

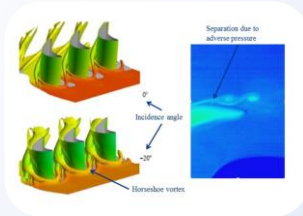


PI: Vikram Shyam

Team: Ali Ameri, Phil Poinatte, Doug Thurman, Adam Wroblewski, Chris Snyder



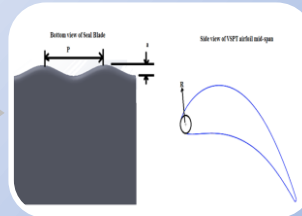
Outline



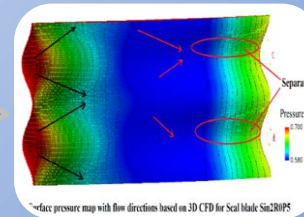
Motivation



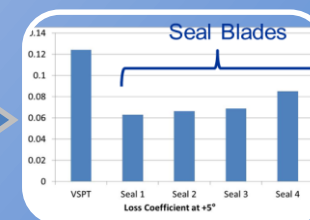
Background



Extraction and Application



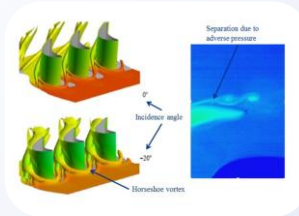
Simulation and Testing



Results and Conclusions



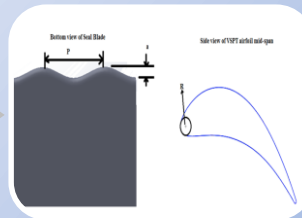
Outline



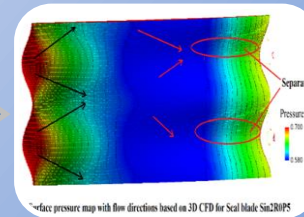
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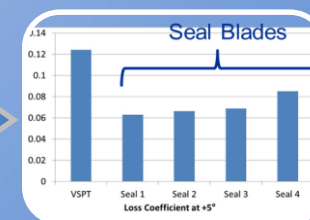
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Extraction and Application



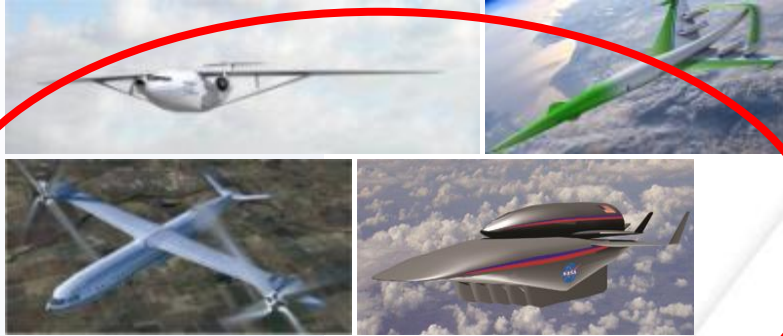
Simulation and Testing



Results and Conclusions



NASA Aeronautics Programs

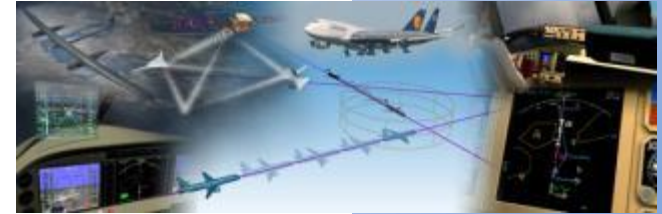


Fundamental Aeronautics Program

Conduct fundamental research that will produce innovative concepts, tools, and technologies to enable revolutionary changes for vehicles that fly in all speed regimes.

Integrated Systems Research Program

Conduct research at an integrated system-level on promising concepts and technologies and explore/assess/demonstrate the benefits in a relevant environment



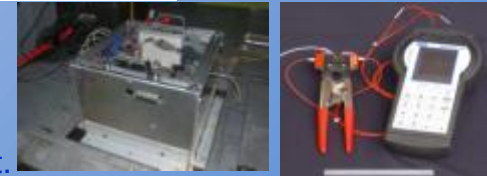
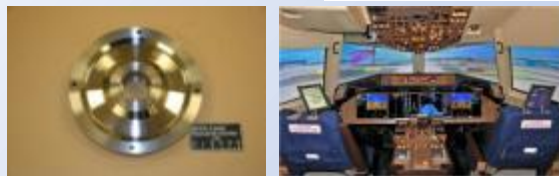
Airspace Systems Program

Directly address the fundamental ATM research needs for NextGen by developing revolutionary concepts, capabilities, and technologies that will enable significant increases in the capacity, efficiency and flexibility of the NAS.



Aviation Safety Program

Conduct cutting-edge research that will produce innovative concepts, tools, and technologies to improve the intrinsic safety attributes of current and future aircraft.



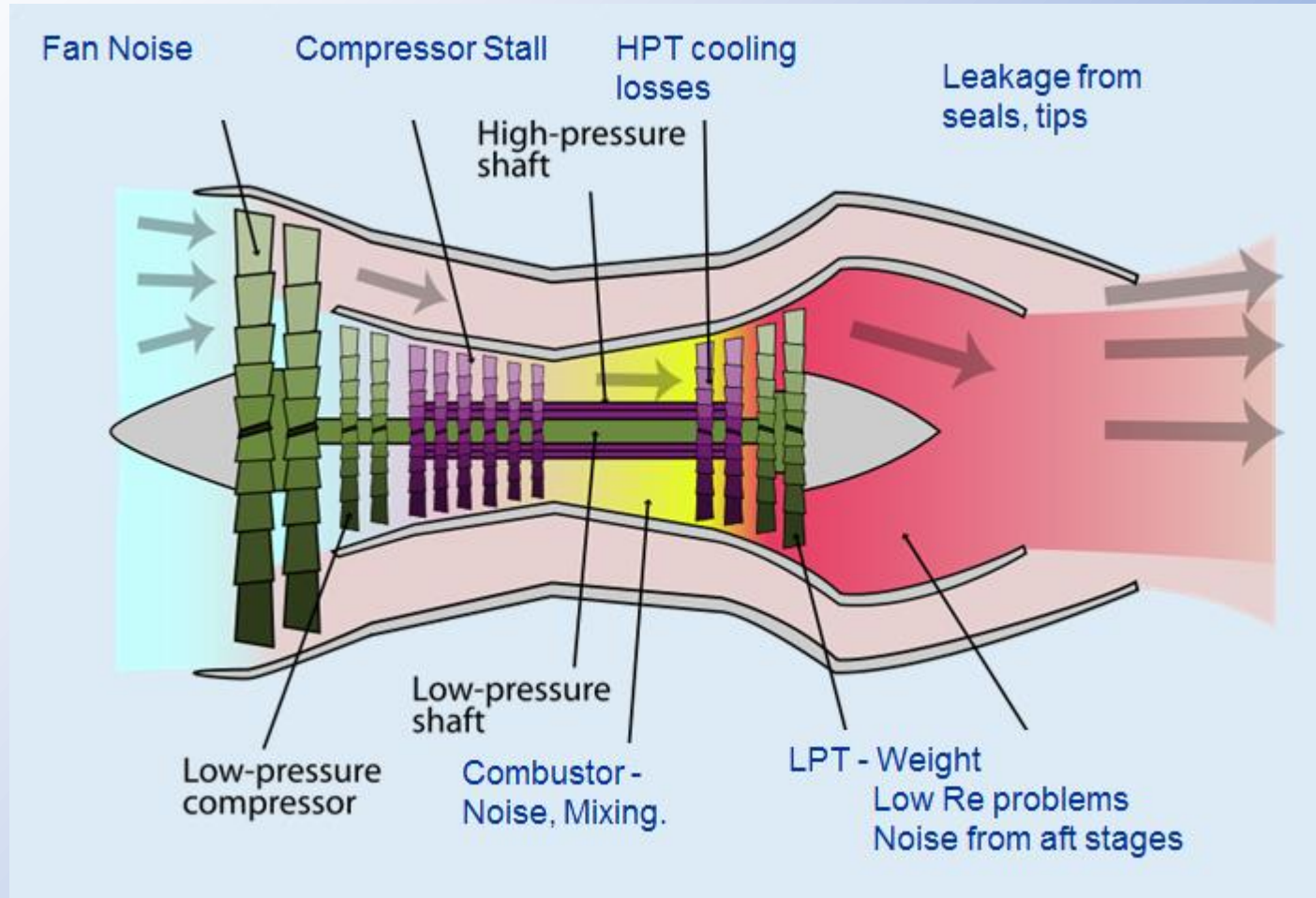
Aeronautics Test Program

Preserve and promote the testing capabilities of one of the United States' largest, most versatile and comprehensive set of flight and ground-based research facilities.





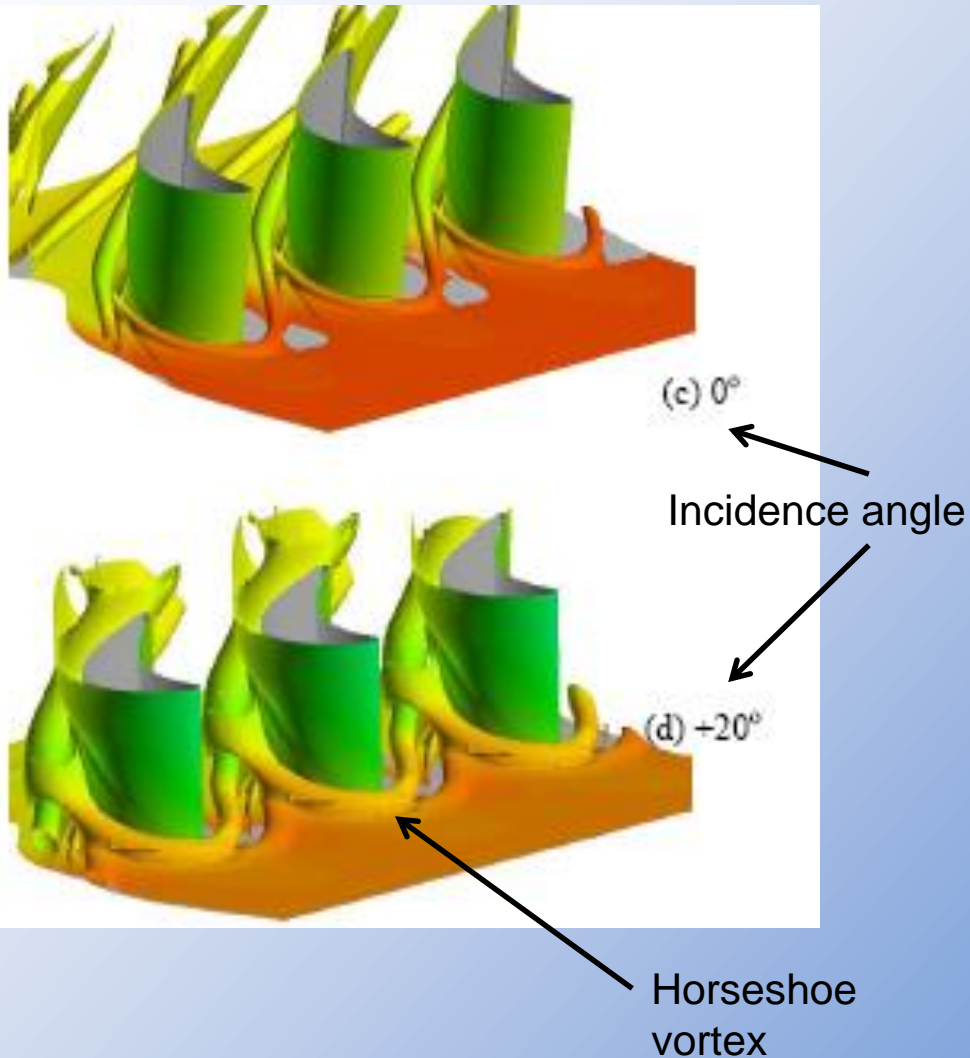
Engine Performance Hits



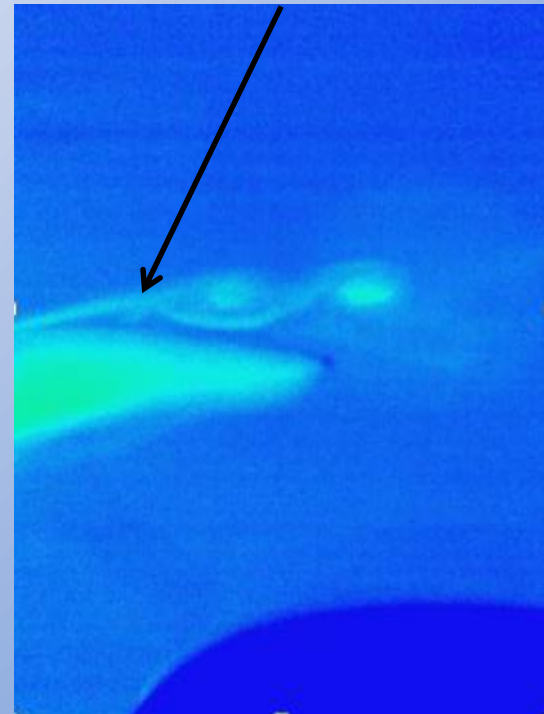
http://en.wikipedia.org/wiki/File:Turbofan_operation_lbp.svg



Incidence, Low Reynolds Number Challenges

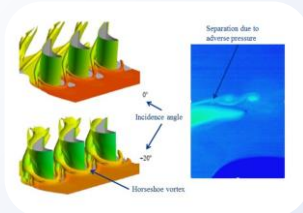


Separation due to adverse pressure





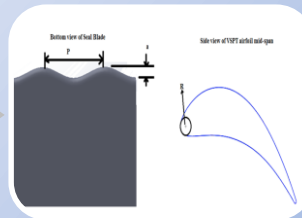
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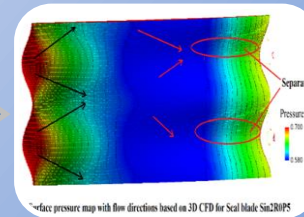
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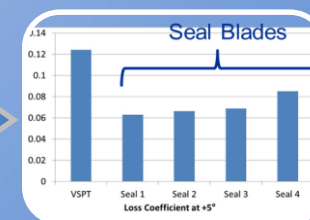
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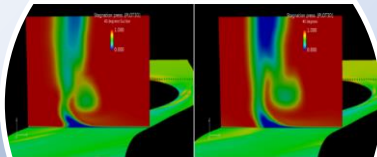
Extraction and Application



Simulation and Testing



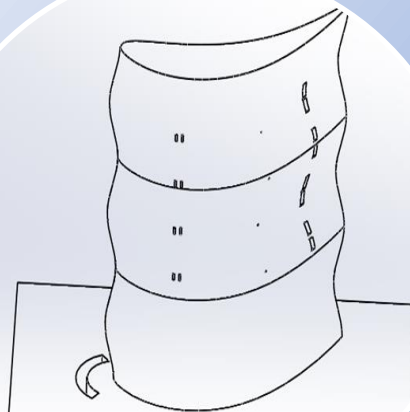
Results and Conclusions



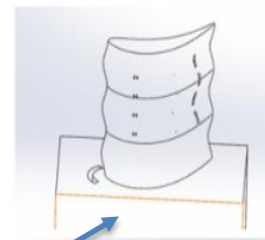
Slot upstream of
Leading edge at the
hub for suction



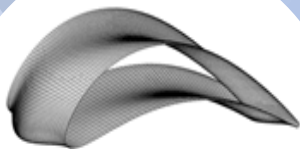
Trailing edge slots with
spanwise pulsing
(adjacent slots pulse
out of phase)



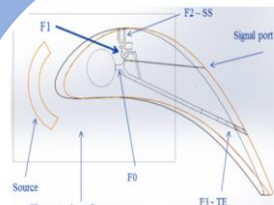
Holistic concept



Plenum to remove
incoming signals



Seal Blade for
operability, acoustics



Fluidic network to
direct traffic and
manage frequency
content

Shyam V., Ameri A., Poinsatte P., Thurman D., Wroblewski A., Snyder C., Culley D., Raghu S., "Holistic Aeropropulsion Concepts", NARI Seedling Fund Phase 1 final report,
http://nari.arc.nasa.gov/sites/default/files/Shyam_Holistic%20Concepts_Final%20Report%20for%20FY13%2054%2022_single_column_v3_0.pdf



Alternative Approaches

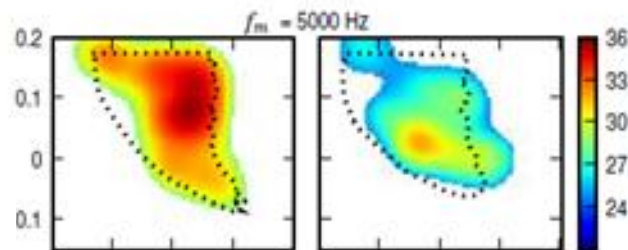
- Flow control
 - Requires power
 - Local effects that could be detrimental elsewhere
 - Cannot adjust to changing environment
 - VGJs (Vortex generating jets) extensively researched
 - Blowing into BL is common
- Design compromise by averaging over mission
- Noise reduction by blowing into wake costs 5% compressor bleed – unacceptable



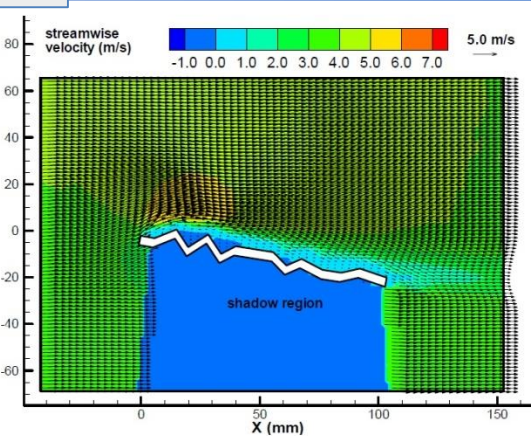
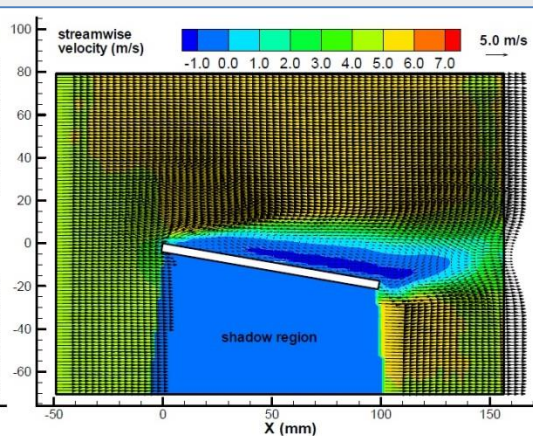
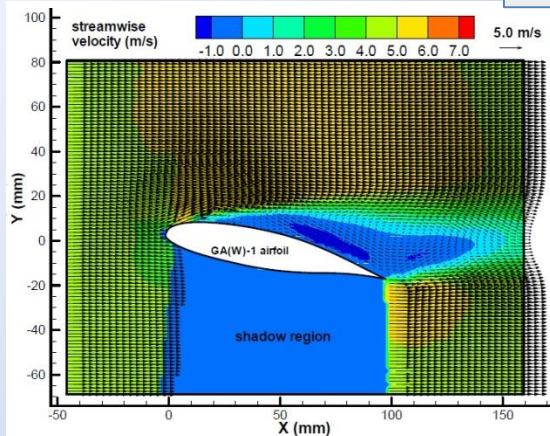
Bio-inspired Approaches



Fish et al., "The Tubercles on Humpback Whales' Flippers: Application of Bio-Inspired Technology" .



Geyer et al., "Silent Owl Flight, Experiments in the Aeroacoustic Wind Tunnel"

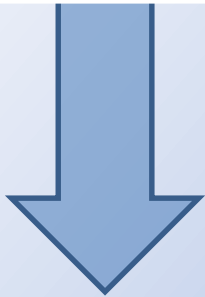


Tamai et al., "Aerodynamic Performance of a Corrugated Dragonfly Airfoil Compared with Smooth Airfoils at Low Reynolds Numbers"



Harbor Seal

- “Harbor seals use their whiskers to analyze water movements (hydrodynamic trail following).
- This structure effectively changes the vortex street behind the whiskers and reduces the vibrations that would otherwise be induced by the shedding of vortices from the whiskers (vortex-induced vibrations).”
 - Hanke et al (2010)



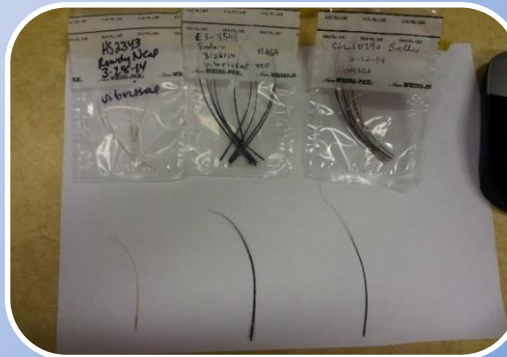
Hypothesis: Whiskers must have some degree of incidence tolerance to enable detection of prey proximity and direction



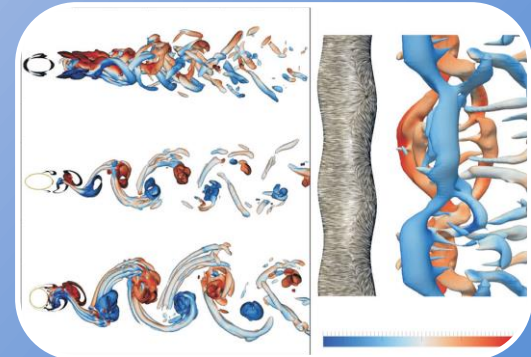
Harbor Seal



Seal swimming



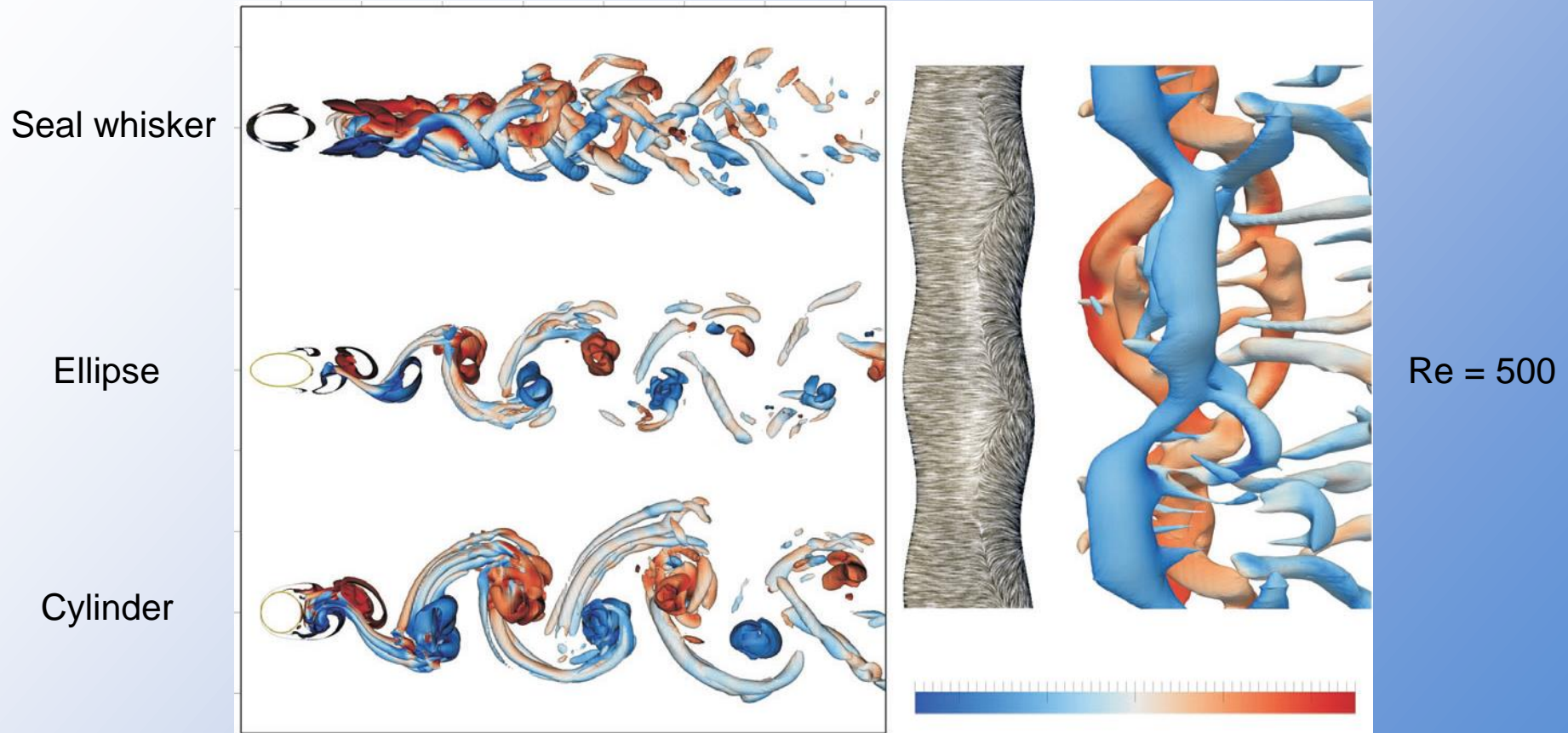
Whisker samples



VIV results from Witte et al. (2012)



Harbor Seal

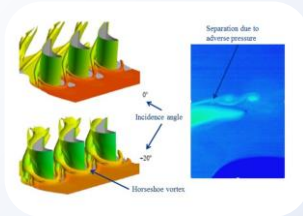


PIV on vibrissae at U of Rostock. Witte et al. 2012. Figure shows Q-criterion

- 40% mean drag coefficient reduction over cylinder
- 90% reduction of unsteadiness



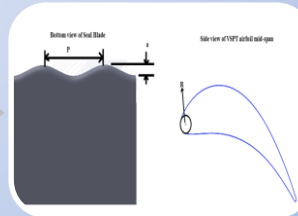
Outline



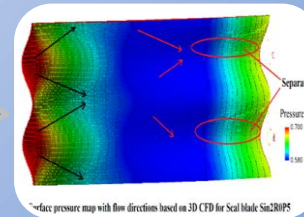
Motivation



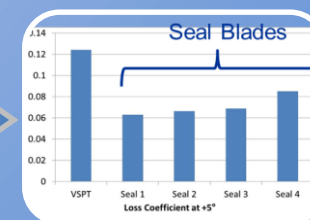
Background



Extraction and Application



Simulation and Testing



Results and Conclusions



- Create span-wise pressure gradient on suction side using span-wise undulations
- Push adverse gradient to valleys near trailing edge

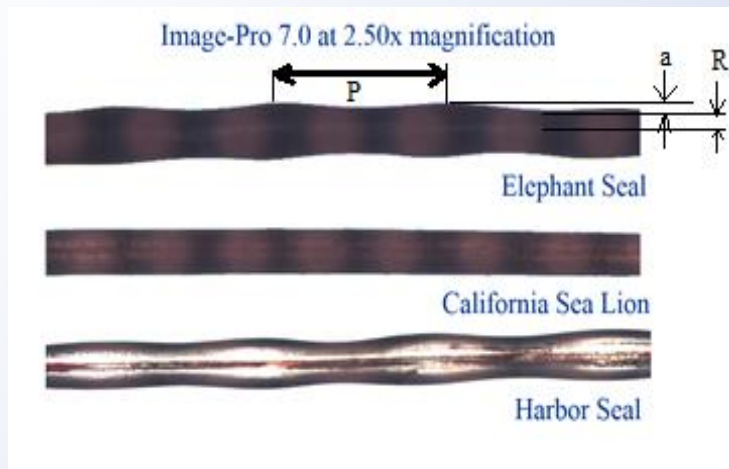


Figure 4. Scans of Pinniped vibrissae using optical microscope showing vibrissae parameters

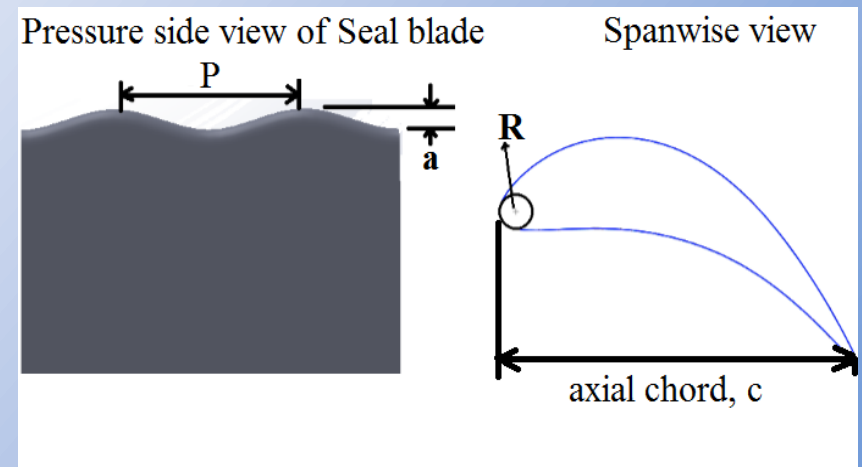
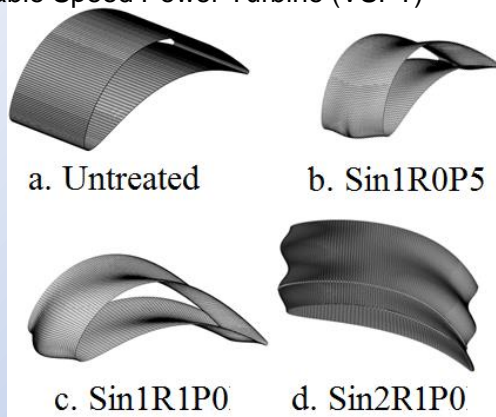


Figure 5. Parameters of undulations for the 'Seal Blade'

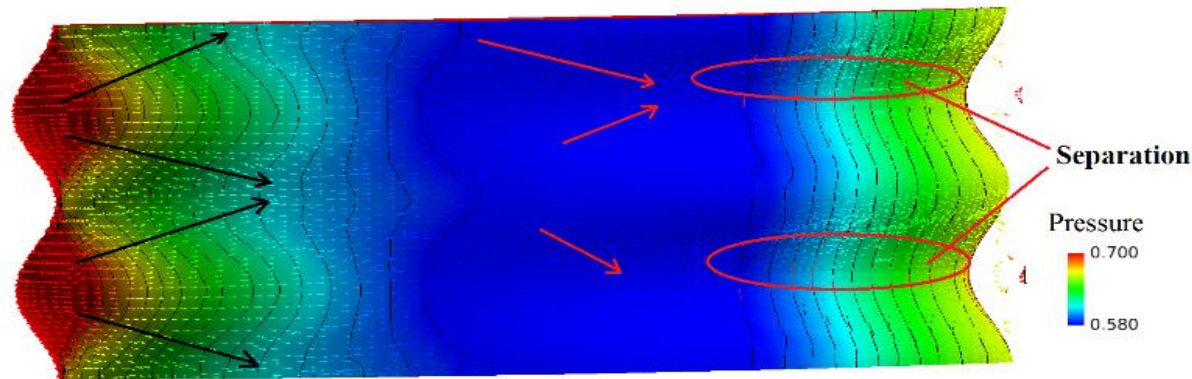
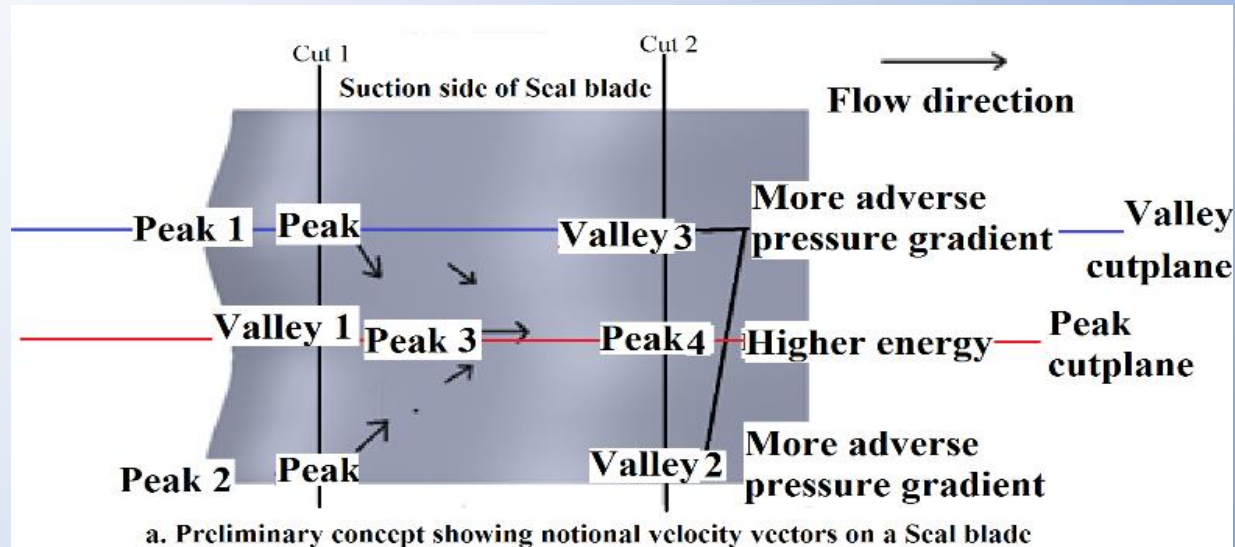
Variable Speed Power Turbine (VSPT)



Parameters	Seal	Sin1R0P5	Sin1R1P0	Sin2R0P5	Sin2R1P0
Reference Radius, R	0.54	0.46	0.46	0.46	0.46
Peak to Peak, P	1.82	1.55	1.55	3.00	3.00
LE amplitude, a	0.12	0.12	0.23	0.12	0.23
ratio R/P	0.29	0.30	0.30	0.15	0.15
ratio a/P	0.07	0.07	0.15	0.04	0.08



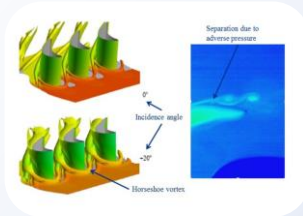
- Trailing edge valleys occur at span-wise location of leading edge peaks
- Peaks transition to valleys at crown location



b. Surface pressure map with flow directions based on 3D CFD for Seal blade Sin2R0P5



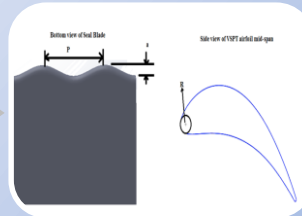
Outline



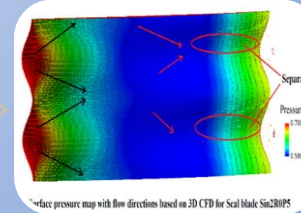
Motivation



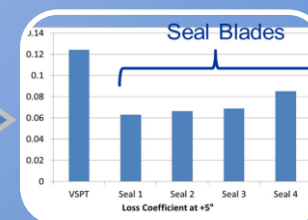
Background



Extraction and Application



Simulation and Testing



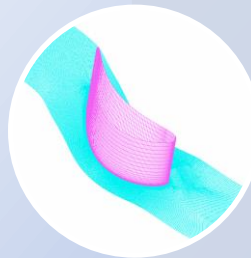
Results and Conclusions



Feasibility Study of Biomimetic Concept



Water table visualization
• CFD qualitative validation



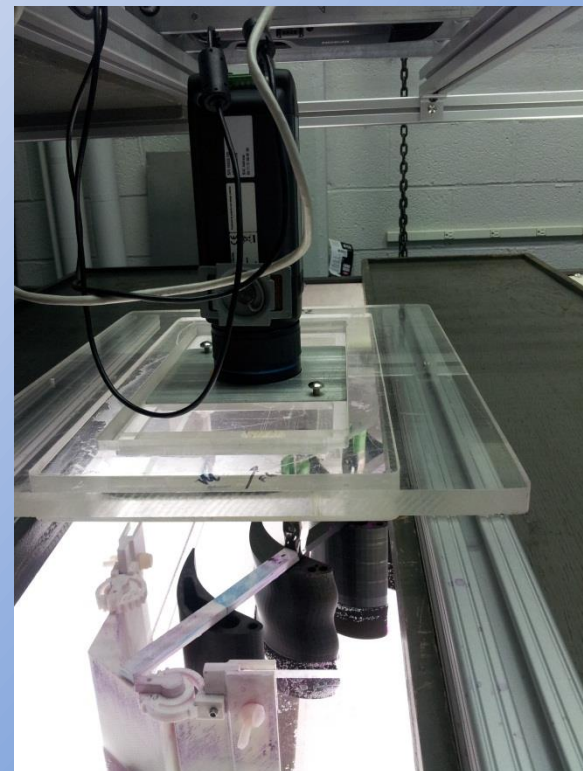
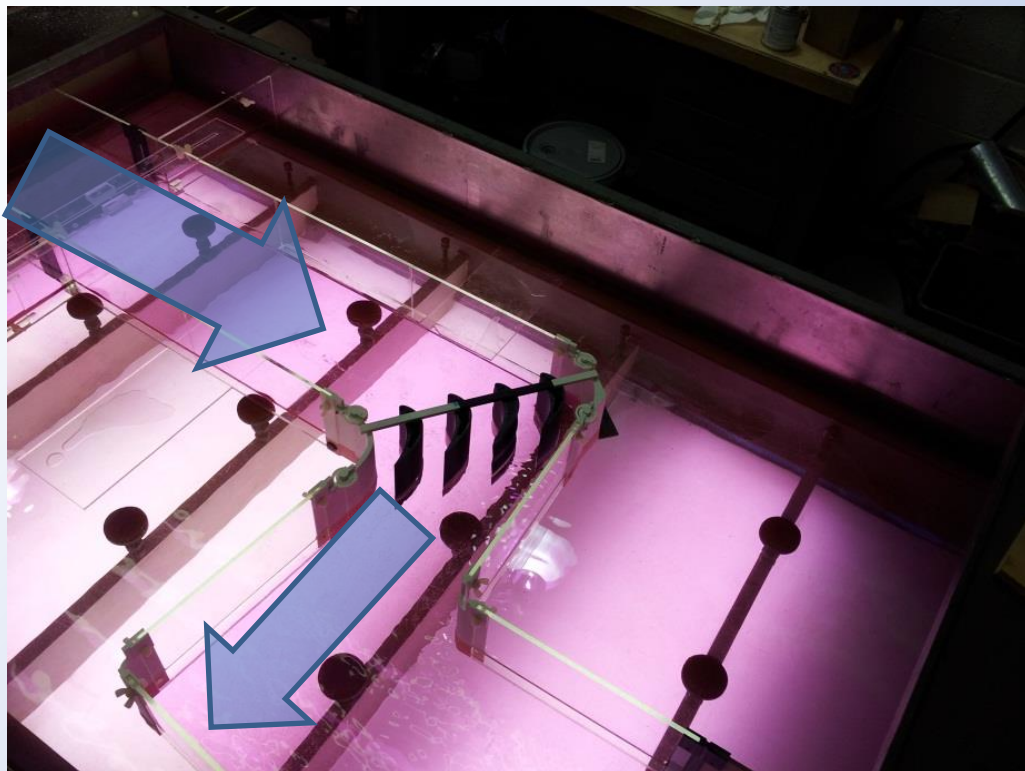
Unsteady 3D CFD using Glenn-HT

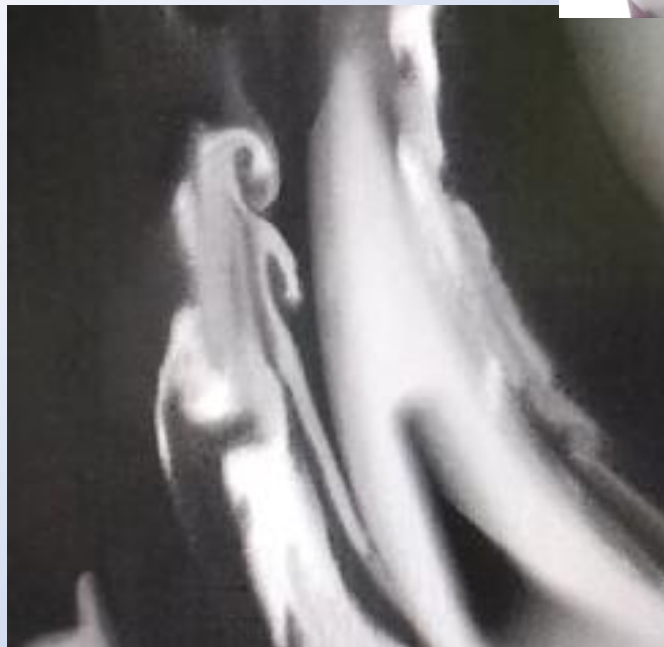
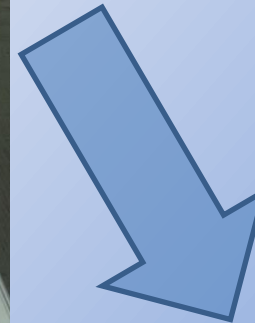
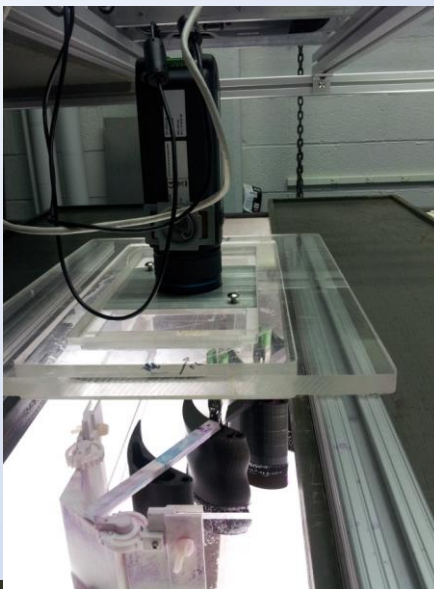
- Cp distribution at various span-wise locations
- Average wake pressure-loss coefficient 10% chord downstream of TE
- Multiple incidence angles



Wind Tunnel Testing

- SW2 cascade facility
- Total pressure surveys at 10% chord downstream of TE
- Hotwire surveys at 10% chord downstream of TE
- Multiple incidence angles





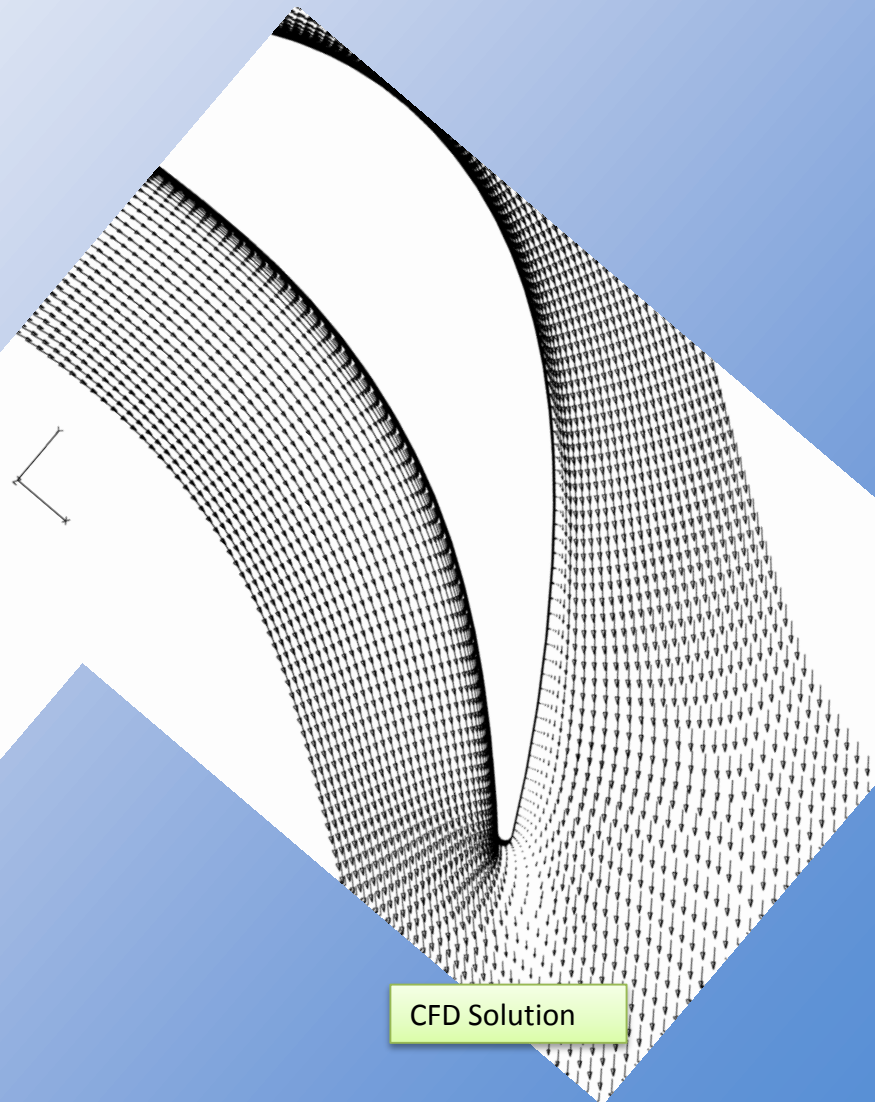
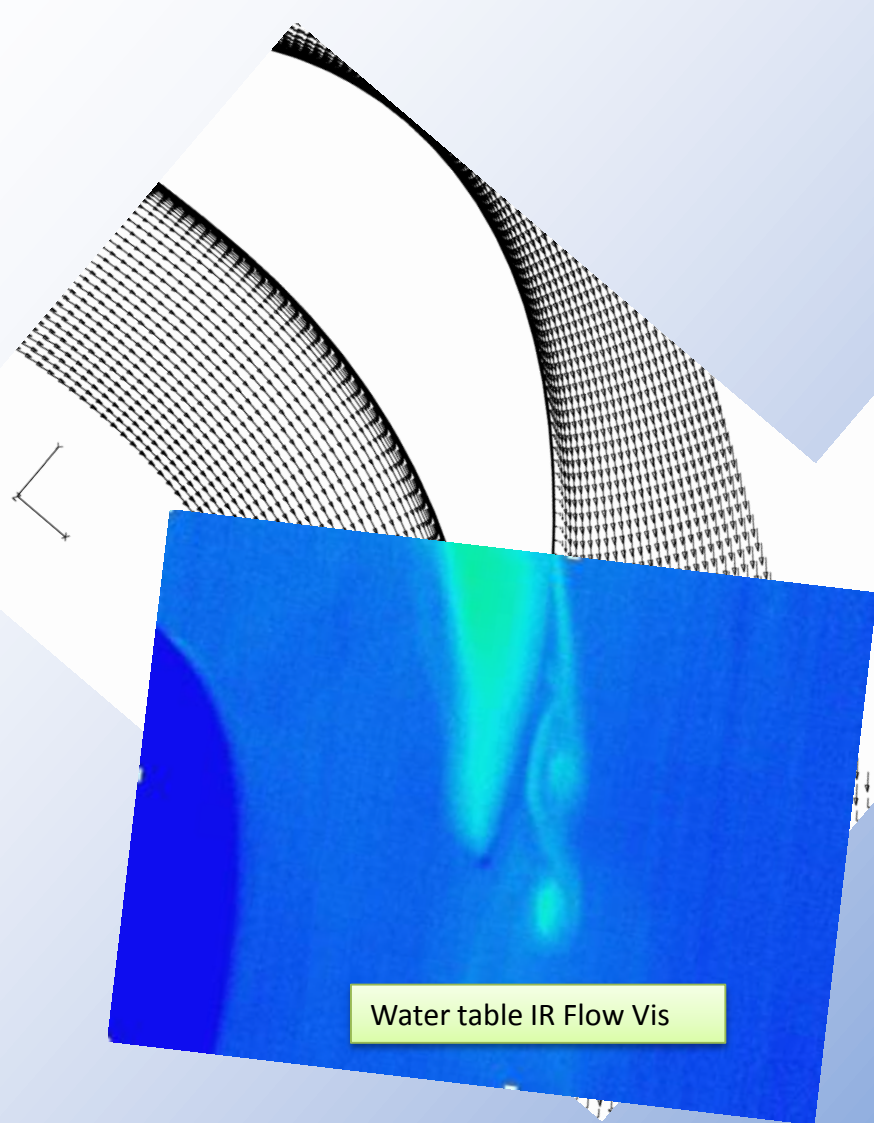
VSPT – 0 incidence

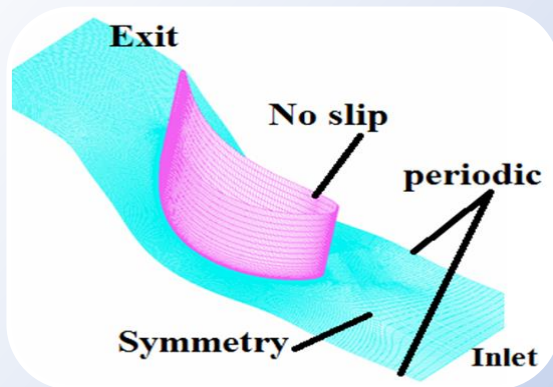


Seal Blade – 0 incidence



CFD Qualitative Validation





CFD setup



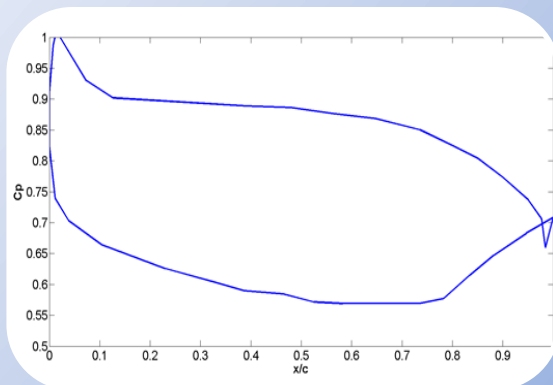
a. SW-2 test facility



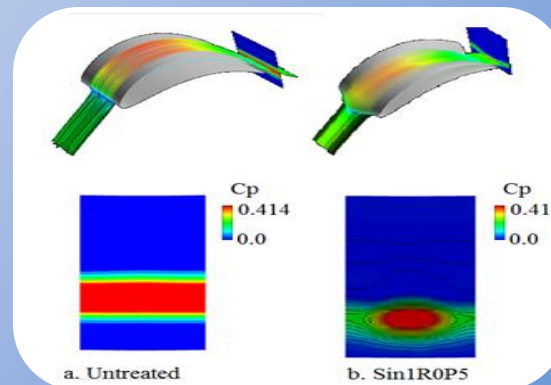
b. Test blades installed in SW-2 wind tunnel

Wind tunnel SW-2

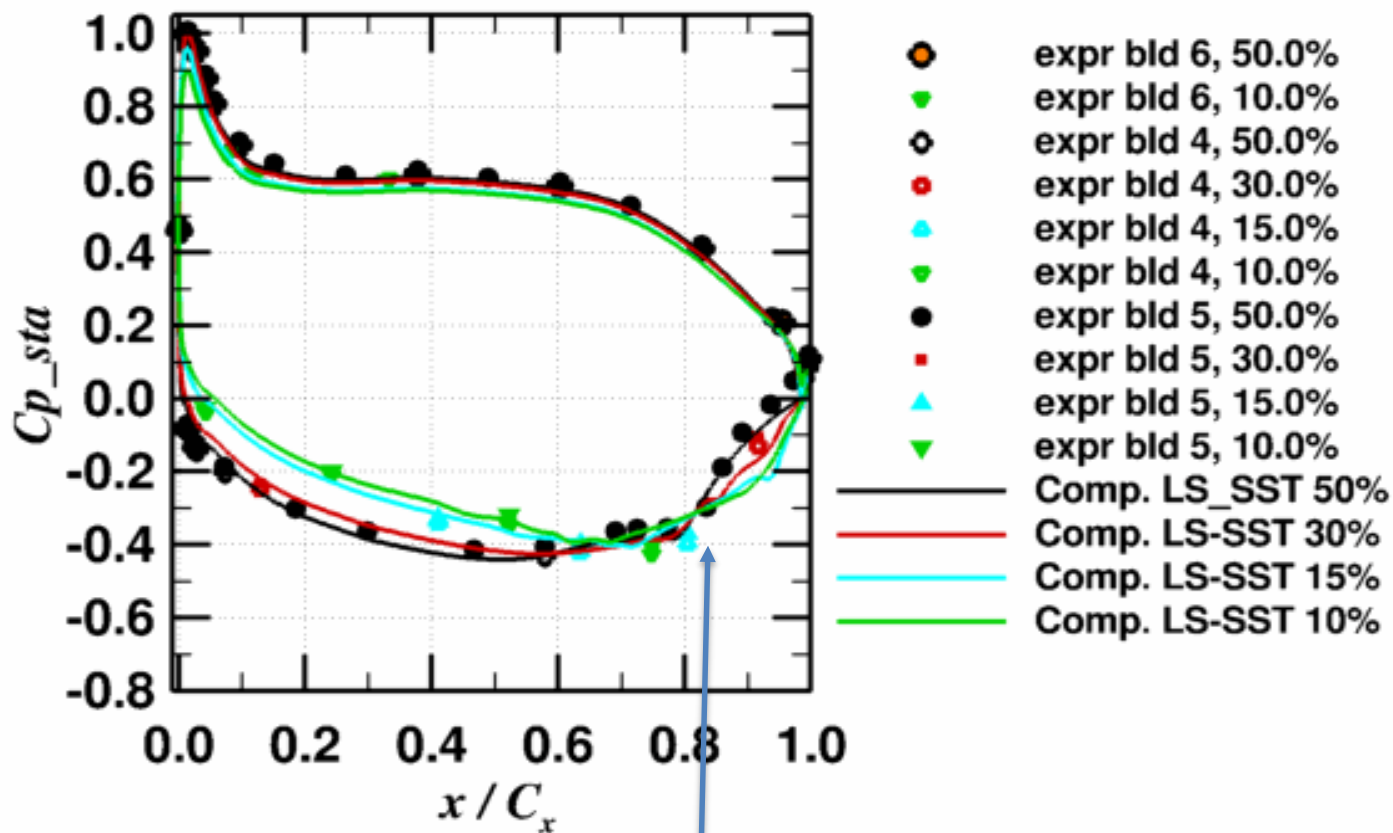
Low inlet turbulence ~ 4%,
Re = 100,000



Pressure profiles - CFD



Blade pressure distribution – CFD and experiment

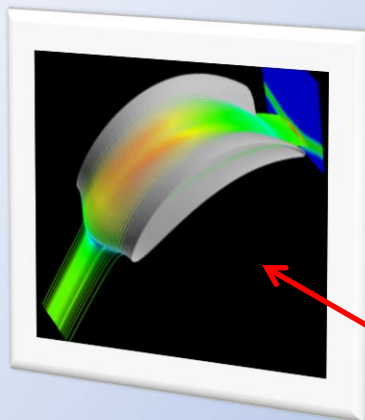
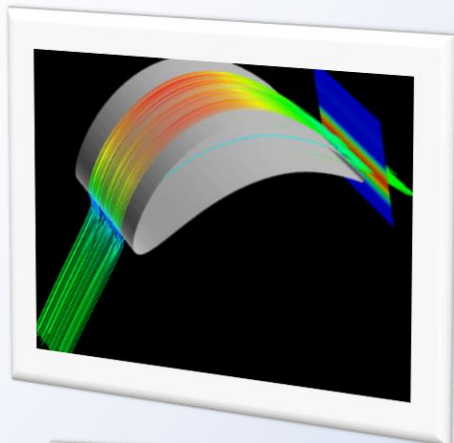


Separation captured by CFD (black line)

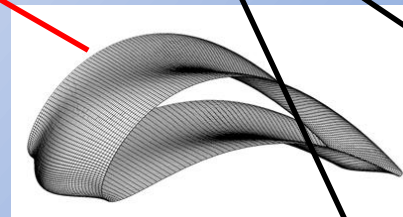


Untreated

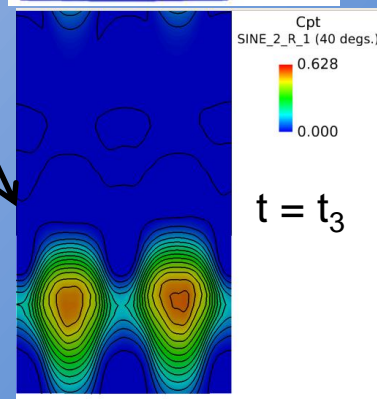
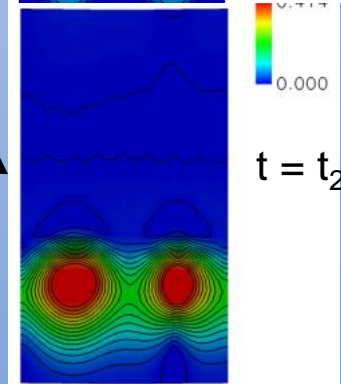
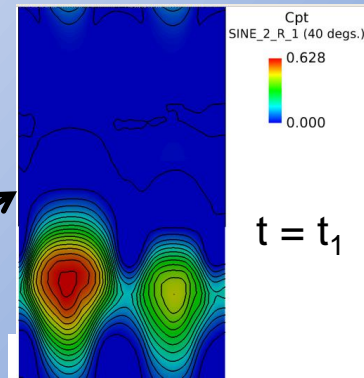
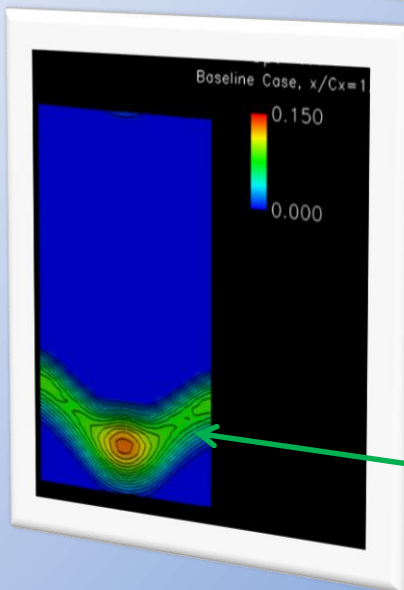
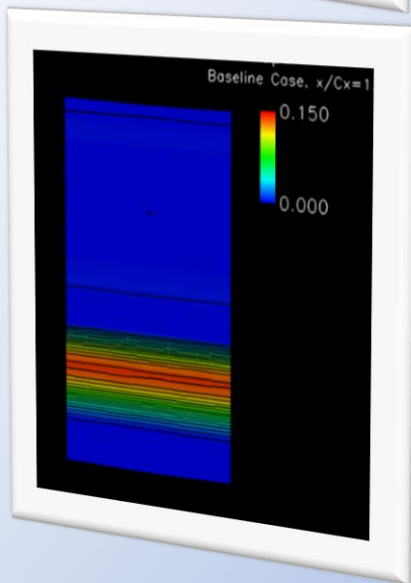
Seal Blade



Noise reduction through wake control

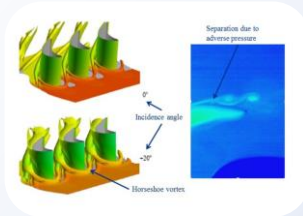


Fuel burn reduction due to elimination of separation





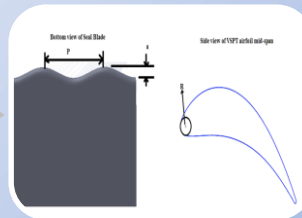
Outline



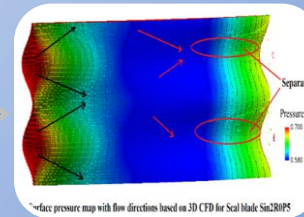
Motivation



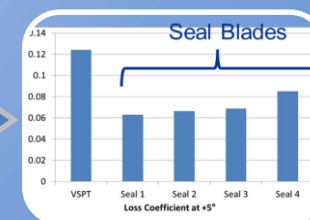
Background



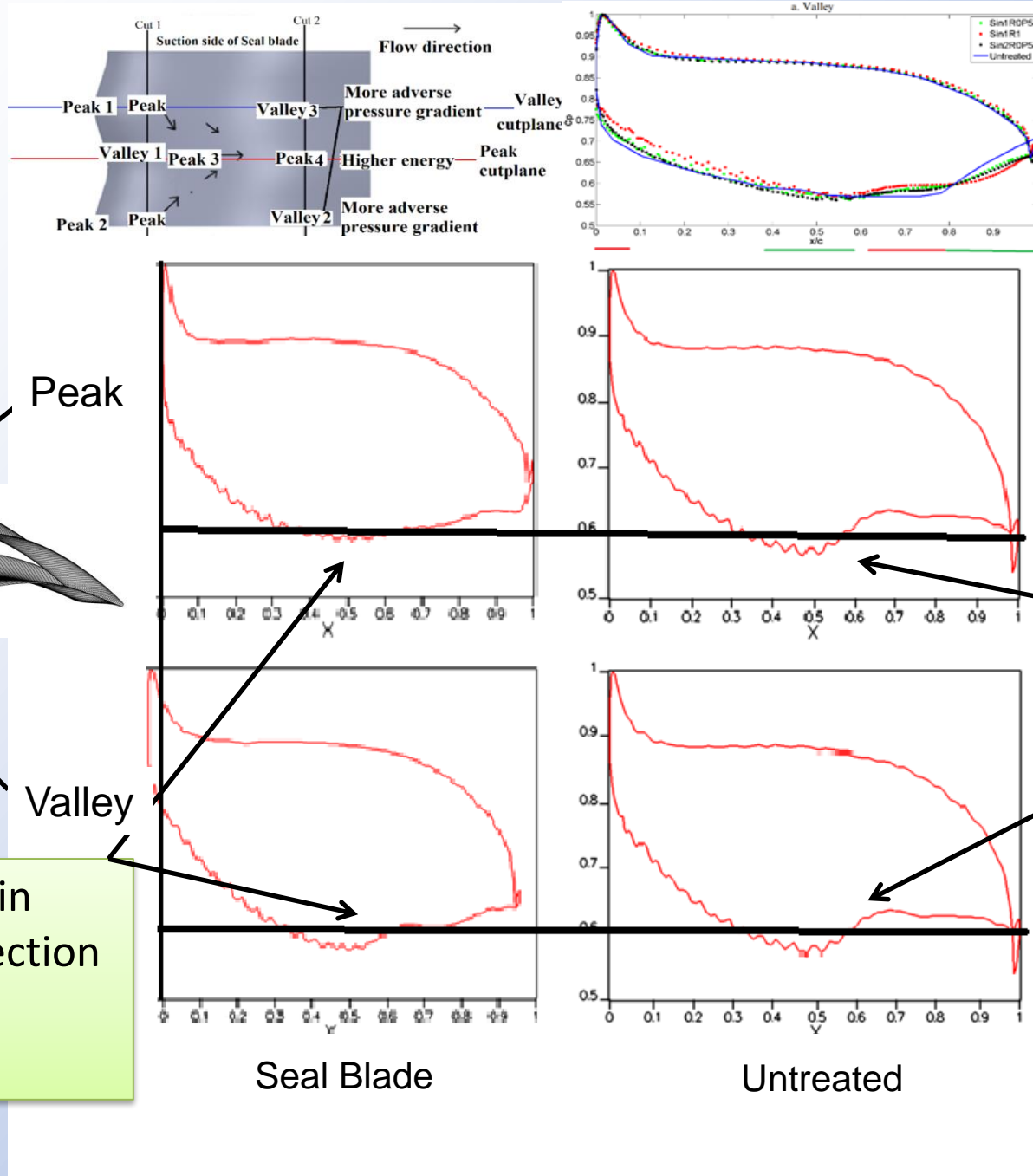
Extraction and Application



Simulation and Testing



Results and Conclusions



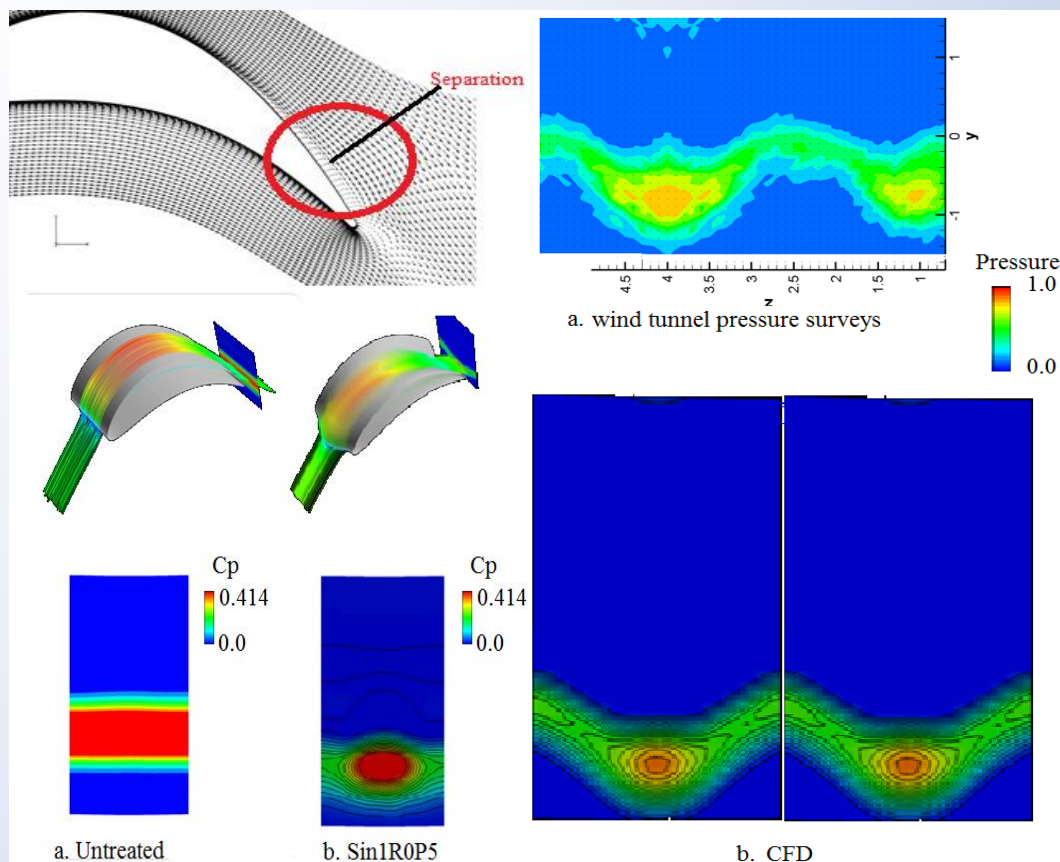


Figure 14. Bottom - pressure loss coefficient for a. Untreated blade and b. Sin1R0P5 Seal blade at +5° incidence angle. Top - Relative location of planes at $x/c = 1.1$.

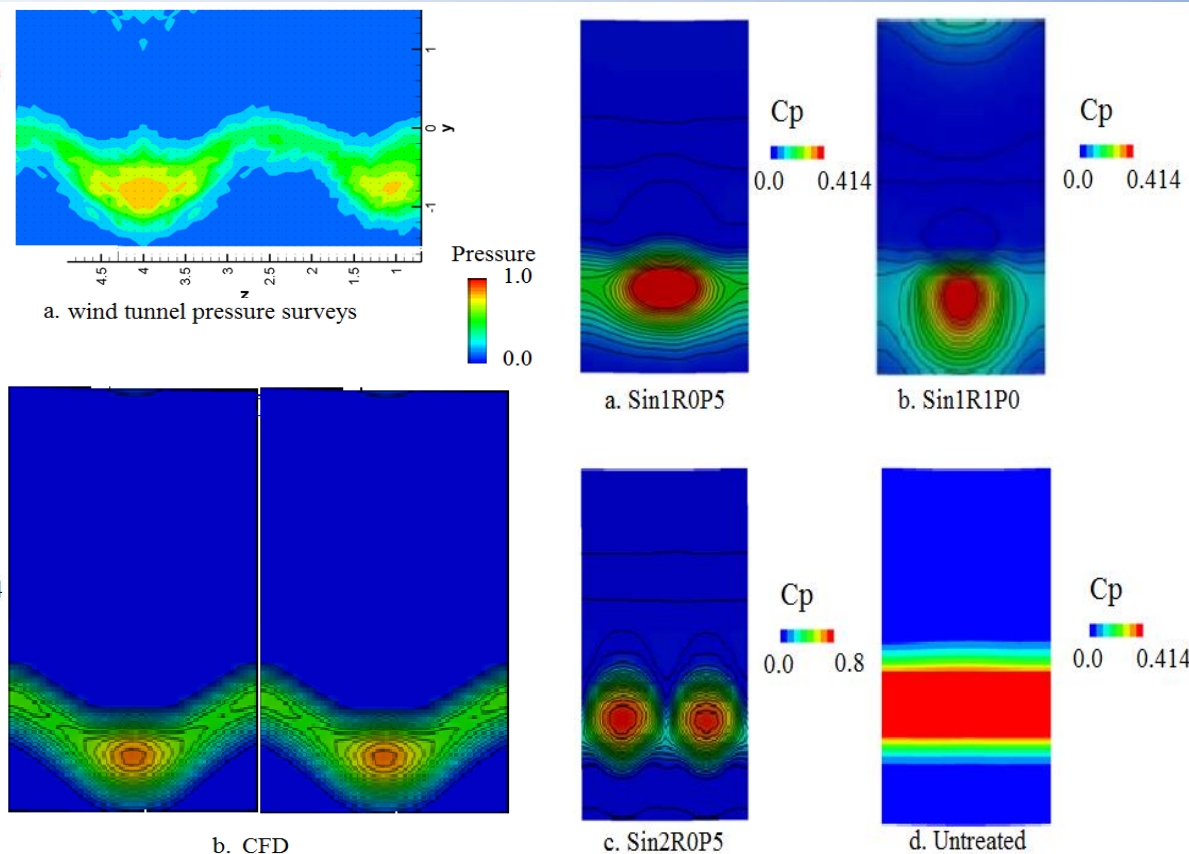


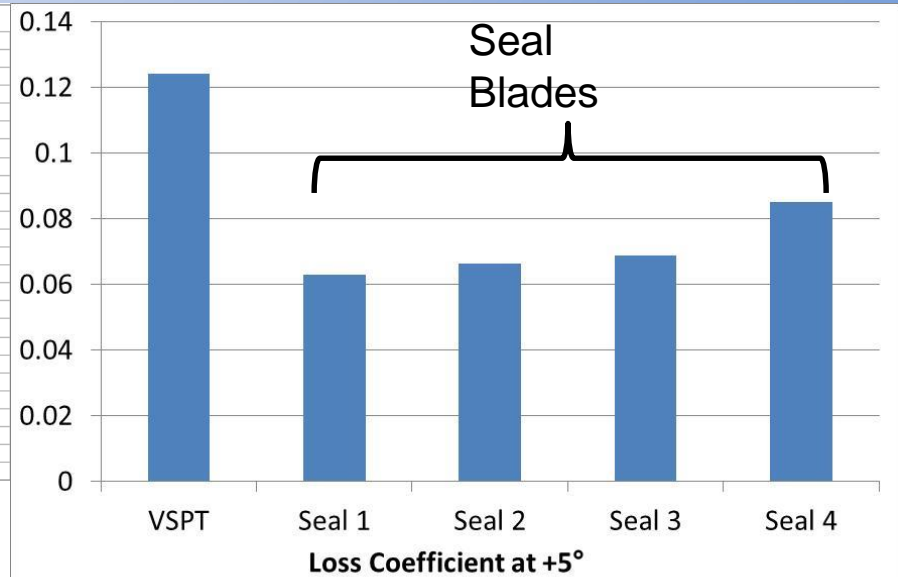
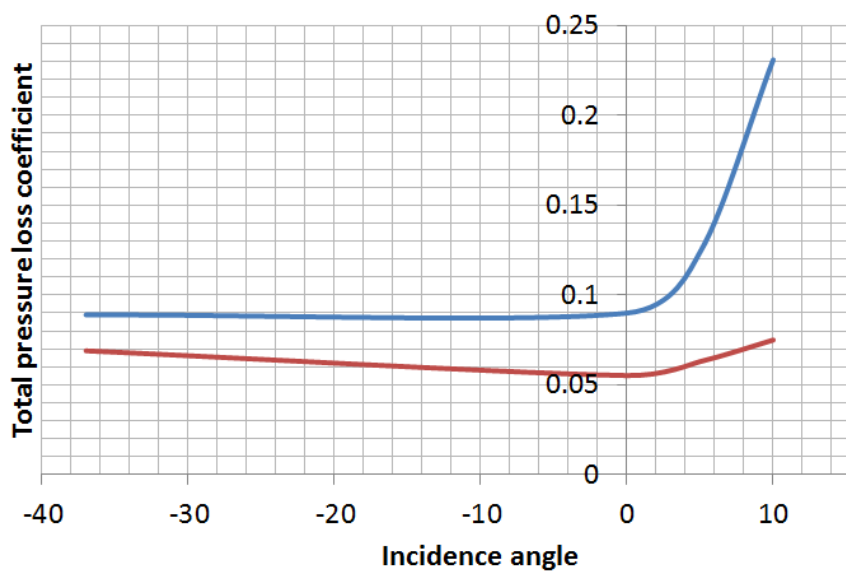
Figure 15. Static pressure in the wake of Sin1R0P5 Seal blade obtained from a. Wind tunnel total pressure survey of the wake at $x/c = 1.1$ and b. CFD simulation at +5° incidence angle

Figure 17. Wake pressure loss coefficients for Seal blades compared to Untreated blade.



Incidence tolerance over wide range leads to fuel burn reduction

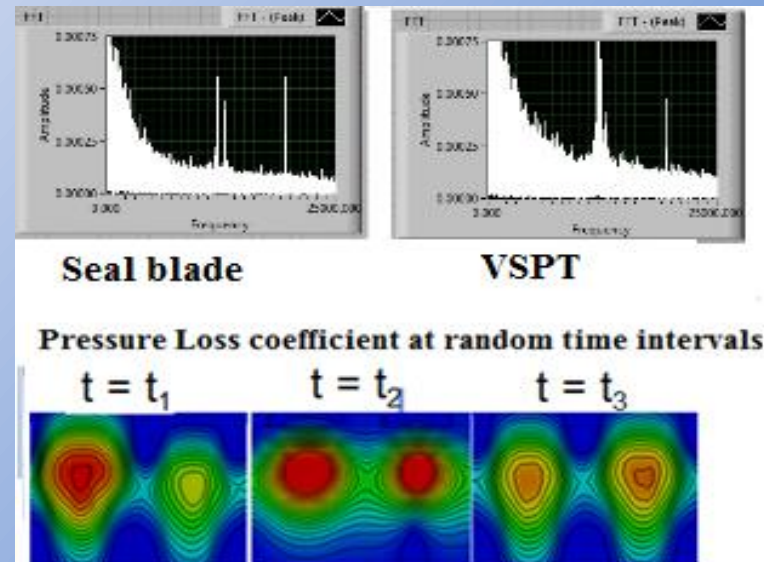
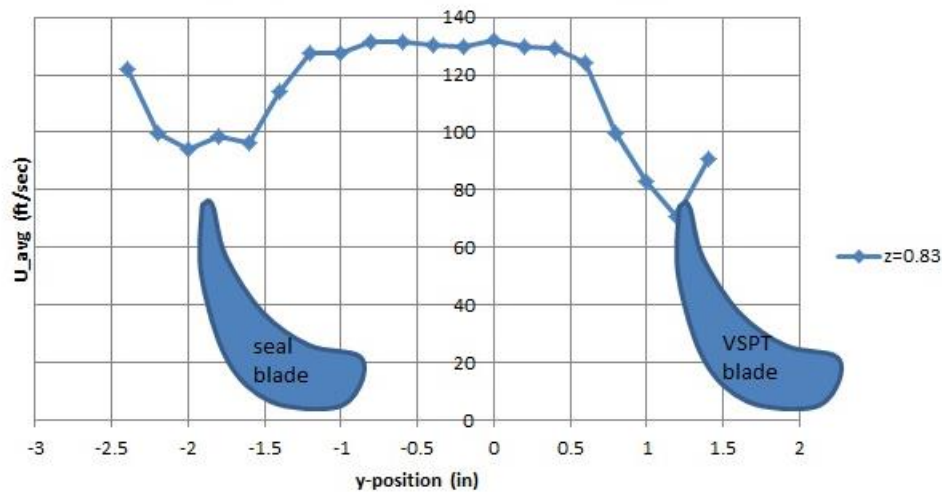
50% improvement in pressure recovery leads to fuel burn reduction





Circumstantial Evidence

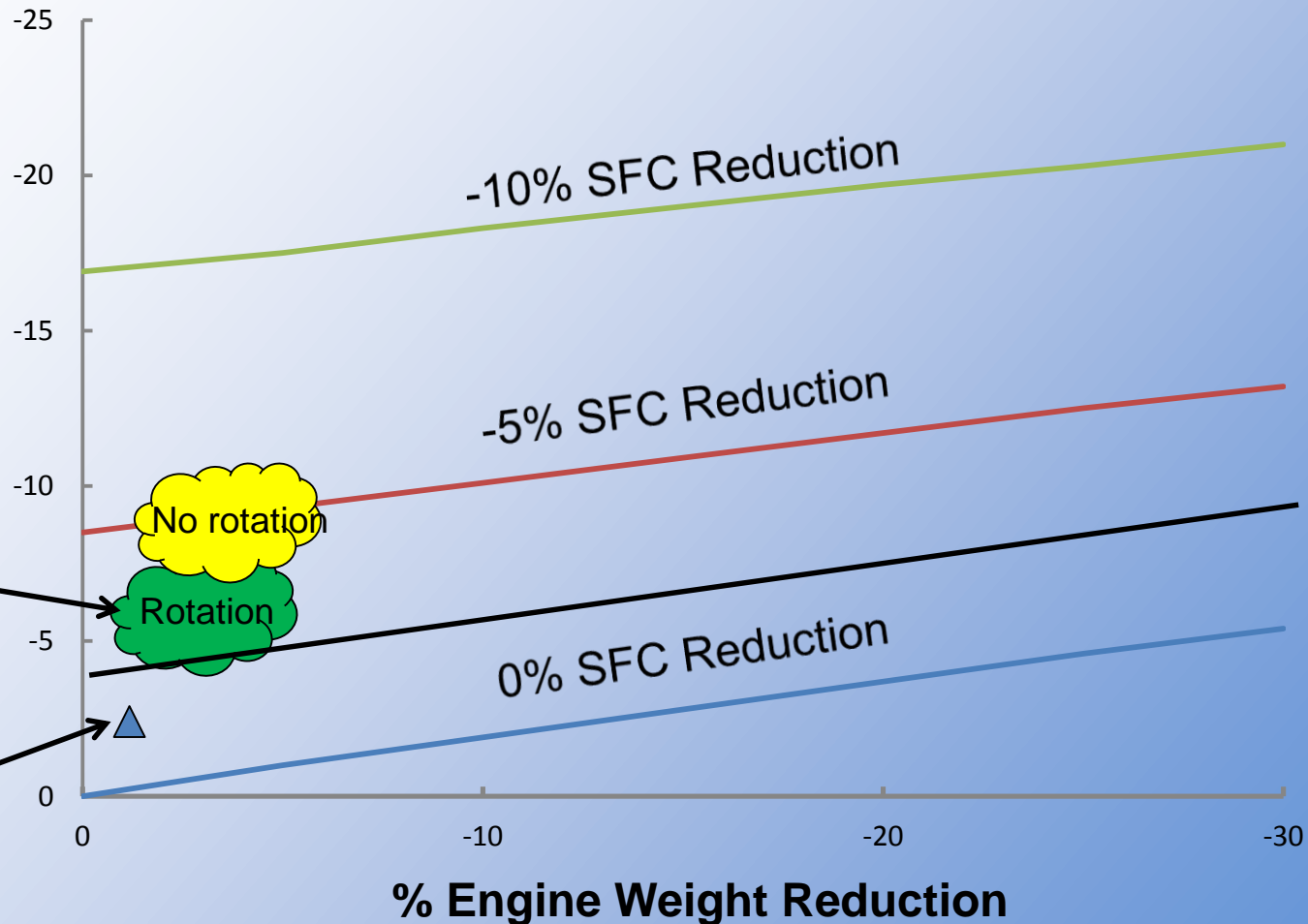
Hotwire survey, seal blade, slot 1



Possible reduction in broadband noise



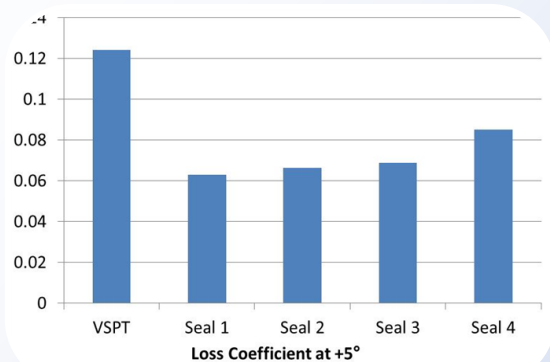
% Fuel Burn Reduction



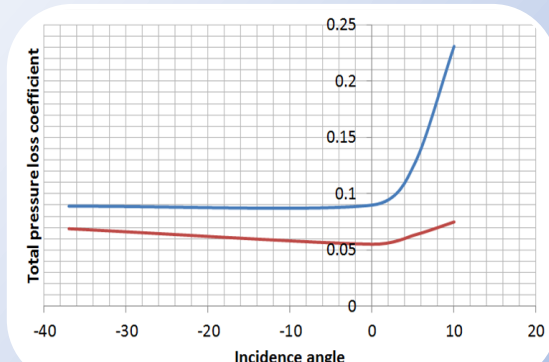
- » This was previous work for a 300 PAX aircraft
- » Benefits might be slightly lower for N2A (767 class) aircraft



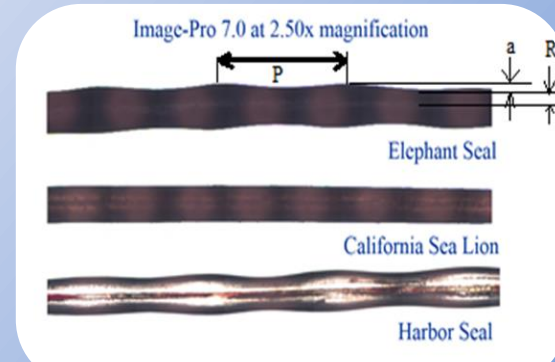
Conclusions



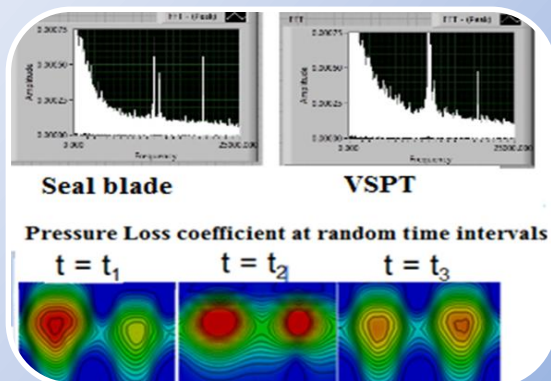
Bio-inspired blade showed 50% drag reduction over baseline



Blades treated with the Seal Vibrissa-like undulations were shown to be insensitive to incidence change



Blade with seal whisker LE parameters showed best results



Possible benefits to noise reduction



Several other applications could benefit more directly

