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.
- Development of a parametric open rotor geometry
- **Simulation validation in progress**

Future Work / Schedule:

- Further validations
- Computer simulation campaign
- Parametric study if funded

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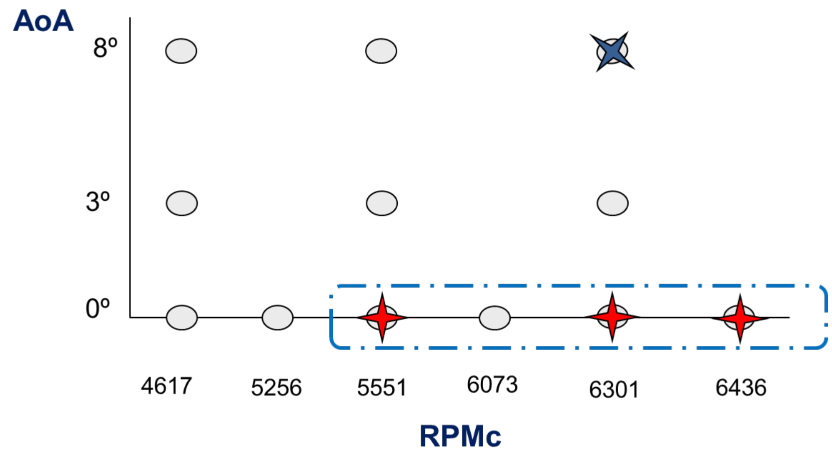
Validation Plan

- 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
  - A. NASA reports on F31/A31
  - B. GE data on F31/A31 (proprietary)
- Focus on the upper-half of the RPM range
  - RPM : 5551 – 6436 (corrected speed)
- **First phase** of validation focus on AoA = 0º
  - Currently undergoing
- **Second phase** focuses on non-zero AoA
  - Defined at 2^{nd} highest rotor speed, 6301 RPMc
  - Future work

Nominal Take-Off (NTO) no pylon
NASA Experimental Campaign (*)



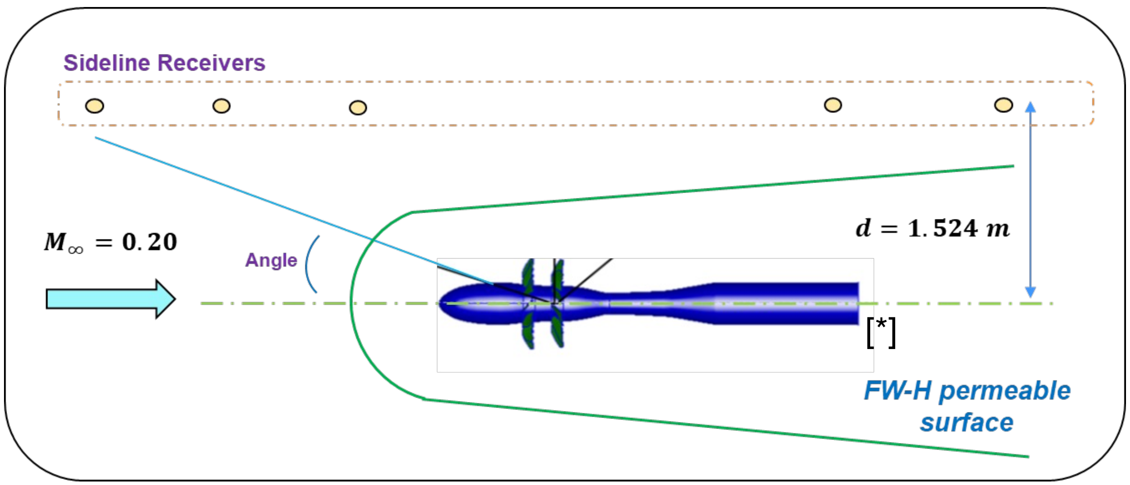
[*] Sree, D., "Far-Field Acoustic Power Level and Performance Analyses of F31/A31 Open Rotor Model at Simulated Scaled Takeoff, Nominal Takeoff, and Approach Conditions", Technical Report I, NASA/CR – 2015-218716, 2015

CAA Simulation

- Assessment of our set-up for the Lattice Boltzmann method (LBM) simulation for Open Rotor case
  How do our predictions compare to experimental data?

Validation cases

- Experiments on F31A31 12x10 open rotor in the low speed wind tunnel (LSWT) at NASA [†]
- One case:
  - ✓ Mach = 0.20
  - ✓ Blade angles: 40.1 (front rotor) & 40.8 (aft rotor)



Simulation

- ❑ Unsteady aerodynamics based on a Lattice Boltzmann commercial solver (PowerFlow)
  - Mach = 0.20
  - Discretization size ~ 600 -900 Million voxels
  - Smallest resolution = 0.125 - 0.250 mm
    - At blade tips , and blade LE & TE
  - Time step : 1.7×10^{-7} $secs$
  - Computational cost :
    - ~10,000 core-hours / revolution
- ❑ Simulation run for 12 - 15 rotor revolutions in order to collect flow data for aeroacoustics analysis

[*] Nark *et al.*, "Isolated Open Rotor Noise Prediction Assessment Using the F31A31 Historical Blade Set", AIAA paper 2016-1271
[†] Far-Field Acoustic Power Level and Performance Analyses of F31/A31 Open Rotor Model at Simulated Scaled Takeoff, Nominal Takeoff, and Approach Condition

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)

Calibration Procedure

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

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

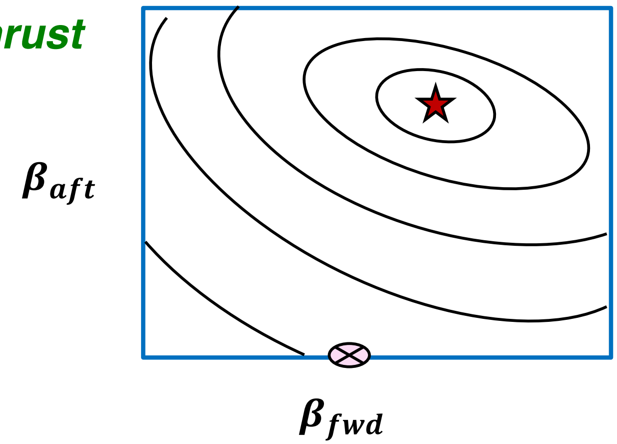
$$L = \|w^T \Delta\|_2$$

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

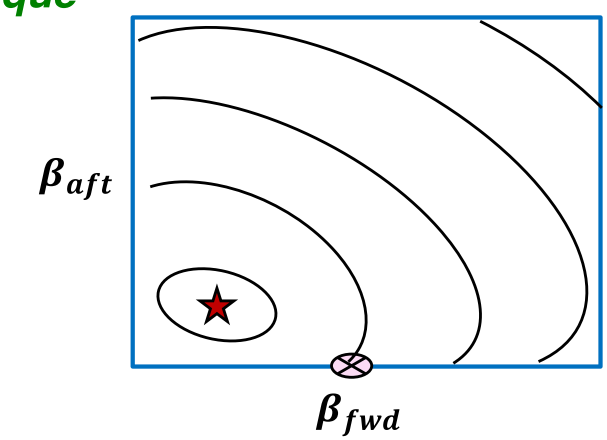
Cost Functions Isocontours: $\bar{L}$

(Illustration)

Thrust



Torque



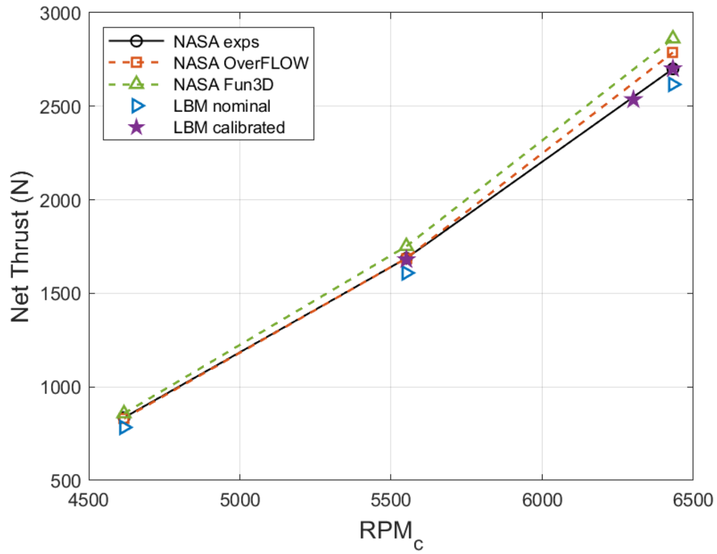
Aero Performance Comparison

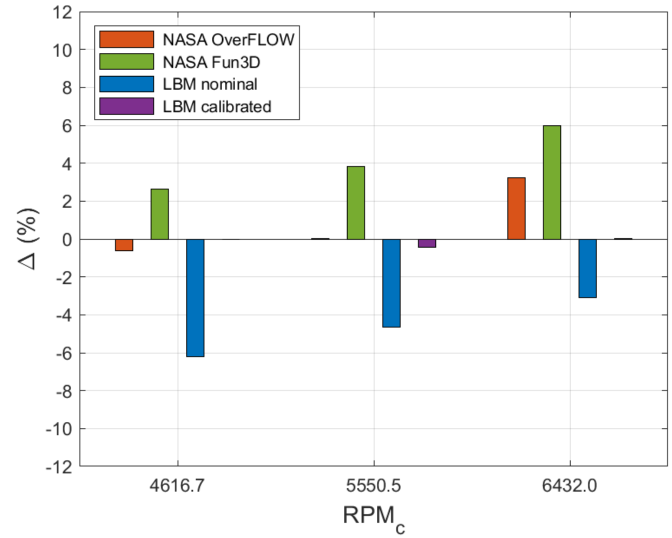
Trends

Discrepancy
(between different Simulations & NASA exps.)

Thrust

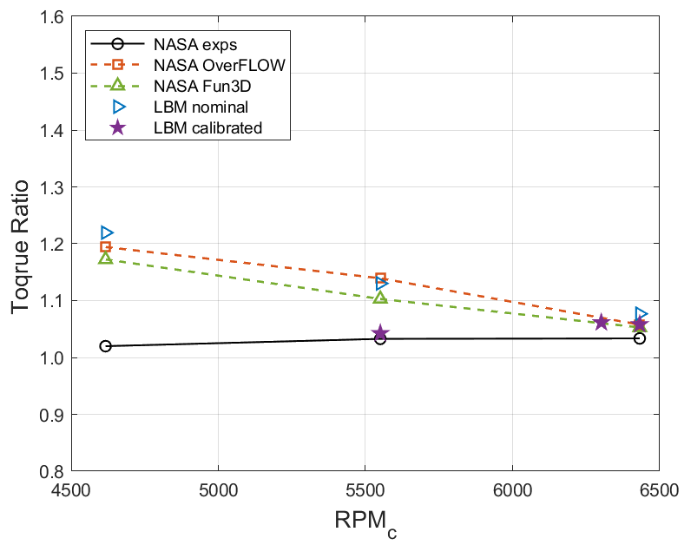
- Low discrepancy is ensured due to pitch calibration

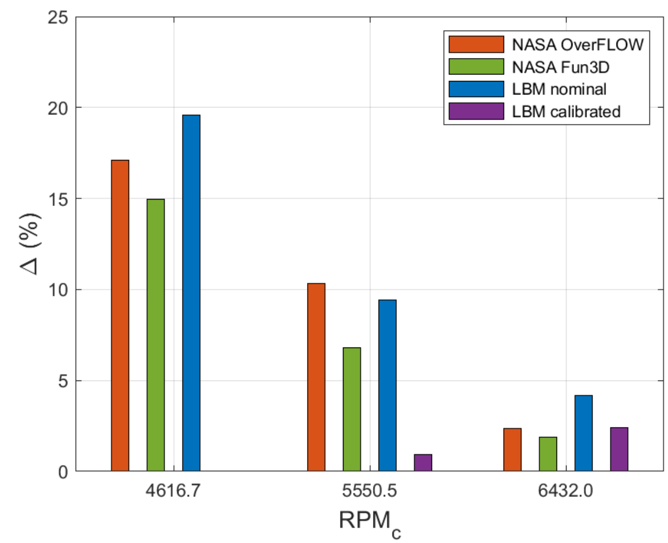




Torque Ratio

- Torque ratio has small discrepancy values



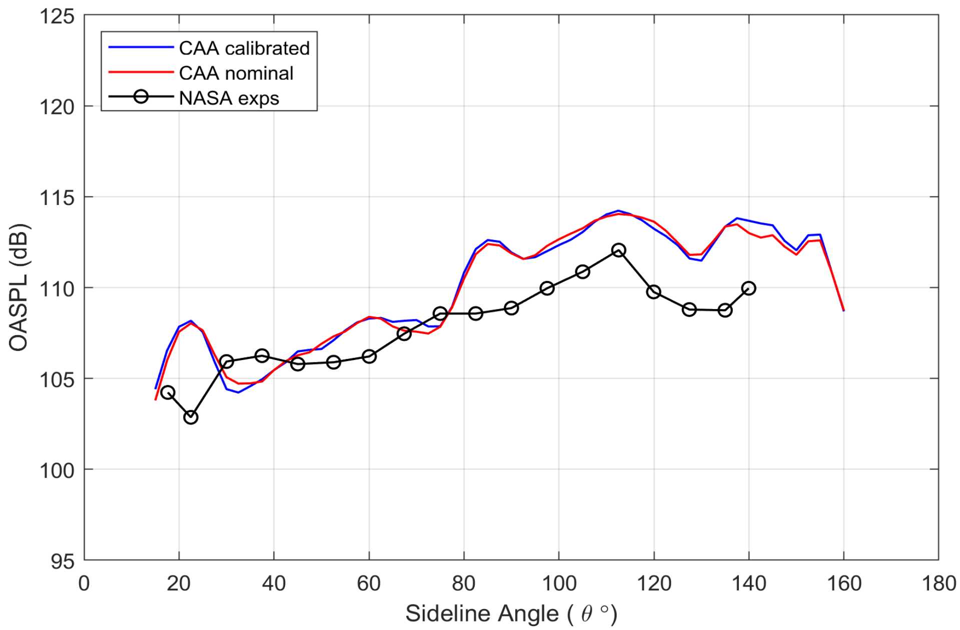


Noise Discrepancy

Calibration Effects on Acoustics Overall Metrics

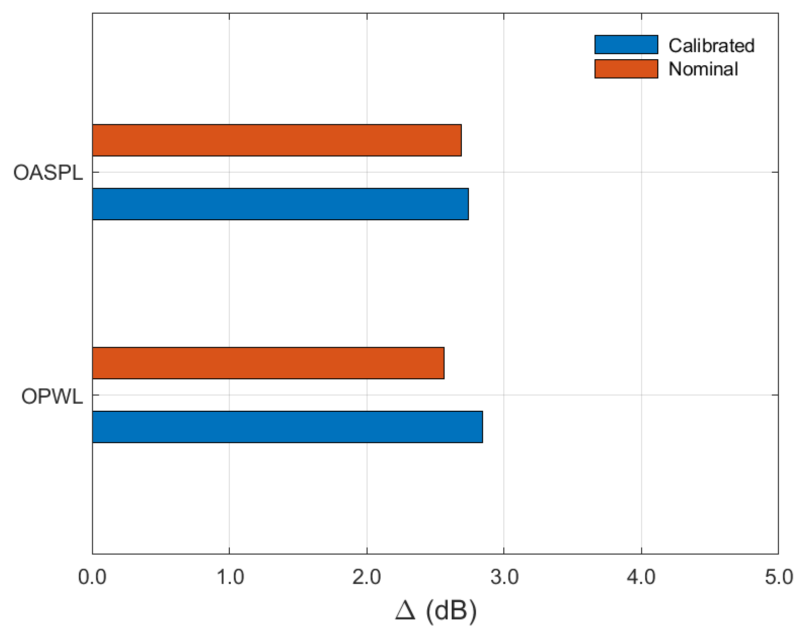
- ❑ Overall sound pressure level (OASPL) exhibit very small variation between calibrated and nominal, ~ 0.05 dB
  - Calibrated case is 0.05 dB higher (OASPL RMSE)
  - Note that thrust in calibrated pitch setting is a bit higher
    - ✓ Nominal pitch underpredicted thrust
- ❑ Overal power level (OPWL) variation between nominal & calibrated pitch is about 0.3 dB.
- ❑ However, changes are more noticeable at spectra level

OASPL directivity



OASPL & OPWL discrepancy

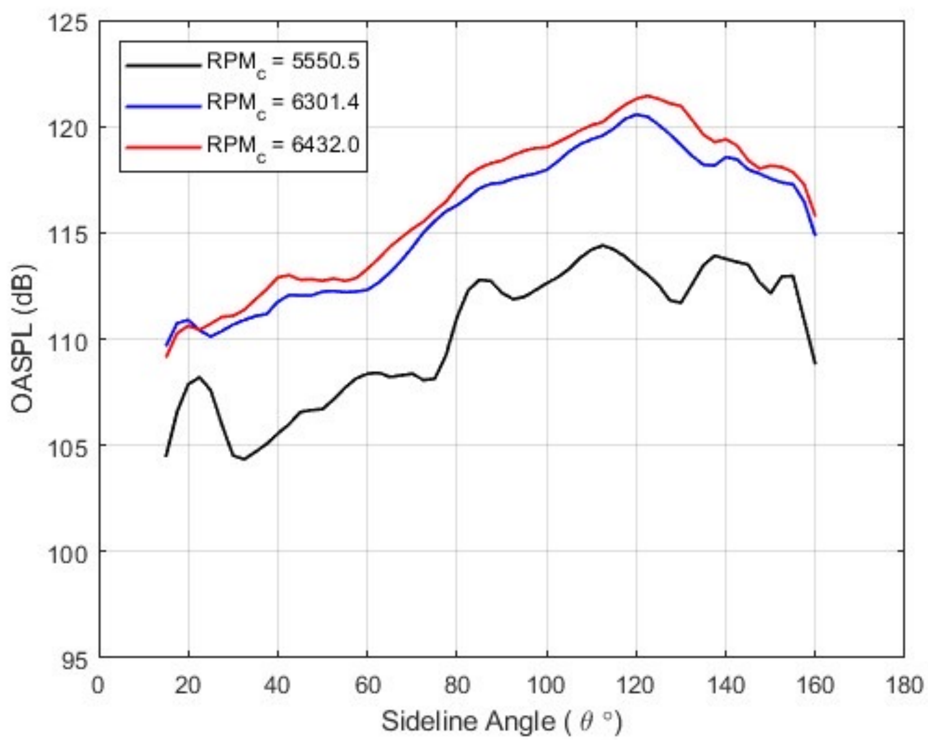
(between CAA & NASA exps.)



Noise Discrepancy (cont.)

- First stage of validation focuses on cases at zero angle of attack (AoA = 0)

OASPL Directivity
(CAA predictions)



REMARKS

- ❑ Discrepancies among cases range between 1.6 - 2.75 dB, approximately
- ❑ Largest discrepancy is at the lowest rotor speed
- ❑ Currently increasing resolution at lowest rotor speed to confirm if discrepancy remains the same

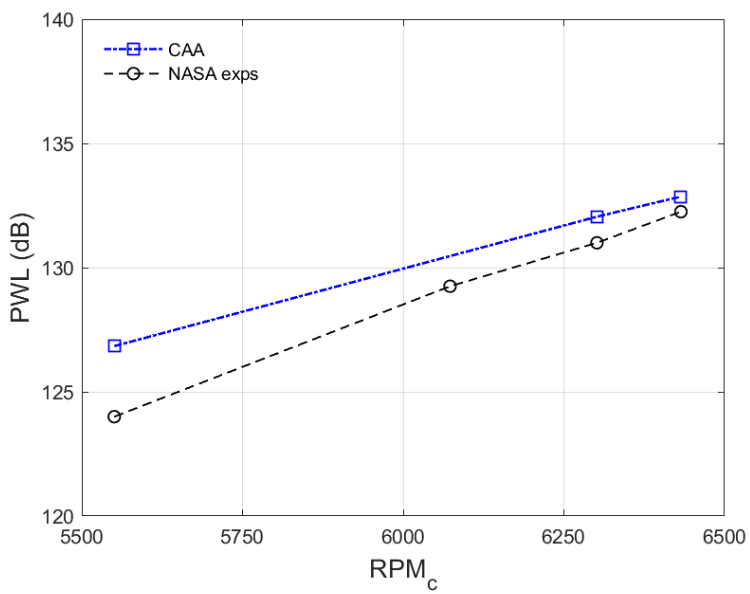
Noise Discrepancy (cont.)

ACOUSTIC POWER LEVEL

- ❑ Trends with RPM consistent with that of NASA experiments
- ❑ Discrepancies smaller for highest RPM
- ❑ Note calculations carried out with 18 receivers (for consistency with NASA experiments)
    - Adding more receivers (higher resolution), which is attainable with simulations, may slightly change OASPL & OPWL values

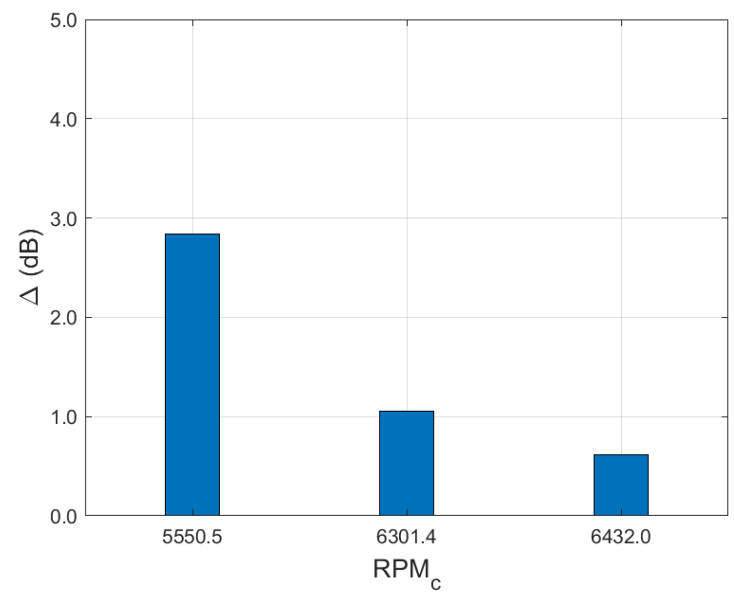
OPWL Trends

(CAA predictions vs. NASA exps.)



OPWL Discrepancy

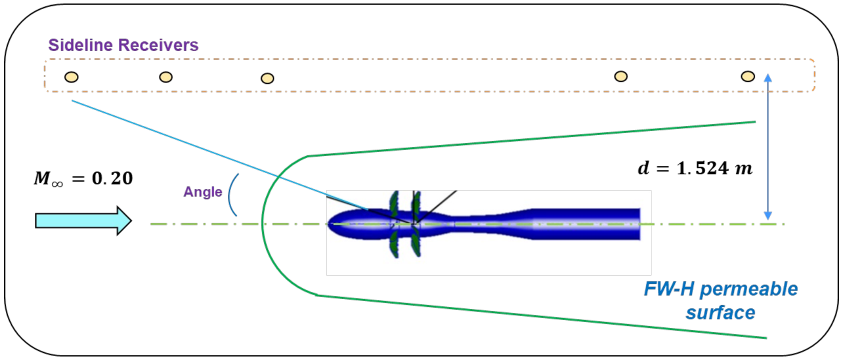
(between CAA & NASA exps.)



Remarks and Next Steps

Remarks:

- ❑ LBM simulations were carried out for 12x10 F31A31 open rotor
- ❑ Numerical prediction show the following agreement:
    - In OASPL, 1.60 – 2.75 dB with experiments
    - In OPWL, 0.50 – 2.80 dB with experiments
    - Level of discrepancy seems comparable with previous numerical simulations from NASA



Next Steps

- ❑ Validations at **nominal** pitch settings for comparisons with calibrated pitch settings
- ❑ Validation at **non-zero** angle of attack (AoA ≠ 0 º)