National Aeronautics and
Space Administration

Computational Study of Broadband Noise generated from an Optimum Hovering Rotor

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UNWG Subgroup 1: Monthly Meeting

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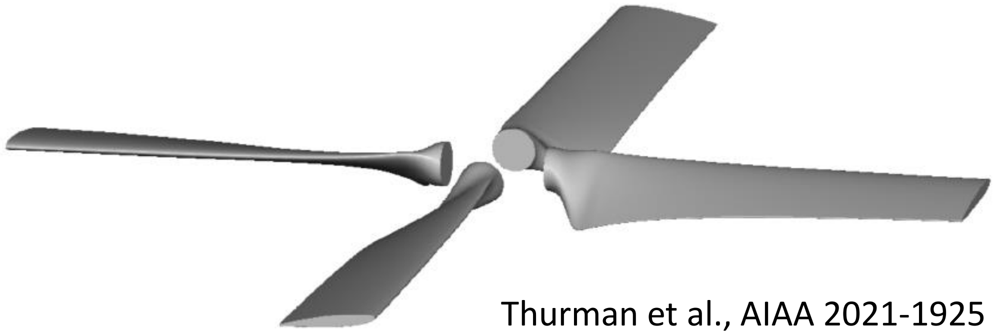
Outline

- Motivation
  - ➢ Move away from COTS blades
  - ➢ Study different broadband noise mechanisms
  - ➢ Investigate different additive manufacturing techniques
- Technical Approach
  - ➢ Geometry
  - ➢ Experimental Setup
  - ➢ Computational Setup
- Results
  - ➢ Experimental
  - ➢ Aerodynamic Performance
  - ➢ Computational Aerodynamics
  - ➢ Computational Tonal Noise
  - ➢ Computational Broadband Noise
- Summary

- Effort to move away from COTS rotor blade sets
  - ➢ Analytically defined rotor blades
  - ➢ Uniform inflow over rotor (BEMT)
  - ➢ Minimum induced power requirement
  - ➢ Distributable to academia

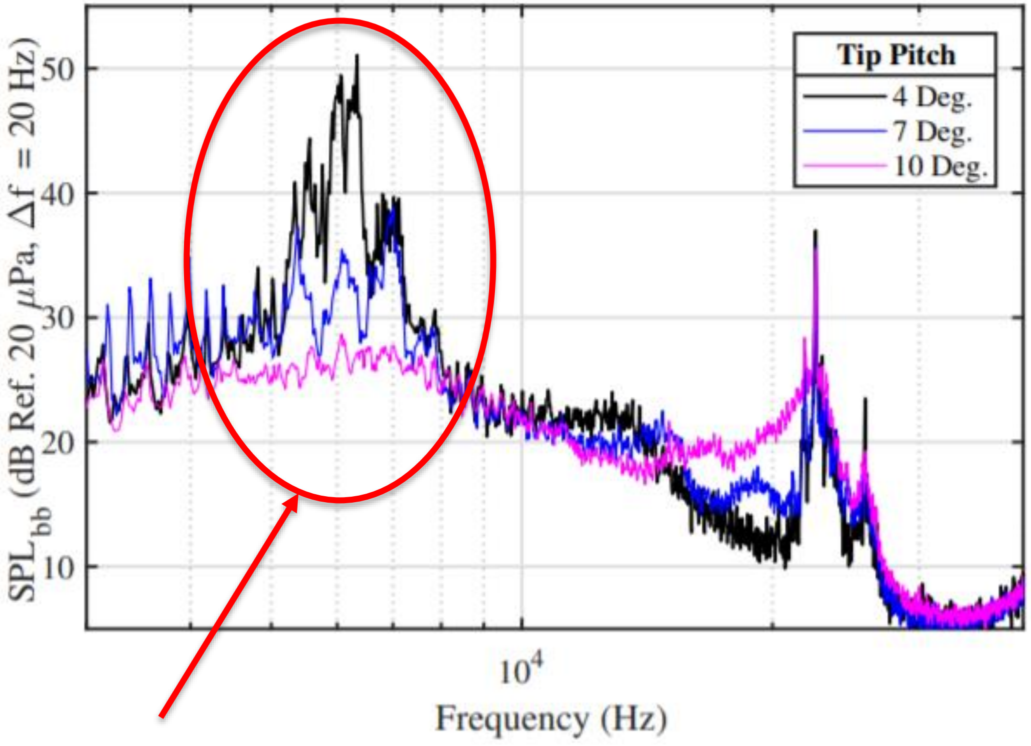
Ideally Twisted Rotor



Thurman et al., AIAA 2021-1925

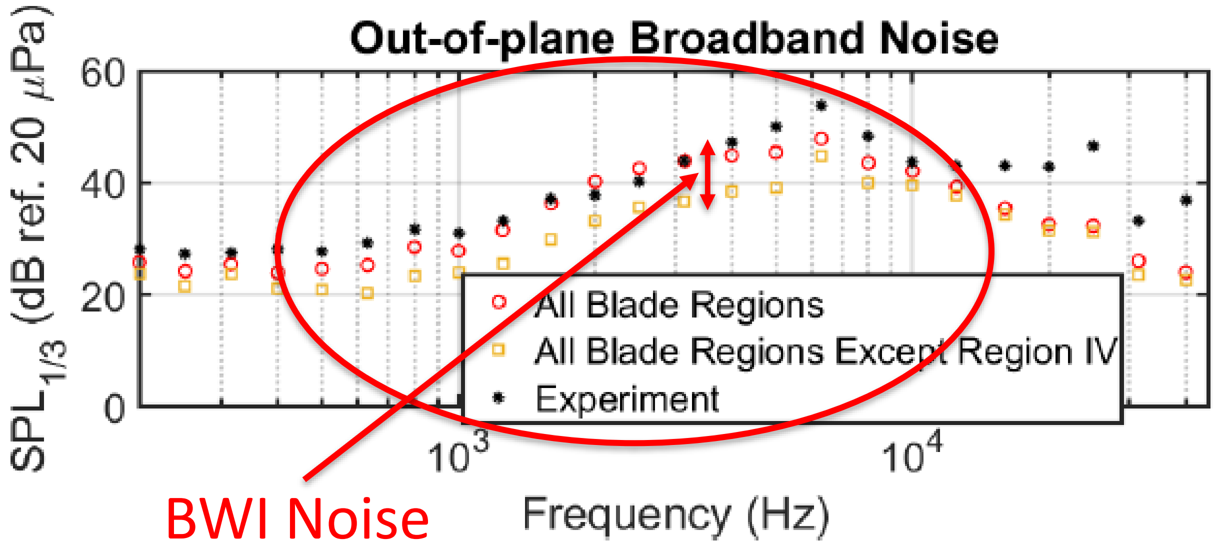
- Study different broadband noise mechanisms
  - Blade self-noise
    - Laminar boundary layer vortex shedding (LBL-VS) noise
  - Blade-wake interaction (BWI) noise

- Study different broadband noise mechanisms



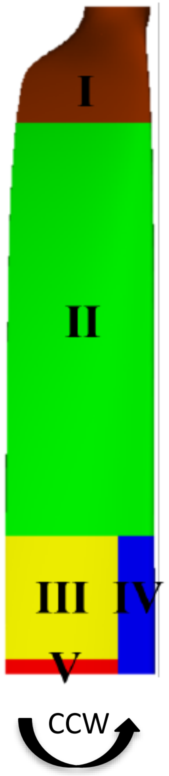
LBL-VS Noise

Pettingill et al., AIAA 2021-1928

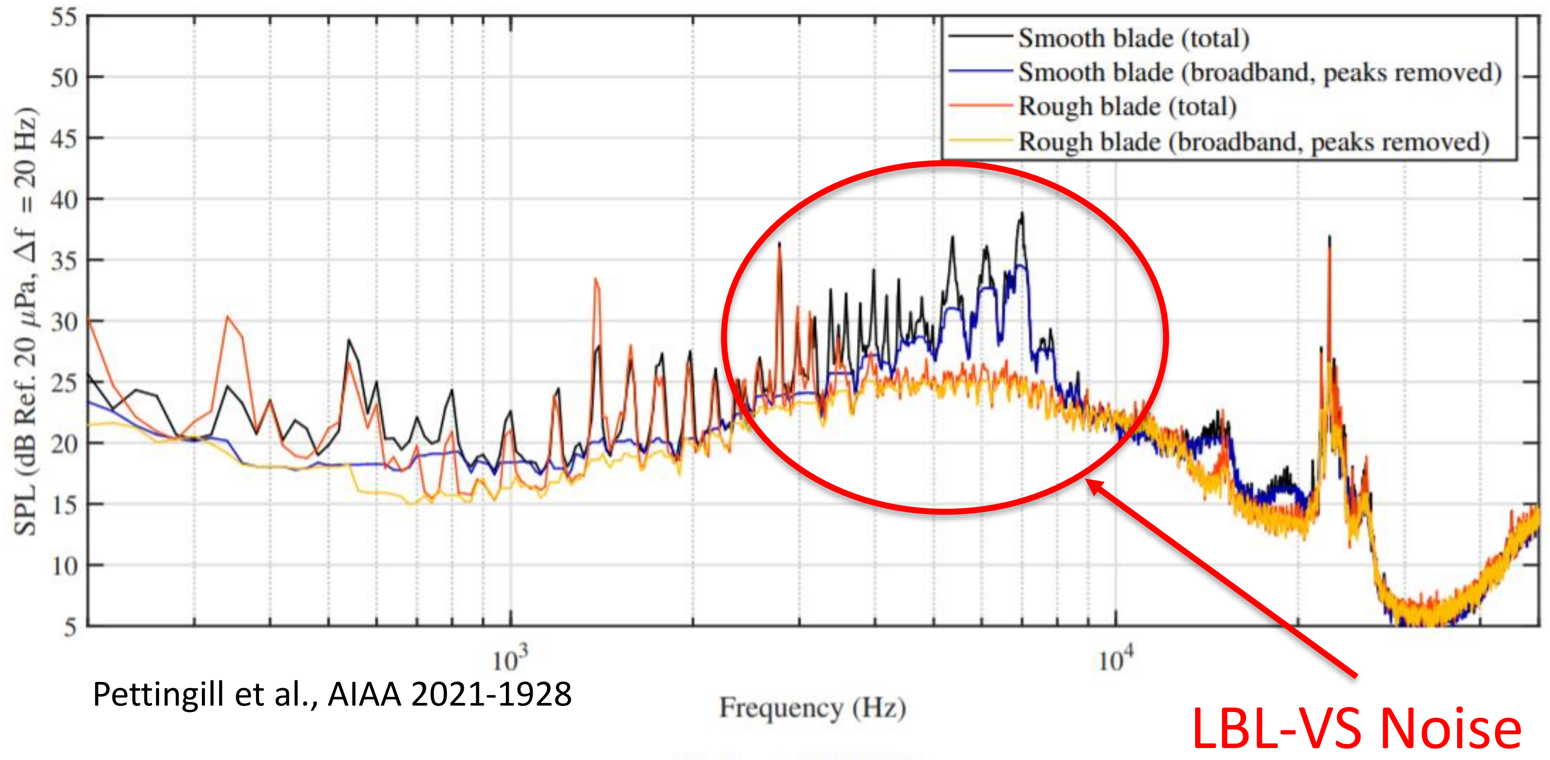


BWI Noise

Thurman et al., AIAA 2021-1925



- Investigate different additive manufacturing techniques
  - Stereolithography (SLA) vs. selective laser sintering (SLS)



Pettingill et al., AIAA 2021-1928

(b) $\Omega_c \approx 3000$ RPM

Technical Approach: Geometry

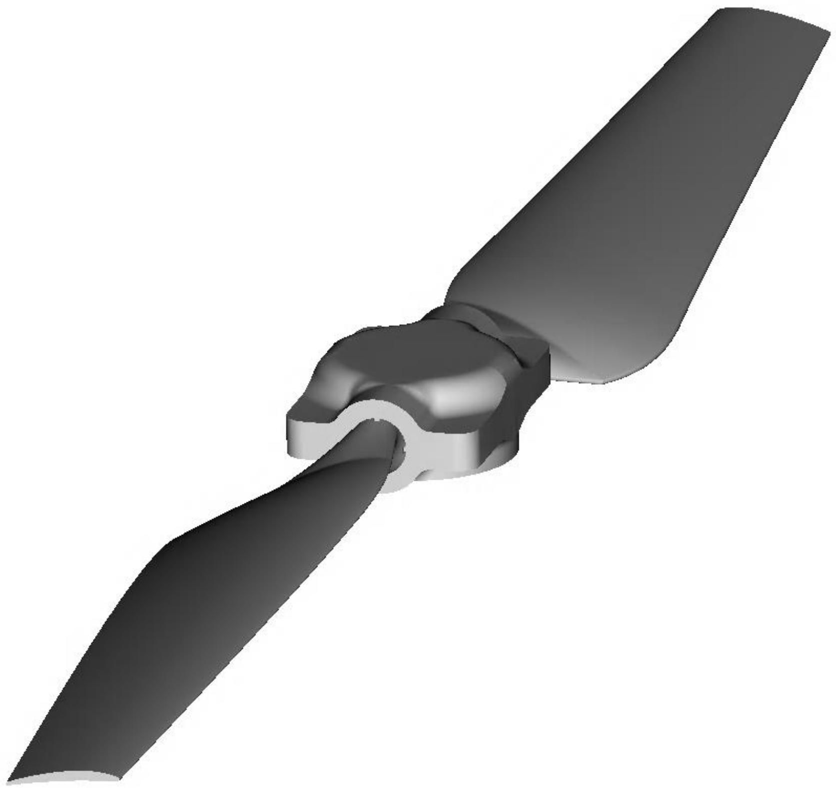
- Optimum hovering rotor (analytically defined)

    - Minimum induced power requirement

$$\theta_{tw}(r) = \frac{1}{r}\left(\frac{4C_{T_{design}}}{5.73\sigma(r)} + \sqrt{\frac{C_{T_{design}}}{2}}\right) - \alpha_0$$

    - Minimum profile power requirement

$$c(r) = \frac{c_{tip}}{r}$$



Technical Approach: Geometry

- Design conditions

➢ R = 7.5 in

➢ Ω = 3950 RPM

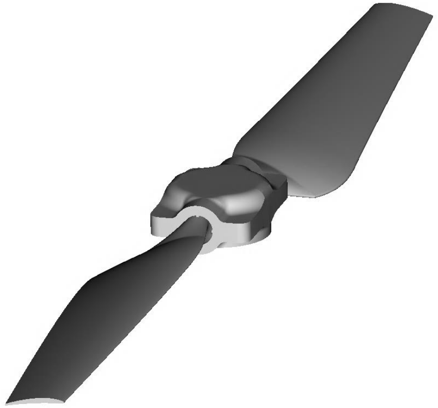
➢ T_{design} = 1.875 lb

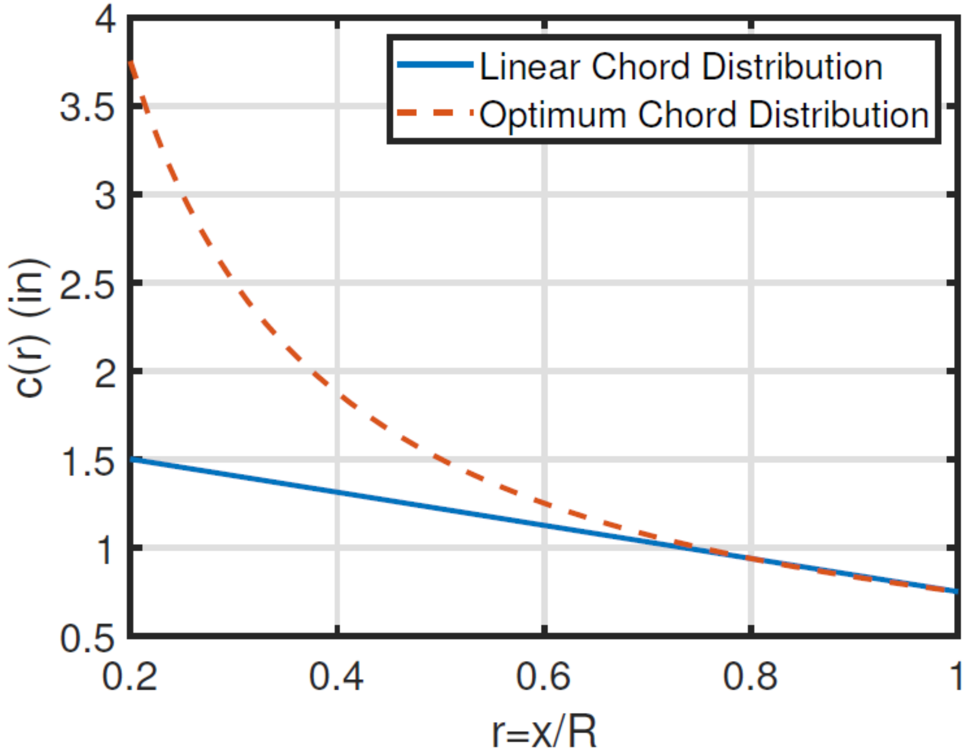
➢ c_{tip}= 0.75 in

➢ H = 0.03c

➢ NACA 5408 airfoil: α_0 = -4.84˚

➢ Taper = 2.5 to 1





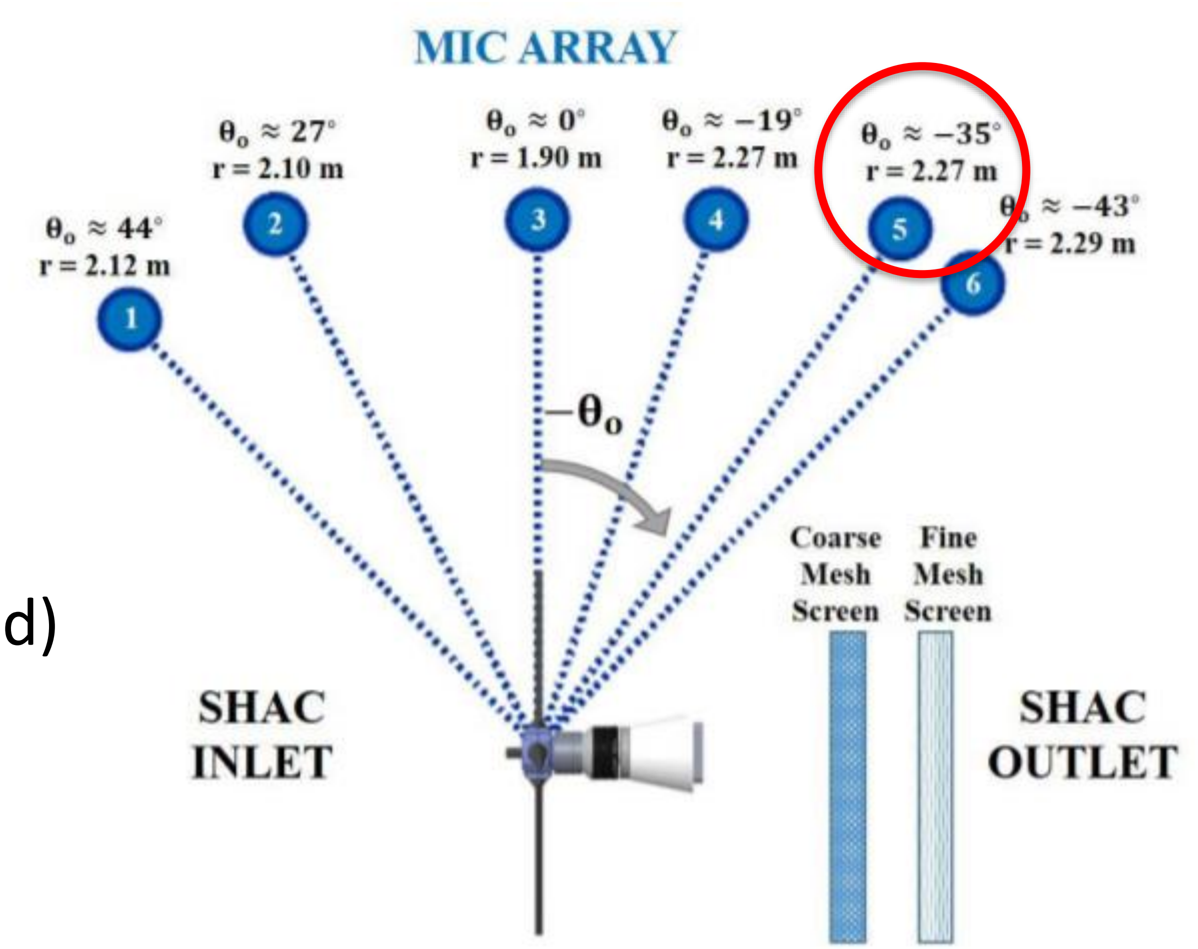
Technical Approach: Experimental Setup

- Blade materials

➢ SLA1 (Protolabs – Accura Xtreme)

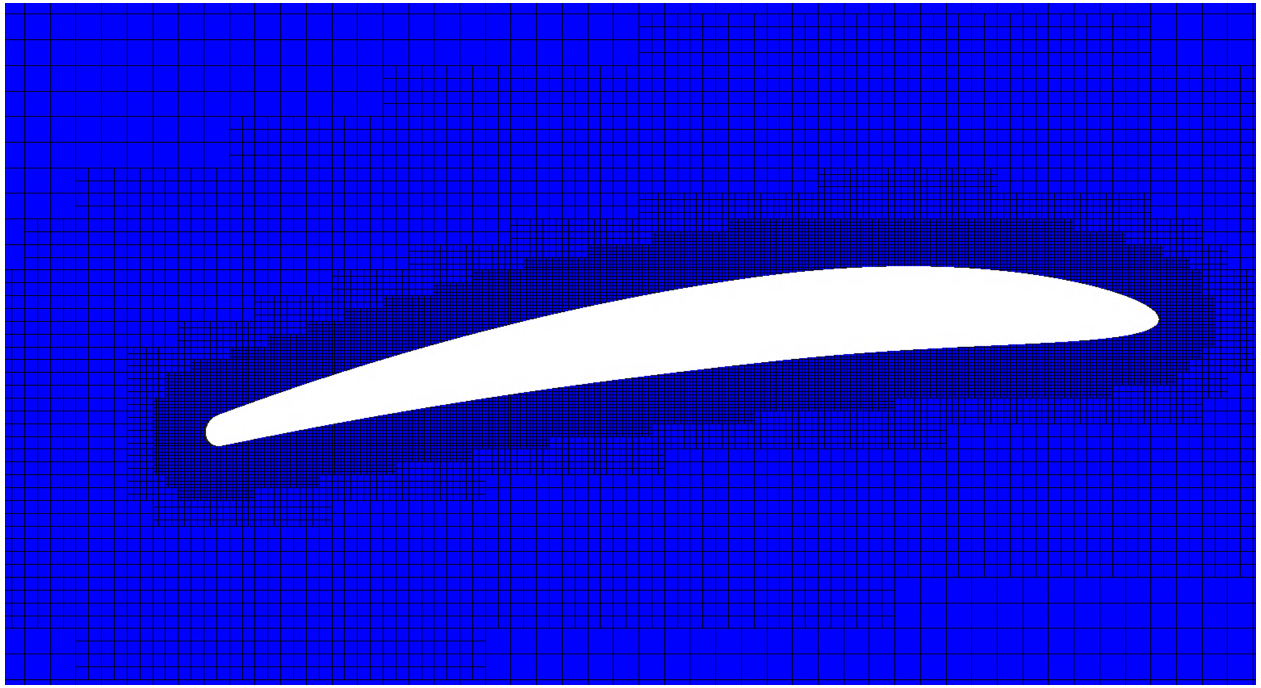
➢ SLA2 (Formlabs – Rigid 10K)

➢ SLS (Protolabs – PA12 Mineral-filled)



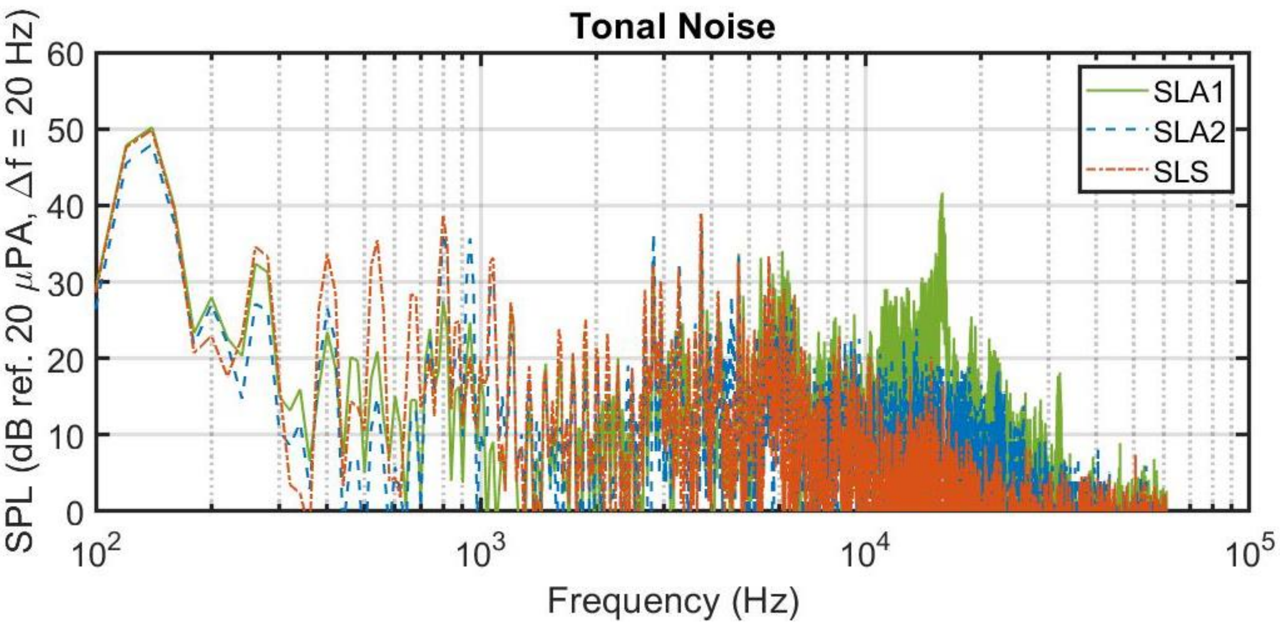
Technical Approach: Computational Setup

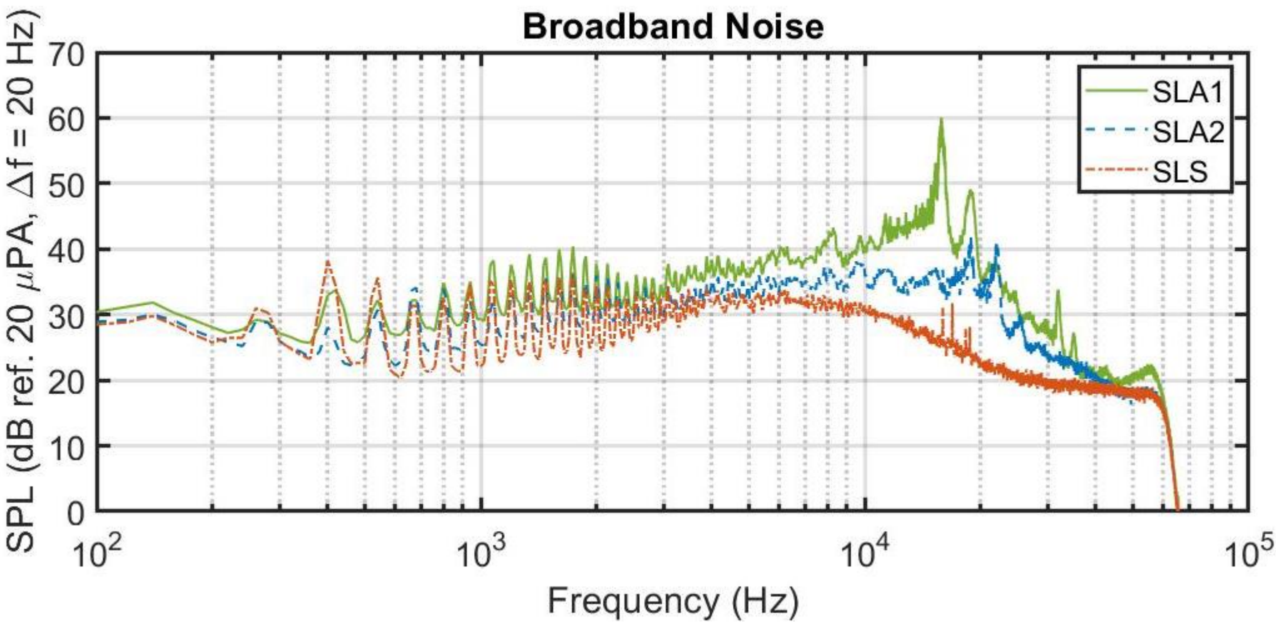
Case	Wall-functions	Finest Voxel Size (inches)	Finest Voxel Size (%c_{tip})
Transitional	Automatic (laminar/turbulent)	0.0025	0.33
Turbulent	Fully turbulent	0.0025	0.33



Results: Experimental

Case	Thrust (lb)
SLA1	1.91
SLA2	1.74
SLS	1.75

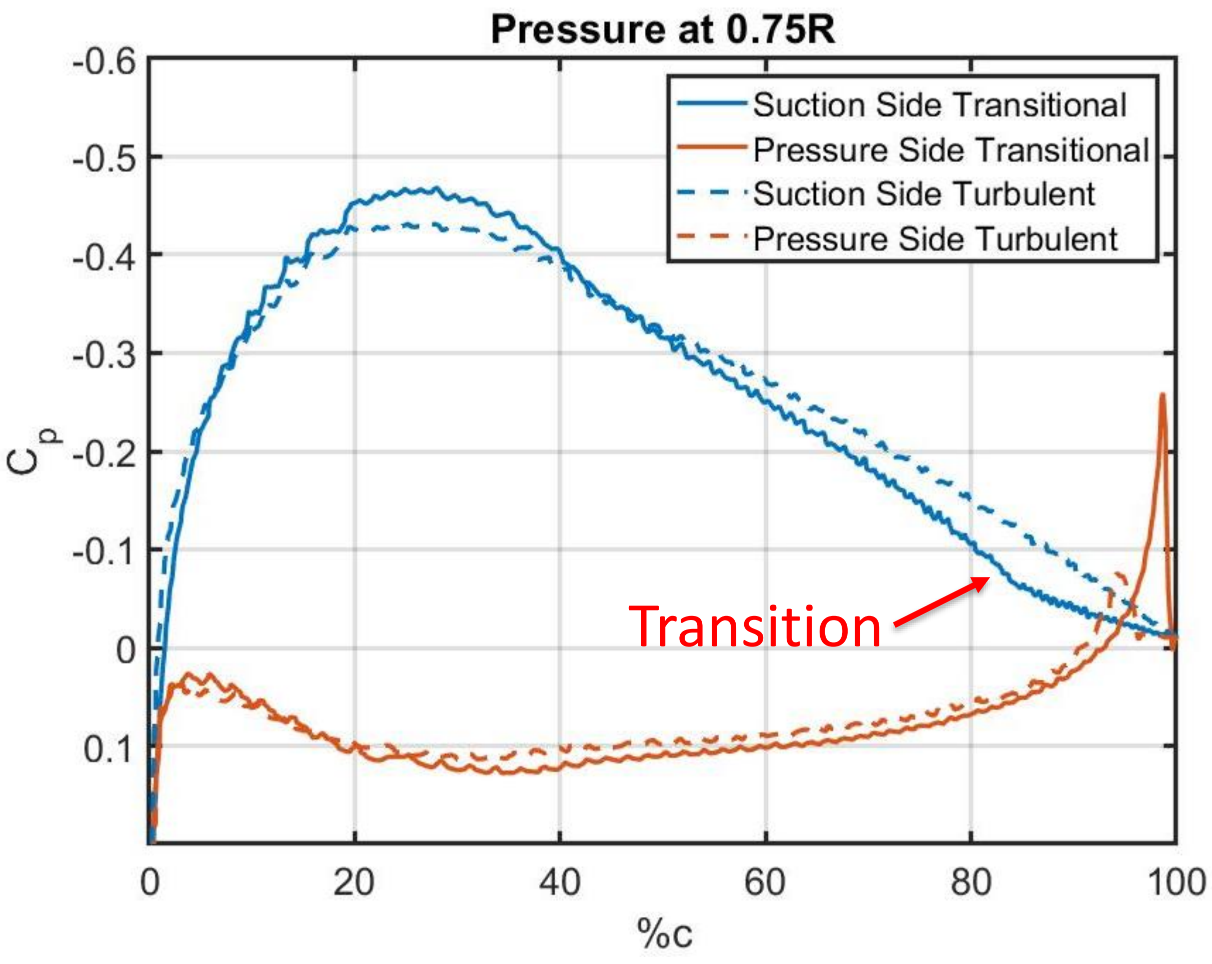


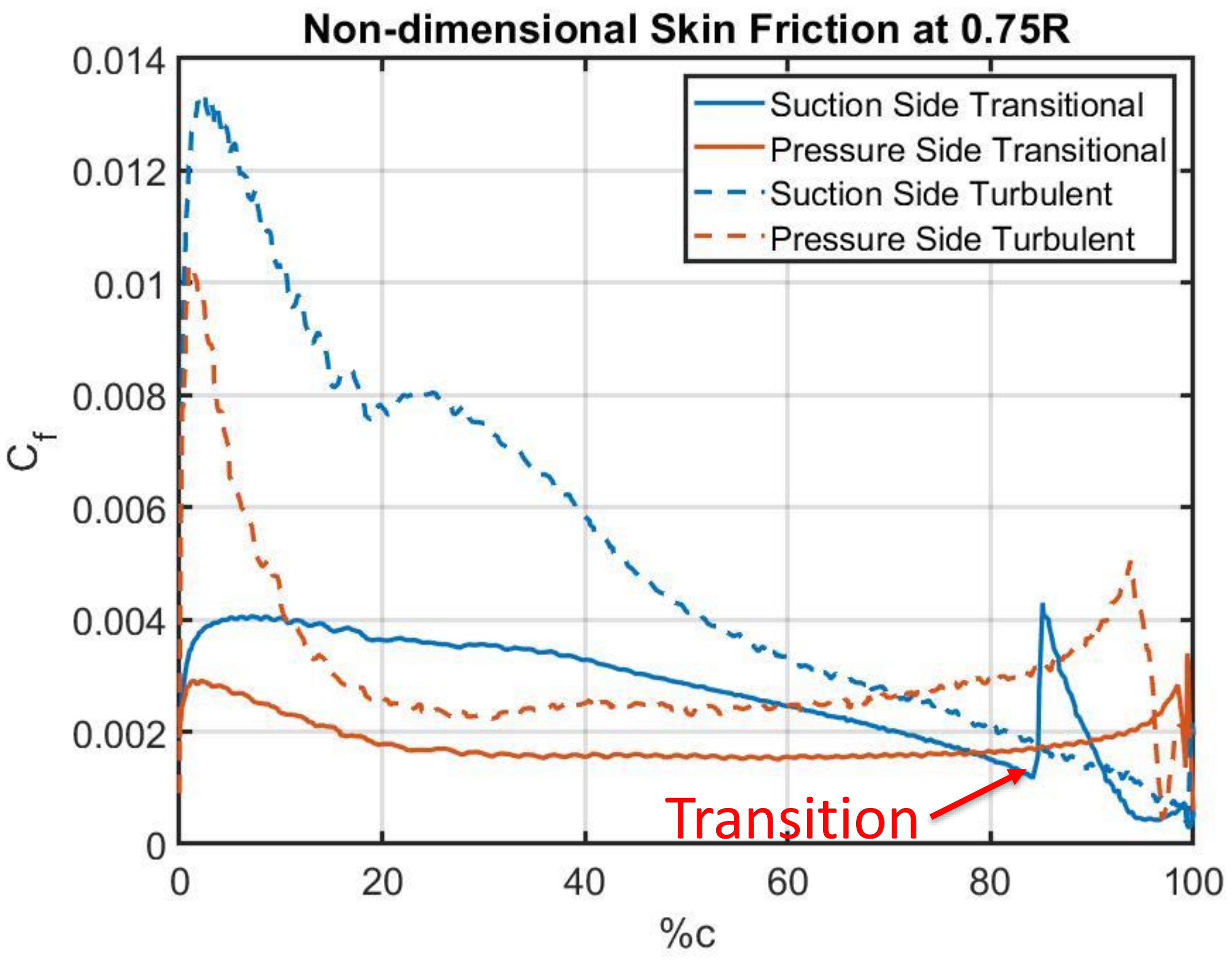


Results: Computational Aerodynamics

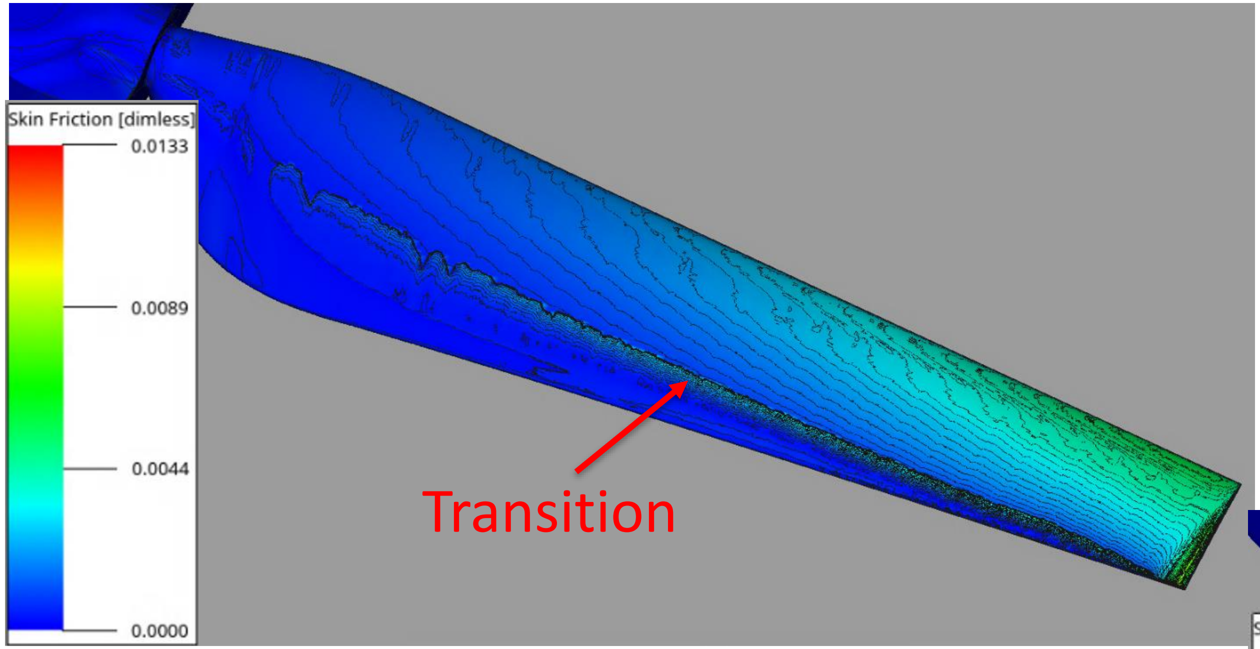
Case	Thrust (lb)
SLA1	1.91
SLA2	1.74
SLS	1.75
Transitional	**1.58 (9.20% from SLA2)**
Turbulent	**1.67 (4.57% from SLS)**

Results: Computational Aerodynamics



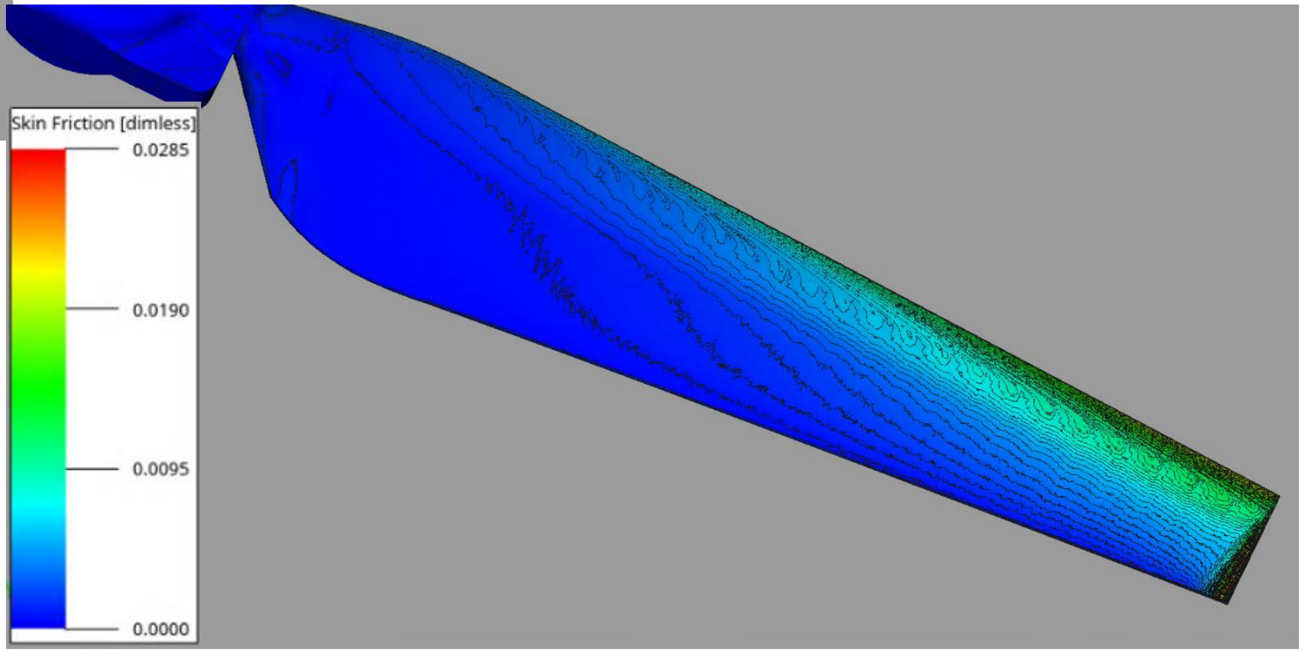


Results: Computational Aeroynamics

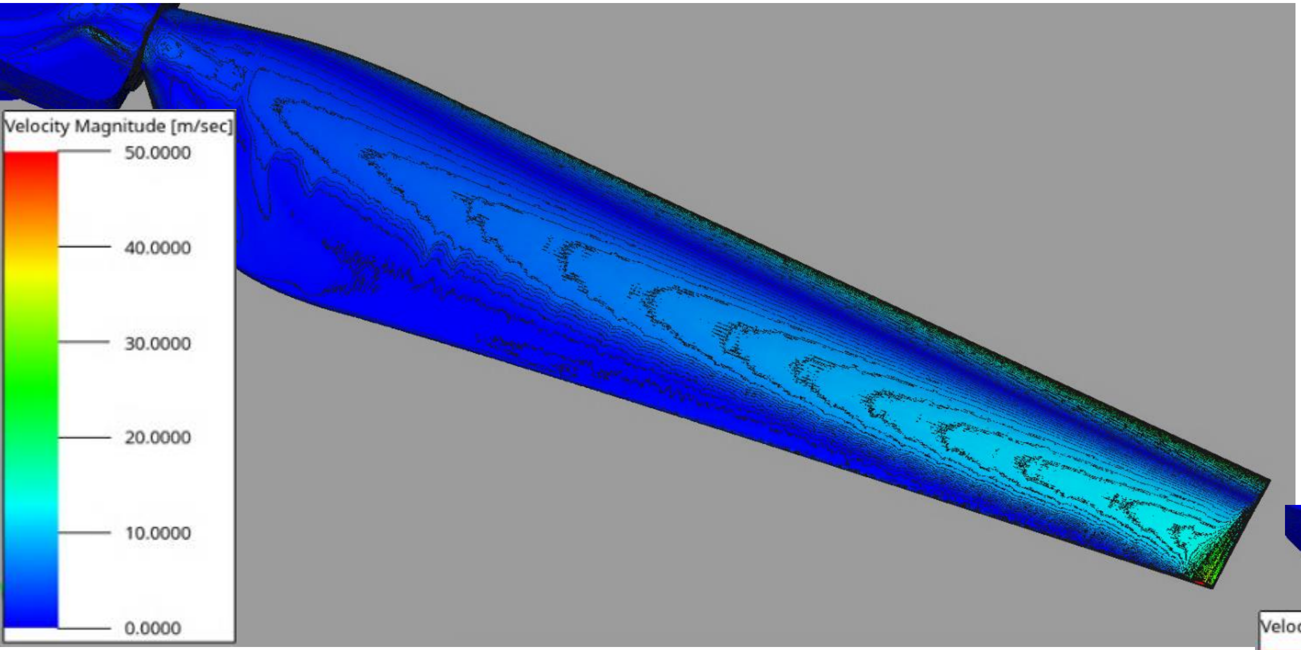


Skin Friction: Transitional

Skin Friction: Turbulent

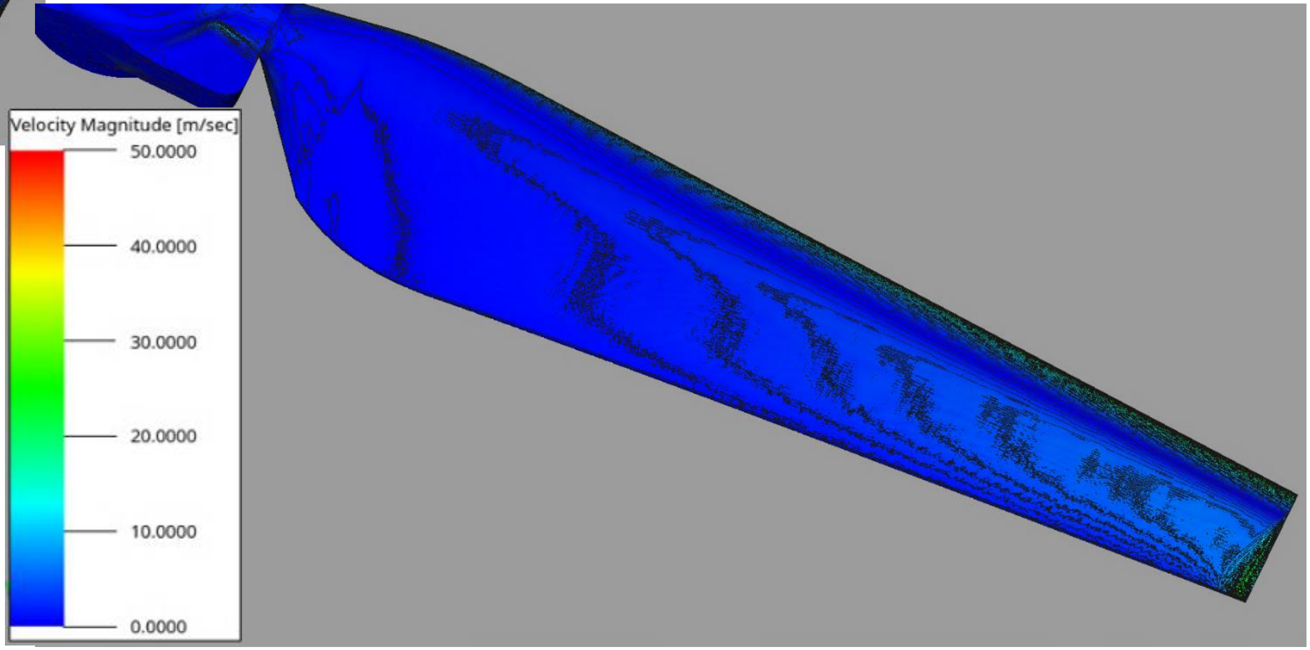


Results: Computational Aerodynamics



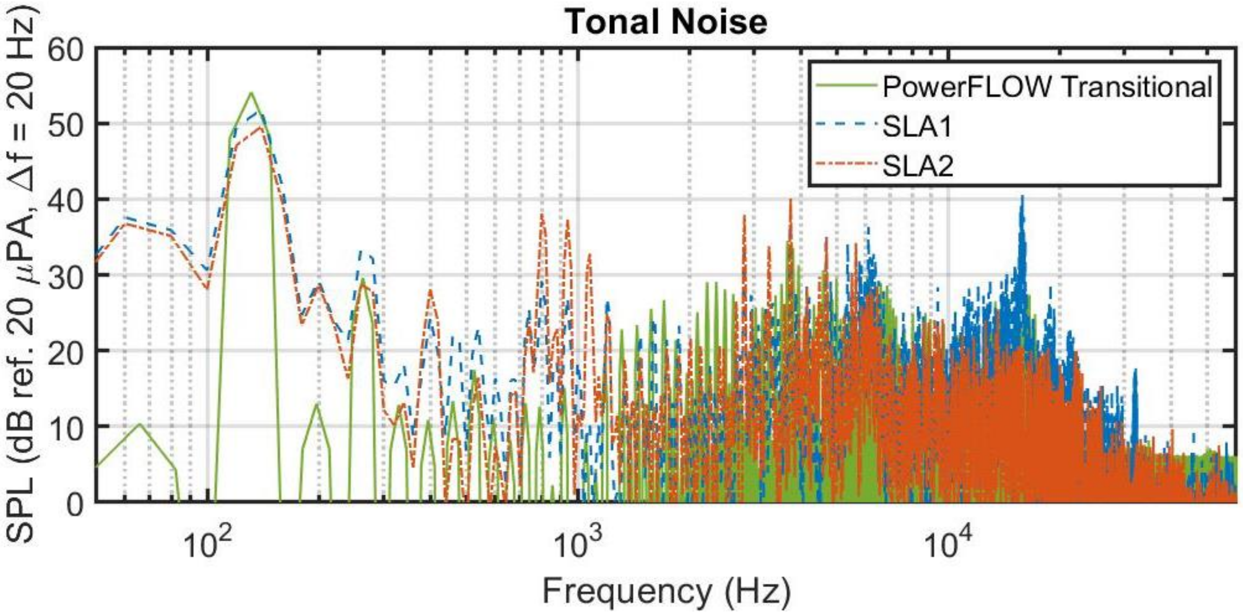
Velocity: Transitional

Velocity: Turbulent

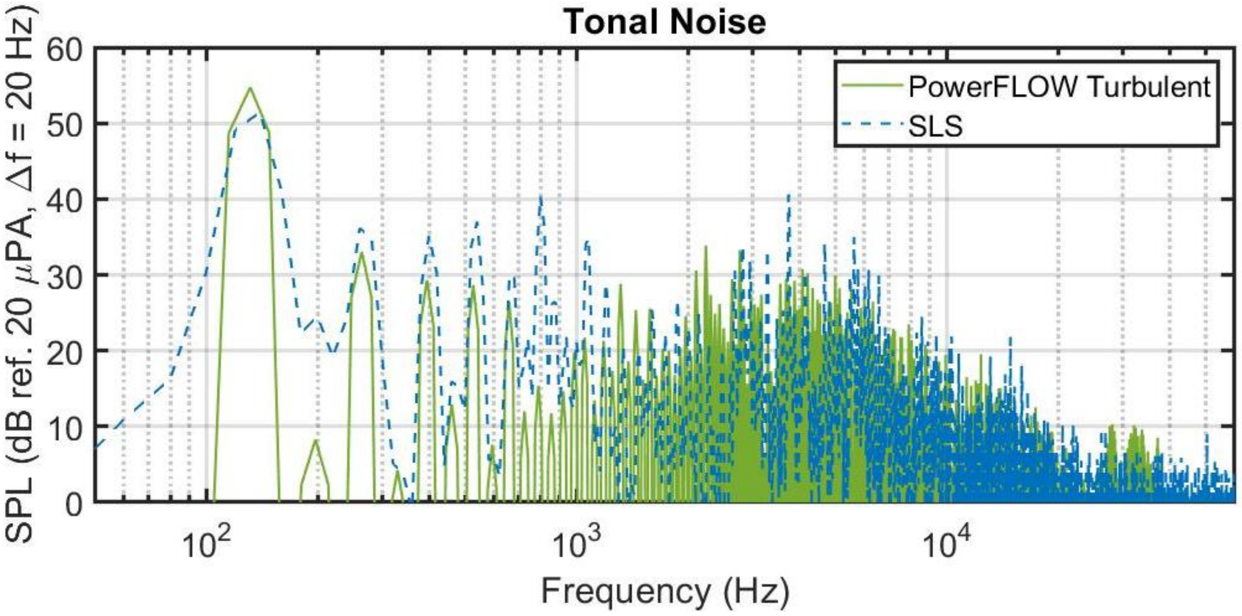


Results: Computational Tonal Noise

Transitional

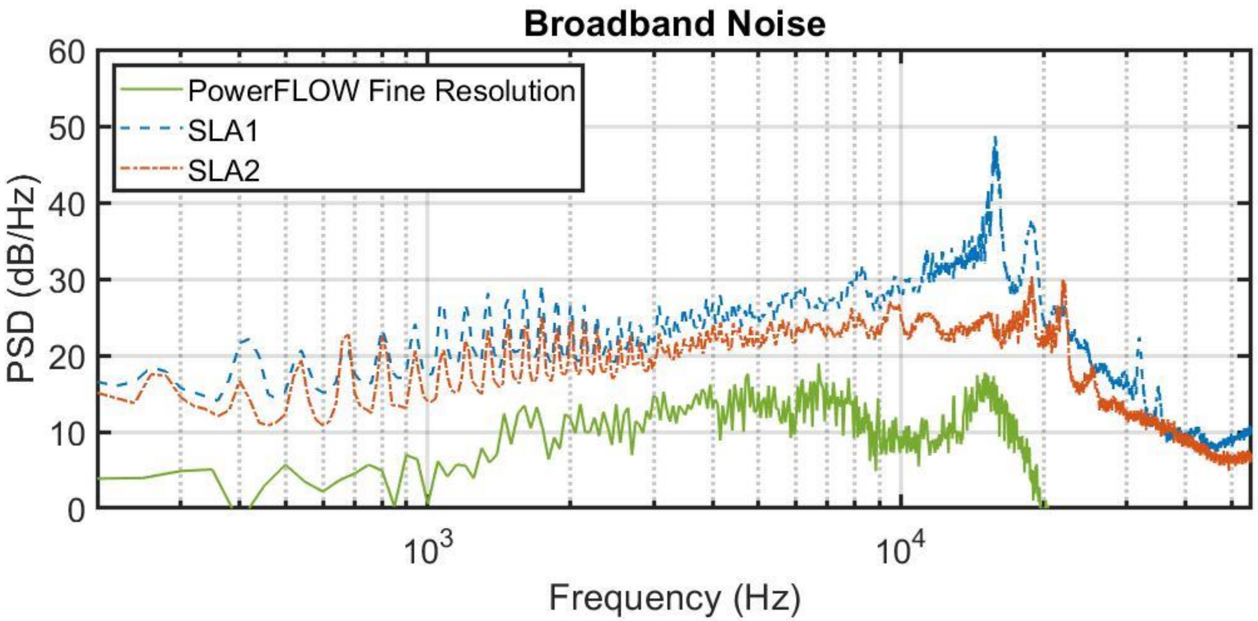


Turbulent

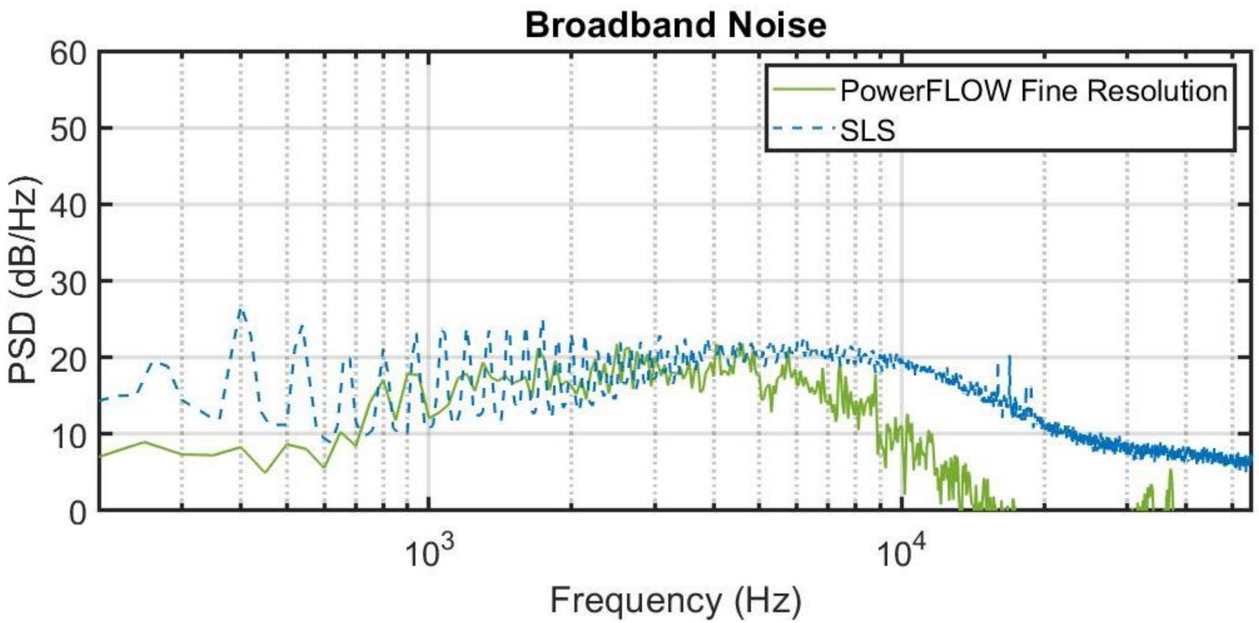


Results: Computational Broadband Noise

Transitional



Turbulent



Summary

- LBL-VS noise is highly dependent on surface roughness.
- Different wall-functions can be used to simulate different boundary layer regimes.
- PowerFLOW is able to predict boundary layer transition (possibly separation bubble).
- Broadband noise results may be improved by increasing cell resolution.

Acknowledgments

- Revolutionary Vertical Lift Technology (RVLT) Project funding

Questions?