ASCENT Project 076

Improved Open Rotor Noise Prediction Capabilities

Georgia Institute of Technology

PI/Co-PI: Dr. Dimitri Mavris / Jimmy Tai

PM: Chris Dorbian

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 – unsteady aero & CAA
- Definition of sensitivity study methodology and its execution

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 approach Validation

Future Work / Schedule:

- Further validations
- Computer simulation campaign
- Parametric study

This research was funded by the U.S. Federal Aviation Administration Office of Environment and Energy through ASCENT, the FAA Center of Excellence for Alternative Jet Fuels and the Environment, project Ascent 076 through FAA Award Number 13-C-AJFE-GIT-078 under the supervision of Chris Dorbian. Any opinions, findings, conclusions or recommendations expressed in this this material are those of the authors and do not necessarily reflect the views of the FAA.

Study of Design Parameter Sensitivities

- Rotor parameters
- Installation Effects
- Frame Integration

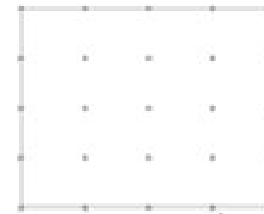
Determining design parameters

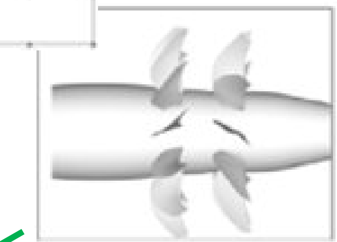
- Effective Perceived Noise Level

Defining Responses

Sampling of design parameters.

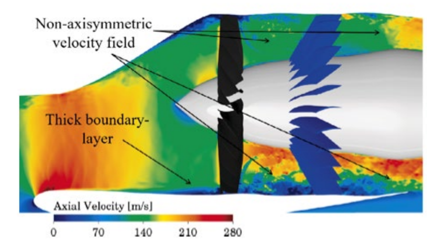
(input space)



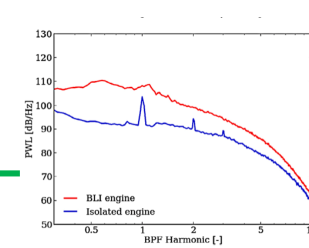


- Unsteady Aerodynamics
- Computational Aeroacoustics

Simulation



(c) $t/T = 7$



(a) *BLI and isolated engines*

Responses

Sensitivity Analysis

Outcome:

Ranking – by noise impact - of design parameters

Term	Contrast		Lenth t-Ratio	Individual p-Value
Δx	0.012462		22.51	<.0001*
TE/LE	0.001700		3.07	0.0123*
PC	-0.001144		-2.07	0.0520
Δy	-0.000309		-0.56	0.5891
Δz	-0.000124		-0.22	0.8226
Δx*Δx	0.001559	*	2.82	0.0182*
Δx*TE/LE	-0.000192		-0.35	0.7329
Δx*PC	-0.000309		-0.56	0.5891
TE/LE*PC	0.000296		0.53	0.6068
PC*PC	0.000037	*	0.07	0.9475
Δx*Δy	0.000490		0.89	0.3469
TE/LE*Δy	-0.002367		-4.27	0.0023*
PC*Δy	0.000139		0.25	0.8048
TE/LE*Δz	-0.001682		-3.04	0.0127*
PC*Δz	-0.000429	*	-0.77	0.4078
Δx*Δx*TE/LE	-0.002138	*	-3.86	0.0043*
Δx*TE/LE*PC	0.000789		1.42	0.1523
TE/LE*PC*PC	0.000062	*	0.11	0.9118
Δx*TE/LE*Δy	-0.000821		-1.48	0.1394
TE/LE*PC*Δy	0.000746		1.35	0.1699
TE/LE*PC*Δz	-0.000234	*	-0.42	0.6777

Development of Parametric Geometry

ASCENT
AVIATION SUSTAINABILITY CENTER

- ❑ Accomplishments on

  I. **Defining open rotor design parameters**
  II. Developing a parametric geometry module
  III. Sensitivity analysis

- ❑ Good part of work since spring meeting has been on validating computer simulations

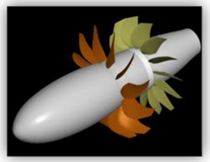
  - Validation with experimental data from F31A31 open rotor in NASA low speed wind tunnel (LSWT)
  - Comparison with previous simulations

Design Parameter Definition

- Objective:
  - Summarize the state of research on Open Rotor aeroacoustics
  - Define a super-set of design parameters shown to influence open rotor acoustics
  - **Down-selection** of design parameters from the super-set
- Design parameters are divided in three groups:
  - Rotor parameters
  - Pylon installation parameters
  - Airframe integration parameters
- **Review of publicly available open rotor literature has been completed**

Design Parameters

Rotor



Pylon Installation

Airframe Integration

Development of Parametric Geometry

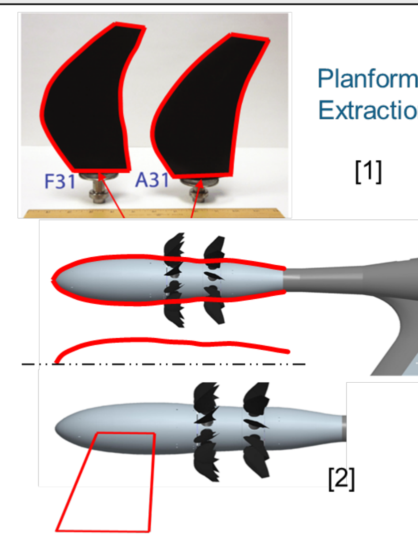
- ❑ Accomplishments on
  - I. Defining open rotor design parameters
  - **II. Developing a parametric geometry module**
  - III. Sensitivity analysis

- ❑ Good part of work since spring meeting has been on validating computer simulations
  - Validation with experimental data from F31A31 open rotor in NASA low speed wind tunnel (LSWT)
  - Comparison with previous simulations

Parametric geometry module

- To support the Sensitivity Analysis, we need a way to generate new geometries – **a parametric model** – from a Design of Experiments (DoE)
- Design parameters were identified during the literature review
- Parameterization is based on F31 A31 open rotor blades
- Parametric model is **complete** with a focus on **rotor and pylon installation design**

Rotors → Nacelle → Pylon



Planforms Extraction

[1]

[2]

[2]

Parameter
Diameter of rotor
Aft rotor clipping
Rotor spacing
Pitch Angle
Number of blades
Blade Shape

Parameter
Fuselage-Rotor Spacing
Pylon-Rotor Spacing
Angle of Attack (Twist)
Pylon Sweep

[1] Rizzi, S. A., et al., "Auralization of Flyover Noise from Open-Rotor Engines Using Model-Scale Test Data," Journal of Aircraft, Vol. 53, No. 1, 2016.
[2] Sree, D., "Near-Field Acoustic Power Level Analysis of F31/A31 Open Rotor Model at Simulated Cruise Conditions," NASA, 2015,

Development of Parametric Geometry

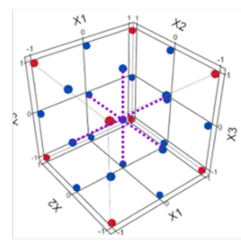
- Accomplishments on
  - I. Defining open rotor design parameters
  - II. Developing a parametric geometry module
  - **III. Sensitivity analysis**

- Good part of work since spring meeting has been on validating computer simulations
  - Validation with experimental data from F31A31 open rotor in NASA low speed wind tunnel (LSWT)
  - Comparison with previous simulations

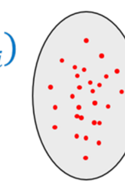
Sensitivity Analysis Methodology

- **Seek to quantify the strength** of inputs (different designs) on the output (a noise metric)
- **Strength contribution** to output can be from **individual** inputs or from **interactions**
- Utilize a regression model for creating relationships between designs and noise metric
- Designs are described on a space of parameters, which in turn are represented by a sampling plan (discrete points)
- Work on this procedure is **in progress**

Regression Model



x_i → Simulation (Aero & CAA) → $f(x_i)$



Sampling Plan

- Due to large simulation cost, selection of sampling plan (DOE's) is very important
- Would like to maximize information while minimizing sample points
- Currently, evaluating DOE type with lower sample size increase while accounting for desired effects

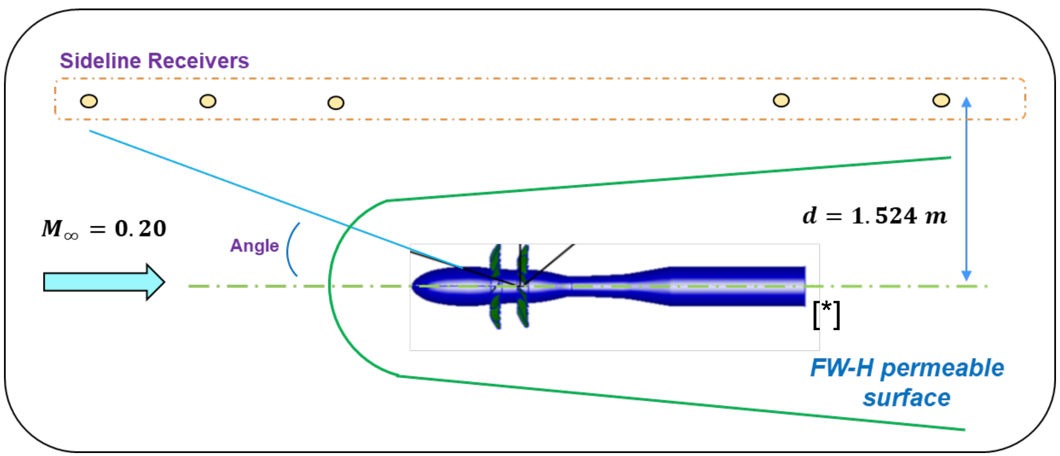
Resolution	Number of design variables	Effects Studied
III		
IV		
V		

Validation

- 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 case

- Experiments on F31A31 12x10 open rotor in the low speed wind tunnel (LSWT) at NASA [†]
- One case:
  - ✓ Mach = 0.20 & RPM = 5551
  - ✓ Blade angles: 40.1 (front rotor) & 40.8 (aft rotor)



Simulation

- Unsteady aerodynamics based on a Lattice Boltzmann commercial solver (PowerFlow)
  - ➢ Mach = 0.20 & RPM = 5551
  - ➢ Discretization size = 599 Million voxels
  - ➢ Smallest resolution = 0.375 mm
    - ➢ => at blade tips , and blade LE & TE)
  - ➢ Time step : $0.28 \times 10^{-6}\ secs$
  - ➢ Computational cost :
    ~10,000 core-hours / revolution

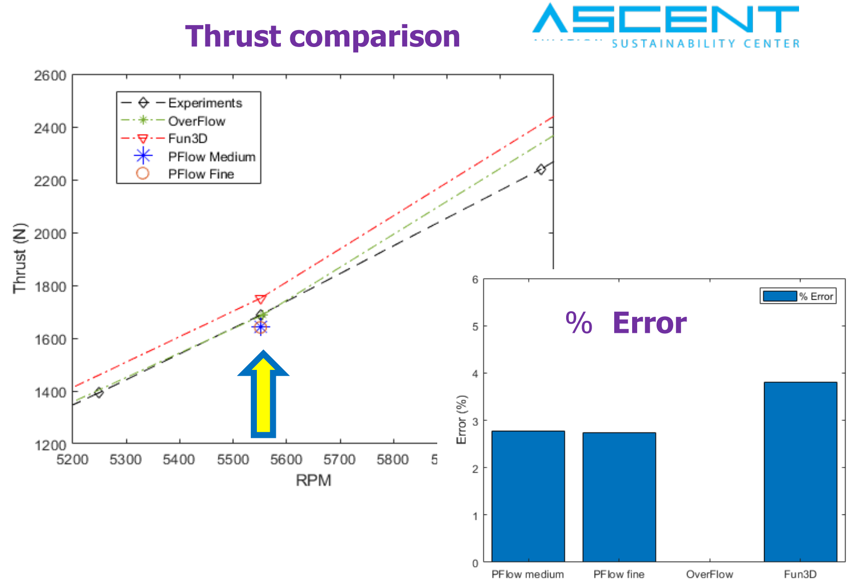
- Simulation run for 5 rotor revolutions in order to collect flow data for aeroacoustics analysis

[*] 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

Validation

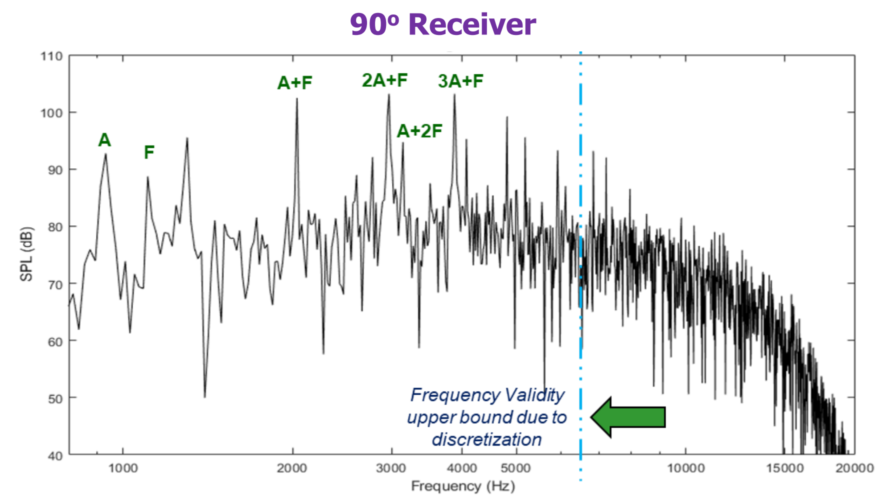
Aerodynamics: Thrust

- Our results exhibit relatively small errors (~2.7%) in predictions of rotor forces
- Result can be considered in good agreement with experiments
- And comparable to previous simulations (NASA)



Aeroacoustics: Farfield Receivers

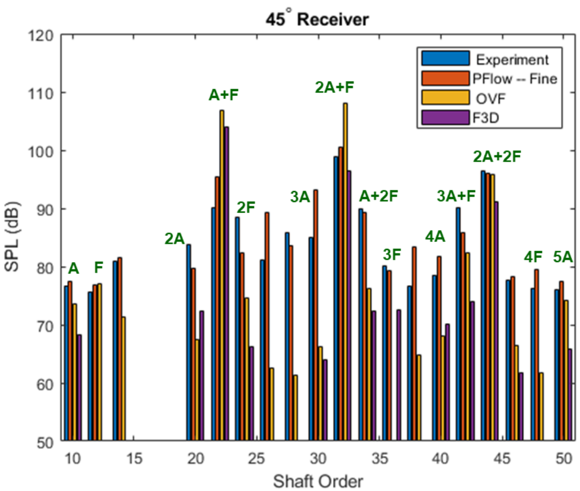
- Comparisons of SPL tones at specific receivers
- Comparisons of SPL directivity at particular tones.

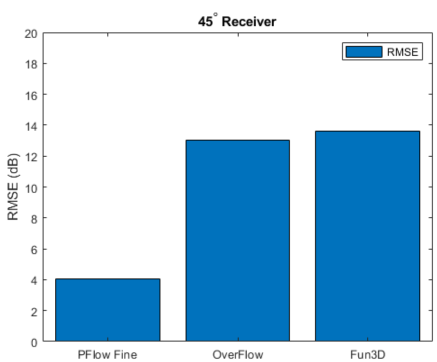


Validation: Results

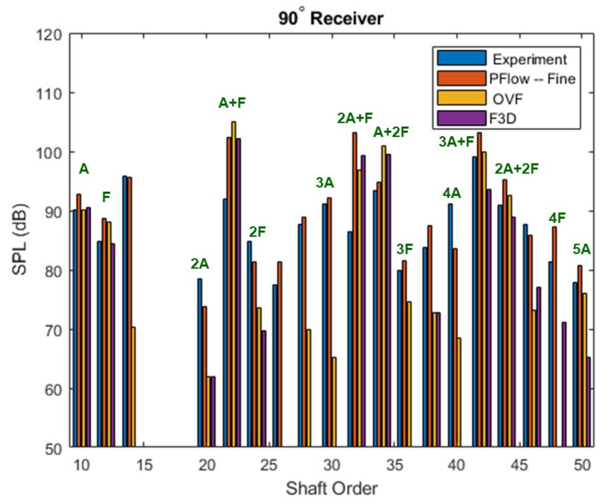
Comparison with Experiments & Previous Numerical Simulations

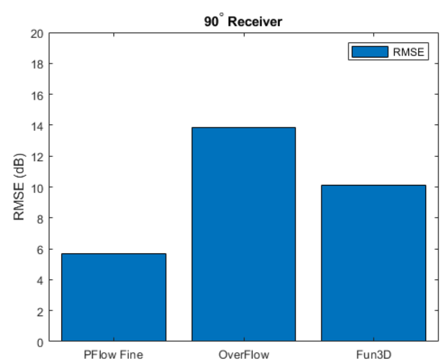
45º Receiver



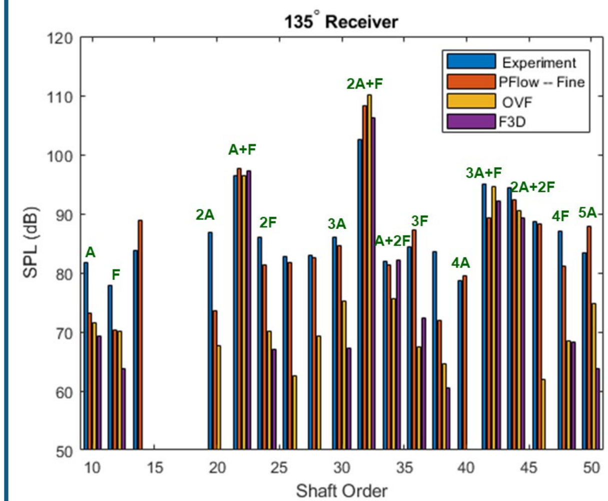


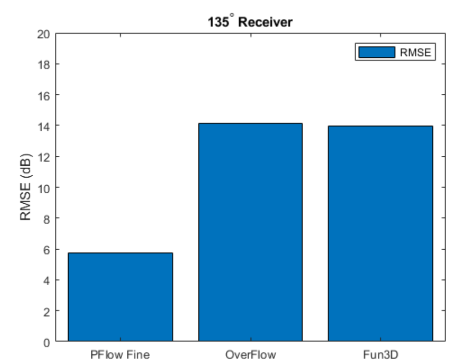
90º Receiver





135º Receiver

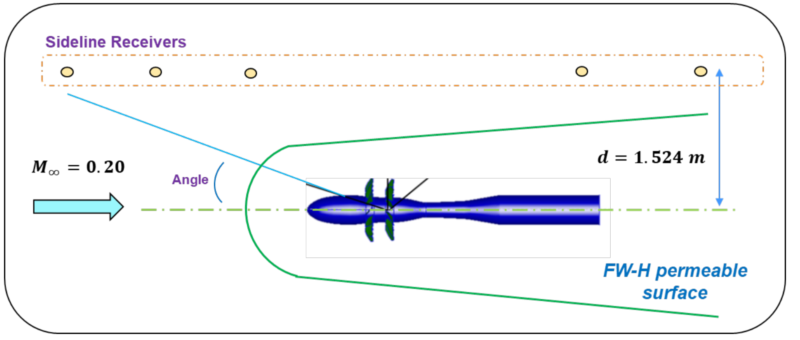


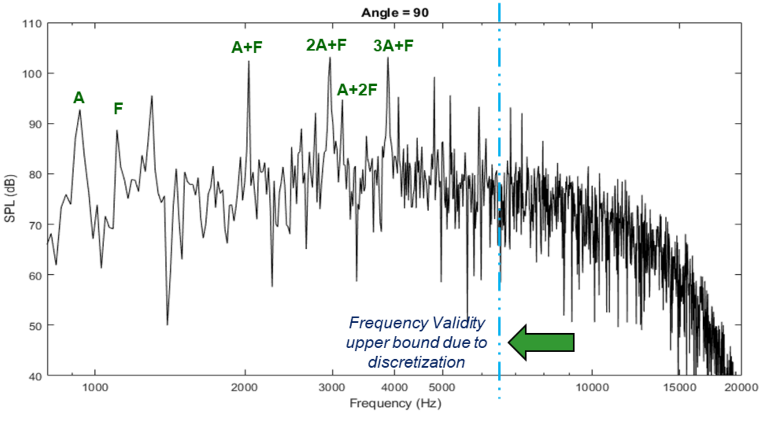


Remarks and Next Steps

Remarks:

- ❑ LBM simulations were carried out for 12x10 F31A31 open rotor
- ❑ Unlike previous simulations, permeable FWH surfaces are utilized
  - Therefore, effects of scattering are included
- ❑ It can be said that our results exhibit good agreement with LSWT data and are comparable with previous numerical simulation
  - Although most error metrics examined suggest modest improvements over previous numerical simulations
- ❑ Therefore, results that computational approach is acceptable for open-rotor design





Next Steps

- ❑ More extensive validations will be carried out with GE data
- ❑ Scaling of Parametric model
  - Currently, geometry model based on a Wind Tunnel model
  - Need to scale up geometry according to thrust levels of single aisle aircraft
- ❑ Simulation Campaign