
# NASA Revolutionary Vertical Lift Technology Project Research

Susan A. Gorton, Project Manager

Aircraft Noise and Emission Symposium

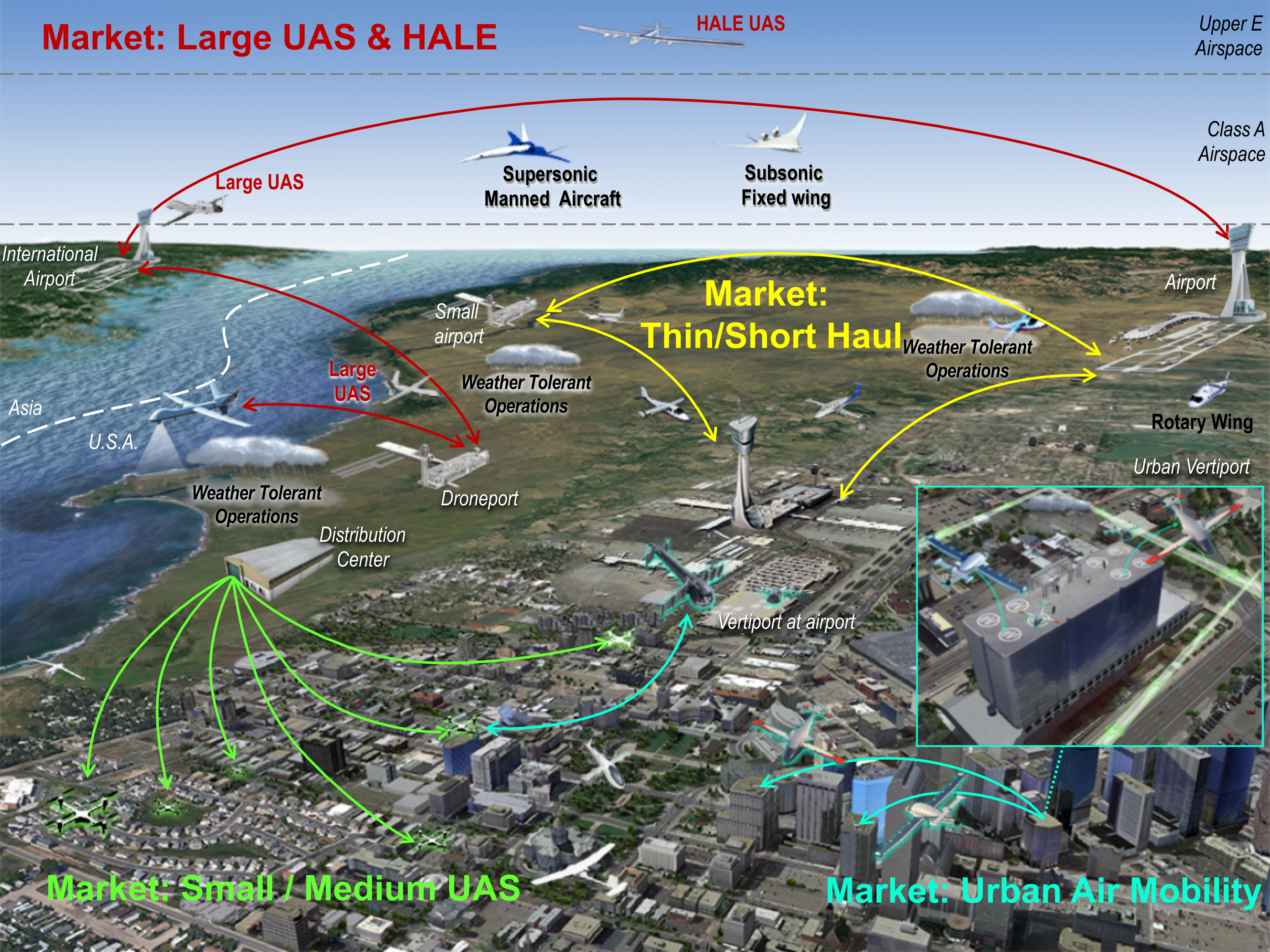
February 27, 2018

# Outline

- NASA Vision for Future Civil Aviation
- NASA Vertical Lift Strategy
- NASA Concept Vehicle Overview
- NASA Roadmap for Noise Research
- Selected Noise Research Highlights
- Concluding Remarks

# A Vision for the Future of Civil Aviation

- There will be a radical increase in new and cost-effective uses of aviation
- The skies will accommodate thousands of times the number of vehicles flying today
- Travelers will have the flexibility to fly when and where they want in a fraction of the time that it takes today
- All forms of air travel will be as safe as commercial air transport is today
- Significantly reduced carbon footprint and noise from aviation


Market: Large UAS & HALE
HALE UAS
Upper E Airspace
Class A Airspace
Large UAS
Supersonic Manned Aircraft
Subsonic Fixed wing
International Airport
Airport
Market: Thin/Short Haul
Small airport
Weather Tolerant Operations
Large UAS
Weather Tolerant Operations
Asia
U.S.A.
Rotary Wing
Urban Vertiport
Weather Tolerant Operations
Droneport
Distribution Center
Vertiport at airport
Market: Small / Medium UAS
Market: Urban Air Mobility

# NASA Technology Investment Strategy FY17+

**Overarching Vertical Lift Strategy**

**Enable a broad expansion of vertical lift applications**
- **Improve current configuration cost, speed, payload, safety, and noise**
- **Open new markets with new configurations and capability**
- **Capitalize on convergence of technology in electric propulsion, autonomy and flight controls**

FY17+ NASA technology emphasis

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Very small | Small | Very Light | Light | Medium | Med-heavy | Heavy | Ultra Heavy |
| <10 lbs | <55lbs | < 1500lbs | <6000lbs | <12,000lbs | <25,000lbs | <50,000lbs | <100,000lbs |

Technology applicability scales up and down in many areas

# NASA-developed Concept Vehicles for UAM

**Objective:** Identify NASA concept vehicles that can be used to focus and guide NASA research

- Open, publicly-available configurations
- Provide focus for trade studies and system analysis
- Push farther than current market trends
- Provide a range of configurations
- Cover a wide range of technologies and missions that are being proposed

(Choose one feature from each column to arrive at a vehicle to study)

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| 6 | 8 x 50 nm | Air Line | (multi-) Tilt rotor | Turboshaft |
| 15 | | | Lift + cruise | Hydrogen fuel cell |
| 30 | | | Vectored thrust | |
| | | | Compound | |

# NASA-developed Concept Vehicles for UAM

## *NOT "BEST" DESIGNS; NO INTENT TO BUILD AND FLY*

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**Quadrotor "Air Taxi"**

**Side by Side "Vanpool"**

**Tilt wing "Airliner"**

- Aircraft designed through use of NASA conceptual design and sizing tool for vertical lift, NDARC.
- Concepts described in detail in publication "Concept Vehicles for Air Taxi Operations," by W. Johnson, C. Silva and E. Solis. AHS Aeromechanics Design for Transformative Vertical Lift, San Francisco, Jan. 2018.

# Research Areas for Urban Air Mobility

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aircraft optimization
rotor shape optimization
hub and support drag minimization
airframe drag minimization

## ROTOR-ROTOR INTERACTIONS
performance, vibration, handling qualities
aircraft arrangement
vibration and load alleviation

## PROPULSION EFFICIENCY
high power, lightweight battery
light, efficient, high-speed electric motors
power electronics and thermal management
light, efficient diesel engine
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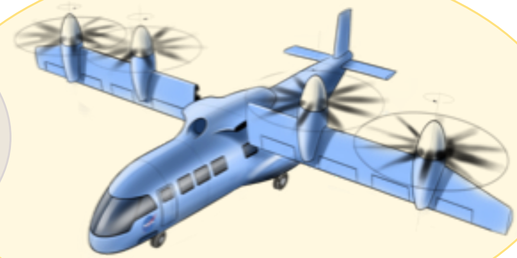
efficient powertrains

**Quadrotor + Electric**



**Tiltwing + TurboElectric**

## ROTOR-WING INTERACTIONS
conversion/transition
interactional aerodynamics
flow control

## SAFETY and AIRWORTHINESS
FMECA (failure mode, effects, and criticality analysis)
component reliability
crashworthiness
propulsion system failures

**Side-by-side + Hybrid**

## AIRCRAFT DESIGN
weight, vibration
handling qualities
active control

## STRUCTURE AND AEROELASTICITY
structurally efficient wing and rotor support
rotor/airframe stability
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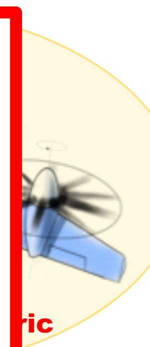


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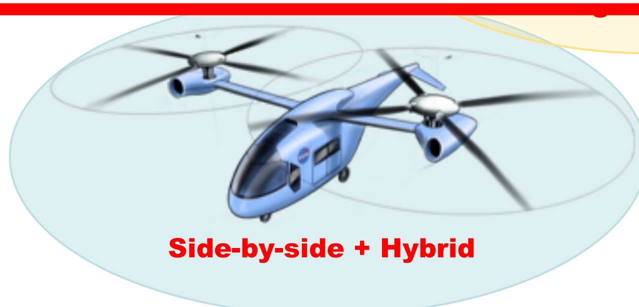


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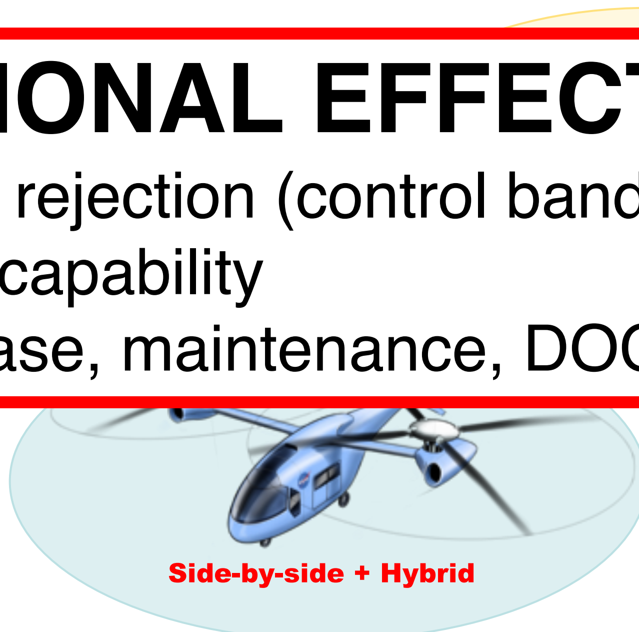


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# Noise Research Roadmap

| FY18 | FY19 | FY20 | FY21 | FY22 | FY23 |
|---|---|---|---|---|---|

**Safe & Certifiable VTOL**

- Demonstration of Design and Flight Operation Methods for Reduced Vertical Take-off and Landing (VTOL) Aircraft Noise
- Multi-level, Multi-Discipline Design and Optimization Demonstration

**Source Noise Modeling**

- Validate Fast Acoustic Modeling
- Include Broadband Noise Modeling
- Improve Acoustic Prediction Tools

**Low Noise Flight Operations**

- Validate Low Noise Prediction Tools; Develop Cockpit Noise Display
- Update HAI Fly Neighborly info
- Explore Acoustically-Aware Flight Control
- UAM Noise Modeling and Community Noise Mitigation

**Human Response to Noise**

- Psychoacoustics Evaluation of Low Noise Designs and Flight Ops
- Assessments of Sound Metrics for Annoyance

**Low Noise Technologies**

- Rotor/Rotor and Rotor/Body Interaction Noise
- Closed Loop Control and Active Noise Control

# NASA-FAA-Army Low Noise Operations Flight Test Completed

**OBJECTIVES:**

1. Obtain data to help identify low noise maneuvering techniques and corresponding flight procedures.
2. Obtain source noise for aircraft modeling tools

**APPROACH:**

Developed low noise flight procedures to minimize the impact of helicopter operations. NASA and the FAA tested 6 helicopters in order to develop general “rules of thumb” for low noise flight procedures.

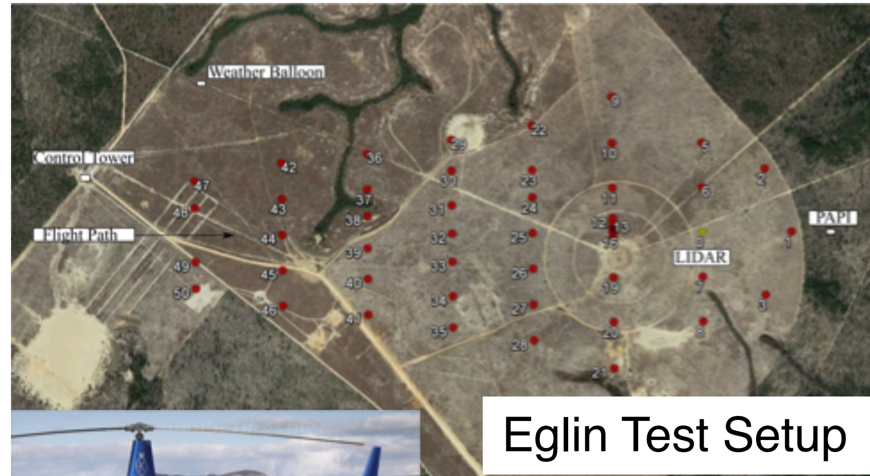
**ACCOMPLISHMENTS:**

- R-44 and R-66 were tested at Eglin AFB in both steady and dynamic flight conditions with all priority points acquired.
- Bell 207L, Bell 407, AS350, EC130H were tested at Amedee Airfield with all priority points acquired.

**SIGNIFICANCE:**

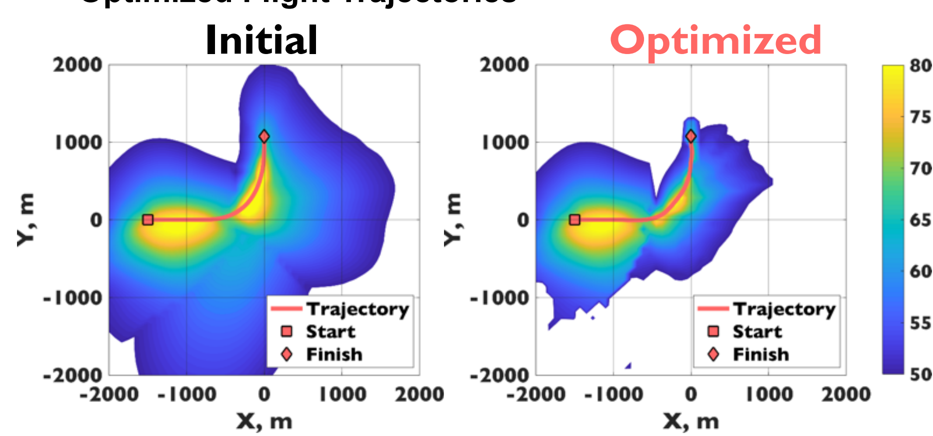
Analysis of configurations and flight operations have resulted in generalizations for low noise trajectories. These will be incorporated into the Fly Neighborly information and upcoming workshops.

The data will be used to calibrate NASA tools and contribute to the development of real-time acoustic information as a cockpit display.






**Optimized Flight Trajectories**






NASA POC: M. Watts, E. Greenwood

**Partners**: FAA, Army

# Low Noise Ops Application to Urban Air Mobility

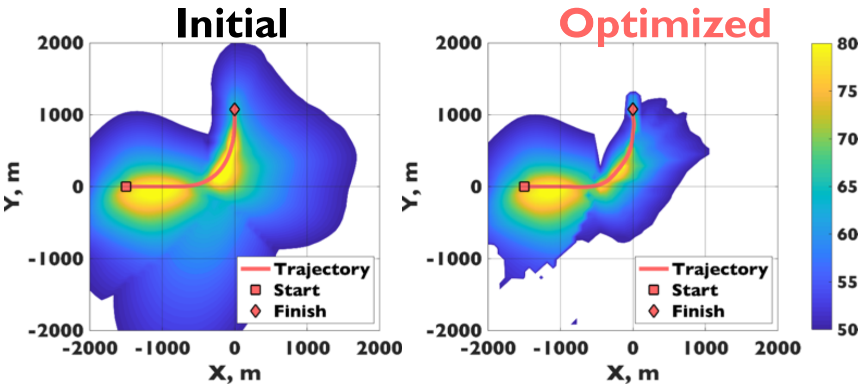
**OBJECTIVES:** Determine optimal trajectories and operational models for low noise UAM

**APPROACH:**
Apply new, fast acoustic rotorcraft tools to UAM vehicles. Include constraints for safety and passenger comfort. Incorporate real-time noise awareness into flight controller. Explore control of noise exposure through phase control.

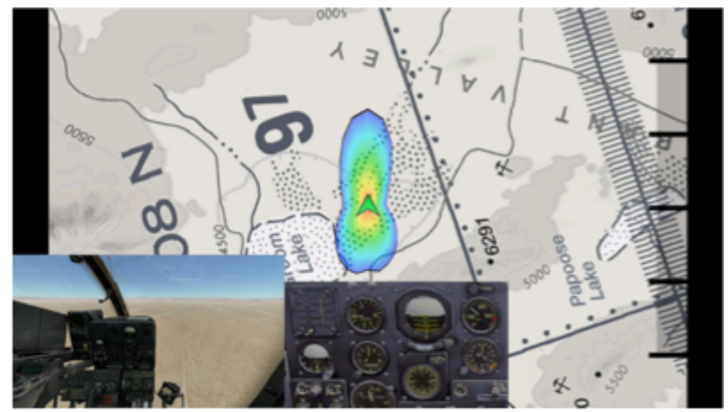
**ON-GOING WORK**
- Apply helicopter noise tools to UAM configurations.
- Real time display and desktop simulation training tool under development
- An acoustic constraint within the flight control simulation for an electric VTOL tilt-wing vehicle has been demonstrated
- Development of a framework for onboard trajectory generation is underway
- Development of noise reduction strategies using phase and RPM control is underway

**SIGNIFICANCE:** Groundwork being accomplished for development of acoustically-aware vehicles and flight controllers

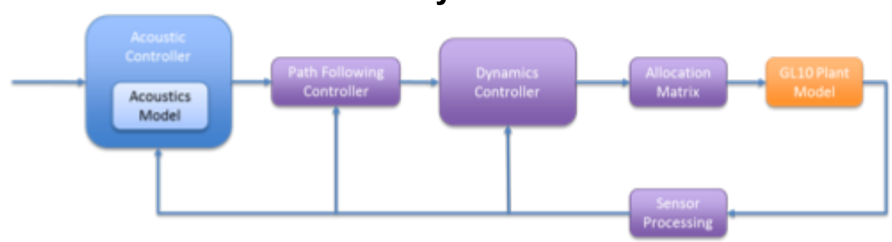
**Optimized Flight Trajectories**




**Pilot or (Autopilot) Real Time Noise Awareness**




**Acoustically Aware Vehicle**



# Preliminary Demonstration of Active Noise Control on a Single sUAS Rotor

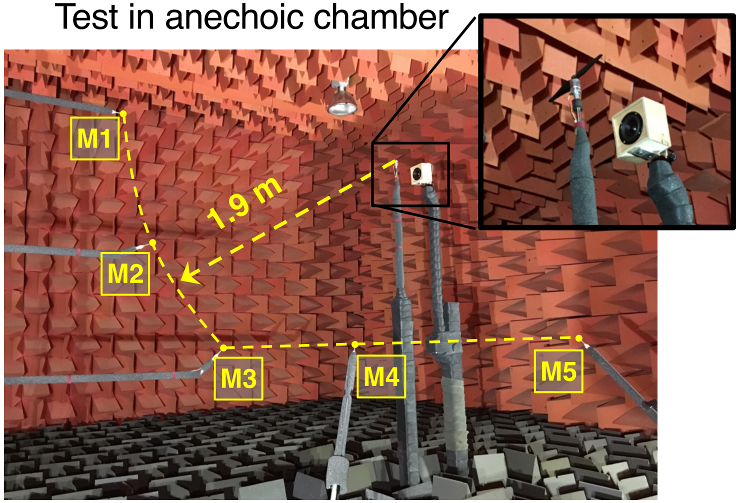
**OBJECTIVE** Assess the feasibility of actively reducing noise from small UAS using speakers attached to the vehicle.

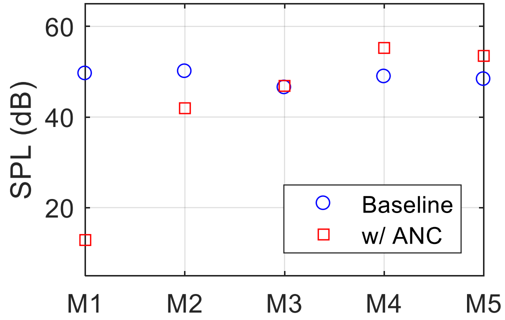
**APPROACH** Demonstrate active noise control on a single sUAS rotor in the laboratory. Tests were performed at 6000 RPM, which corresponds to a blade passage frequency (BPF) of 200 Hz.

**ACCOMPLISHMENTS** Used a 3”-diameter speaker to attenuate tonal noise produced by a 9.4”-diameter rotor. Results confirm that active noise control can work in this application. **Tonal reductions of over 30 dB** were achieved at the error microphone. The reductions are directional and an increase is seen at other locations.

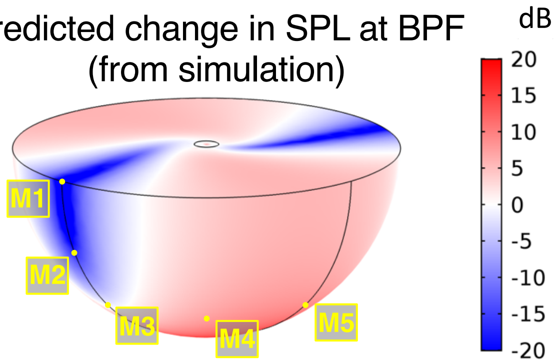
**SIGNIFICANCE** The demonstration shows that significant attenuation is possible at specific azimuthal and elevation angles using a loudspeaker. This capability could be particularly useful if combined with acoustically-aware flight operations. Noise could be controlled and directed to non-sensitive locations.

Test in anechoic chamber




Predicted change in SPL at BPF (from simulation)



# Human Response (Annoyance and Detection/ Localization)

**OBJECTIVE** Use psychoacoustic tests and assessment to determine if sound quality metrics (fluctuation strength, tonality, impulsiveness, roughness, and sharpness) can determine annoyance levels. Assess vehicles ranging from sUAS to UAM to helicopters.

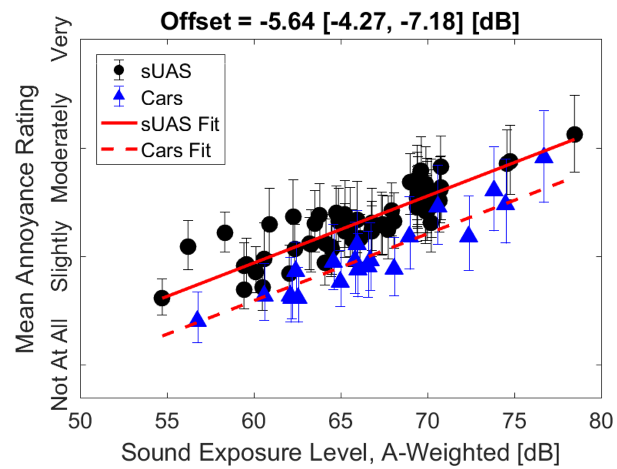
**APPROACH** Using the Exterior Effects Room, conduct human subject experiments and analyze the results. EER testing has been conducted for sUAS compared to vehicles and for helicopters in a variety of flyover conditions. UAM vehicles will be modeled in future work.

**ACCOMPLISHMENTS**

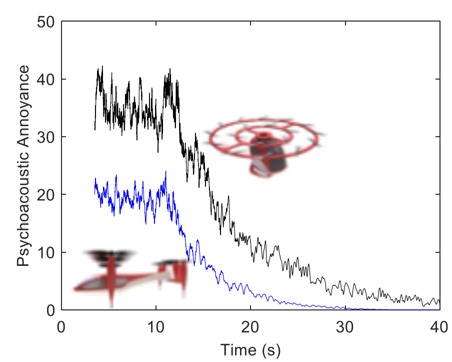
- Developed method to auralize rotorcraft flyover using source noise description based on recordings of flyover data
- sUAS annoyance initially characterized
- Demonstrated tool set for predicting UAM community noise from computations and synthesized signals.

**SIGNIFICANCE** Preliminary annoyance information has been obtained and analysis is underway to characterize sound quality metrics that correlate to annoyance for several vertical flight vehicle classes. Additional testing and validation is planned for annoyance metrics with additional vehicle types.

**Exterior Effects Room, NASA Langley** (N. Pera, S Rizzi, S. Krishnamurthy, C. Fuller, A. Christian, "A Recording-Based Method forAuralization of Rotorcraft Flyover Noise," AIAA SciTech Forum, Jan. 2019)




**Annoyance rating for sUAS characterized** (Christian, A. and R. H. Cabell, "Initial Investigation into the Psychoacoustic Properties of Small Unmanned Aerial Vehicle Noise," AIAA Aviation, June 2017)




**Psychoacoustic annoyance for initial NASA UAM study** (S. Rizzi, "NASA's Acoustic Modeling and Simulation Tools for Perception-Influenced Design of Urban eVTOL Systems," Uber Elevate Summit, April 2017.)

# Summary

NASA RVLT is focused on

- Overcoming significant barriers to the use of vertical lift vehicles in expanded missions
- Providing technology leadership
  - Technologies to demonstrate low noise and reduce annoyance
  - Efficient configuration concepts that reduce fuel burn
  - Technologies that improve speed, safety, mobility, payload

- Developing vision of the future for vertical lift; identifying technical challenges for new markets
  - Methods to assess advanced innovative concepts
  - Pathfinder for next gen emerging market technologies