FAA ASCENT Rotorcraft Research at Penn State

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Penn State VLRCOE Annual Review
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ASCENT
AVIATION SUSTAINABILITY CENTER

ASCENT Aviation Sustainability Center

- 16 universities and affiliates
- $19M in 2023 from FAA (+ NASA, DoD, and EPA)
- Goals include
  - Reduce noise and emissions
  - Enable commercial-scale use of sustainable aviation fuels
  - Improve health and quality of life in and around airports
- Research topic areas
  - Aircraft Technology
  - Alternative Fuels
  - Emissions
  - Noise
  - Operations
  - Supersonics
  - Tools

ASCENT Projects Compliment VLRCOE

Several rotorcraft related ASCENT projects at Penn State:

- Project 38: Rotorcraft Noise Abatement Procedures Development
  - Tools for developing noise abatement procedures for helicopters
  - Active since 2017 (ASCENT 06 since 2014)
- Project 49: Urban Air Mobility Noise Reduction Modeling
  - Acoustic modeling of varied UAM configurations and operations
  - Active since 2020
- Project 77: Measurement to Support Noise Certification for UAS/UAM Vehicles and Identify Noise Reduction Opportunities
  - Measurement procedures and data for varied UAS/UAM aircraft
  - Active since 2020

Project Personnel

- 7 graduate students
- 4 faculty

Project 38

- PI: Kenneth S. Brentner
- Co-PIs: Eric Greenwood, Joseph F. Horn
- GRA: Sagar Peddanarappagari, MS

Project 49

- PI: Kenneth S. Brentner
- Co-PIs: Eric Greenwood, Joseph F. Horn
- GRAs: Bhaskar Mukerjee, PhD; Ted Ze Feng Gan, PhD

Project 77

- PI: Eric Greenwood
- Co-Pis: Kenneth S. Brentner, Eric N. Johnson
- GRAs: Vitor T. Valente, PhD; Joel Rachaprolu, PhD; Rupak Chaudary, PhD; EzzEldin ElSharkaway, MS

ASCENT Project 38

- Rotorcraft noise increasingly important with general public
  - HAI's "Fly Neighborly Guide" is helpful for community noise
    - Since publication, new rotorcraft and operations have been developed
  - Need for more detailed data and information about noise produced from the operation of rotorcraft
  - Need for detailed and specific noise abatement procedures

Bell 407

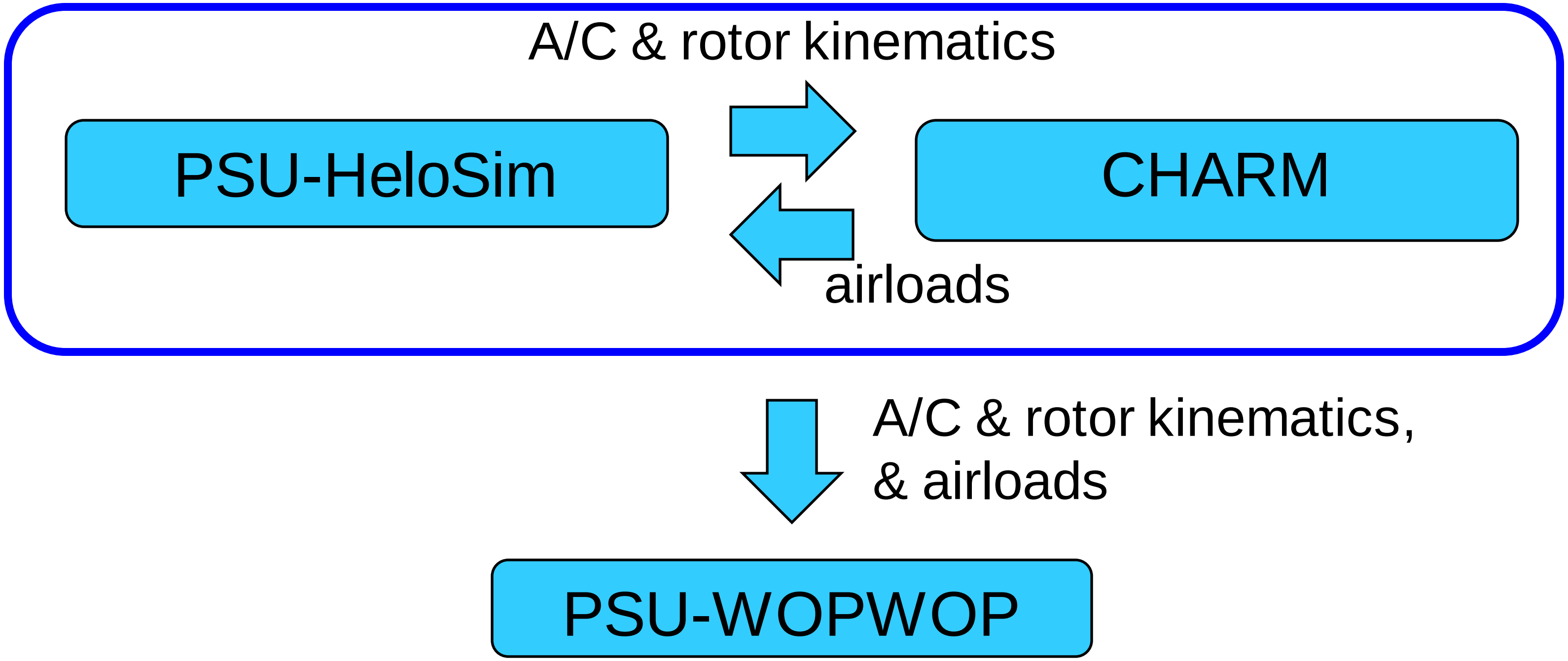
- This project investigates noise abatement flight procedures of rotorcraft through modeling
  - Physics based modeling of noise leveraging previous research performed for NASA and DoD
  - Comprehensive modeling of the many sources of rotor noise
  - Complete vehicle modeling during example flight procedures
    - Flyover
    - Approach, departure
    - Turn maneuvers, etc.

Sikorsky S-76D

Noise Prediction System

Components:

- PSU-HeloSim: flight simulation code for helicopters
- CHARM: aeromechanics modeling code by CDI
- PSU-WOPWOP: acoustic propagation solver



CHARM: Comprehensive Hierarchical Aeromechanics Rotorcraft Model

NASA/FAA/Army Noise Abatement Test

R44

Selected due to different engine power and size

R66

AS350

Selected due to different tail rotor technology (Fenestron on EC130)

EC130

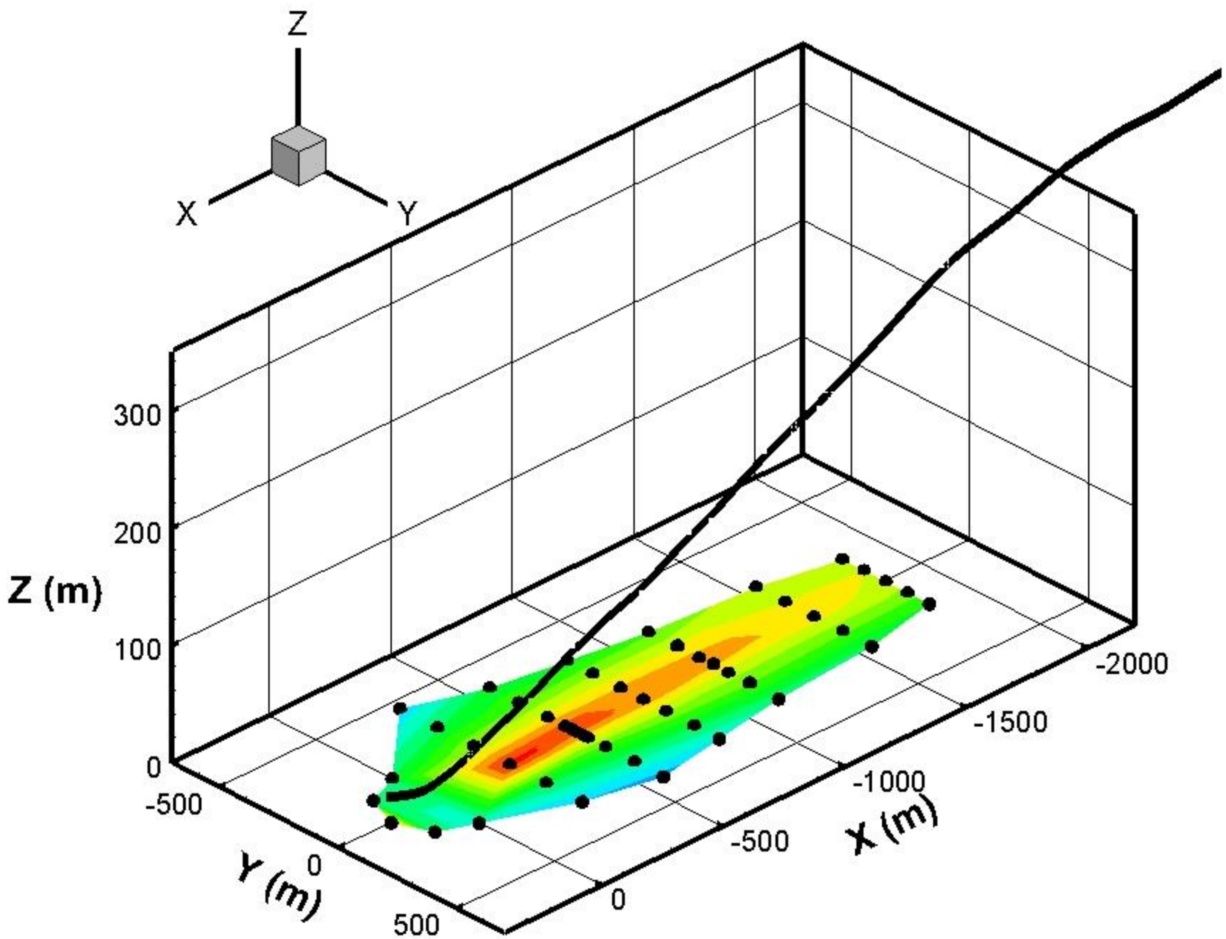
Bell 407

Selected due to different number of MR blades

Bell 206L

Watts, M. E., Greenwood, E., Smith, C. D., and Stephenson, J. H., "Noise Abatement Flight Test Data Report," NASA/TM-2019-220264, March 2019.

Approach Noise Footprints
80 KIAS, 6° FPA

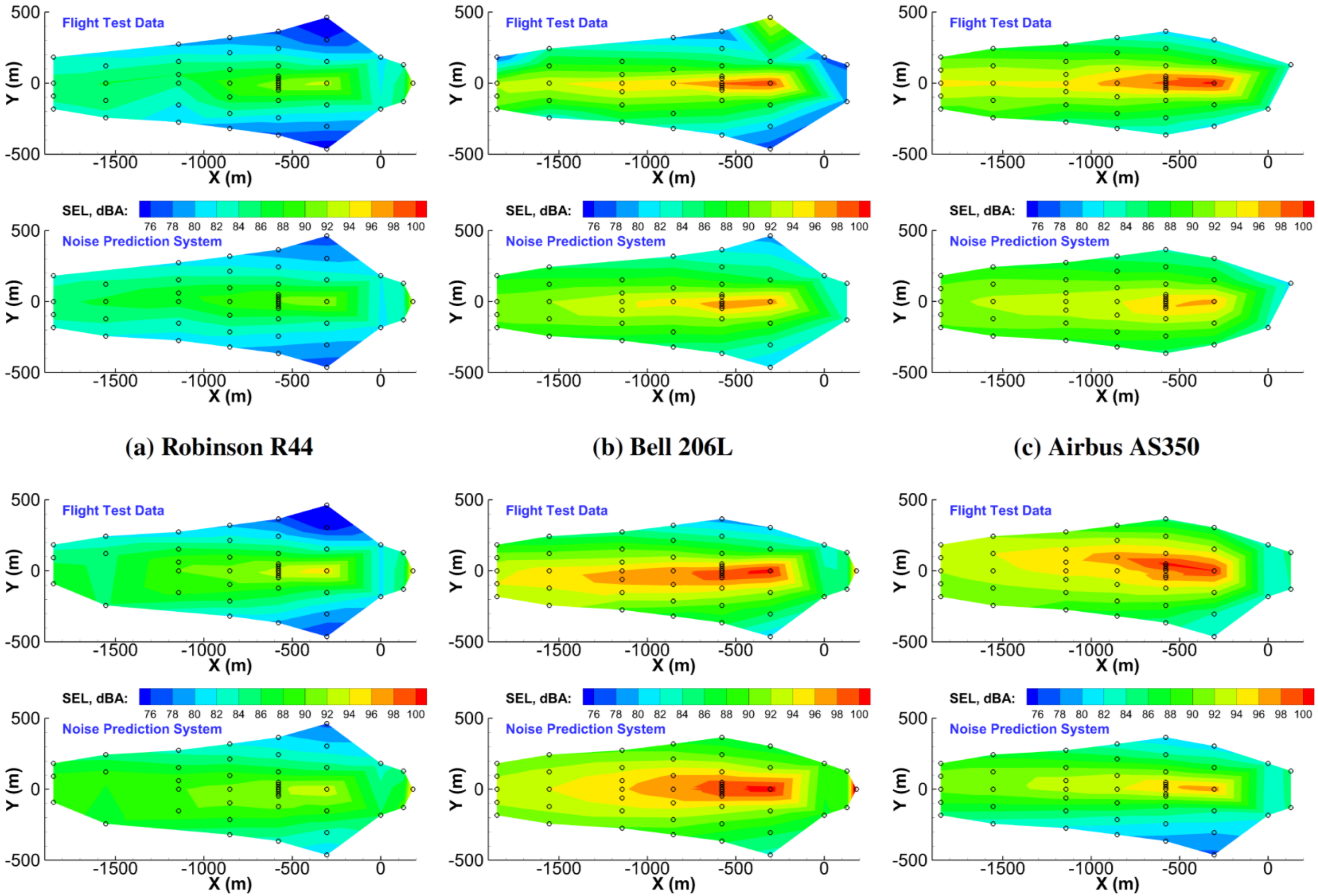


Bell 407

Measured vs. Predicted SEL Footprints

Flight test

Prediction



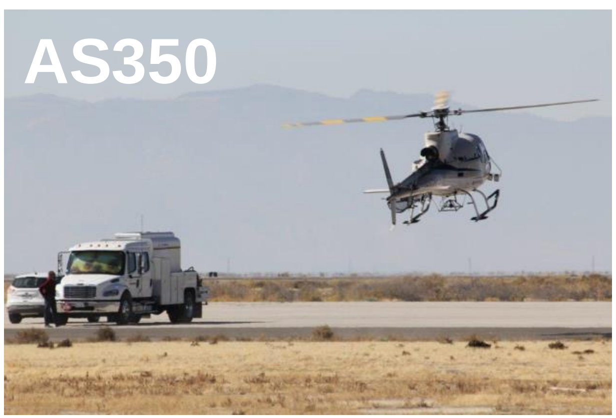
(a) Robinson R44 (b) Bell 206L (c) Airbus AS350

Flight test

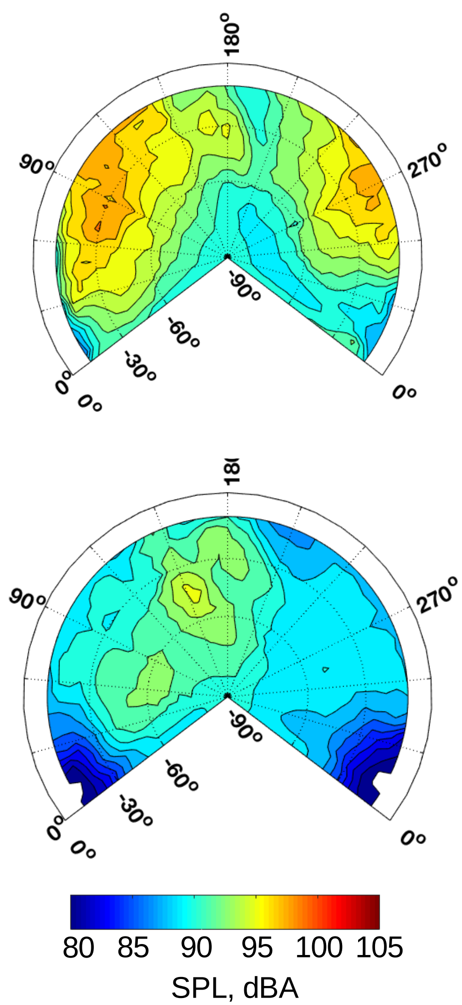
Prediction

(d) Robinson R66 (e) Bell 407 (f) Airbus EC130

Shrouded Rotors



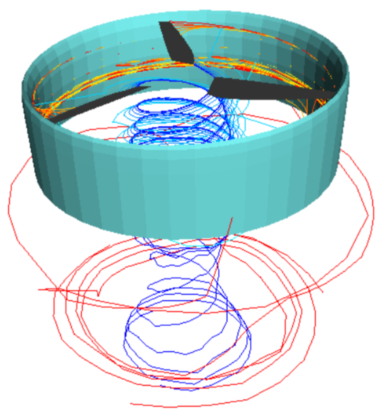
Measured Noise Hemispheres
~75 KIAS, 8° FPA

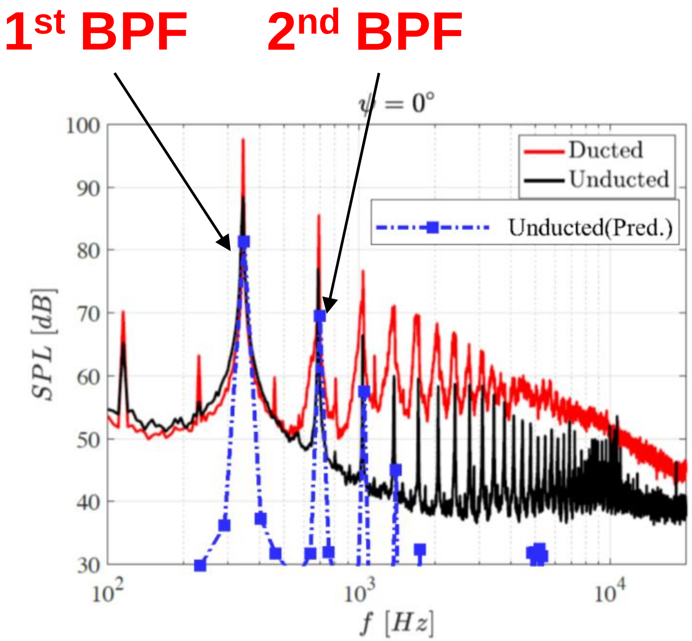


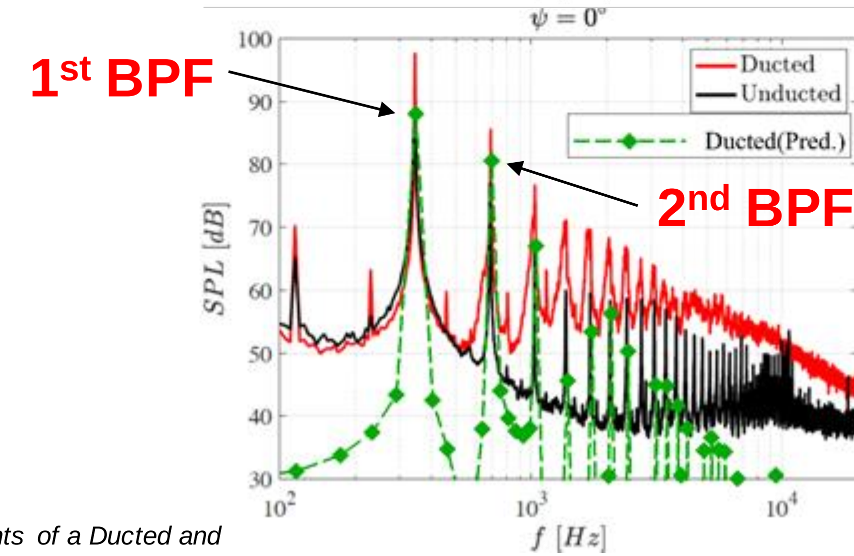
- Shrouded rotor acoustics differ from open tail rotor
- Need midfidelity approach to model shrouded rotors
- Current research investigating approximate scattering methods

Shrouded Rotors

- Use CHARM panel methods to model shrouded rotor airloads
- "Reradiate" acoustic pressures on shroud to approximate acoustic scattering
- Trends agree with experiments by Cupoletti and Riley



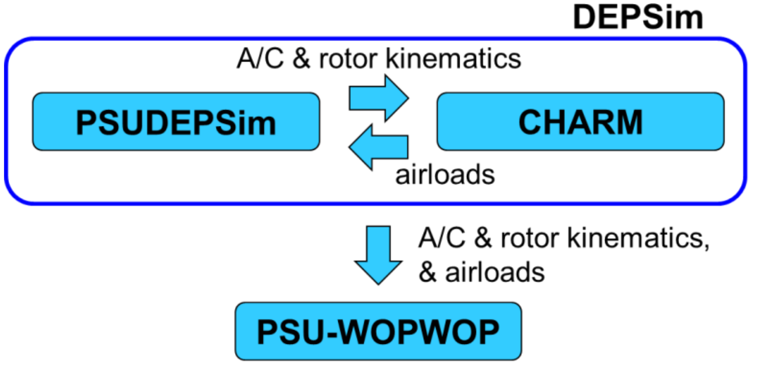




Cupoletti, D., and Riley, T., "Time-Resolved Flow Field and Acoustic Measurements of a Ducted and Unducted Rotor," 28th AIAA/CEAS Aeroacoustics Conference, Southampton, UK, June 2022.

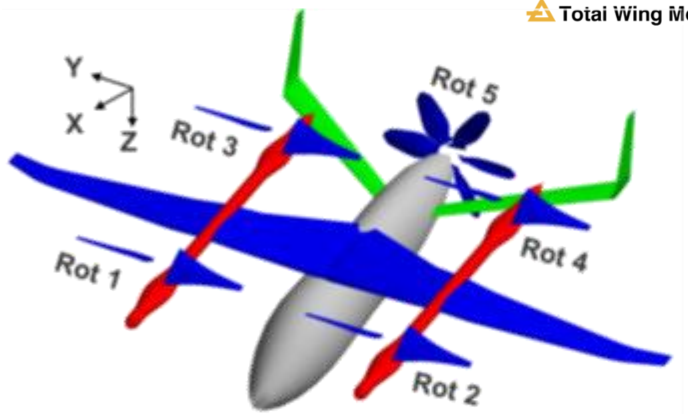
Project 49

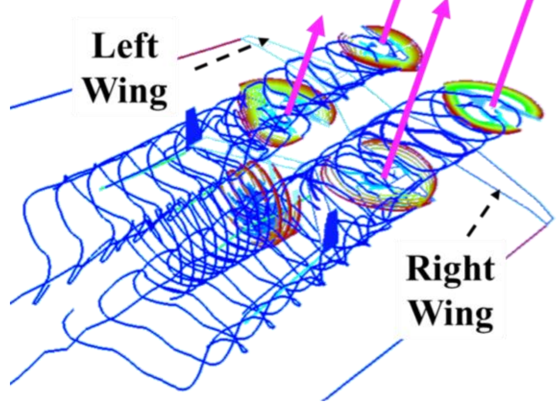
- Noise is widely recognized as one of the foremost barriers to development and public acceptance of UAM operations
- Information about acoustic characteristics of UAM is needed:
  – To design quiet configurations
  – To understand how to operate UAM quietly
  – To inform the approach to noise certification
  – To understand the impact on communities
- Development of robust noise prediction system:
  – PSUDEPSim: flight simulation code for DEP aircraft
  – CHARM: aeromechanics modeling code by CDI
  – PSU-WOPWOP: acoustic propagation solver
- DEPSim/PSU-WOPWOP system enables systematic investigation of UAM configurations, flight physics, and noise emission
- System allows investigating:
  – Fundamental noise mechanisms of novel variable rotational speed rotors
  – Nature of multi-rotor noise
  – Trim strategies of compound aircraft



Aircraft Trim

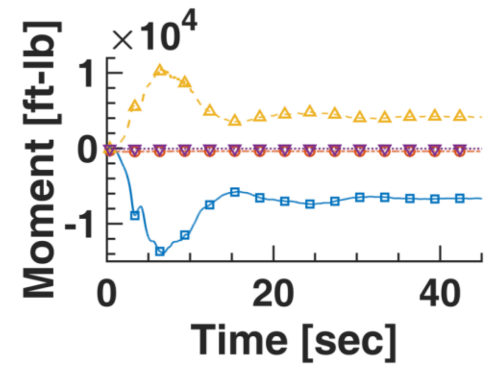
- PSU Ref. Vehicle 2
- Roll moment induced by pusher propeller
- Interaction between front rotors and wing reduces roll control effectiveness
- Less control effort using rear rotors only for roll



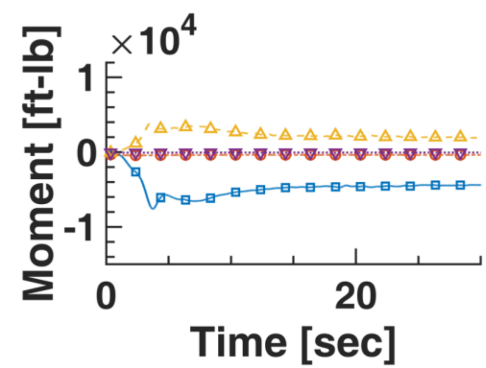


Total Rotor Moment - CHARM On | Total Rotor Moment - CHARM Off | Total Wing Moment - CHARM On | Total Wing Moment - CHARM Off

All rotor roll trim

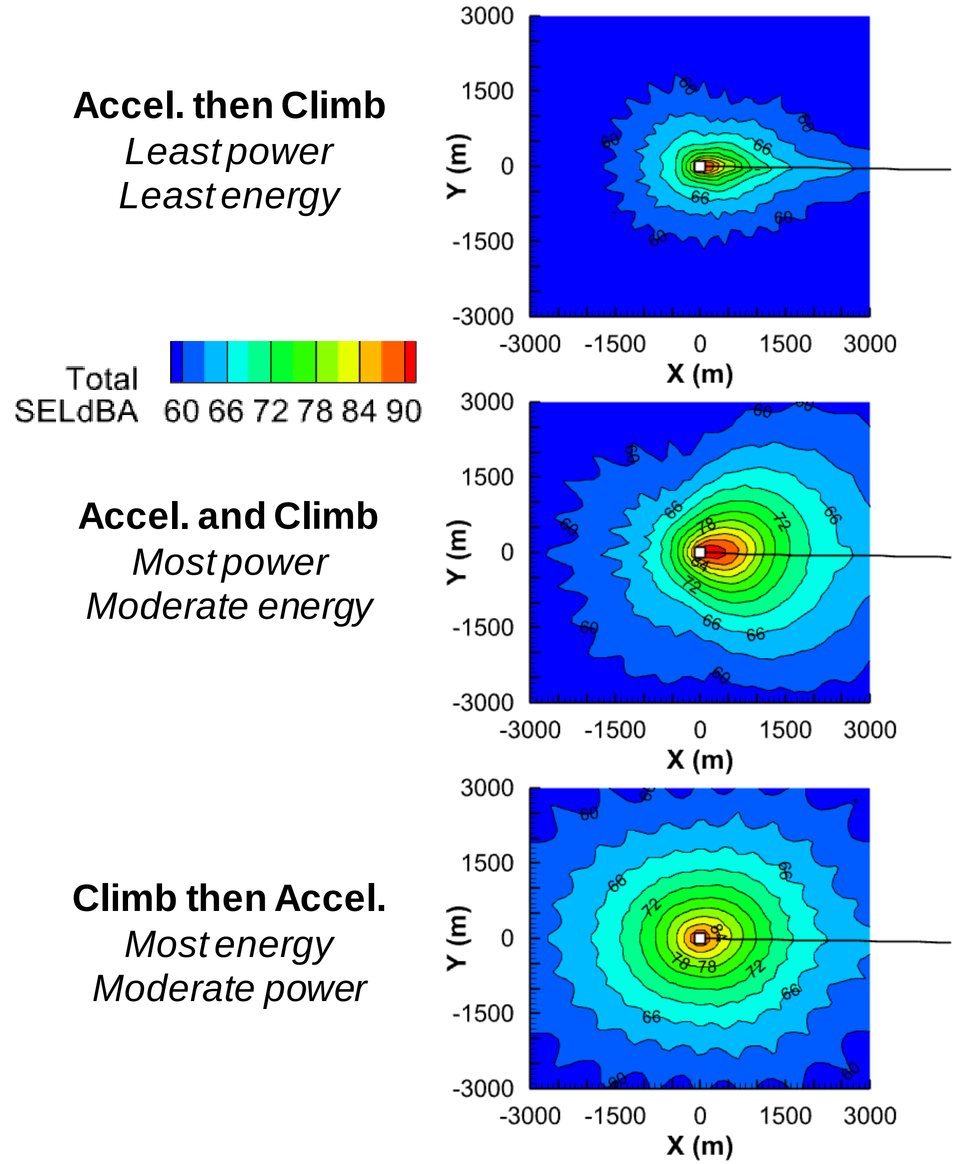


Rear rotor roll trim



Departure Transition Maneuvers

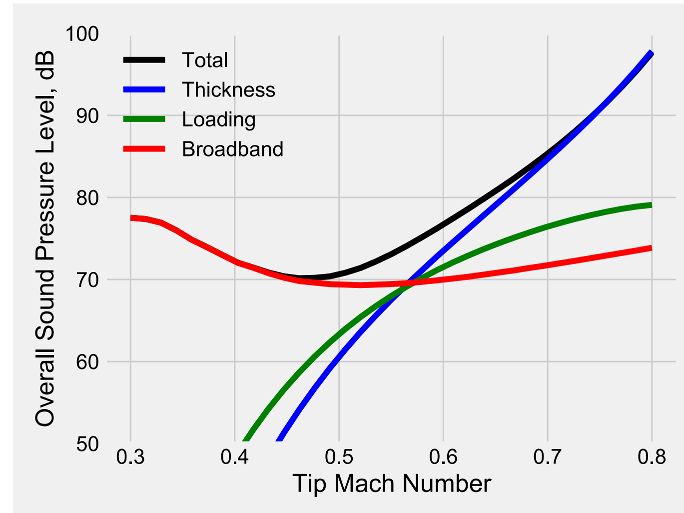
- Defined rotor RPM and pitch schedule to minimize stall
- Simulated departure transitions from hover to cruise
- Tradeoffs between climb angle, noise, energy, and power



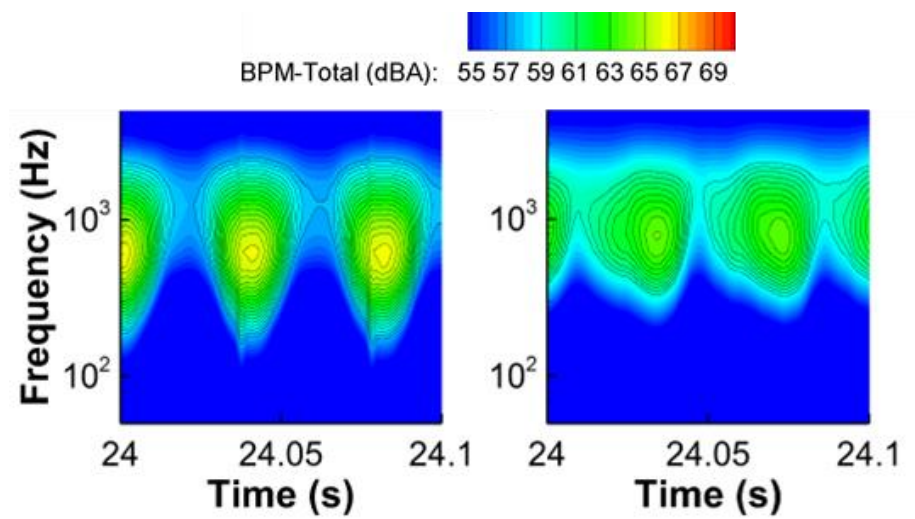
Broadband Noise

- Broadband noise may become dominant as tip speeds are reduced
- Increased focus on broadband noise prediction for eVTOL
- Improved existing airfoil self-noise models to predict modulation of broadband noise

Notional Rotor Noise Trends with Tip Mach



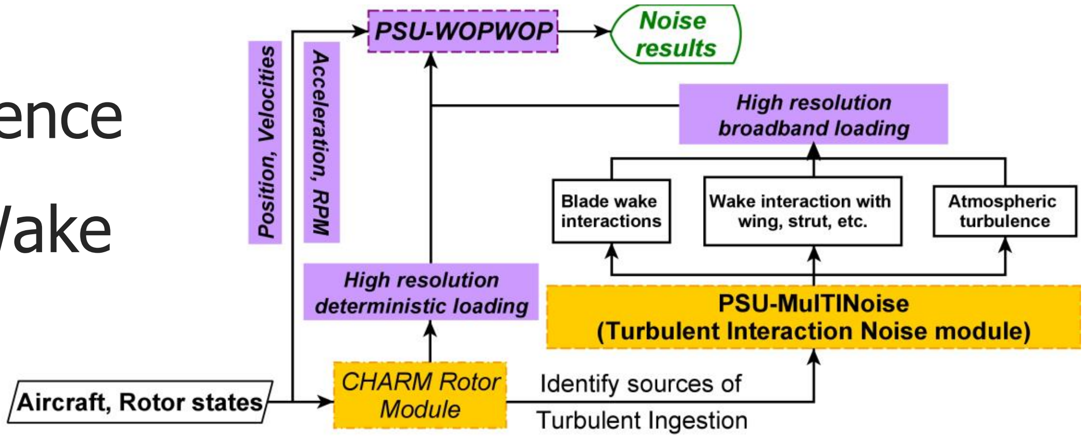
Self-Noise Modulation for eVTOL rotor at 10 KIAS

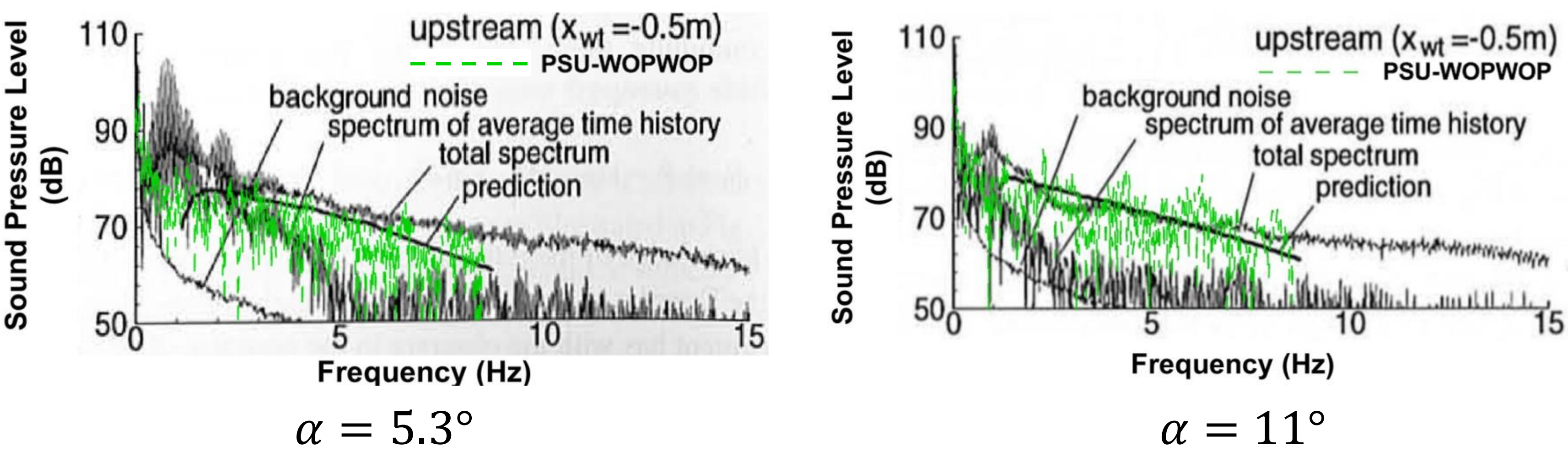


Variable Pitch **Variable RPM**

Turbulent Interaction Noise

- Developed framework for modeling noise due to interactions with turbulence
- Initial focus on Blade-Wake (BWI) interaction noise





Comparison of prediction with HART rotor BWI noise analysis by Brooks and Burley

Brooks, T.F., and Burley, C.L., "Blade Wake Interaction Noise for a Main Rotor," Journal of the American Helicopter Society, Vol. 49, No. 1, January 2004.

ASCENT Project 77

- **Existing methods of characterizing aircraft noise assume "stationarity"**

- **UAS and UAM noise is likely to be highly variable**
  - Smaller vehicles are more susceptible to disturbances
  - RPM control often used to stabilize or maneuver vehicle
  - "Nearly-coherent" addition of tonal noise
  - May be highly over-actuated, e.g., no "unique" trim

- **Need new techniques to *reliably* characterize noise radiation**
  - Noise certification
  - Input data for environmental impact analyses
  - Semiempirical modeling and design of low noise operations
  - Inform flight control and design changes to reduce noise

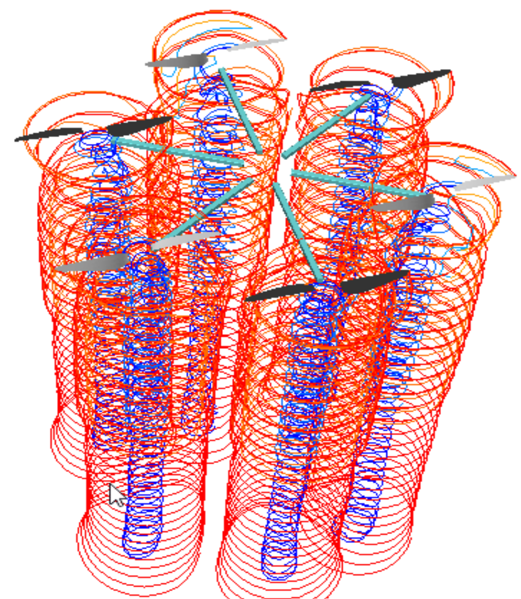
Boeing Cargo Air Vehicle

Beta Ava XC

Approach

- Leverage noise prediction tools (e.g., Project 49) to conduct simulated acoustic experiments
- Develop flight procedures and processing methods to characterize and reduce variability and uncertainty
- Collect acoustic data on a variety of UAS and UAM aircraft configurations
- Explore the effects of design changes, operating procedures, and flight control laws on noise

Large reconfigurable UAS in flight



Aerodynamic prediction using CDI's CHARM free vortex wake

Ground Instrumentation

Instrumentation

- Acoustics
  - Up to 36 microphones
  - 131 kHz @ 24 bit
  - GPS time synchronization
- Survey-grade GPS position (~6″ accuracy)
- 4′ met stations
- Soon: ultrasonic anemometers

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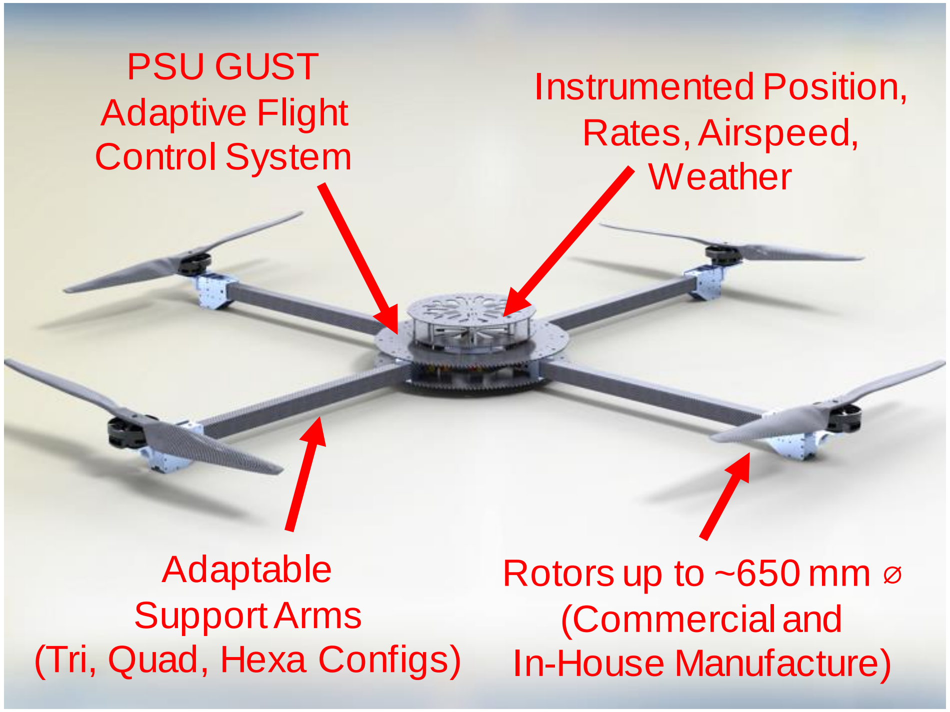
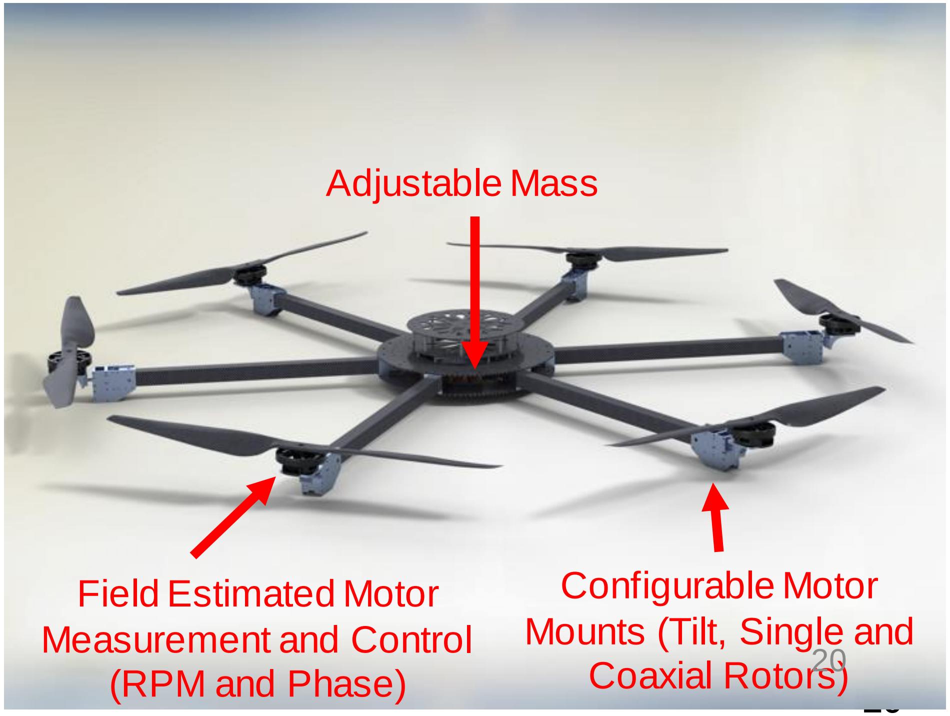
Reconfigurable Research UAS

- Large reconfigurable UAS (1.5m tip-to-tip)
- Large payload capacity (25kg+ max gross weight)
- Space, weight, and power for additional sensors
  - Ultrasonic airspeed measurement
  - Real Time Kinematic Differential GPS
- Planned provision for rotor tilt and aerodynamic surfaces



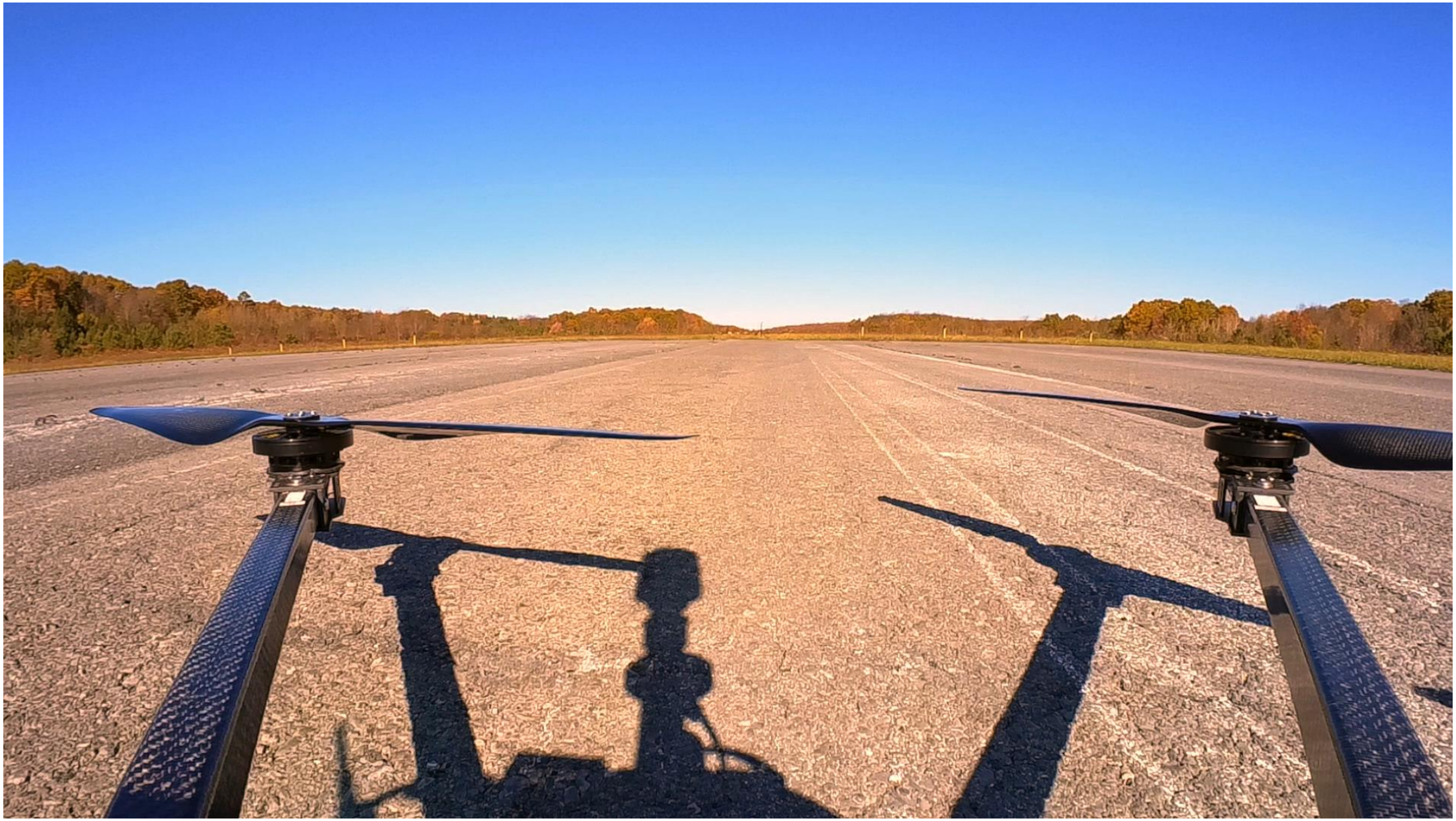


2023 UAS Noise Measurements

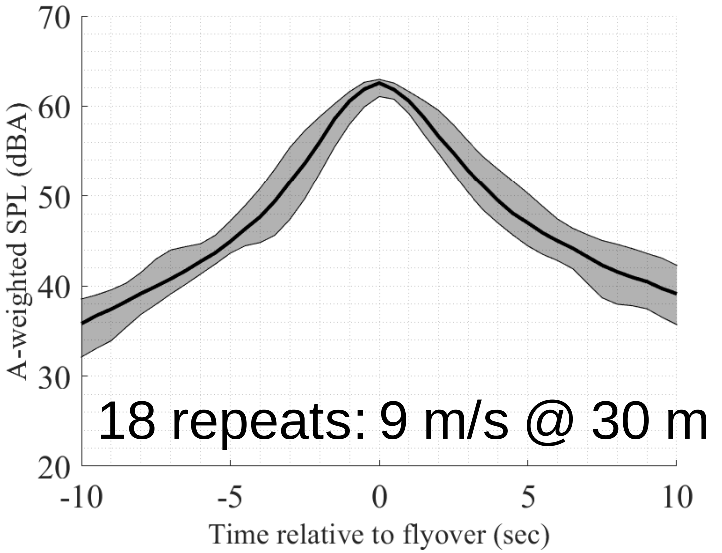
ASCENT
AVIATION SUSTAINABILITY CENTER

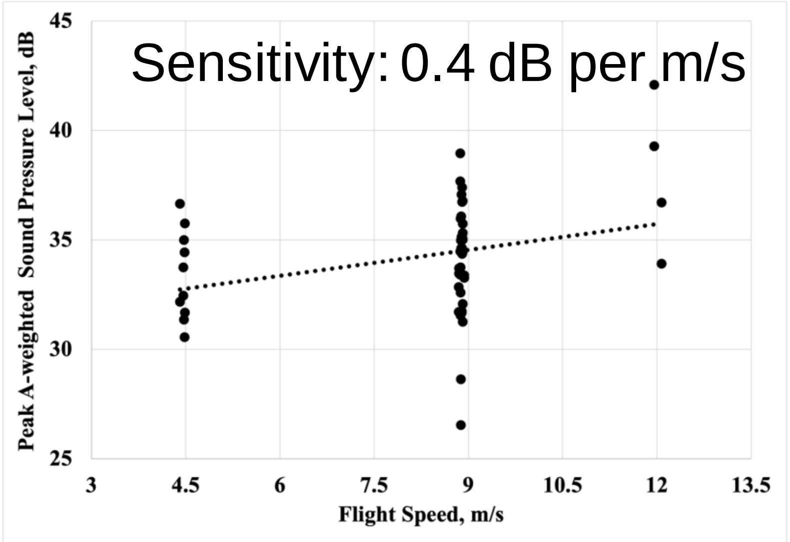
- Over 6 hours of flight time
- Different conditions tested at different speeds and altitudes:
  - Hover
  - Flyover
  - Climb/Descent
  - Simulated Approach/Takeoff

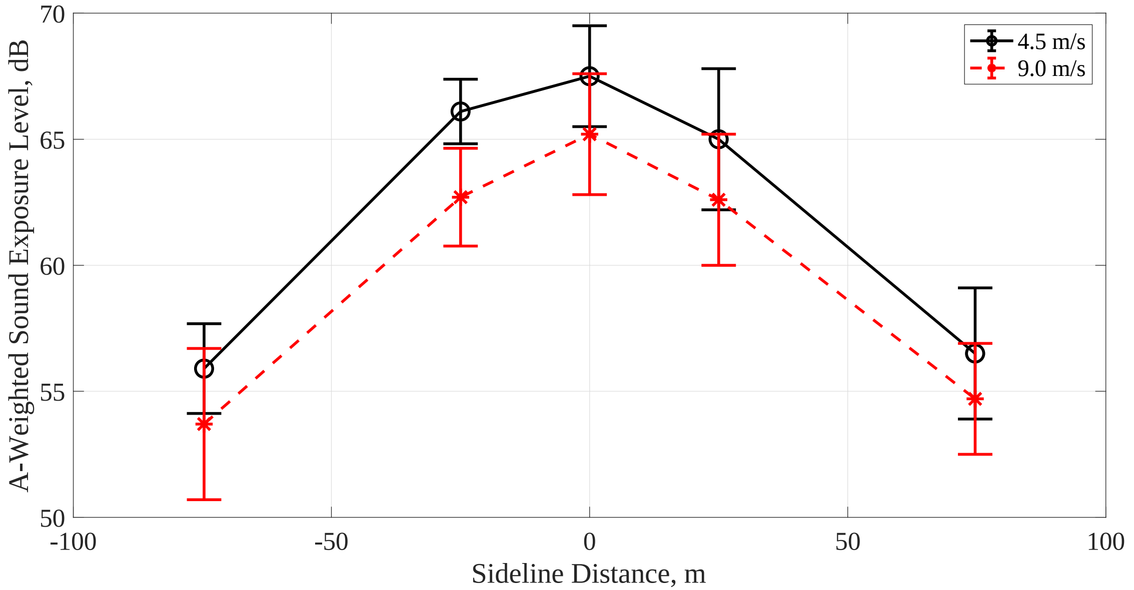
Simulated Approach/Takeoff



Acoustic Variability for Tarot X8







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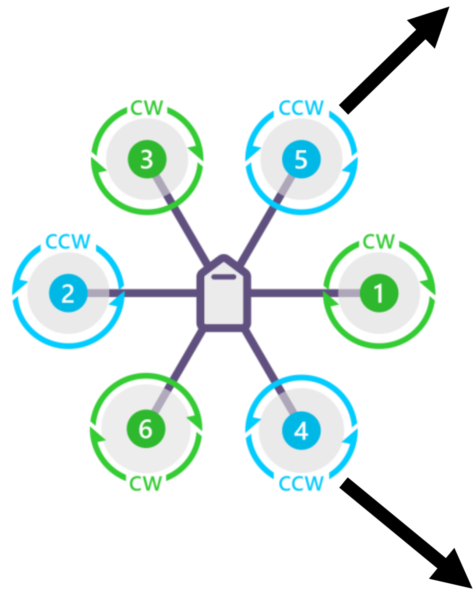
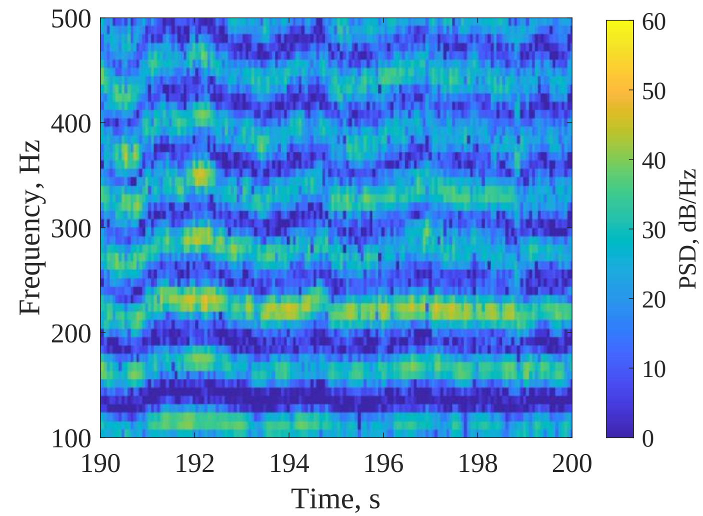
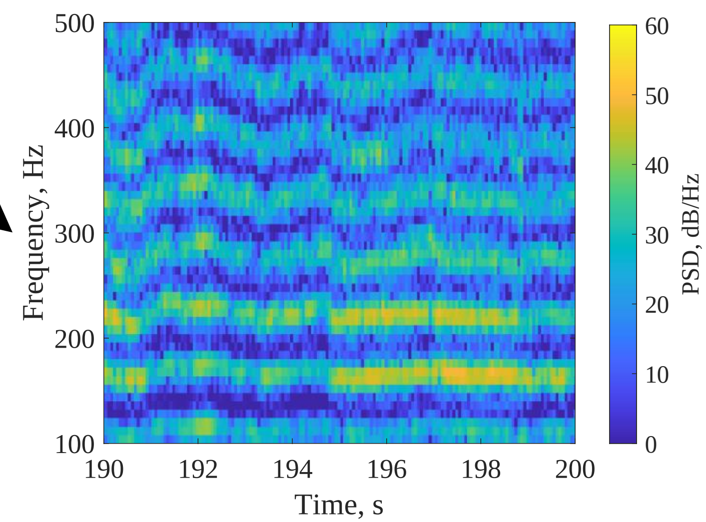
Rotor Source Separation Process

- Variable rotor RPM causes increased acoustic variability
- Developed rotor source separation technique for flight test data
- Requires onboard measurement of rotor RPM





Forward right rotor (R5)



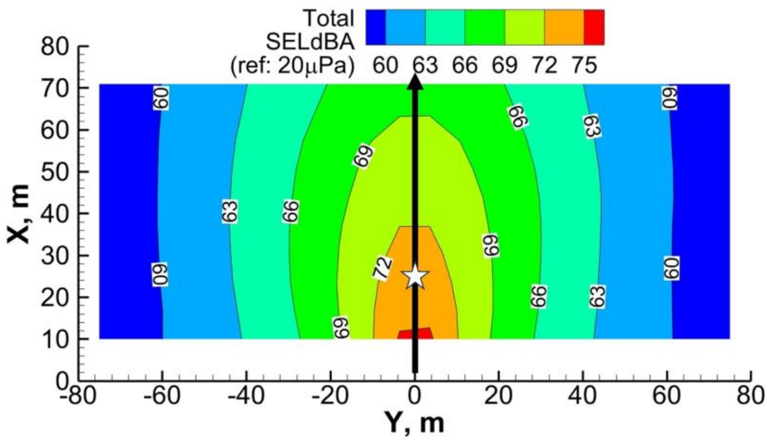
Aft right rotor (R4)

UAS Noise Predictions

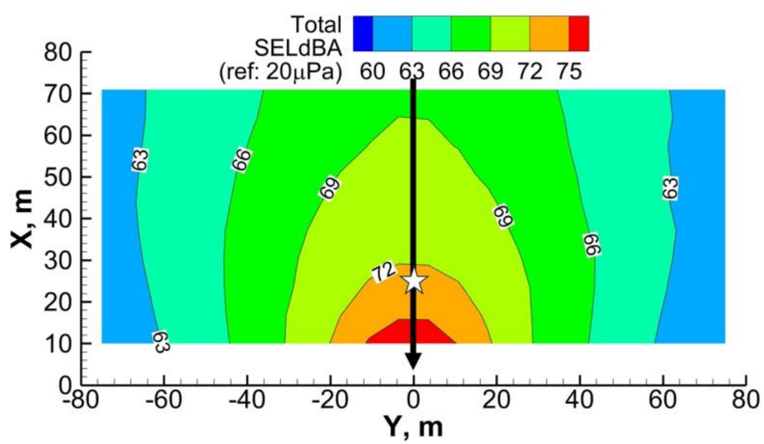
Leverage ASCENT 49 Noise Prediction System

- Simulate and inform experiments
- Investigate low noise operations

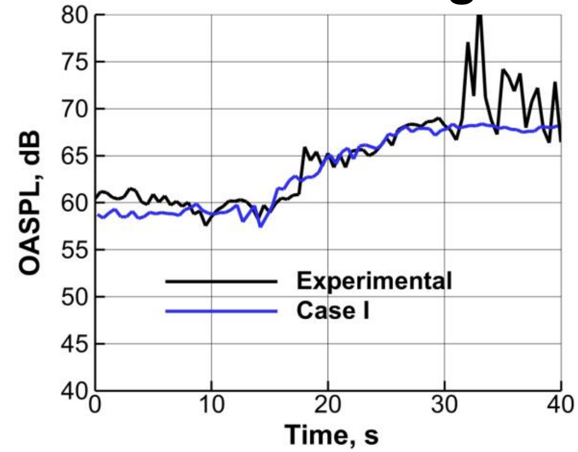
Predicted Takeoff Footprint



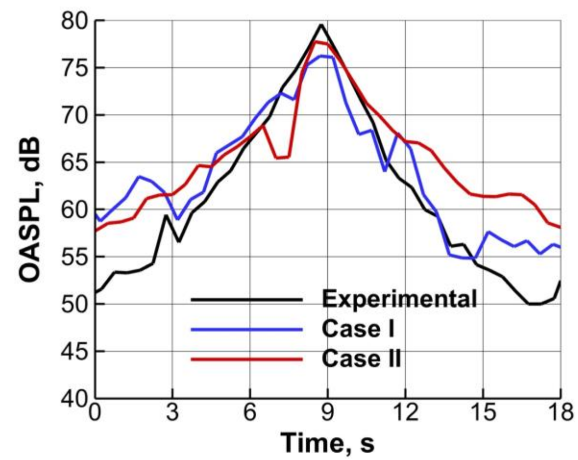
Predicted Approach Footprint



Vertical Flight



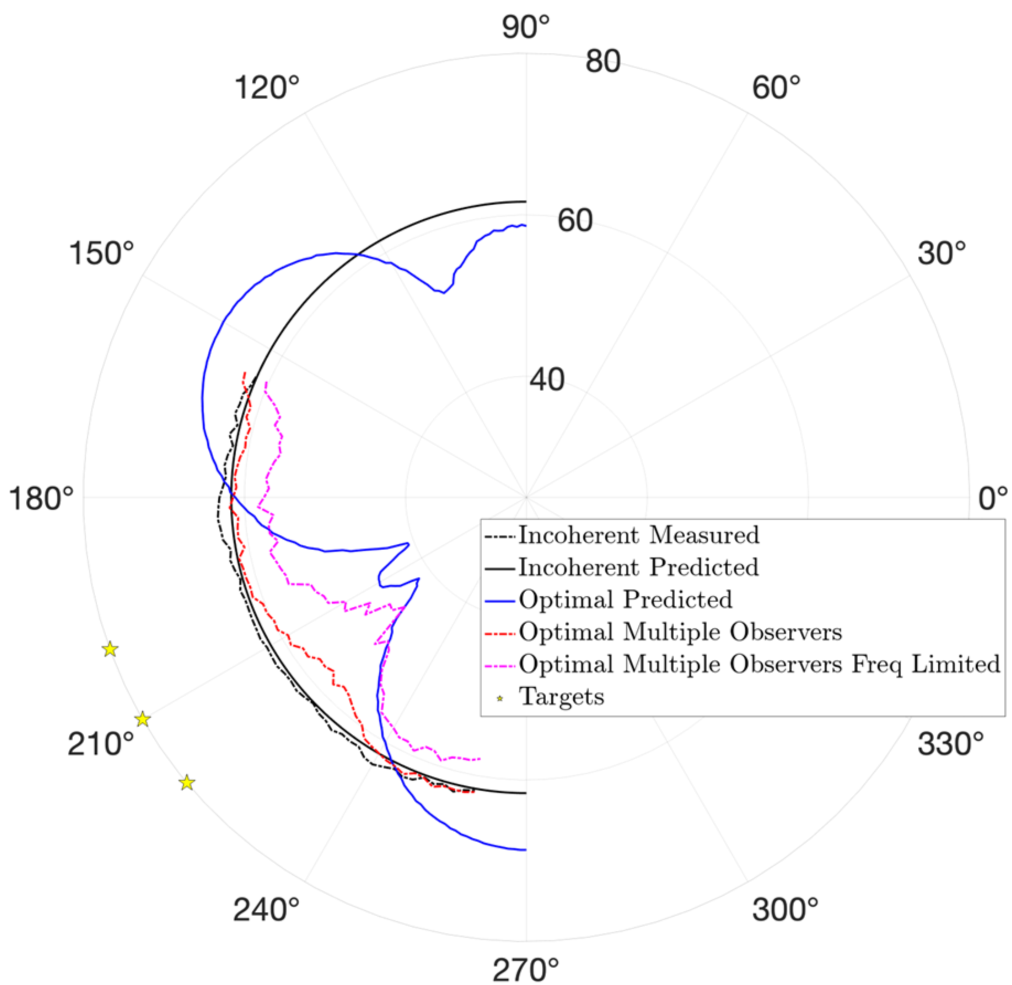
Level Flight



Multirotor Noise Reduction by Synchrophasing

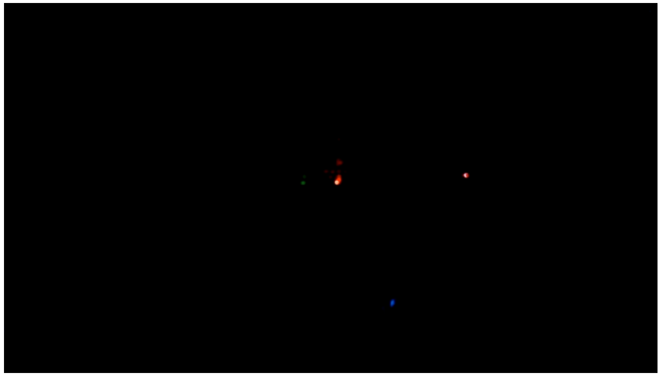
- Developed practical electronic synchrophasing controller for UAS
- Semiempirical synchrophasing approach
  - Characterize individual rotor signals
  - Model phase changes due to position of rotors and observers
  - Determine optimal phases for noise reduction at target observers
  - Evaluate acoustic performance
- Applied to small reconfigurable UAS in Penn State's anechoic chamber

Preliminary Results

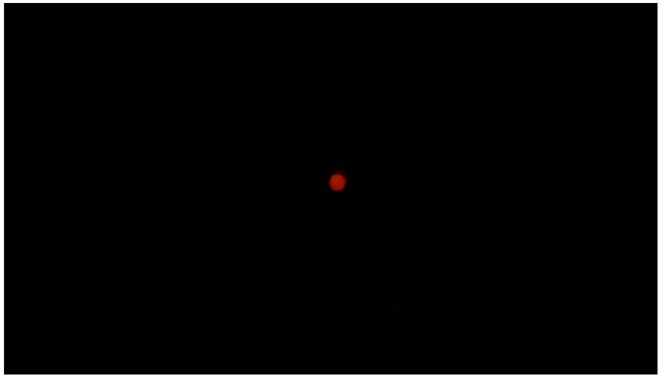


15 dB reduction in low frequency noise

Phase Control Off



Phase Control Active



Strobe triggered by laser tachometer on one motor

Beta Technologies ALIA-250

Several rounds of measurements with Beta Technologies to characterize ALIA-250 UAM:

- Flyover
- Full scale isolated rotor
- Hover / Transition *

*Planned for later this year

Concluding Remarks

- ASCENT helps support a "critical mass" of rotorcraft aeroacoustics research at Penn State
  - Theory
  - Simulation
  - Experiment
  - Noise Reduction
- ASCENT is complementary to VLRCOE research
  - Task 1.1: Proprotor and Wing Interactional Aerodynamics for Performance and Acoustics
  - Task 1.2: Scaling for Interactional Aerodynamics and Acoustics of Multi-rotor Systems
  - Task 3.3: Acoustically Aware Vertical Lift Autonomy
- Students benefit from "cross-pollination" of ideas and skills

Thank You!