PennState
College of Engineering

AEROSPACE
ENGINEERING

Effective Helicopter Noise Abatement Operations

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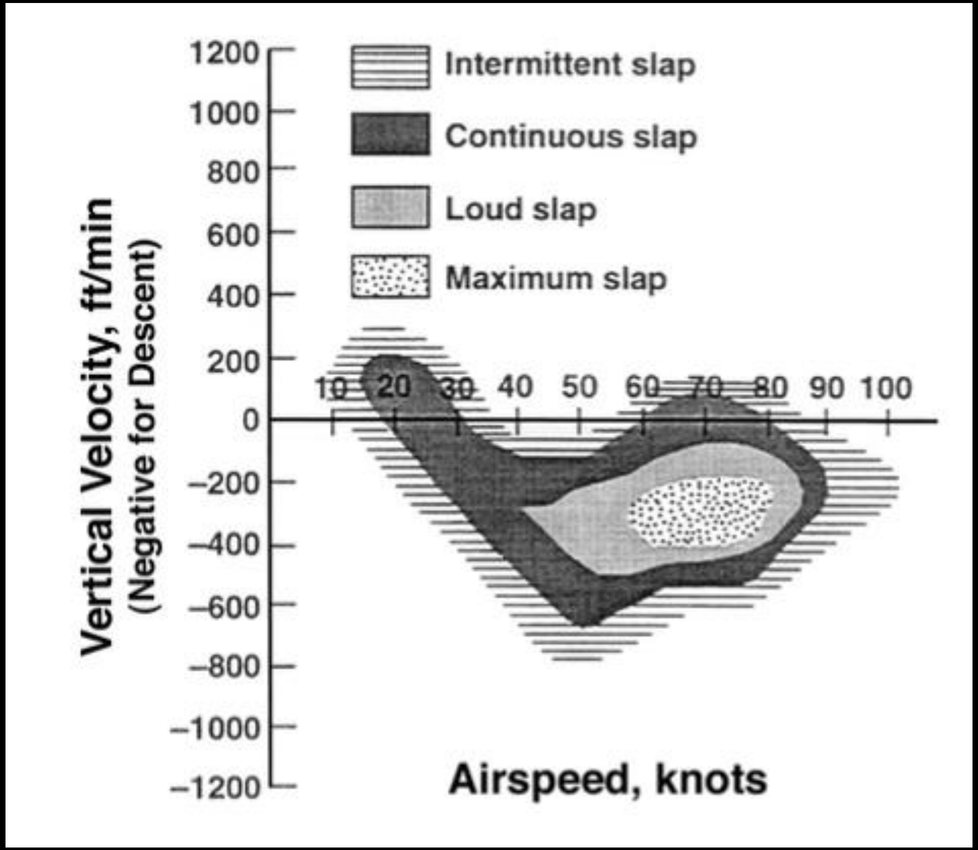
The Pennsylvania State University

What help do pilots get to fly quietly?



Bell 212
HAI Fly Neighborly Guide

ROBINSON
MODEL R44

SECTION 4
NORMAL PROCEDURES

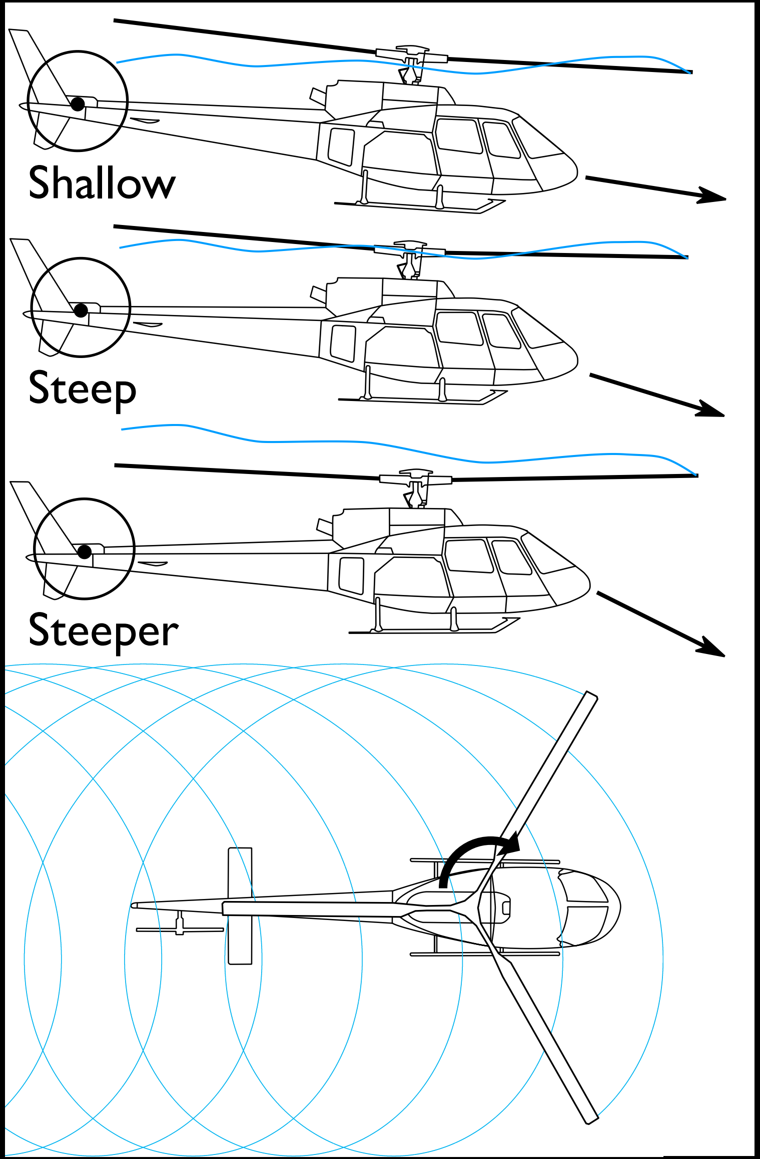
NOISE ABATEMENT

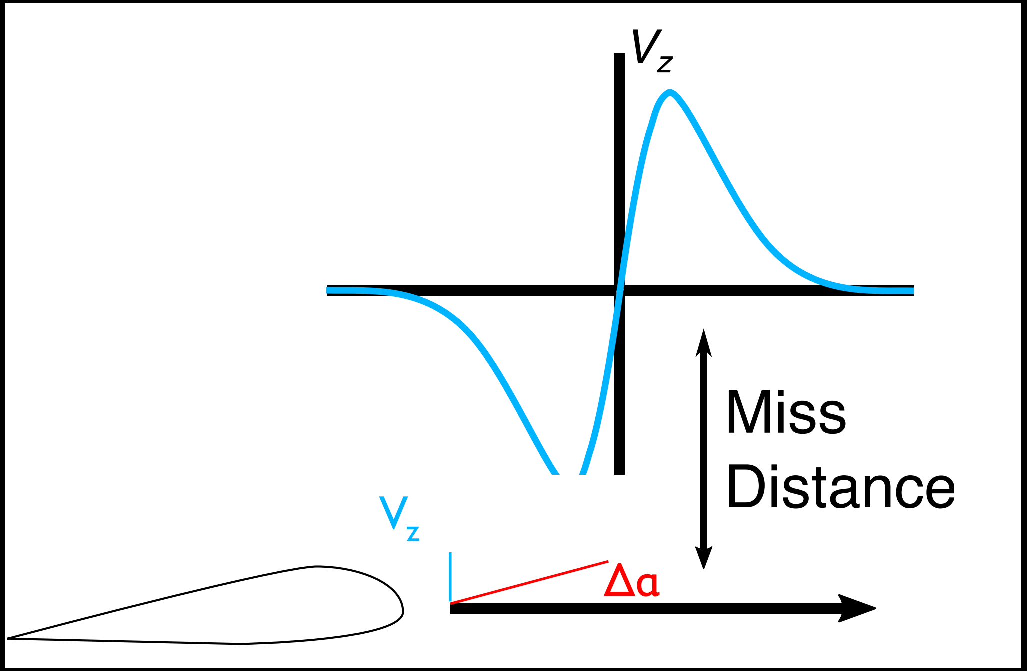
To improve the quality of our environment and to dissuade overly restrictive ordinances against helicopters, it is imperative that every pilot minimize noise irritation to the public. Following are several techniques which should be employed when possible.

1. Avoid flying over outdoor assemblies of people. When this cannot be avoided, fly as high as practical, preferably over 2000 feet AGL.
2. Avoid blade slap. Blade slap generally occurs at airspeeds below 100 KIAS. It can usually be avoided by maintaining 100 KIAS until rate of descent is over 1000 FPM, then using a fairly steep approach until airspeed is below 65 KIAS. With the right door vent open, the pilot can easily determine those flight conditions which produce blade slap and develop piloting techniques to eliminate or reduce it.
3. When departing from or approaching a landing site, avoid prolonged flight over noise-sensitive areas. Always fly above 500 feet AGL and preferably above 1000 feet AGL.
4. Repetitive noise is far more irritating than a single occurrence. If you must fly over the same area more than once, vary your flight path to not overfly the same buildings each time.
5. When overflying populated areas, look ahead and select the least noise-sensitive route.

Robinson R44
Flight Manual Supplement

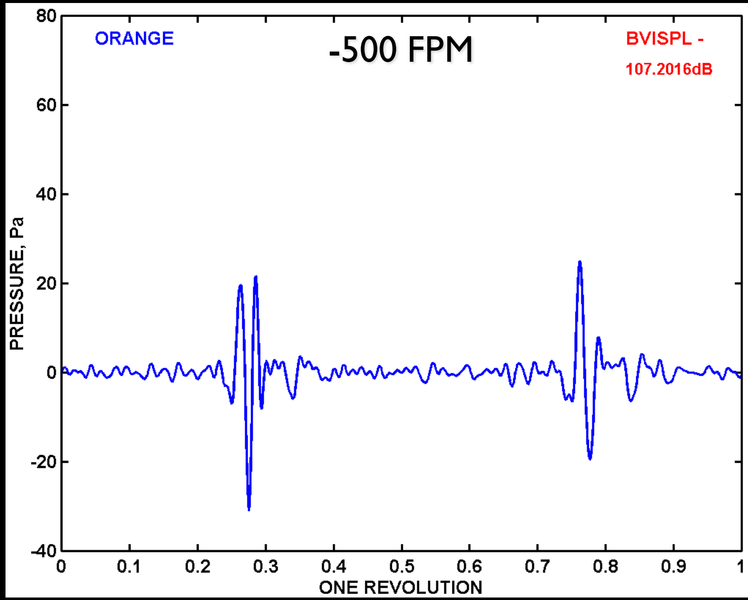
“Blade slap” is usually Blade-Vortex Interaction noise

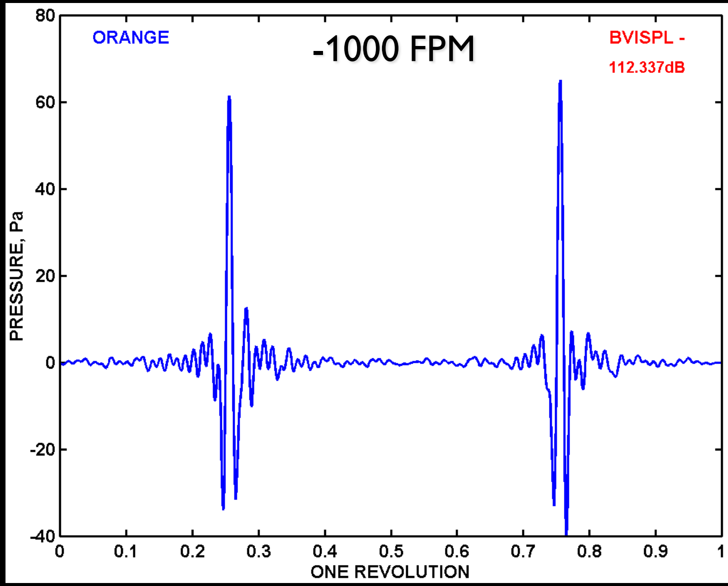




- Occurs when rotor tip vortex wake passes near rotor blades
- Rapid change in airloads results in impulsive noise
- Tends to dominate annoyance metrics when it occurs
- Magnitude and directivity strong function of <u>rotor operating condition</u>

2006 NRTC Bell 206 Acoustic Flight Test


ORANGE
-500 FPM
BVISPL -
107.2016dB
PRESSURE, Pa
ONE REVOLUTION
80
60
40
20
0
-20
-40
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1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-1000 FPM
BVISPL -
112.337dB
PRESSURE, Pa
ONE REVOLUTION
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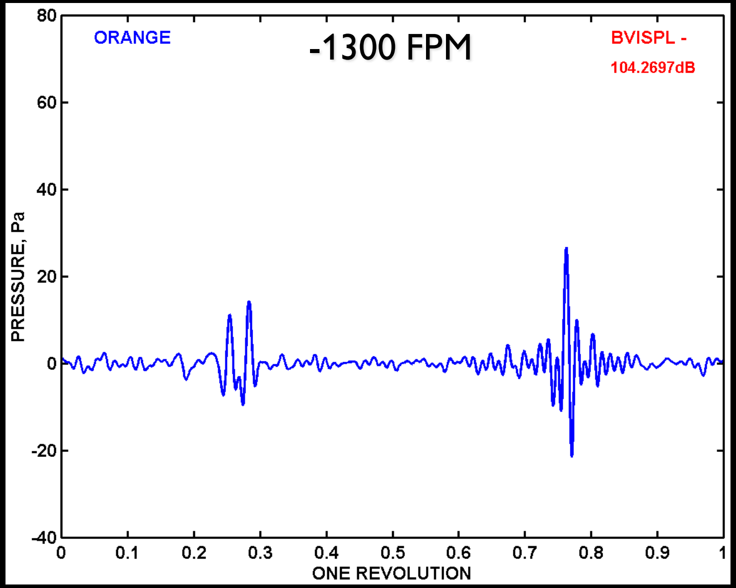
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BVISPL -
104.2697dB
PRESSURE, Pa
ONE REVOLUTION
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60
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20
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-20
-40
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0.1
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0.4
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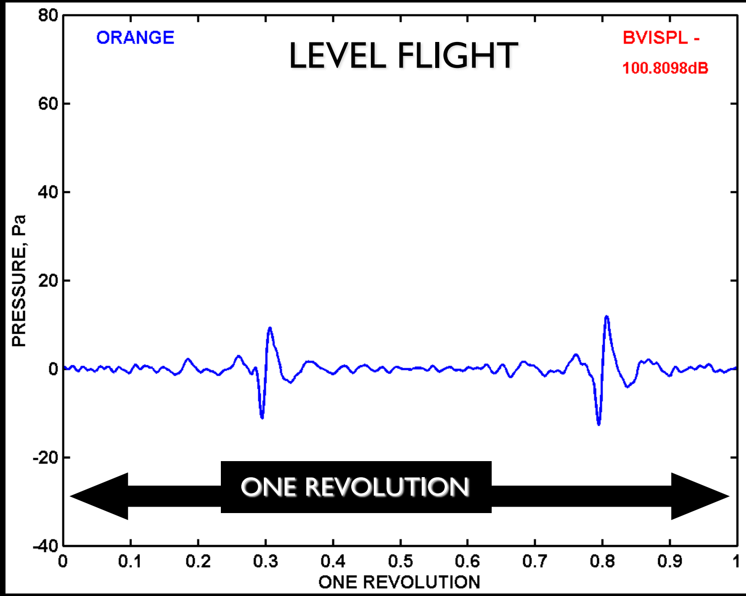
1


ORANGE
LEVEL FLIGHT
BVISPL -
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PRESSURE, Pa
ONE REVOLUTION
ONE REVOLUTION
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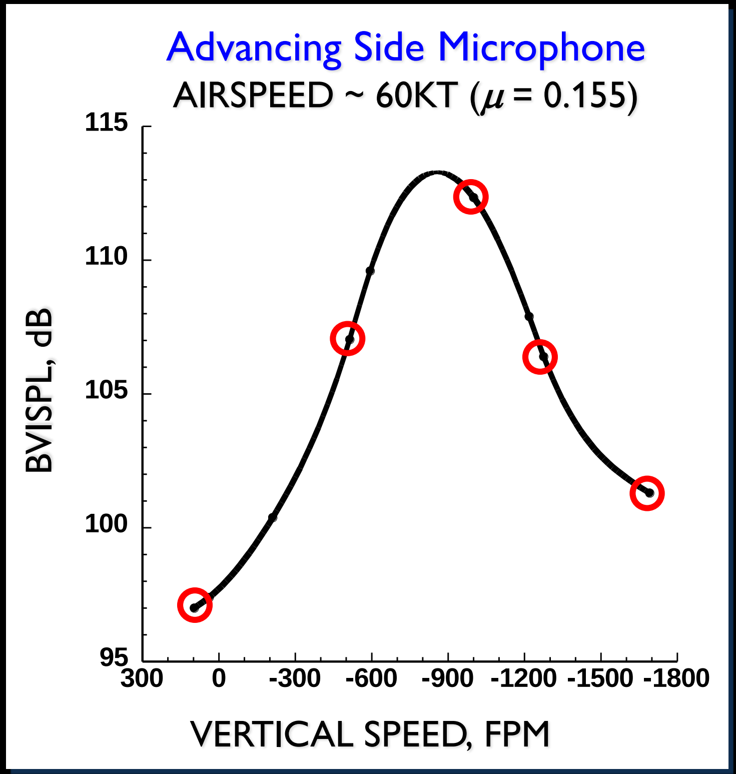
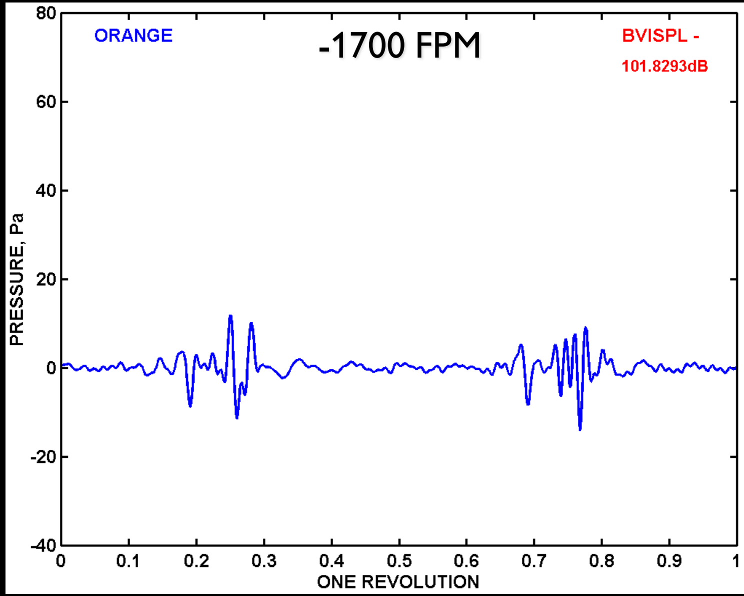
60
40
20
0
-20
-40
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


Advancing Side Microphone
AIRSPEED ~ 60KT (μ = 0.155)
BVISPL, dB
VERTICAL SPEED, FPM
115
110
105
100
95
300
0
-300
-600
-900
-1200
-1500
-1800


ORANGE
-1700 FPM
BVISPL -
101.8293dB
PRESSURE, Pa
ONE REVOLUTION
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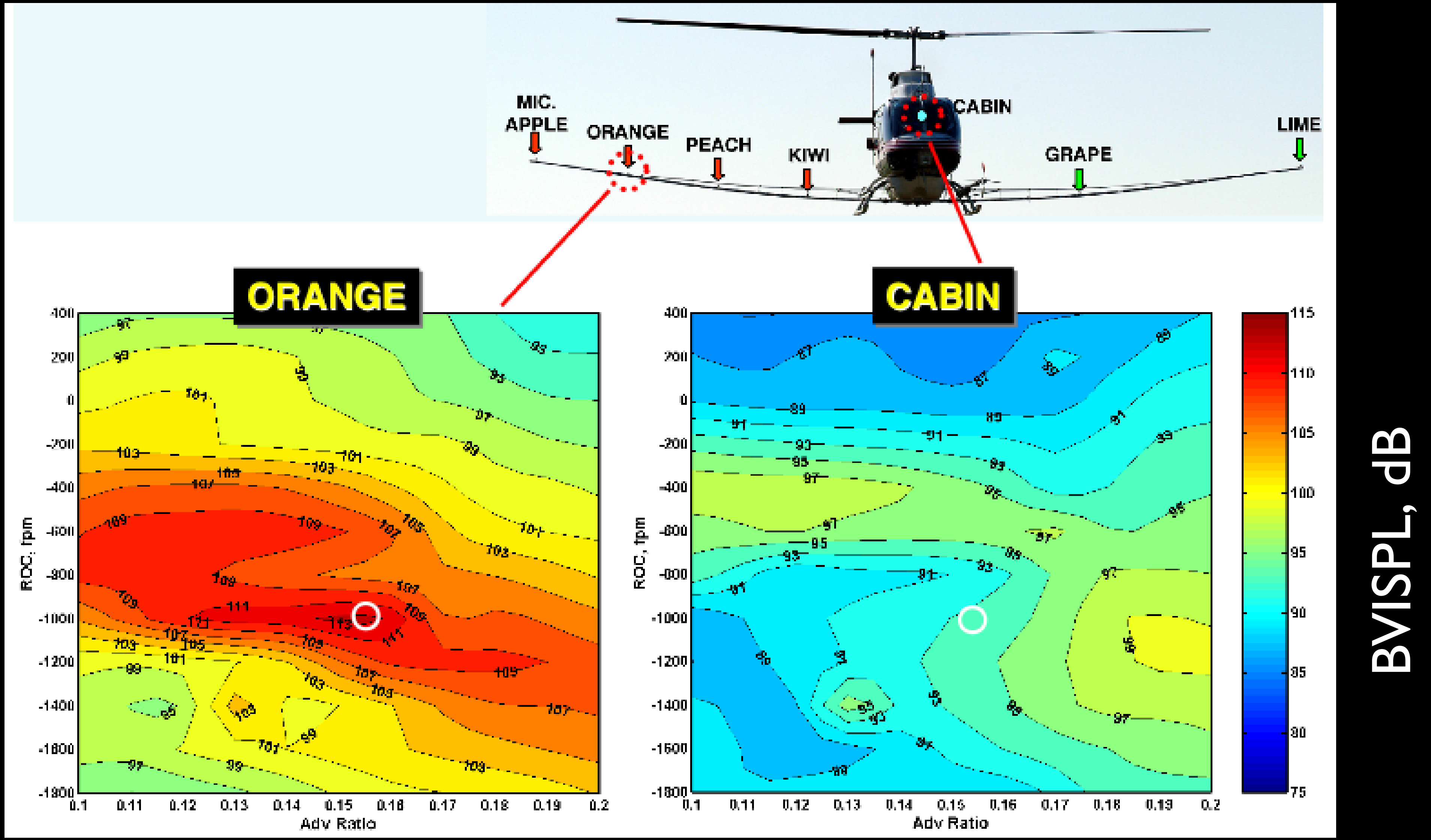
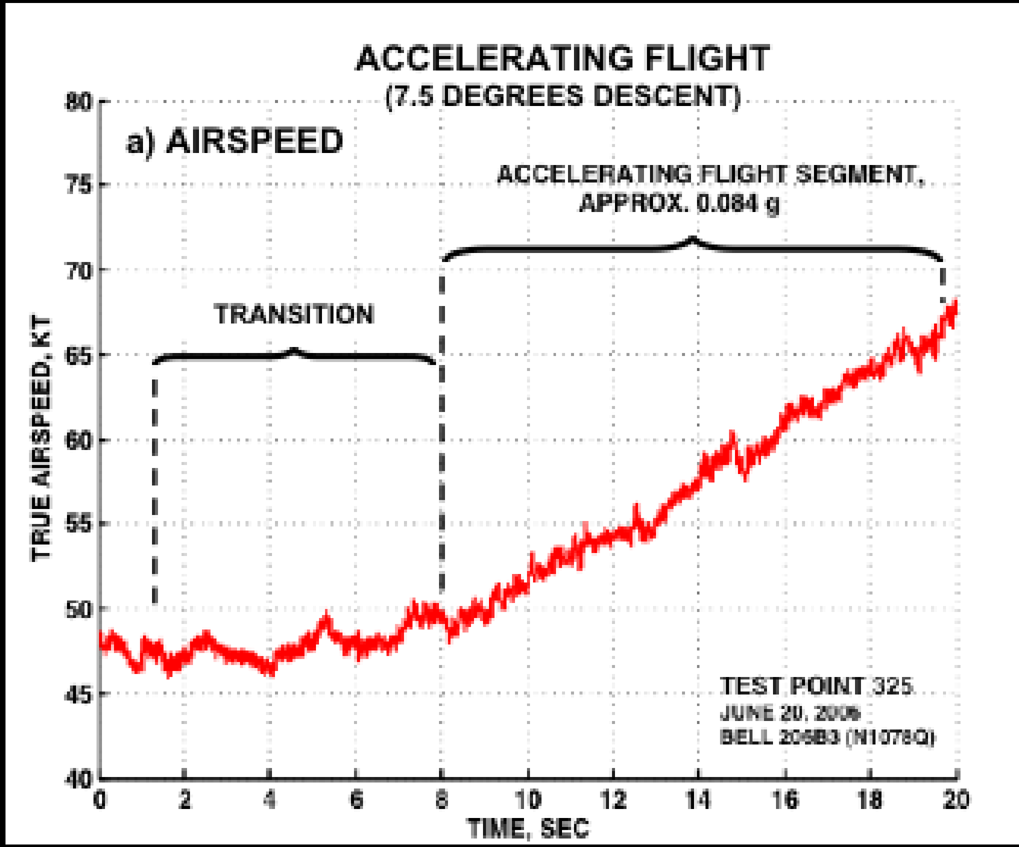
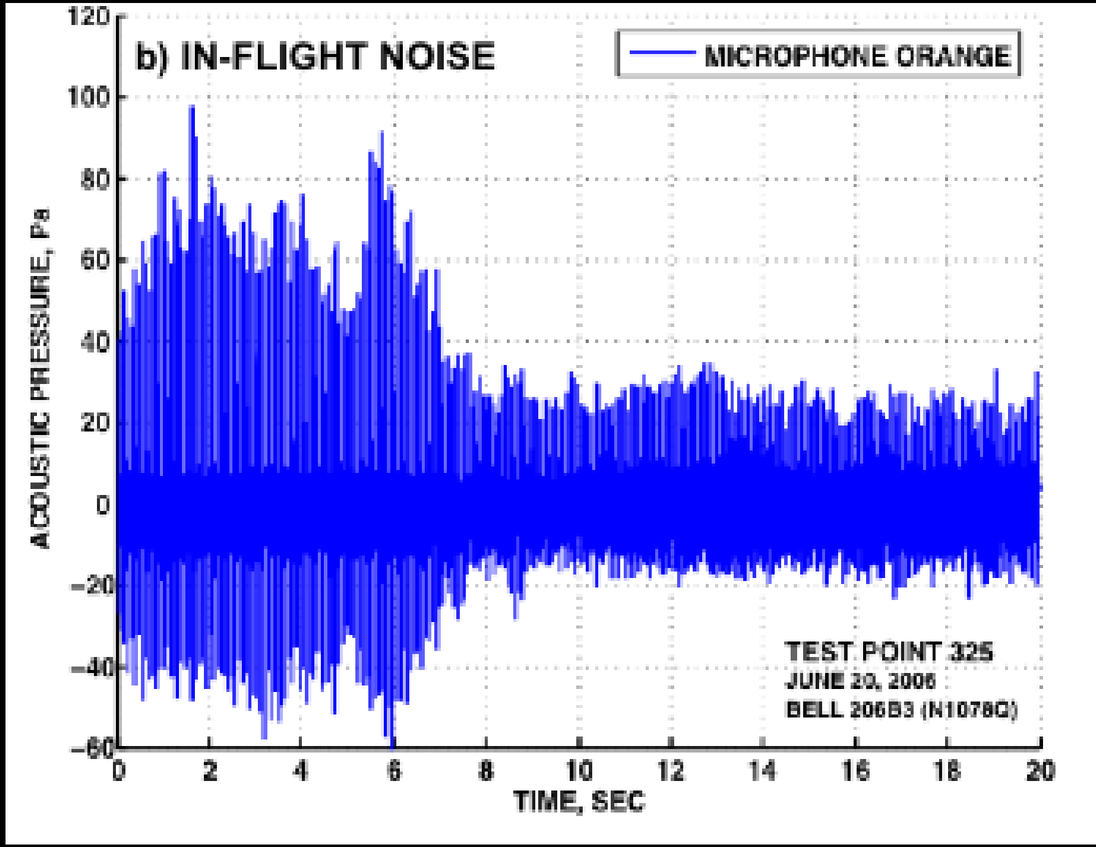
60
40
20
0
-20
-40
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

You can't trust your ears to tell you what's happening outside the aircraft!

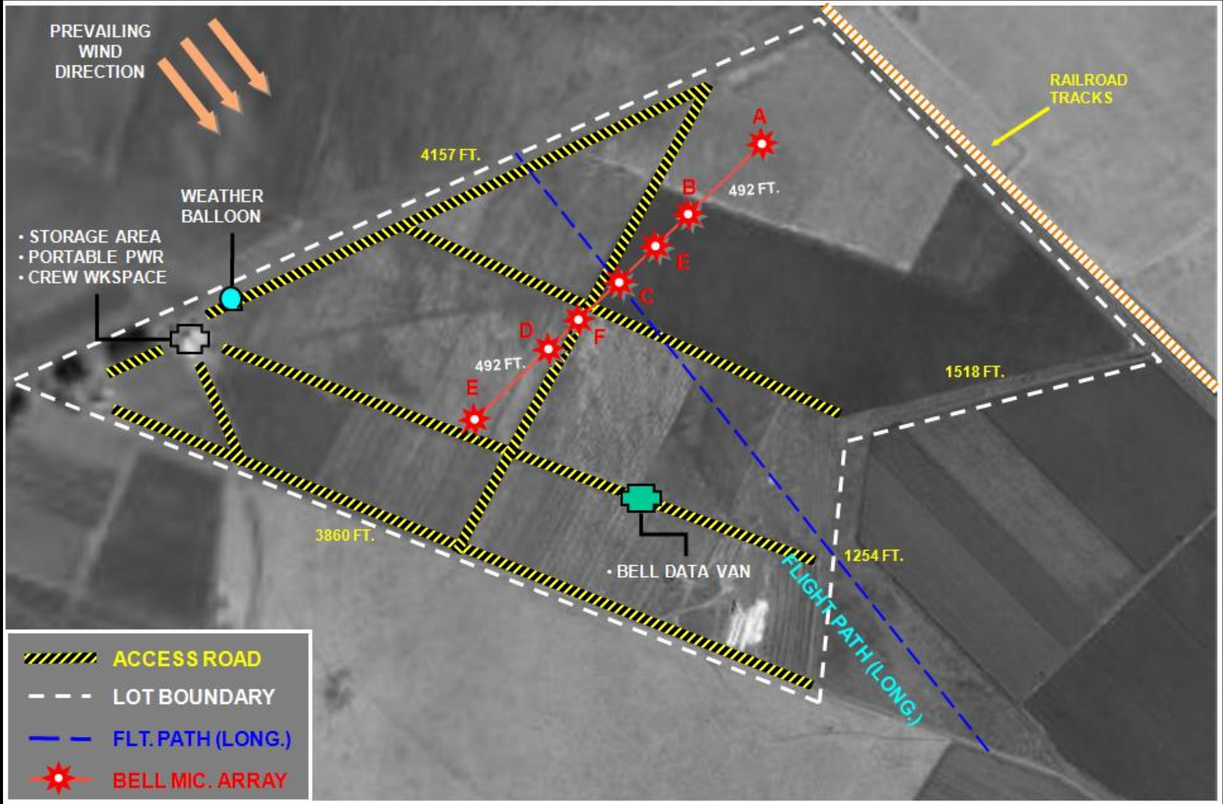


Acceleration has a powerful influence on BVI noise

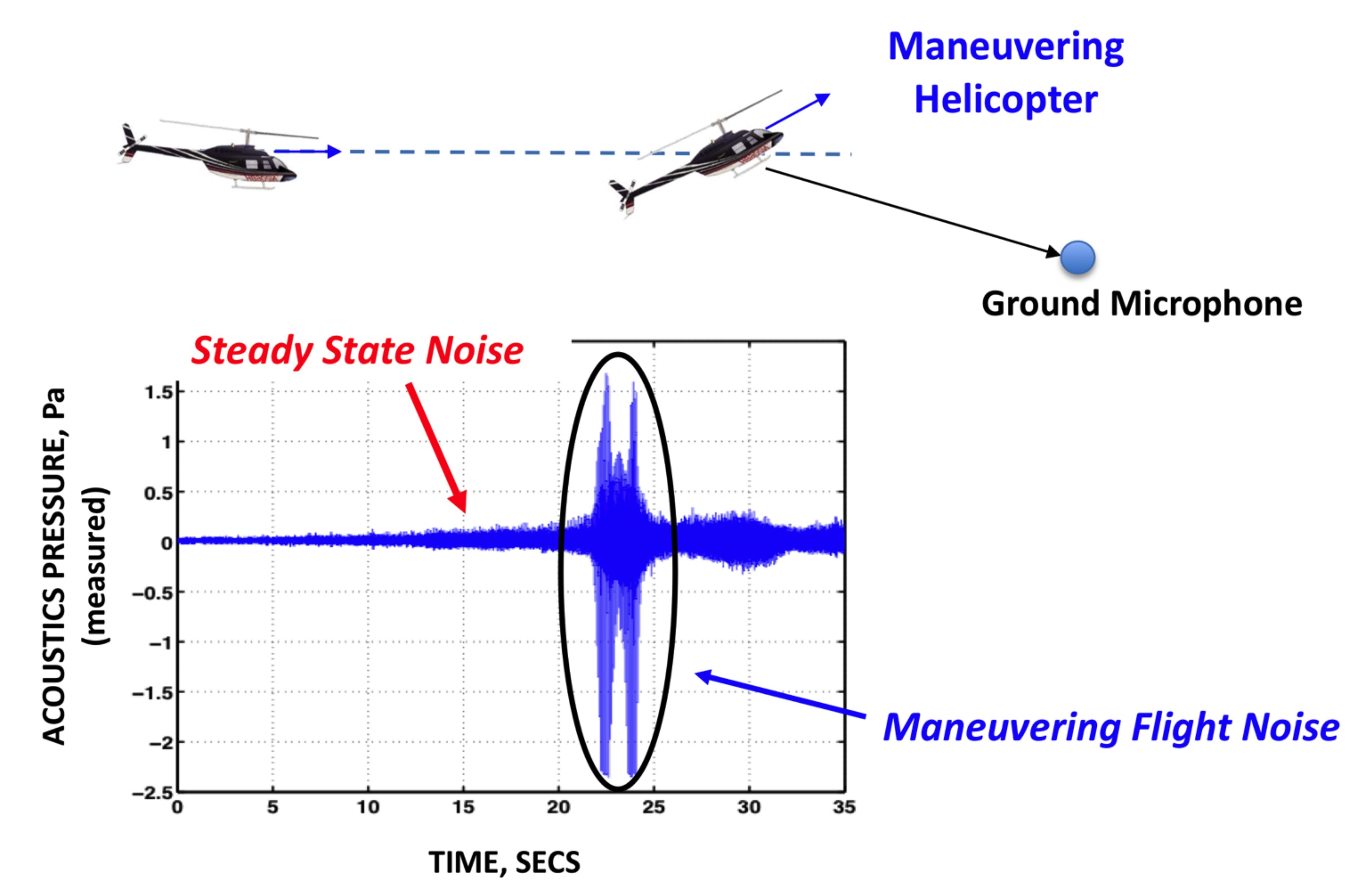




2007 NRTC Bell 206 Acoustic Flight Test



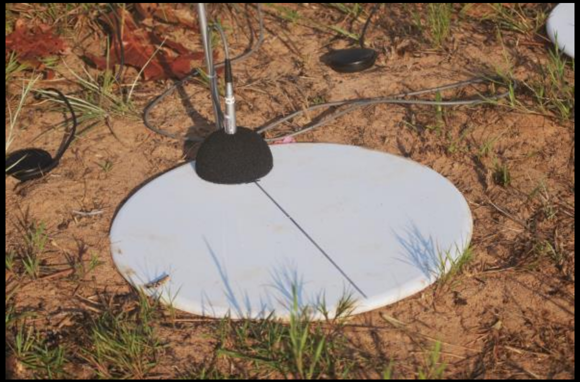
Rapid maneuvers are often *very* noisy

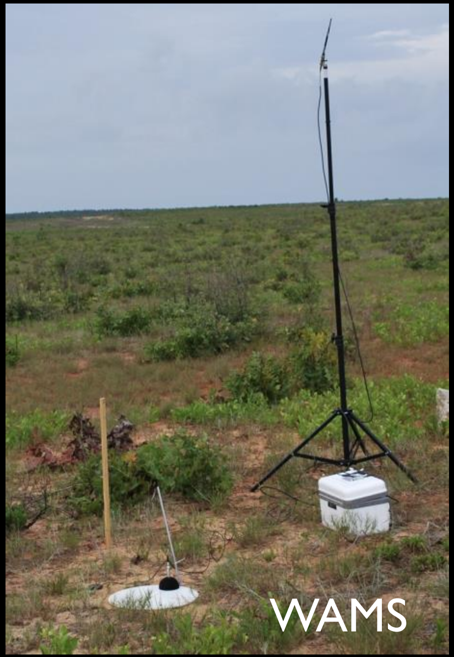


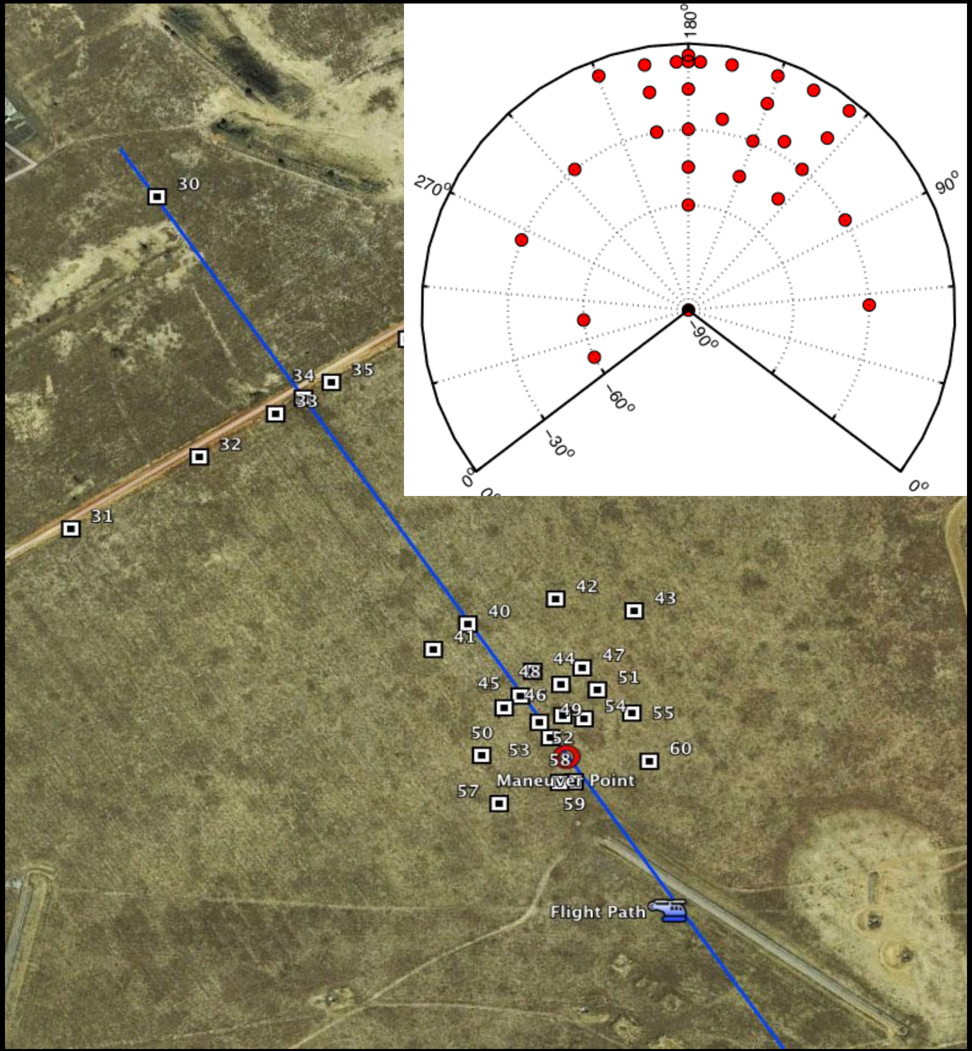
2011 NASA/Bell/Army Maneuver Noise Test

Command & Control Trailer

Microphone on Ground Board

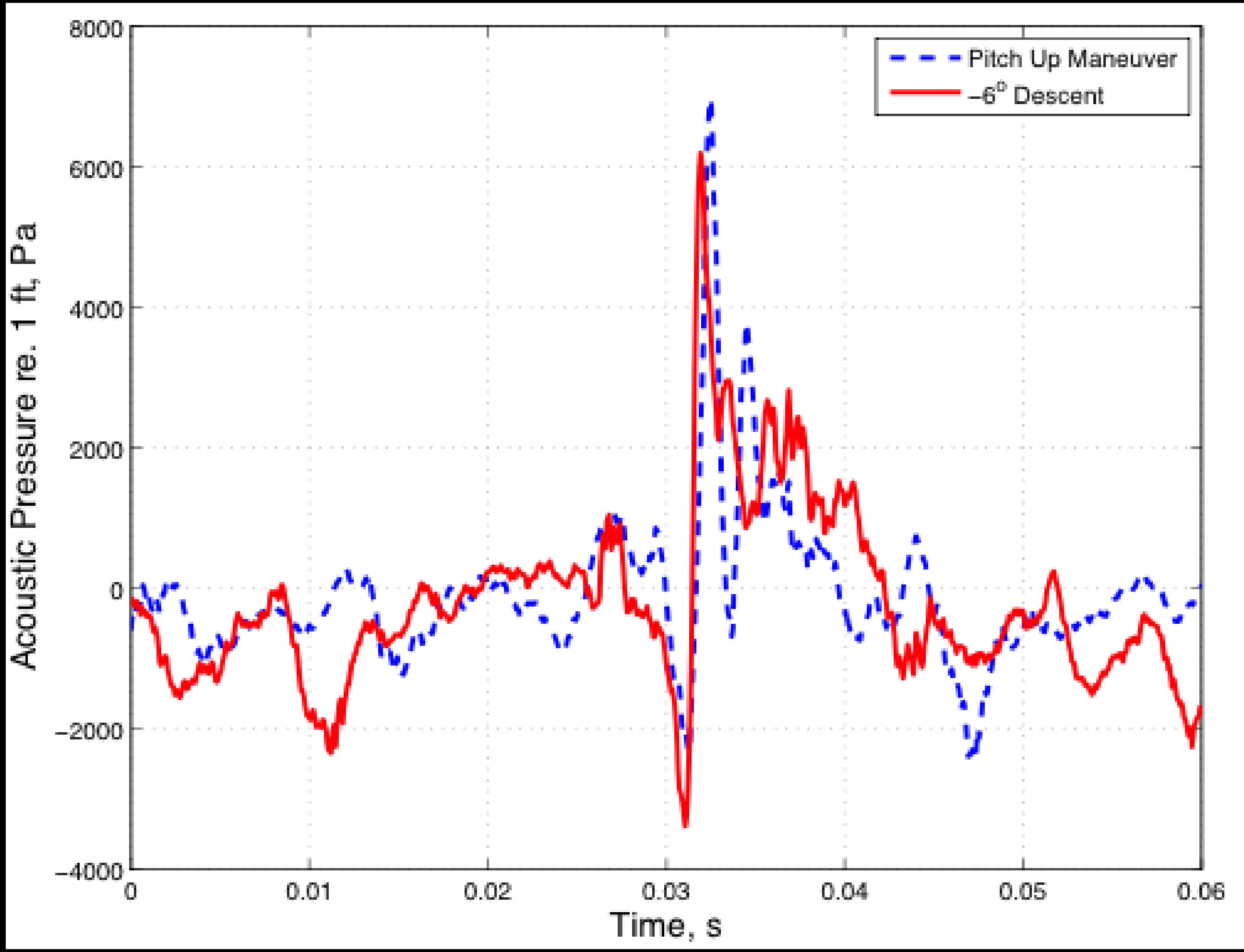






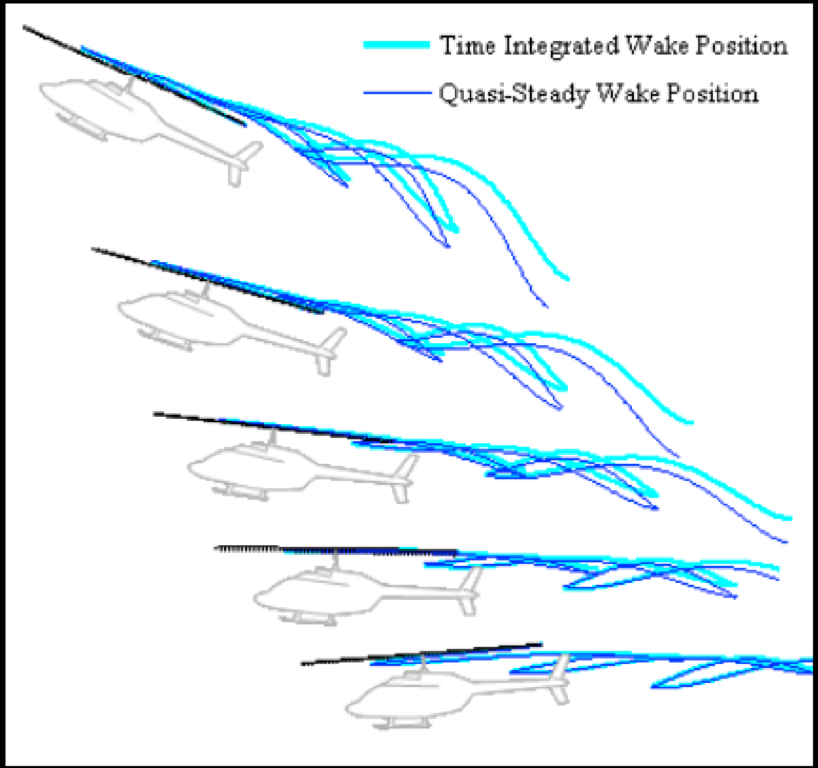
Eglin Maneuver Array

When you can look at it the right way, maneuvering noise doesn't seem different than steady flight

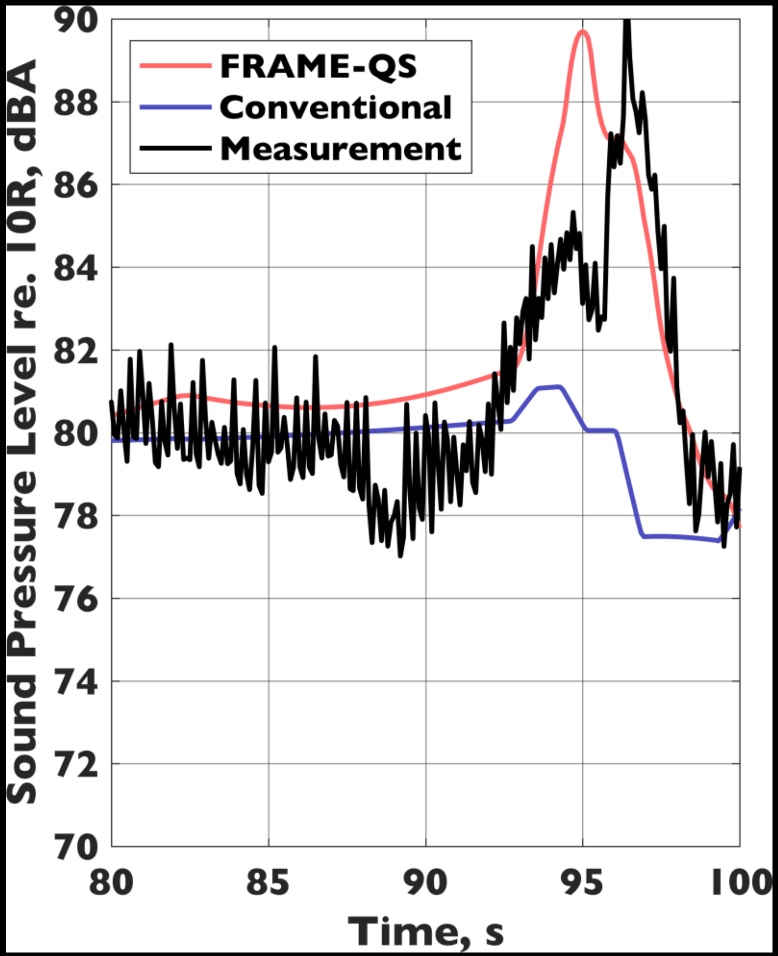


Can we use the steady flight noise data we normally collect to model maneuvers?

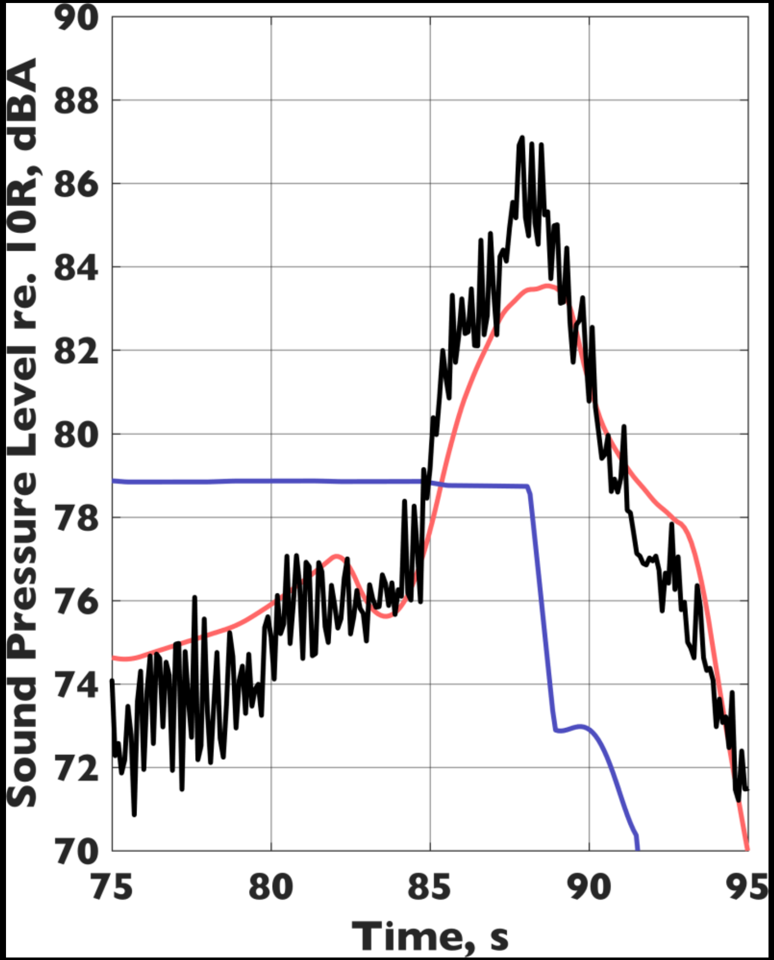
Yes! By mapping the rotor aerodynamics to acoustics!



Sickenberger, R.D., Modeling Helicopter Near-Horizon Harmonic Noise due to Maneuvers, PhD Dissertation, University of Maryland, May 2013.



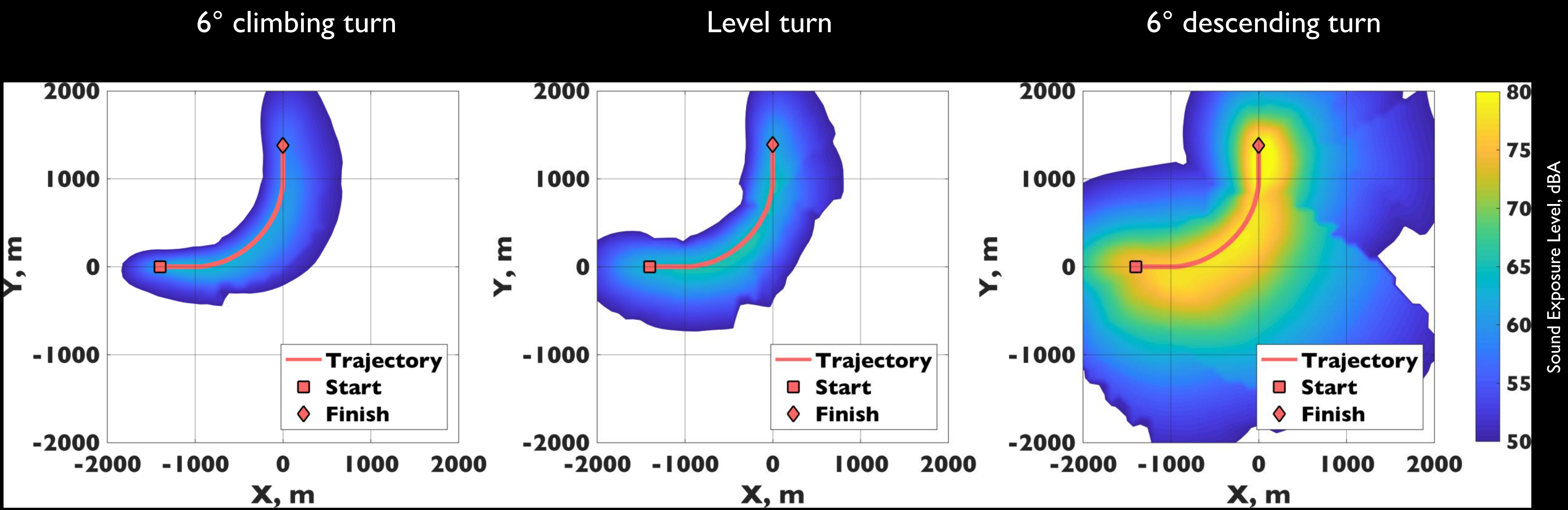
Pitch Up



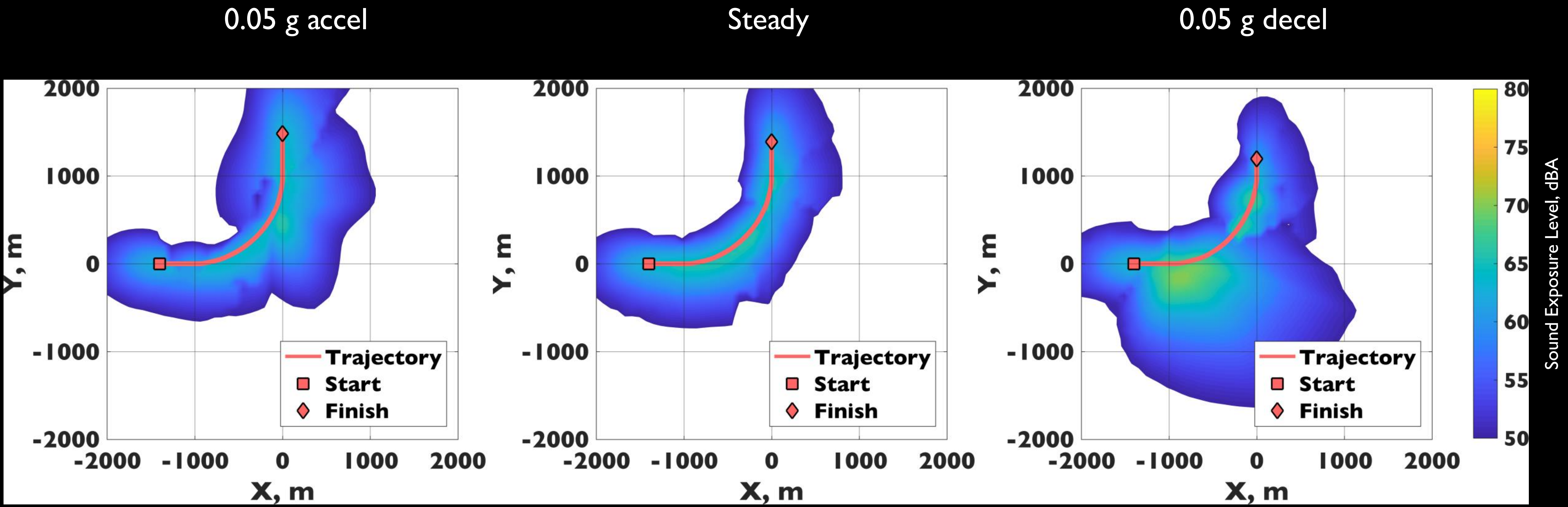
Advancing Side Roll

Can we use our models to develop useful guidance for pilots?

Descending turns can be very loud!



Deceleration also tends to increase noise.



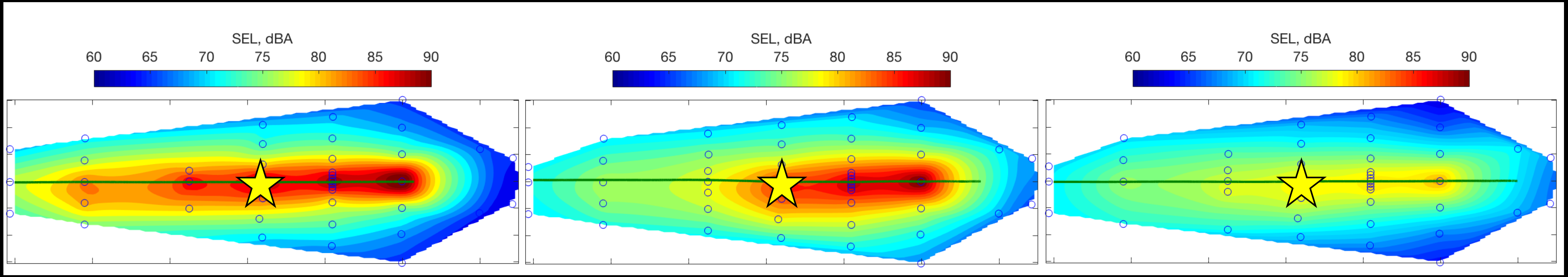
Noise Abatement Guidance

- Avoid tendency to decelerate during maneuvers, such as turns or pull-ups
- Sustained acceleration leads to high noise levels; however, a little acceleration can add margin to BVI onset during noise sensitive maneuvers
- Keep noise sensitive areas inside of turns
- Avoid descending during turns toward the advancing side of the rotor
- Steeper climbs reduce noise on the ground, so long as the pull-up into climb is gradual

But, is this good advice for all helicopters?

2017 NASA / FAA Noise Abatement Test

R44 Noise Abatement Approaches



Least Effective Approach Flown	Prior Noise Abatement Guidance	Best Approach Flown
Shallow Decelerating Approach	Normal Decelerating Approach	Steep Approach to Flare
-3.5°Flight Path Angle 80 KIAS – 20 KIAS, 0.05g decel	-4.5°Flight Path Angle 80 KIAS– 20 KIAS, 0.05g decel	-6°Flight Path Angle 80 KIAS until 0.15g flare to 20 KIAS
100.3 EPNdB 97.2 dBA SEL	96.3 EPNdB 93.1 dBA SEL	90.2 EPNdB 85.4 dBA SEL

10.3 EPNdB / 12.0 dBA SEL benefit re. Least Effective
6.3 EPNdB / 8.0 dBA SEL benefit re. Historical Guidance

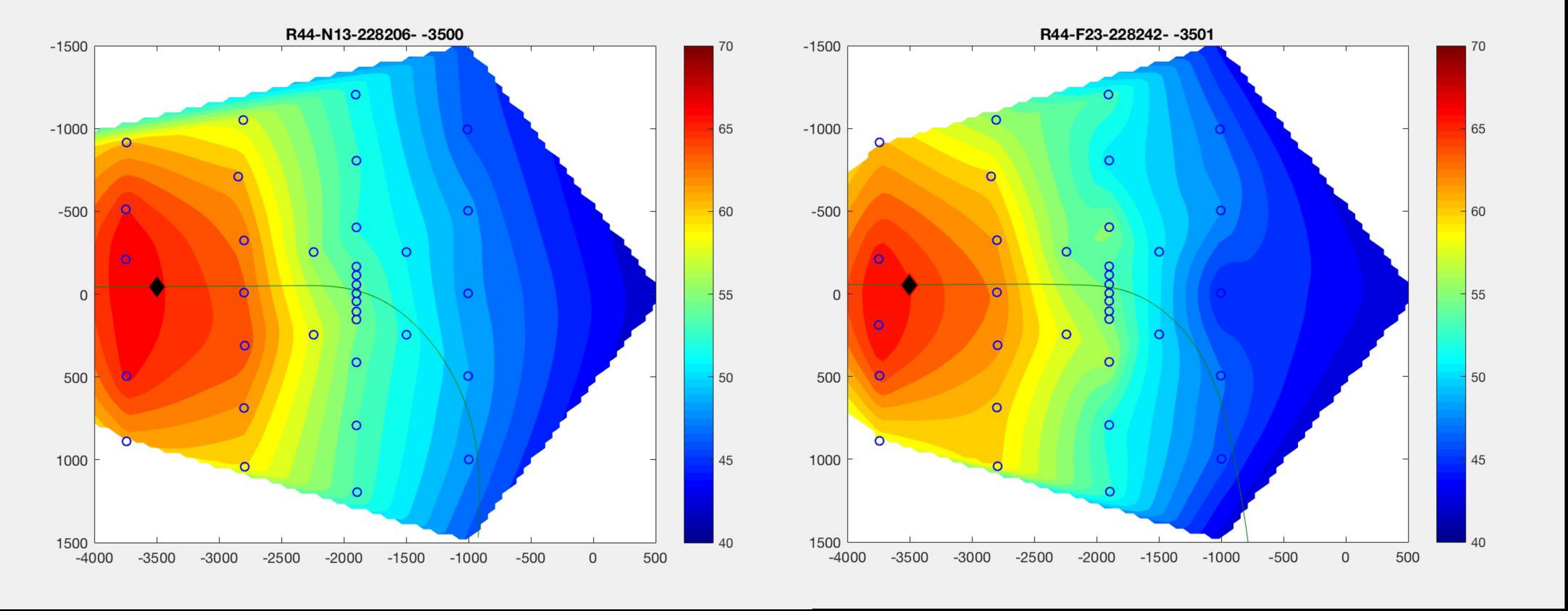
R44 Maneuvers

Level Turn

Descending Turn

dBA

Y, feet



X, feet

X, feet

2019 NASA / FAA Medium Helicopter Noise Abatement Test

Noise Abatement Guidelines

- General-purpose rules of thumb
- Validated for all ten aircraft
- Now included as a part of HAI’s Fly Neighborly Curriculum
- Feedback from early adopters indicates that it’s working!

Fly Neighborly

Helicoper Noise Abatement Recommendations

Level Flight:

- Accelerations are quieter than decelerations
- Straight flight is quieter than turning flight

Turning Flight:

- Turning away from the advancing blade (especially when decelerating) is quieter than turning into the advancing blade
- Level turns are quieter than descending turns

Descending Flight:

- Straight-in flight is quieter than turning flight
- Steeper approaches are quieter than shallow approaches

Decelerations:

- Level flight decelerations are quieter than descending or turning flight decelerations

Maneuvering:

- Smooth and gentle control inputs are quieter than rapid control inputs

These recommendations are flight tested and scientifically vetted by the U.S. Department of Transportation and NASA to support the Fly Neighborly Goals.

Take the Fly Neighborly training at: https://go.usa.gov/xQPCW

Fly neighborly procedures/recommendations should be executed in the safest manner possible and followed only to the extent safety is not compromised.

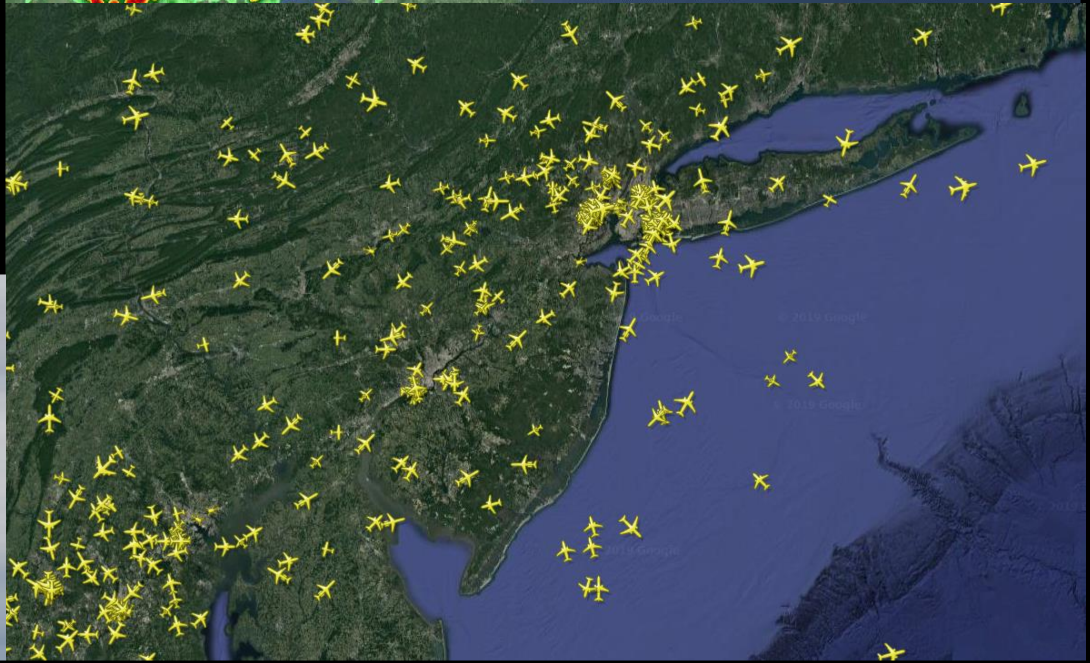
Federal Aviation Administration

Helicopter Association International

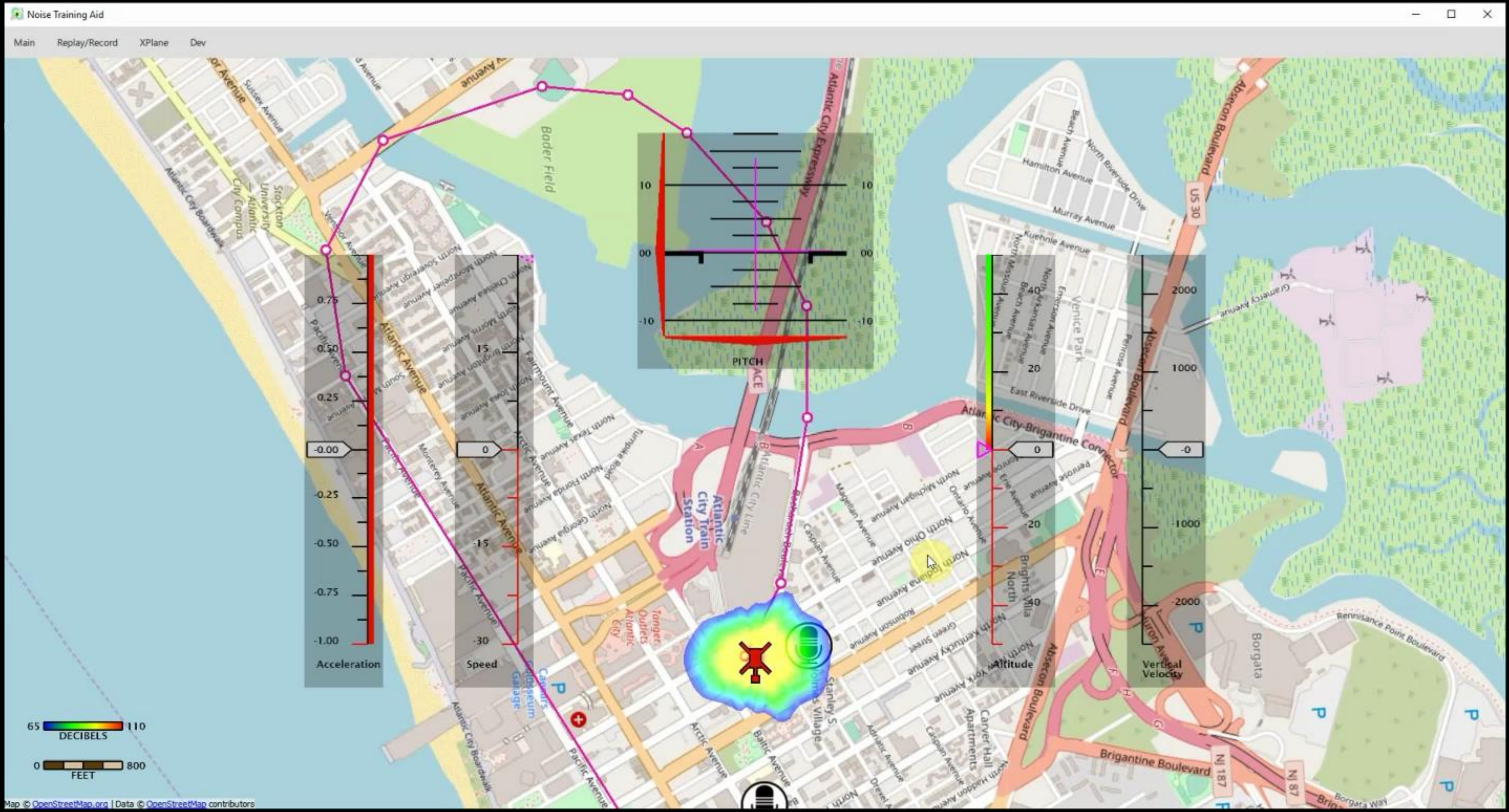
The Best Laid Plans…

… may be obsolete tomorrow due to changes in:

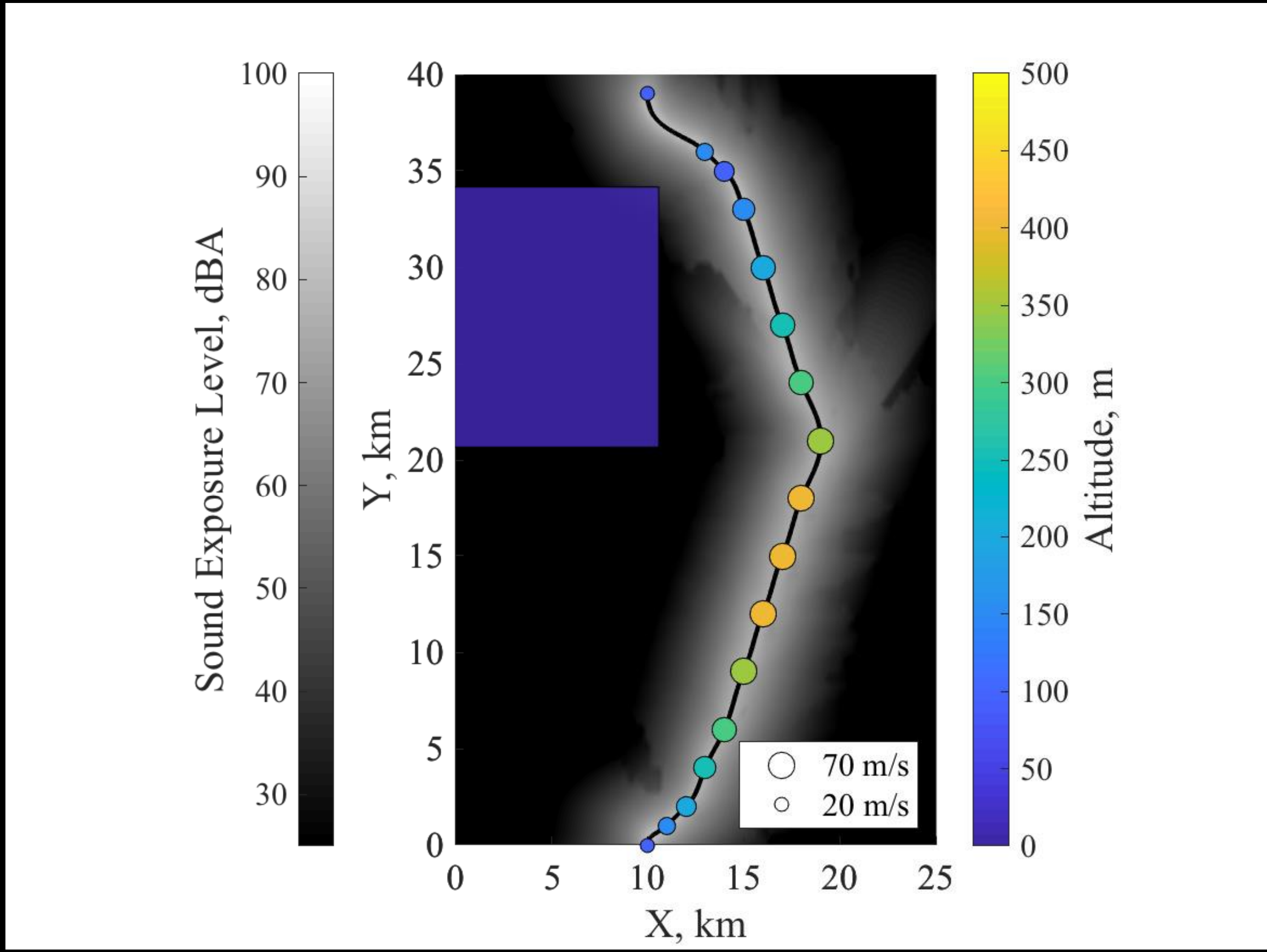
- Mission objectives
- Vehicle configuration
- Weather
- Air traffic



Real Time Noise Awareness



On Demand Mission Planning



Area:

- Spans 20 x 40 km, similar area to Las Vegas, Rome, or Beijing

Mission:

- Takeoff at Y = 0 km
- Land at Y = 40 km
- Closed airspace from 0 - ∞ m

Trajectory:

- About 20 minutes of flight time
- About 10 seconds computer time
- About one minute between nodes

Dynamic Replanning

eVTOL Noise

Rotor-Rotor Interaction
(e.g. Boeing PAV)

Rotor-Wing Interaction
(e.g. Cora)

Rotor-Stator Interaction
(e.g. Bell Air Taxi)

- Electric motors don't help, the engines weren't the problem!
- Lower harmonic noise is less important with lower tip speeds
- Fluctuations in airloads cause loading noise at higher frequency harmonics:
  - Blade-Vortex Interaction (BVI)
  - Rotor-Rotor Interactions
  - Rotor-Wing Interactions
  - Rotor-Stator Interactions
- Rotor broadband will also be more significant:
  - Airfoil Self Noise
  - Blade-Wake Interaction

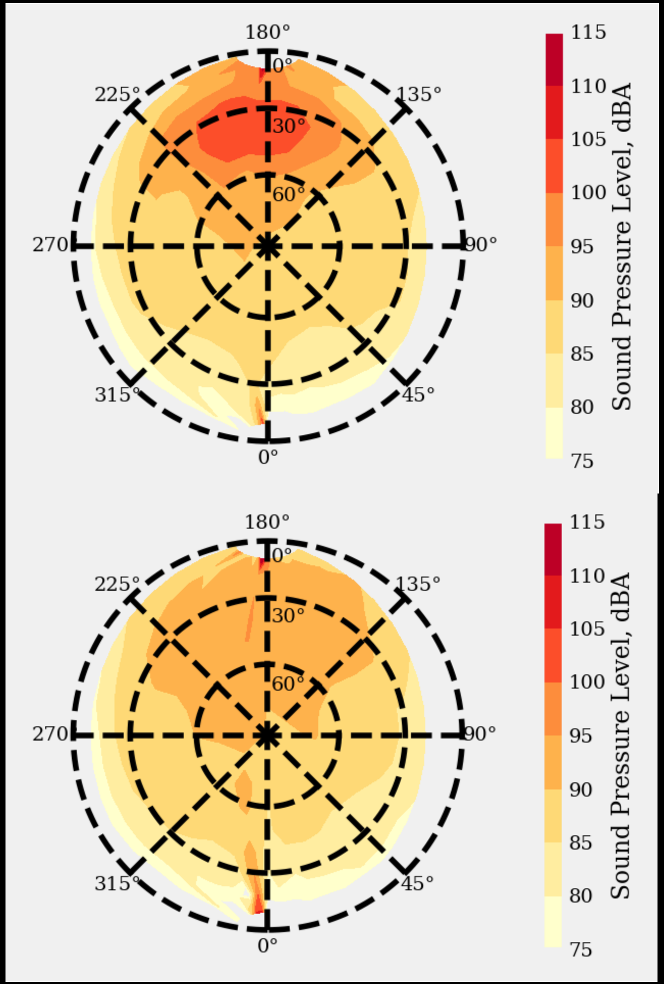
Vehicle Configuration Control

- Most eVTOL have nonunique trim
- These nonunique trim states can be exploited for noise reduction
- “Acoustically-aware” flight controls should optimize vehicle configuration for best balance between noise exposure and performance

XV-15, 70 KIAS, -6° FPA

Nacelle @ 80°

Nacelle @ 60°



Concluding Remarks

- A decade of sustained research in low noise helicopter operations is yielding real reductions in community noise exposure
- Real-time noise modeling will soon provide operators with effective tailored guidance
- "Acoustically-aware" autonomy will eventually enable ultra-low-noise VTOL operations in and around communities

Fin

2016 NASA / Army Altitude Variation Test

AS350

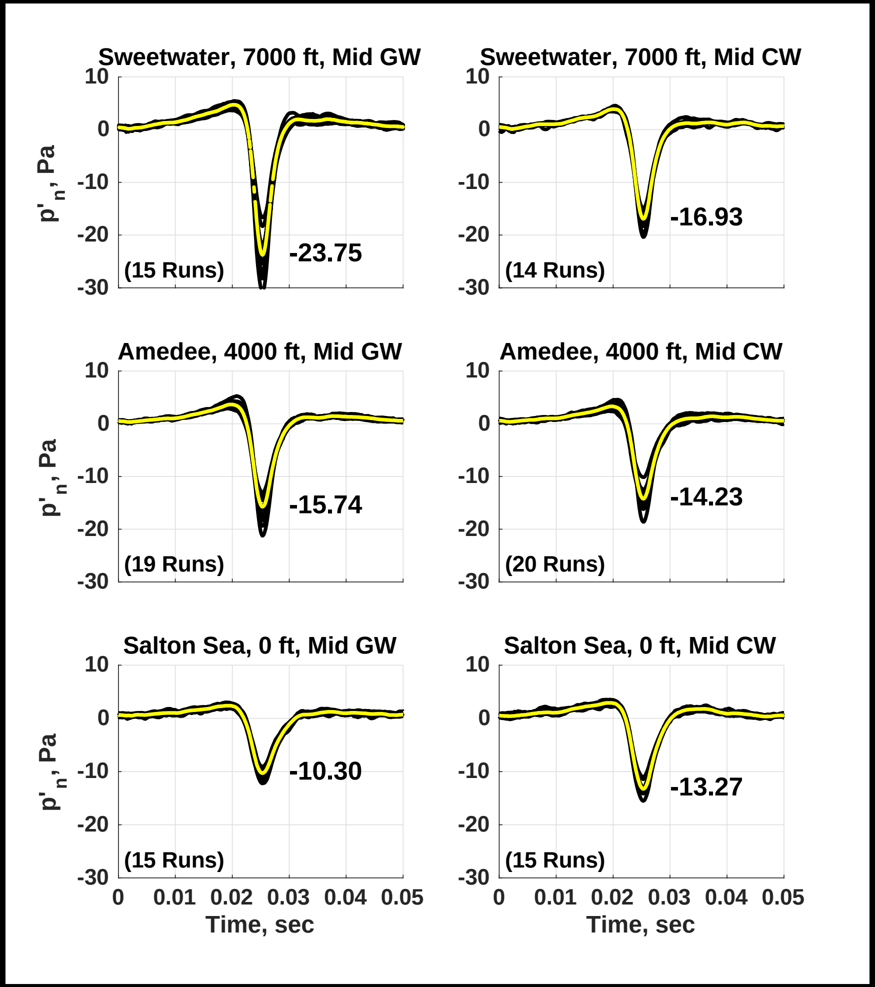
EH-60L

4000 feet
Amedee Army Auxiliary Airfield

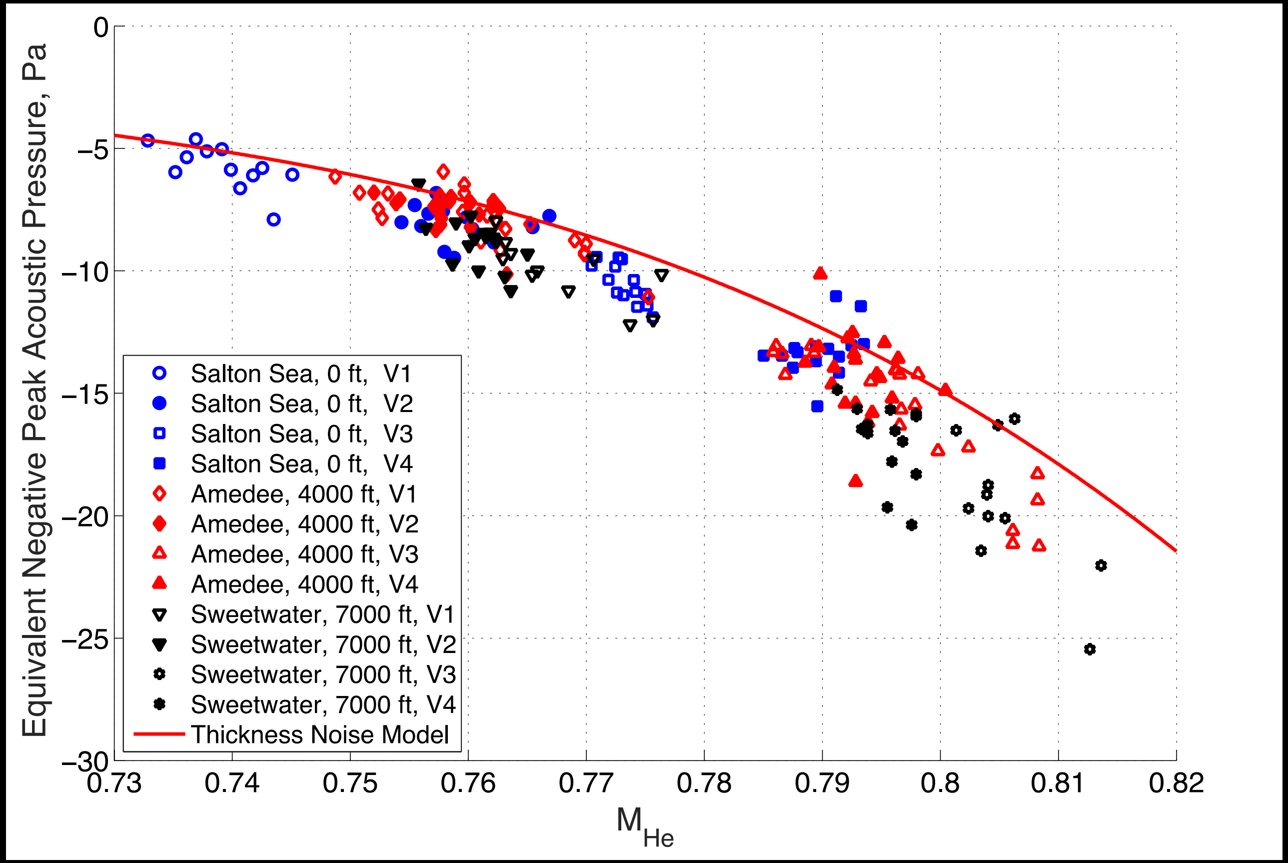
7000 feet
USMC Mountain Warfare Training Center

Sea Level
US Navy Salton Sea Facility

Ambient conditions can change noise for the "same" condition by a factor of two!

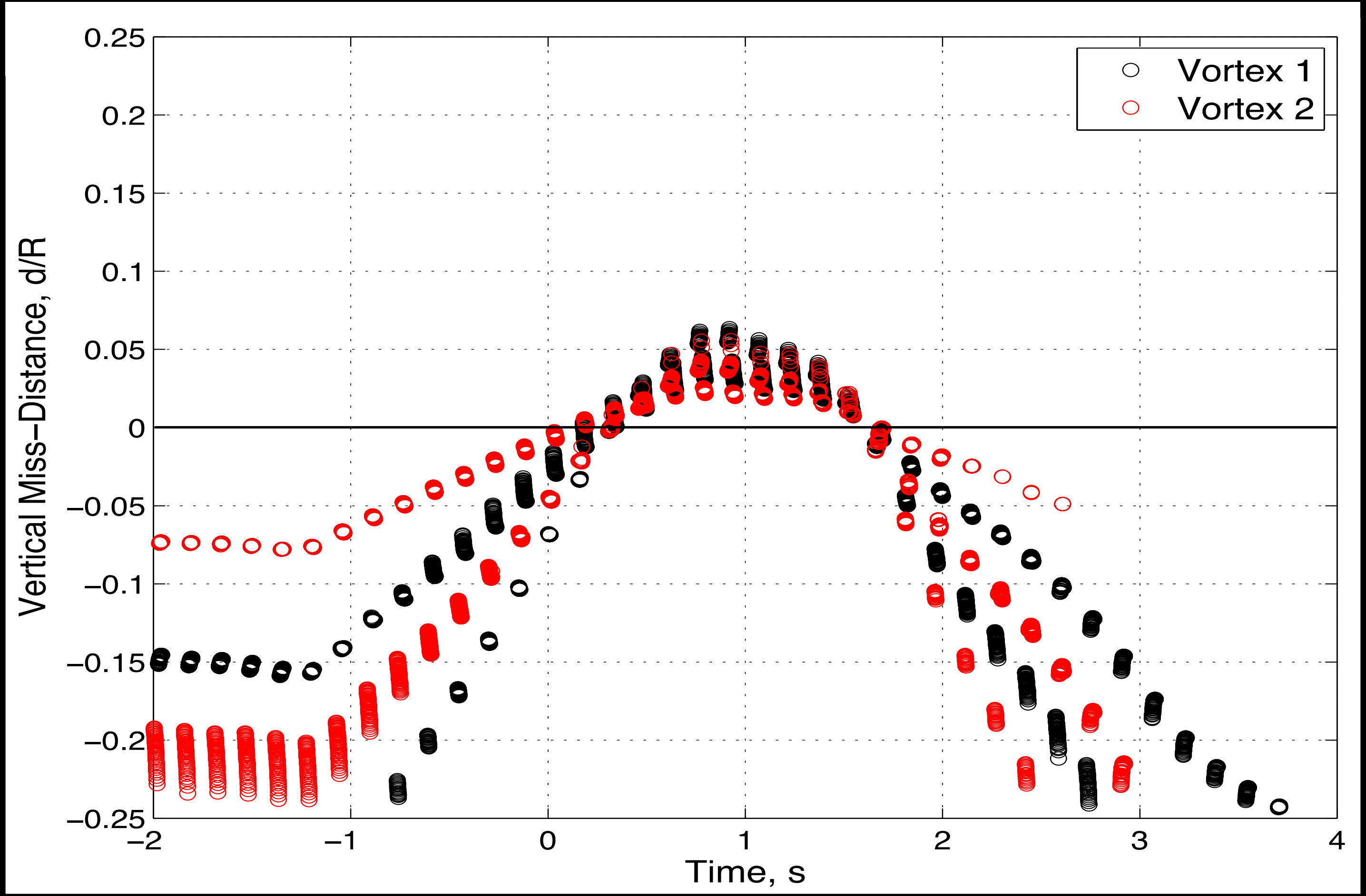


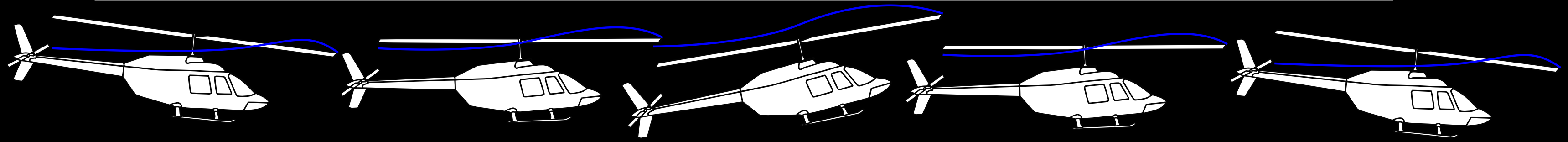
130 KIAS Nondimensional



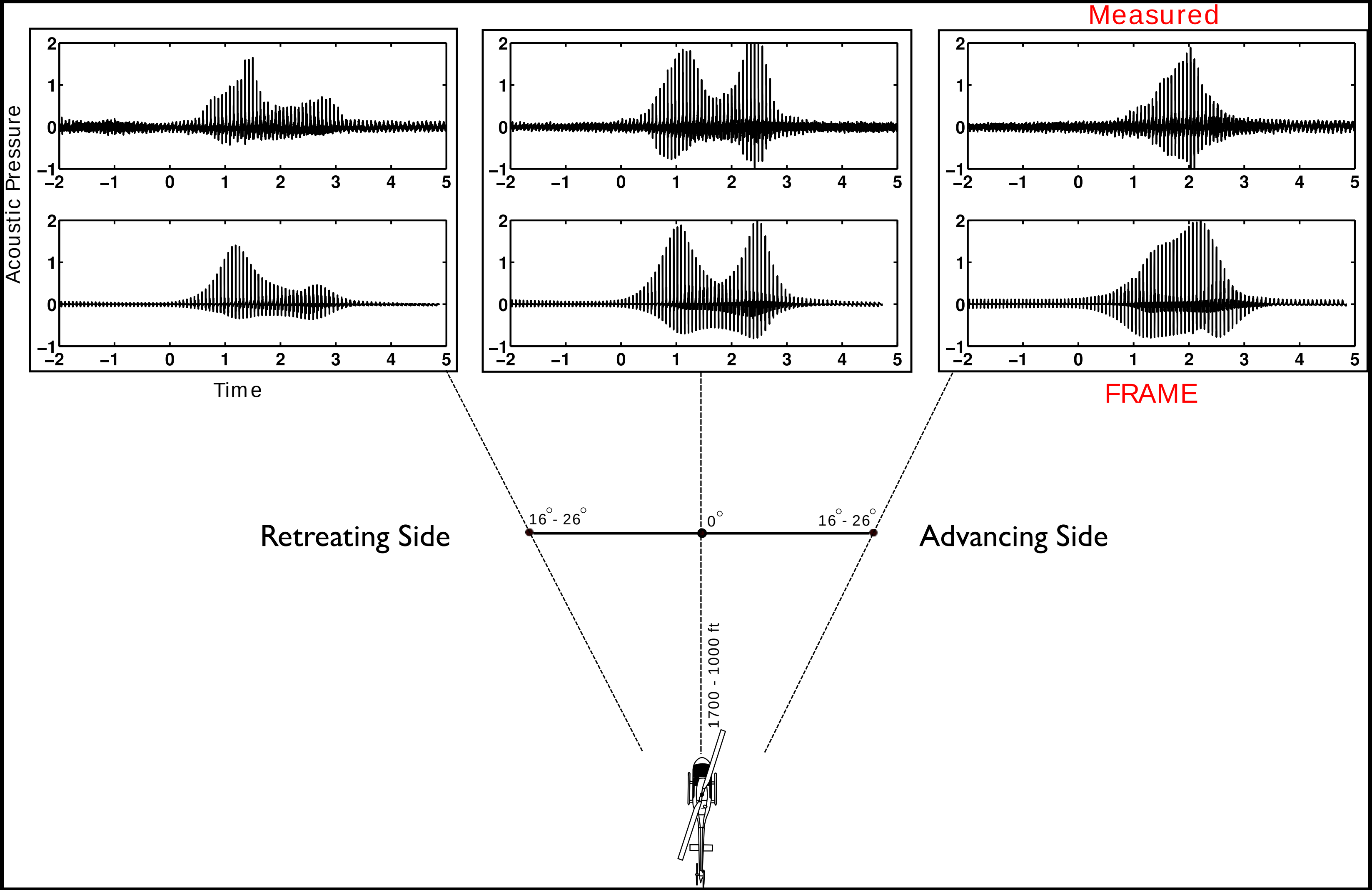
Nondimensionalization to the rescue!

Motion moves the wake up into the rotor… and then right back down through it





But, with a good wake model, we *can* predict the noise



Effects of Sideslip