, 217)

Topic One

Recommendation: A dedicated technology maturation effort be performed on the most promising noise mitigation technologies and that opportunities be sought to evaluate their efficacy in flight.

Current status (inside or outside UNWG):

- Confusion on what opportunities for noise mitigation, what noise reductions are most promising
- Automotive applications for low-speed fans may be applicable
- Optimization but only aero and acoustic has been combined. Still need to combine this will other disciplines structures, vibrations, operations, etc.
- Ducted rotor studies have been performed, capturing acoustic differences
- Why isn't blade shape on one of the technologies list in white paper?

Why is this not being addressed by UNWG:

- Few vehicles are flying with these noise technologies are being developed
- Technology demonstrators provide testbeds, variability and design space is too large to capture all designs
- Baseline predictions are still being performed, not enough validated to provide confidence if applied to noise reduction technologies
- Problem complexity compared to existing vehicles, number of noise sources and installation makes capturing noise physics challenging
- Prediction and validation should come before noise reduction technologies
- Don't know what the main focus areas should be? Ducted rotor? Etc. what would apply to most vehicles.
- Lack of maturity in transitional flow modelling

Topic One

Recommendation: A dedicated technology maturation effort be performed on the most promising noise mitigation technologies and that opportunities be sought to evaluate their efficacy in flight.

What approach should be taken to address the topic:

- CLEAN for UAM could help, publish technology maturation with different stakeholders
- Scale down larger vehicles technologies to UAM vehicles, don't reinvent the wheel, adapt to new challenge
- Study other technologies that may already exist (i.e. wind turbine broadband noise reduction, automotive, helicopters) and assess applicability to UAM design space (and potential pitfalls like aeroelastic effects)
- 'most promising' may not be feasible, suggest removing
- Focusing on high TRL technologies that may not be most promising but immediately applicable
- Mapping of all existing technologies that may be applicable to UAM vehicles, taking stock of what's already done (similar to Charles Tinney's charts from yesterday)
- Focus on not just reducing magnitude but also directivity and noise signature (abatement procedures)
- Include software to provide noise benefit coming from vehicle operations

Topic One

Recommendation: A dedicated technology maturation effort be performed on the most promising noise mitigation technologies and that opportunities be sought to evaluate their efficacy in flight.

What resources (skills, schedule, ROM funding) are required:

- Literature review defining stock of existing noise reduction technologies that may be applicable to UAM vehicles (multiple organization effort). SG1 monthly ask for volunteers (Eric Greenwood recently published paper on UAM noise mitigation (https://doi.org/10.1177/1475472X221107377), IJA, good start but only open rotors and not other vehicle/platform applicable)
  - Follow on university engagement to research potentially benefits
- Standard testbed available for multiple groups to leverage technologies. Would require organization to standup and allow dissemination and access to design. Heavy weight commercial drone to get us partway there? What would be the flight condition requirements for reproduction in a tunnel? Also do standard numerical testbed?
- Joint workshop on prediction of noise from publicly available data (SG1 datasets). Blind prediction effort, geometry -> prediction, comparison after.

Other:

Topic Three

Recommendation: Additional work is recommended to define appropriate methods to evaluate acoustic dependence and variability with respect to the vehicle state.

Current status (inside or outside UNWG):

- On going work to define vehicle design to state (Joby proprietary data)
- NASA flight test team is waiting for vehicle and ability to publish

Why is this not being addressed by UNWG:

- Vehicles are not flying, and we don't predict well for known configurations
- Is this a regulation problem, should FAA/ICAO define test. They are limited in scope currently (3 mics, etc.)

Topic Three

Recommendation: Additional work is recommended to define appropriate methods to evaluate acoustic dependence and variability with respect to the vehicle state.

What approach should be taken to address the topic:

- Wait for experimental data and vehicle designs that define the flight conditions and state
- Approach FAA/ICAO with request to expand their certification requirements (with testing requirements in mind). Keep other metrics in mind during testing and refine certification process (existing certification process are 'resistant' to change, we must be very careful in initial requirements.). Characterization of sound source, blind study. What sound propagation physics will lead to challenges (like pseudo-tones for previous certifications).
- Component based certification. Current studies only include benign flight conditions (low turbulence uniform inflow). Ask manufacturers to stress test propeller to get range of acoustic signatures. More realistic flight conditions during component tests and numerical computations. Quantify the variability as a function of turbulent and/or disturbed inflow. Include propagation variability. Include simulations in the certification process with UQ. Depending on site and season (wind turbine). History of this with helicopters find max noise descent angle (fried egg plot).
- Define atmospheric conditions where UAM vehicles are to be operated (gusts, turbulence, etc.) to feed augmentation simulations (define urban environment atmospheric operational bounding box for acoustically relevant operating conditions). Required for safety, potential source of information.

What resources (skills, schedule, ROM funding) are required:

- Multiple vehicle flight test with 20+ hours with each vehicle and highly dense array to record publishable data
  - Are flight test environments really the same as realistic flight environments?
  - Highly specify atmospheric conditions with enough fidelity for propagation and ground effects
- Resources to perform addition simulations to augment experiments with numerics (dozens of full vehicle simulations)
  - Can we start with components to define source under those conditions to feed propagation

Other:

Breakout Session Topics

(1) A dedicated technology maturation effort be performed on the most promising noise mitigation technologies and that opportunities be sought to evaluate their efficacy in flight. Deliverables: Template, Report–Out (Rooms 127, 130)

(2) Manufacturers work with appropriate organizations to develop low noise guidance for piloted operations and automated low-noise procedures for autonomous operations that are specific to their products. **Deliverable: Template**

(3) Additional work is recommended to define appropriate methods to evaluate acoustic dependence and variability with respect to the vehicle state. Deliverables: Template, Report–Out (Rooms 127, 128)

(4) Need adequate measurement and analysis methods for evaluating unsteady acoustic emissions in a stochastic manner that yields repeatable quantifiable results and uncertainties. **Deliverable: Template**

(5) Comprehensive evaluation of metrics that supplement the day-night average sound level be performed for communicating community noise impact of UAM vehicle noise. **Deliverable: Template**

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(7) That regulators and policy makers work to clarify the boundaries of responsibilities in managing UAM noise, and support development of guidance for vertiport planning regarding both location identification and environmental assessment at the proposed locations. **Deliverable: Template**

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Room 126 Topics (2) & (4)

Recommendations:
(2) Manufacturers work with appropriate organizations to develop low noise guidance for piloted operations and automated low-noise procedures for autonomous operations that are specific to their products. [WP Gap §2.3.1.2 WP Rec §2.4]
(4) Need adequate measurement and analysis methods for evaluating unsteady acoustic emissions in a stochastic manner that yields repeatable quantifiable results and uncertainties. [WP Gap New WP Rec New]

Objectives:
- Current status (inside or outside UNWG):
- Why is this not being addressed by UNWG:
- What approach should be taken to address the topic:
- What resources (skills, schedule, ROM funding) are required:
- Other:

Room 126: Topic (2) SG1 Tools & Technologies

Recommendation: (2) Manufacturers work with appropriate organizations to develop low noise guidance for piloted operations and automated low-noise procedures for autonomous operations that are specific to their products.

Our interpretation:

- There is a need for operational guidance from the OEM's on the vehicle that fits within the operational envelope to get from point A to B.
- Appropriate organizations: could be regulatory, could be industry organizations (e.g., HAI for Fly Neighborly), or operators
- Low noise guidance: could be metric related (e.g., Level@ Ref distance) or operational (FPA within an envelope)
- Specific to their products: nod to the variability of the configurational landscape. Do we categorize into vehicle types (e.g., lift+cruise etc.)?
- Balance between site specific operational guidance vs. operating state / vehicle acoustic emission
- Needs: Source - Mechanisms /tools to understand noise emission and Receptor – guidelines/requirements/metrics/limits

Current status (inside or outside UNWG):

- Are there parallels to other transportation industries? Are there operational requirements related to existing standards?
- What are the existing helicopter regulations – do we build off those and expand for eVTOL ops?

Why is this not being addressed by UNWG:

- Organizations might have different priorities
- Complexity of multipoint objectives: single vs. multiple operations in a vertiport environment
- Some SGs are focused on the smaller problem: e.g. blade design and less focused on the operational pieces.
- Tools for prediction of full footprints for maneuvering/operations are just now becoming available

Room 126: Topic (2) SG1 Tools & Technologies

Recommendation: (2) Manufacturers work with appropriate organizations to develop low noise guidance for piloted operations and automated low-noise procedures for autonomous operations that are specific to their products.

What approach should be taken to address the topic:

1. Appropriate Organizations need to be Identified → Define the stakeholders
2. Understand existing requirements / desires / needs → Catalog the relevant standards
3. Categorize the Operational Situations (Rooftop Operations / Overflight situations / Airport Environments / flight projects / trajectories)
4. Appropriate noise metrics need to be defined, so that designers can target those (they could be related to particular operations)
5. Tools and technologies need to address not only source emission, but also environmental / situational effects such as reflections/scattering/ shielding/ urban canyon effects

- Automated Procedures
  - OEM is in the position to make the judgement on the appropriate envelopes / procedures for a given vehicle / operational mode (E.g. Lowest power for safe flight)
- Noise considerations: Are you looking at instantaneous noise (e.g., Lmax) vs. integrated noise (SEL/DNL)?
- Balance between site specific operational guidance vs. operating state / vehicle acoustic emission
- Needs:
  - Source - Mechanisms /tools to understand noise emission
  - Receptor – guidelines/requirements/metrics/limits

Room 126: Topic (2) SG1 Tools & Technologies

Recommendation: (2) Manufacturers work with appropriate organizations to develop low noise guidance for piloted operations and automated low-noise procedures for autonomous operations that are specific to their products.

What resources (skills, schedule, ROM funding) are required:

- The operational requirements need to be defined then the OEMs can work on the optimization
- Tools for noise prediction – full trajectories in site specific locales – are needed that support the metrics identified
  - Tools exist to get pressure time histories. Majority of the effort needs to be on the metrics and needs
  - Community involvement and needs in terms of metrics and other considerations is needed
  - Wider work force needed to utilize the (complex) noise prediction tools
- Collaboration between Industry/Academia/Research Institutions important to develop these tools
- Schedule
  - Metrics need to be identified ASAP
- ROM: Likely need multiple people over a year + for refining tools to apply to low noise procedure and autonomous design. Could be efficiencies for common tool development to particular OEMs. Also need resources for liaison to communities. FAA AEDT / AAM / SUAVE / NiceOPS (or similar) tool needs to have UAM capability added for the purposes of operational and vertiport planning (also including urban effects).

Other:

Room 126: Topic (4) SG2 Ground & Flight Test

Recommendation: (4) Need adequate measurement and analysis methods for evaluating unsteady acoustic emissions in a stochastic manner that yields repeatable quantifiable results and uncertainties.

Current status (inside or outside UNWG):

- ICAO has started to address this for hover – might leverage those guidelines/ analysis/ mathematical approaches
- There are some emerging tools for quantifying the unsteady / nondeterministic acoustic emissions
- Potential parallels between MR/TR phasing uncertainty research and noise emission for conventional helicopters might help inform this topic

Why is this not being addressed by UNWG:

- Hadn't been identified as a thing yet. ;-)

Room 126: Topic (4) SG2 Ground & Flight Test

Recommendation: (4) Need adequate measurement and analysis methods for evaluating unsteady acoustic emissions in a stochastic manner that yields repeatable quantifiable results and uncertainties.

What approach should be taken to address the topic:

- Could this be quantified akin to a 'safety factor'?
- Need to quantify uncertainty (e.g., error bars) on all measurements as routine matter
- Closer coupling between the modeling (SG1) and the measurement (SG2) could help
- Need to quantify the uncertainties or relative acoustic spread for these kinds of phenomena → Can that be informed via analytical modeling and then verified with flight testing?
- Need to consider the regulatory side – if there is this stochastic variability, how do designers need to take that into consideration on the design side?
- Repeatability – This feeds into the test design / test plan itself
- Consider the difference between quantifying uncertainty in the source vs. uncertainty in the measurement→ yields different test designs.

Room 126: Topic (4) SG2 Ground & Flight Test

Recommendation: (4) Need adequate measurement and analysis methods for evaluating unsteady acoustic emissions in a stochastic manner that yields repeatable quantifiable results and uncertainties.

What resources (skills, schedule, ROM funding) are required:

- **Flight test #1** – Back-to-Back both in a wind tunnel and in an outdoor environment → Tool validation purpose
  - Different test organizations running them using different equipment built to the same specifications.
  - Need to categorize the ***likely*** operating states (e.g., if you have X likely controller states that yield a particular flight condition, you need to test them all) → Will need to prioritize them (perhaps using analytical tools to help understand the acoustic landscape a priori). Might also be fruitful to understand whici of those X controller states yield high vs. lower noise emissions.
  - Might need mechanisms to override automated controller inputs → for **validation** of tool sets.
  - Need to target quiet-mid-loud states.
  - Need to track everything (e.g., rotor phasing). Identify what can be controlled vs. what is random (e.g., phase lock)
  - Round robin comparison of the results.
- **Flight Test #2** → quantify stochastic pieces from less controlled vehicle operational modes → Community Acceptance
  - E.g., Flyover noise quantification- need lots of repeats
  - Is there a way to remove the uncertainties caused by (e.g., the controller) by controlling that (assigned control inputs rather than automated process)? That will allow us to quantify stochastically the results with reduced uncertainty. Alternatively, if you can't control the uncertainty (controller) fly enough passes so that you can quantify it.
  - Eventually expand to other environments: E.g., urban environments / buildings etc… Tools will be needed to be validated for these
- Other: Other subgroups need to provide inputs:
  - Metrics - consider human response, tools/modeling outputs for validation – what kind of spectral info / fidelity / time history detail is needed?
  - Modeling – guidelines on how analysis is being conducted (e.g., signal processing of predicted p(t), range of frequencies)
  - Length of time in the sample (applies both to measurement and modeling)
  - Is the measurement data being used for validation or to see an empirical model?

Breakout Session Topic 2

Manufacturers work with appropriate organizations to develop low noise guidance for piloted operations and automated low noise procedures for autonomous operations that are specific to their products.

Current status (inside or outside UNWG):
The work is still evolving. It takes time to develop low noise operational procedures such as the Fly Neighborly program (helicopters). Operating procedures used in noise certification vs. that used in daily operations – there are differences, but also some linkages.

Why is this not being addressed by UNWG:
- The development is still evolving.
- Flight profiles and operating procedures are closely tied to aircraft design, technical capability and operational efficiency. Specific information is often considered proprietary.
- Specific sites of operation (e.g. terrains, vertiport features, and UTM requirements) can influence the actual procedures as well. One example is glide slope angles & limitations.

What approach should be taken to address the topic:
- It is helpful to develop typical (nominal) flight profiles, assuming typical obstacles and conditions.
- The profiles/procedures can be developed in sets to cover range of aircraft designs, weights/seeds, and use case scenarios.
- Such sets of profiles, once developed, can serve as reference flight profiles that can be used in, conducting general noise analysis and studies, and even in noise certification.
- For noise certification, there are interests in using such flight profiles/procedures as long as they are "representative" – no need to be identical to actual operations. There are also interests in identifying "nosiest" flight segments.

What resources (skills, schedule, ROM funding) are required:
- While companies can help develop such typical/nominal/reference profiles/procedures, "somebody" needs to step up to further define, guide, encourage and coordinate the work, and then develop and establish uses cases. That "somebody" could be NASA, or NASA/FAA, details TBD.

Breakout Session Topic 8

To develop a strategy and framework for community engagement before UAM noise concerns arise. Being prepared to address local community noise concerns early in the process will be critical to success for this market. Initial flight operations should not come as a surprise to the affected community. Modern tools such as virtual reality with auralization could provide effective ways to inform and engage the public

Current status (inside or outside UNWG):

- SG4 members have tried to address this topic
- Difficult topic, multi-facets
  - Which community? That benefits from AAM vs. that does not.
  - Timing of engagement can be difficult to determine
    - Wait & See" approach vs. early engagement (preemptive).

Why is this not being addressed by UNWG:

- Uncertainties and risks associated with each approach (Wait&See, vs early engagement)
- Design concept evolving, uncertainty in noise prediction (a/c, ops…), noise sensitivity,
- Risk of engaging too early - 1st impression matters, so is trust.
  - Credibility issues need to be addressed.
- Which community? The definition is not straight forward, but very important.

Breakout Session Topic 8 (con't)

What approach should be taken to address the topic:

Variety of approaches is needed for diverse audience/communities

- Use social media campaigns to engage esp. younger generations
- PR activities (seen today by companies)
- Air shows and other public events
- Company outreach to invite community members to "test fly".
- Virtual reality as a general tool
  - Realism
    - May need detailed information on operations (i.e. flight patterns), instead of a single flight event.
    - Level of accuracy required of noise prediction is still TBD.
  - Accessibility
    - Online version would be helpful, in addition to specialized facilities.
- Published data, studies and reports as references that are publically accessible.
  - Noise sensitivity studies, noise metrics, noise threshold
- Community engagement is not a single step, but as a iterative process

What resources (skills, schedule, ROM funding) are required:

- Companies (esp. small ones) feel the need to engage community, but see limitation in sources.
  - Could be a full-time position to manage noise (analyze data, predict noise…)
- A company can potentially work with consulting firms for community outreach, but needs to address barriers of sharing proprietary design (and operation) information to 3rd parties.

Topic #3

Recommendation: **Additional work is recommended to define appropriate methods to evaluate acoustic dependence and variability with respect to the vehicle state.**

Current status (inside or outside UNWG): Current techniques for existing aircraft are well defined because little variability exists in how current fixed wing and rotorcraft fly approach and departure maneuvers; Limited data exists for *some* representative vehicle designs.

Why is this not being addressed by UNWG: Many vehicle designs and broad vehicle states exist and comparatively little test data/opportunity to collect that data with existing manufacturers and even less opportunity to share with the tool development community.

What approach should be taken to address the topic: Attempt to classify broad vehicle states (transition, purely VTOL, others?) and base measurement techniques on those categories for different segments of flight (takeoff/departure, transition [where appropriate], cruise, approach and landing). Leverage input from tool development groups to inform array designs.

What resources (skills, schedule, ROM funding) are required: Reference vehicles in each of the aforementioned vehicle categories that manufacturers are willing to share with the experimentalist and tool development communities, 1-2-year effort, cost would exceed $1M

Other:

Topic #6

Recommendation: **Until early entrants are fielded, and community noise studies can be performed, laboratory studies be performed to help inform how different the annoyance to short-term exposure of UAM vehicle noise is from that of existing aircraft noise sources. Assessments can then be made to determine the sensitivity of noise exposure estimates to changes in the metric or to its level.**

Current status (inside or outside UNWG): Launching online psychoacoustic study (including some UNWG members) as well as work being performed by other non-coordinated groups on this topic.

Why is this not being addressed by UNWG: There is an opportunity to perform psychoacoustic studies on sUAS vehicles, but far fewer large UAM-category vehicles already flying and available for researchers to partner with to get more representative data.

What approach should be taken to address the topic: Building partnerships/establishing agreements to obtain preliminary recordings from UAM manufacturers to be used for testing. OEMs seek assurance that sensitive/proprietary data will remain protected when used in this way. There is a desire to develop a consensus on study architecture. Consider additional (potentially not aircraft) noise sources for the given mission.

What resources (skills, schedule, ROM funding) are required: Need software management for remote studies, proper advertising of studies and incentives for participants, focus on partnerships with OEMs and city planners/managers, nominal 9-to-12-month cycle for a given study, $500-750k?

Other:

Breakout Session Topics

(1) A dedicated technology maturation effort be performed on the most promising noise mitigation technologies and that opportunities be sought to evaluate their efficacy in flight. Deliverables: Template, Report–Out (Rooms 127, 130)

(2) Manufacturers work with appropriate organizations to develop low noise guidance for piloted operations and automated low-noise procedures for autonomous operations that are specific to their products. **Deliverable: Template**

(3) Additional work is recommended to define appropriate methods to evaluate acoustic dependence and variability with respect to the vehicle state. Deliverables: Template, Report–Out (Rooms 127, 128)

(4) Need adequate measurement and analysis methods for evaluating unsteady acoustic emissions in a stochastic manner that yields repeatable quantifiable results and uncertainties. **Deliverable: Template**

(5) Comprehensive evaluation of metrics that supplement the day-night average sound level be performed for communicating community noise impact of UAM vehicle noise. **Deliverable: Template**

(6) Until early entrants are fielded, and community noise studies can be performed, laboratory studies be performed to help inform how different the annoyance to short-term exposure of UAM vehicle noise is from that of existing aircraft noise sources. Assessments can then be made to determine the sensitivity of noise exposure estimates to changes in the metric or to its level. Deliverables: Template, Report–Out (Rooms 128, 209)

(7) That regulators and policy makers work to clarify the boundaries of responsibilities in managing UAM noise, and support development of guidance for vertiport planning regarding both location identification and environmental assessment at the proposed locations. **Deliverable: Template**

(8) To develop a strategy and framework for community engagement before UAM noise concerns arise. Being prepared to address local community noise concerns early in the process will be critical to success for this market. Initial flight operations should not come as a surprise to the affected comm unity. Modern tools such as virtual reality with auralization could provide effective ways to inform and engage the public.
Deliverables: Template, Report-Out (Rooms 209, 217)

Breakout Topic 4

Recommendation: Need adequate measurement and analysis methods for evaluating unsteady acoustic emissions in a stochastic manner that yields **repeatable quantifiable results and uncertainties**.

Current status (inside or outside UNWG):

- Results can vary greatly with measurement environment
- Helicopter rule of thumb: StDev needed to be less than 1.5 dB for 90% confidence. Used that for conditions, except for Hover.
- Multiple repeats to give insight into repeatability
- Only few measurements, some not shareable – need data to fully assess

Why is this not being addressed by UNWG:

- Hard!
- Lack of data to work with
- Requires vehicle state information

What approach should be taken to address the topic:

1. Need to develop technique that yields repeatable results while reducing test time
2. Need to understand dependencies, what are key variables – need compiled list; Begin to understand sensitivities w.r.t. parameters
3. Control laws need to be understood - minimize changes?
4. Can we make use of sUAS or other small scale aircraft to study variability?
5. Data from past helicopter tests to get started?
6. Establish minimum flight conditions
7. Acquire ambient/environmental conditions and/or acoustic measurements onboard vehicle?
8. Measurements under best and worst case scenarios (e.g., high wind gusts, flight control input)

What resources (skills, schedule, ROM funding) are required:

- (5) Helicopter flight test review – single person literature review
- (2 and 4) interns, SBIR opportunities?

Other:

Notes:

- Analysis vs measurement – could be separated
- Need to develop technique that yields repeatable results while reducing test time
- Could be very vehicle specific
- Vehicle state varies much quicker on UAM than helicopter – what are relevant time scales?
- Nested problems within this rec

Breakout Topic 7

Recommendation: That regulators and policy makers work to **clarify the boundaries of responsibilities in managing UAM noise**, and support development of **guidance for vertiport planning** regarding both location identification and environmental assessment at the proposed locations.

Current status (inside or outside UNWG):

- Identified new certification procedures may be needed
- Brainstorming recommendation on what should be done (technical advisory)
- Ongoing effort to track community response

Why is this not being addressed by UNWG:

- Clarifying boundaries not fully UNWG issue; multiple parties should be involved
- Difficult to develop generalized guidance

What approach should be taken to address the topic:

- Define clear indication of responsibility to manage noise – potentially more responsibilities for operators (mitigation) and vertiports
- Learn from helicopter operations (Fly Neighborly Program)
- **Consistent guidance is beneficial on a national level**, need collaboration b/w FAA and local govt.
- Fleet noise assessment using AEDT or a similar tool; trajectory into and out of vertiport should be considered
- Noise monitoring systems at vertiports
- Hand off roles to other groups/entities as they mature

What resources (skills, schedule, ROM funding) are required:

- Coming from monitoring/advisory role, minimum resources (from UNWG)

Other:

Notes:

- Clarify boundaries – educate community
- Is this an FAA or other problem? Local noise ordinances? OEM? Vertiport?
- Vertiport planning - vehicle and fleet unknowns make this difficult
- FAA vertiport guidance?
- Responsibility may change depending on ”who’s in control”
- Keep tabs on VFS infrastructure group

Topic 5

Comprehensive Evaluation of Supplemental Metrics (1)

Recommendation: Comprehensive evaluation of metrics that supplement the day-night average sound level be performed for communicating community noise impact of UAM vehicle noise.

Current status (inside or outside UNWG): Environmental Impact assessment and community engagement with Urban-Air Port, first operational airport deployed in Coventry, UK; Supplemental metric: Laeq (standard in UK), audio file presentations; SG3 has had success demonstrating auralization to management; Early simulation of auralizations (EASA); Wing Aviation environmental assessment study for drone deliveries at Frisco (TX) Station – a supplemental metric was used to analyze the number of times over a 24-hour period the UA operations would exceed LAmax 60 dB (Ref Draft Environmental Assessment - Frisco and Little Elm, TX, section 3.5.3)

Why is this not being addressed by UNWG: Prioritized tasks; Limited data (auralizations) available; Proprietary concerns; Prototype vs. Production (risk of “noisy” stigma for immature designs)

What approach should be taken to address the topic: Monitor OEM progress and appropriate prioritization of supplemental metrics useful in communicating noise impacts; Associate supplemental metrics with currently understood community metrics (simple vehicle drive-bys); Progressively improve fidelity of simulation for range of UAM / AAM vehicle noise to inform public and receive feedback; Early production vehicle measurements / auralizations

What resources (skills, schedule, ROM funding) are required: Analytical, design maturity, virtual reality, AI, machine learning, test data, experience communicating technical details with non-technical audiences

Other: Next slide

Topic 5

Comprehensive Evaluation of Supplemental Metrics (2)

Recommendation: Comprehensive evaluation of metrics that supplement the day-night average sound level be performed for communicating community noise impact of UAM vehicle noise.

Other (post-meeting comments):

- During our meeting on 20 Oct, it was discussed that SG3 has had success using auralization (during meetings or controlled demonstrations) that could be considered for communicating community noise impact of UAM vehicle noise
- Consider that topic 5 is a recommendation for comprehensive evaluation of supplemental metrics (metrics supplemental to DNL metric and associated 65 db threshold for noise compatible land use)
- Refer to Draft Environmental Assessment - Frisco and Little Elm, TX, section 3.5.3, for an example supplemental metric used for 'communicating to the public' in an environmental assessment
- In this context, it will be a challenge to quantify the use of auralization as a supplemental metric that can be reported in an environmental assessment
- We should have further discussion to consider if auralization should be promoted as a supplemental metric in the context of environmental assessment (NEPA) reports
- Whether it is considered a supplemental metric or not (in the context of environmental assessment reports), auralization should have a place in communicating community noise impact of UAM vehicle noise during public meetings or controlled demonstrations

Topic 7

Regulatory Boundary Responsibilities (1)

Recommendation: That regulators and policy makers work to clarify the boundaries of responsibilities in managing UAM noise, and support development of guidance for vertiport planning regarding both location identification and environmental assessment at the proposed locations.

Current status (inside or outside UNWG): Various states and local municipalities are developing UAM / AAM advancements, Vertiport infrastructure, flight corridors, etc.; Understanding of historical heliport issues related to: DOT/FAA/ND-00/2 State Regulation of Heliport Design

On-going East Hampton / aviation group litigation, state Supreme Court decision

Why is this not being addressed by UNWG: Lack of state / local authority perspective in SG4

What approach should be taken to address the topic: Engage state / local authorities as appropriate through SG4 liaison; Develop international federal / local perspectives (not US-centric); State / local authorities to consider: Los Angeles, Orlando, Ohio DOT, Coventry (UK), Saudi Arabia (5G air traffic management / infrastructure), North Central Texas Council of Governments (NCTCOG), published CONOPS, CAELUS; Identify locales (international), POCs, begin outreach to local / state POCs; Literature review; Historical helicopter perspective; Demographic metadata

What resources (skills, schedule, ROM funding) are required: Experience engaging with sensitive community groups and local / state authorities; State / local perspectives on noise concerns

Other: Next slide

Topic 7

Regulatory Boundary Responsibilities (2)

Recommendation: That regulators and policy makers work to clarify the boundaries of responsibilities in managing UAM noise, and support development of guidance for vertiport planning regarding both location identification and environmental assessment at the proposed locations.

Other (post-meeting comments):

– During our meeting on 20 October, we discussed that the design of ***private*** heliports is regulated, NOT by the FAA but by the 50 States (see historical helicopter issues related to the linked report); It is our understanding that ***public*** heliports that receive federal funding are regulated by the FAA

– An additional link was added for a news story published on 19 October, indicative of on-going disputes related to federal / state / local jurisdiction

Topic 6, Breakout Room 209

- Recommendation: Until early entrants are fielded, and community noise studies can be performed, laboratory studies be performed to help inform how different the annoyance to short-term exposure of UAM vehicle noise is from that of existing aircraft noise sources. Assessments can then be made to determine the sensitivity of noise exposure estimates to changes in the metric or to its level.
  - Question: How can laboratory studies help inform the community testing?
- Current status (inside or outside UNWG):
  - The Implementation Phase (Phase 2) of the UAM Vehicle Noise Human Response Study can help with this recommendation but needs further discussion and it is only a potential goal.
  - NASA developing an annoyance model based on sound quality, noise and number, and audibility through recent and upcoming testing.
- Why is this not being addressed by UNWG:
  - Current laboratory studies seek to establish annoyance model (TUSQ, Noise and number test); preparation for community noise studies is not focus. We need to have an "in-between" laboratory test that helps inform community testing and how to meet community test objectives. Among these features are visual components and having people respond within contexts.
  - Non-acoustic aspects of community response are important but very difficult to replicate in lab setting (e.g., visual cues, task interruption)
  - Metrics used during design to minimize annoyance and metrics to quantify community impact may be different.

Topic 6, Breakout Room 209

- What approach should be taken to address the topic:
  - Continue development of annoyance model based on acoustics (without non-acoustic factors).
  - Consider input from experimental psychologists to improve understanding of non-acoustic factors
  - Consider using approach in like NASA's Acoustics Week for rotorcraft testing as an intermediate step (sound juries in the field)
    - Requires relevant vehicles to be available; could be problematic for early studies, OEM cooperation. Use of synthesized sounds in a field test may require improvements to auralizations
  - Consider alternative test venues and scenarios (e.g., task interruption) and understand annoyance response.
  - Knowledge from the "in-between" laboratory testing can be transferred to inform UAM operations and design which can be used for community testing. Metrics that are developed from the testing, which may be operations-based, can be used by consultants to measure acoustic impact in communities.
- What resources (skills, schedule, ROM funding) are required:
  - Completion of planned development of annoyance model.
  - Revisit idea of Acoustics Week as test scenario?
  - Use the LaRC Interior Effects Room to simulate a realistic condition.

Topic 8, Breakout Room 209

- Recommendation: To develop a strategy and framework for community engagement before UAM noise concerns arise. Being prepared to address local community noise concerns early in the process will be critical to success for this market. Initial flight operations should not come as a surprise to the affected community. Modern tools such as virtual reality with auralization could provide effective ways to inform and engage the public.
- Current status (inside or outside UNWG):
  - NLR looking into what ways people will accept this noise. How is the UAM noise different from other sounds?
  - Existing strategies for engagement between airports and local communities for runway modifications
  - Some OEMs are engaging with local governments.
- Why is this not being addressed by UNWG:
  - Lack of priority at this time (?)

Topic 8, Breakout Room 209

- What approach should be taken to address the topic:
  - Communicate early and often. Give notice to local community before noise source is applied.
  - Provide options for local community members to influence project. Use community centers near where people live for the engagement
  - To reduce bias, differentiate UAM noise from existing aircraft noise sources (drone delivery and powered personal aircraft).
  - Describe value of noise source to community members.
  - Human response testing on UAM noise could simultaneously serve as community outreach.
  - FAA and/or OEMs need to engage with experts on community outreach.
  - Understanding of CONOPS needed when communicating with the community.
- What resources (skills, schedule, ROM funding) are required:
  - UNWG members develop the community engagement tools. Can make the tools available to be used in virtual reality booths.
  - Platforms through council members or local governance exist to engage community.