# Smart Twisting Active Rotor (STAR) Wind Tunnel Test and Preliminary Predictions – Blade-Vortex Interaction (BVI) Noise Reduction in Low-Speed Descent Flight Conditions


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# Outline

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- Measured vs. Predicted Trim Quantities
- Acoustics at Maximum BVI Noise Flight Path Angle
- Conclusions

# Introduction

# Some Prior Work in Active Rotors

**Higher Harmonic Control** (HHC) of Blade Pitch Control:
- Change pitch control with actuators on **swashplate**.

Examples:
Harmonic Aeroacoustic Rotor Test (HART; HART II)

**Individual Blade Control** (IBC) of Blade Pitch Control:
- Change pitch control with actuators on **pitch link**.

Example:
Full-Scale UH-60 Wind Tunnel Test; Bo105 Helicopter

**Active Flaps** to Affect Blade Twist/Pitch:
- Change twist/pitch with torsional moments caused by deflection of **blade flaps**.

Examples:
SMART Rotor; EC145 Flight Test

**Active Twist** to Affect Blade Twist/Pitch:
- Change twist/pitch with torsional moments caused by piezoelectric actuators embedded in the **blade structure**.

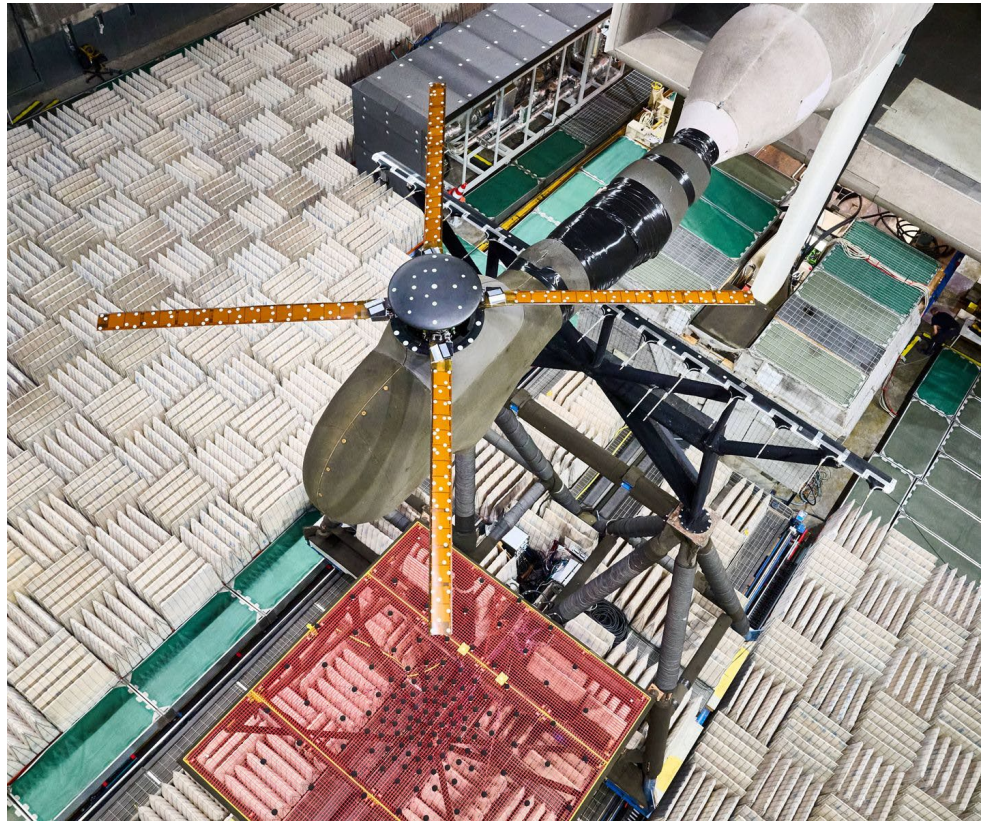
Examples:
NASA/Army/MIT Rotor;
University of Maryland Small Scale Test;
STAR Rotor

Focus of current work

# STAR Rotor and Flight Conditions

# STAR Rotor and Flight Conditions

| Characteristic | Value |
|---|---|
| Number of Blades | 4 |
| Rotor Radius | 2.0 [m] |
| Mean Chord | 0.121 [m] |
| Linear Twist Rate | -8.0° / radius |
| Airfoil | NACA 23012 with trailing edge tab |
| Nominal RPM | 1041 |
| Rotation | Clockwise |
| Hub | Coincident Flap & Lag hinge |



Flight conditions in the paper (all at advance ratio = 0.15):

- **Flight Path Angle (FPA) Sweep:** 6° (climb) to -12° (descent)
- **Baseline Case (FPA):** -7° (descent)
- **2p, 3p, 4p Active Twist Phase Sweeps**

# Analysis Tools

# Analysis Tools

Comprehensive Analyses and Acoustics:

| Comprehensive Analysis | Acoustics | Wake Model | Team |
|---|---|---|---|
| CAMRAD II | AARON | Single Trailer Free Wake | US |
| CAMRAD II | CIISound | Single Trailer Free Wake | KARI |
| CAMRAD II | CIISound | Single Trailer Free Wake | Konkuk University |
| S4 | APSIM | Adaptive Prescribed Wake | DLR-CA |
| HOST/MESIR/MENTHE/ARHIS | PARIS | Full Span Free Wake | ONERA |

CFD/CSD and Acoustics:

| Comprehensive Analysis | CFD | Acoustics | Team |
|---|---|---|---|
| HOST | FLOWer | APSIM | DLR-CFD |
| rFlow3D | | rNoise | JAXA-CFD |

# Maximum Blade-Vortex Interaction (BVI) Noise Flight Path Angle

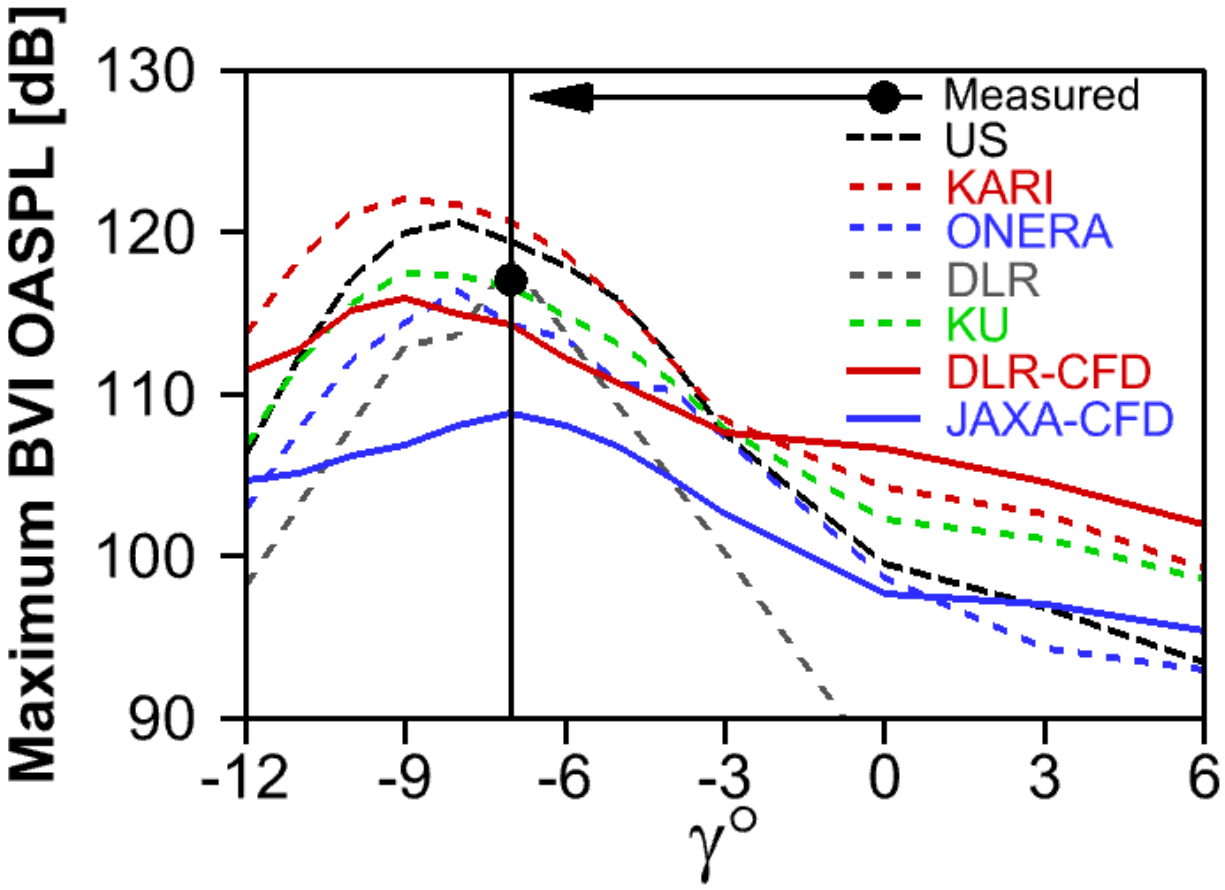
# Maximum BVI Noise Flight Path Angle

Measured data:
Max determined by combination of:

- Power-integrated SPL from phased array
- High-pass filtered LE blade pressures

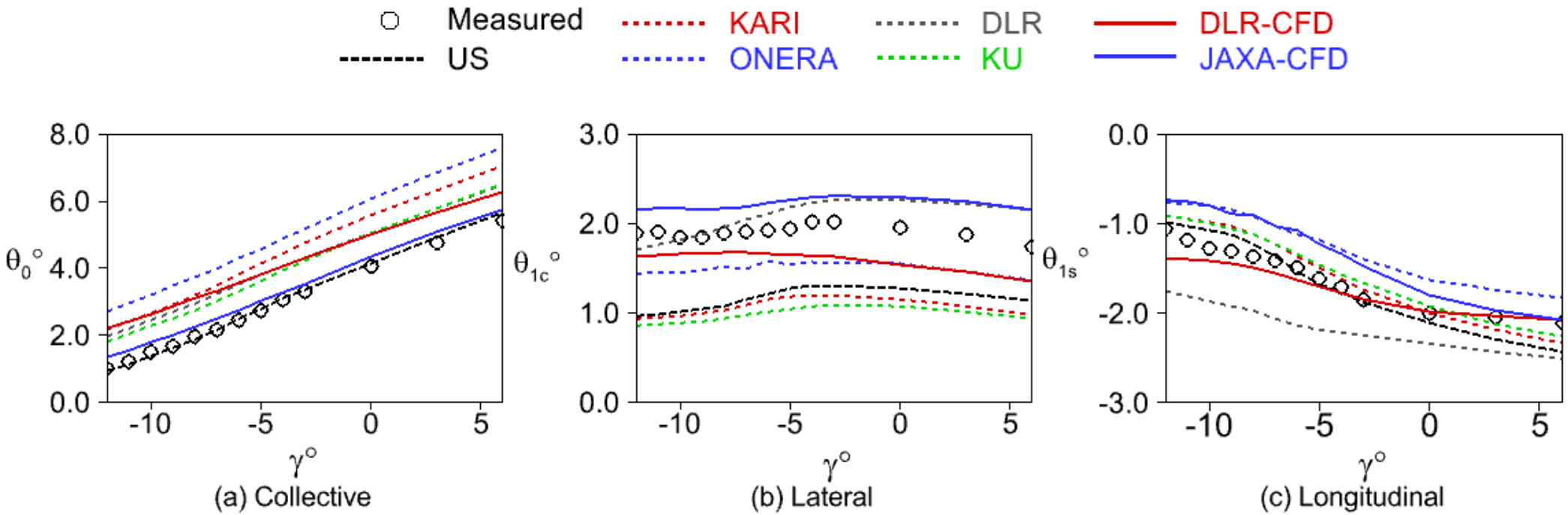
Predictions:

- Maximum BVI noise on plane under rotor
- Predictions all follow the same general trend
- Peak magnitudes vary widely
- Peak flight path angles between -7 and -9 deg



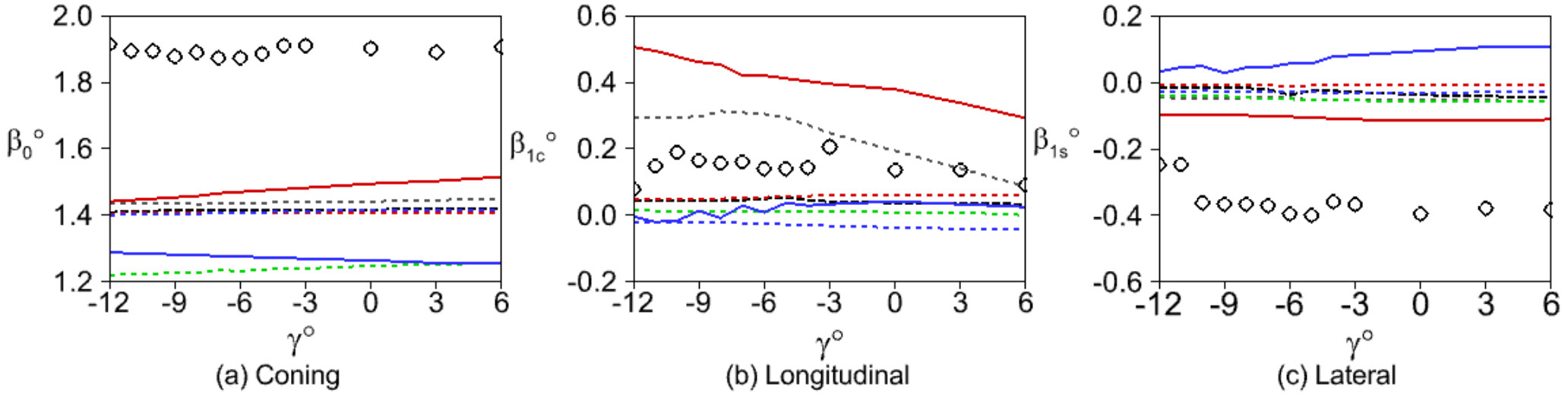
# Measured vs. Predicted Trim Quantities

# Measured (Blade 1) vs. Predicted Blade Pitch



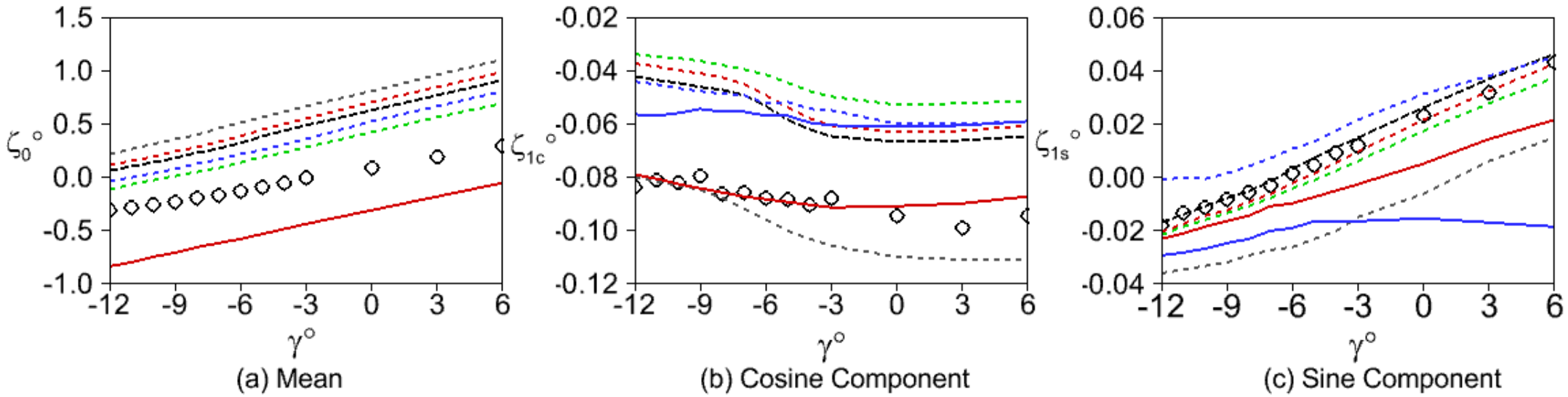

| Component | Comments |
|---|---|
| Collective | All but two partners predict that a higher collective is required than was measured. **Differences possibly due to steady twist differences and/or fuselage-rotor interference.** |
| Lateral | Most partners underpredict the lateral cyclic. **Differences possibly due to missing fuselage-rotor interference.** |
| Longitudinal | Most partners predict this component well. |

# Measured (Blade 1) vs. Predicted Flap Hinge Angle




| Component | Comments |
|---|---|
| Coning | All partners underpredict this by a constant. **Speculation is that this is a measurement bias**. |
| Longitudinal | Most partners predict this well (within a few 10ths of a degree). |
| Lateral | There is a small constant offset in the predictions of -0.35°. **Cause is currently unknown.** |

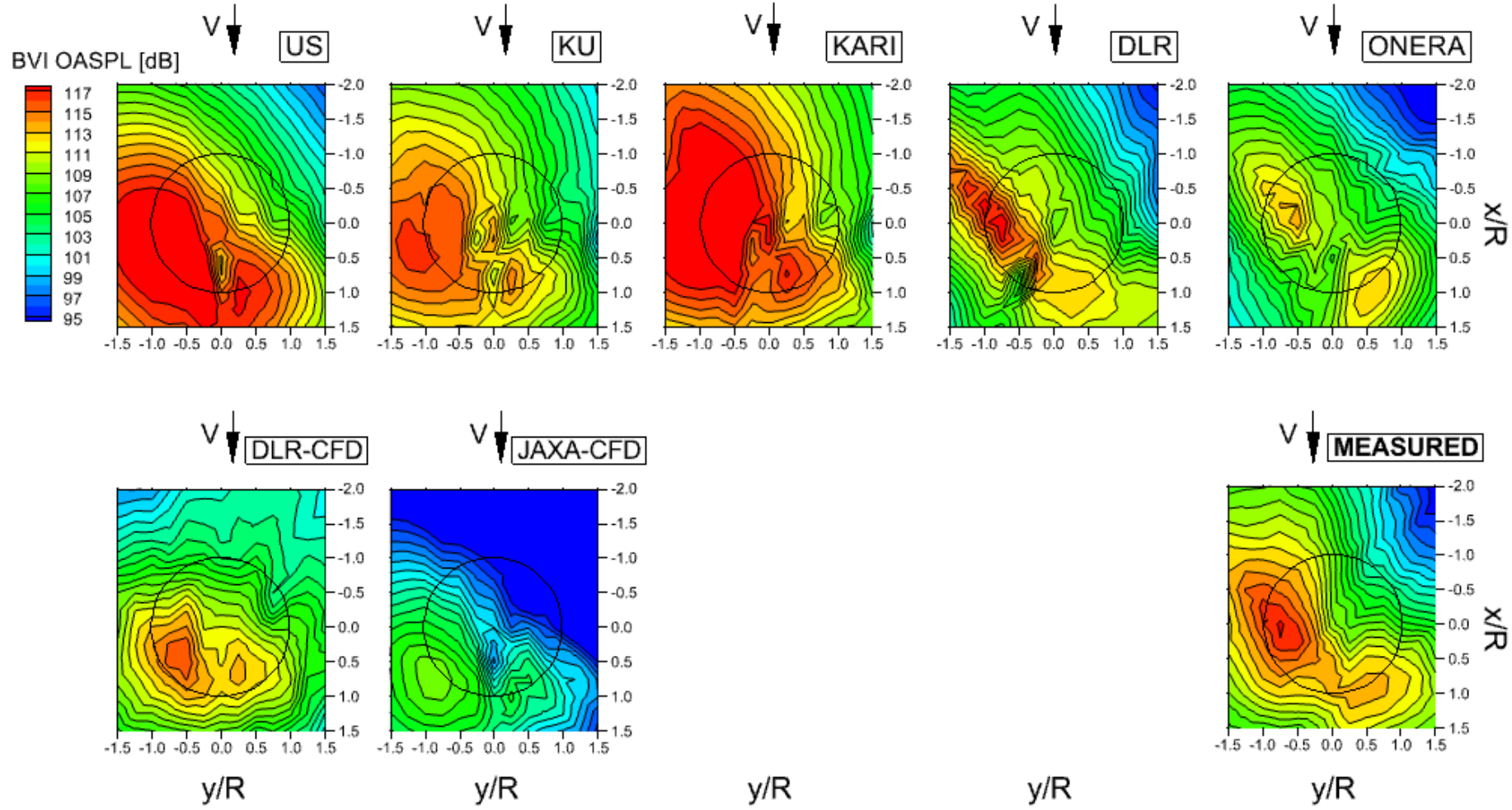
# Measured (Blade 1) vs. Predicted Lag Hinge Angle




| Component | Comments |
|---|---|
| Mean | All partners (except one) predict a mean lag at the lag hinge; whereas the measurement shows lead for descent and lag for climb. **Measurement post analysis identified a pre-lag (~0.6 degrees) that is not accounted for here.** |
| Cosine/Sine | These components are measured in hundredths of degrees; therefore, any differences are very small and not expected to be of any significance. |

# Acoustics at Maximum BVI Noise Flight Path Angle

# Acoustics on Plane Under The Rotor



# Conclusions and Future Work

This presentation focused on the flight path angle sweep and the baseline case. The paper includes examination of 2p, 3p, and 4p active twist phase sweeps.

- The measured maximum BVI OASPL [dB] measured flight condition was a 7-degree descent. Across all teams, the predicted condition ranged from a 7- to a 9-degree descent.

- Over the range of climb/descent angles, measured vs. predicted trim pitch control angles indicate possible missing aerodynamic influences in the predictions, such as the influence of a fuselage that is not normally included in the comprehensive analysis calculations.

- Offsets in the mean flap hinge angle between the measured vs. predicted data across the flight conditions suggest that there may be a bias in the measured flap hinge angle.

- Offsets in the mean lag angle between the measured vs. predicted data are speculated to be from the newly determined pre-lag from the elastomeric damper. This pre-lag value is not included in the current predictions but can be included in subsequent calculations.

- Differences in the acoustic results are known to be related to differences in aerodynamics and blade motion. Therefore, to improve aerodynamic and blade motion predictions, processed measured data will be needed to aid in calibrating and/or improving the comprehensive (and CFD) models.

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