Use of HART-II Measured Motion in CFD

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HART-II Workshop, April 28, 2008
Montréal, Canada

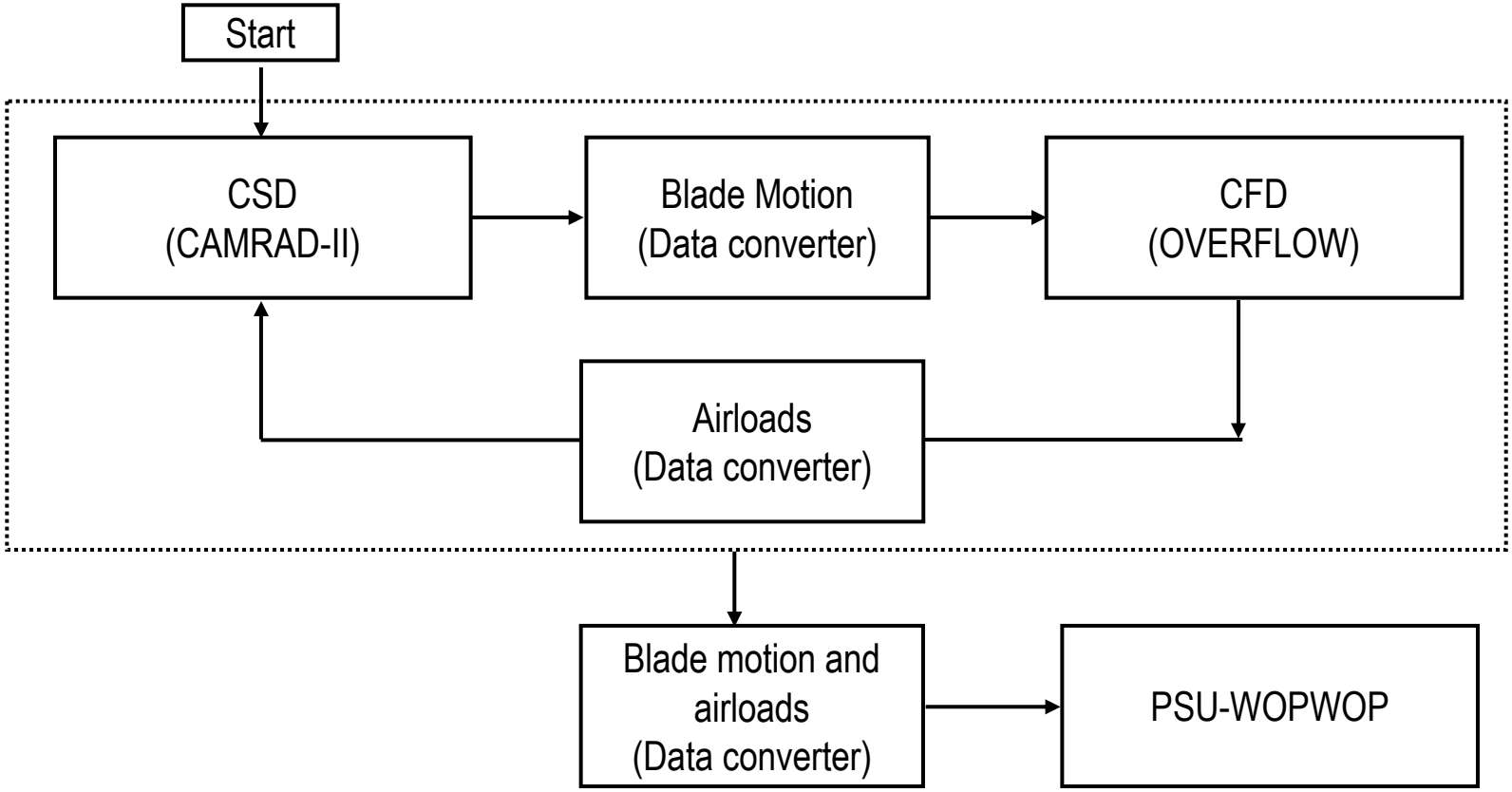
Outline

- Introduction
- Implementation of measured motion
- Predictions using measured motion
- Predictions using measured motion vs.
  Predictions using coupled motion (still in work)
- Summary

Introduction

- Historically, comprehensive analyses used for input to acoustic calcs…
- Historical analyses focused on: Lifting line aerodynamics + beam models
  - Beam models have evolved into finite beam models (or higher)
    - Ability to model more general blade configurations
  - Lifting line aerodynamics still used, predominantly.
    - Assumptions often violated
- Need to evolve lifting line aerodynamics to 1st principles.
  - CFD instead of lifting line
- Current analyses focused on: CFD + CSD coupling
  - Beam models still very good (CSD typically from comprehensive analysis)
  - Generally, CFD replaces aerodynamics in comprehensive analysis.
  - BUT, Need a way to examine both pieces individually...

(Loosely) Coupled CFD/CSD Methods



NOTE: It can be hard to decipher which piece is a problem, if one occurs.

- Reads OVERFLOW outputs
- Generates loading file
- Generates patch file
- Includes elastic motion

Dissection of Coupled Method

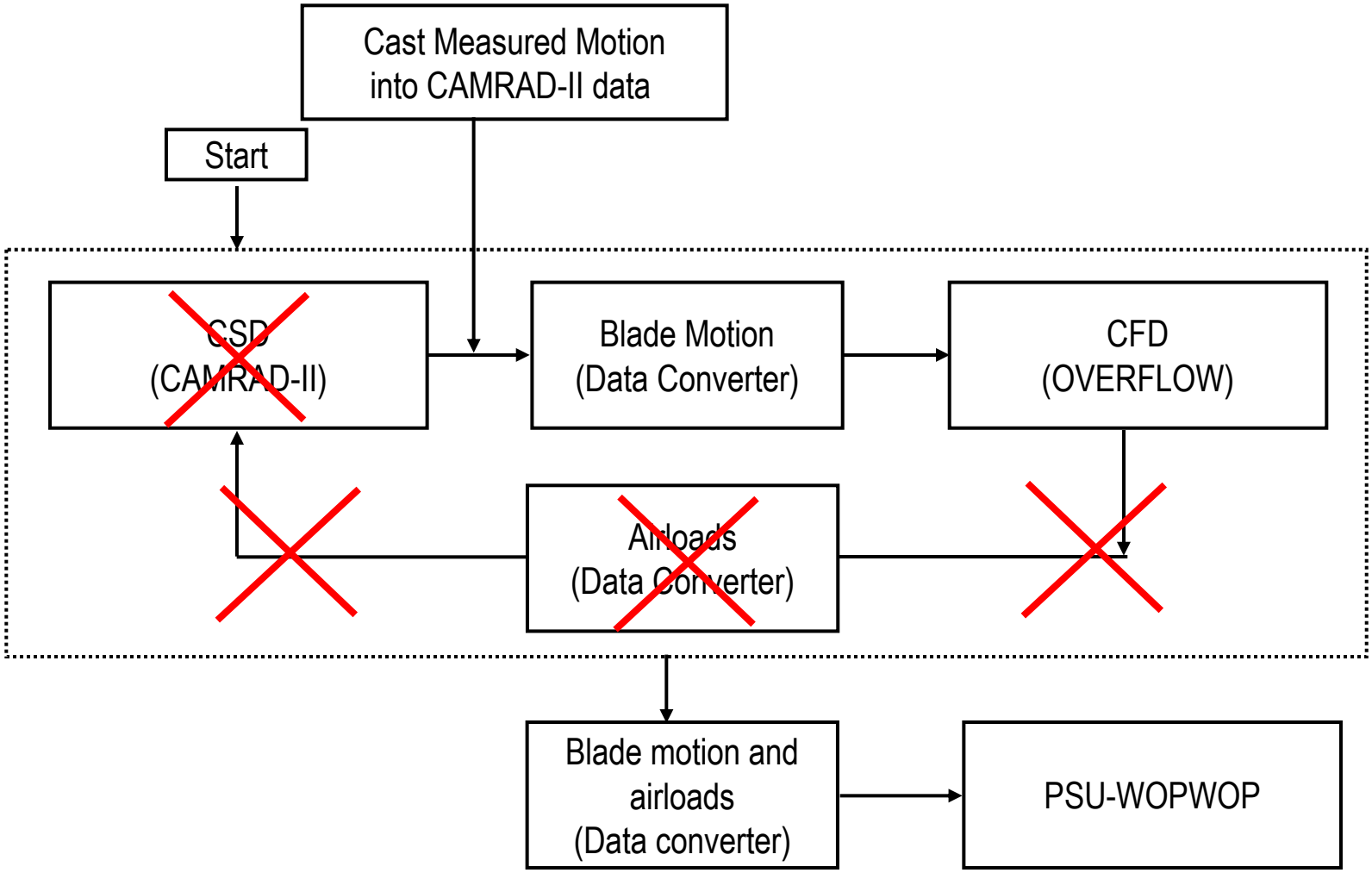
Goal: Try to examine each piece of method in isolation.

Why: If successful, this should help understanding of each component.

- Step 1: Isolate CFD method using measured blade motion.
  - Ideally, this should generate "correct" airloads, noise, etc.
  - Assumes all blades are periodic AND are identical in motion.

- Step 2: Isolate CSD with "correct" airloads from Step 1 above.
  - Ideally, this should generate "correct" blade motions.
  - (Not being done yet… still working on Step 1)…

Step 1: Isolate CFD method.



Measured Motion to CAMRAD-II data

- Need 3 displacements and 3 rotations at each location.
- Measured elastic data only contains 2 displacements and 1 rotation…
  - Must assume something for missing data.
- CFD grid already includes 2.5˚ pre-cone and built-in twist.
- Θ_0 , Θ_{1c} , Θ_{1s} , $\Theta_{3P\text{-}HHC}$ are measured quantities also.

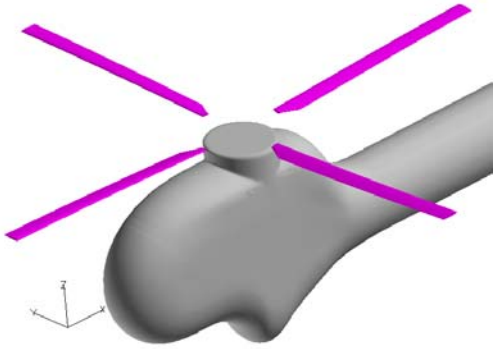
Measured Motion to CAMRAD-II data (cont)

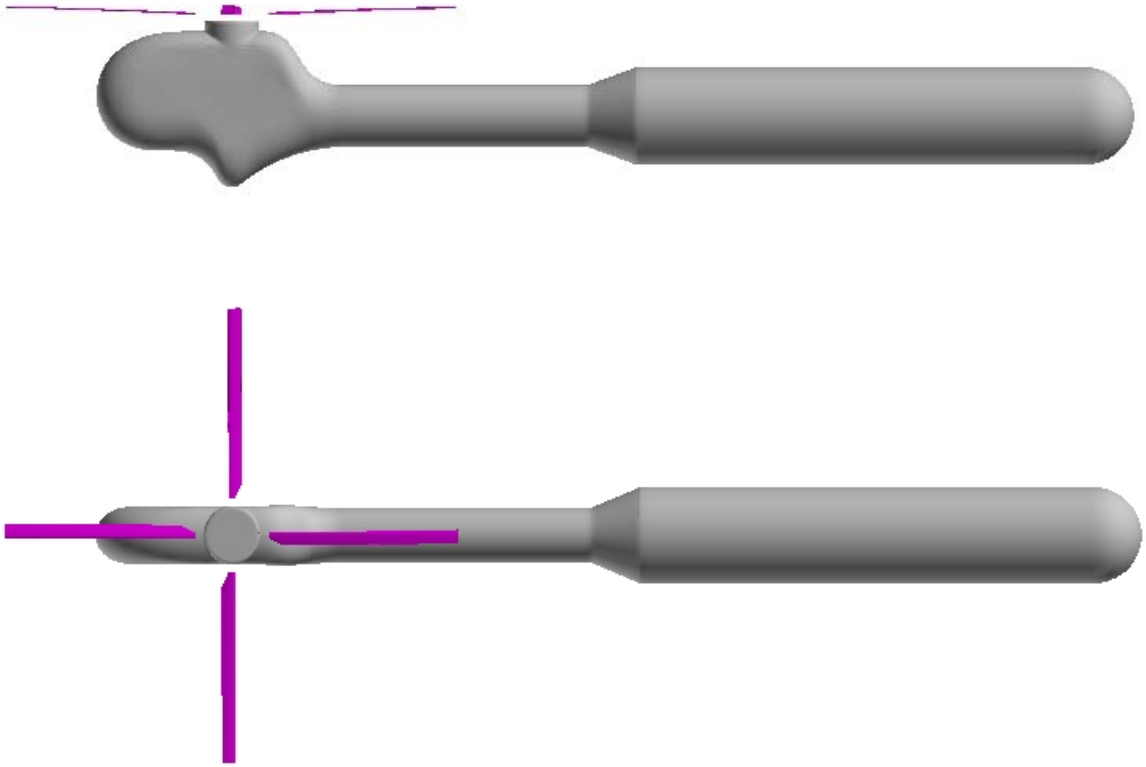
- Linear displacement of each location :
  - Flap = measured local elastic flap
  - Lag = measured local elastic lag
  - Extension = 0.0 **(ASSUMPTION)**

- Angular rotation of each location :
  - Flap = $\tan^{-1}$ (local flap deflection / r) **(ASSUMPTION)**
  - Lag = $\tan^{-1}$ (local lag deflection / r) **(ASSUMPTION)**
  - Pitch = $\Theta_0 + \Theta_{1c} + \Theta_{1s} + \Theta_{3P\text{-}HHC}$ + measured local elastic torsion

- These quantities are reconstructed using formulae and data in van der Wall document…
- All measured quantities are from Blade-1 data.
- This motion is then used as if it had come from CAMRAD-II…

Grid Configuration





- Blade: (3 grids each)
  - main: 273 x 113 x 33
  - tip: 158 x 48 x 33
  - root: 68 x 66 x 33
- Sting: (15 grids)
  - 630,861 points
- Background: (76 grids)
- Pringle grids: (3 per blade)

- Level 1 spacing = 0.10c
- First off body point… $y^+ < 1.0$
- Total grid points = 68,171,477

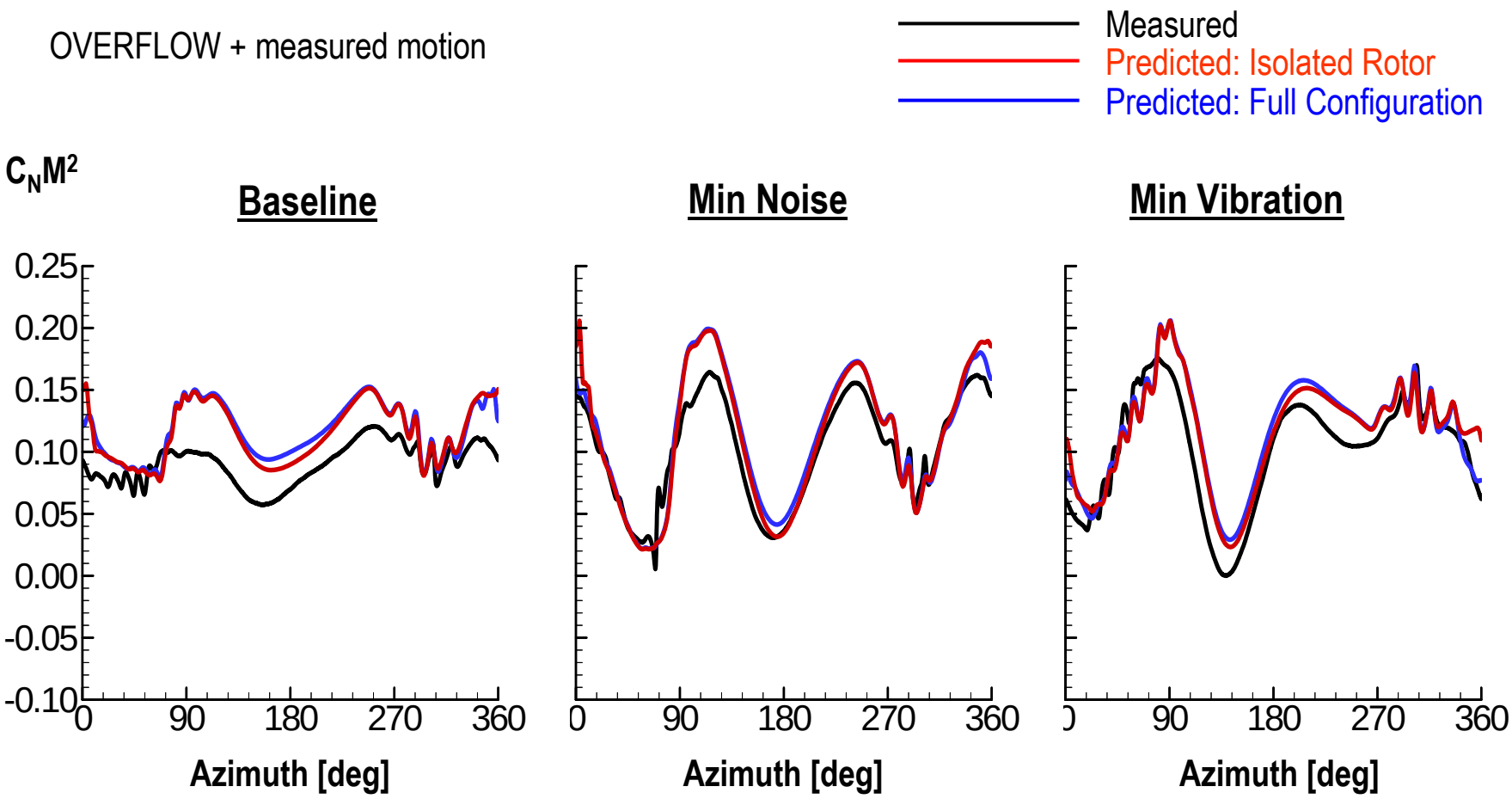
- Isolated rotor: identical to full configuration, but…
- Do not include sting grids…
- Level-1 specified "bricks" are same in both configurations.

Results with Measured Motion:

- Isolated Rotor
- Full Configuration

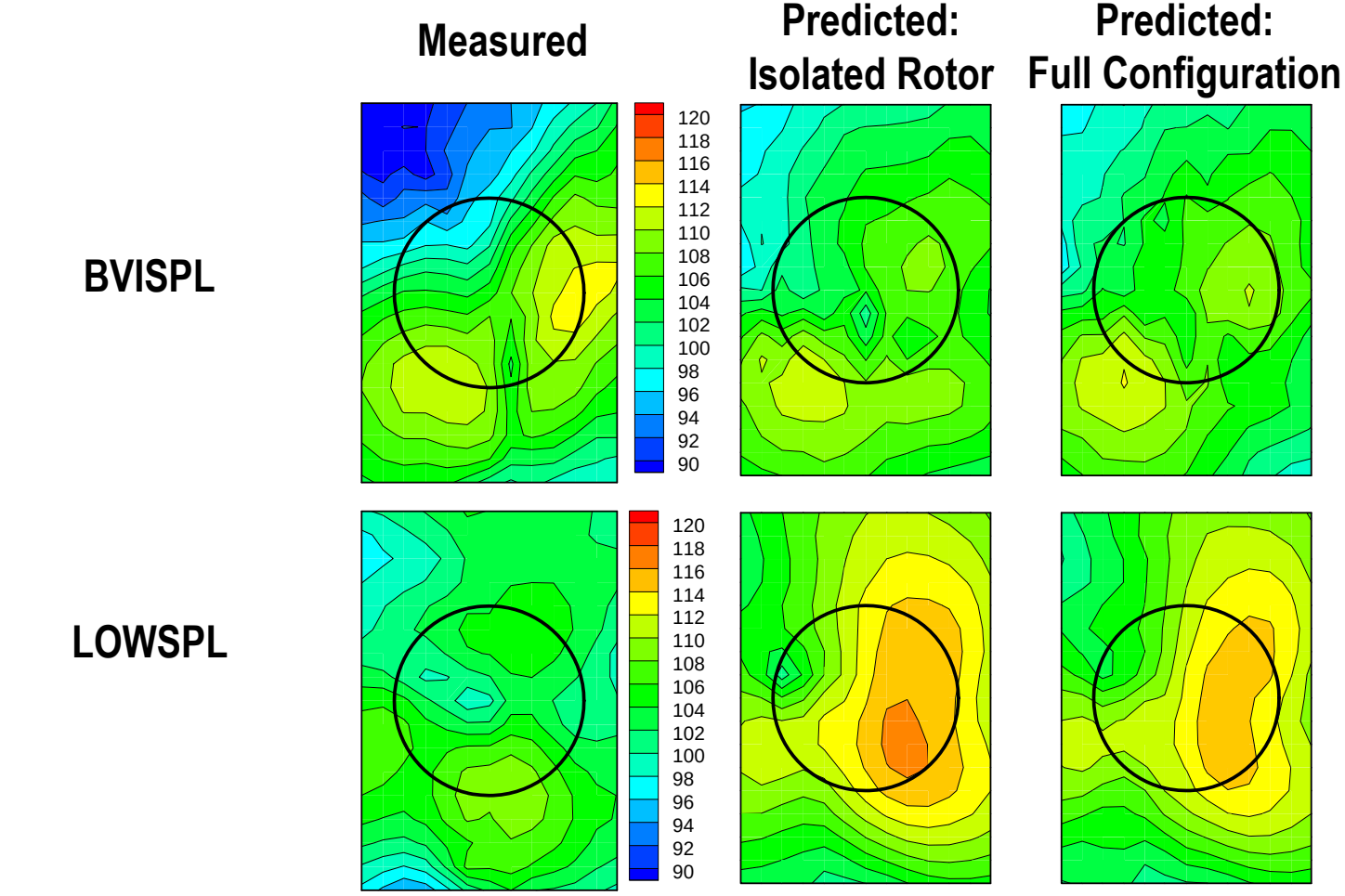
$C_N M^2$ Predicted with Measured Motion

OVERFLOW + measured motion



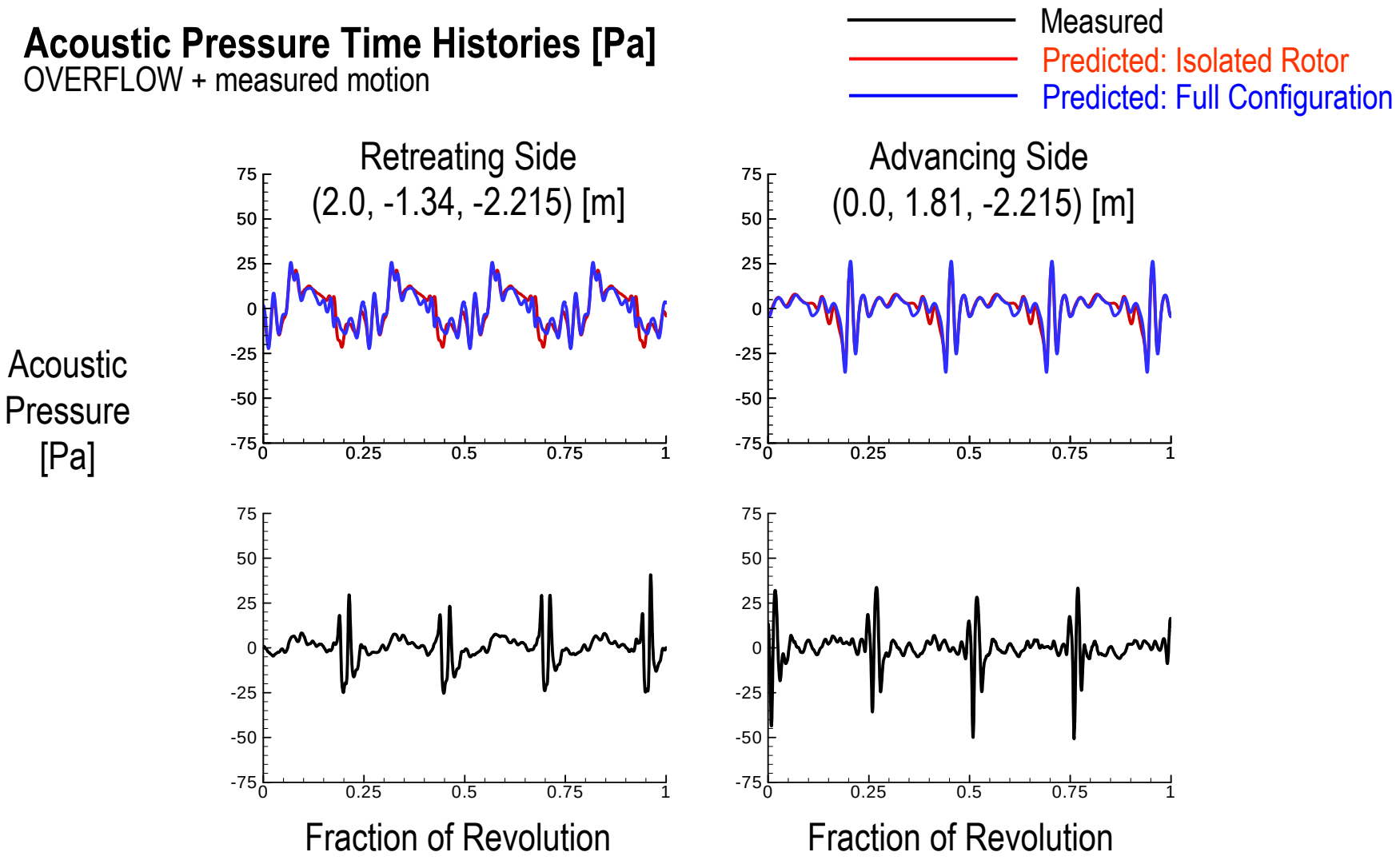
Baseline: Using Measured Motion

OVERFLOW + measured motion



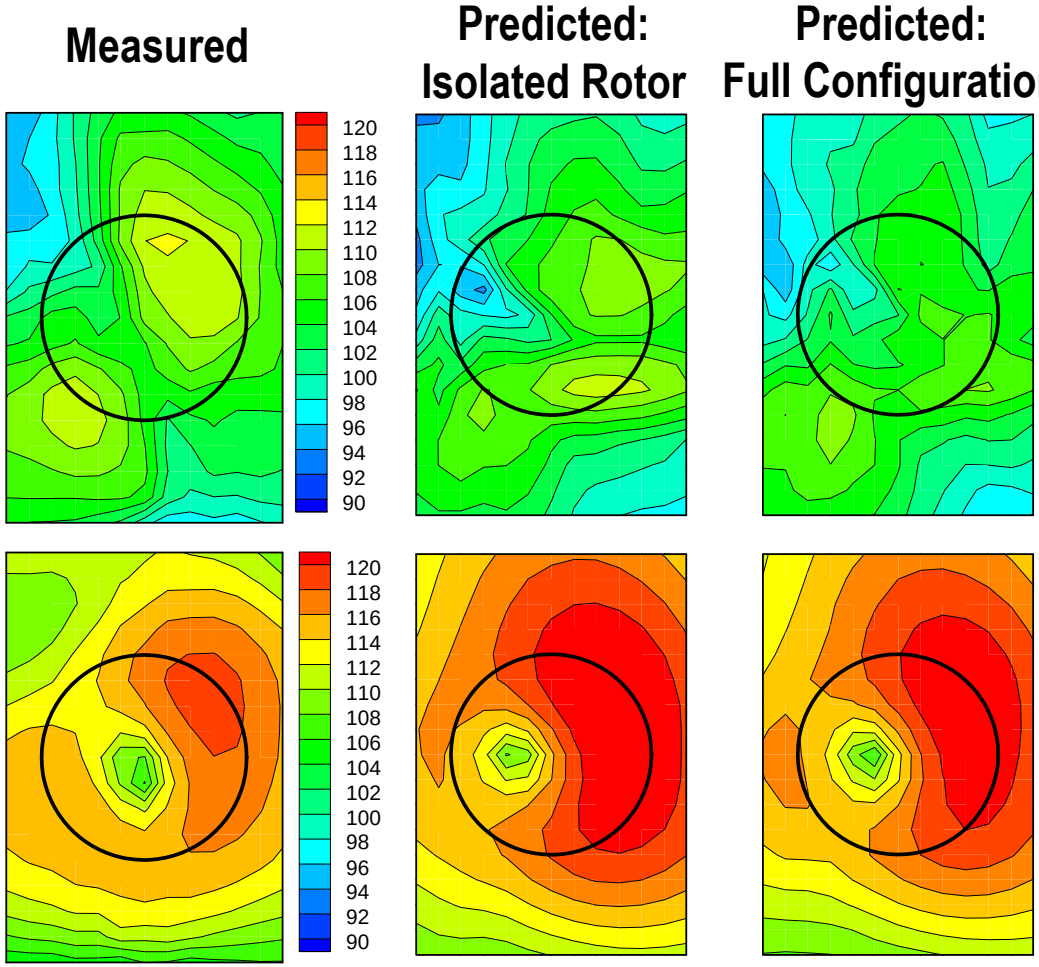
Baseline: Using Measured Motion

Acoustic Pressure Time Histories [Pa]
OVERFLOW + measured motion



Min Noise: Using Measured Motion

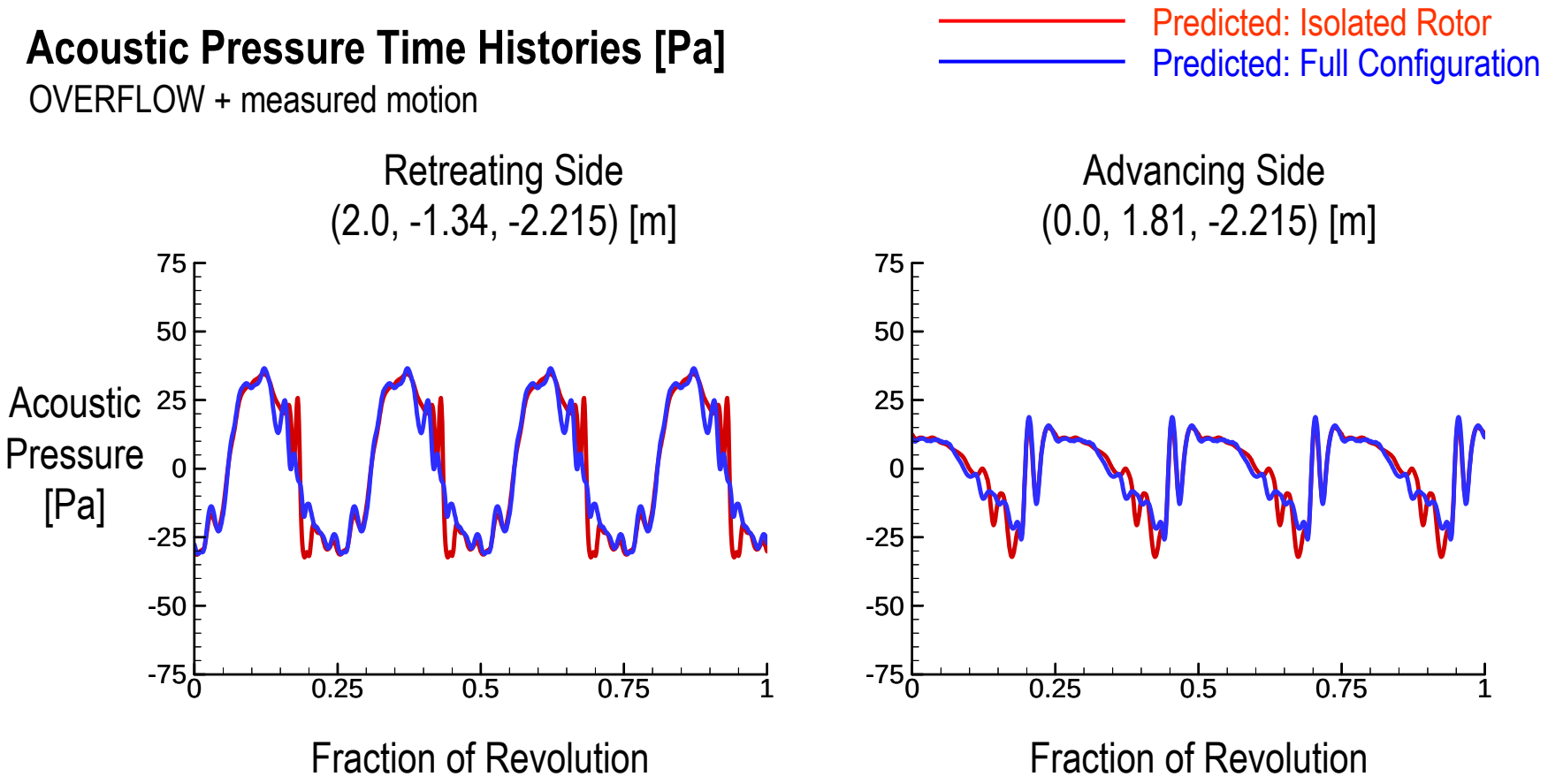
OVERFLOW + measured motion



Min Noise: Using Measured Motion

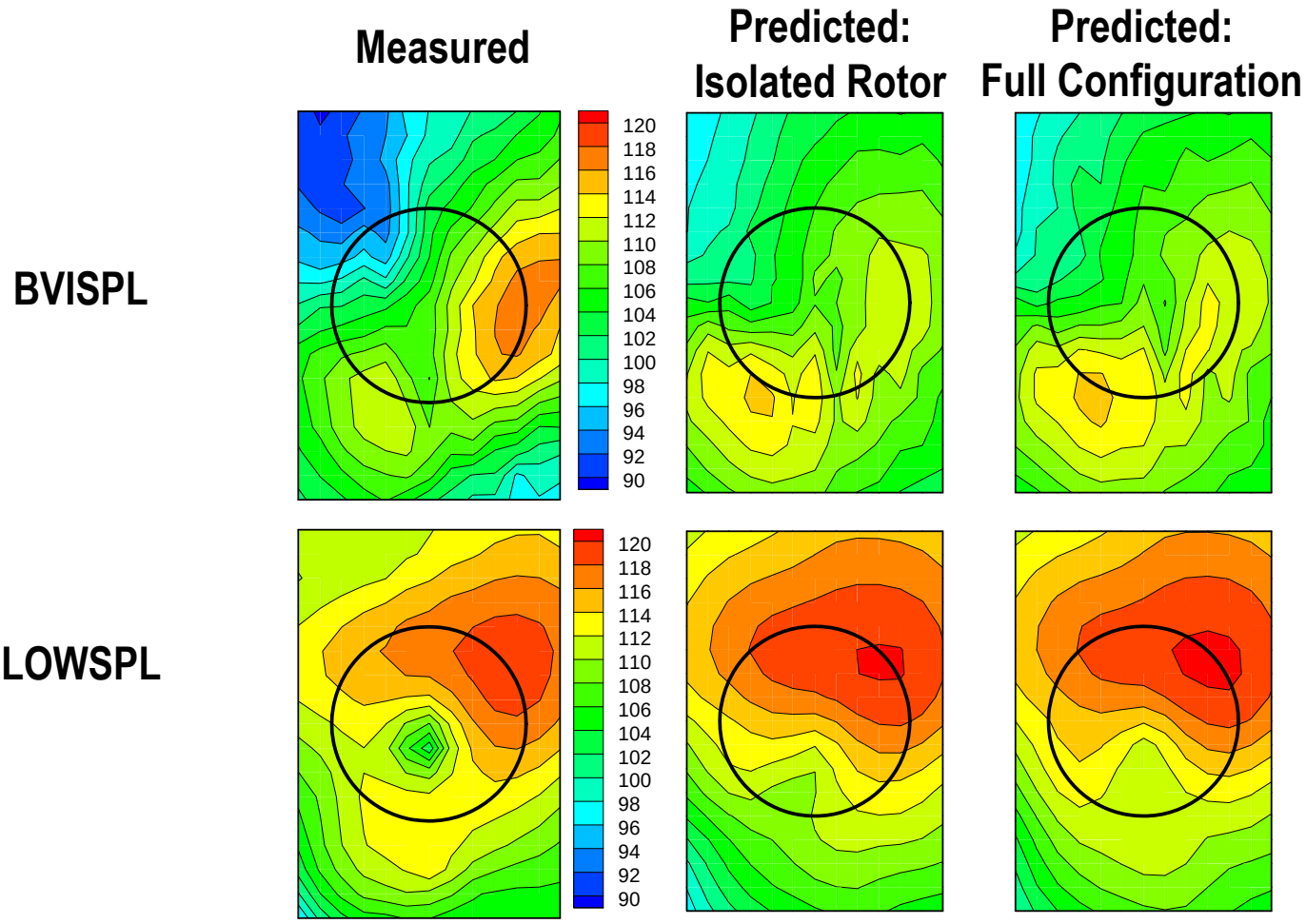
Acoustic Pressure Time Histories [Pa]

OVERFLOW + measured motion



Min Vib: Using Measured Motion

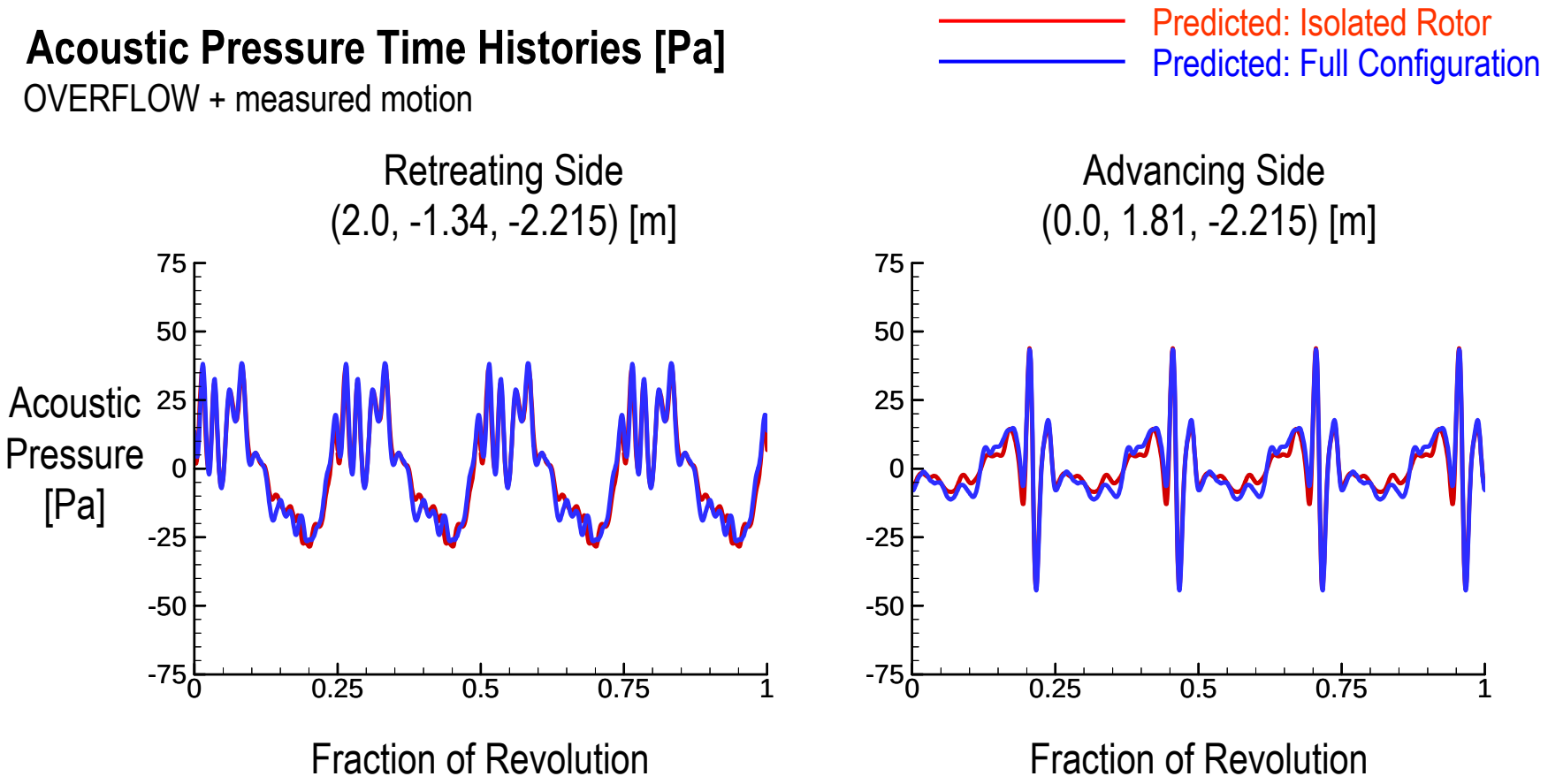
OVERFLOW + measured motion



Min Vib: Using Measured Motion

Acoustic Pressure Time Histories [Pa]

OVERFLOW + measured motion



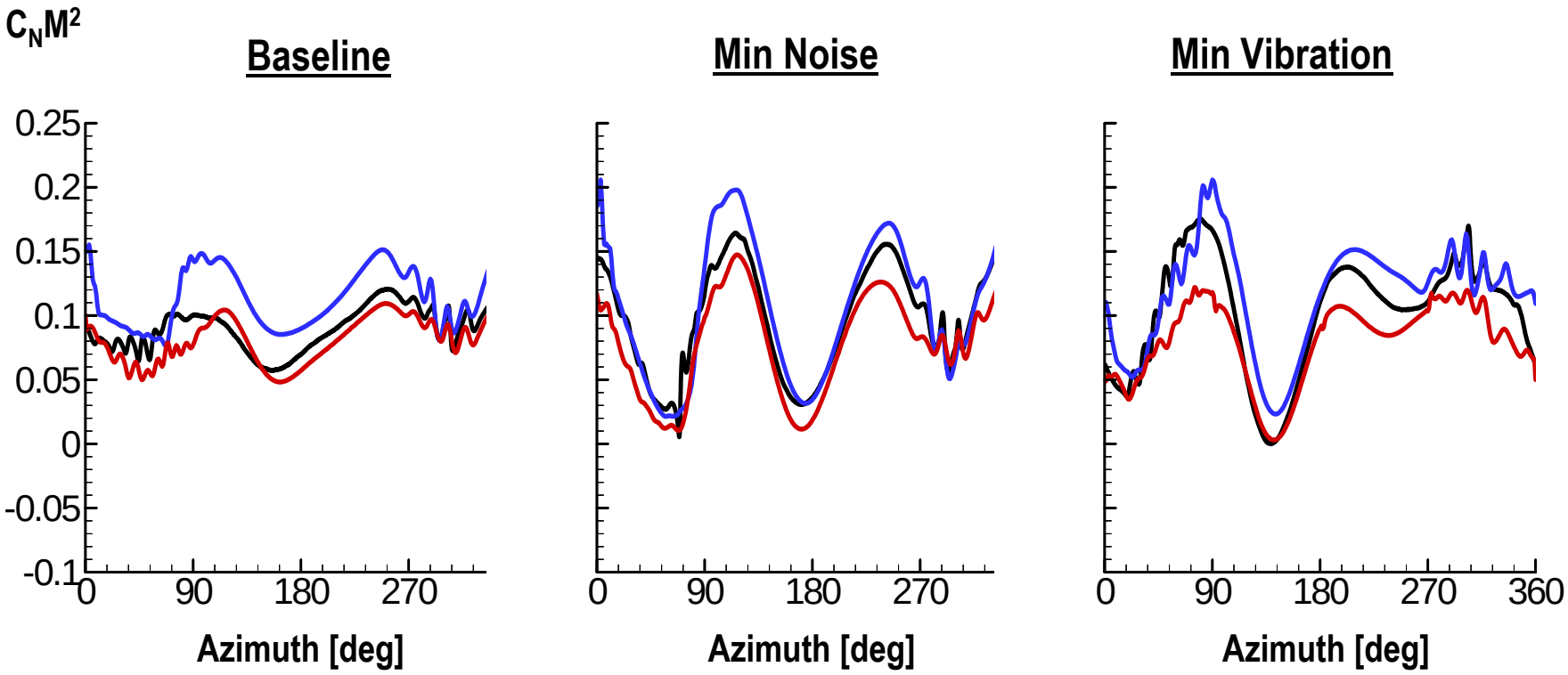
Full Configuration:

Measured Motion
vs.
Coupled Motion

$C_N M^2$: Measured Motion vs. Coupled

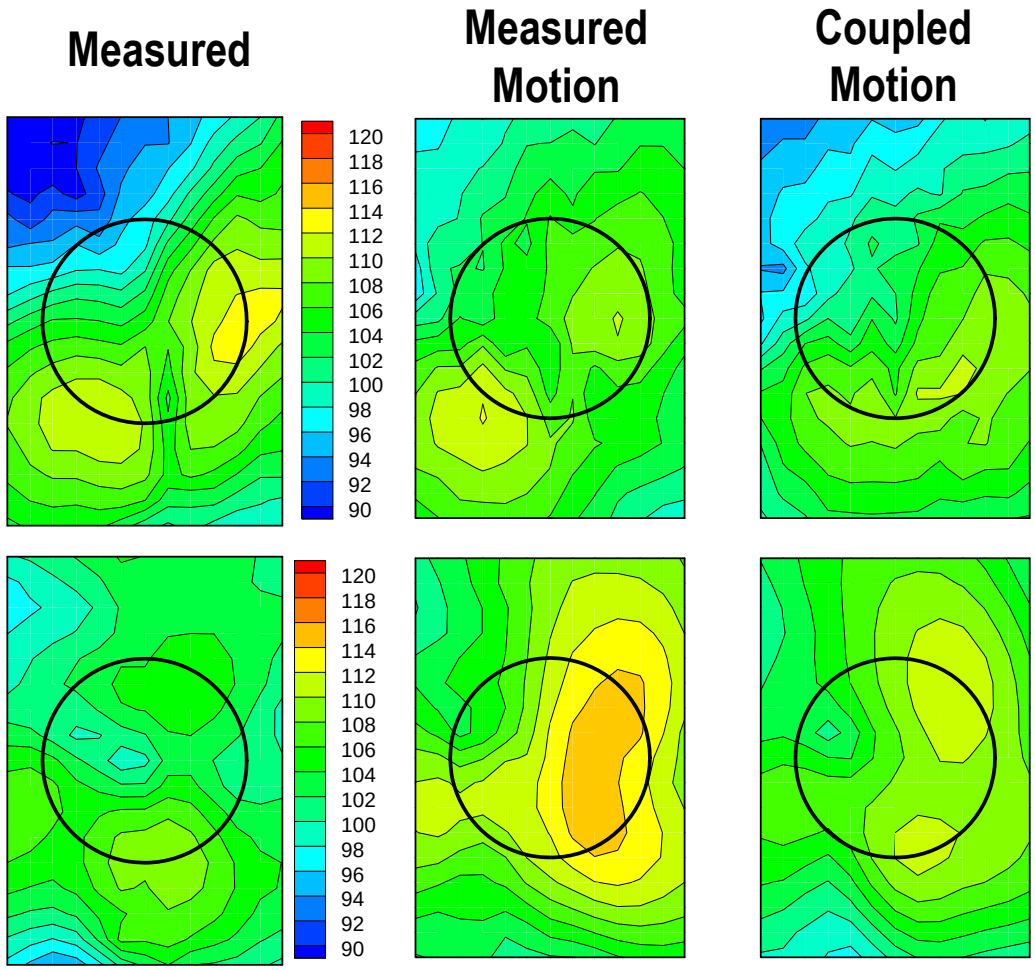
Full Configuration

Measured
Predicted: With Coupled Motion
Predicted: With Measured Motion



Baseline

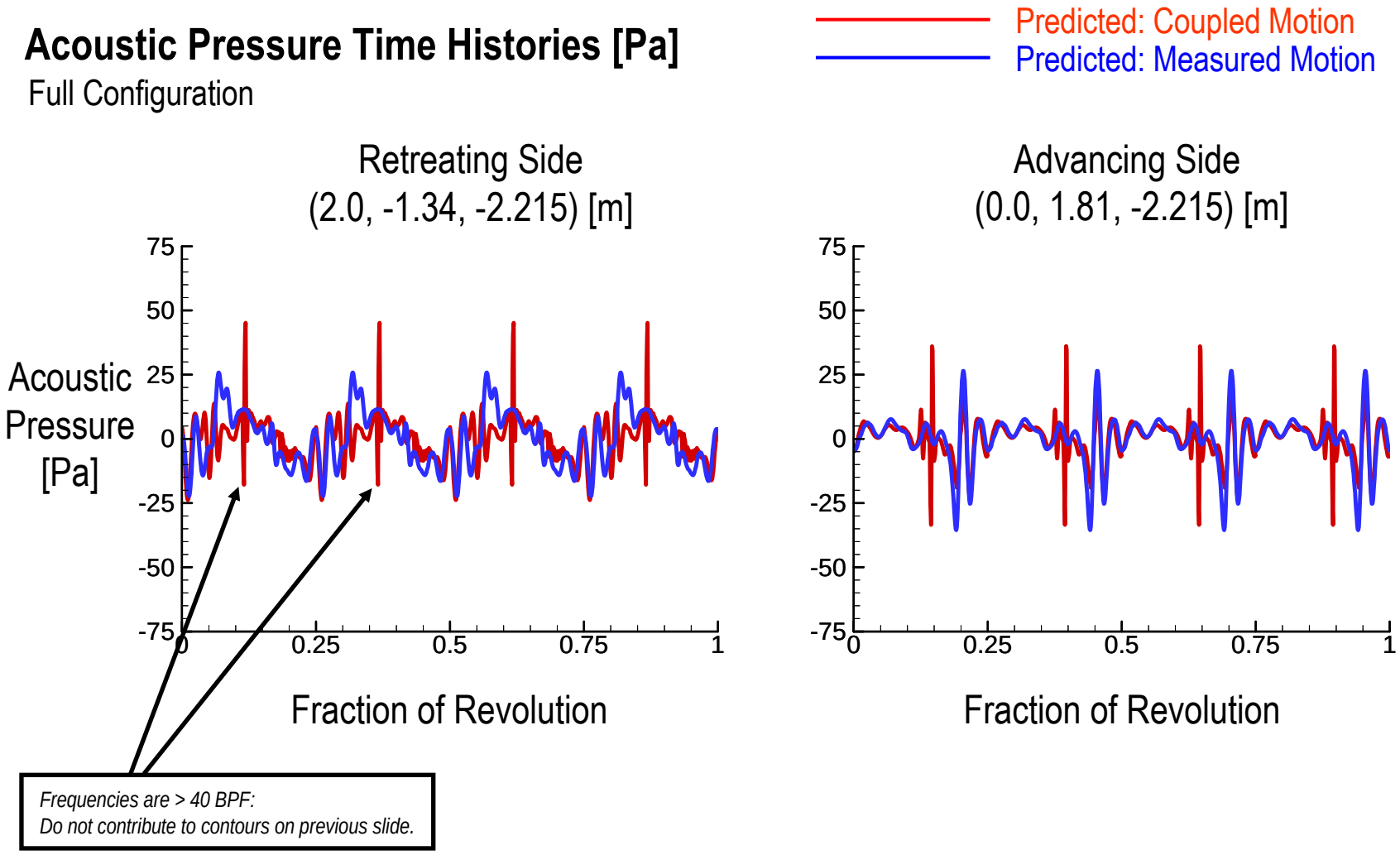
Full Configuration



Baseline: Meas. Motion vs Coupled Motion

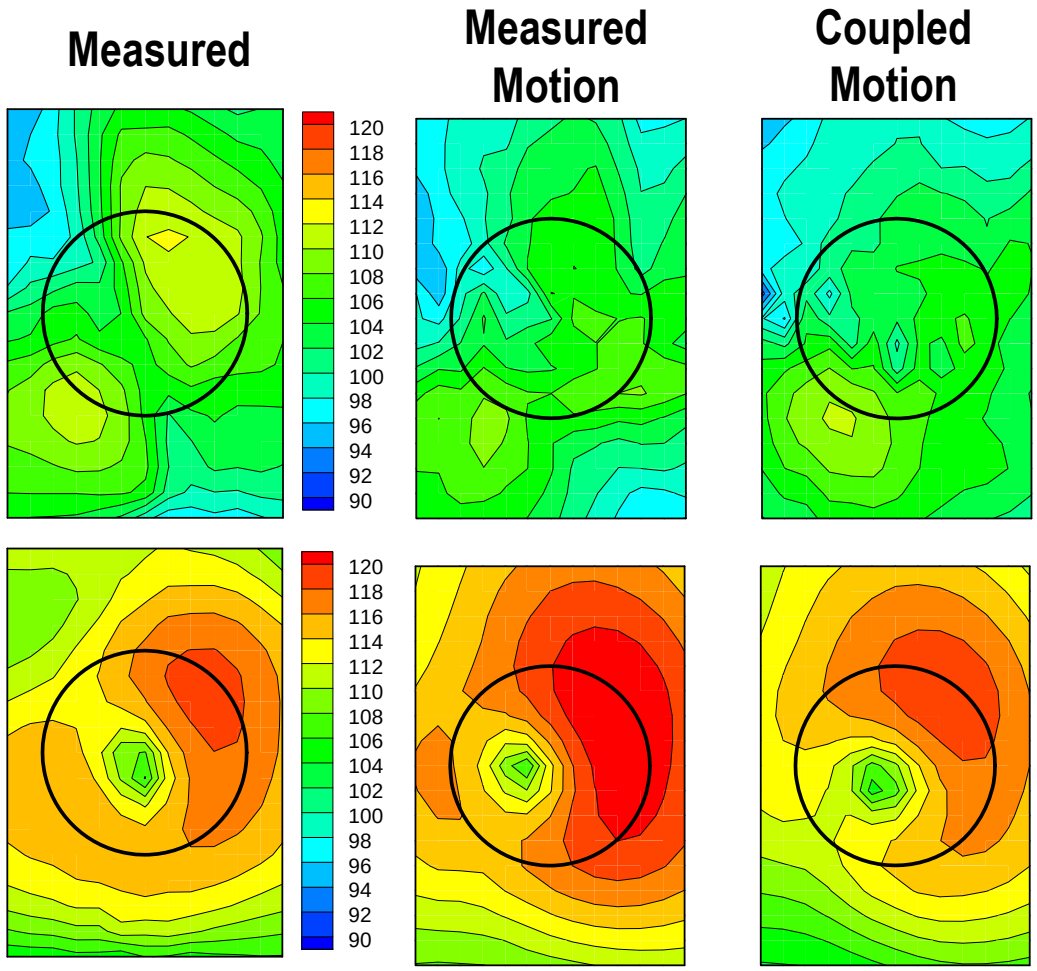
Acoustic Pressure Time Histories [Pa]

Full Configuration



Min-Noise Case

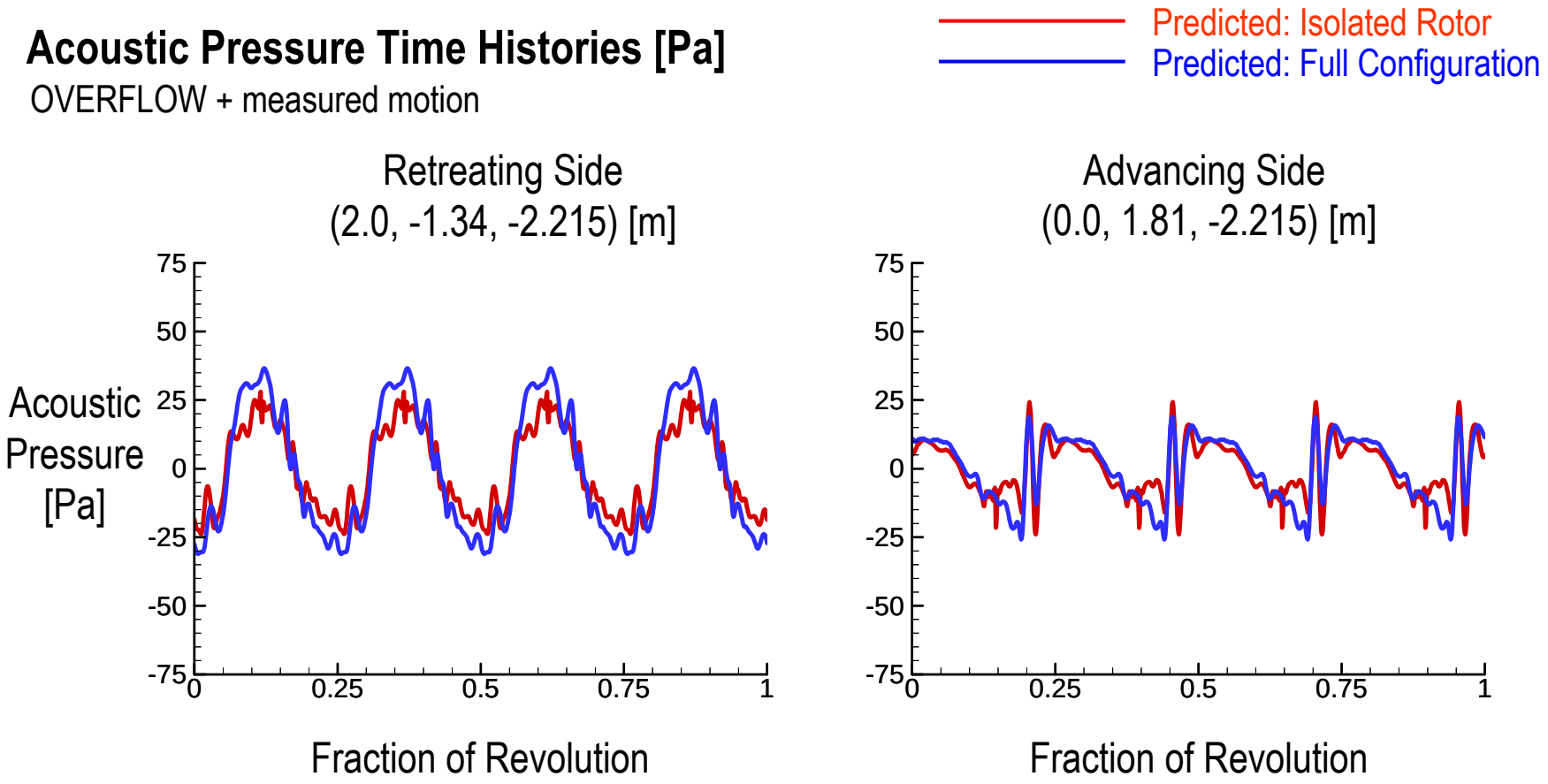
Full Configuration



Min Noise: Meas. Motion vs Coupled Motion

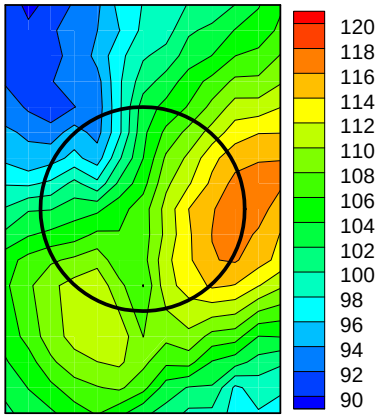
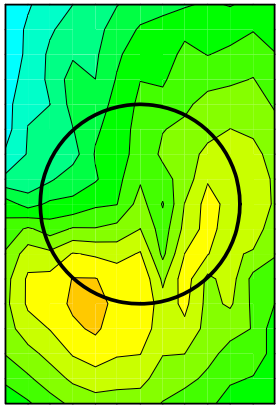
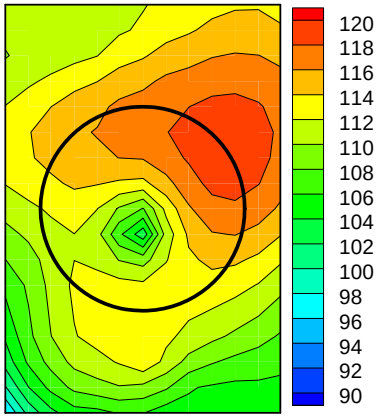
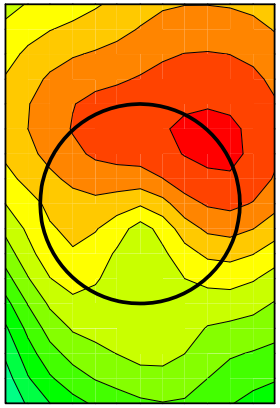
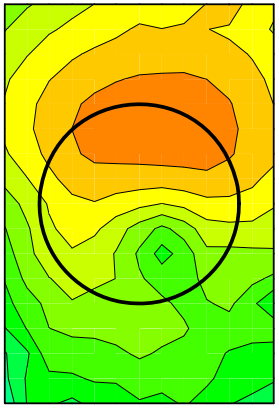
Acoustic Pressure Time Histories [Pa]

OVERFLOW + measured motion



Min-Vibration Case

Full Configuration

	Measured	Measured Motion	Coupled Motion
BVISPL			*Mid-Frequency not yet converged.*
LOWSPL			

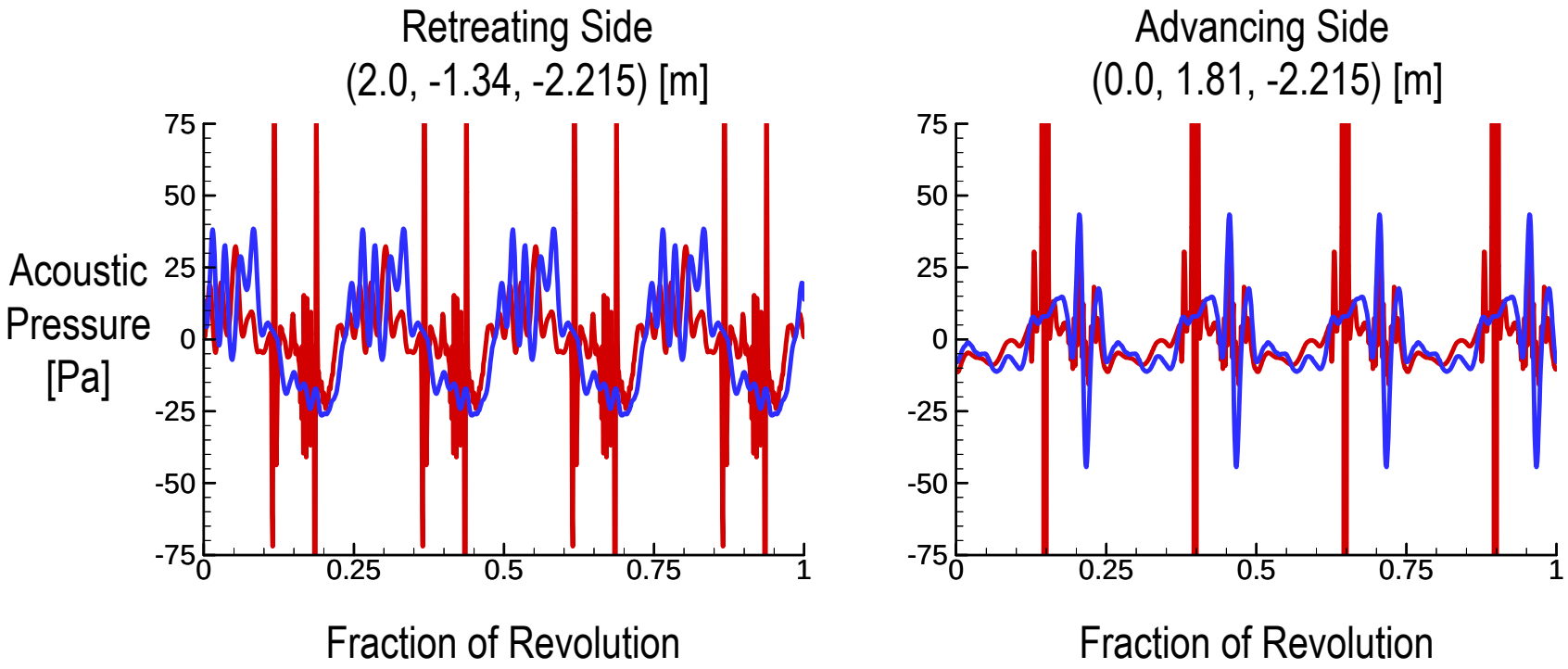
Min Vib: Meas. Motion vs Coupled Motion (Not converged yet)

Acoustic Pressure Time Histories [Pa]

OVERFLOW + measured motion

Predicted: Isolated Rotor

Predicted: Full Configuration



Low frequency components are "converged"… see CNM2 plots.
Mid & High frequency content are not yet converged.

Summary

- Work is still in progress.
- Using measured motion in CFD:
  - Temporary by-pass of CSD to (hopefully) aid understanding.
  - Why is thrust is so high with the measure data?
    - Blade 1 vs Blade 2, 3, 4 ?

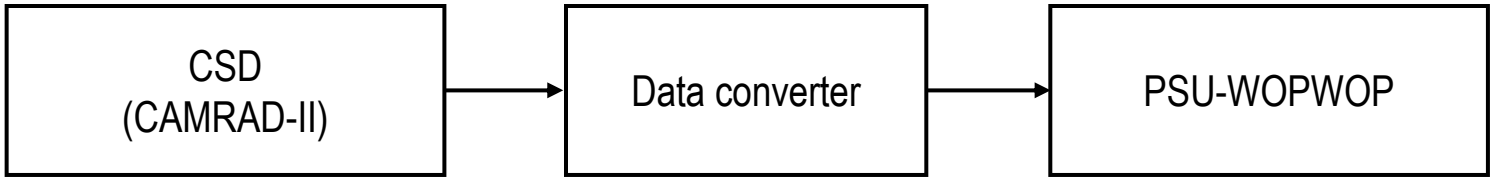
- MV coupled motion case not yet converged.
- Next will be “Step 2”: Put predicted airloads back into CSD code.
- Work is being documented into a NASA report.

<u>Wish list:</u>

1. Measured acoustic pressure time histories for MN and MV cases.
2. Surface pressures (at r/R=0.87)
3. Impedance properties of sting foam.

Backup slides

Historical Prediction Methods

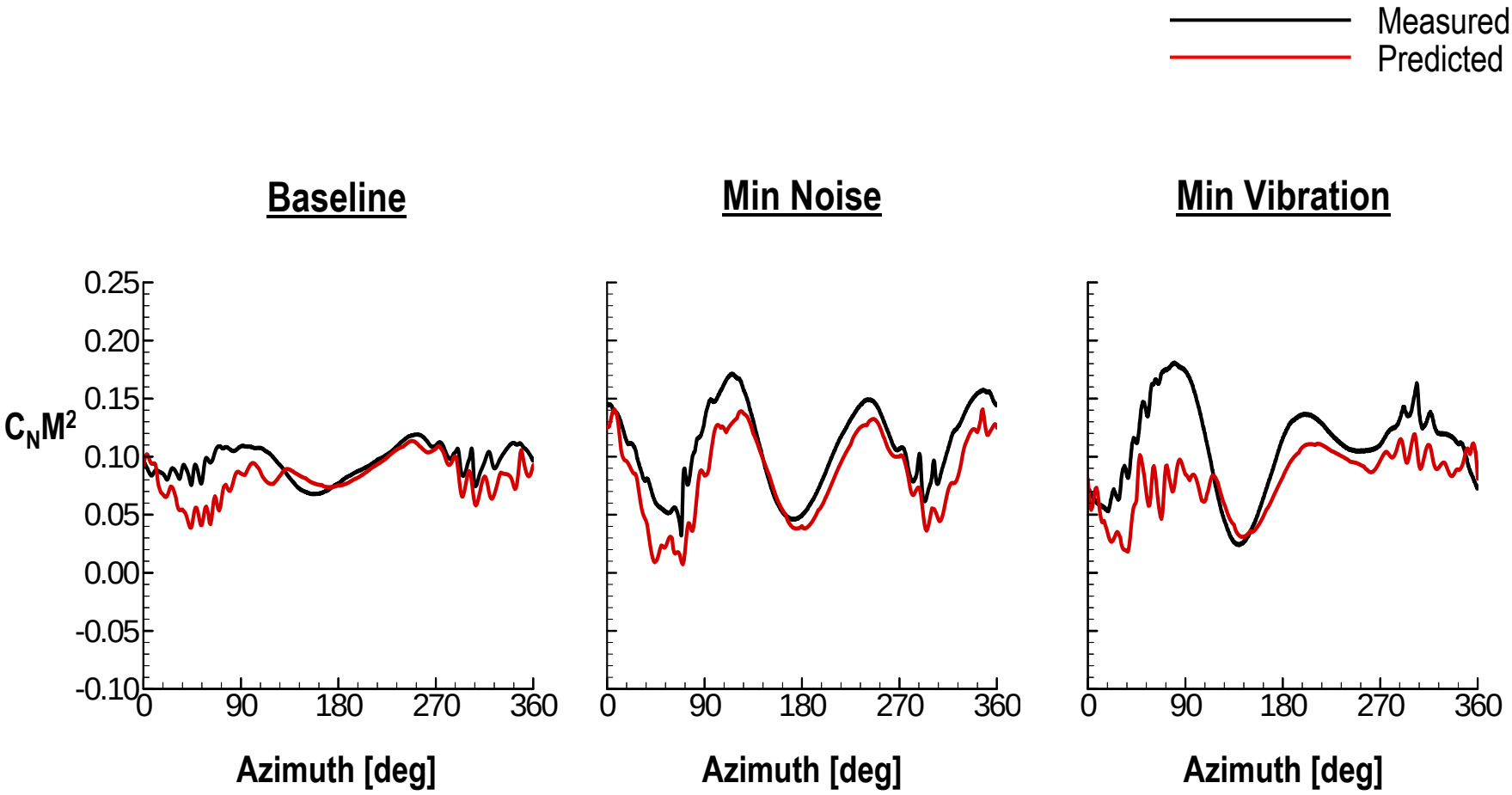


- Comprehensive Analysis
- Trim to Thrust and Hub Moments
- Lifting Line aerodynamics
- Blade dynamics

- Reads CAMRAD-II output
- Generates loading/function file
- Generates patch file
- Generates namelist input file
- Assumes rigid blade motion

- Tone noise prediction
- Time domain calculation
- Outputs acoustic pressure
- Also, outputs SPL information

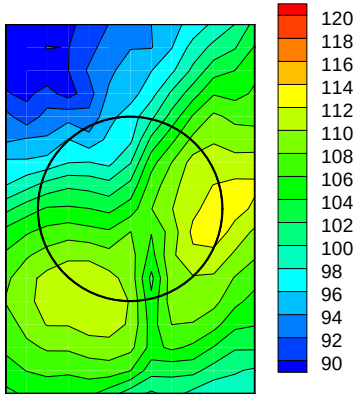
Historical Methods Example: $C_N M^2$



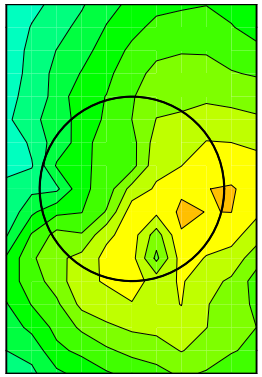
Previous Methods: BVI Directivity

Baseline

Measured

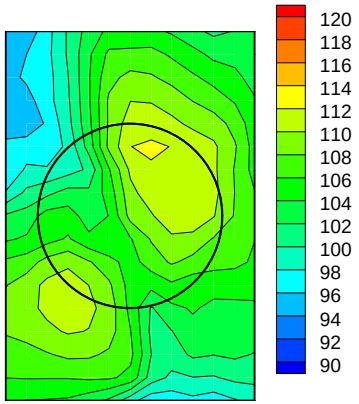


Predicted

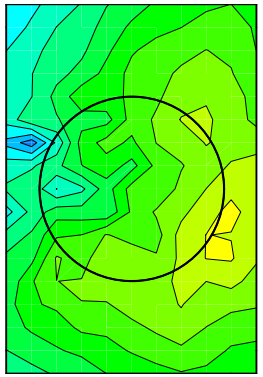


Min Noise

Measured

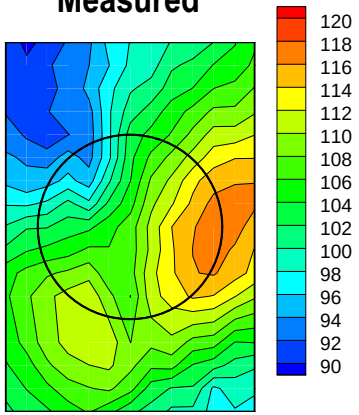


Predicted

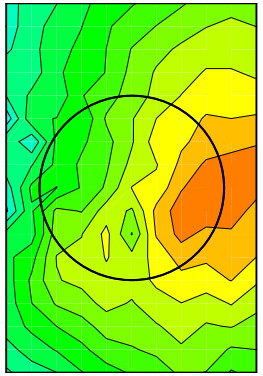


Min Vibration

Measured



Predicted



Issues with Previous Methods

- Fast…
- Loading usually assumed to be compact chordwise.
- Blade motion in acoustics often assumed to be rigid.
  - NOTE: Limitation of data transfer method, NOT of CAMRAD-II or PSU-WOPWOP.
- Isolated rotor… hard to include a fuselage.
- Typically, must "tune" parameters to get good comparisons.

Next… Start looking at couple CFD/CSD method

Work timeline…

Presentation shows results from the following timeframe:

- Winter 2007:
  - Obtained codes: OVERFLOW-DARPA-Y, PSU-WOPWOP v3.3.0, grids, converters
- Spring 2007:
  - Re-grided HART-II blades, grided HART-II sting, coupled cases w/ CAMRAD-II
  - Data Converters re-written for more generality
  - Questioned why there are differences
- Summer/Fall 2007:
  - Cast measured motion into CAMRAD-II variables
  - Began examining possible use of FSC for scattering.
- Winter/Spring 2008:
  - BL, MN, MV cases with “measured” motion.
  - Each with and without the sting in the CFD calculations.
  - Acoustics for all cases.
  - Began porting elastics and co-processing to OVERFLOW 2.1o

Other CFD notes…

- Spalart-Allmaras
- 2nd order dual time stepping w/ Newton subiterations (15 / step)
  - 0.125 degree physical time steps
- 4th order spatial differencing of inviscid terms
- Iterate OVERFLOW until $C_N M^2$ converged.
  - Measured motion cases converged within ~3-4 revs.

Isolated CFD Results: Thrust

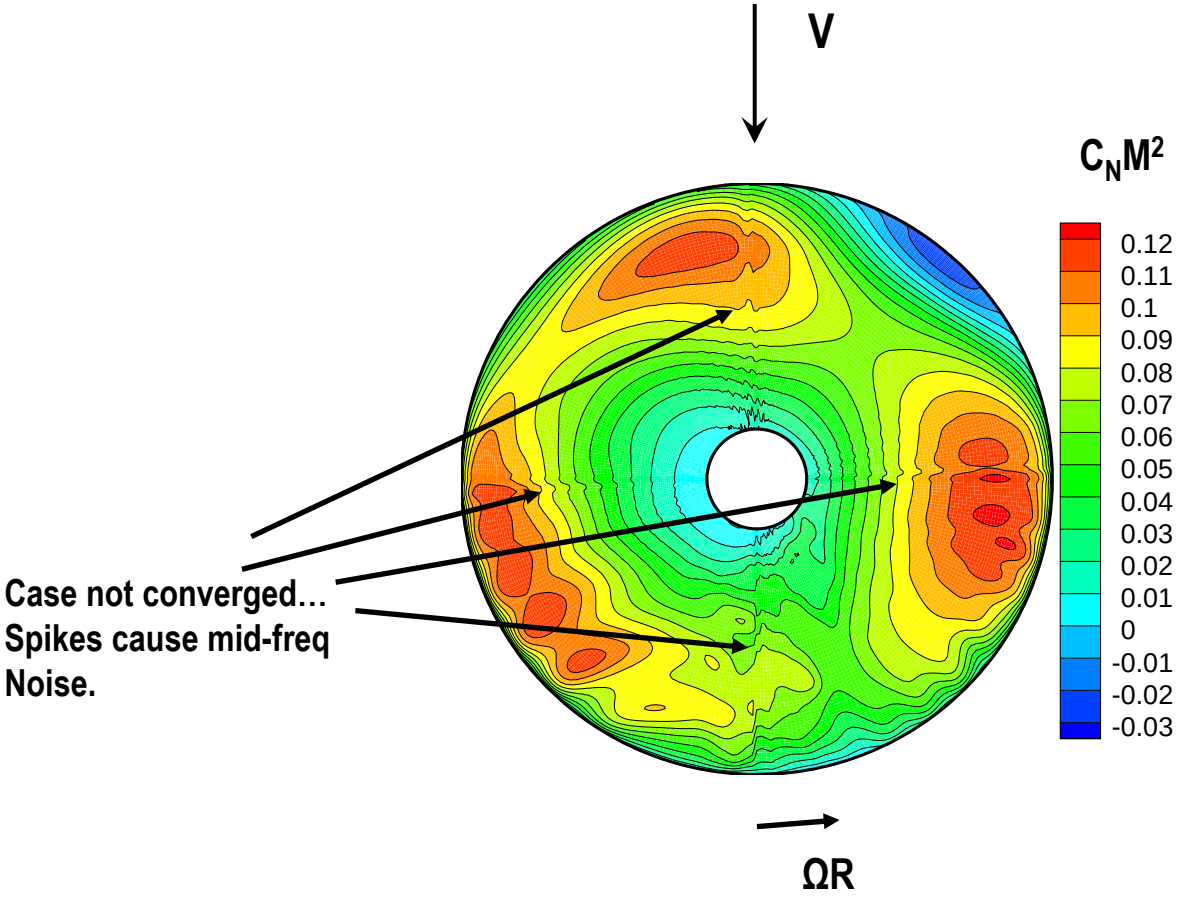
OVERFLOW + measured motion

Thrust (Nominal = 3300 N)

Case	Isolated Rotor [N]	Error	Full Configuration [N]	Error
BL	4295	+30%	4318	+31%
MN	4320	+28%	4242	+29%
MV	4339	+31%	4362	+32%

- In all cases, thrust is consistently ~30% over-predicted.
- The reason for this is not yet known.

Min-Vibration Case: Not converged yet.



Baseline: Using Measured Motion

Acoustic Pressure Time Histories [Pa]

OVERFLOW + measured motion