National Aeronautics and
Space Administration

NASA
Revolutionary Vertical Lift Technology Project

Acoustic Assessment of an MD530F Helicopter in Maneuvering Flight

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Source: NASA

Overview

Test Description & Data Reduction

Snapshot Array for Maneuvers

Pitching Maneuvers

Rolling Maneuvers

Conclusions


Source: NASA

Objective

Investigate methods to capture, process, and analyze noise emissions from unsteady flight conditions in preparation for future UAM/FVL flight tests.

Source: NASA

Test Description & Data Reduction

Flight Test Description

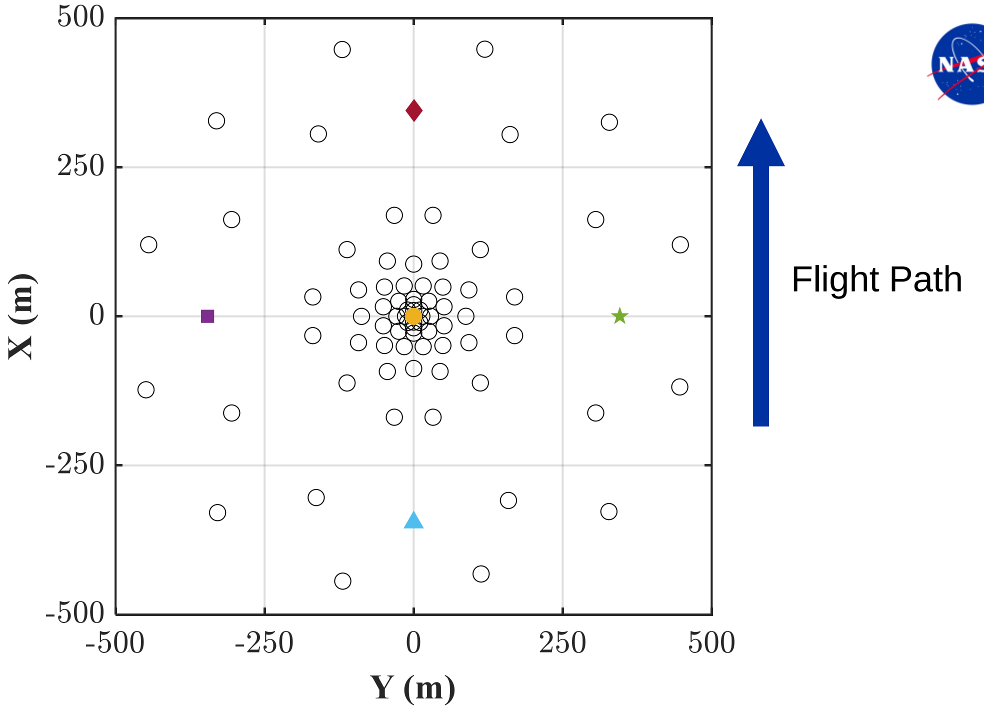
- Research methods for collecting UAM/FVL noise
- NASA/Army Comprehensive Rotorcraft Acoustic Flight Test Team (CRAFTT)
- Amedee Army Airfield at Sierra Army Depot
- 11 sorties over 6 flight days, total 21 flight hours
- MD530F helicopter
- 79-element microphone array
- Unsteady maneuvers flown
    - Initiated over array center
    - Two runs each
    - Pilot attempted ‘single-input”
    - No adjustments to maintain speed or altitude

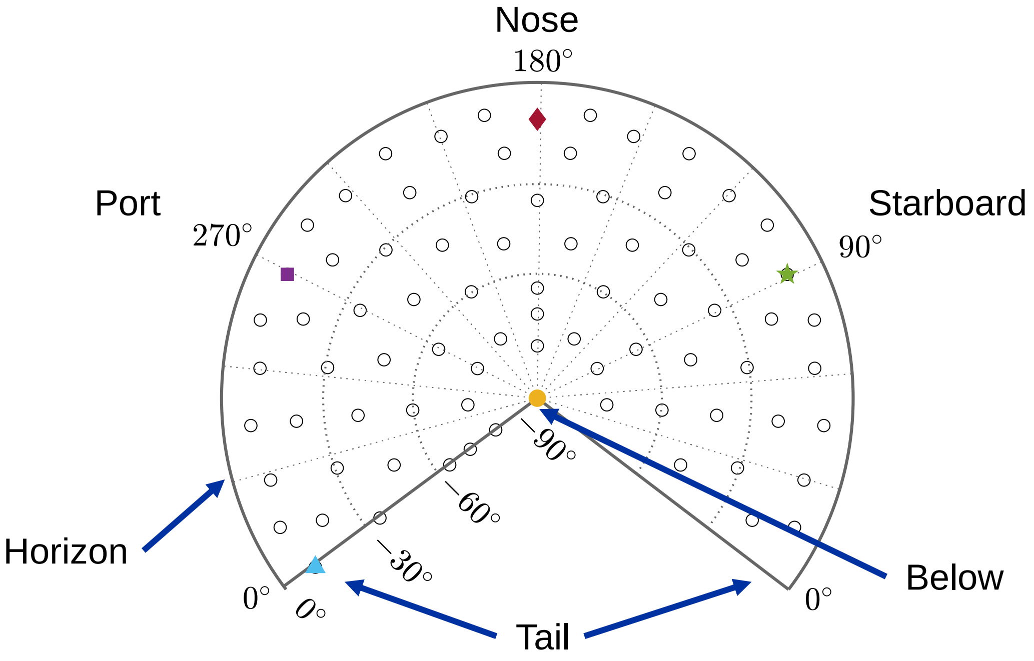
Source: NASA

Condition Code	Description	Entry Speed	Entry Altitude
M1	Cyclic roll right, fast	75 kts	61 m AGL
M2	Cyclic roll left, fast	75 kts	61 m AGL
M3	Cyclic roll right, slow	75 kts	61 m AGL
M4	Cyclic roll left, slow	75 kts	61 m AGL
M5	Pitch up, cyclic	75 kts	61 m AGL
M6	Pitch up, collective	75 kts	61 m AGL
M7	Pitch up, cyclic and collective	75 kts	61 m AGL
L3	Steady, level flight	75 kts	61 m AGL

Microphone Array

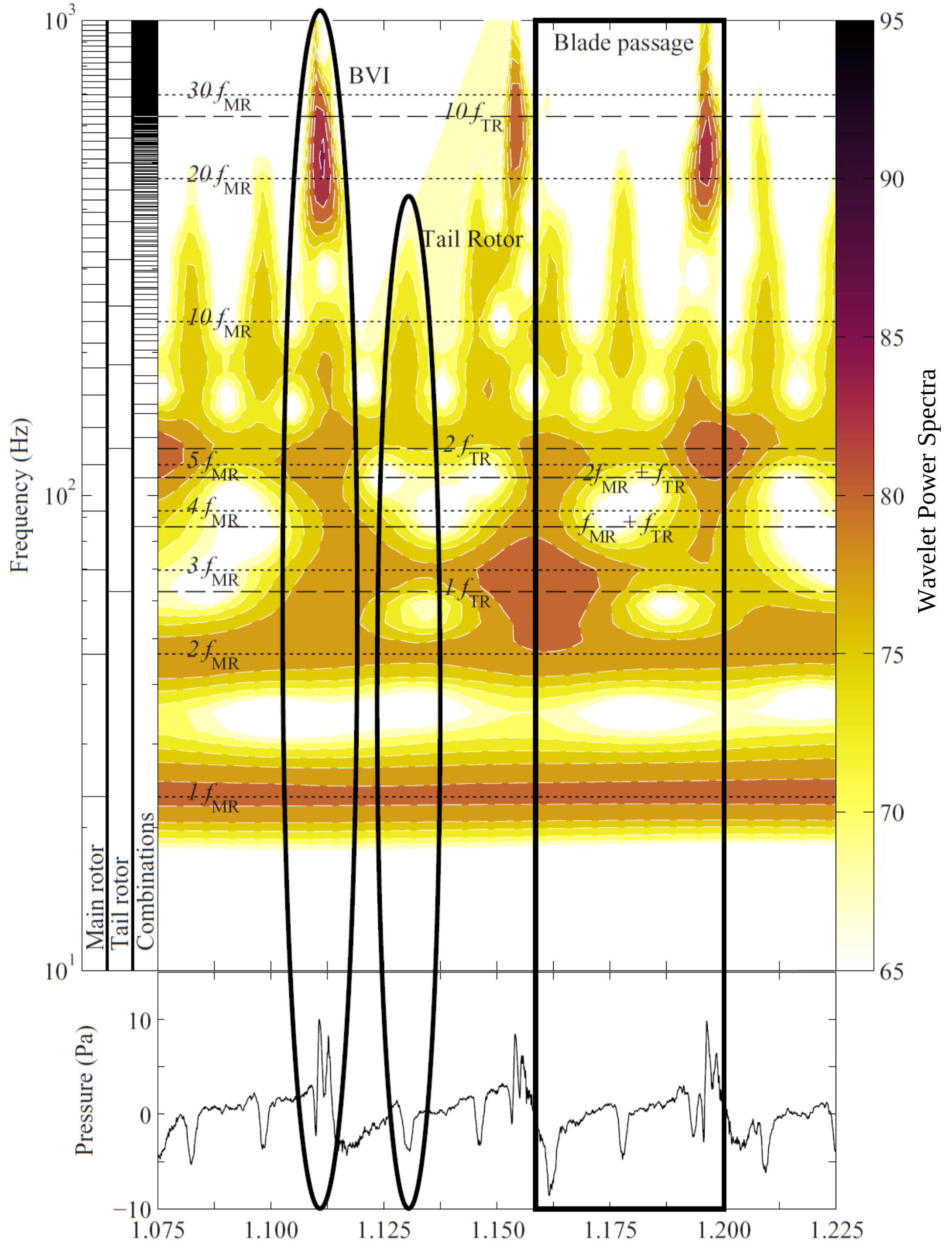
- Snapshot Array design
  - Mathematically defined distribution of points
  - Good hemispherical coverage at an instant in time
  - Does not rely on steady vehicle conditions throughout a flyover
- Ground-based coordinate system
  - +X: along flight path
  - +Y: to port (left)
  - +Z: up
- Vehicle state data collected by NASA's Aircraft Navigation and Tracking System (ANTS)
  - Vehicle position
  - Velocity
  - Accelerations
  - Pitch, roll, and heading





Data Reduction

- Timing
  - All data recorded with UTC timestamps
  - Acoustic, weather, and vehicle data time-synced
  - Vehicle crosses center of array at t = 0 s
- Vehicle state data
  - Flight path angle (γ) and pitch ($d\alpha/dt$) and roll ($d\varphi/dt$) rates calculated
  - Effective flight path angle, γ_{eff}, accounting for acclerations
- Acoustic data
  - De-Dopplerized in time domain
  - Pressure magnitudes distance-corrected to 30.48 m (100 ft) from vehicle
  - Wavelet transform method used to extract Blade-Vortex Interaction (BVI) noise
    - Analyzes content in time domain
    - Converts pressure time history into wavelet power spectrum
    - Preserves content with:
      - Frequency > 6 x BPF of main rotor
      - Energy density > - 6 dB of main rotor BPF



Stephenson (2014)

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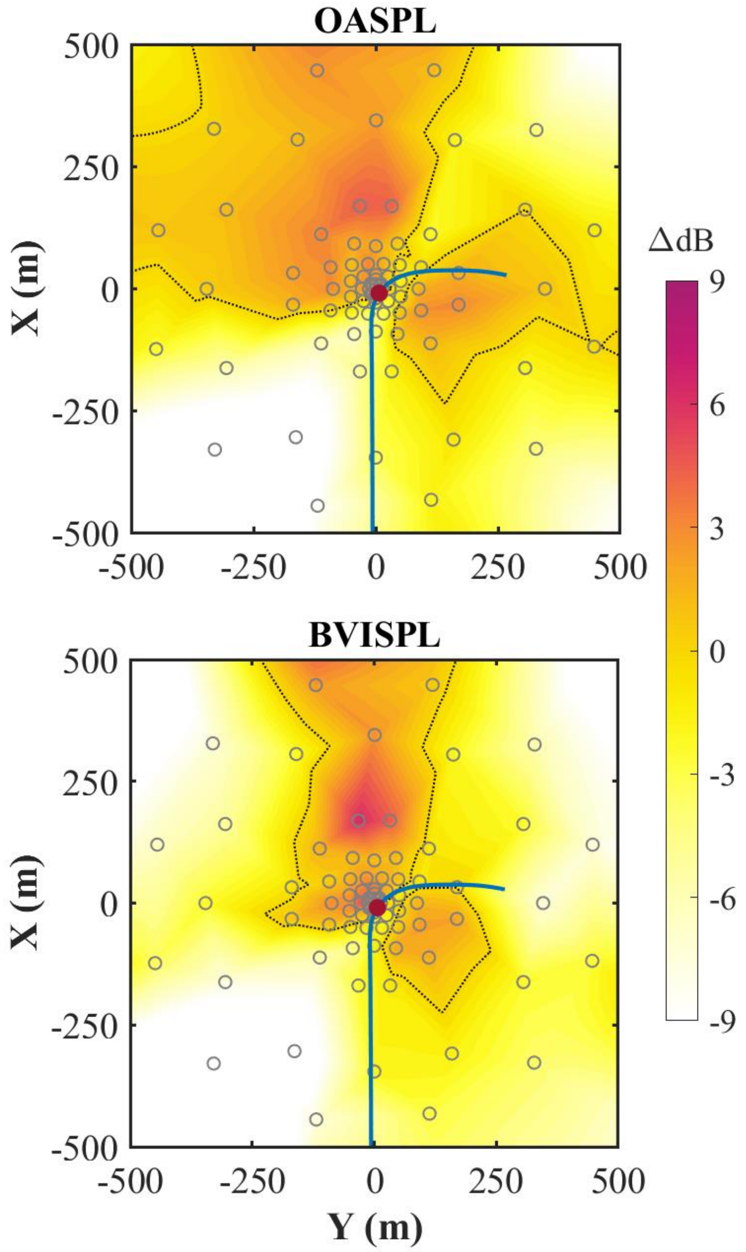
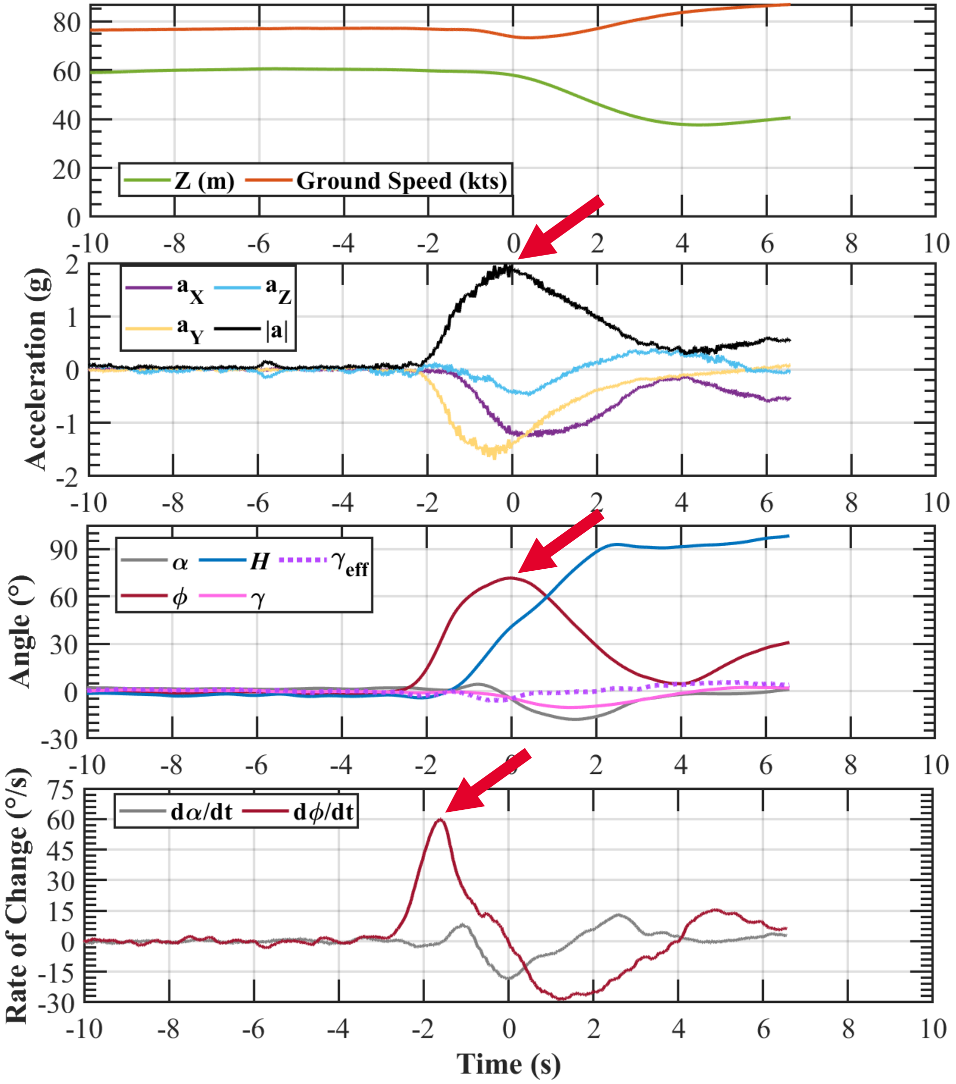


Vehicle State Data – M1 Cyclic Roll Right

ANTS Data



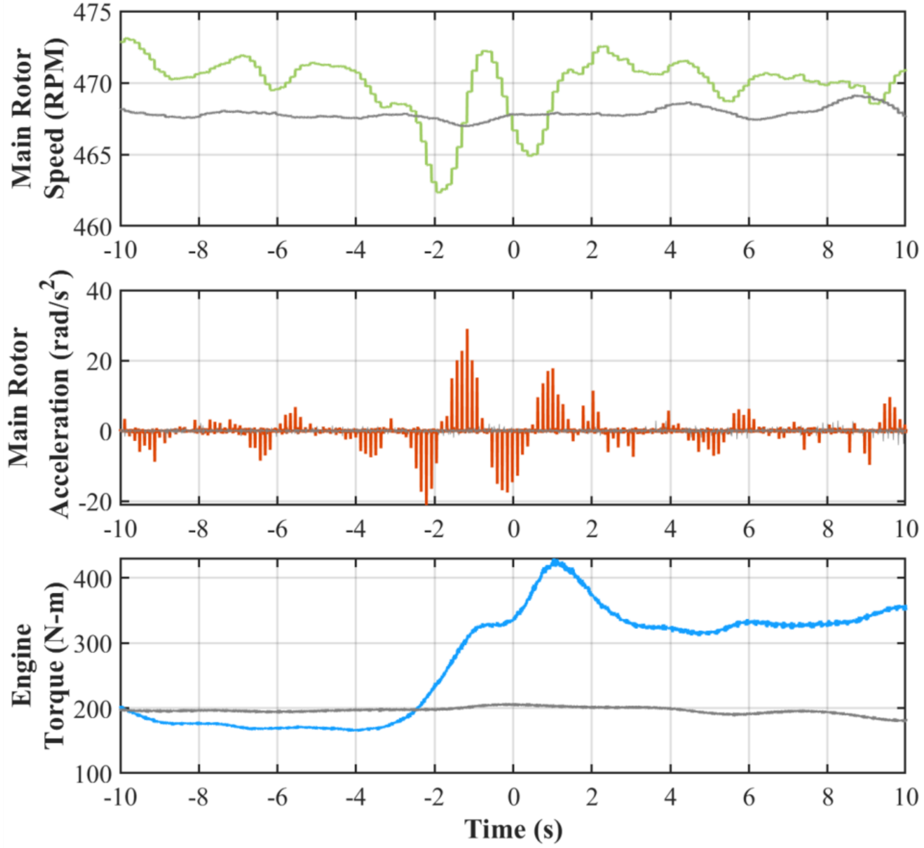
α , Pitch

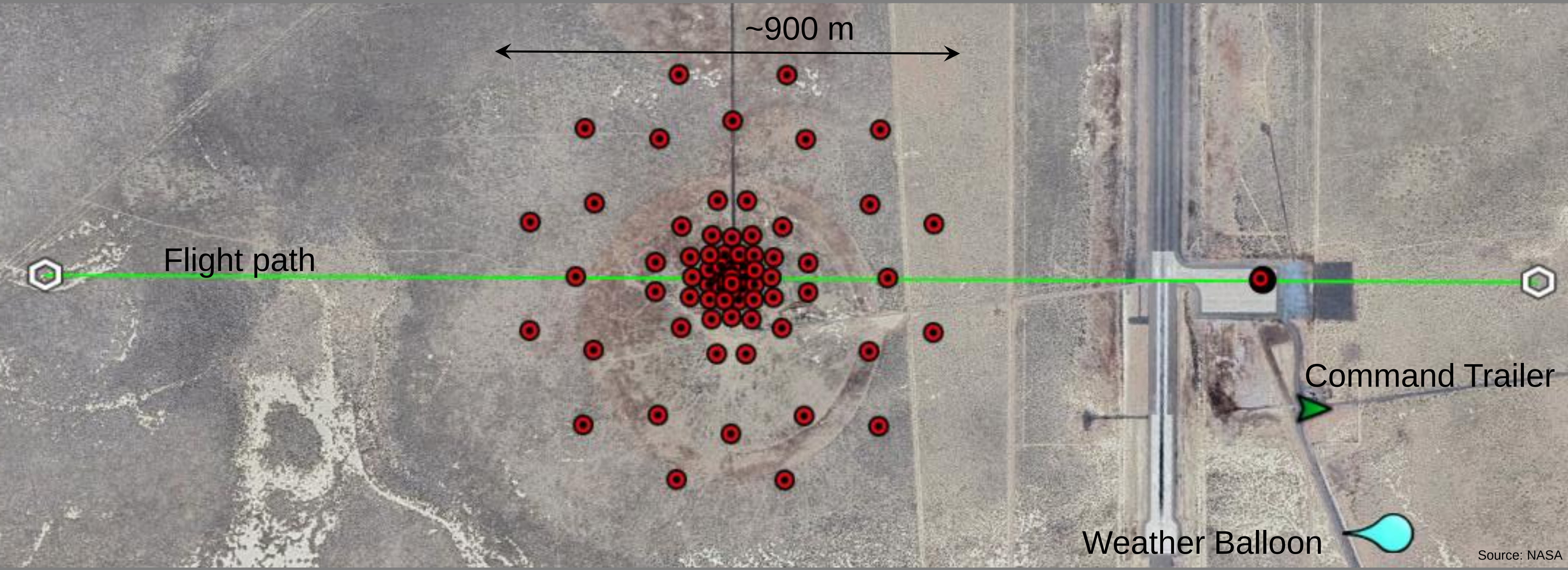
ϕ , Roll

H, Heading

γ , Flight Path Angle

Additional Vehicle Data

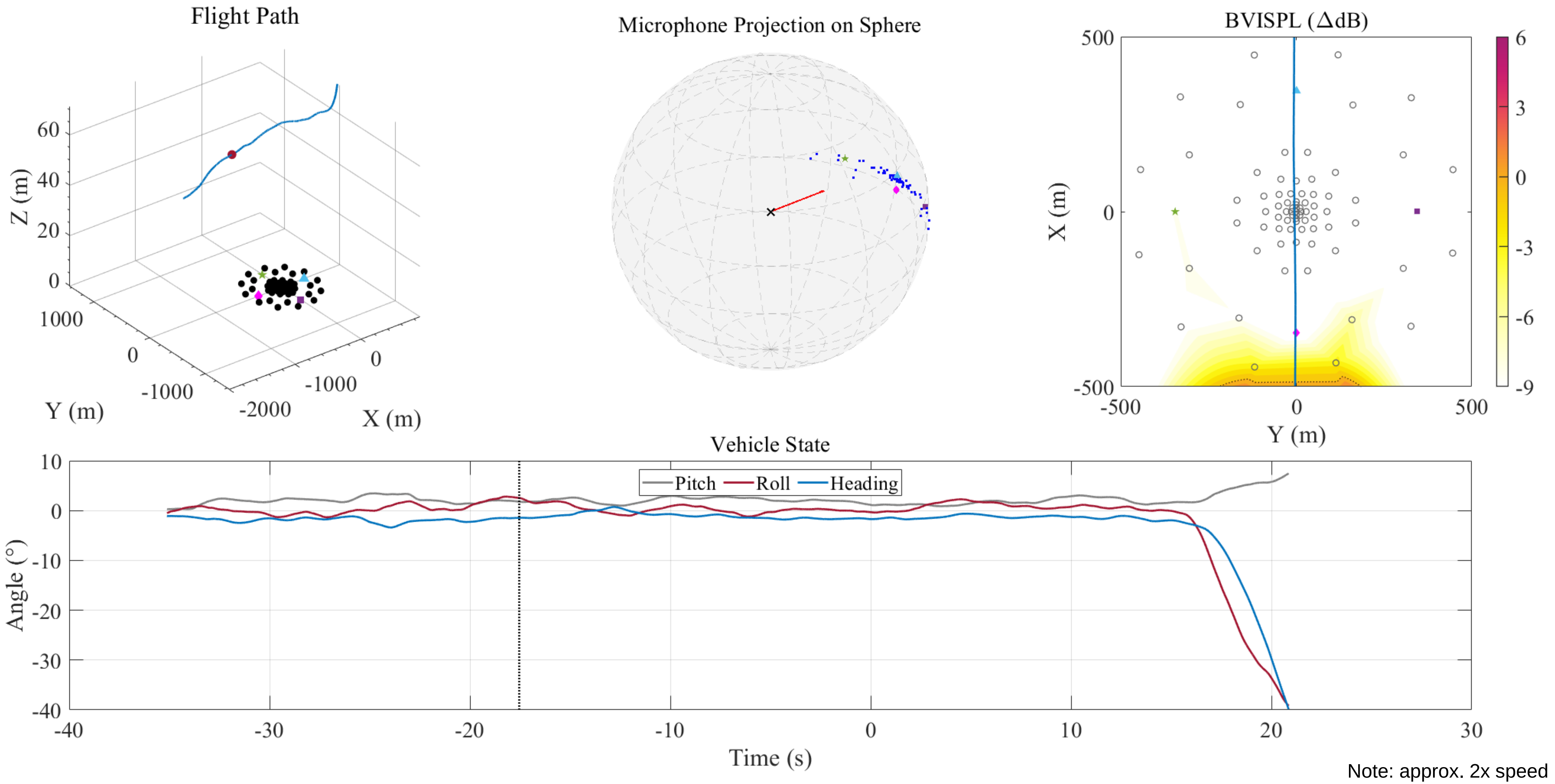




Snapshot Array for Maneuvers

Snapshot Array for Maneuvers

L3 – Steady, Level Flight



Note: approx. 2x speed

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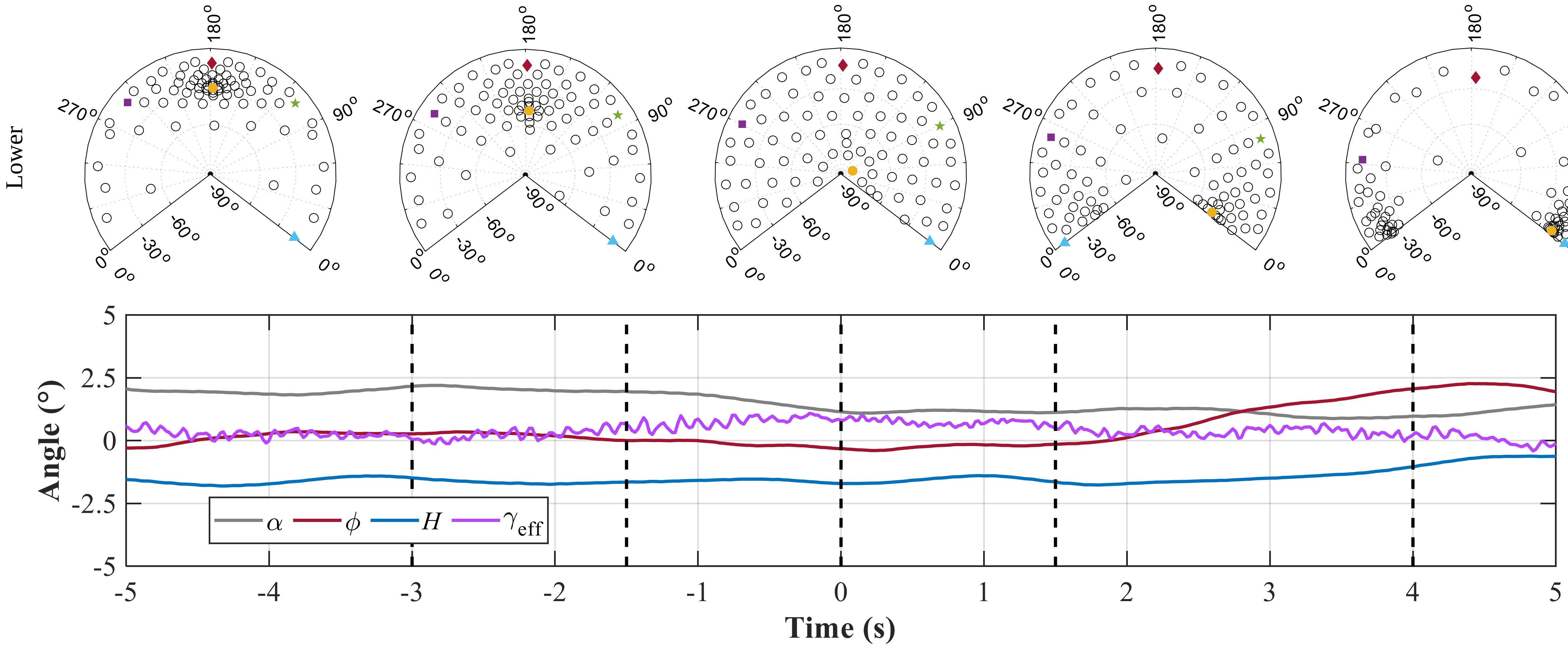
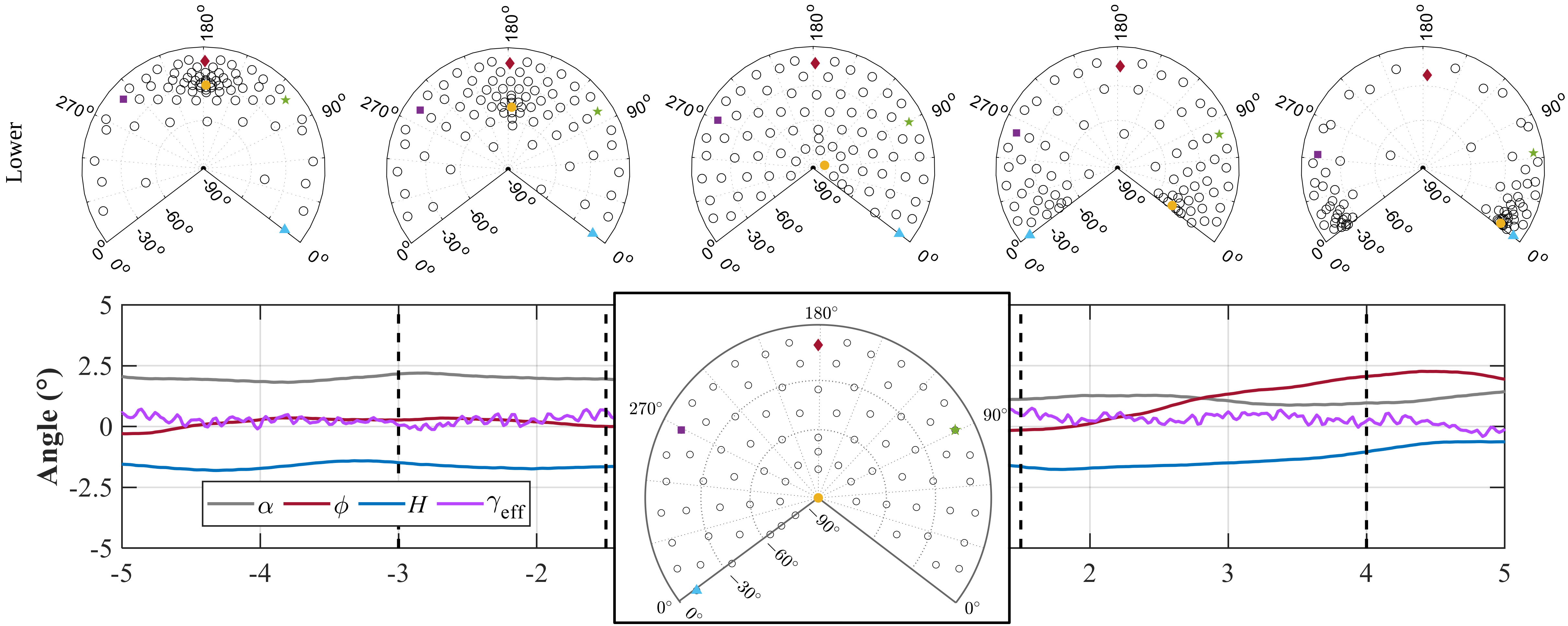


α, Pitch	ϕ, Roll	H, Heading	γ, Flight Path Angle

Snapshot Array for Maneuvers

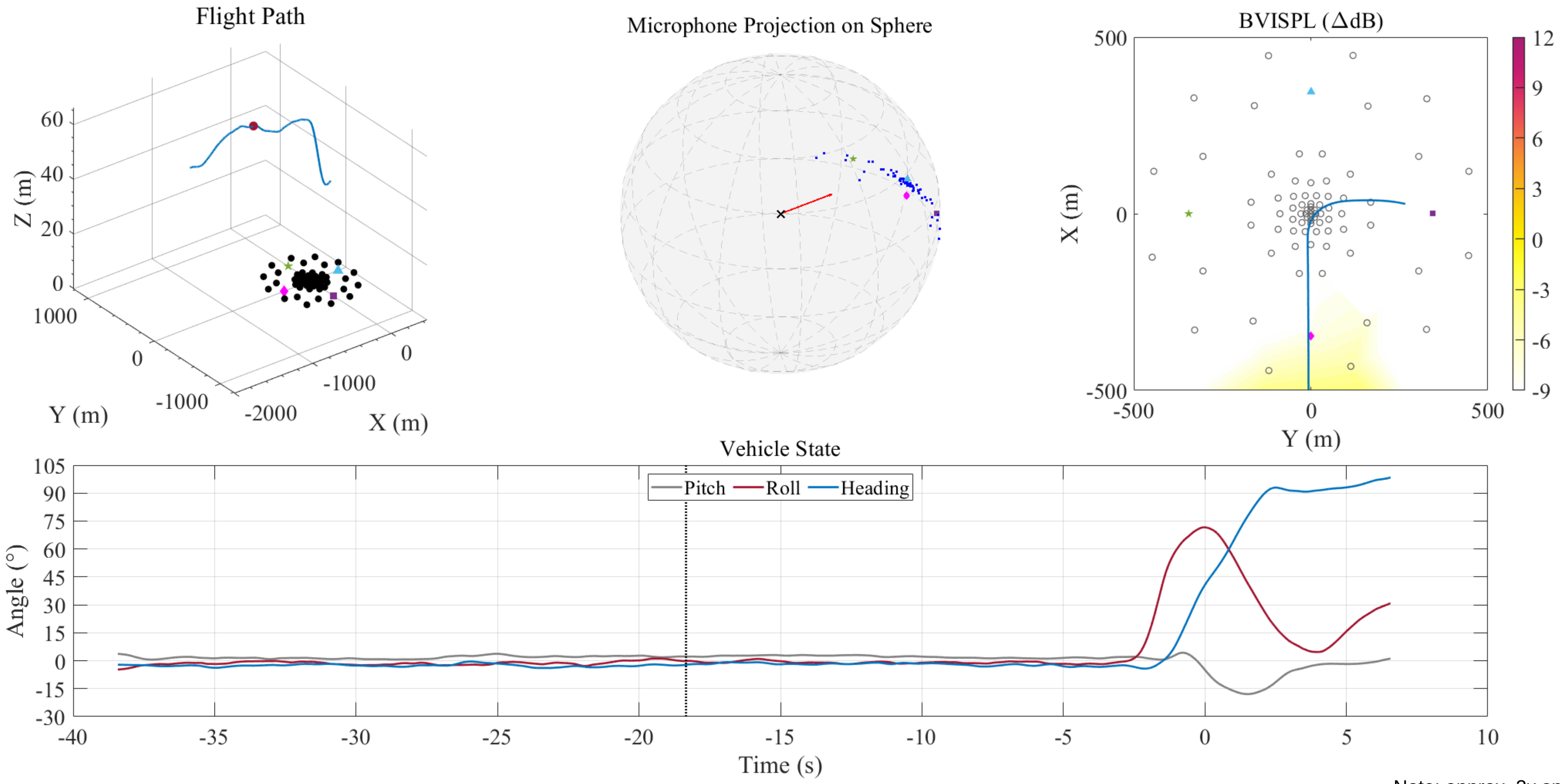
L3 – Steady, Level Flight



α , Pitch ϕ , Roll H, Heading γ , Flight Path Angle

Snapshot Array for Maneuvers

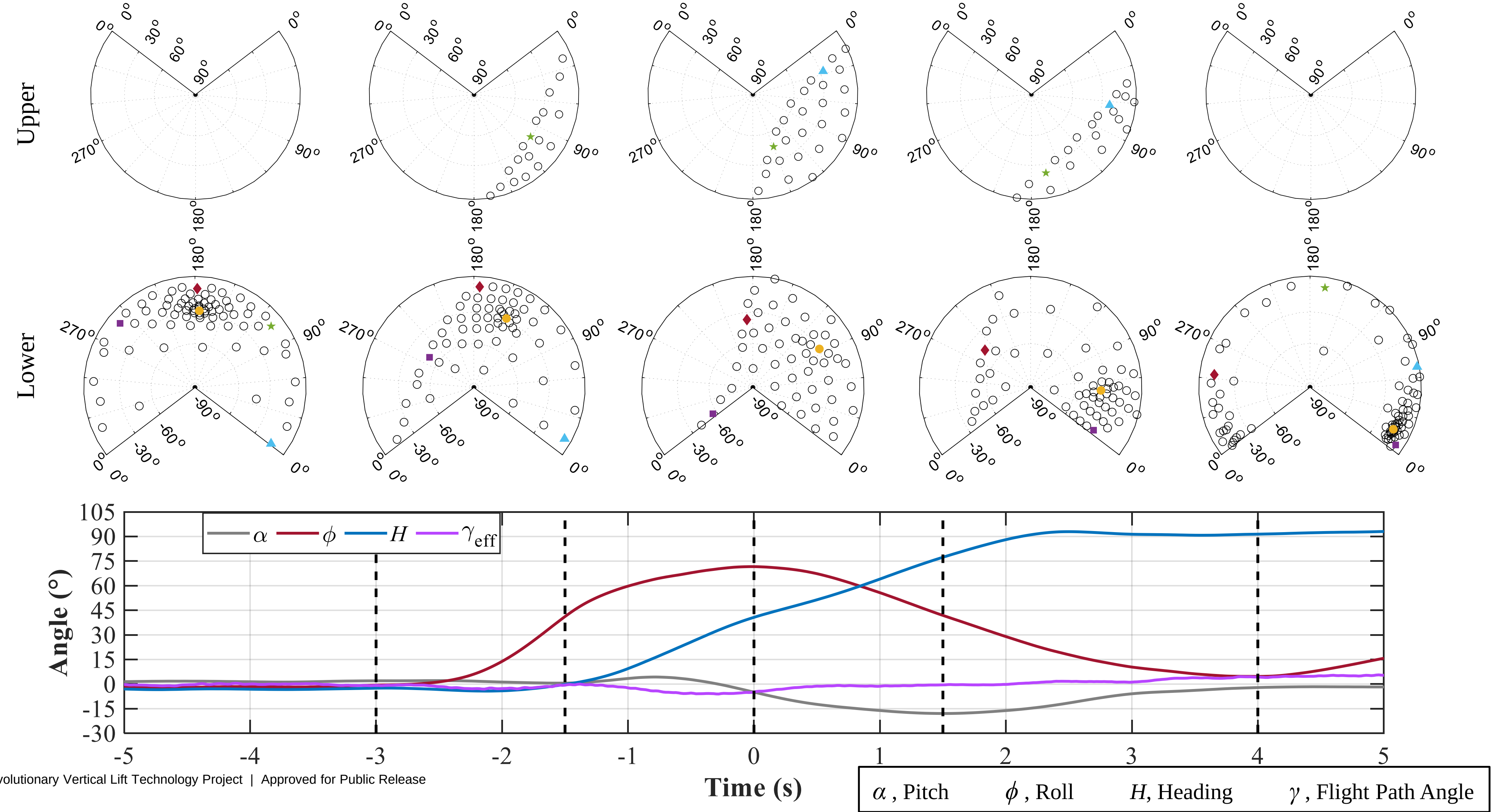
M1 – Cyclic Roll Right, Fast



Note: approx. 2x speed

Snapshot Array for Maneuvers

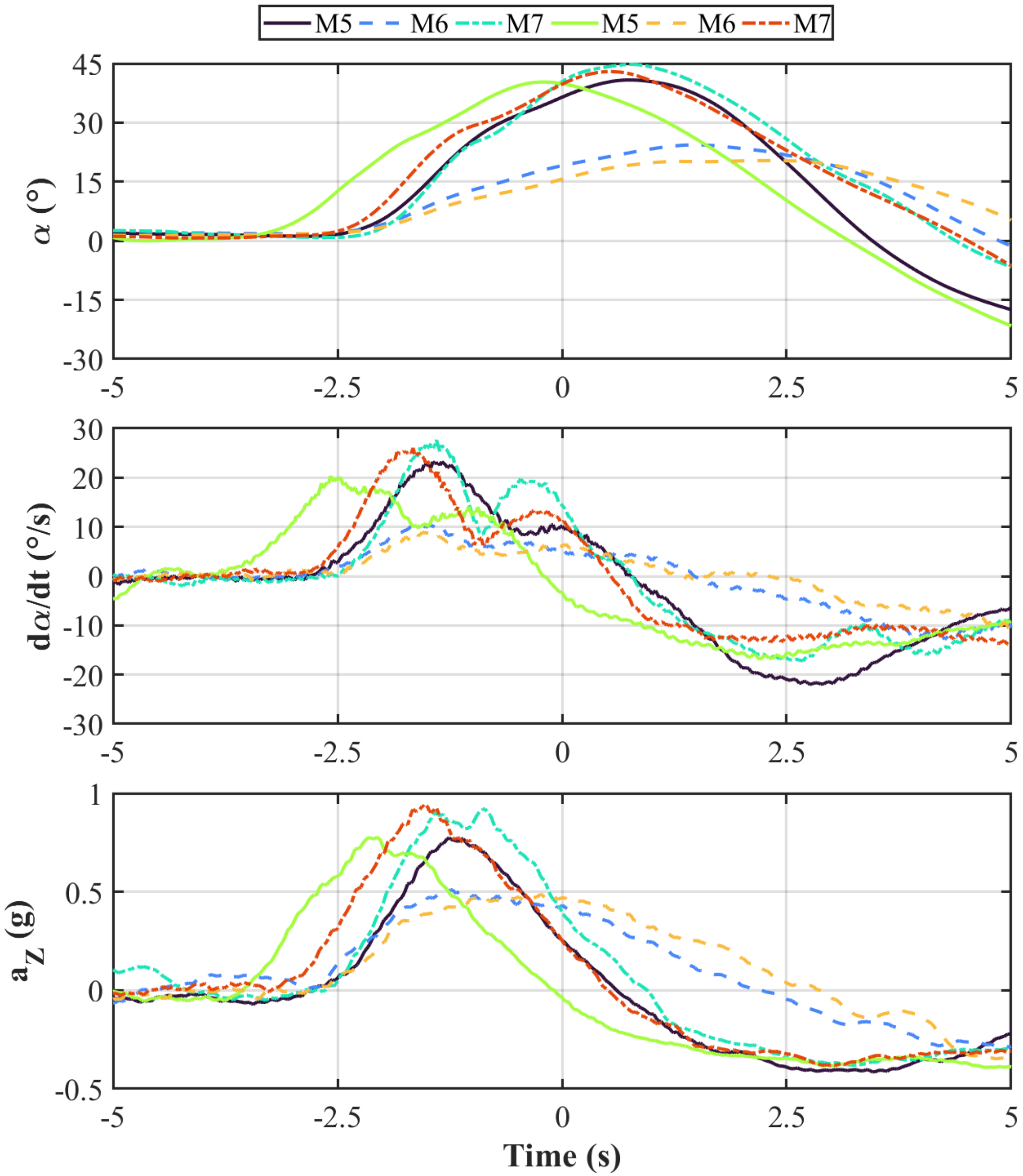
L1 – Cyclic Roll Right, Fast



Pitching Maneuvers

Pitching Maneuvers

- Vehicle state data
  - Pitch-up maneuvers were fairly repeatable
  - Cyclic motion significantly more severe and dominated in combination flights
  - ‘Double-hump’ shape in dα/dt likely due to thermals



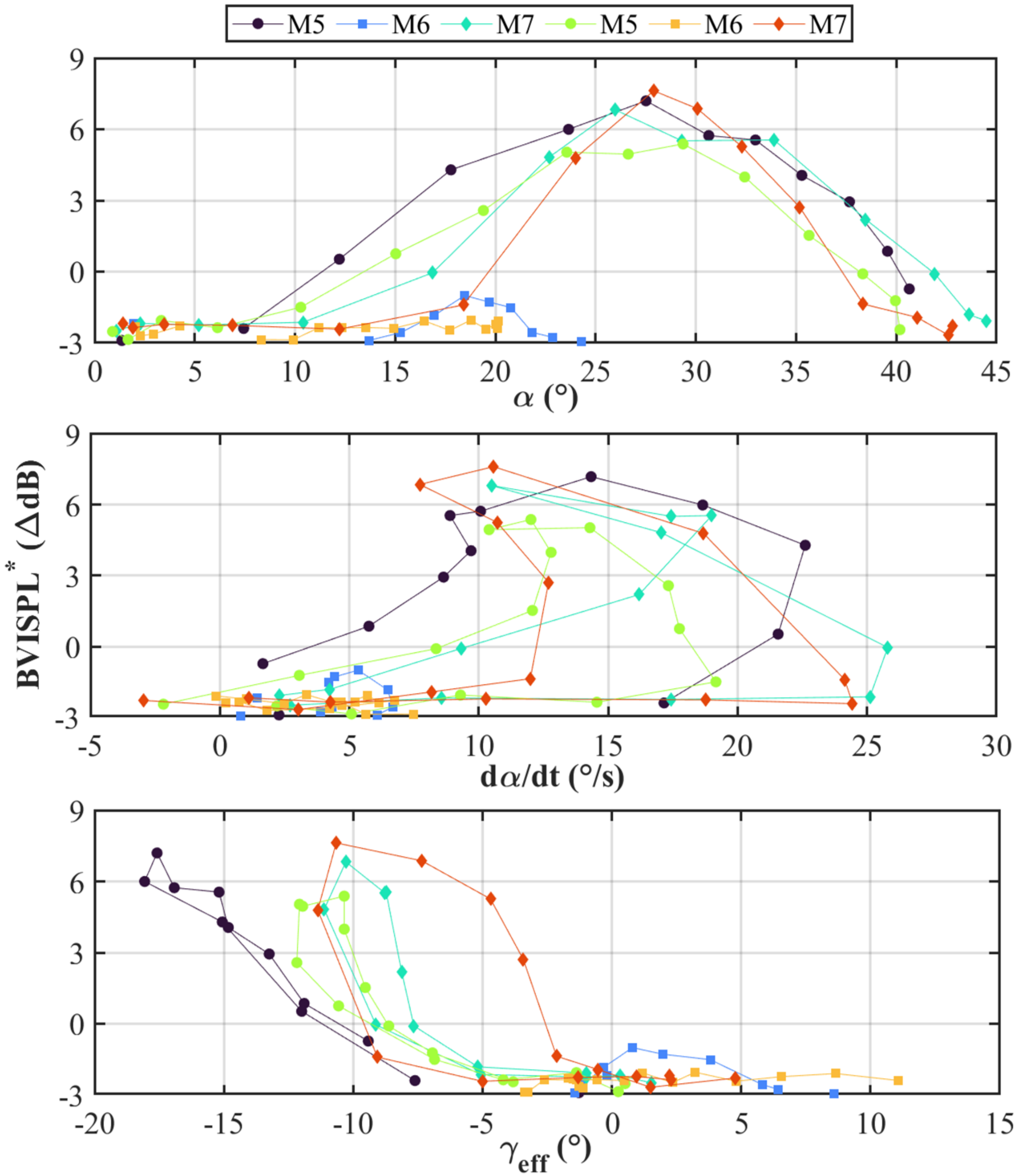
M5	Cyclic
M6	Collective
M7	Cyclic & Collective

Pitching Maneuvers

- Vehicle state data
  - Pitch-up maneuvers were fairly repeatable
  - Cyclic motion significantly more severe and dominated in combination flights
  - ‘Double-hump’ shape in dα/dt likely due to thermals

- Presence of BVI during pitching maneuver?
  - BVISPL* is mean of BVISPL ≥ 3 dB across the array at a given time
  - Peak BVISPL* did not occur at peak pitch angle or peak pitch rate
  - Peak BVISPL* did occur at peak γ_{eff}, which accounts for accelerations

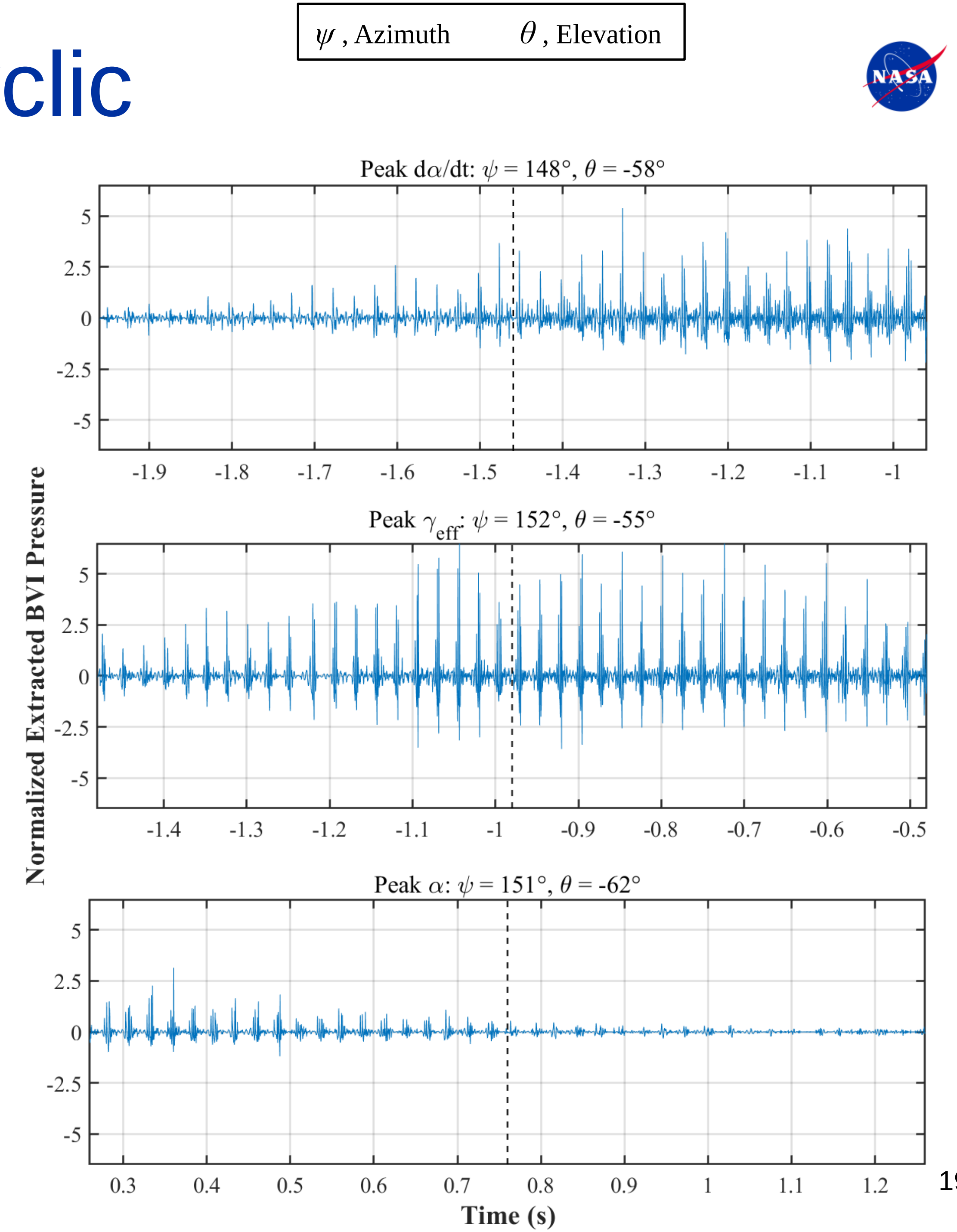
M5	Cyclic
M6	Collective
M7	Cyclic & Collective

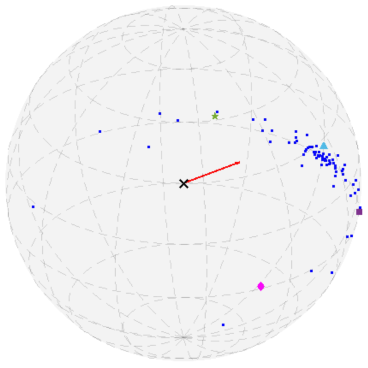


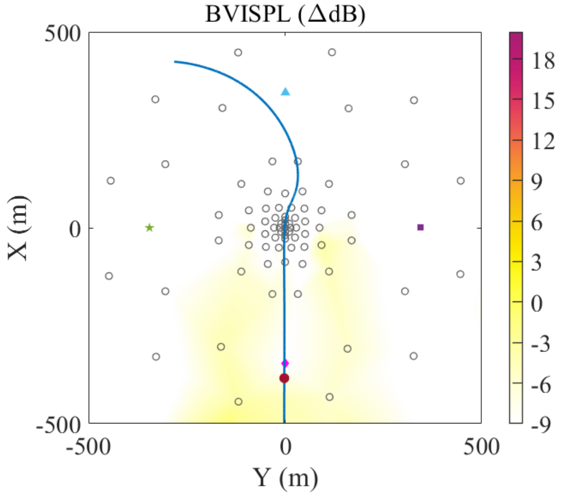
Pitching Maneuver – M5 Cyclic

- Identified directivity of peak BVISPL value
- Interrogated nearest mic to that emission angle at times of different peak values
  - Strong BVI presence at peak γ_{eff}
  - Suggests acceleration is main driver of BVI
  - Weaker BVI presence *near* peak pitch rate
  - No discernable BVI around peak pitch angle

- Is wake above main rotor near the nose? Or is the rotor plane pitching fast enough to catch the wake near the tail?







Note: approx. 2x speed

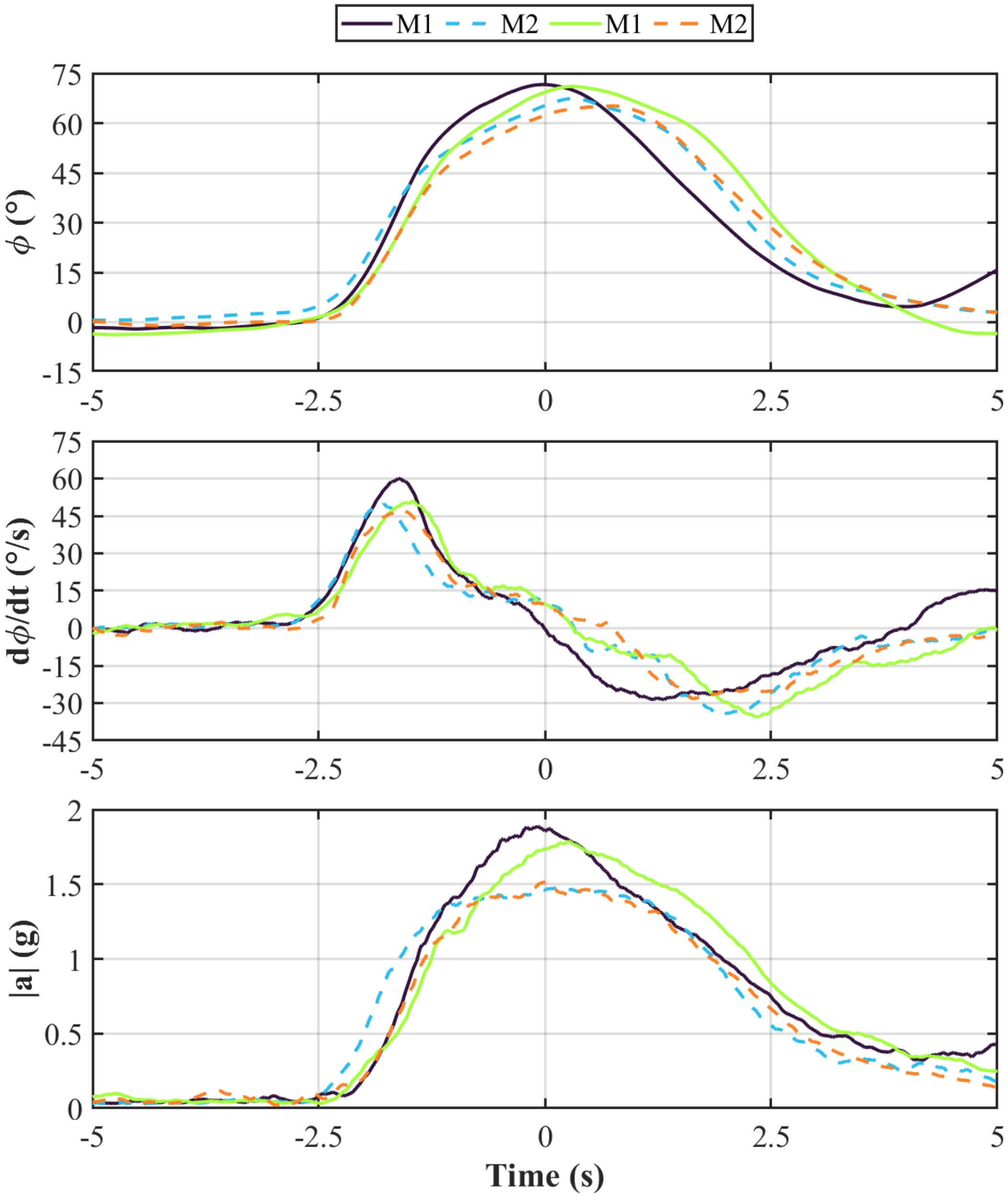
Source: NASA

Rolling Maneuvers

Rolling Maneuvers

- Neglect slow rolls (M3, M4)
- Right vs. left turns repeatable and similar
- Effects on acoustics should be isolated to advancing vs. retreating side of the main rotor
- Expectation:
  - Strong BVI in rolls into advancing side
  - Weak to no BVI in rolls away from advancing side

M1	Roll right (into advancing side), fast
M2	Roll left (away from advancing side), fast

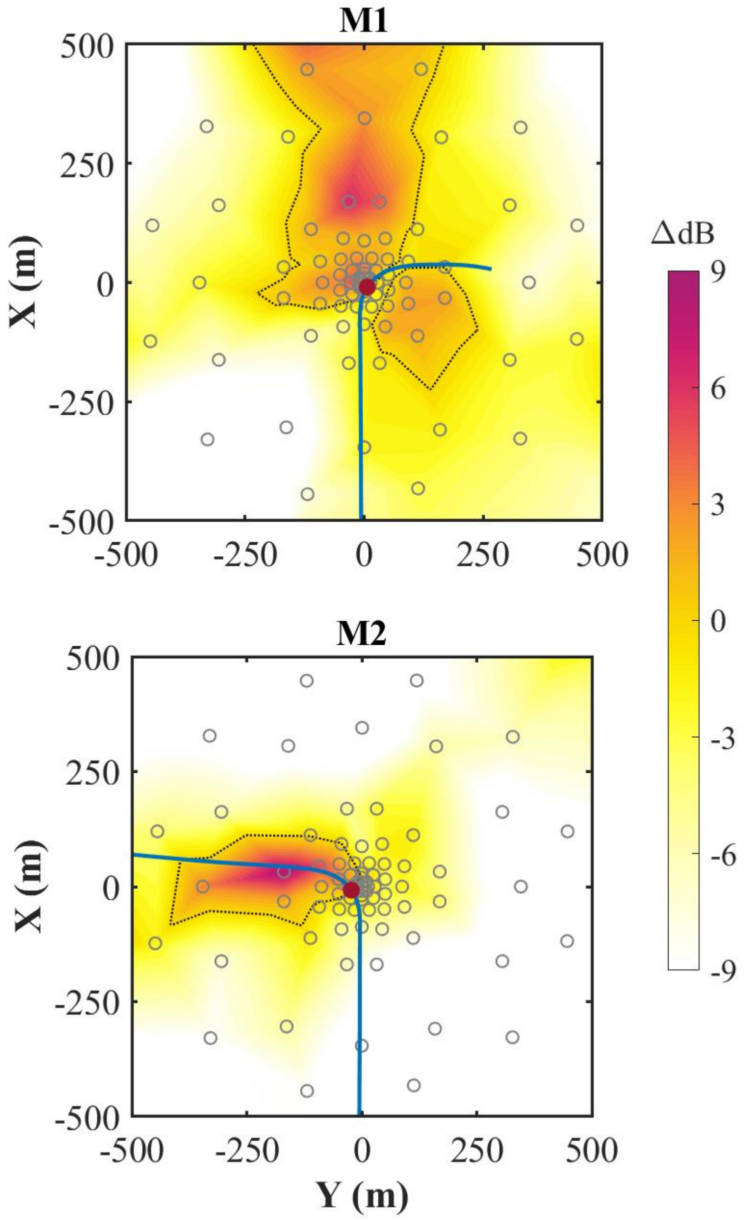


Rolling Maneuvers

- Neglect slow rolls (M3, M4)
- Right vs. left turns repeatable and similar

- Effects on acoustics should be isolated to advancing vs. retreating side of the main rotor
- Expectation:
  - Strong BVI in rolls into advancing side
  - Weak to no BVI in rolls away from advancing side
- Observed:
  - Similar BVI strength for both directions
  - More focused directivity for retreating-side roll

M1	Roll right (into advancing side), fast
M2	Roll left (away from advancing side), fast

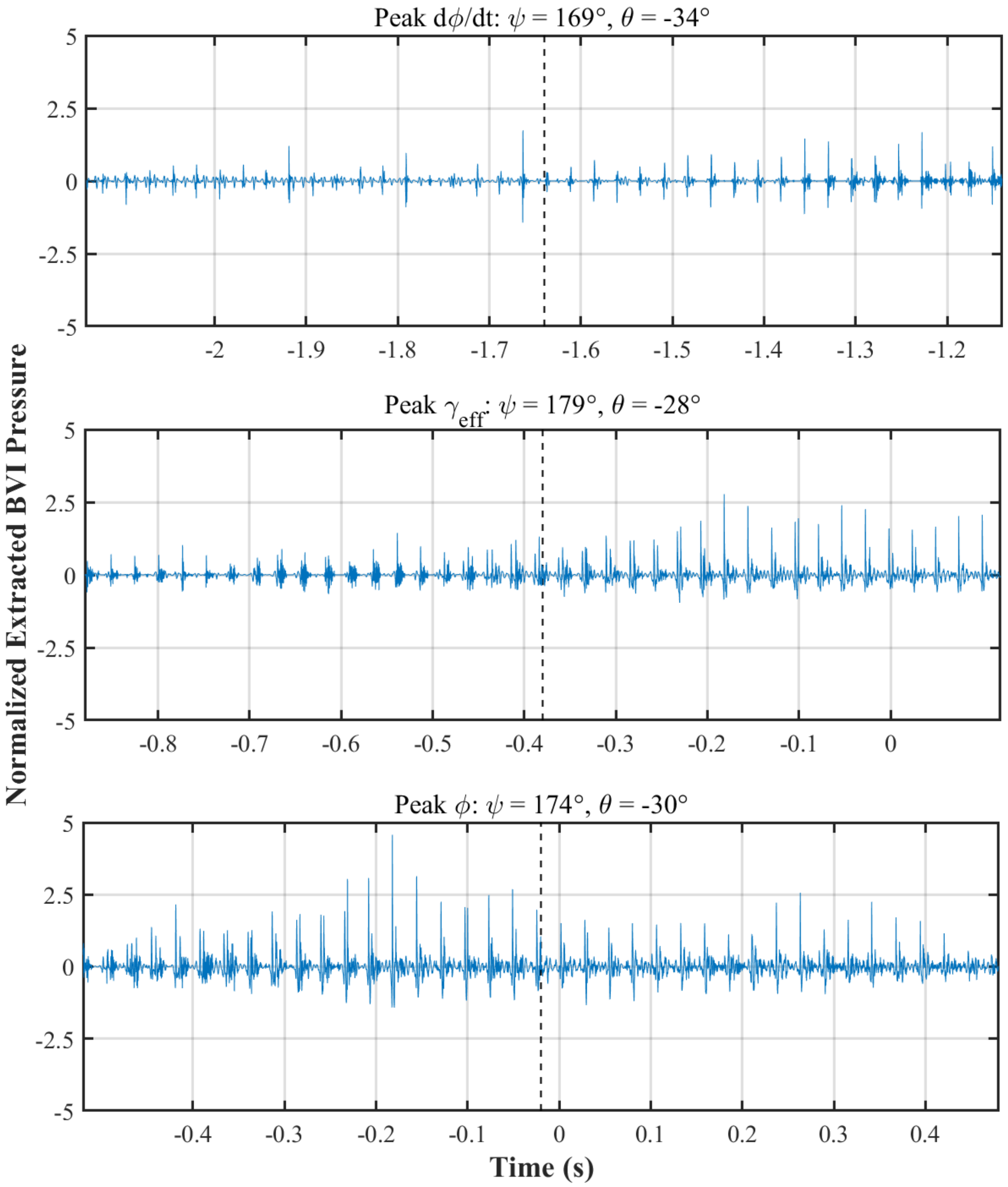


Rolling Maneuver – M1 – Fast Right

ψ , Azimuth θ , Elevation

- Same process as the pitching maneuver
  - Identified emission angle of peak BVISPL value
  - Interrogated nearest mic to that directivity at times of different peak values

- Different trends than pitch
  - No discernable BVI at peak roll rate
  - Weaker BVI presence *near* γ_{eff}
  - Strongest BVI at peak roll angle, not associated with peak acceleration



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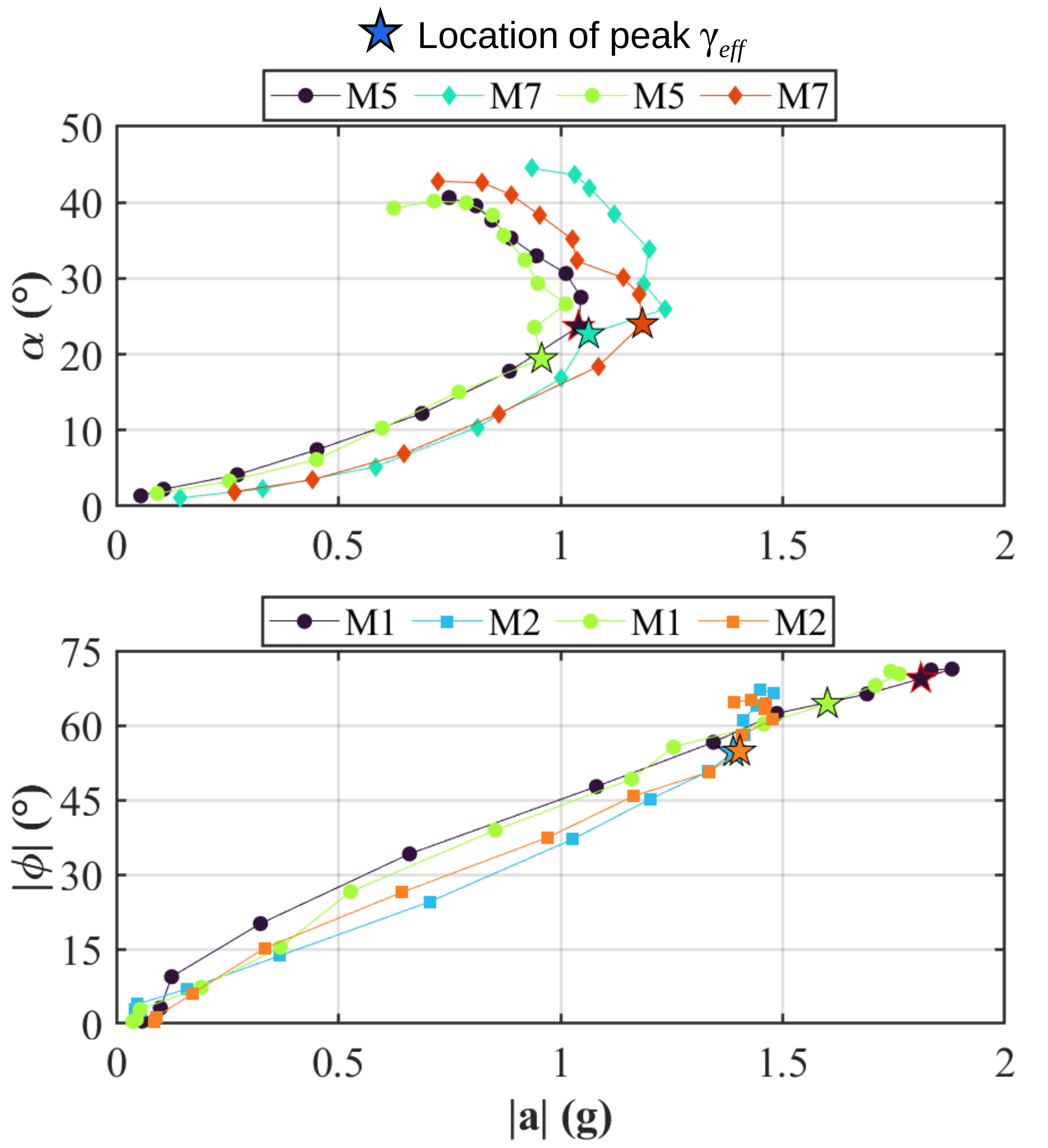
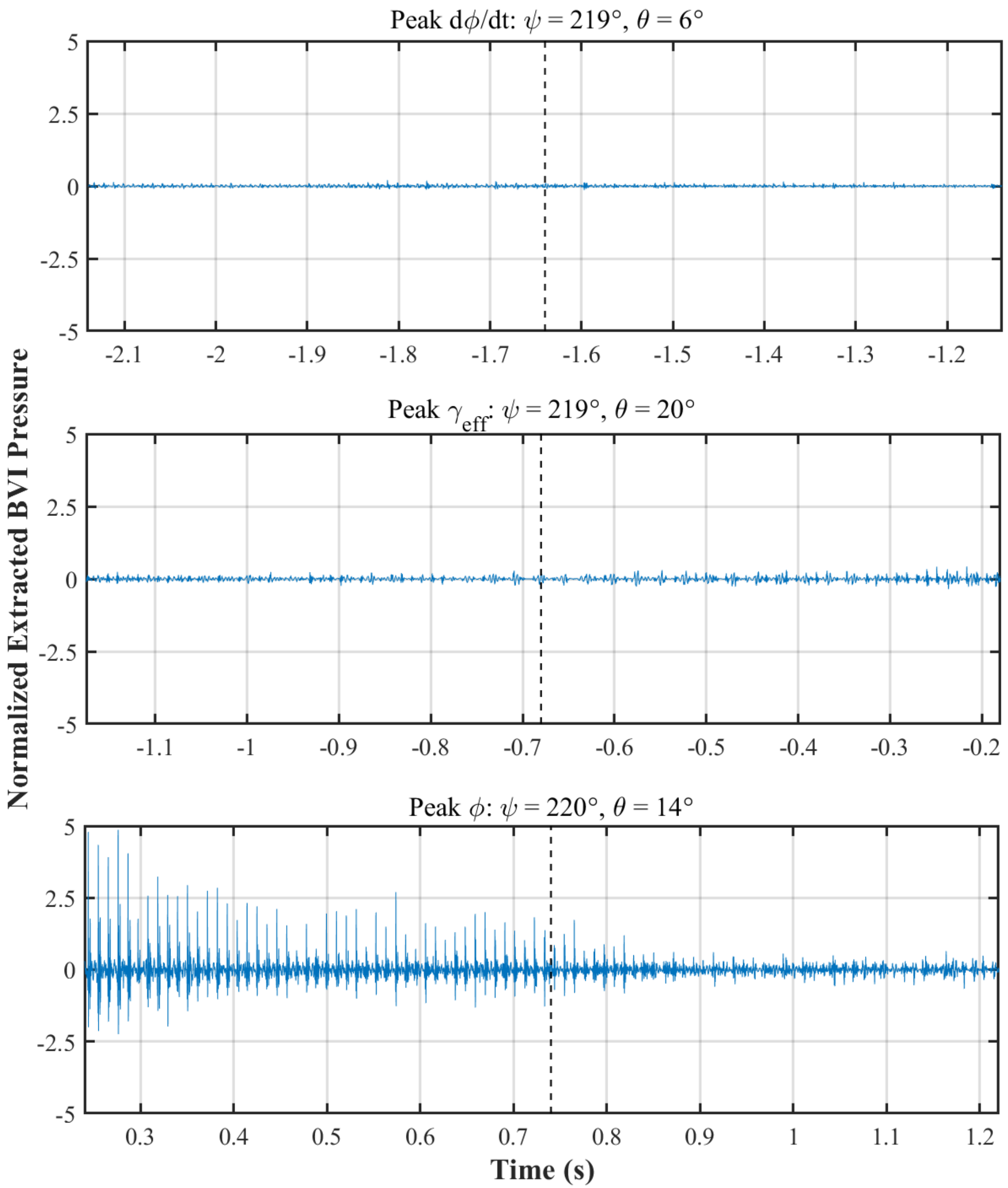
- Different trends than pitch
  - No discernable BVI at peak roll rate
  - Weaker BVI presence *near* γ_{eff}
  - Strongest BVI at peak roll angle, not associated with peak acceleration
- Do these trends *disagree* with pitch?
  - Parabolic vs linear acceleration result of fighting gravity
  - M5 & M7: strongest BVI at peak γ_{eff}
  - M1 & M2: strongest BVI at peak roll angle
  - Both correspond to peak total acceleration
  - Note, is close to peak |*a*| for M1 & M2, hence the weak BVI shortly after



Rolling Maneuver – M2 – Fast Left

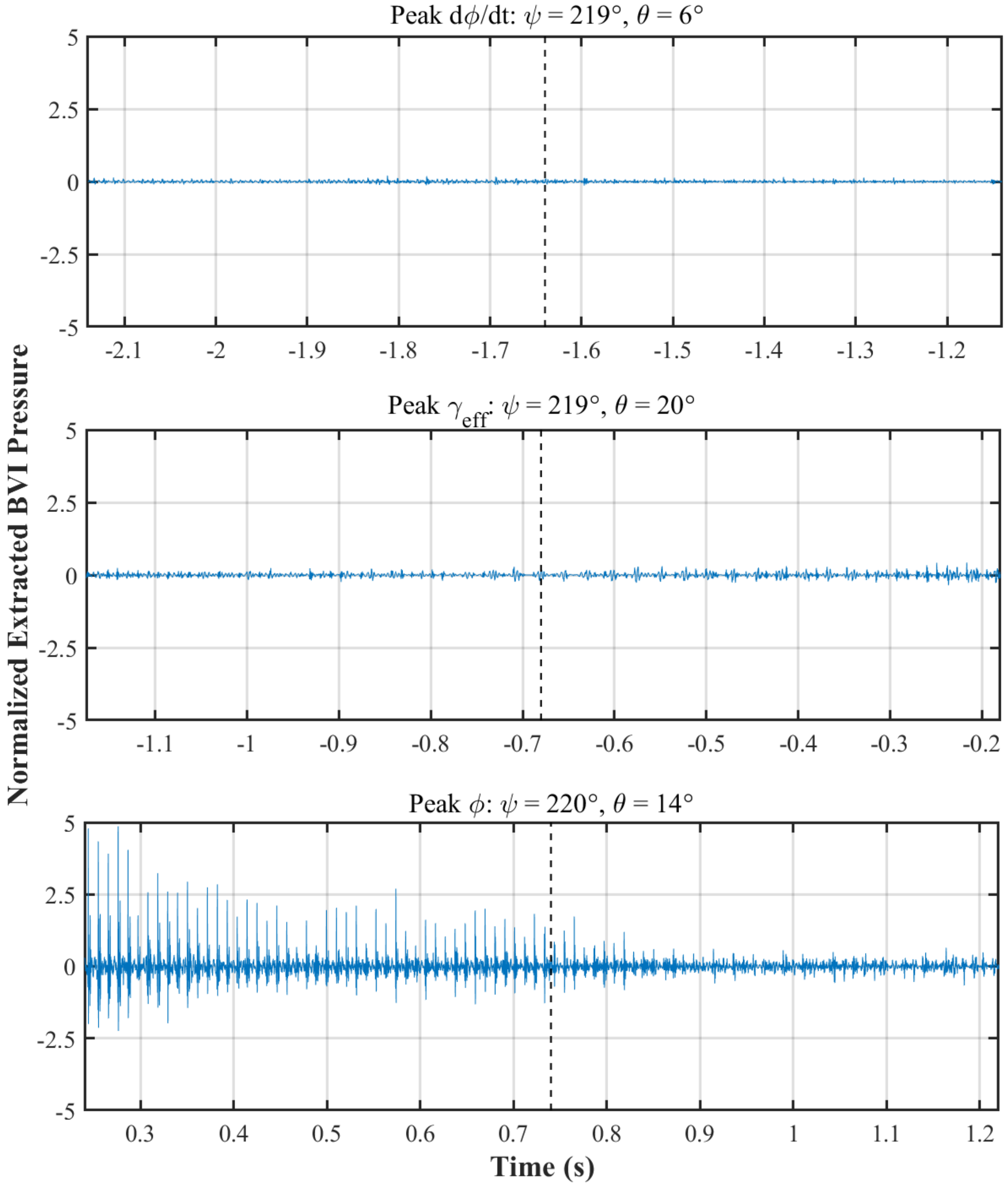
ψ, Azimuth θ, Elevation

- Same process again
  - Identified emission angle of peak BVISPL value
  - Interrogated nearest mic to that directivity at times of different peak values
- Strong BVI present near peak roll angle



Rolling Maneuver – M2 – Fast Left

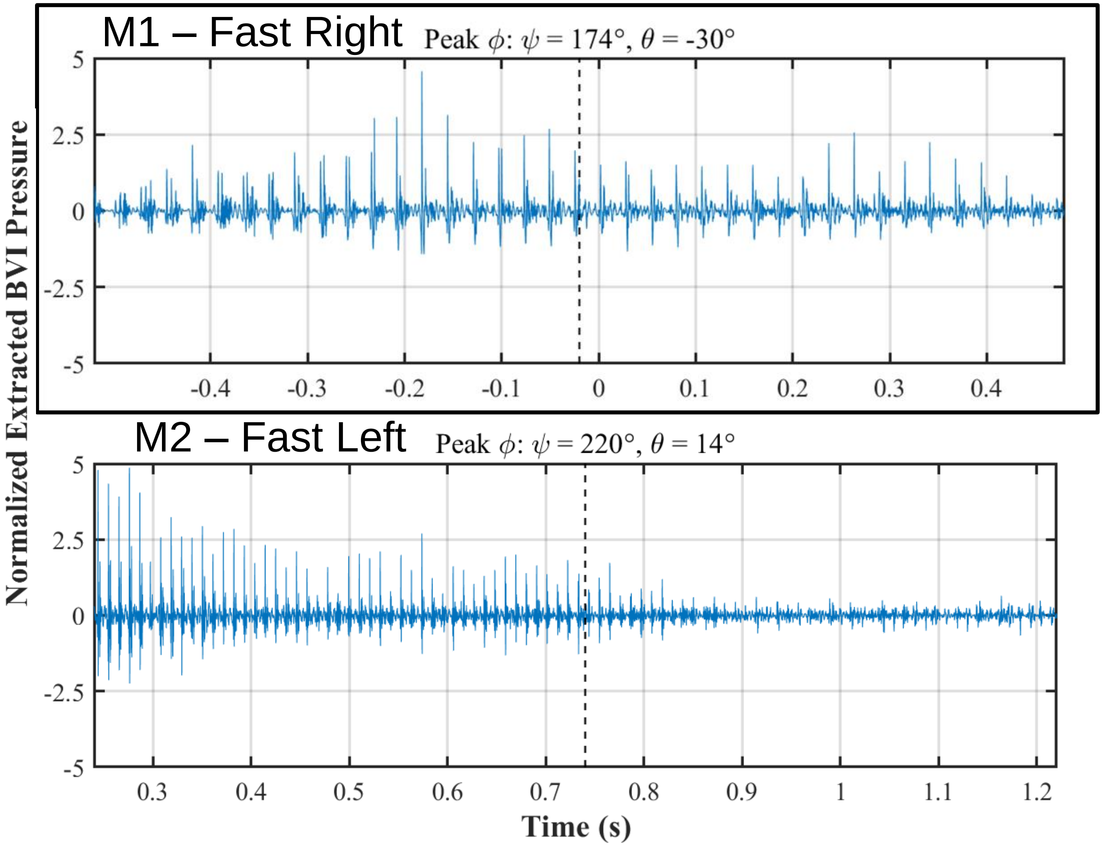
- Same process again
  - Identified emission angle of peak BVISPL value
  - Interrogated nearest mic to that directivity at times of different peak values
- Strong BVI present near peak roll angle
- Emission angle is wrong?
  - BVI expected to be ahead and below the vehicle, possibly favoring the advancing
  - M1 ✓
  - M2 ✗



Rolling Maneuver – M2 – Fast Left

ψ , Azimuth θ , Elevation

- Same process again
  - Identified emission angle of peak BVISPL value
  - Interrogated nearest mic to that directivity at times of different peak values
- Strong BVI present near peak roll angle
- Emission angle is wrong?
  - BVI expected to be ahead and below the vehicle, possibly favoring the advancing
  - M1 ✓
  - M2 ✗
- Period is wrong?
  - Main rotor BPF = 39.75 Hz → T = 0.0252 s
  - Tail rotor BPF = 94.9 Hz → T = 0.0105 s
- M2 is exhibiting BVI associated with the tail rotor
  - Directivity would be ahead and below from the tail rotor plane ✓
  - Tail rotor wake pushed towards starboard
  - Yawing motion during roll left could lead to tail rotor interacting with its own wake → BVI



Conclusions

- Snapshot Array
    - Well-suited to unsteady conditions
    - Limitations at large pitch/roll angles inherent in ground mics

- BVI present in all severe maneuvers (M1, M2, M5, & M7)
    - Main rotor BVI during rolls towards advancing side expected
    - Main rotor BVI during pitch-up maneuvers
    - Wake above rotor near nose during level flight?
    - Rotor plane pitches quickly enough to catch wake near tail?
    - BVI during roll towards retreating side appears to be tail rotor BVI
    - Strong BVI occurs at or near peak acceleration for all cases

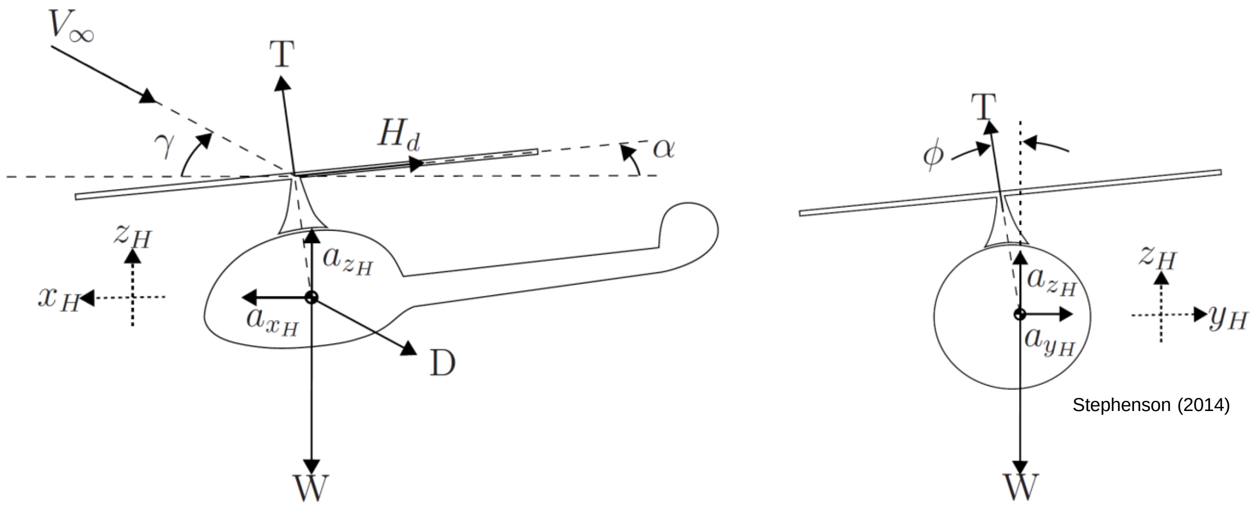
Questions?

Source: C. Stutz

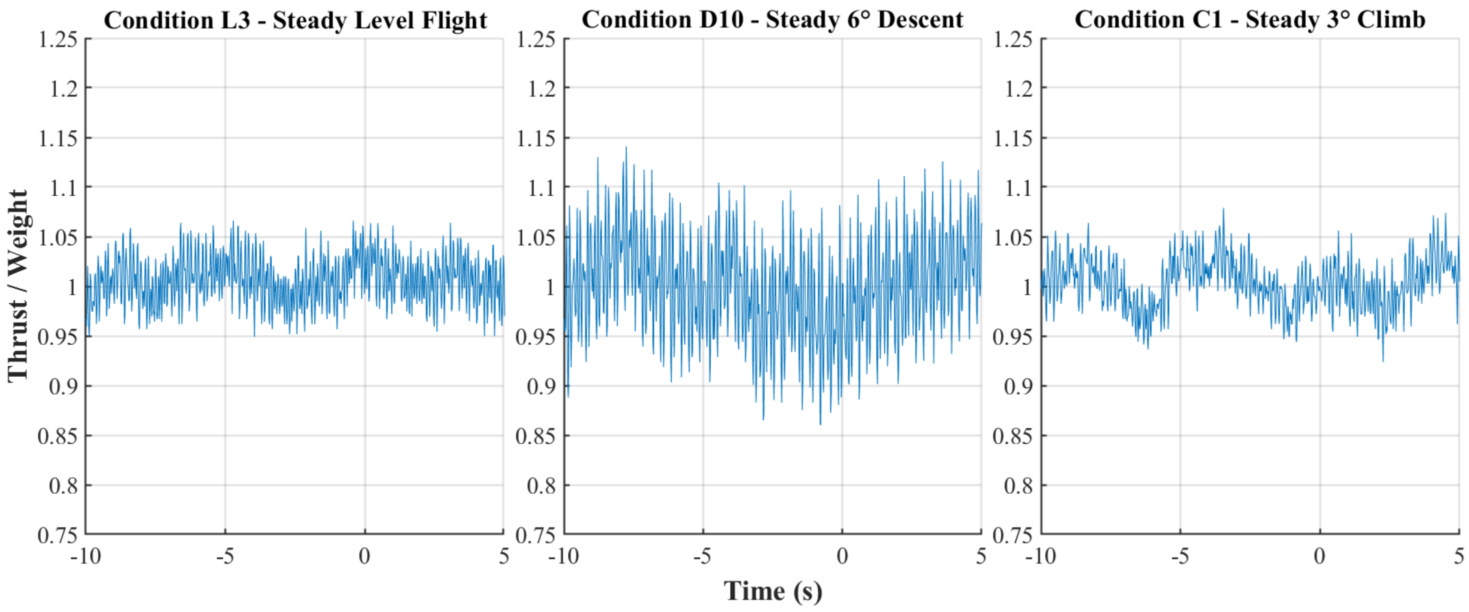
Stephenson (2014) “Extraction of Blade-Vortex Interactions from Helicopter Transient Maneuvering Noise,” Doctoral dissertation, The University of Texas at Aust

Calculating Main Rotor Thrust

- Goal was to use ***only*** ANTS data to estimate rotor thrust
  - Position, velocity, acceleration in (x, y, z)
  - Roll, pitch, and heading angles
- Applied to steady flight conditions
- Compared to CAMRAD II results with 3% - 5% error



Stephenson (2014)



$$0 = T\cos\alpha\,\cos\varphi - Th\sin\alpha - Td\sin\gamma - W(1 - {}^{a_z}/_{g})$$

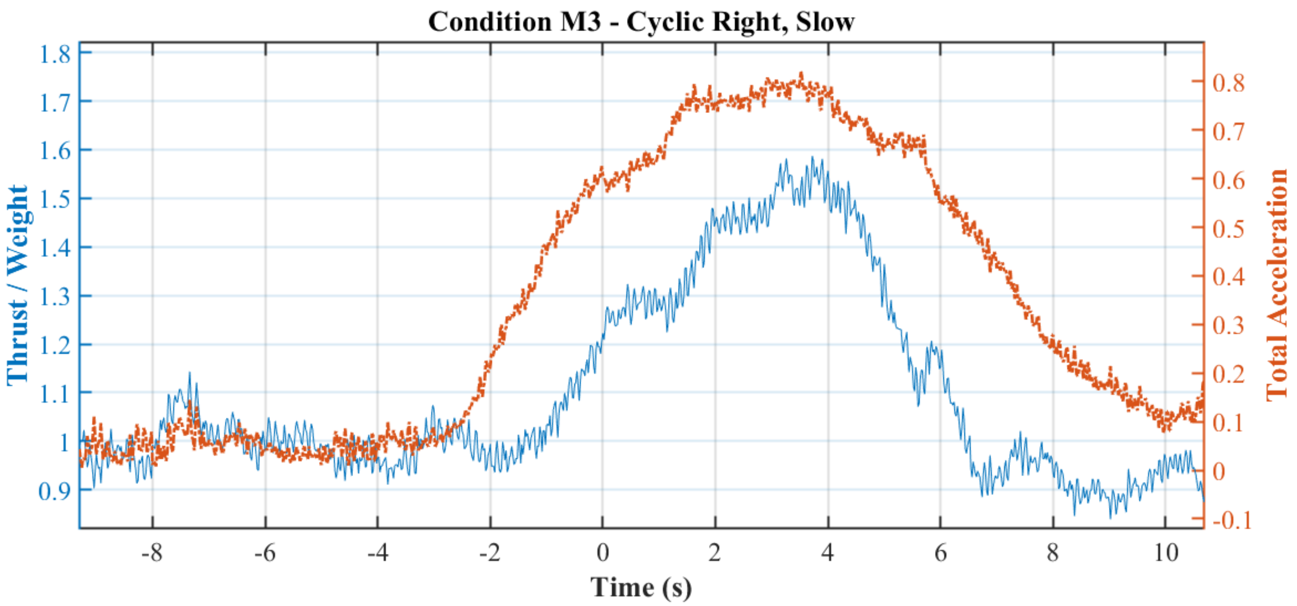
$$0 = T\sin\alpha\,\cos\varphi + Th\cos\alpha - Td\cos\gamma + W\,{}^{a_x}/_{g}$$

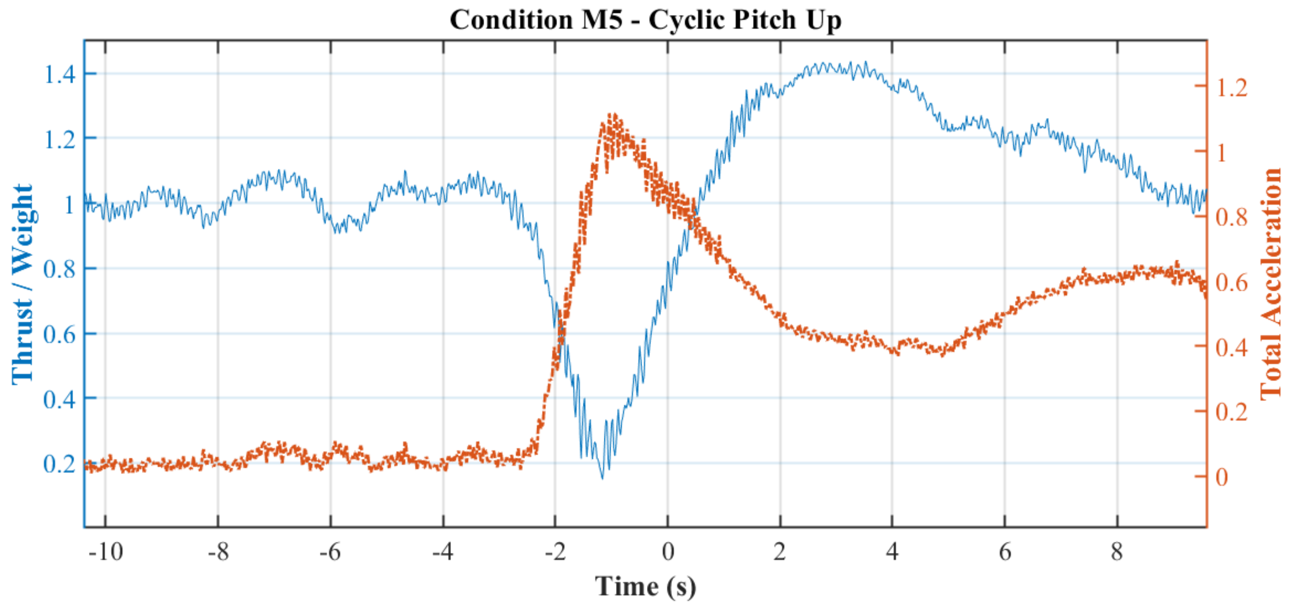
Stephenson (2014)

$$h = \frac{\sigma\, C_{d_0}\,\mu}{4} \qquad d = \frac{f_e\,\mu^2}{2A}$$

Calculating Main Rotor Thrust

- Applied method to unsteady maneuvers
- Still working on CAMRAD II inputs for maneuvers
- Comparison of T/W and |a|
    - *F = ma*
    - Additional force (thrust) should be proportional to additional acceleration
- Slow roll maneuvers appear reasonable
- Aggressive (cyclic) pitch-up maneuvers appear reasonable





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  - *F = ma*
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- Slow roll maneuvers appear reasonable
- Aggressive (cyclic) pitch-up maneuvers appear reasonable
- Fast roll maneuvers appear incorrect
- Centripetal force due to roll?
  - Using center of roll as *R* is wildly wrong
  - Is it better modeled as hanging mass, so *R* is distance from c_g to center of rotor?