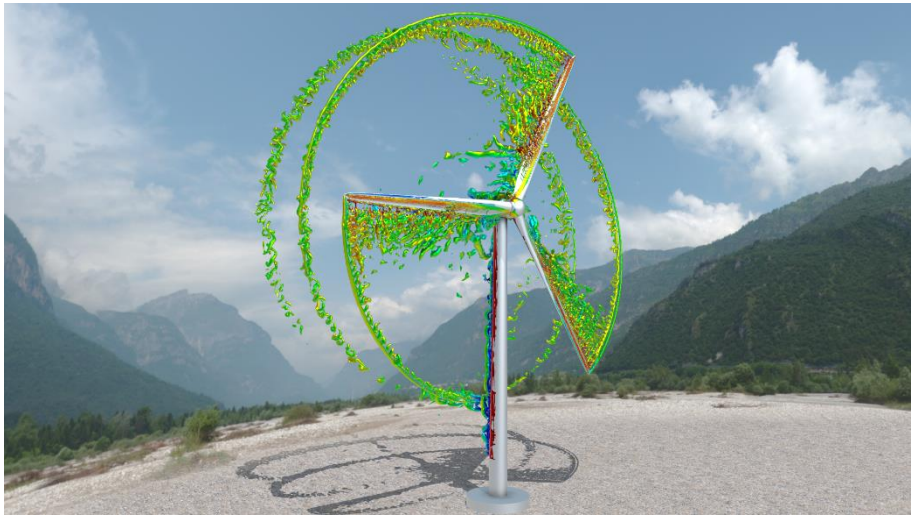
Wind Turbine Aerodynamics and Aeroacoustics



3DEXPERIENCE®

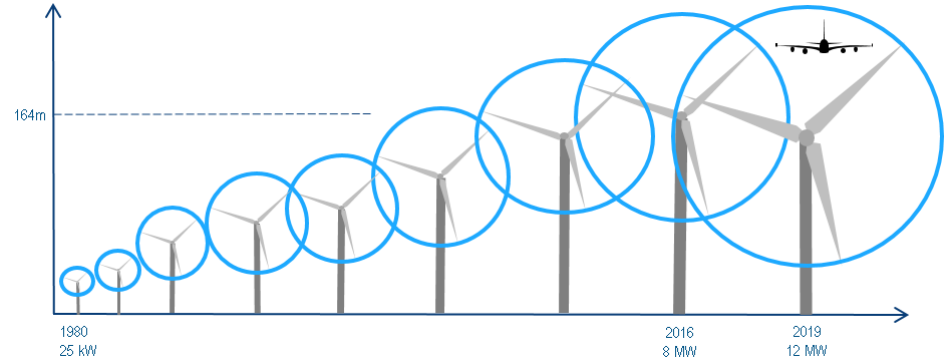
Dr. Wouter VAN DER VELDEN
Industry Process Expert Specialist, Energy & Materials

DASSAULT SYSTEMES | The 3DEXPERIENCE® Company

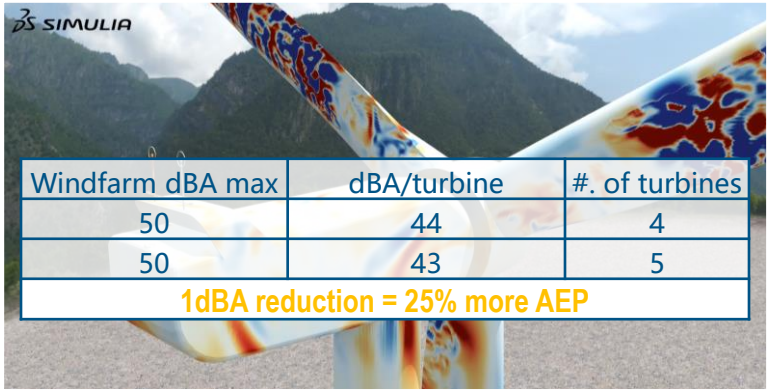
Global Warming

Trends

Increasing Turbine Size



Noise



Windfarm dBA max	dBA/turbine	#. of turbines
50	44	4
50	43	5
1dBA reduction = 25% more AEP		

Challenges

Lowering Cost of Energy

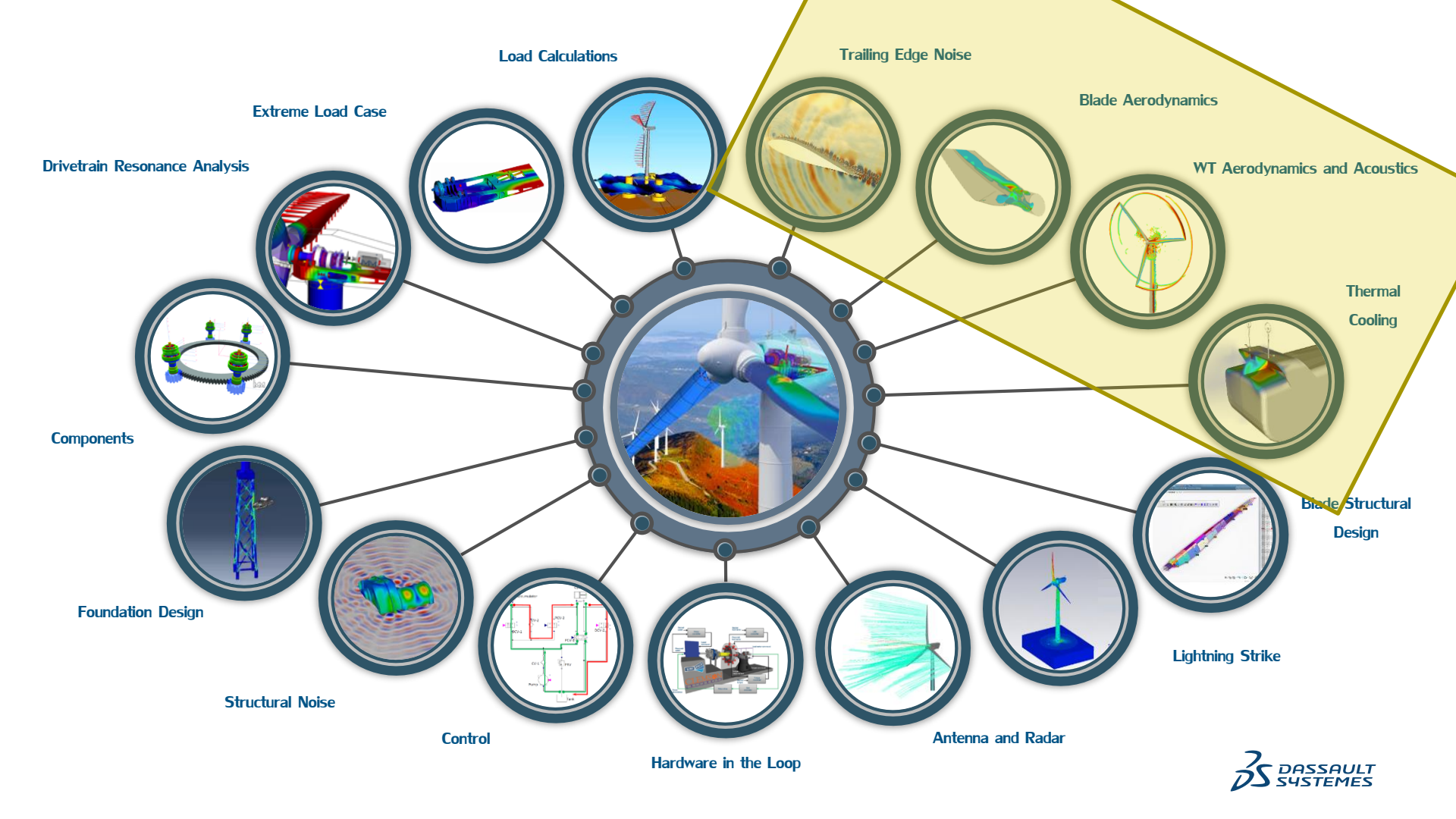
CAPEX

- Generate accurate load predictions
- Reduce turbine cost
- Lower noise
- Minimize prototypes and testing
- Decreasing R&D time and resources
- Enable innovation

OPEX

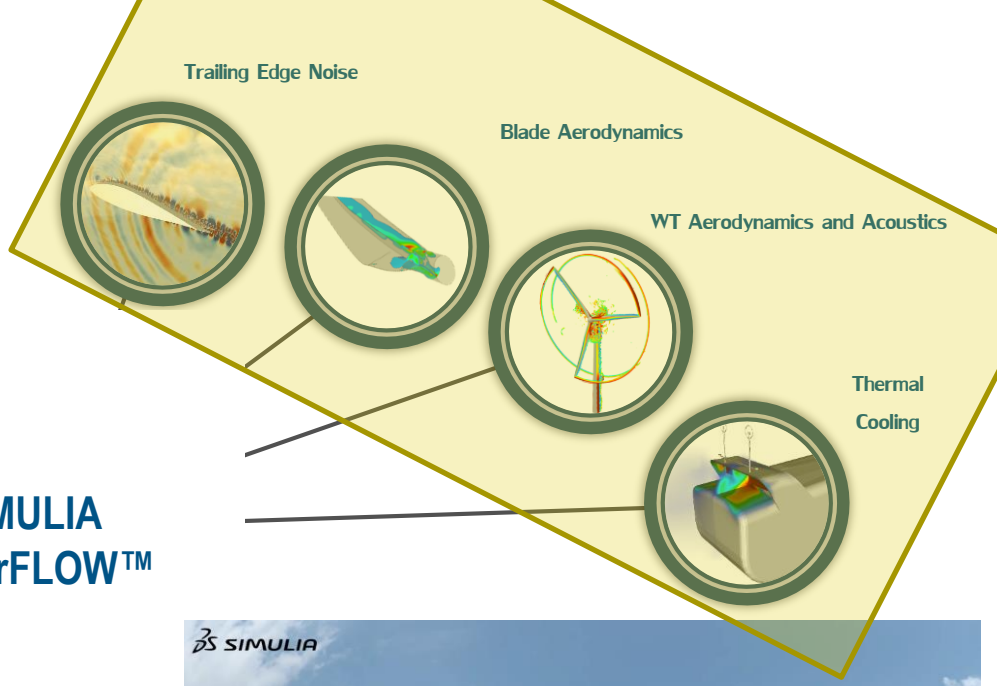
- Avoid risk
- Maximize turbine output
- Increase nighttime operation
- Extend lifetime

Wind Turbine Engineering


Load Calculations
Extreme Load Case
Drivetrain Resonance Analysis
Components
Foundation Design
Structural Noise
Control
Hardware in the Loop
Antenna and Radar
Lightning Strike
Blade Structural Design
Thermal
Cooling
WT Aerodynamics and Acoustics
Blade Aerodynamics
Trailing Edge Noise

- Wind farm and urban siting
- Wind Turbine aero, thermal & acoustics
- Ducted wind turbines
- Vortex generators
- Icing
- Dynamic stall
- Stall noise
- Tip noise
- Trailing edge noise
- ...

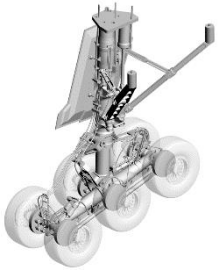
SIMULIA PowerFLOW™

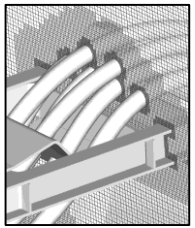


Why PowerFLOW

Robust and streamlined meshing

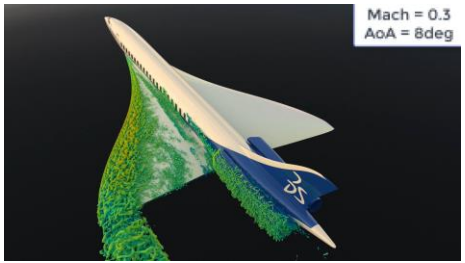
Cut preparation time from weeks to days on fully detailed geometries

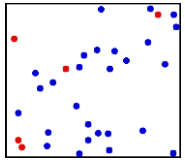




Fast solver

1-to-2 order of magnitude faster than LES for comparable accuracy





Kinetic Theory of Flow Motion

Boltzmann Equation

Discrete Solution on a Lattice

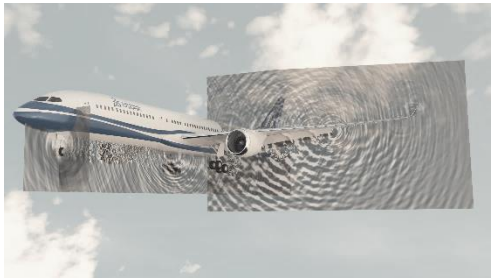
Lattice Boltzmann Model

Inherently Unsteady & Scale-Resolved

LBM/VLES

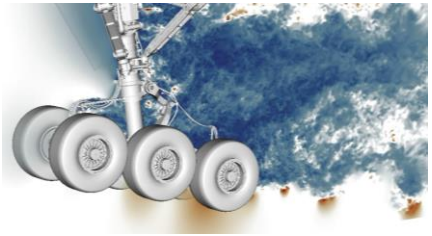
Low Numerical Dissipation

Accurate aeroacoustics near field direct predictions



Complex flows

Ideal for full detailed geometries and off-design



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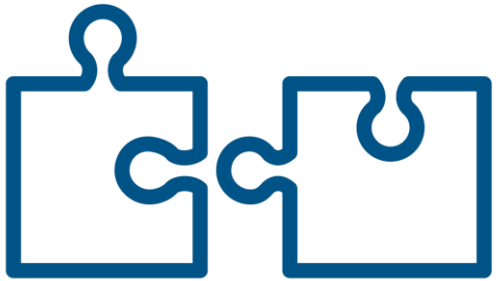
LBM/VLES Foundation in PowerFLOW

Unconventional LB momentum solver:

- Low-dissipation and stable collision operator
- Transonic LB formulation
- Accurate body representation (surfel concept)
- Porous media with interface effects



Very Large Eddy Simulation model:

- Kinetic theory representation of a **gas of eddies** → best establishment of the Boussinesq hypothesis
- Reynolds stresses consequences of a modified dynamic equilibrium
- Non-linear (far from equilibrium) and memory effects of unresolved turbulence scales inherently accounted for

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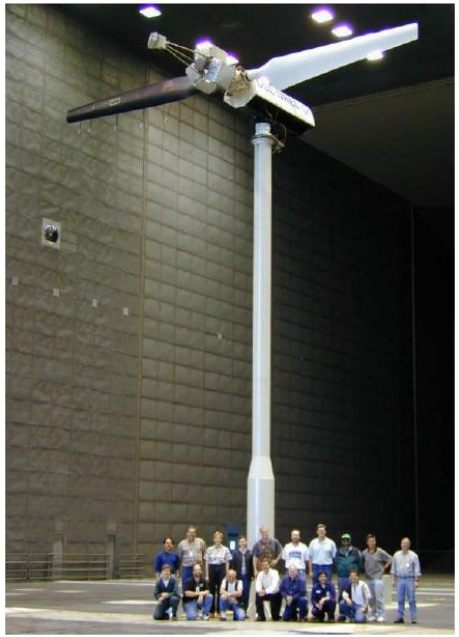
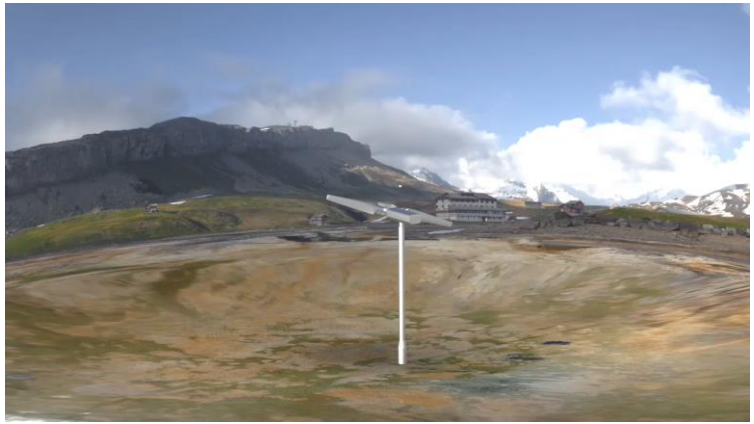
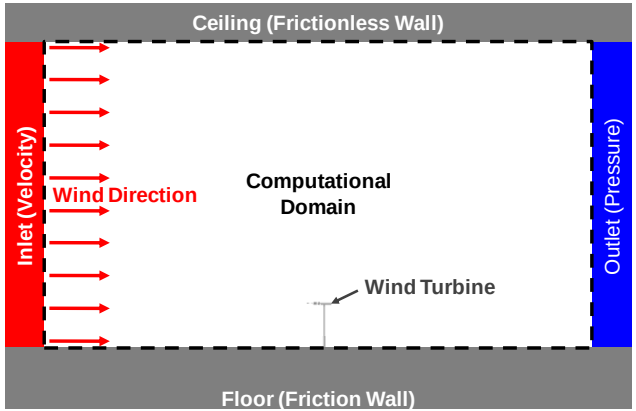
Application overview

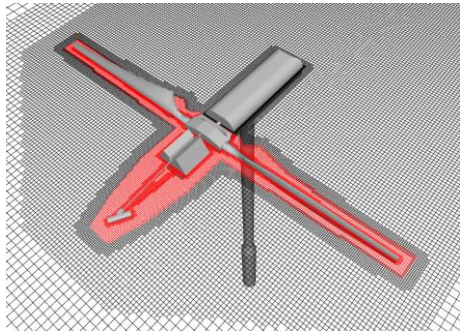
Wind turbine aero, thermal & acoustics

NREL 20kW turbine (1/3)









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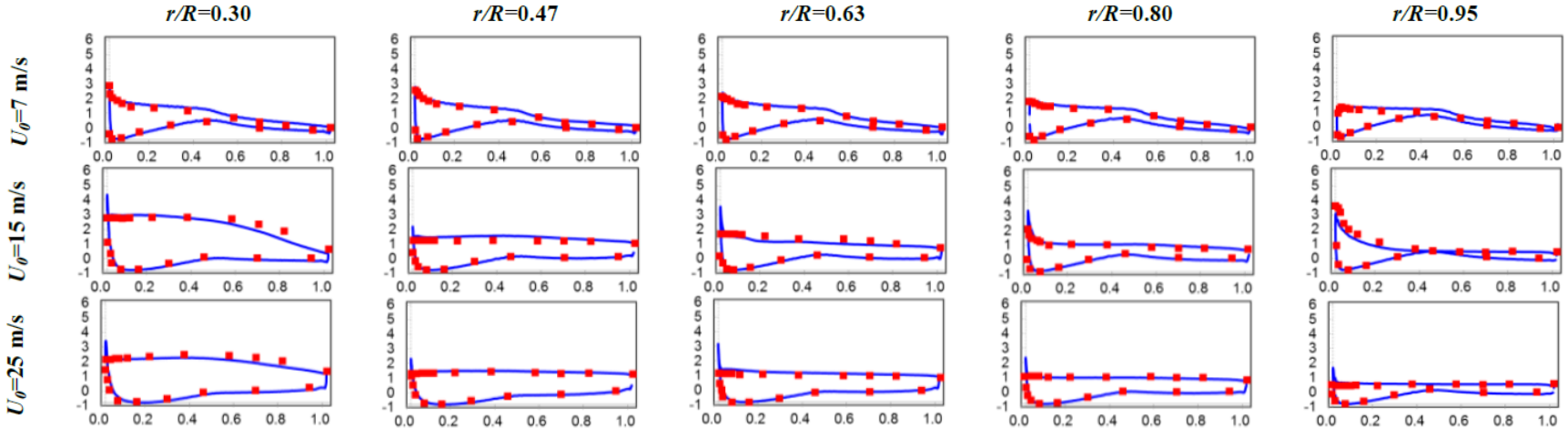
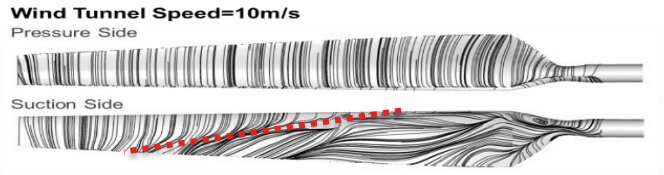
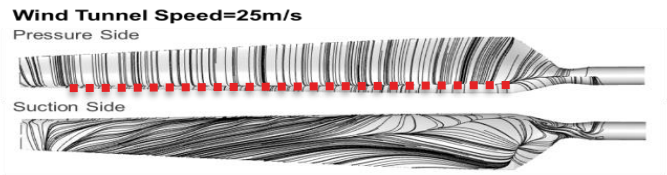
Wind turbine aero, thermal & acoustics

NREL 20kW turbine (2/3)



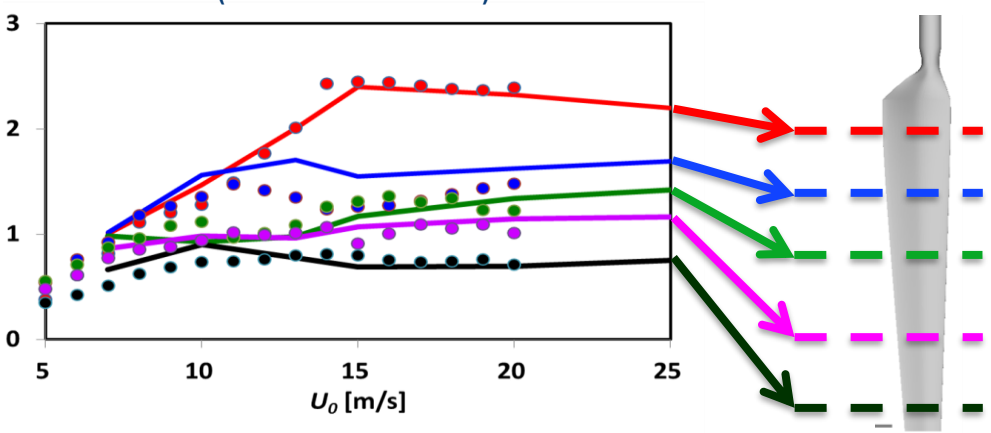




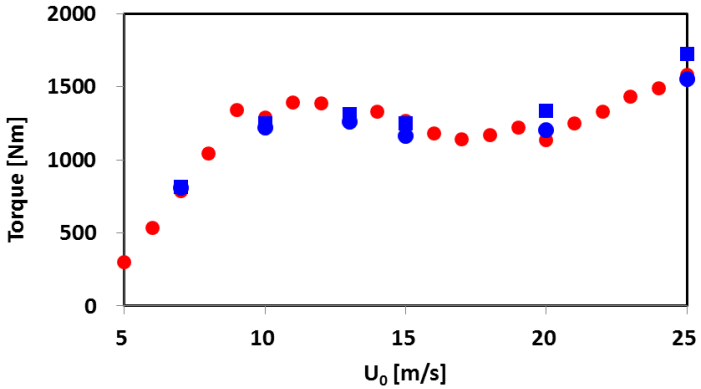
Wind turbine aero, thermal & acoustics

NREL 20kW turbine (3/3)

Normal force coefficient
(dots: measurements)



Torque vs. inflow speed
(red: measurements)



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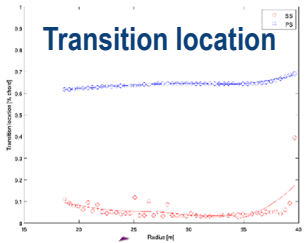
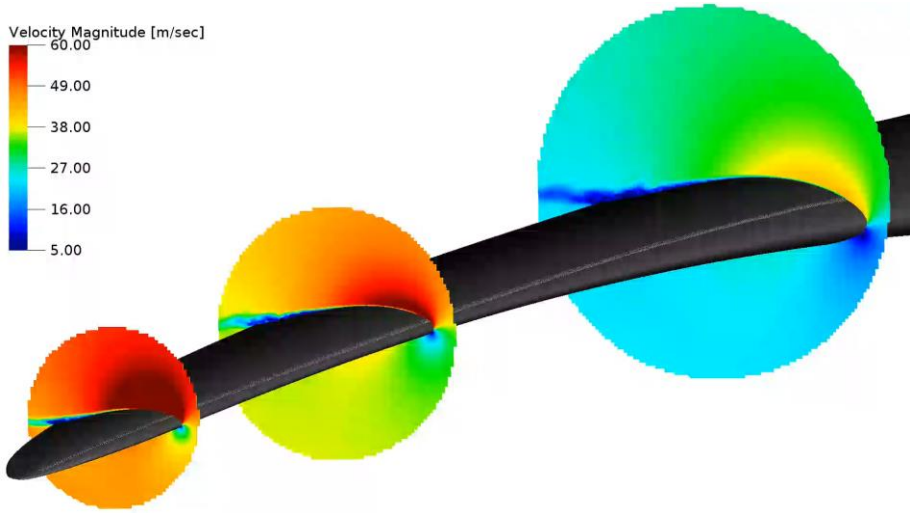
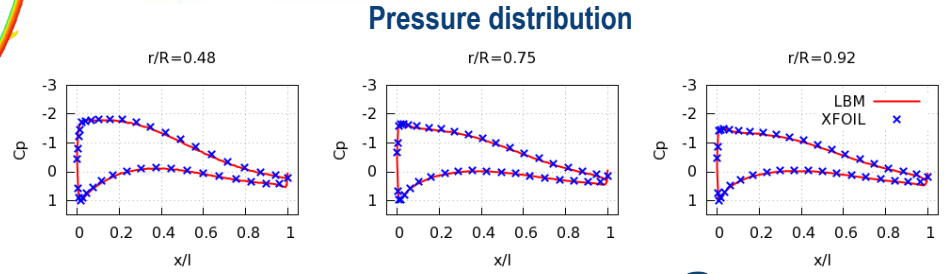
Wind turbine aero, thermal & acoustics

NM80 2.3MW turbine (1/3)

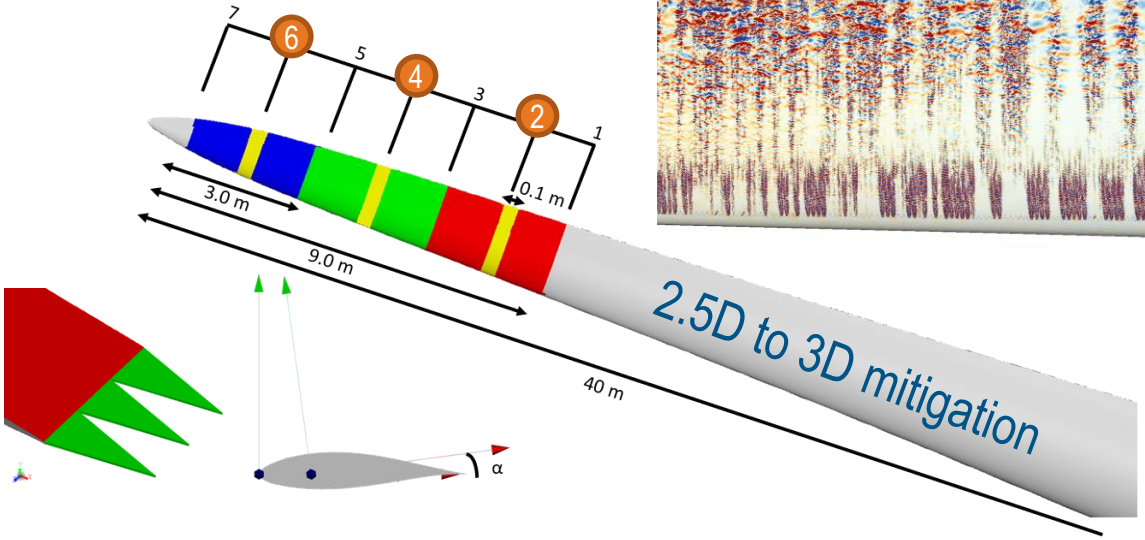






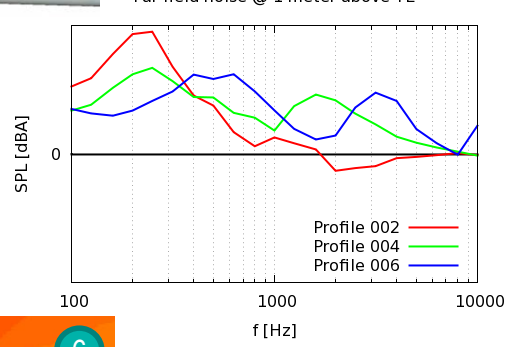
Wind turbine aero, thermal & acoustics

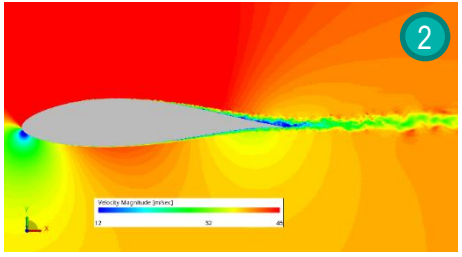
NM80 2.3MW turbine (2/3)

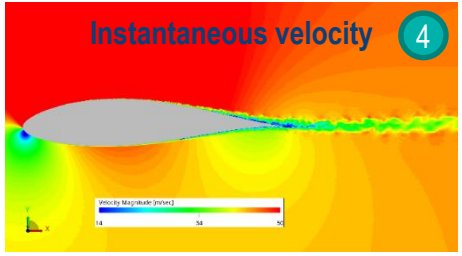


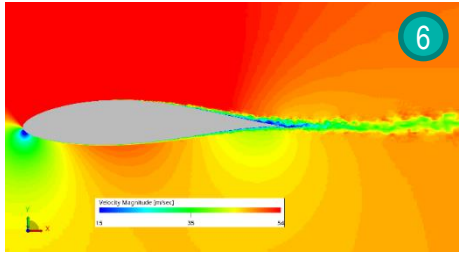
Pressure dilatation field

Far-field noise above trailing edge









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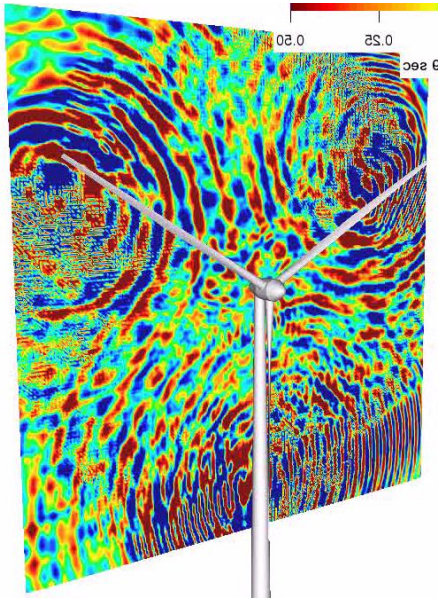
Wind turbine aero, thermal & acoustics

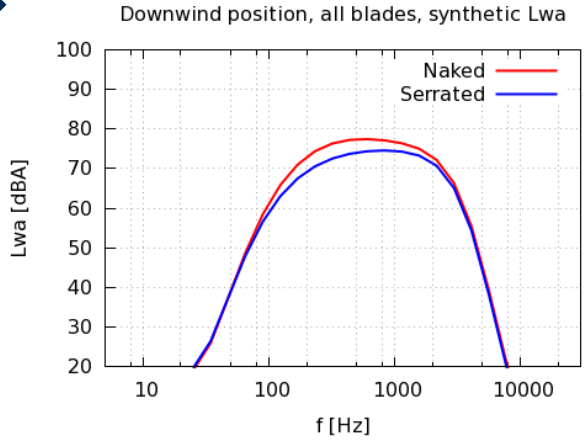
NM80 2.3MW turbine (3/3)

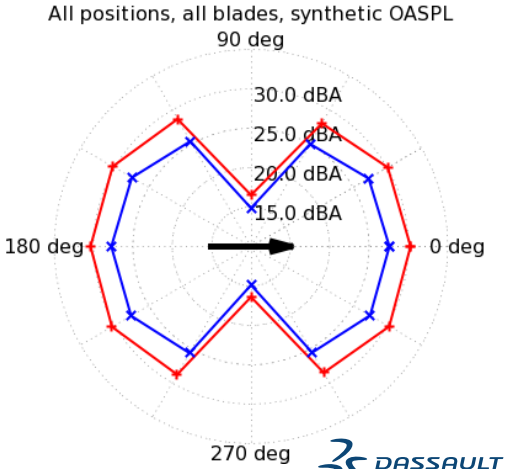


IEC certification noise includes:

- Realistic noise sources
- Doppler effect
- Atmospheric effect
- Ground reflection

10 m 100 m





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Wind turbine aero, thermal & acoustics

Automated workflow

- Noise emission and directivity at residents location is automated
  1. Input airfoil data and characteristics
  2. 2.5D trailing edge noise PowerFLOW workflow run employed on SIMULIA Cloud™ (interactive cluster with +60k cores available)
  3. Direct 2.5D output, such as pressure distribution, boundary layer development, near-field and far-field noise
  4. 2.5D to 3D noise mitigation tool
  5. Residents noise prediction

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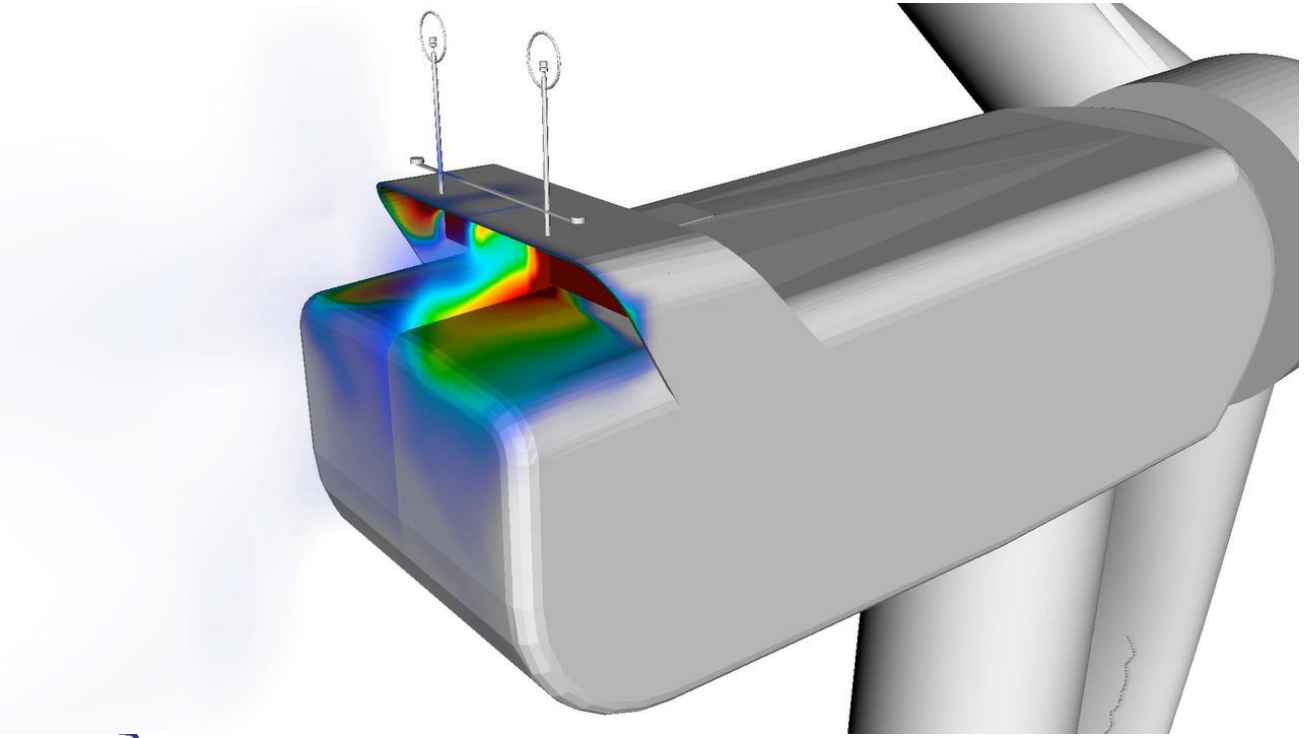
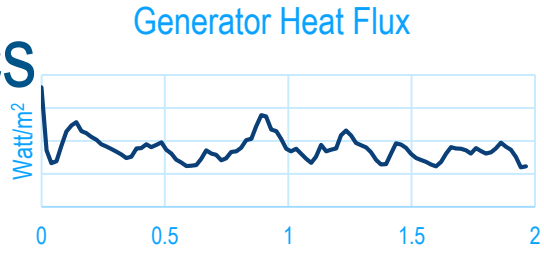
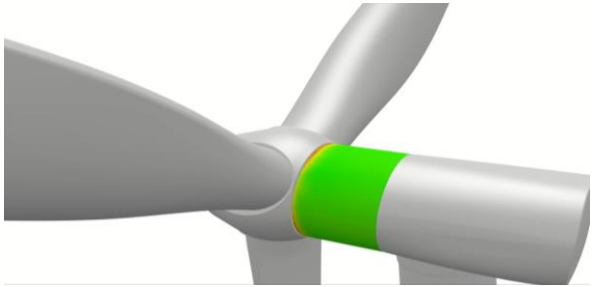
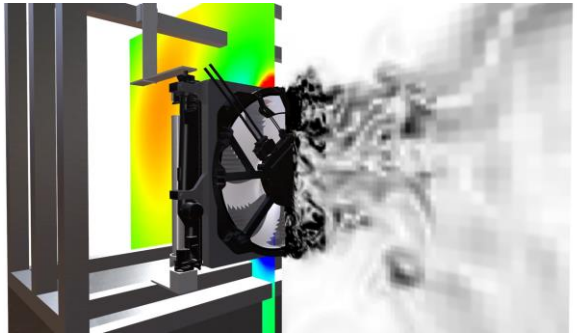
Wind turbine aero, thermal & acoustics

SANDIA / NREL 5MW turbine



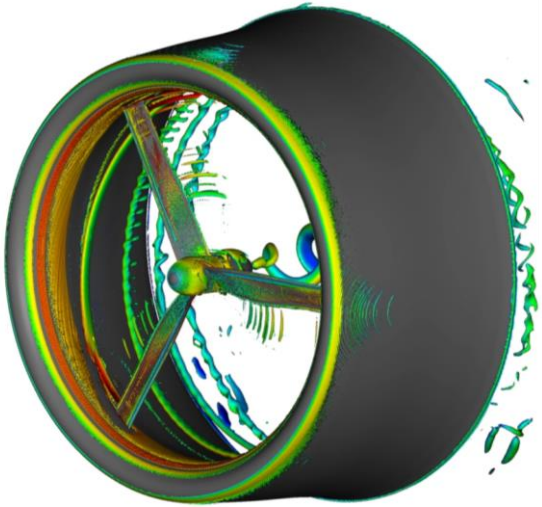


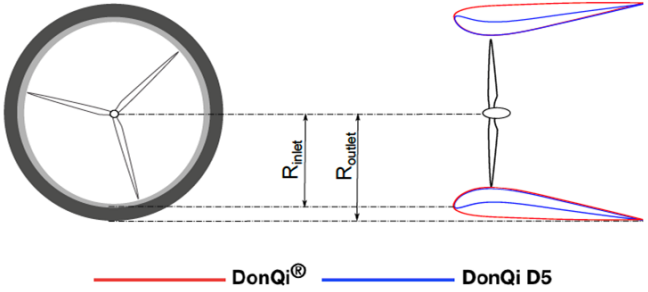




Ducted wind turbines

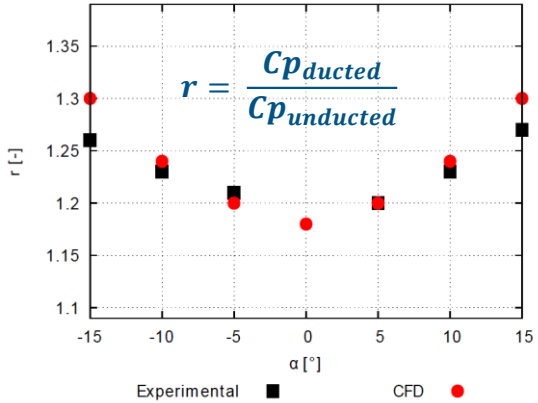
Diffuser Augmented Wind Turbines



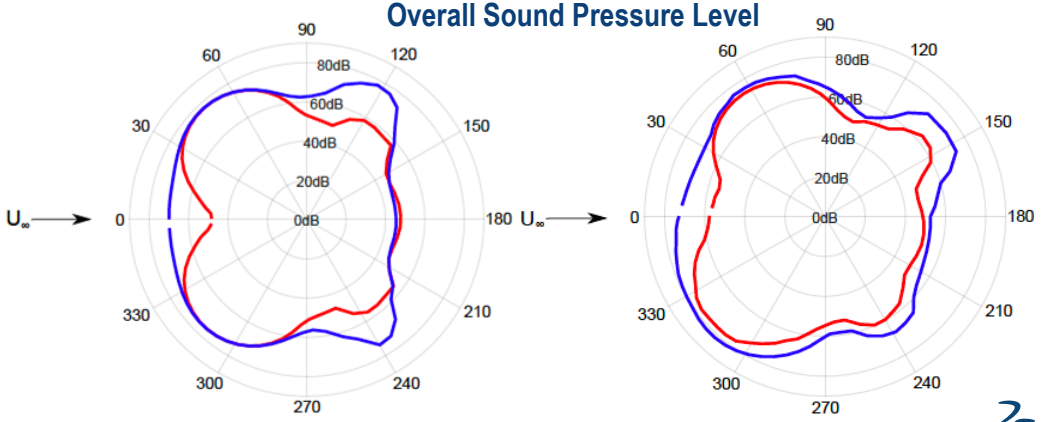


Augmentation factor

$$r = \frac{Cp_{ducted}}{Cp_{unducted}}$$



Overall Sound Pressure Level



α = 0.0 degrees

α = 7.5 degrees

Rotational speed	370 RPM
Reynolds number	330,000
Inflow angle	0 & 7.5 deg

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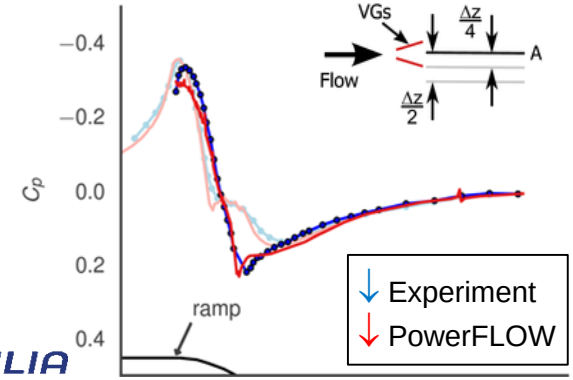
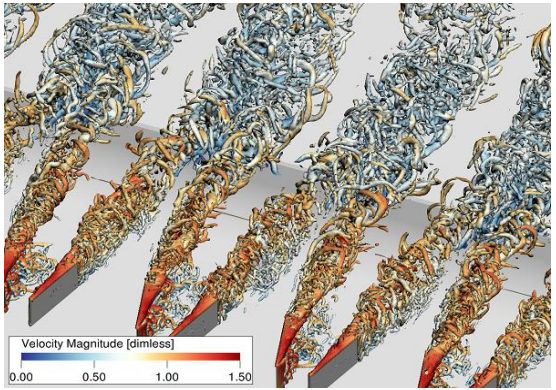
Vortex generators

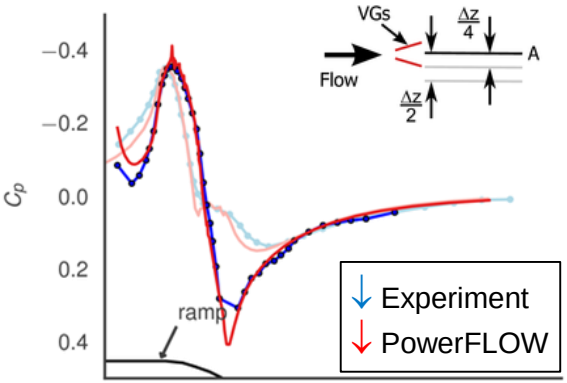
Backward facing ramp

Sub-boundary layer



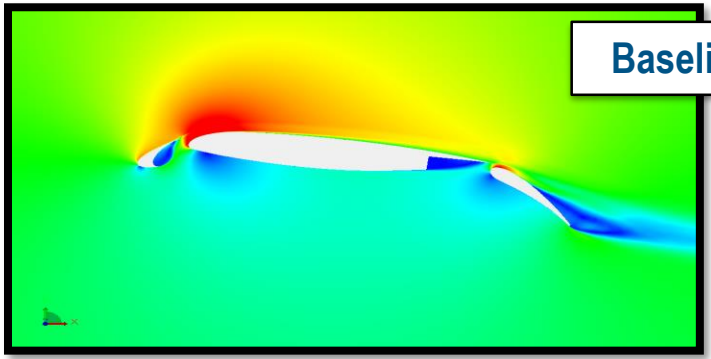
Conventional



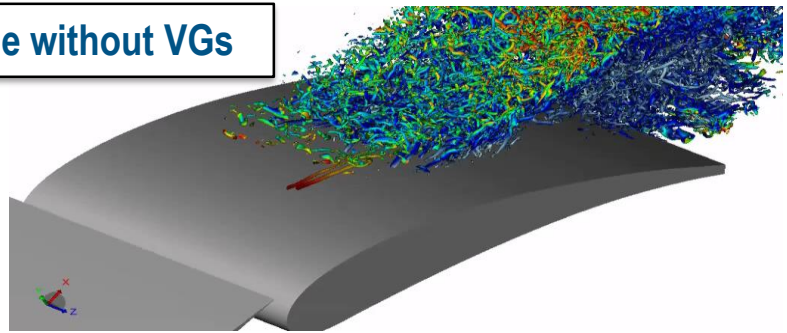


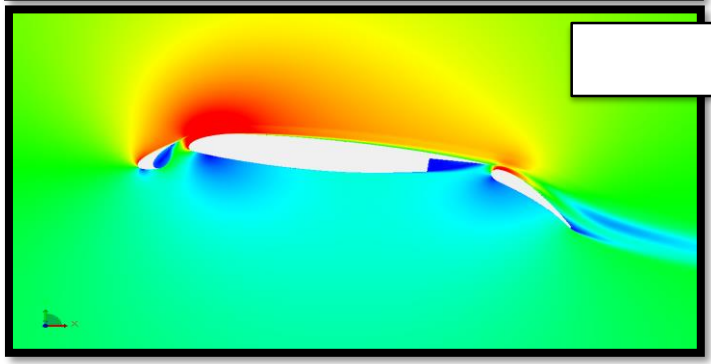
Vortex generators

MD30P30N high lift airfoil

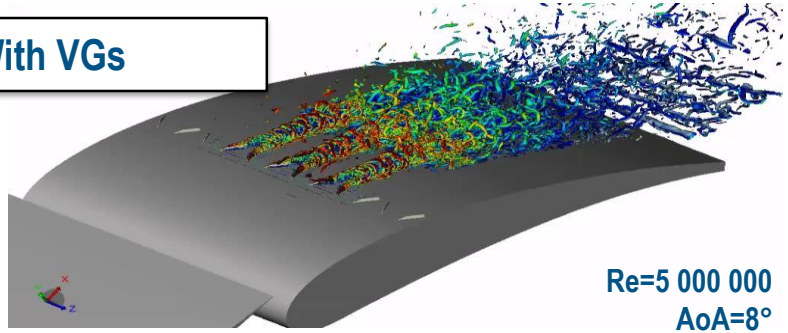


Baseline without VGs





With VGs



Re=5 000 000
AoA=8°

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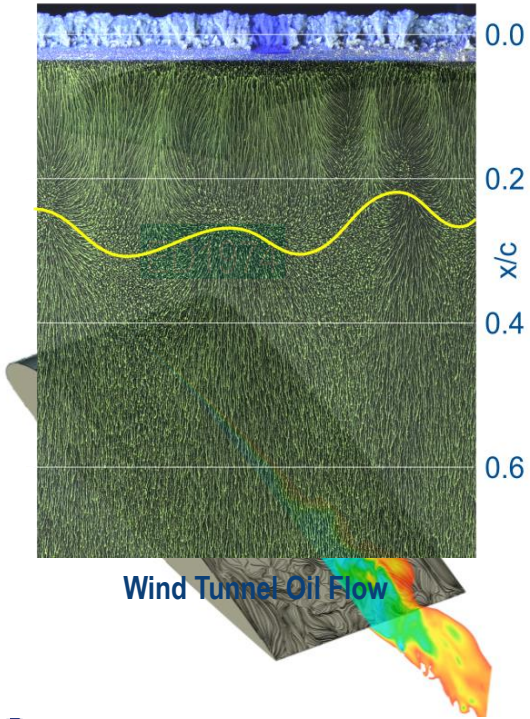
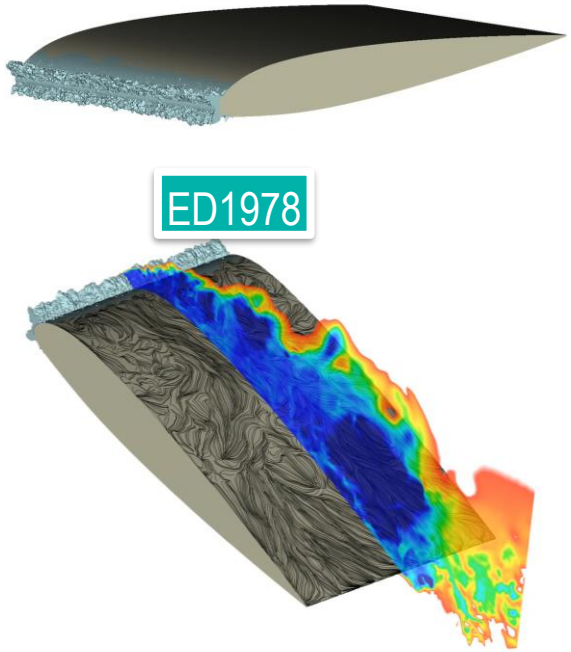
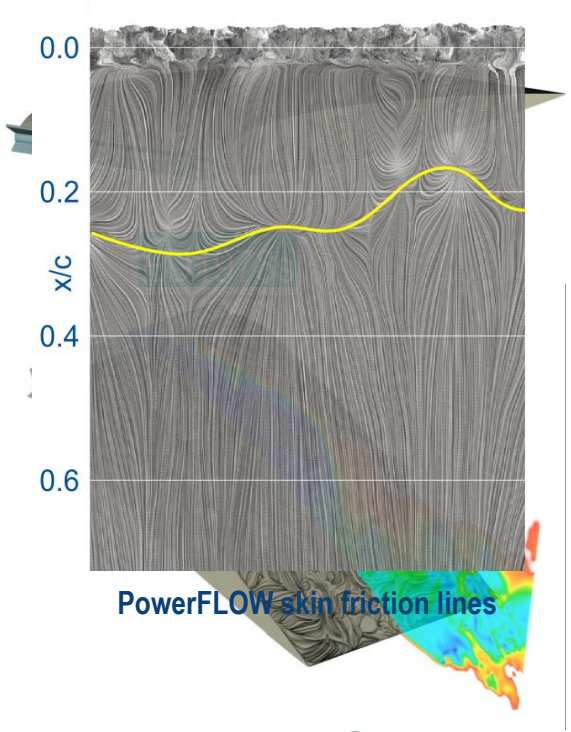
Icing

NASA ED1978 (1/2)



Wind Tunnel Oil Flow

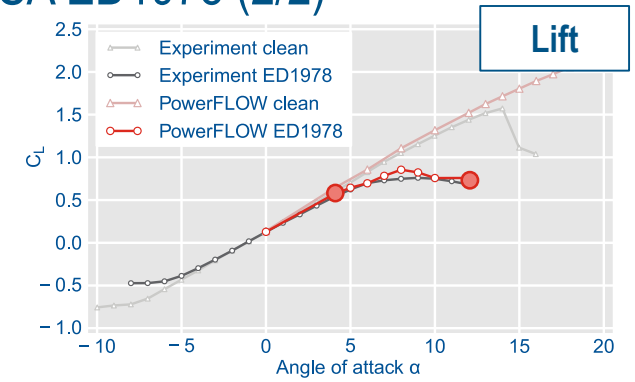


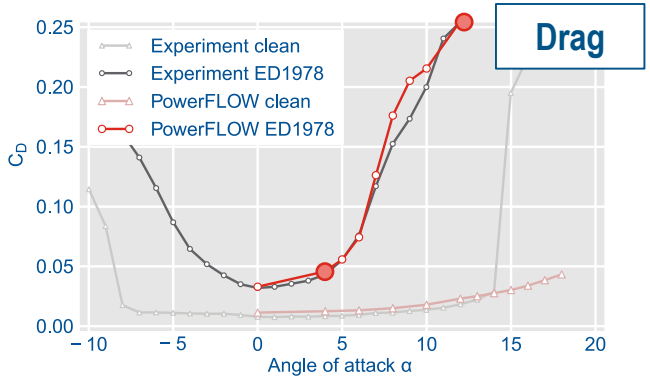


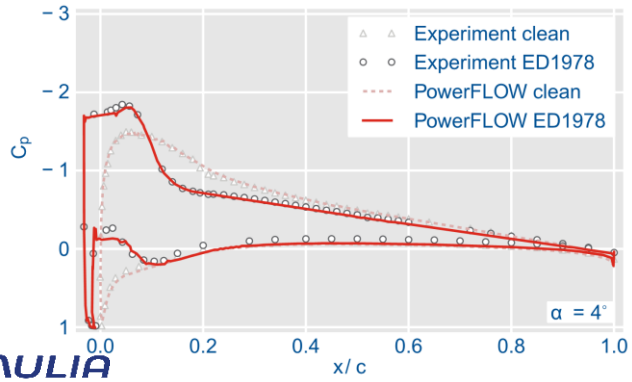
PowerFLOW skin friction lines

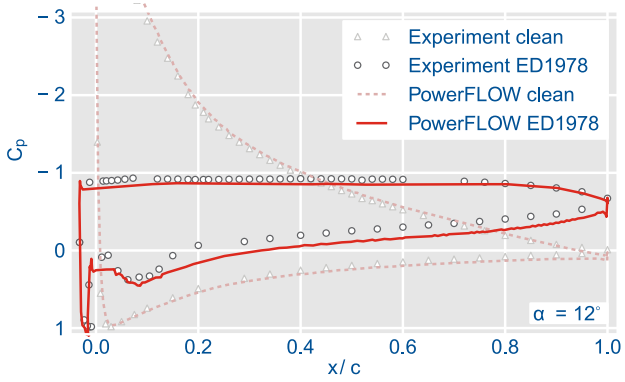
Icing

NASA ED1978 (2/2)

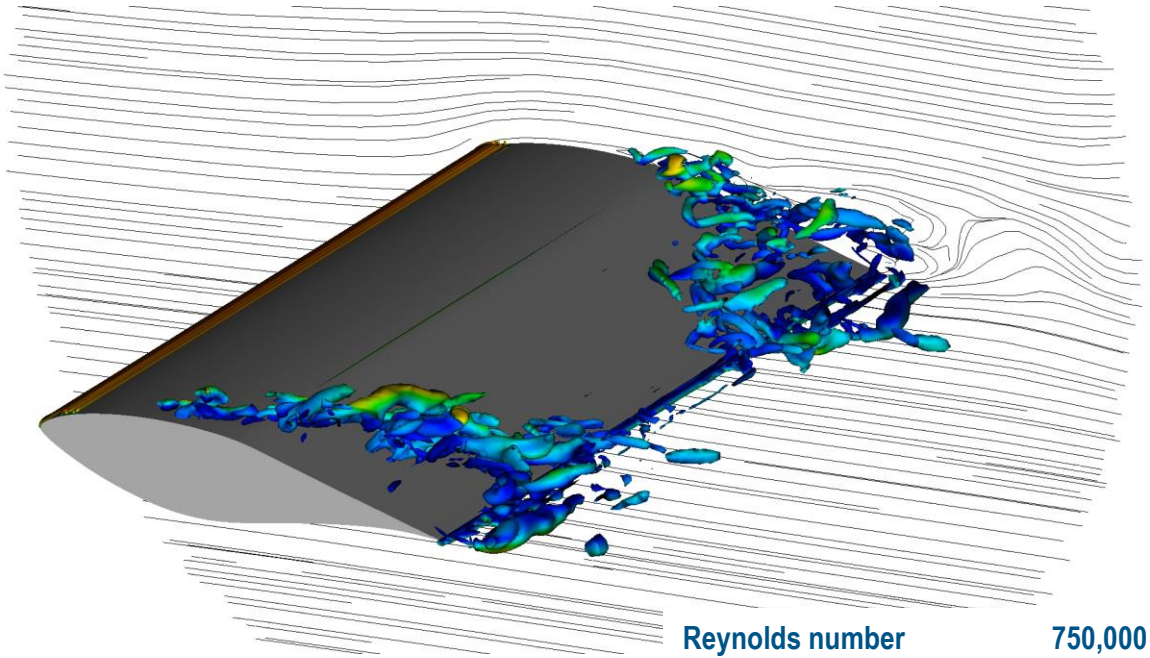




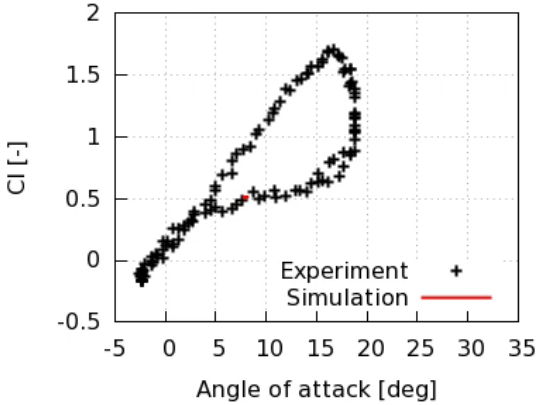


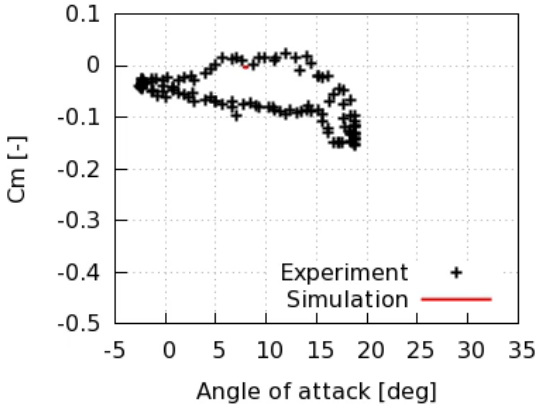


Dynamic stall



Reynolds number	750,000
Mean angle	8 deg
Oscillation angle	+- 10 deg
Oscillation frequency	1.8 Hz





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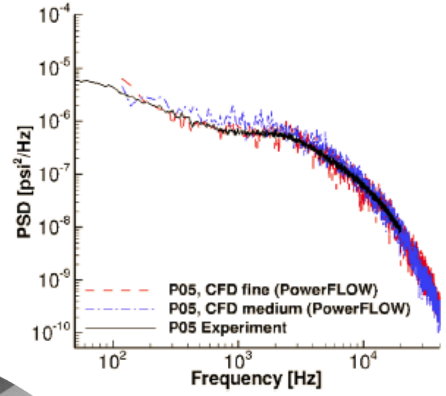
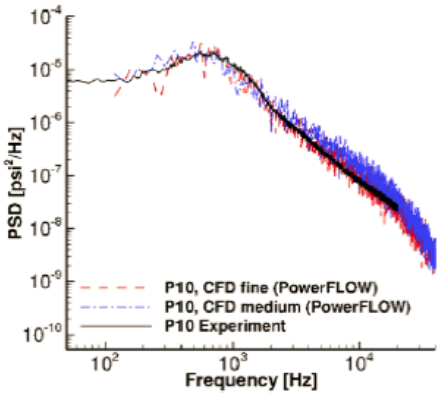
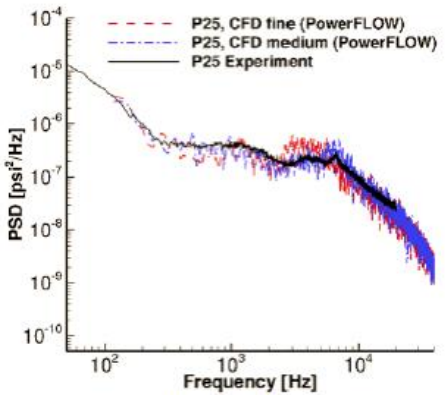
Tip noise



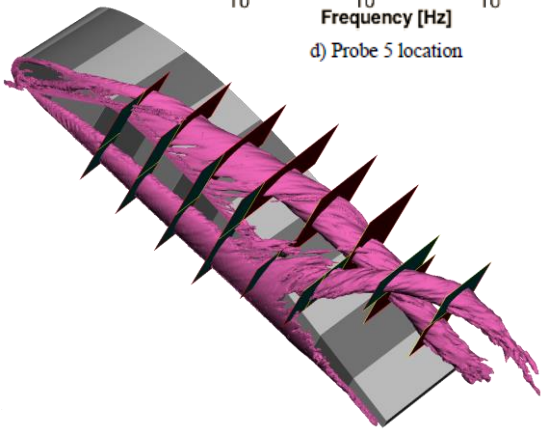
d) Probe 5 location

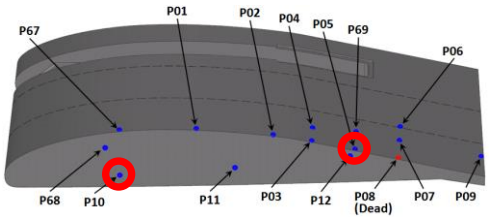


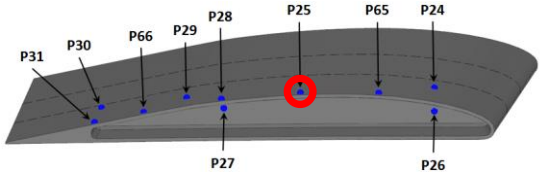
a) Probe 10 location



b) Probe 25 location

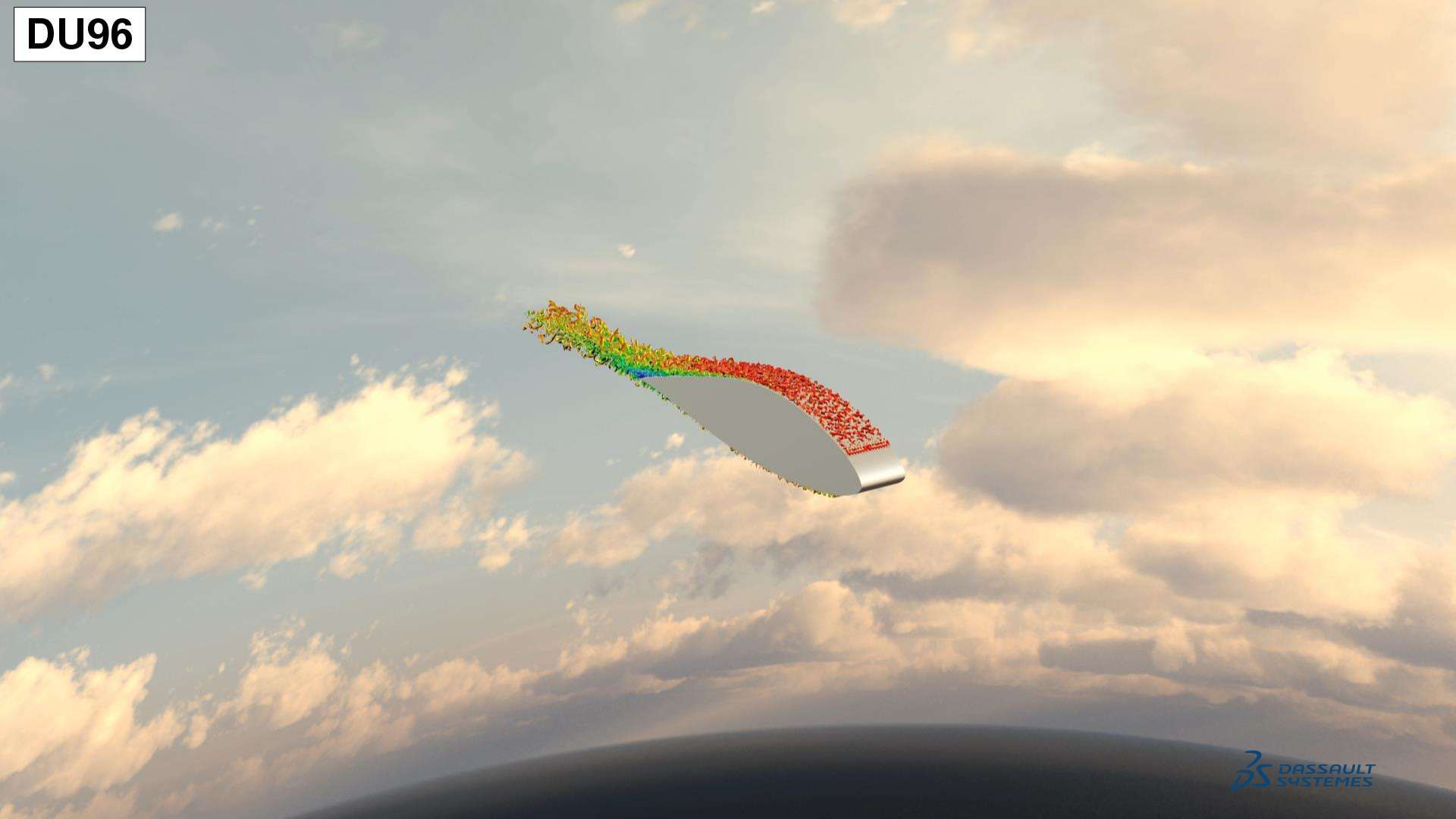






Flap side edge noise benchmark

- 18 scale Gulfstream aircraft
- 0.2 Mach
- 3.4 million Reynolds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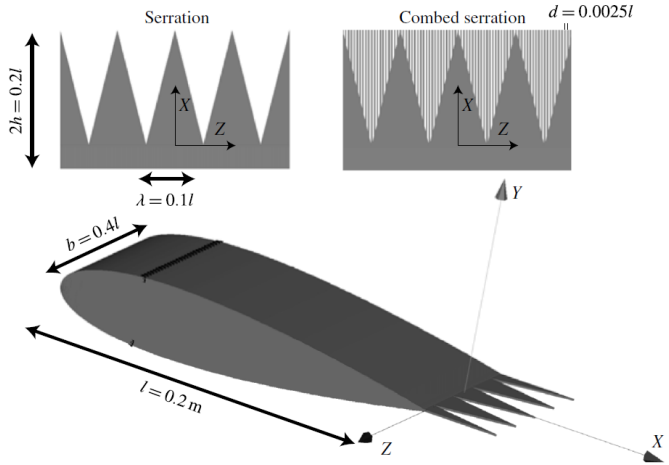
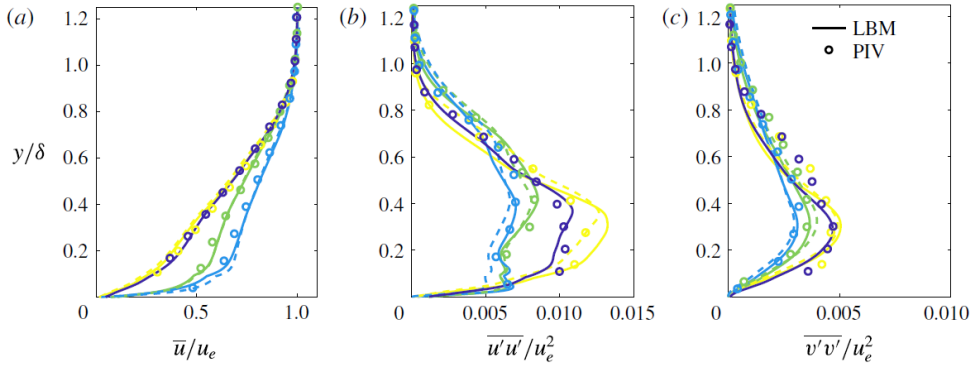
DASSAULT SYSTEMES

Trailing edge noise

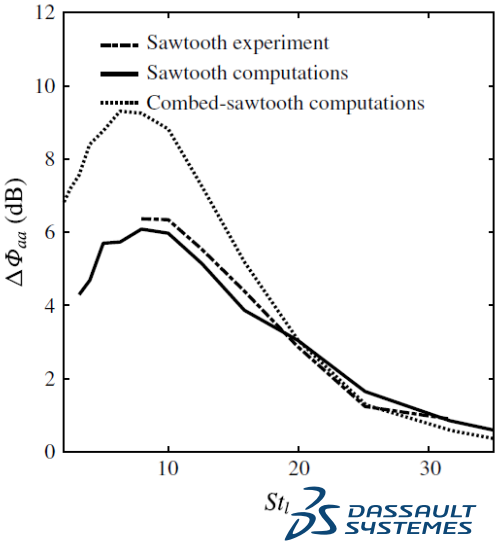
NACA0018 (1/4)

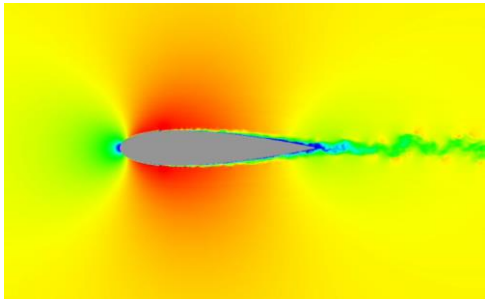


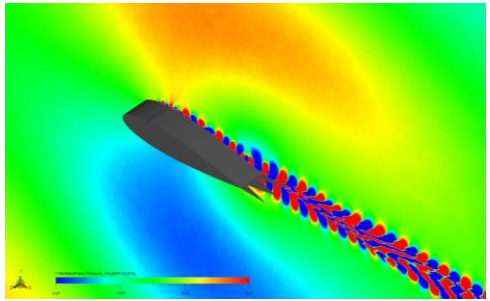
Trailing edge boundary layer characteristics



Far-field noise delta







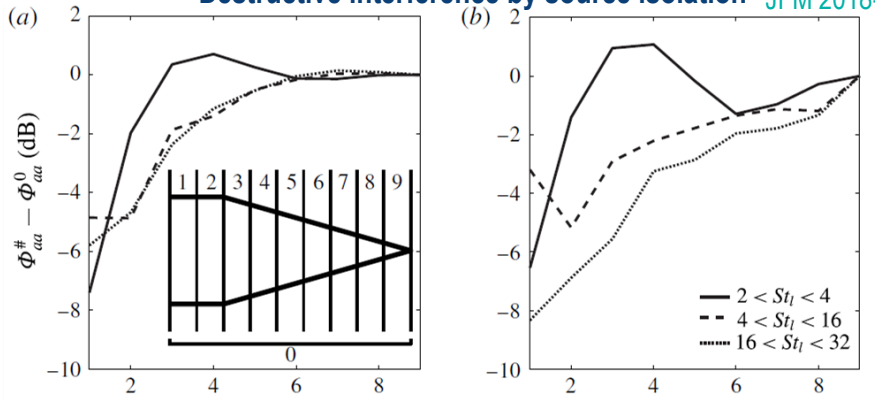
SIMULIA

DASSAULT SYSTEMES

Trailing edge noise

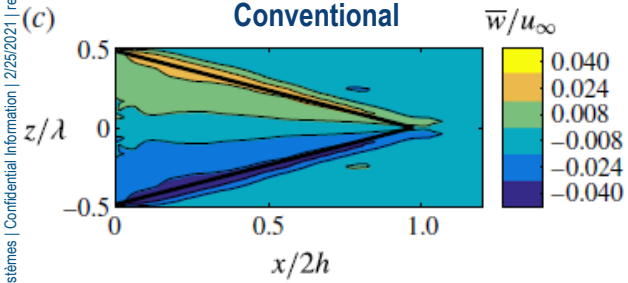
NACA0018 (2/4)

Destructive interference by source isolation JFM 2018-377 / JSV 2017-04-007

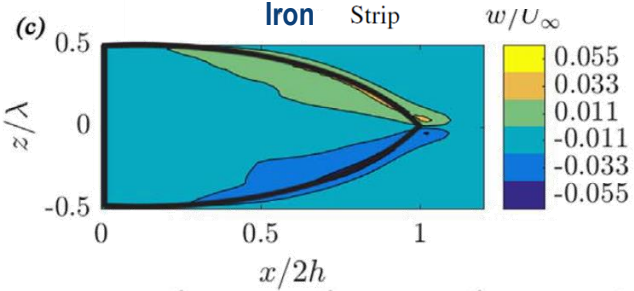


Mean spanwise velocity

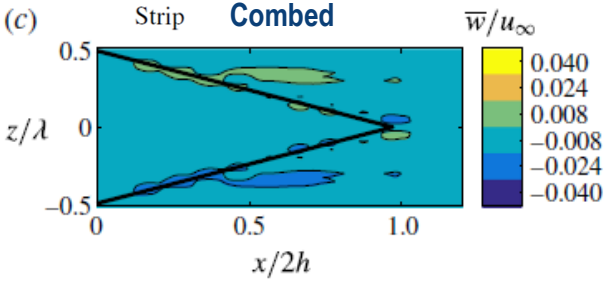
Conventional

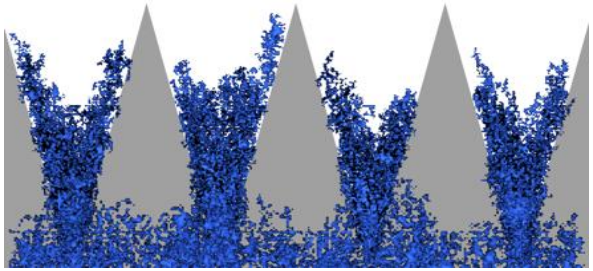


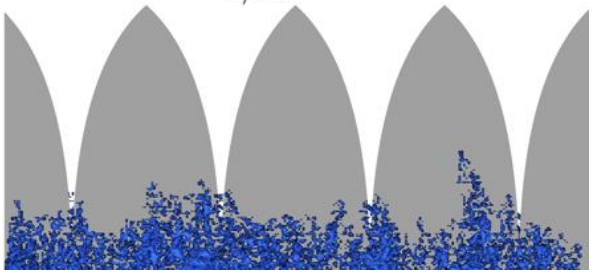
Iron Strip

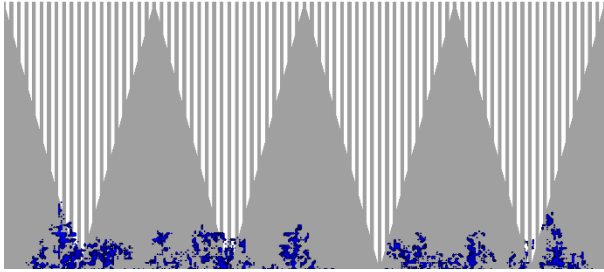


Strip **Combed**









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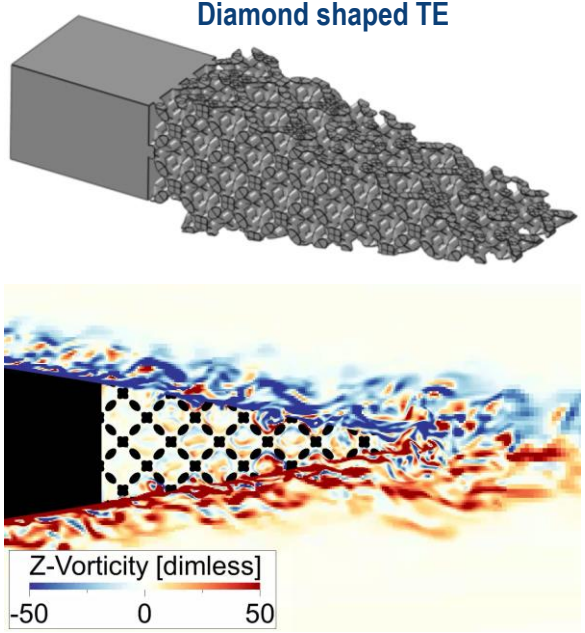
Flow Induced Noise Detection

DASSAULT SYSTEMES

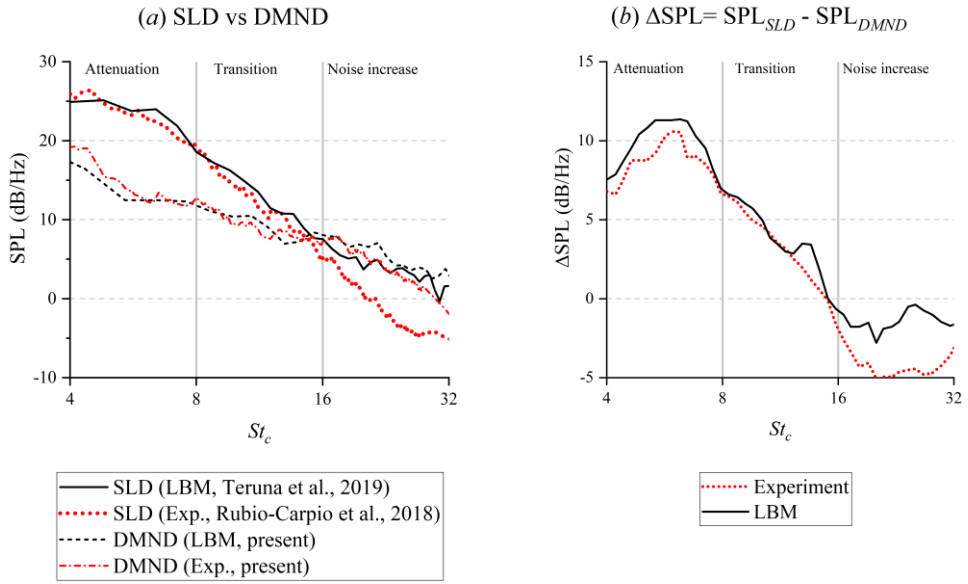
Trailing edge noise

NACA0018 (3/4)

Diamond shaped TE



Noise spectra comparison



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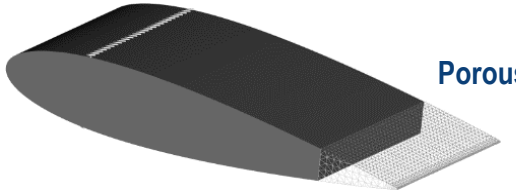
DASSAULT SYSTEMES

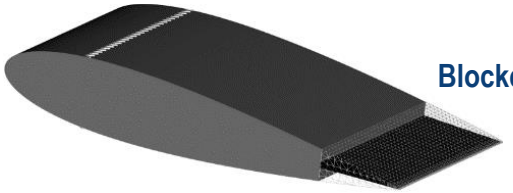
Trailing edge noise

NACA0018 (4/4)

Simplified representations using equivalent fluid model

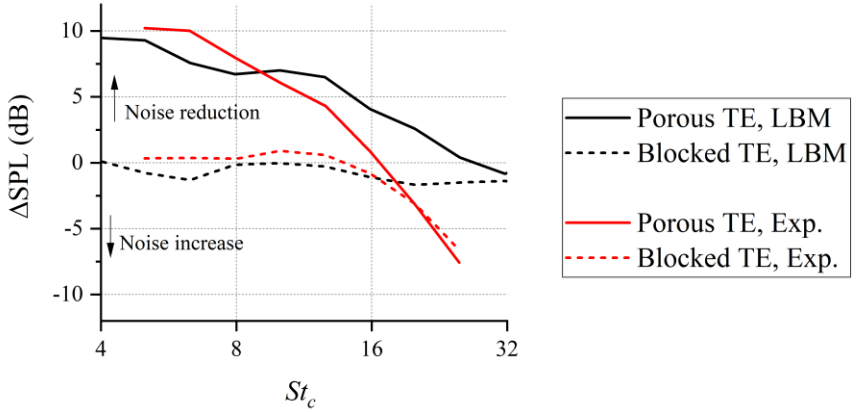


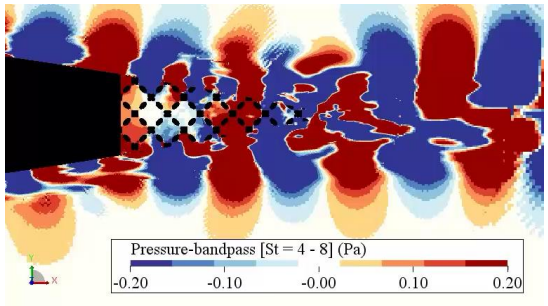
Porous TE

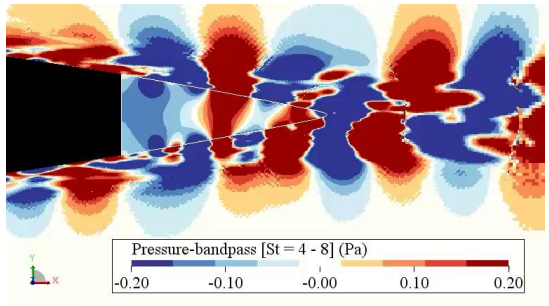


Blocked TE

Noise spectra comparison







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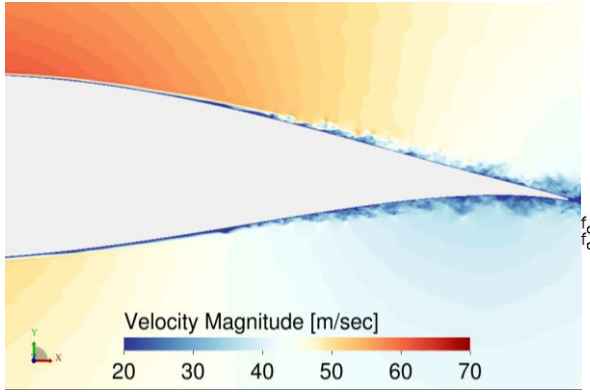
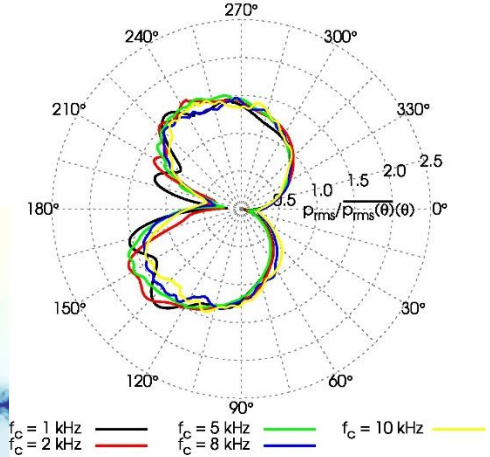
Trailing edge noise

NACA64618

Free-transitional case



Far-field directivity



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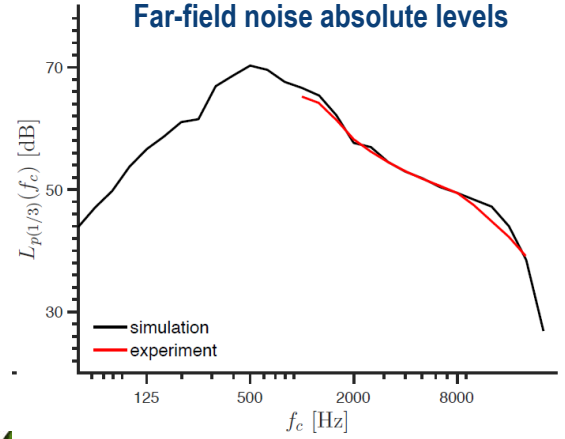
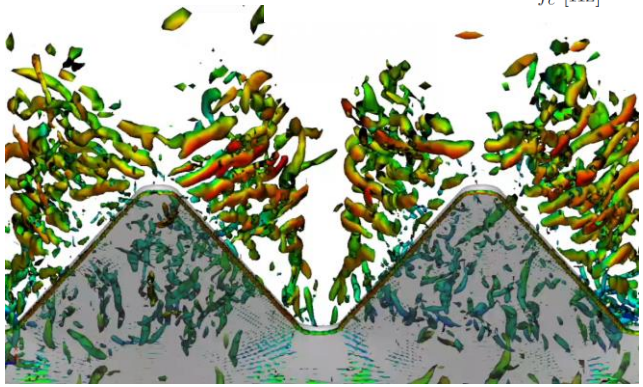
Far-field noise absolute levels





	Case 6			Case 7		
	Experiment	XFOIL	PowerFLOW	Experiment	XFOIL	PowerFLOW
Suction side	0.65	0.62	0.66	0.56	0.52	0.54
Pressure side	–	0.58	0.58	–	0.69	0.72

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What have we learned?

- Detailed fluid portfolio with SIMULIA PowerFLOW for wind turbine aerodynamics and aeroacoustics
- Automated full wind turbine simulation workflows, covering aero, thermal and acoustic
- Validated workflows for component level investigations
  - Vortex generator, icing, stall, tip, trailing edge design

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