ASCENT Project 076

Improved Open Rotor Noise Prediction Capabilities

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Cost Share Partner: GE Aviation

Objective:

- There is a major challenge in meeting noise targets while simultaneously meeting other design constraints.
- The open rotor concept has promising fuel benefits, but there is a need to quantify the impact of design parameters on open rotor noise.
- A study of design parameter sensitivity to CROR system noise responses will be conducted in order to identify impactful design parameters.

Project Benefits:

The study of CROR design parameter sensitivity will identify trends that can aid further research and provide insight to design tradeoffs

Research Approach:

This study is comprised of the following:

- Identification of Open Rotor noise-sensitive design parameters
- Parametric geometry model development
- Simulation campaign for acoustics validation
- Parametric sensitivity study (not yet funded)

Major Accomplishments (to date):

- Identification of open rotor design variables – from previous studies – classified in groups: rotor, pylon installation and airframe integration (Year 1)
- Development of a parametric CROR geometry (Year 1)
- Simulation validation campaign (Year 2)

Future Work / Schedule:

- Parametric study (if funded)

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Validation Plan

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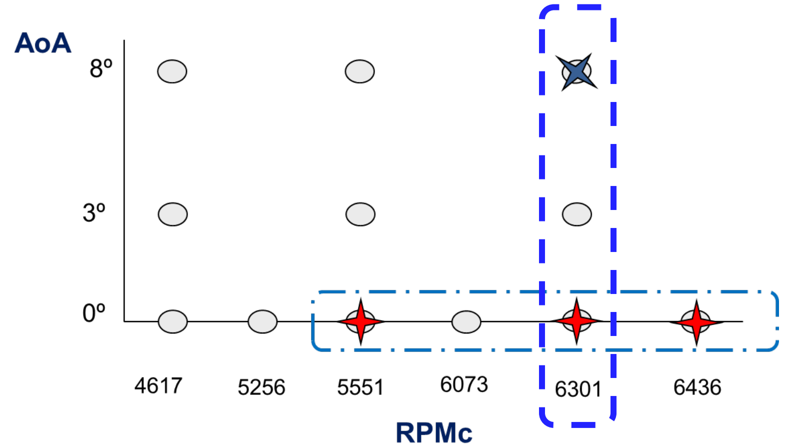
- ❑ Validation cases are taken from NASA/GE experiments on F31A31 CROR (*)
  - Focus on no pylon configuration with NTO pitch settings
- ❑ Validation data from two sources
  - GE Aerospace data on (proprietary) F31/A31
  - NASA data on F31/A31
- ❑ Focus on the upper-half of the RPM range
  - RPM : 5551 – 6436 (corrected speed)
- ❑ And variation with Angle of attack (AoA)
  - Defined at 2nd highest rotor speed, 6301 RPMc

Nominal take-Off (NTO) with no pylon configuration
NASA Experimental Campaign (*)



[*] Sree, D., "Far-Field Acoustic Power Level and Performance Analyses of F31/A31 Open Rotor Model at Simulated Scaled Takeoff, Nominal Takeoff, and Approach Conditions", Technical Report I, NASA/CR – 2015-218716, 2015

Computational Analysis

Unsteady Aerodynamics

Lattice Boltzmann method (LBM) simulations

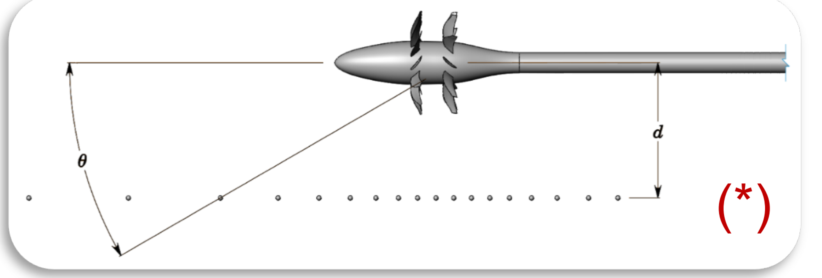
- Boundary values ($V_\infty, T_\infty, p_\infty$) same to WT conditions in experiments
- Sponge region surrounding Open Fan to prevention reflections from outgoing pressure waves.
- Highest resolution = 0.125 mm & time step = 0.370 $\times 10^{-7}$.
- Discretization size: 900 millions
- Transient flow data recorded at rotor surfaces (including hub rotating part) at rate of 190 kHz

Farfield Aeroacoustics

Ffwocs-Williams Hawking (FW-H) solver

- CAA predictions at sideline distance d = 5 feet
- FW-H impermeable surfaces: blades & hub rotating part
- Non-convective FW-H solver in cases with calibrated pitch
- Convective FW-H solver in cases with nominal pitch

Acoustic receiver arrangement



Receiver sets

- 18 receivers, $17.5° < \theta < 140°$ (for comparisons w/ NASA exps.)
- 59 receivers, $15.0° < \theta < 160°$ (for higher spatial resolution)
- ~1300 receivers in a spherical surface for non-zero AoA cases

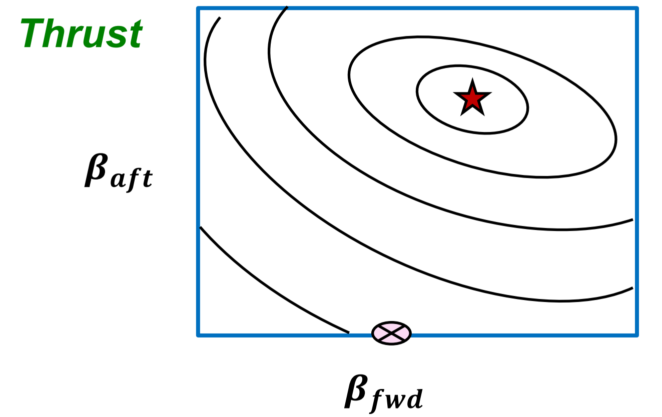
[*] A generic open fan geometry is used for the illustration since F31/A31 geometry is GE proprietary

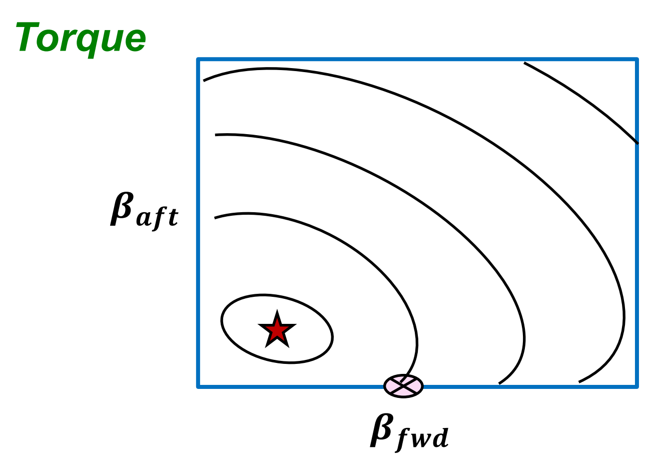
Aerodynamic Calibration

- Interested in noise driven by loading, which is thrust dependent
- Matching thrust seen as necessary condition to place confidence in acoustic predictions
  - Note such condition might not be sufficient for matching acoustics measurements
- CAA predictions are compared to experiments at matched aero performance conditions
  - Not attempting to bring directly CAA predictions close to experimental values (loading conditions might be different)

Cost Functions Isocontours: $\bar{L}$

(Illustration)





Calibration Procedure

- Minimize weighted l^2 - norm of thrust discrepancies (both front and aft rotors) with respect to pitch settings

$$\beta_f^*, \beta_a^* = \arg\min L(\beta_f, \beta_a)$$

$$L = \|w^T \Delta\|_2$$

- Note simultaneous minimization of thrust and torque metrics is not possible – cost function leads to different pitch settings

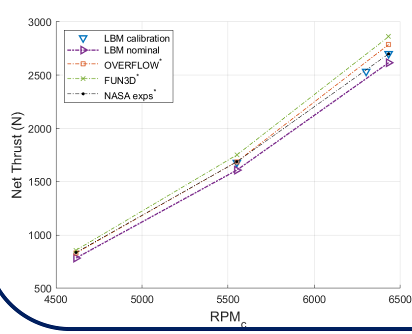
Results: Calibrating Aerodynamics

- ❑ Pitch angles increase when calibrating
    - Thrust at nominal pitch is underpredicted
- ❑ Net Thrust Discrepancy
    - Reduces bellow 1% for calibrated pitch
    - Disagreement as other solvers for nominal pitch
- ❑ Torque ratio
    - Qualitatively off for all solver with nominal pitch
    - Improvement in trend and values with calibrated pitch

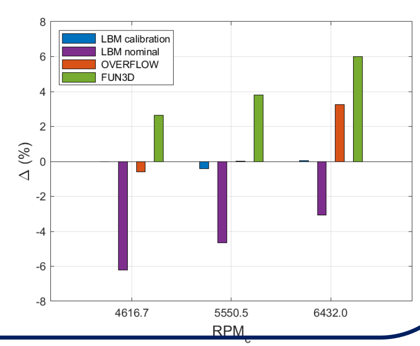
RPMc	$\delta\,\beta_f^*$	$\delta\,\beta_a^*$	***Remark***
5550.5	+ 0.288 °	+ 0.709 °	
6250.5	+ 0.460 °	+ 0.428 °	same as highest rotor speed
6432.0	+ 0.460 °	+ 0.428 °	

Net Thrust Comparisons

Net Thrust

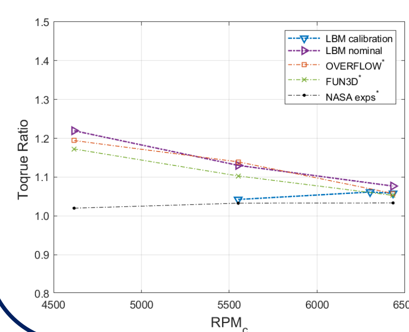


Discrepancy

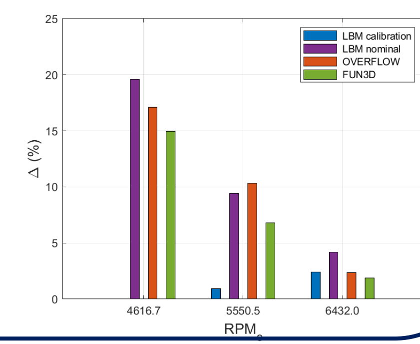


Torque ratio Comparisons

Torque ratio



Discrepancy



Calibration Summary: RPM Trend

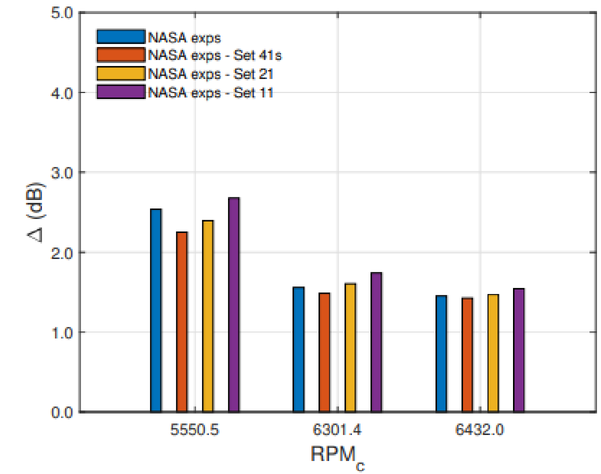
Constant AoA = 0° Cases

Overall Discrepancy Metrics

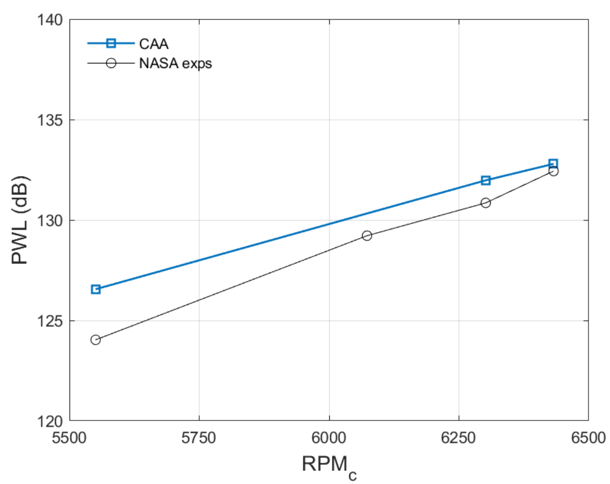
- OASPL:
  - 2.5 to 1.6 dB (5550.5 – 6432 RPM_C)
- OPWL:
  - 2.5 to 0.4 dB (5550.5 – 6432 RPM_C)

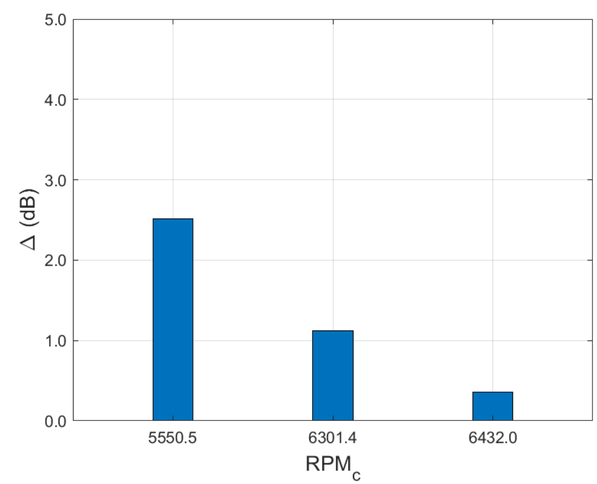
Discrepancy

OASPL



OPWL





Calibration Summary: AoA Trend

Constant rotor speed: RPMc = 6301

Overall Discrepancy Metrics

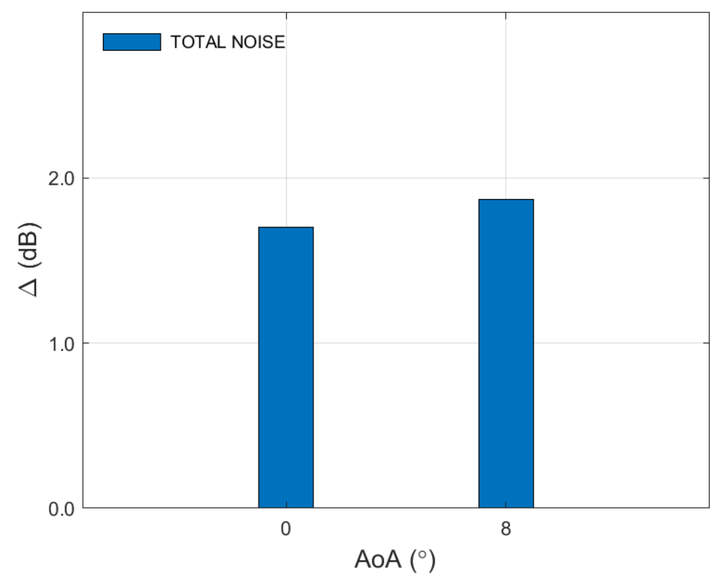
- OASPL:
  - 1.7 to 1.9 dB (0 – 8 AoA)
- OPWL:
  - 1.2 (AoA = 0)

REMARKS

- At non-zero AoA, OPWL requires more data than that of sideline measurement

OASPL

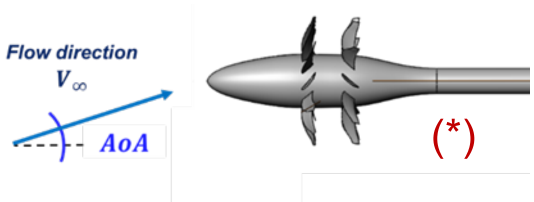
OASPL Discrepancy

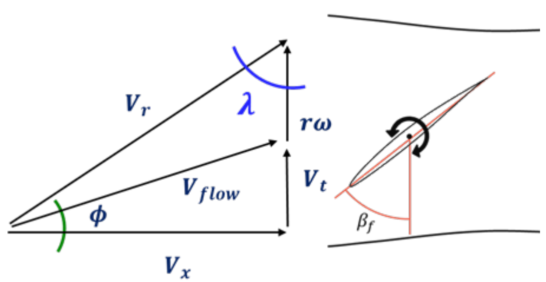


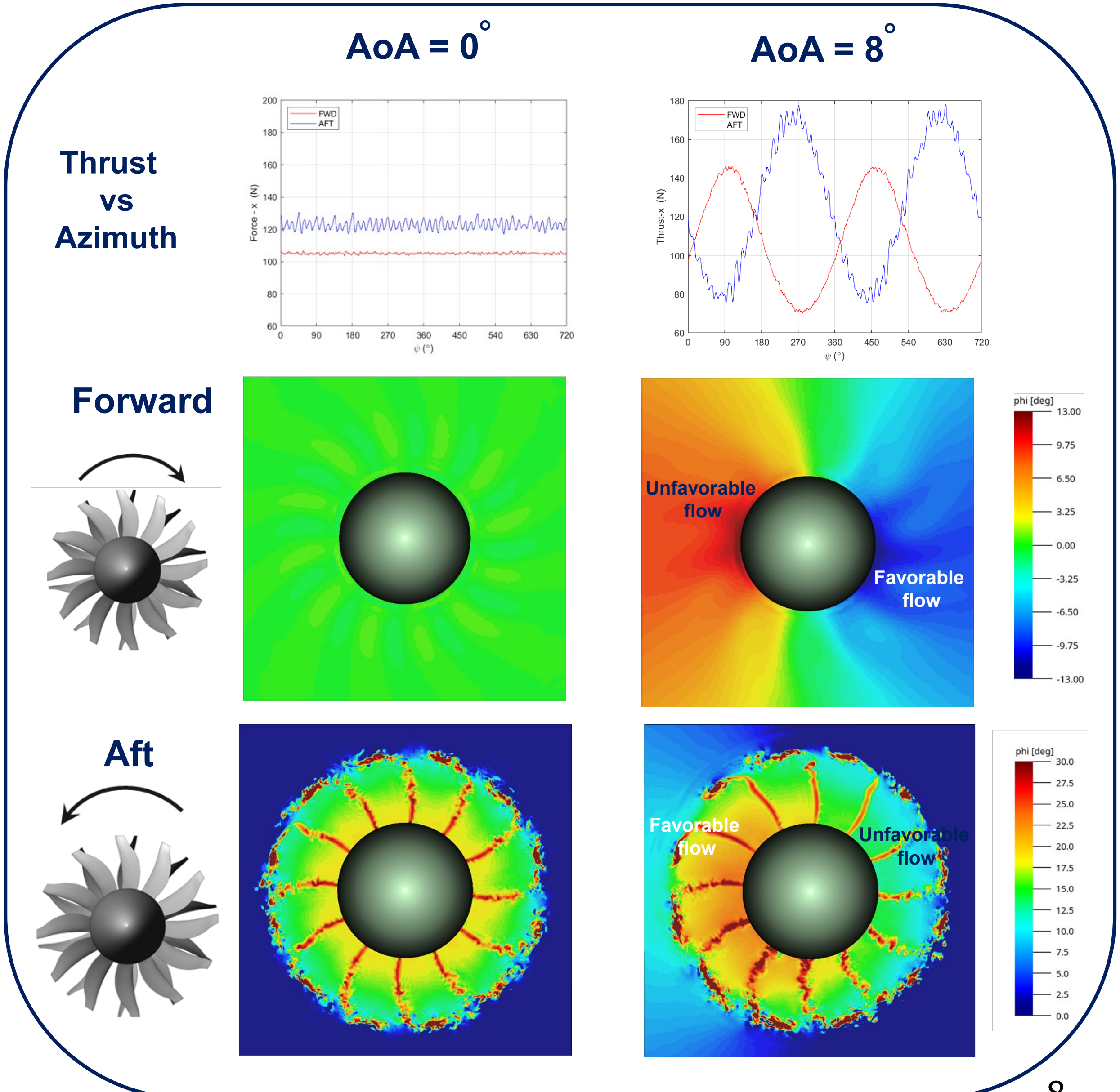
Ingested Flow at non-zero AoA

Flow Angle: $\phi = atn(V_T/V_x)$

- Unsteady thrust tracked at single blade per rotor
- Periodic behavior for non-zero AoA







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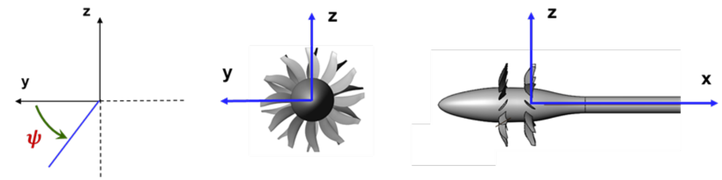
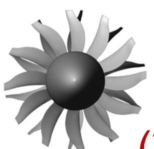
OASPL at non-zero AoA

OASPL directivity



Front View



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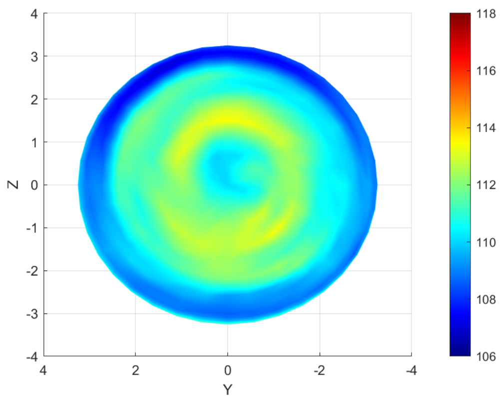
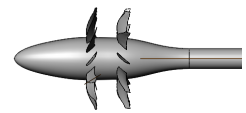


Side View



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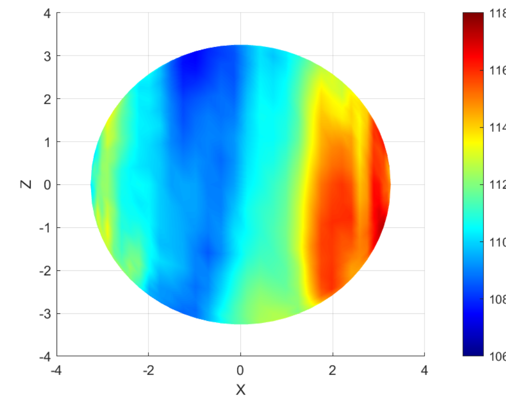
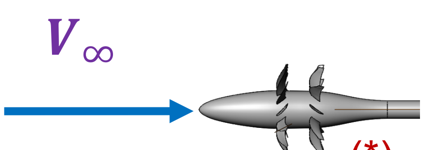


OASPL directivity in polar- azimuthal angles

$AoA = 0°$



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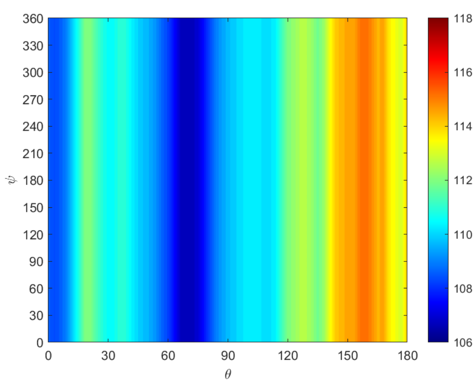
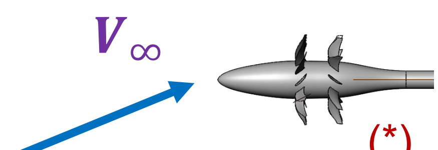


$AoA = 8°$



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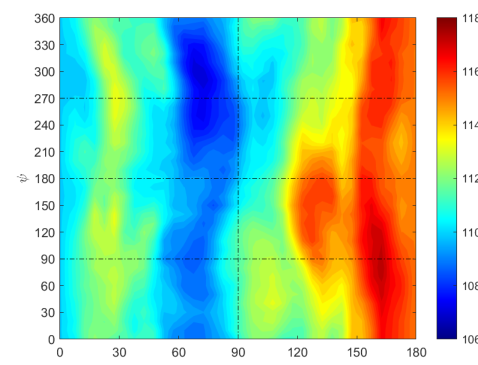

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Remarks

- Calibration in aerodynamics leads to slightly higher levels of noise
    - Thrust at nominal pitch is underpredicted by simulations
    - Adjusting pitch leads to increase thrust, thus noise levels
- Noise field is not axially symmetric due to presence of cross flow
    - Flow component transverse to axis of F31/A31 model
    - Predictions suggest that polar directivity is different at any azimuthal angle
    - Higher noise level are seen in the lower hemisphere (model is tilted away)
    - Lower levels are located in the upper hemisphere
- Unsteady loading exhibit a larger contribution to total noise
- Thickness loading and steady loading exhibit smaller contribution to total noise
    - However, both exhibit lack of axi-symmetry
- Computational cost of LBM simulations is large
    - Challenging if not enough computational resources
    - Number of simulations somehow restricted, depending on HPC budget