

# **Bio-Inspired Trailing Edge Noise Control**

**Ian Clark, Nathan Alexander, and William Devenport, *Virginia Tech***

**Stewart Glegg, *Florida Atlantic University*, Justin Jaworski, *Lehigh University***

**Nigel Peake and Conor Daly, *Cambridge University***

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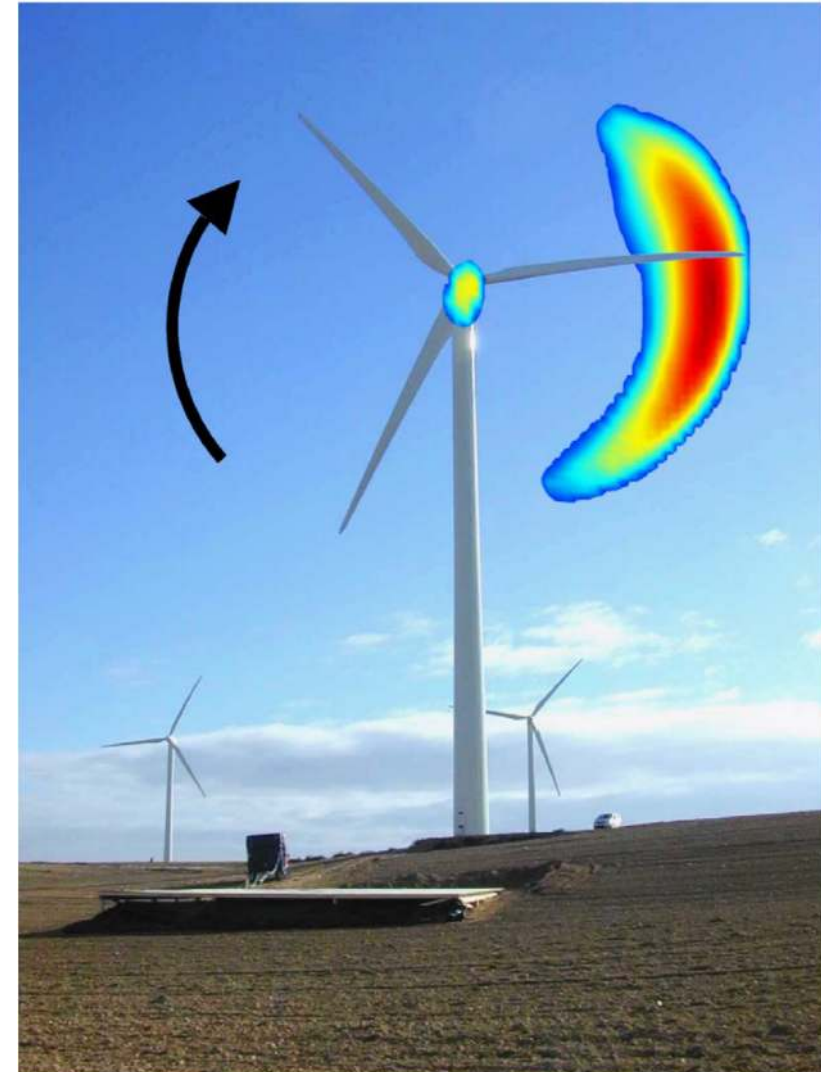
# Motivation

**Wind turbines are regulated for noise which limits their size, location, and operation.**

**A significant percentage of wind turbines are de-rated to comply with these regulations.**

**This results in a loss of Annual Energy Production for each decibel of noise reduction required.**

**We seek to reduce or eliminate the dominant noise source of wind turbines, which is trailing edge noise at the outer portion of the blades (where the most power is produced).**



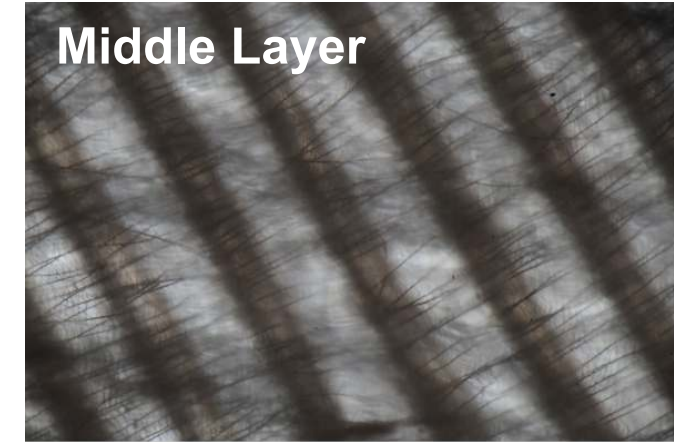
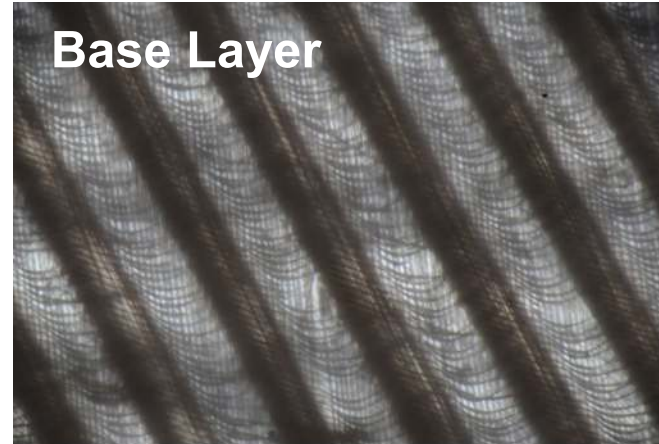
Credit: Oerlemans, S., et al. (2007). "Location and quantification of noise sources on a wind turbine." *Journal of Sound and Vibration* **299**(4-5): 869-883.

# Inspiration

**Certain species of owl that fly silently above 1.5kHz have down-like hairs on their feathers.**

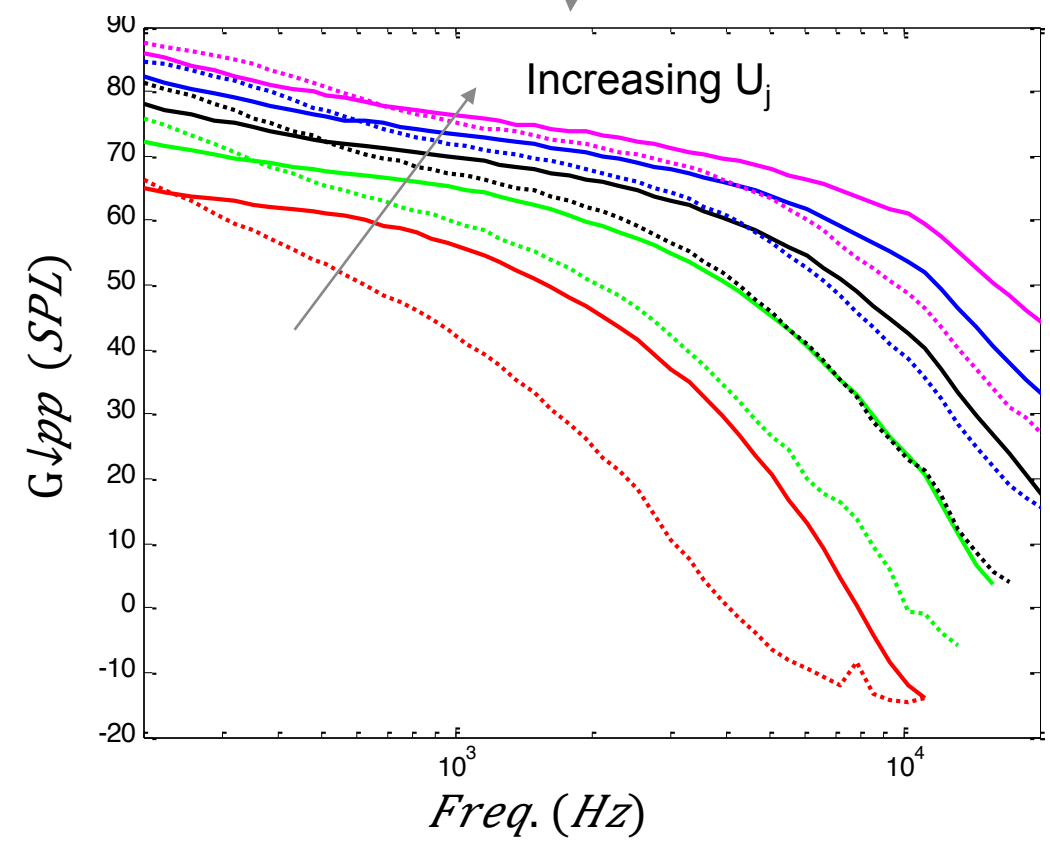
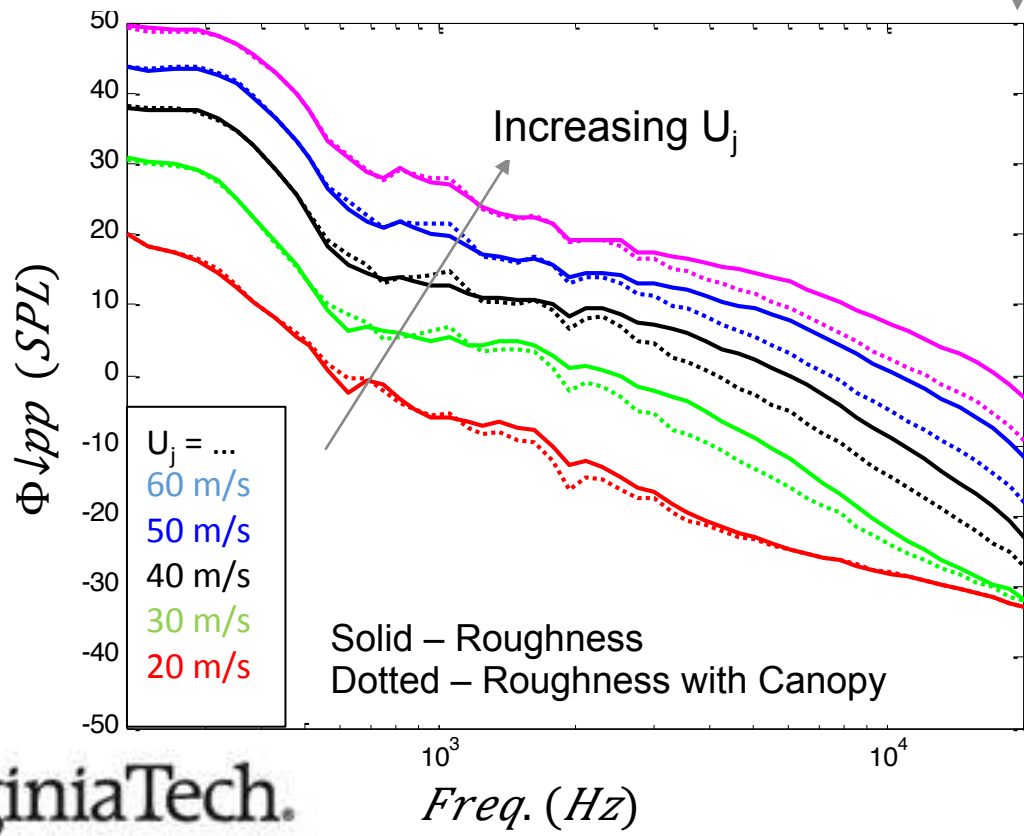
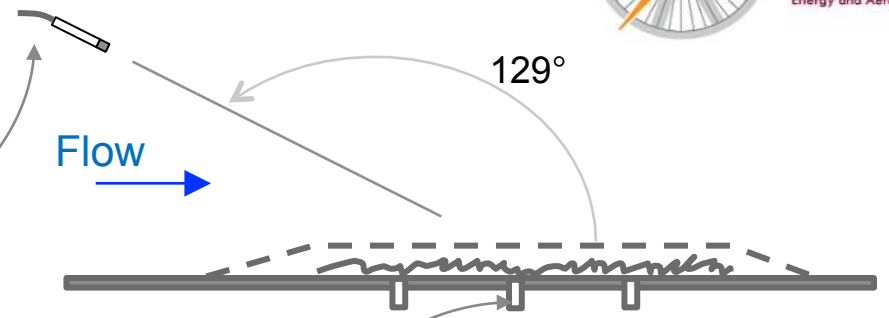
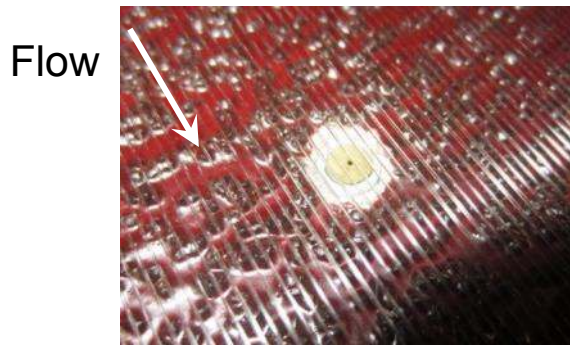
**These hairs tend to form a canopy suspended over the surface of the feather.**

**A similar structure has been shown to attenuate pressure fluctuations at the underlying surface.**



Canopy height  $\cong 0.5\text{mm}$   
Individual hair  $Re \cong 7$   
Canopy open area ratio  $\cong 70\%$

# Unidirectional Fabric Canopy

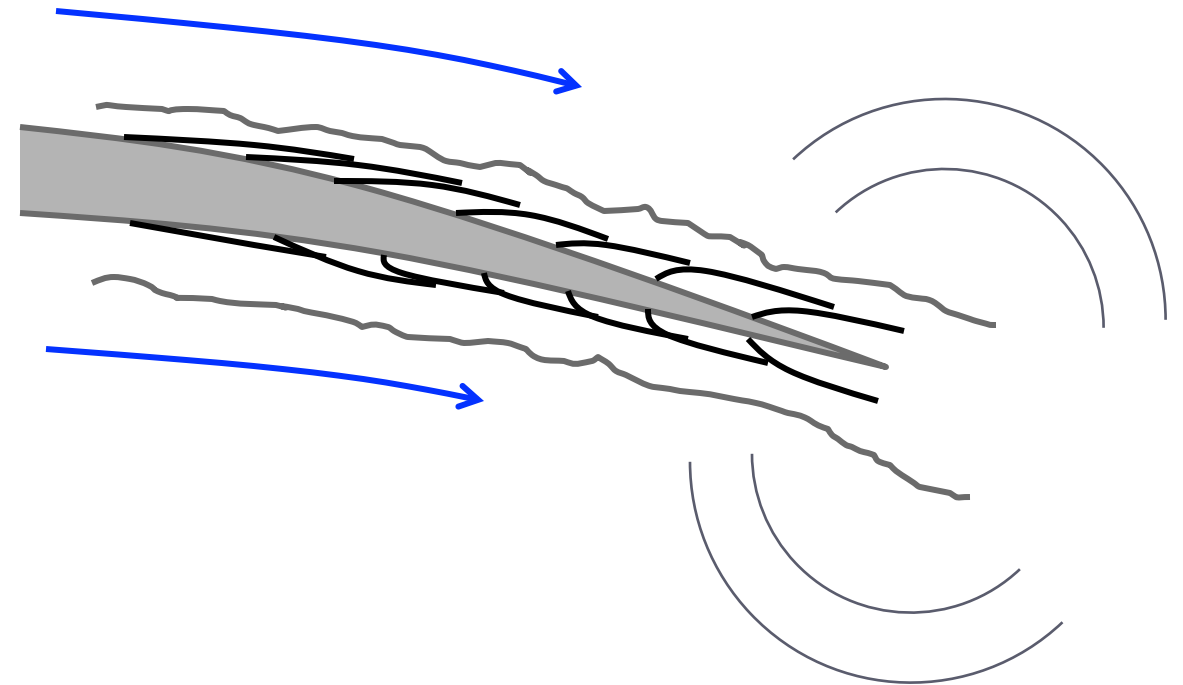


# The Idea

**The canopy can greatly suppress surface pressure fluctuations. Would it therefore not also suppress trailing edge noise?**

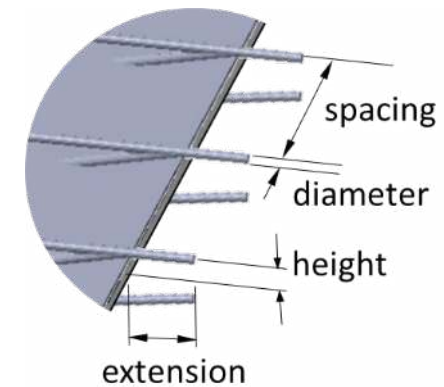
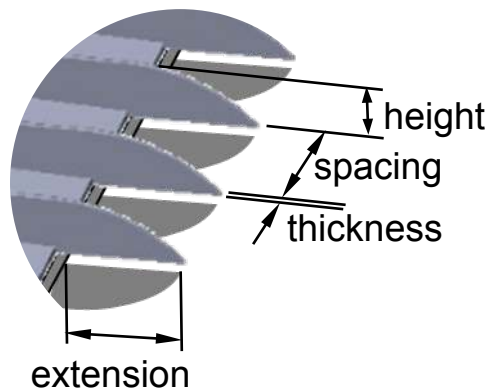
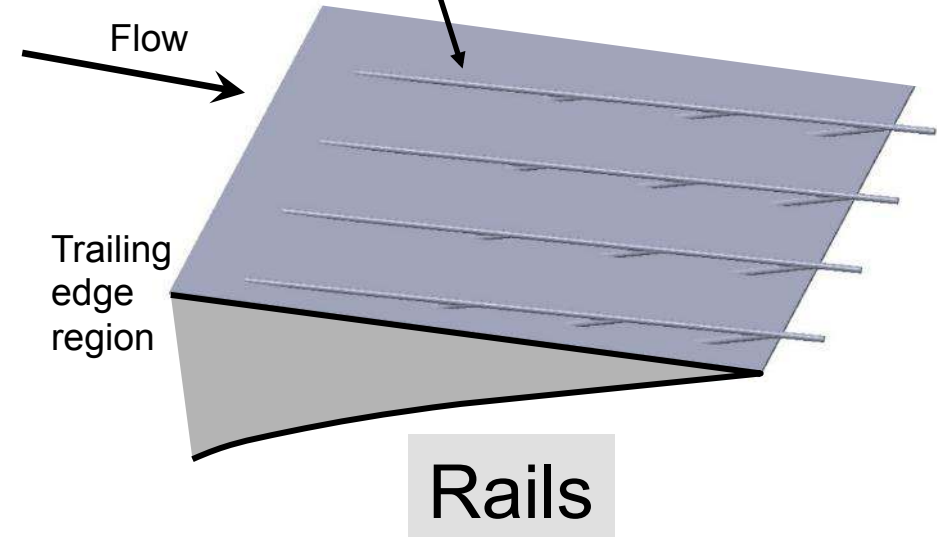
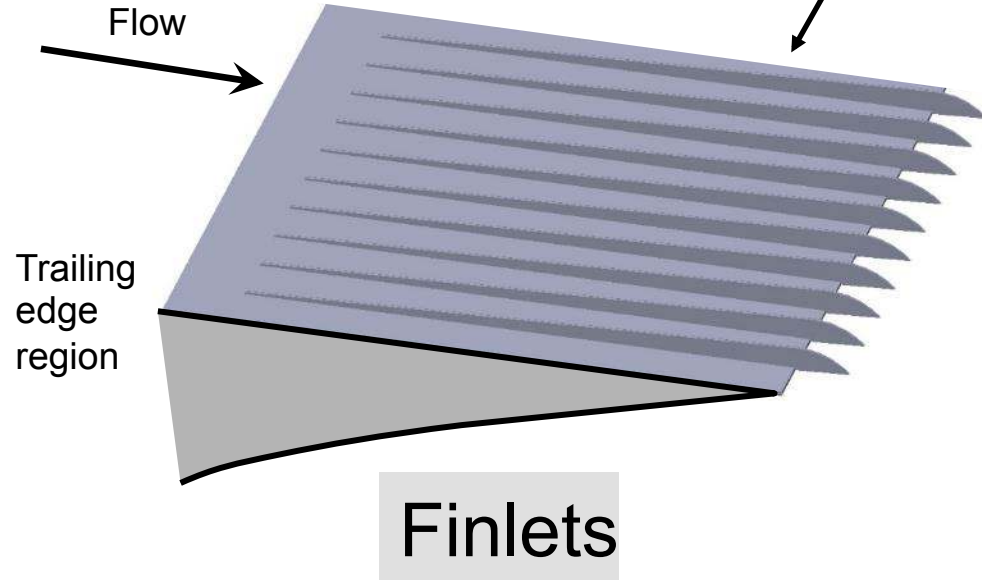
**How could a canopy be applied to an airfoil?**

**Could the hoped-for beneficial effects be achieved without significant adverse effects on the aerodynamics?**

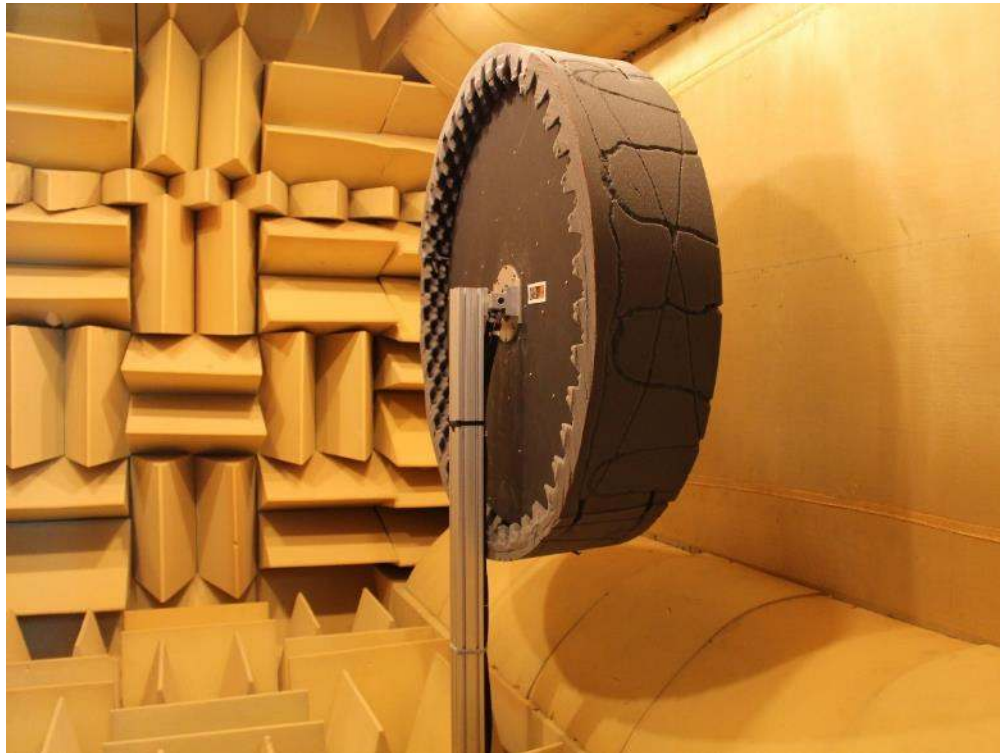


# Two Practical Concepts

Flow-aligned elements on top and bottom surfaces manipulate boundary layers ahead of the trailing edge.



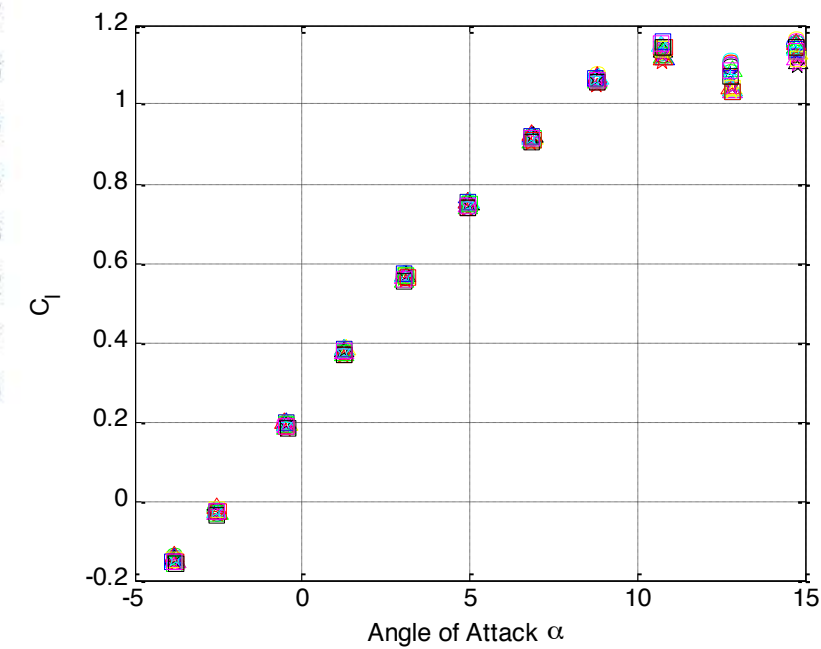
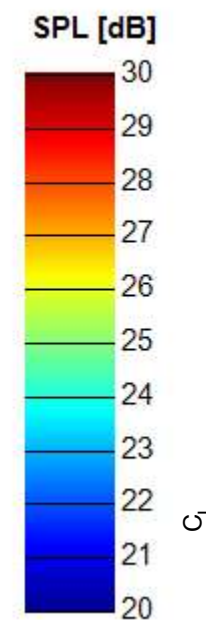
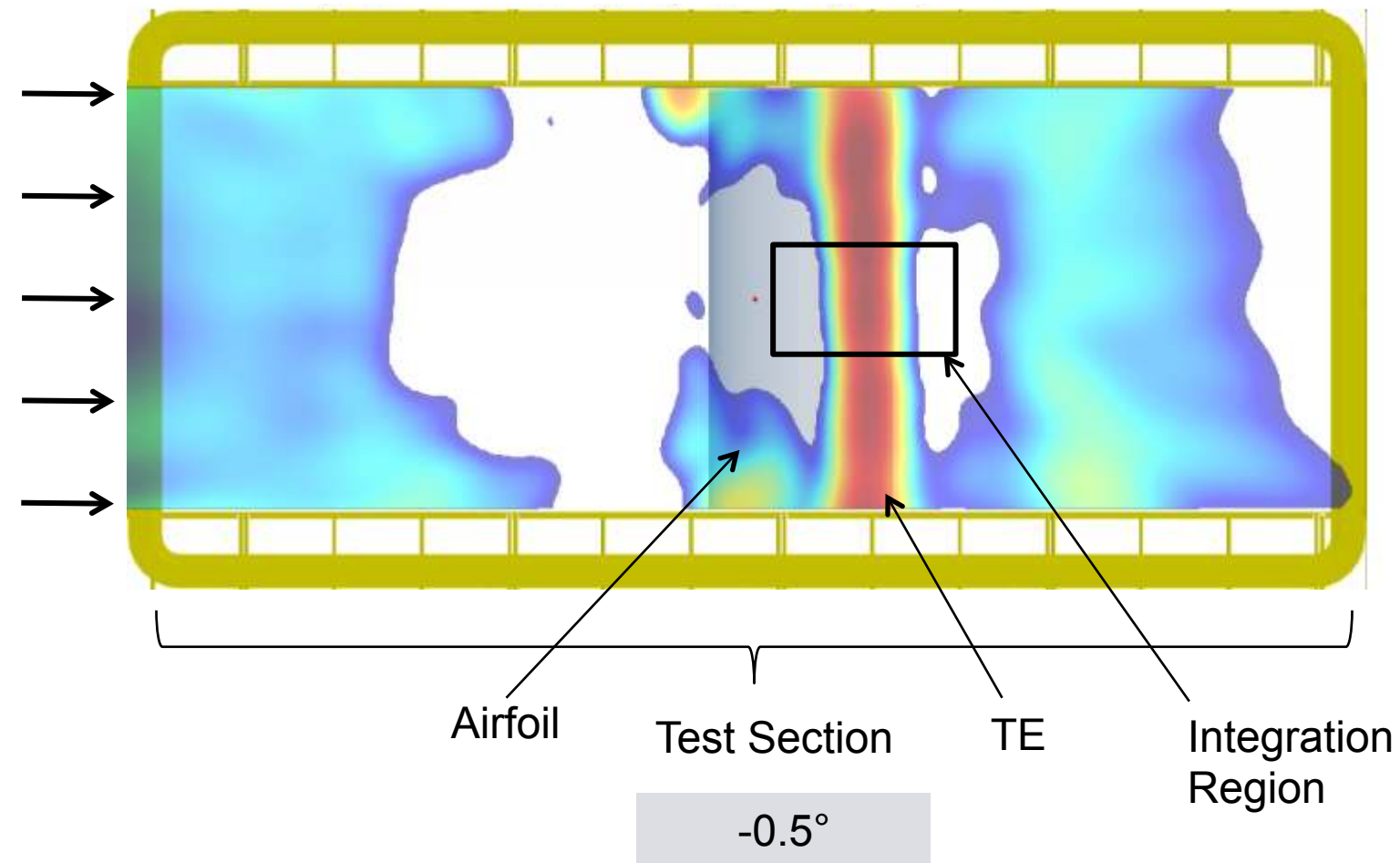
# The Experiment



- 117 microphone phase array for far field acoustics
- Surface pressure taps for  $C_{lp}$  and lift
- Wake rake for drag measurements
- 0.8-m chord DU96-W180 airfoil
- Tripped (0.5mm zigzag tape) at 5%/10% chord
- Flow conditions -  $M=0.15, 0.18$  ( $Re \approx 2.5M, 3M$ )
- $\alpha$  from  $-4^\circ$  to  $15^\circ$ ,  $\alpha \downarrow$  zero lift =  $-2.5^\circ$

# Clean Airfoil

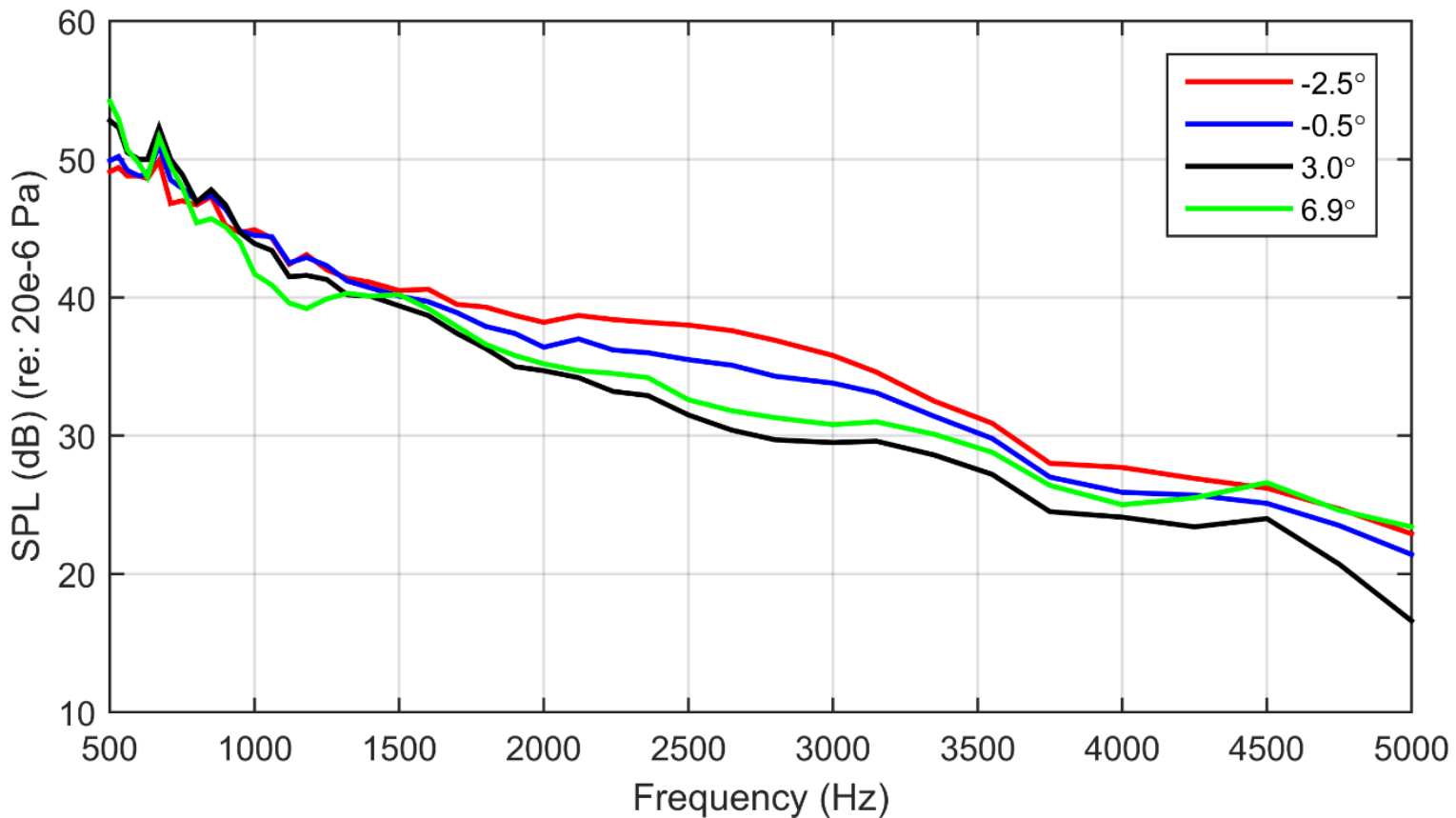
Re = 3M, Tripped, 3000 Hz





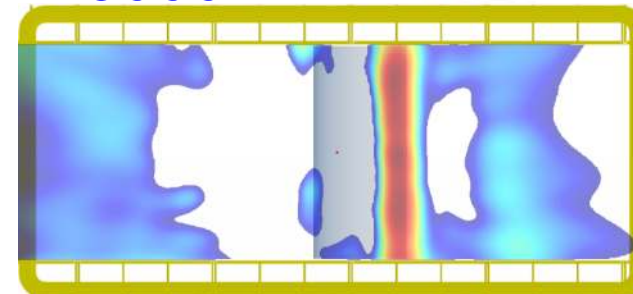
# Clean Airfoil

## Integrated Spectra

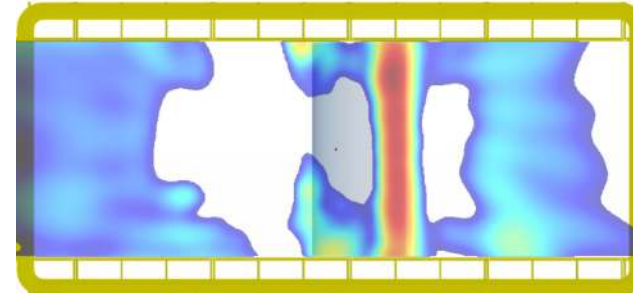


3000 Hz

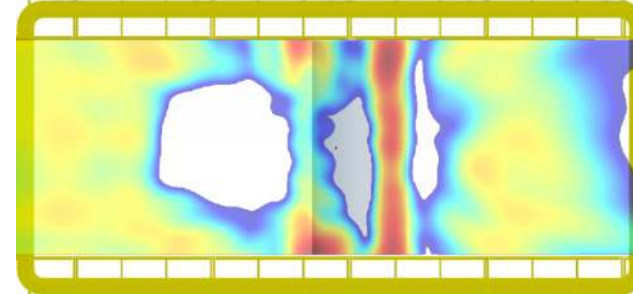
-2.5°



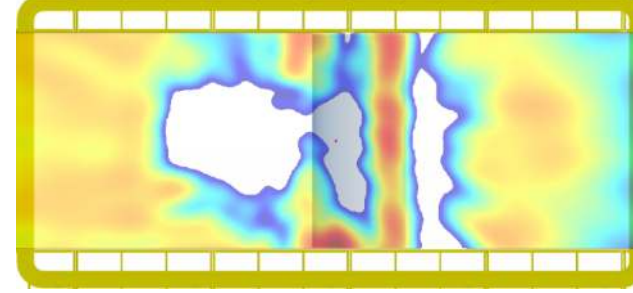
-0.5°



3.0°



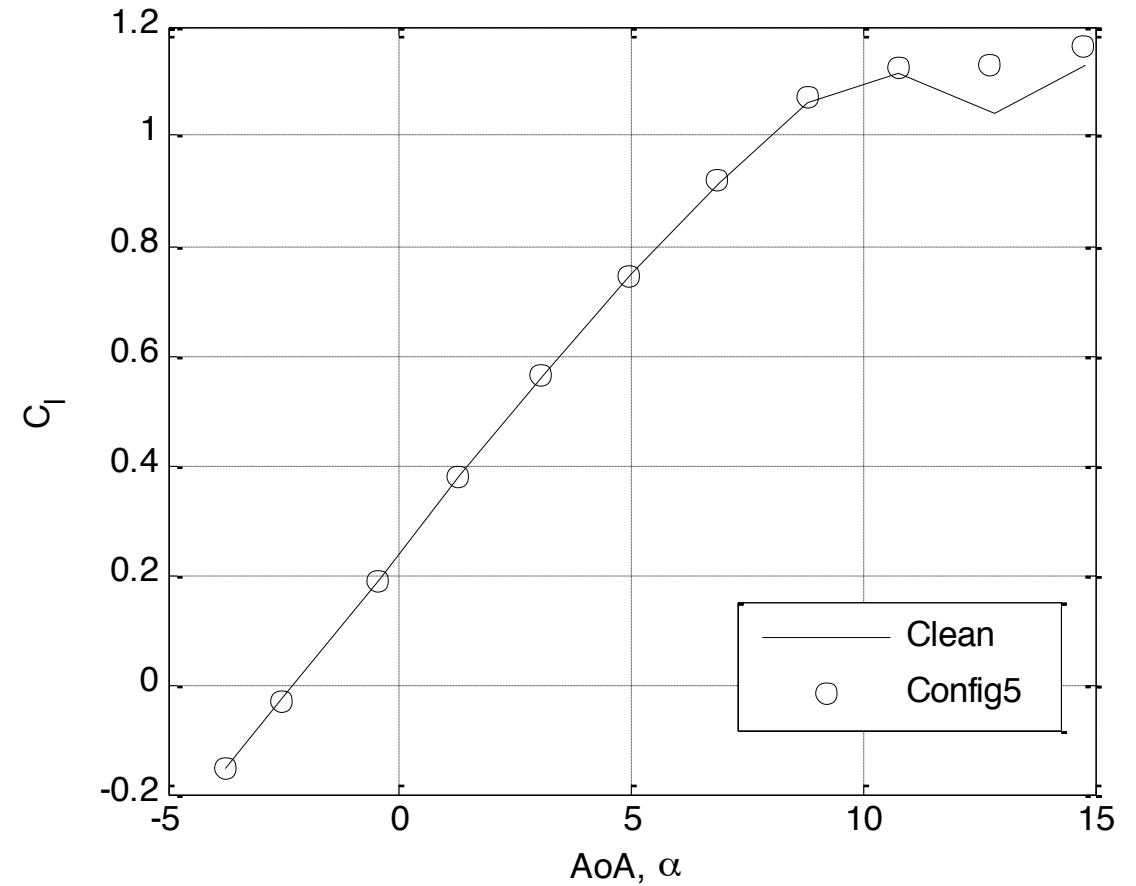
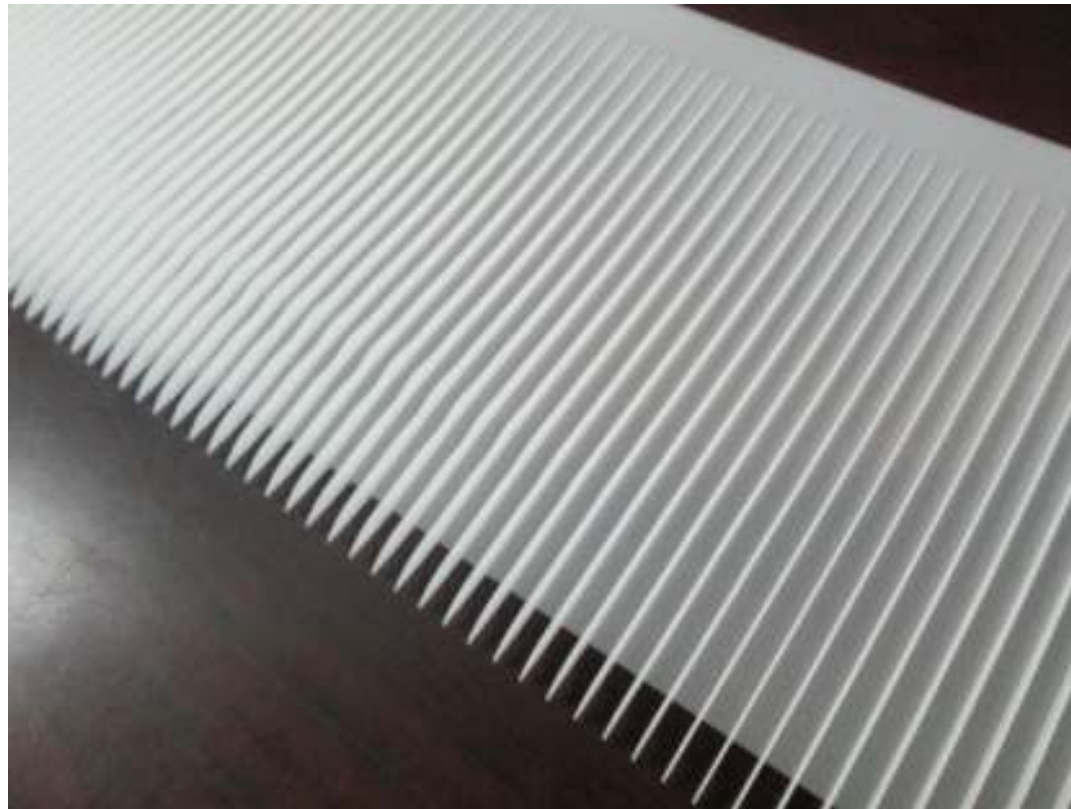
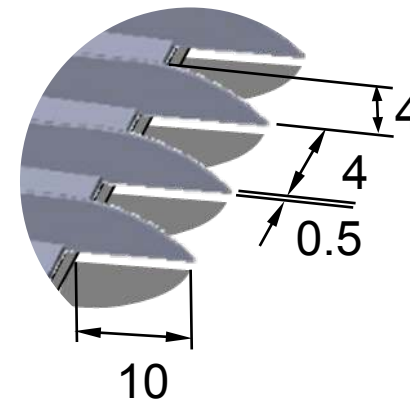
6.9°



# Finlets – Configuration 5

Thickness – 0.5mm  
Spacing – 4mm

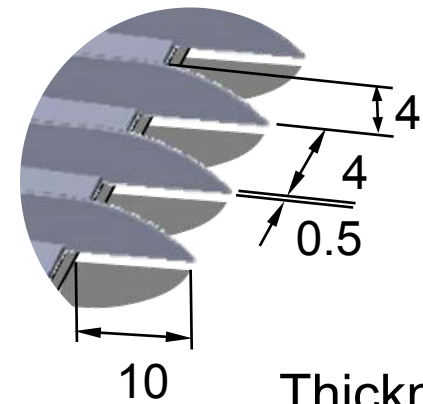
Height – 4mm  
10mm Extension



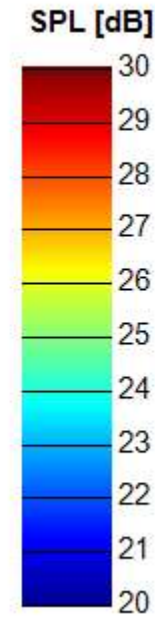
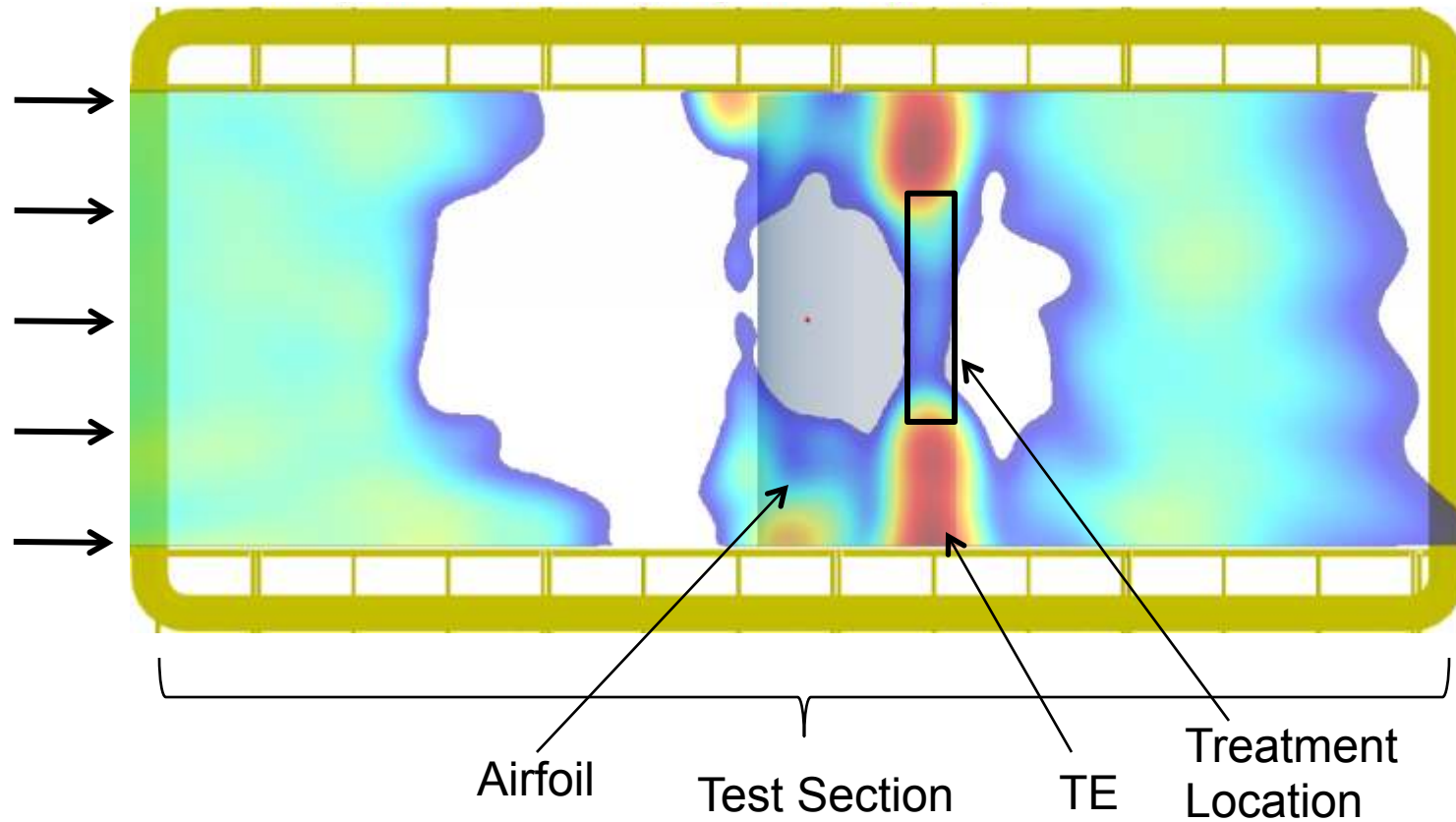
# Finlets – Configuration 5



Re = 3M, Tripped, 3000 Hz



Thickness – 0.5mm  
Spacing – 4mm  
Height – 4mm  
10mm Extension  
( $\delta \approx 20\text{mm}$ )

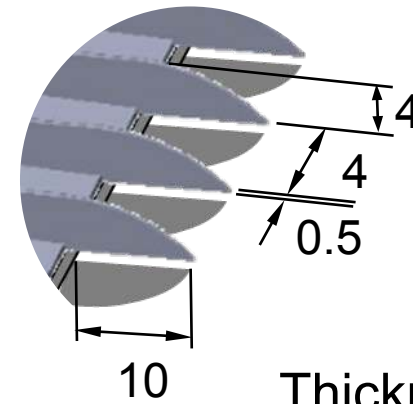


-0.5°

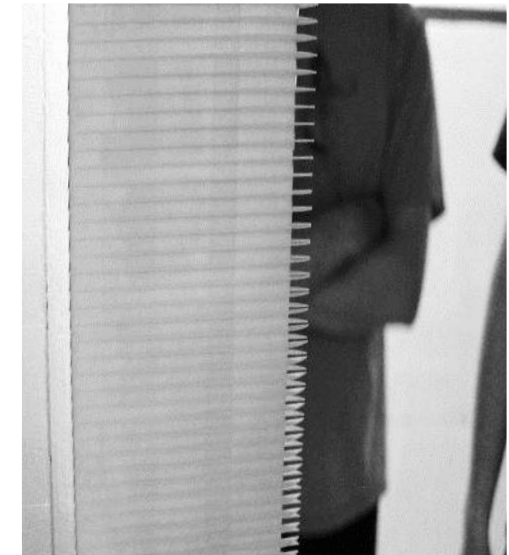
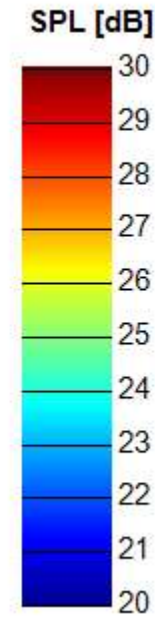
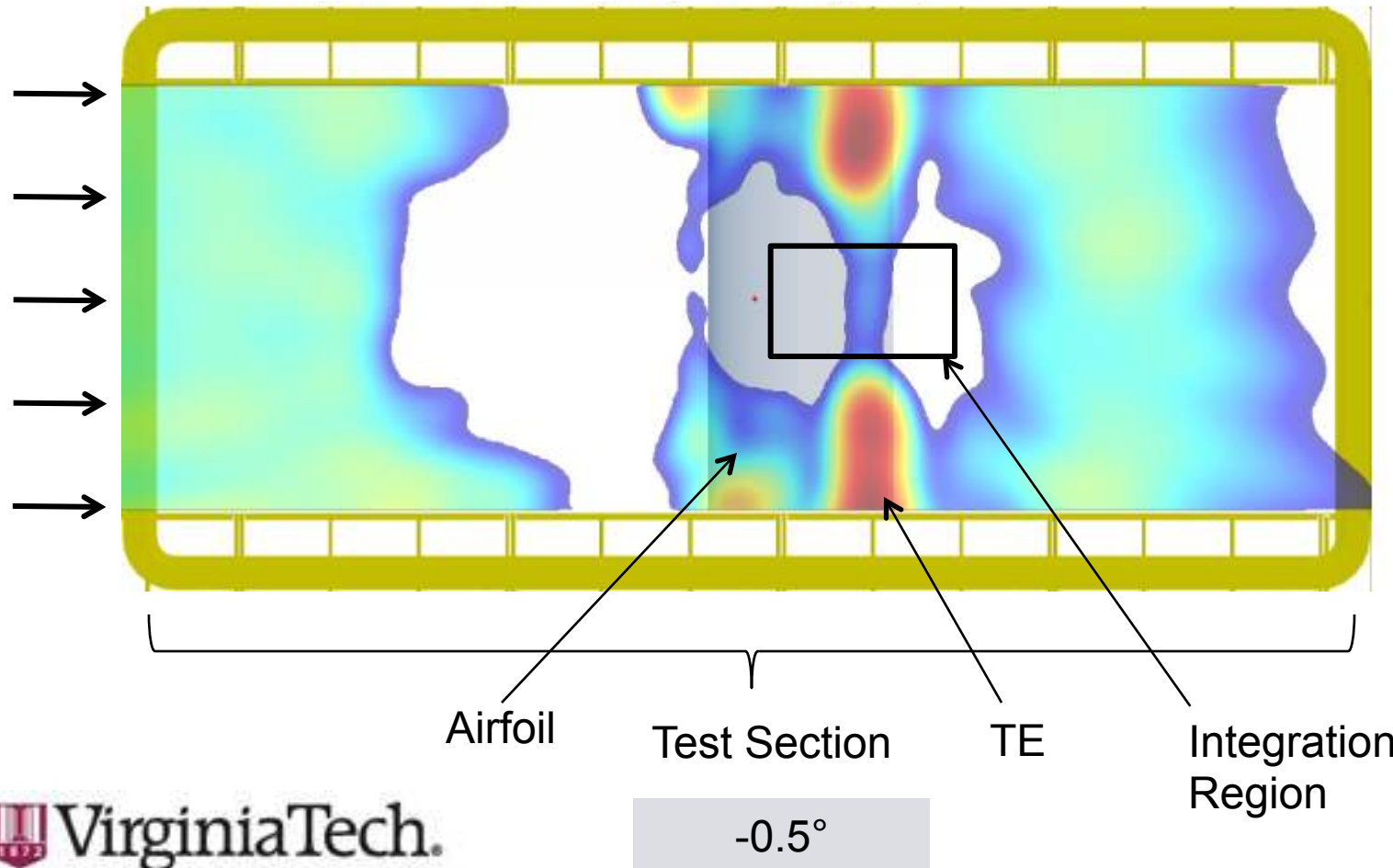
# Finlets – Configuration 5



Re = 3M, Tripped, 3000 Hz

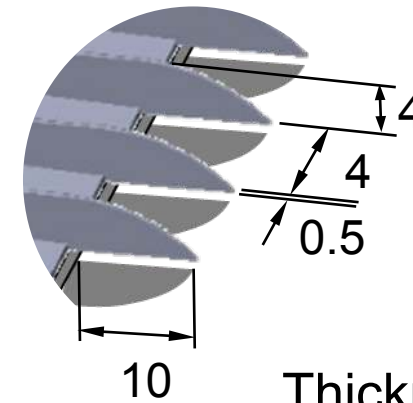


Thickness – 0.5mm  
 Spacing – 4mm  
 Height – 4mm  
 10mm Extension  
 ( $\delta \approx 20\text{mm}$ )



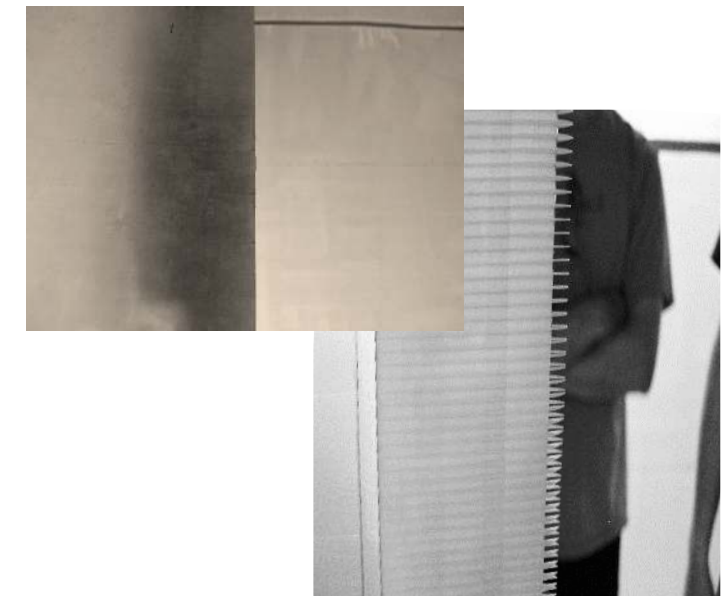
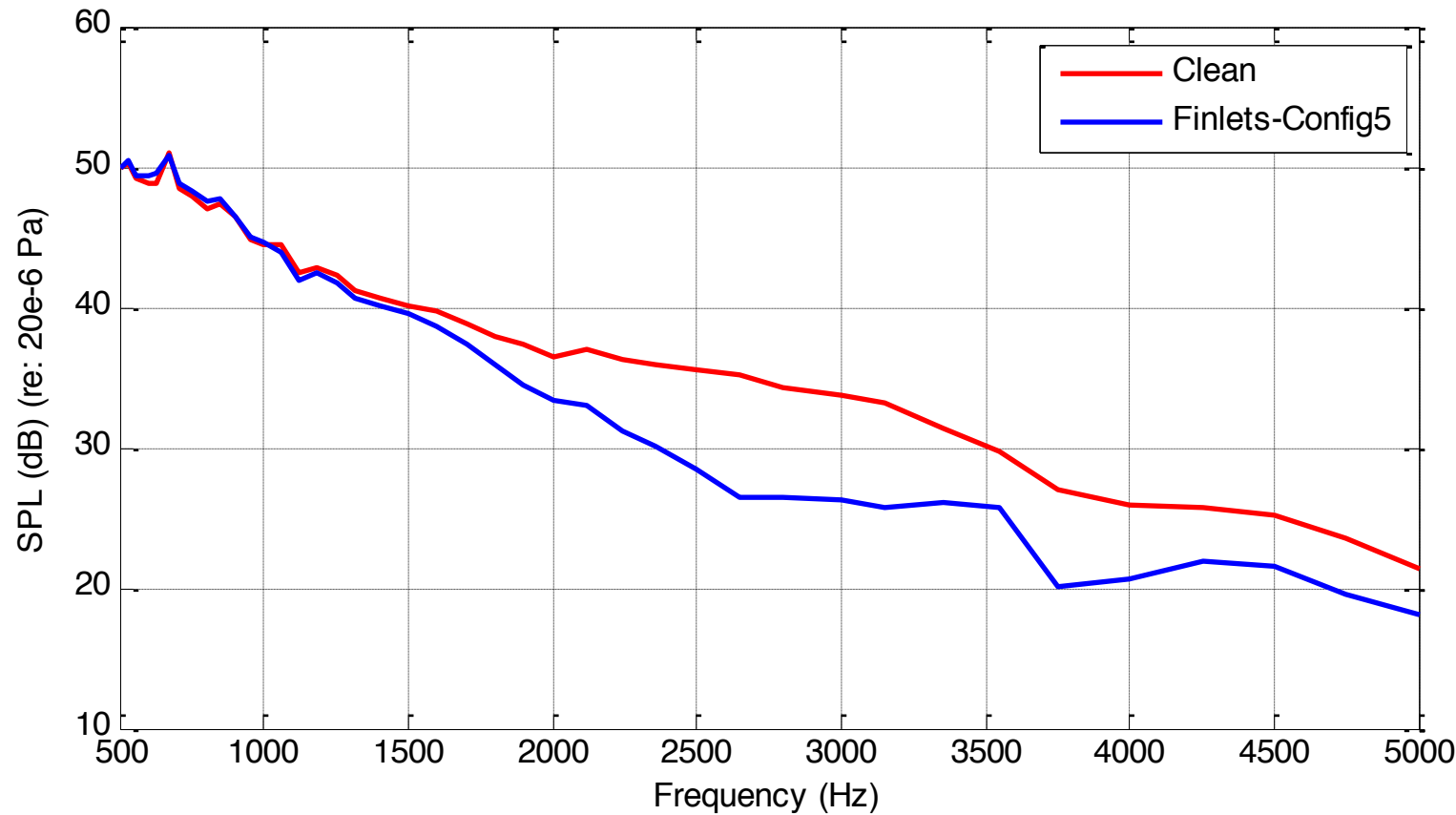
-0.5°

# Effect of Configuration 5 Finlet



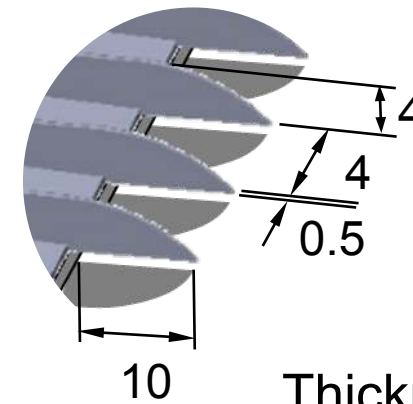
Thickness – 0.5mm  
Spacing – 4mm  
Height – 4mm  
10mm Extension  
( $\delta \approx 15\text{mm}$ )

## Integrated Spectra



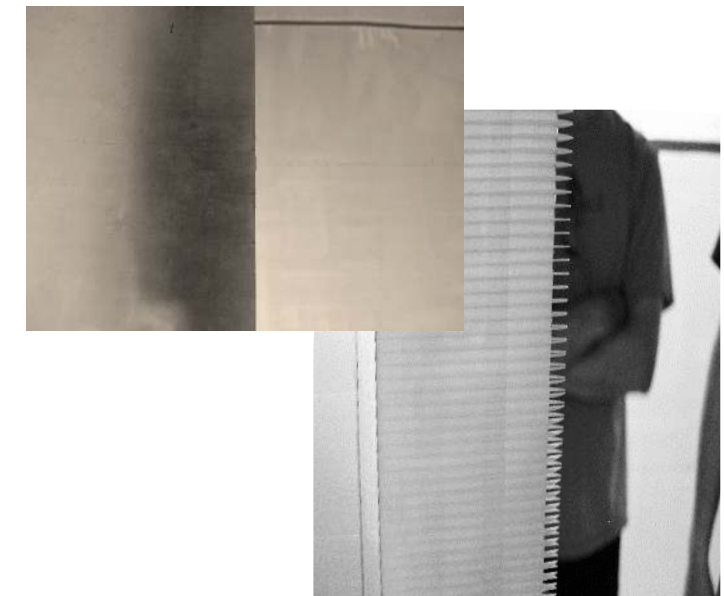
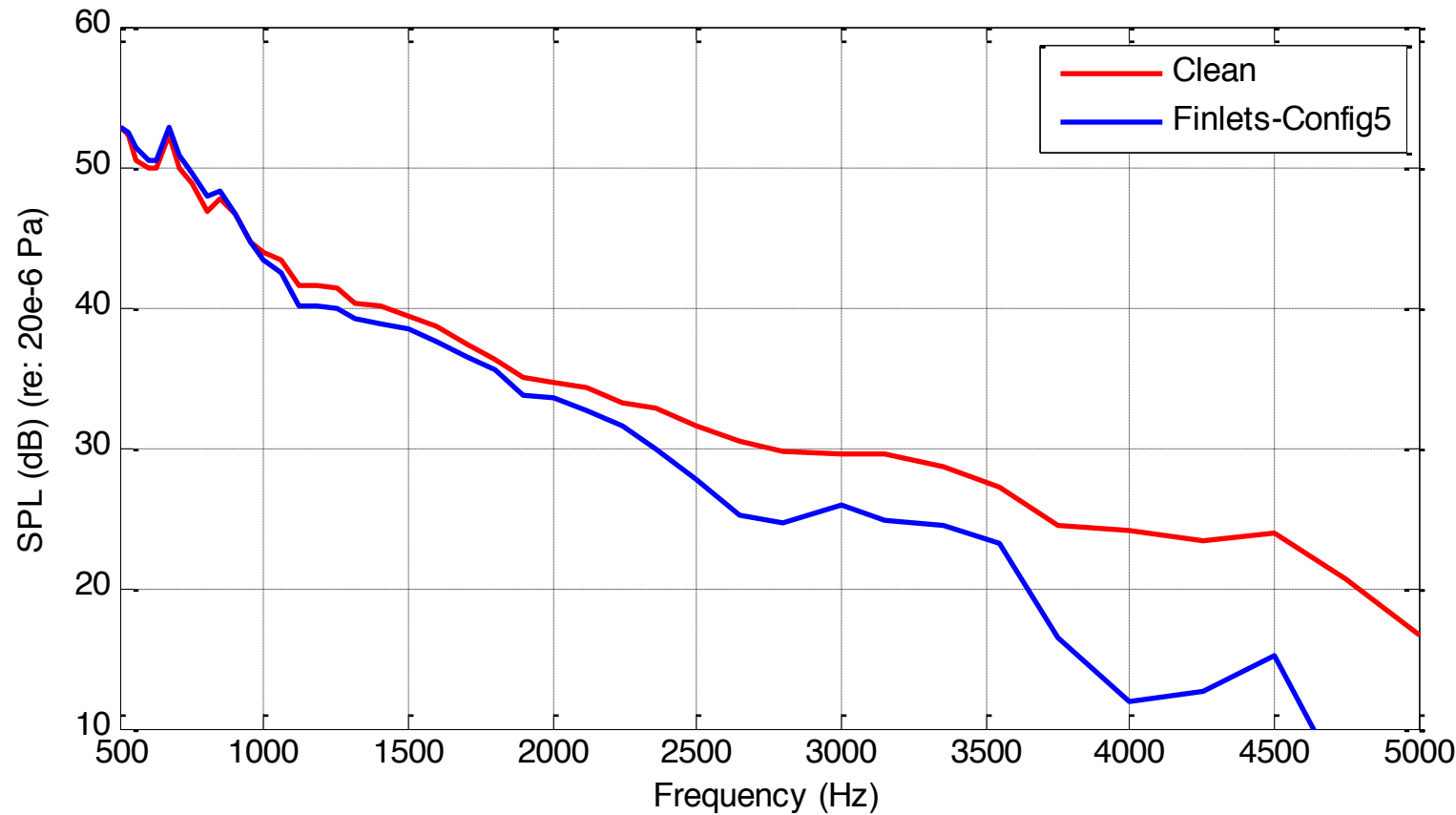
-0.5°

# Effect of Configuration 5 Finlet



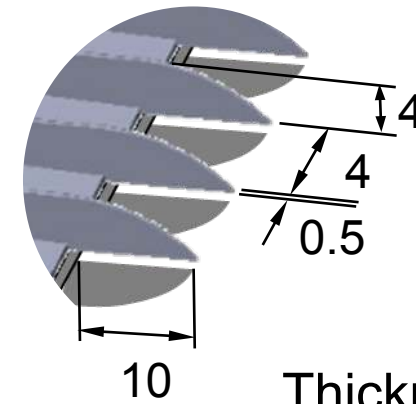
Thickness – 0.5mm  
Spacing – 4mm  
Height – 4mm  
10mm Extension  
( $\delta \approx 30\text{mm}$ )

## Integrated Spectra



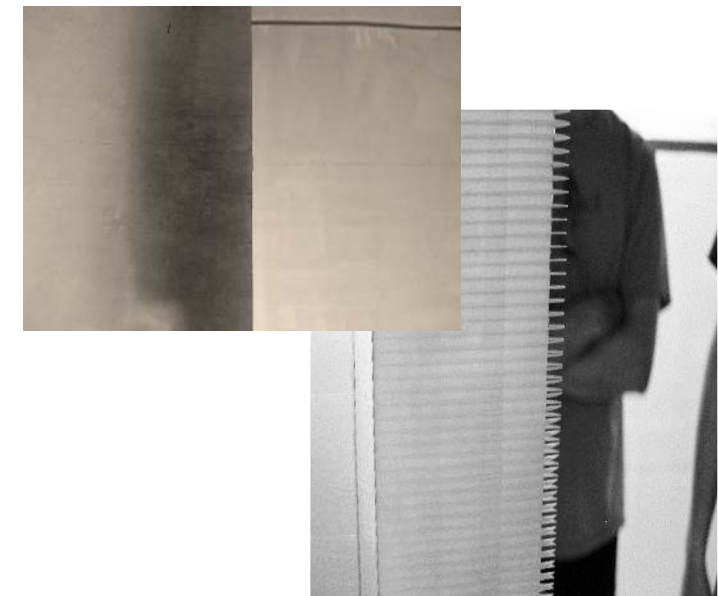
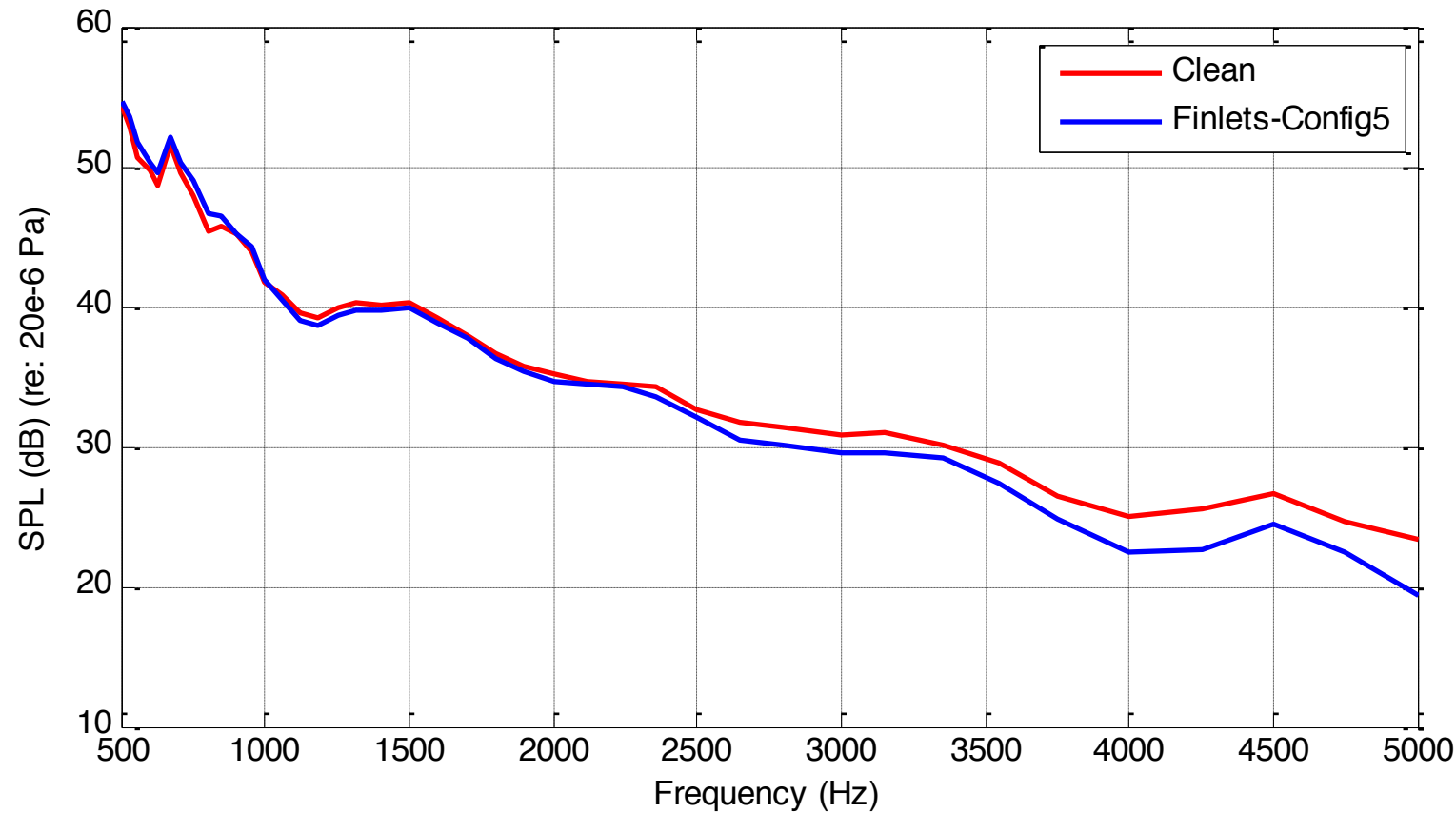
3.0°

# Effect of Configuration 5 Finlet



Thickness – 0.5mm  
Spacing – 4mm  
Height – 4mm  
10mm Extension  
( $\delta \approx 40\text{mm}$ )

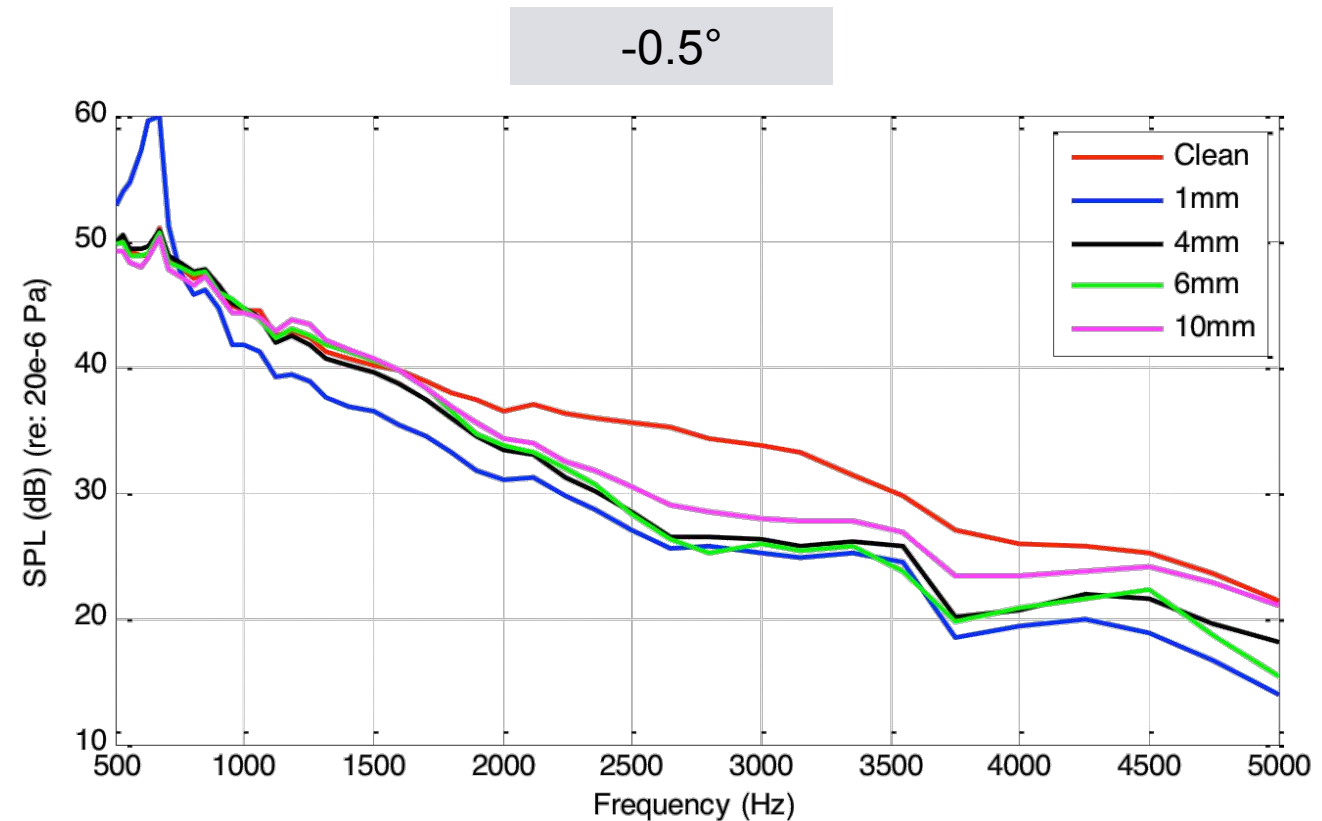
## Integrated Spectra



6.9°

# Effects of Finlet Geometry

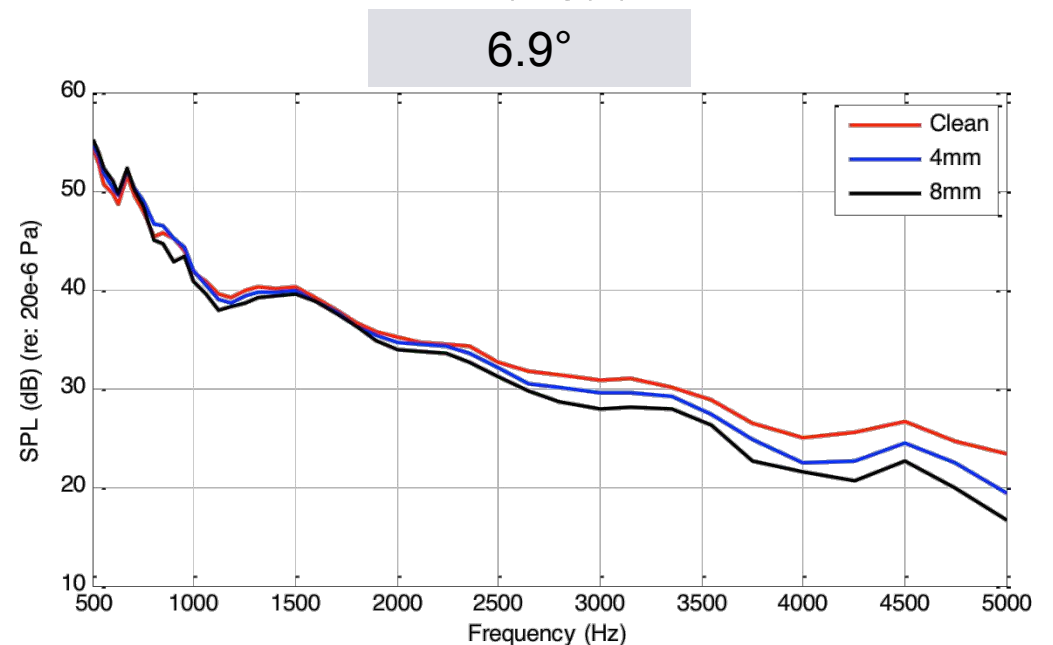
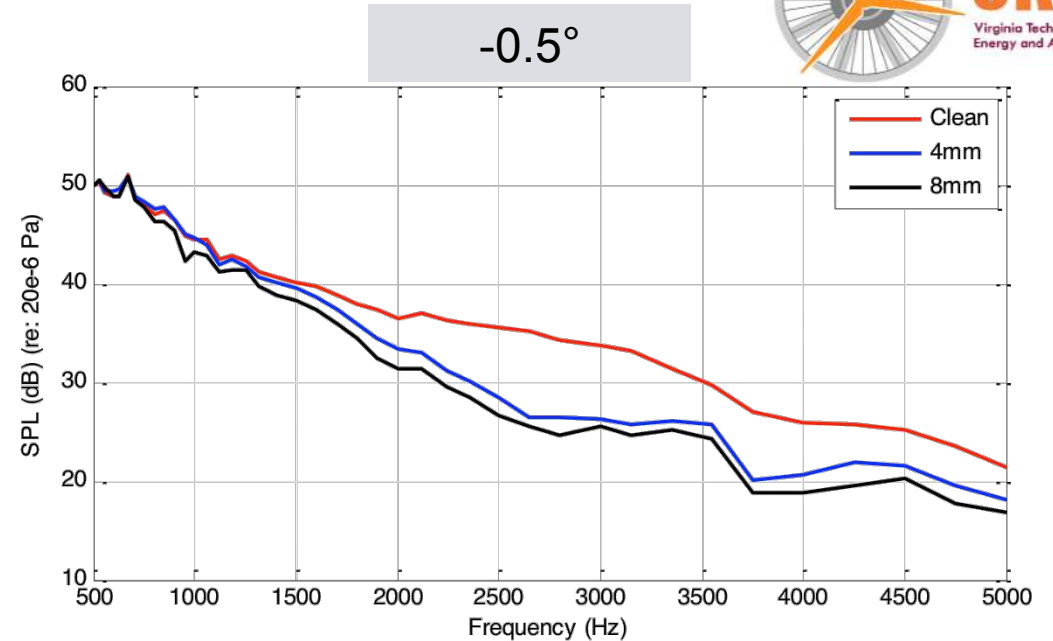
- **Spacing**
  - In general, smaller finlet spacing improves performance
  - However, very small spacings cause vortex shedding
- **Height**
  - Increased height improves performance, particularly at high angle of attack
- **Trailing Edge Extension**
  - Removing the trailing edge extension improves performance, particularly at high angle of attack





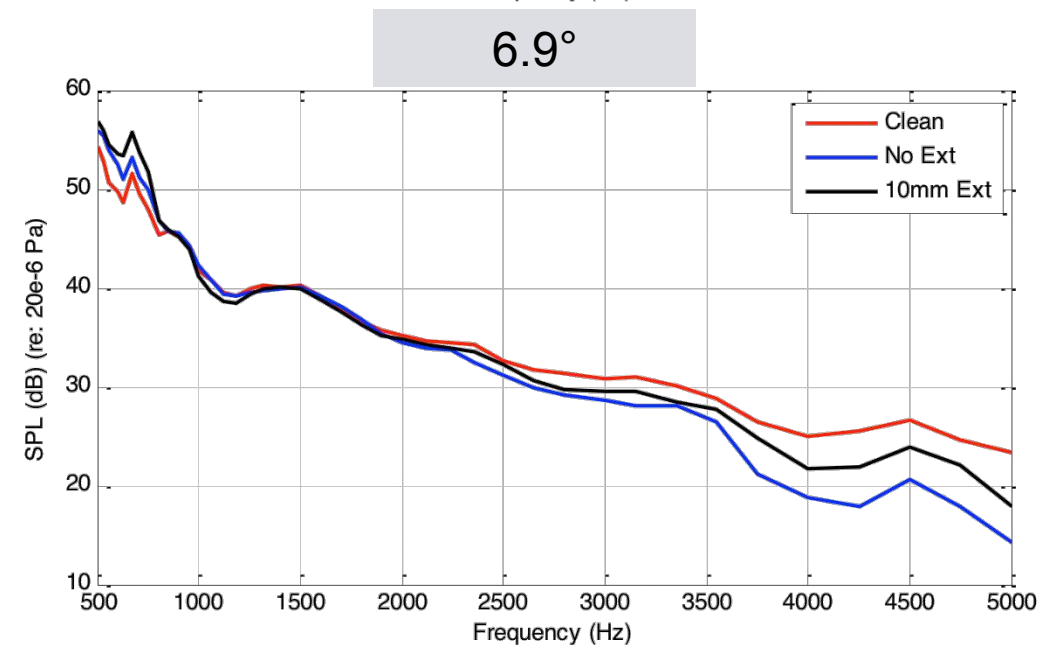
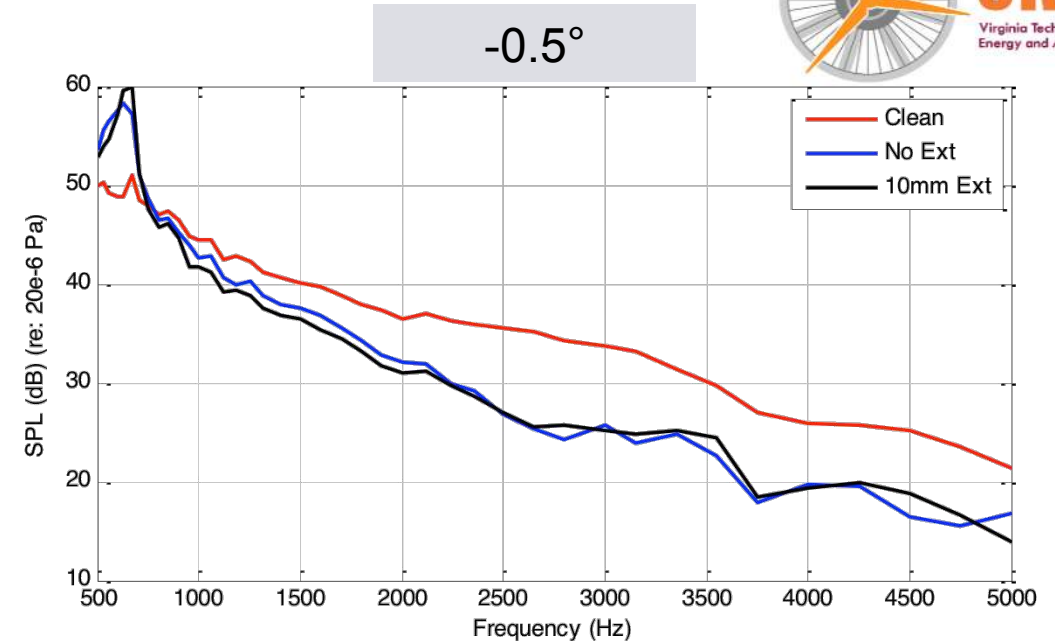
# Effects of Finlet Geometry

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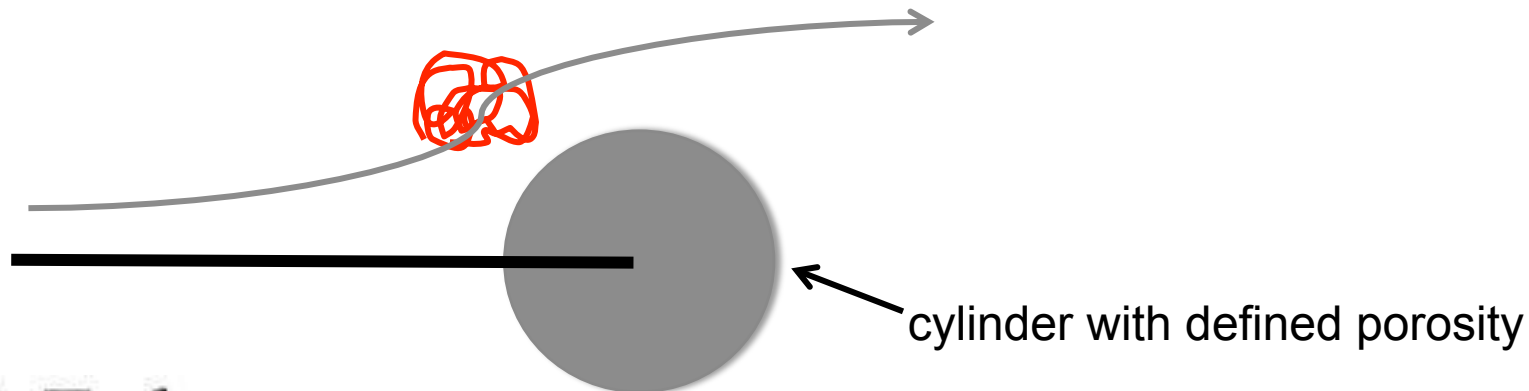
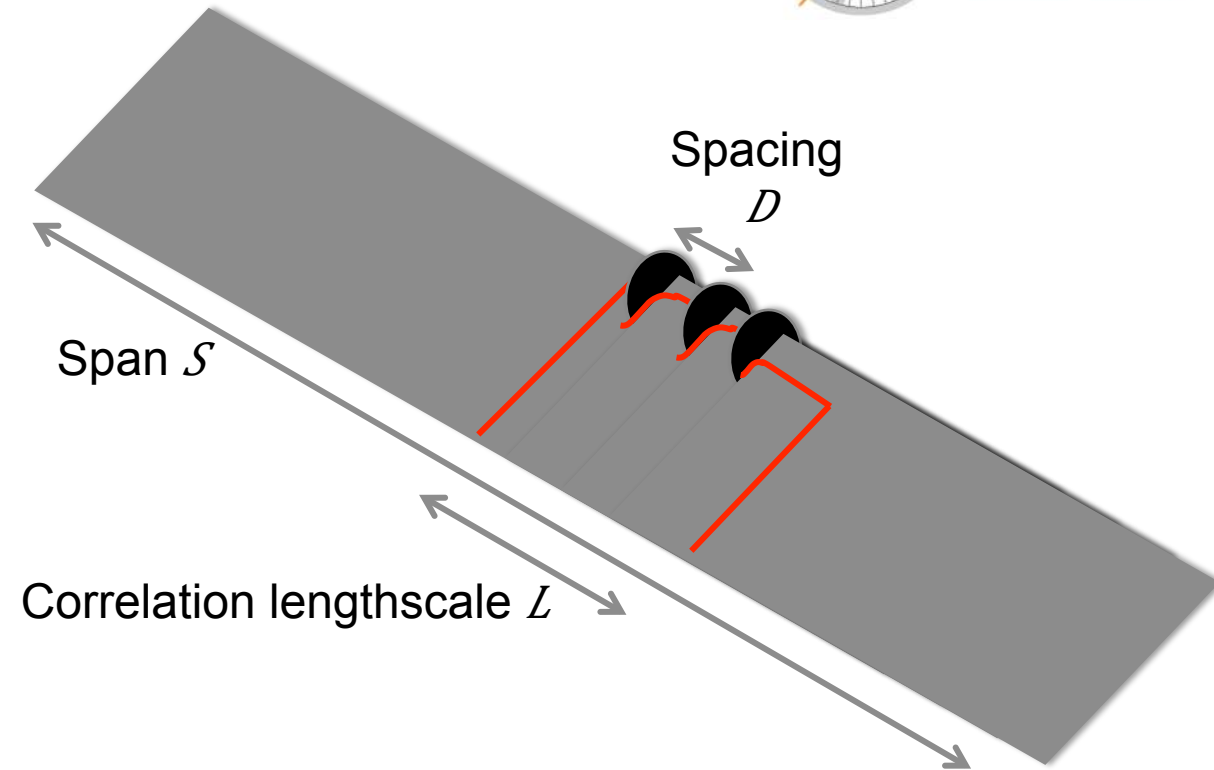
# Effects of Finlet Geometry

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  - Increased height improves performance, particularly at high angle of attack
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  - Removing the trailing edge extension improves performance, particularly at high angle of attack



# What physical mechanisms are we exploiting?

- Break up of the boundary layer eddies?
- Displacing those structures away from the surface/edge?
- Shear sheltering of the edge?
- Suppression of trailing edge shedding?



# Conclusions

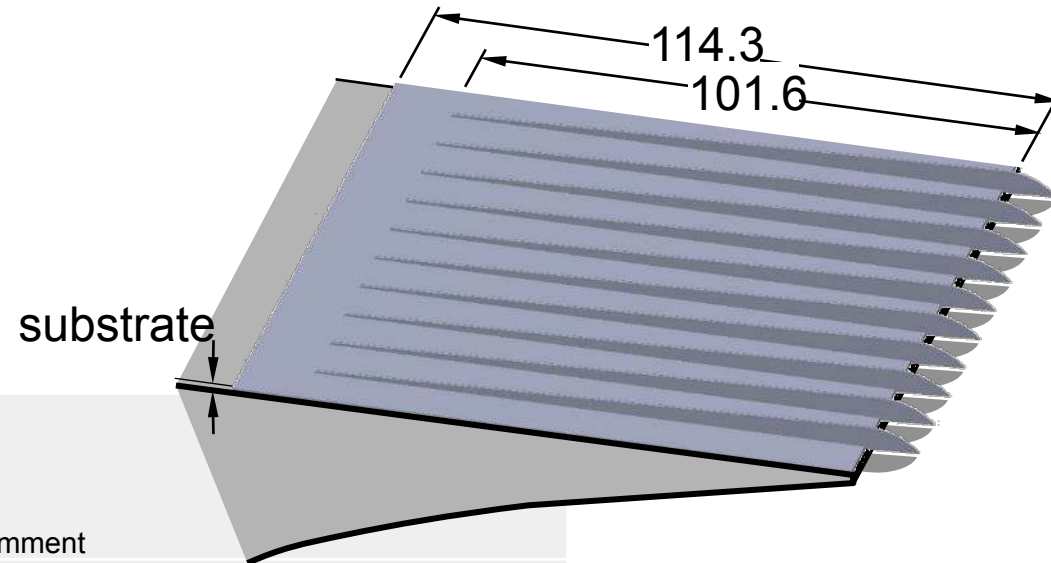


- 1. A new, bio-inspired surface treatment for the suppression of trailing edge noise has been demonstrated.**
- 2. The treatment could be combined with existing trailing edge modifications (serrations, etc.) to maximize noise control.**
- 3. The treatment is effective throughout a wide parameter range and is not highly dependent on a particular geometry, but there appears to be strong potential for optimization.**
- 4. The treatment has been shown to be effective over an angle of attack range that extends over 8 degrees from zero lift.**
- 5. Drag data suggests that the impact of finlets is limited to an increase in skin friction from the additional wetted area.**

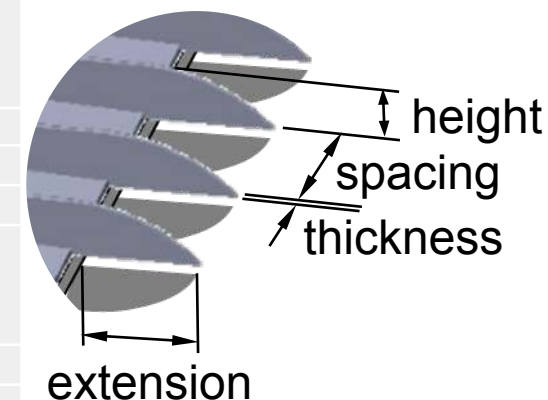
# Extras



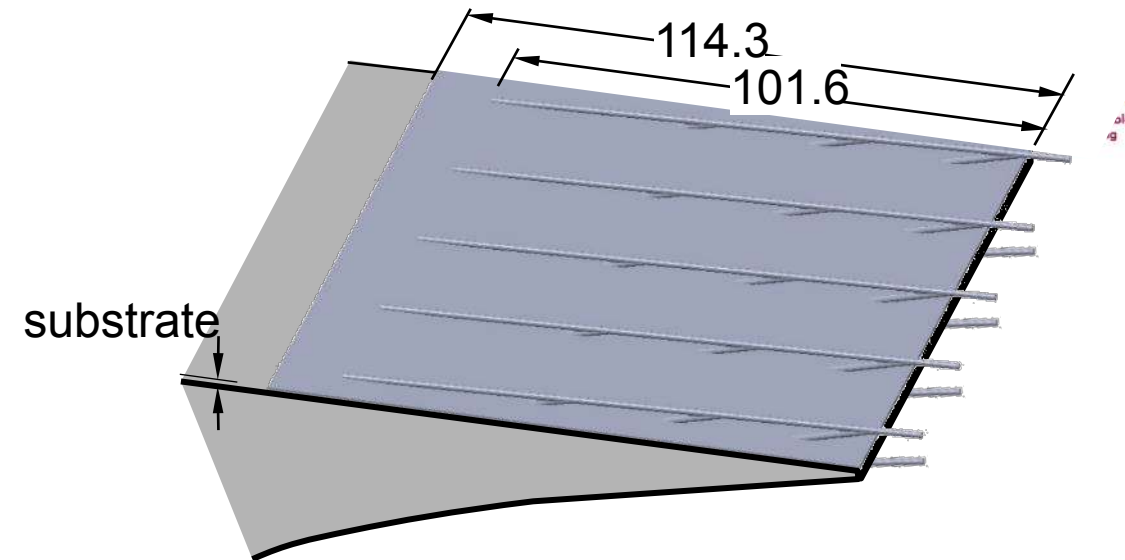
# Configurations - Finlets



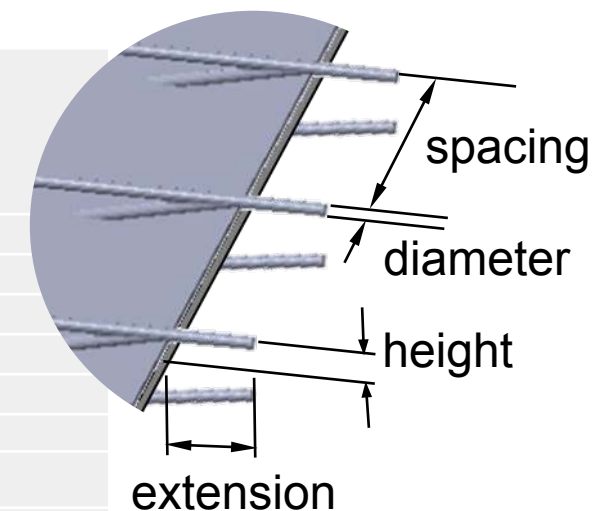
Config#	Runs	Type	Height	Spacing	Thickness	TE extension	Substrate	Suction only	Cp/lift	Drag	Acoustics	Comment
0	All	-	-	-	-	-	-	-	Y	Y	Y	Control cases
2	133-154	Blank	-	-	-	-	0.5	-	Y	Y	Y	
10	683-704	Blank	-	-	-	-	0.75	-	Y	-	Y	
3	463-484	Fin	4	1	0.5	10	0.5	-	Y	-	Y	Fin anchor case
1	419-440	Fin	4	1	0.5	0	0.5	-	Y	-	Y	Effect of extension w. C3
5	243-264	Fin	4	4	0.5	10	0.5	-	Y	-	Y	Effects of fin spacing w. C3
13	804-825	Fin	4	6	0.5	10	0.75	-	Y	-	Y	
7	331-352	Fin	4	10	0.5	10	0.5	-	Y	-	Y	
11	727-748	Fin	2	1	0.5	10	0.75	-	Y	-	Y	Effects of height w. C3
6	287-308	Fin	4	1	0.5	10	0.5	-	Y	-	Y	Effect of fractal length w. C3
12	760-781	Fin	4	1	0.5	10	0.75	-	Y	-	Y	Effect of fractal length/height w. C3
8	375-396	Fin	8	4	0.5	10	0.5	-	Y	Y	Y	Effect of fin height, w. C5
9	639-660	Fin	4	4	2	10	0.75	-	Y	-	Y	Effect of fin thickness w. C5
1S	507-528	Fin	4	1	0.5	0	0.5	Y	Y	-	Y	Effect of no pressure side treatment w. C1
3S	551-572	Fin	4	1	0.5	10	0.5	Y	Y	-	Y	Effect of no pressure side treatment w. C3
8S	980-1001	Fin	8	4	0.5	10	0.5	Y	Y	-	Y	Effect of no pressure side treatment w. C8
26s	1112-1122, 1134-1144	Fin	16	4	0.5	0	0.5	Y	Y	-	Y	High suction-side treatment



# Configurations - Rails

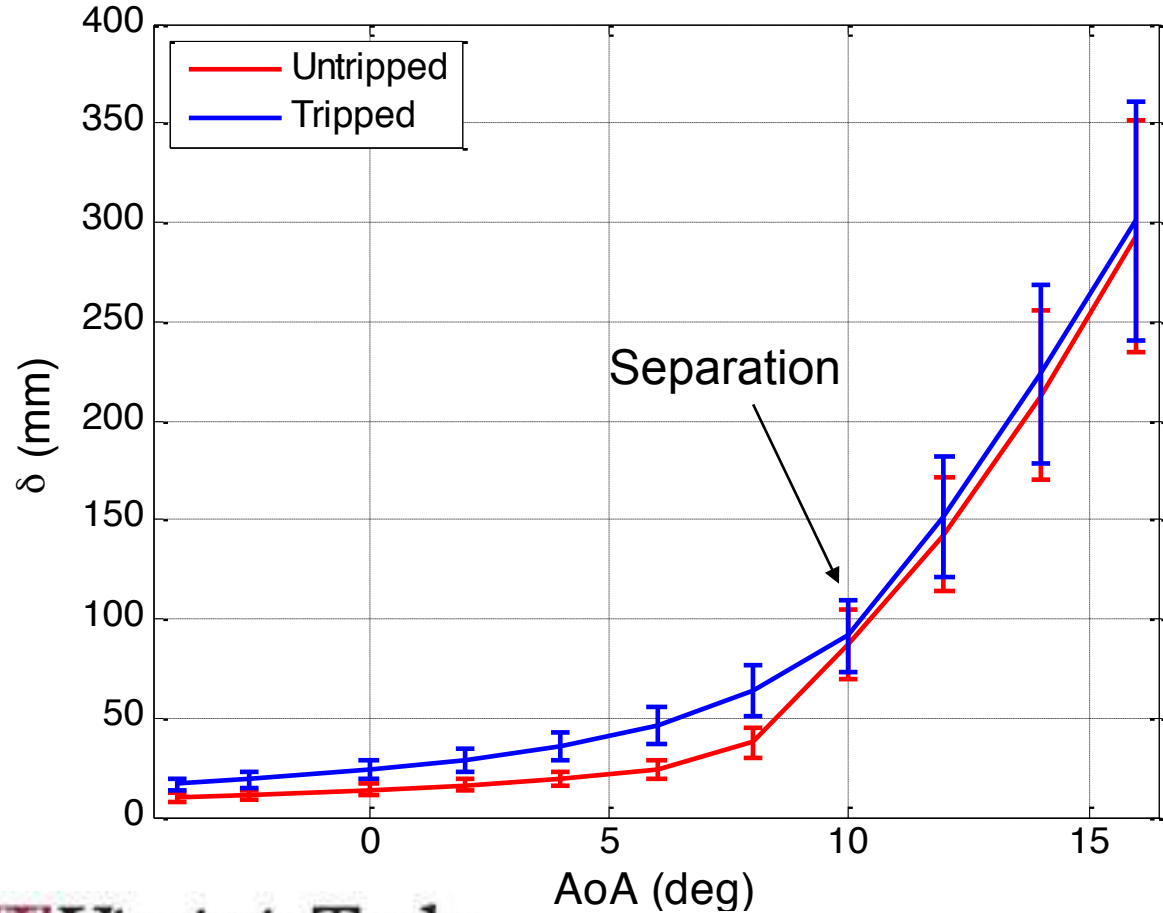


Config#	Runs	Type	Height	Spacing	Diameter	TE extension	Substrate	Suction only	Cp/lift	Drag	Acoustics	Comment
14	848-869	Rail	4	2.5	1.25	10	0.75	-	Y	-	Y	Rod anchor case
15	936-957	Rail	4	2.5	1.25	0	0.75	-	Y	-	Y	Effect of extension w. C14
17	1024-1045	Rail	8	2.5	1.25	10	0.75	-	Y	-	Y	Effect of height w. C14
18	1068-1089	Rail	4	5	2.5	10	0.75	-	Y	-	Y	Effect of dia. & spacing w. C14
20	1211-1232	Rail	8	10	1.25	10	0.75	-	Y	-	Y	Effect of spacing w. C17
19	1167-1188	Rail	4	2.5	1.25	10	0.75	-	Y	-	Y	Effect of fractal length w. C14
Velvet	892-913	Velvet	n/a	n/a	n/a	n/a	n/a	-	Y	-	Y	
Velcro	23-44	Velcro	n/a	n/a	n/a	n/a	n/a	-	Y	-	Y	

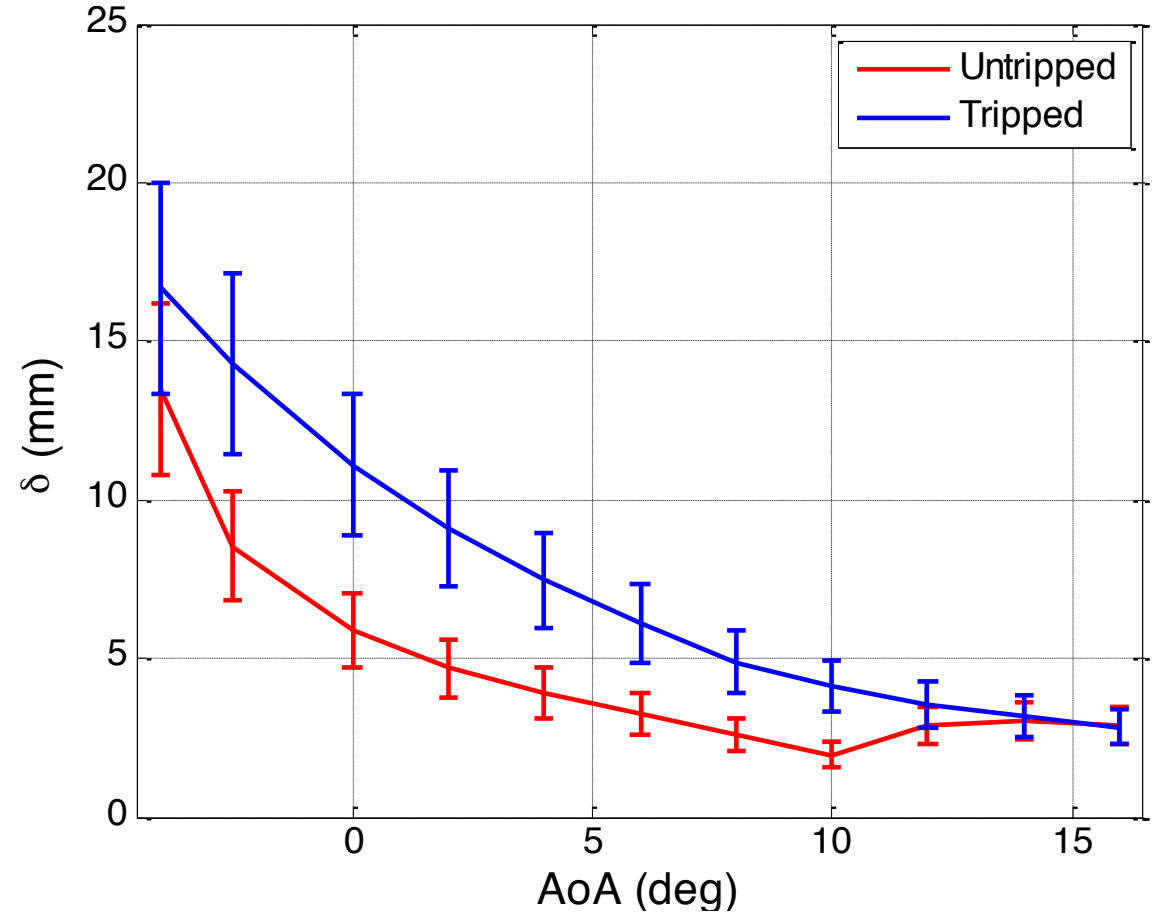


# BL Thickness

U=50m/s,  $\delta$  at 100% Chord, Suction Side

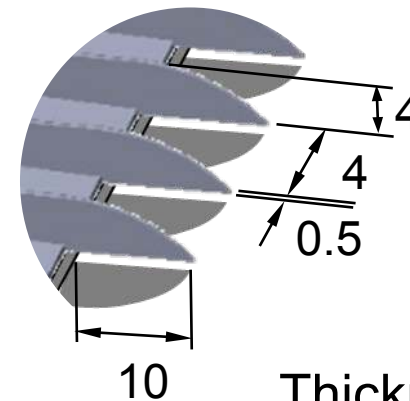


U=50m/s,  $\delta$  at 100% Chord, Pressure Side



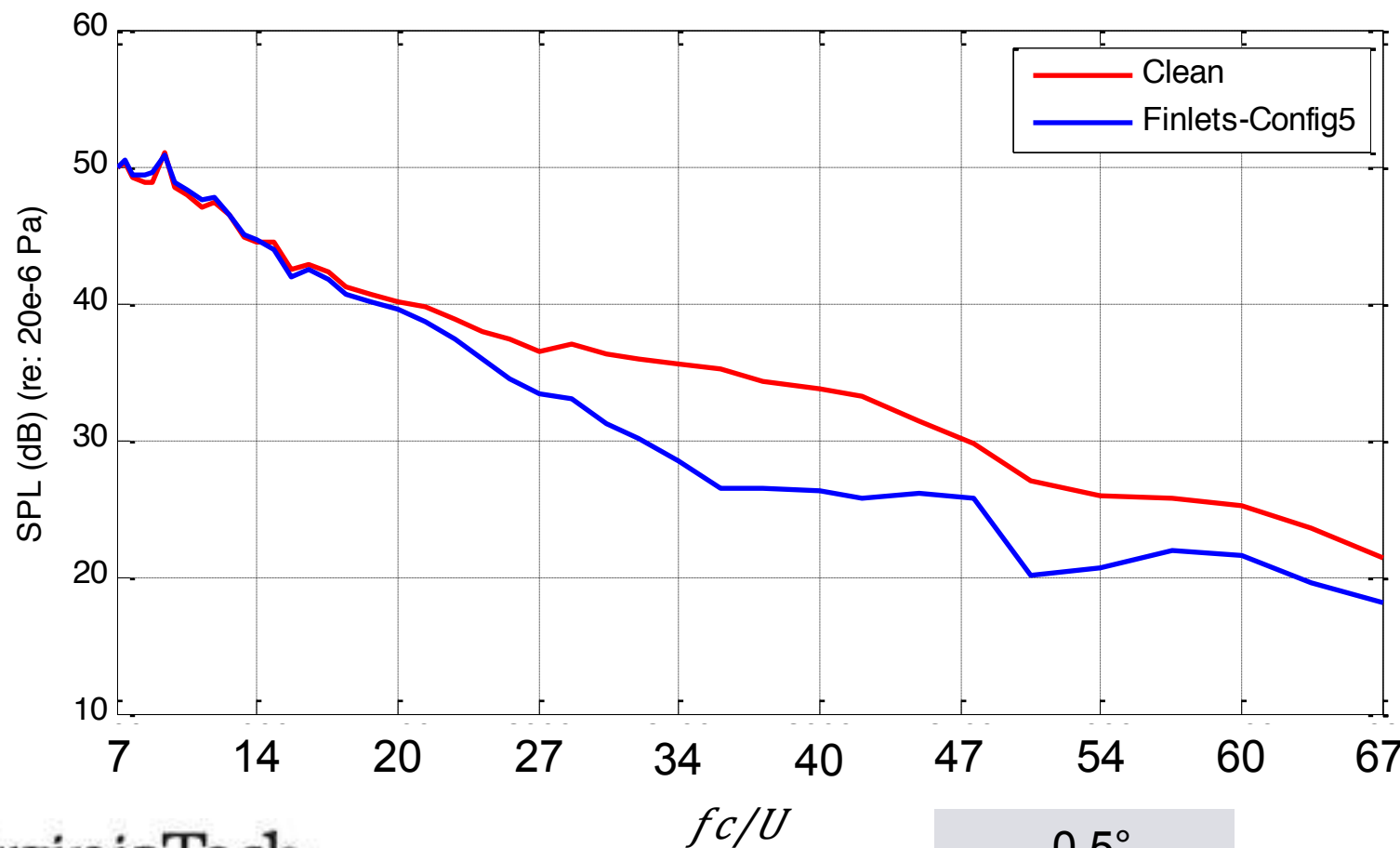


# Effect of Configuration 5 Finlet



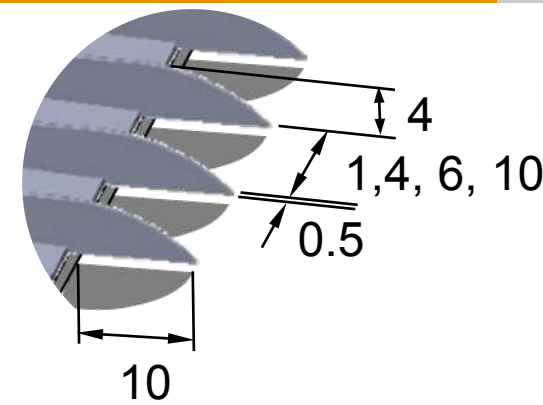
Thickness – 0.5mm  
Spacing – 4mm  
Height – 4mm  
10mm Extension  
( $\delta \approx 15\text{mm}$ )

## Integrated Spectra

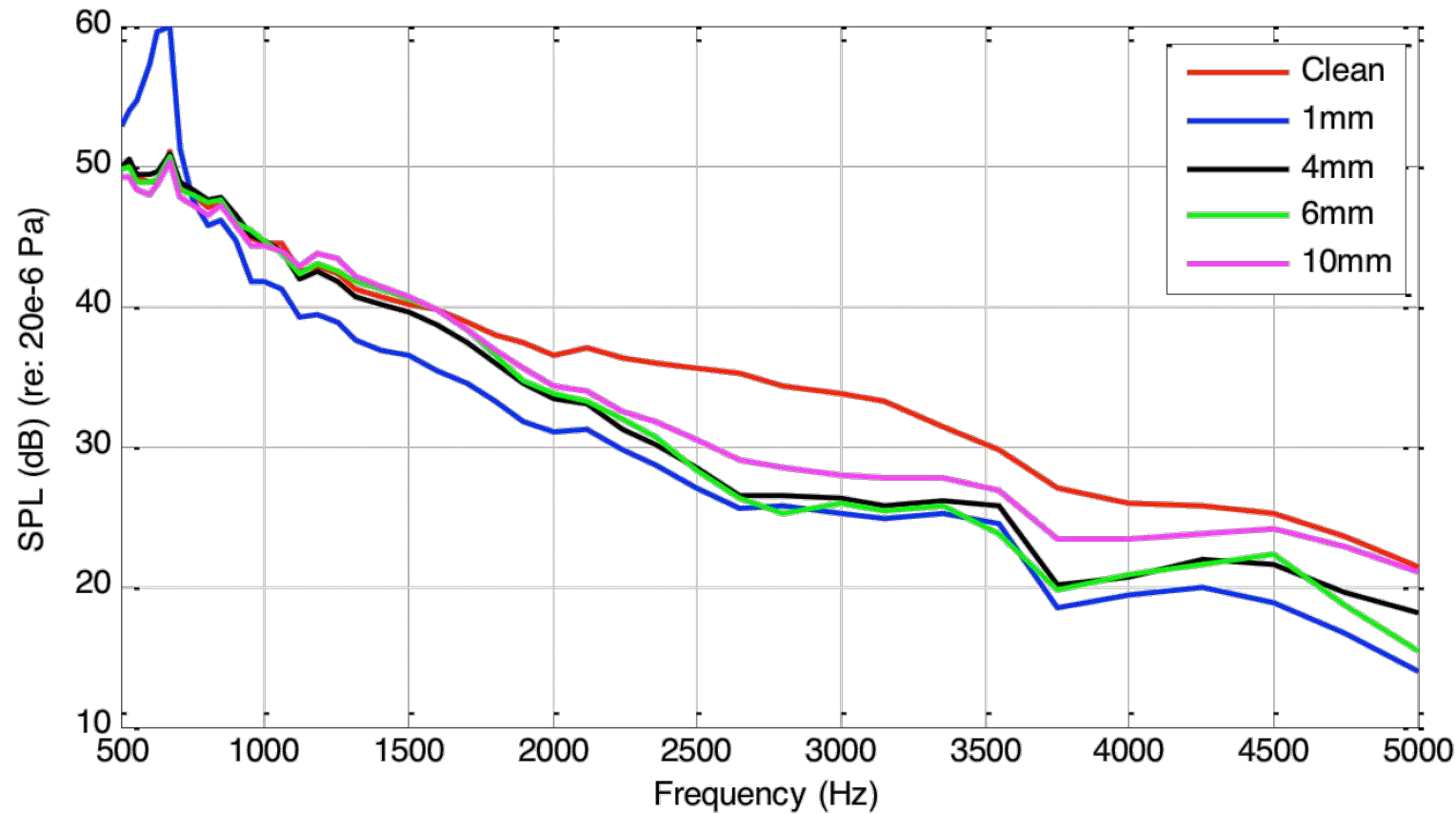


-0.5°

# Finlets – Effect of Spacing

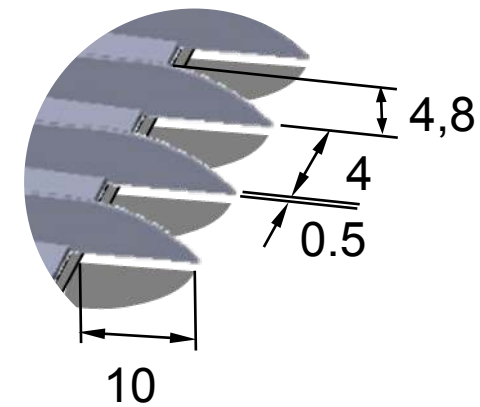


## Integrated Spectra

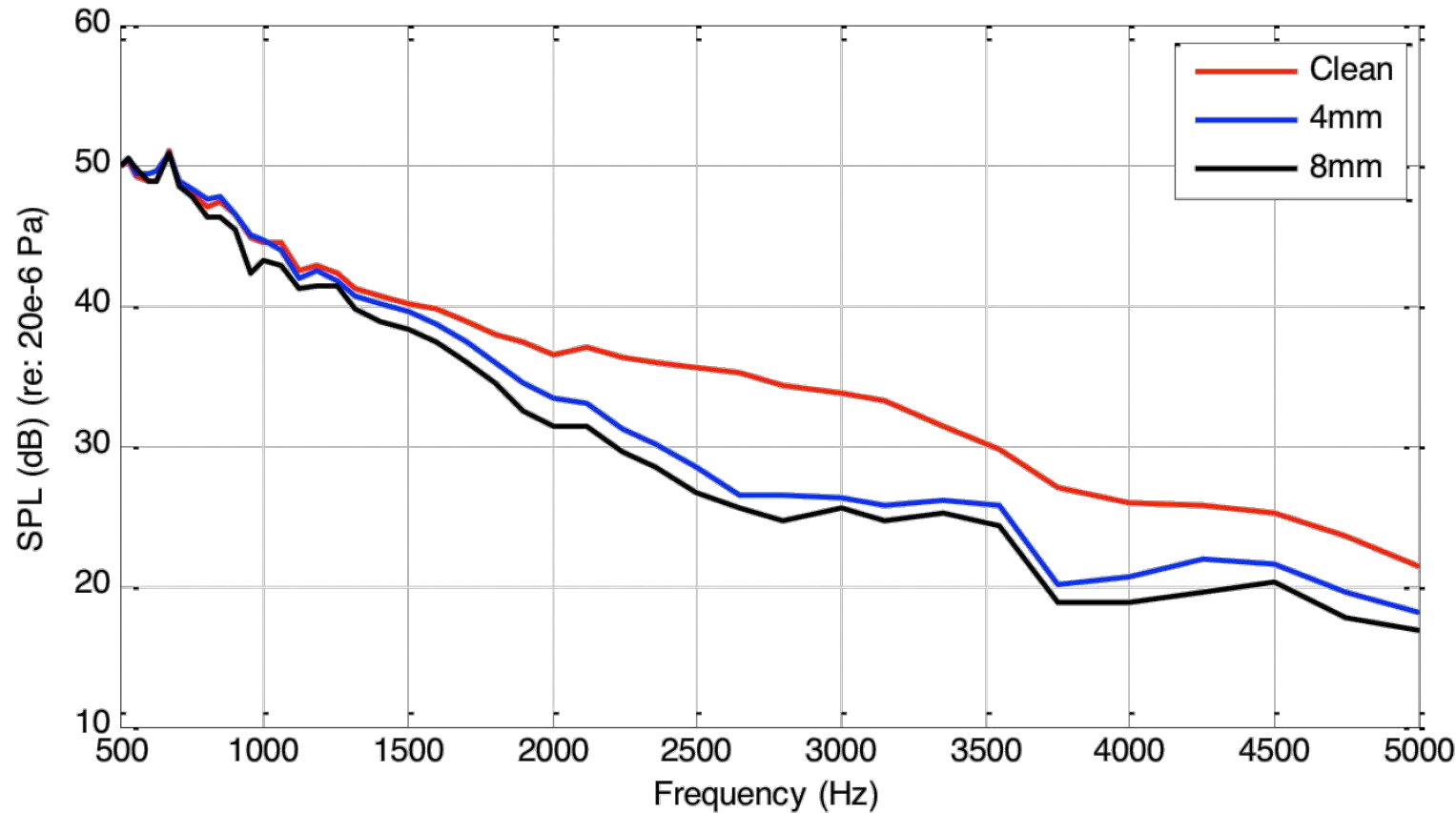


Thickness – 0.5mm  
Spacing – 1, 4, 6, 10mm  
Height – 4mm  
10mm Extension

# Finlets – Effect of Height



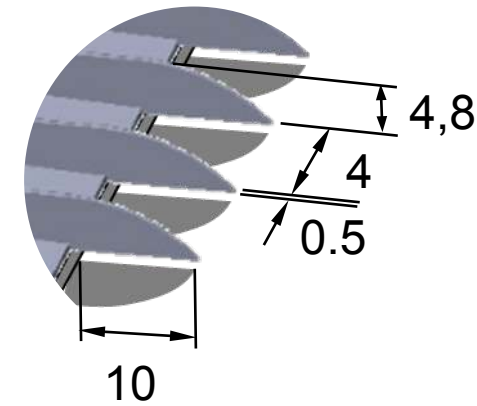
## Integrated Spectra



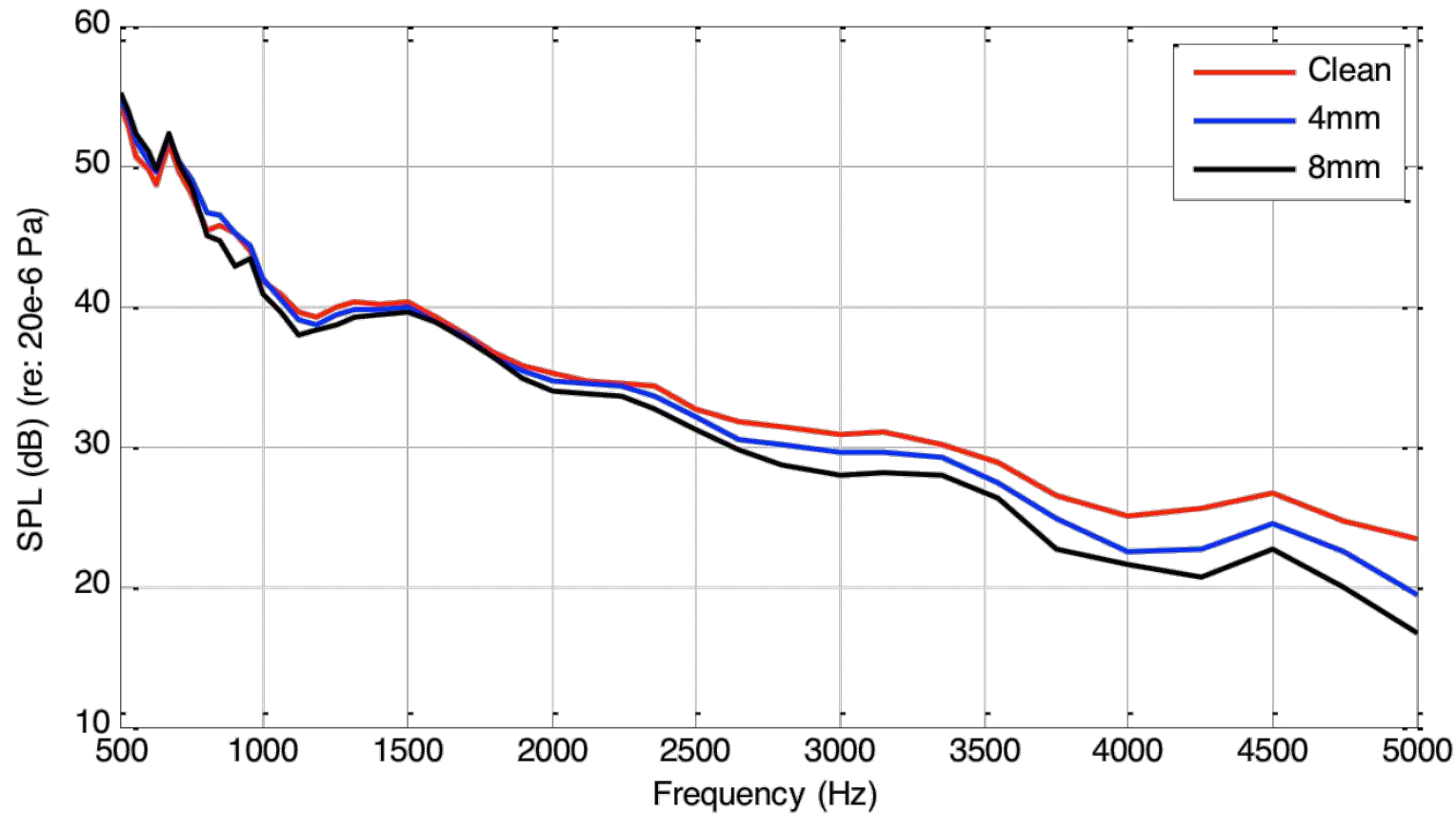
Thickness – 0.5mm  
Spacing – 4mm  
Height – 4, 8mm  
10mm Extension

-0.5°

# Finlets – Effect of Height



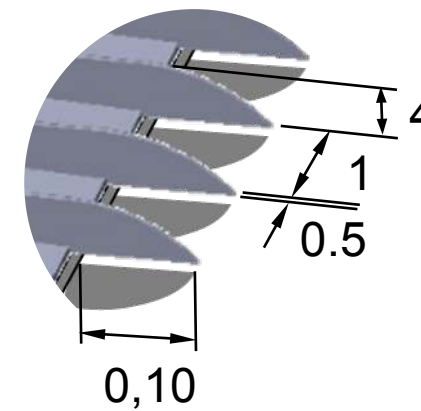
## Integrated Spectra



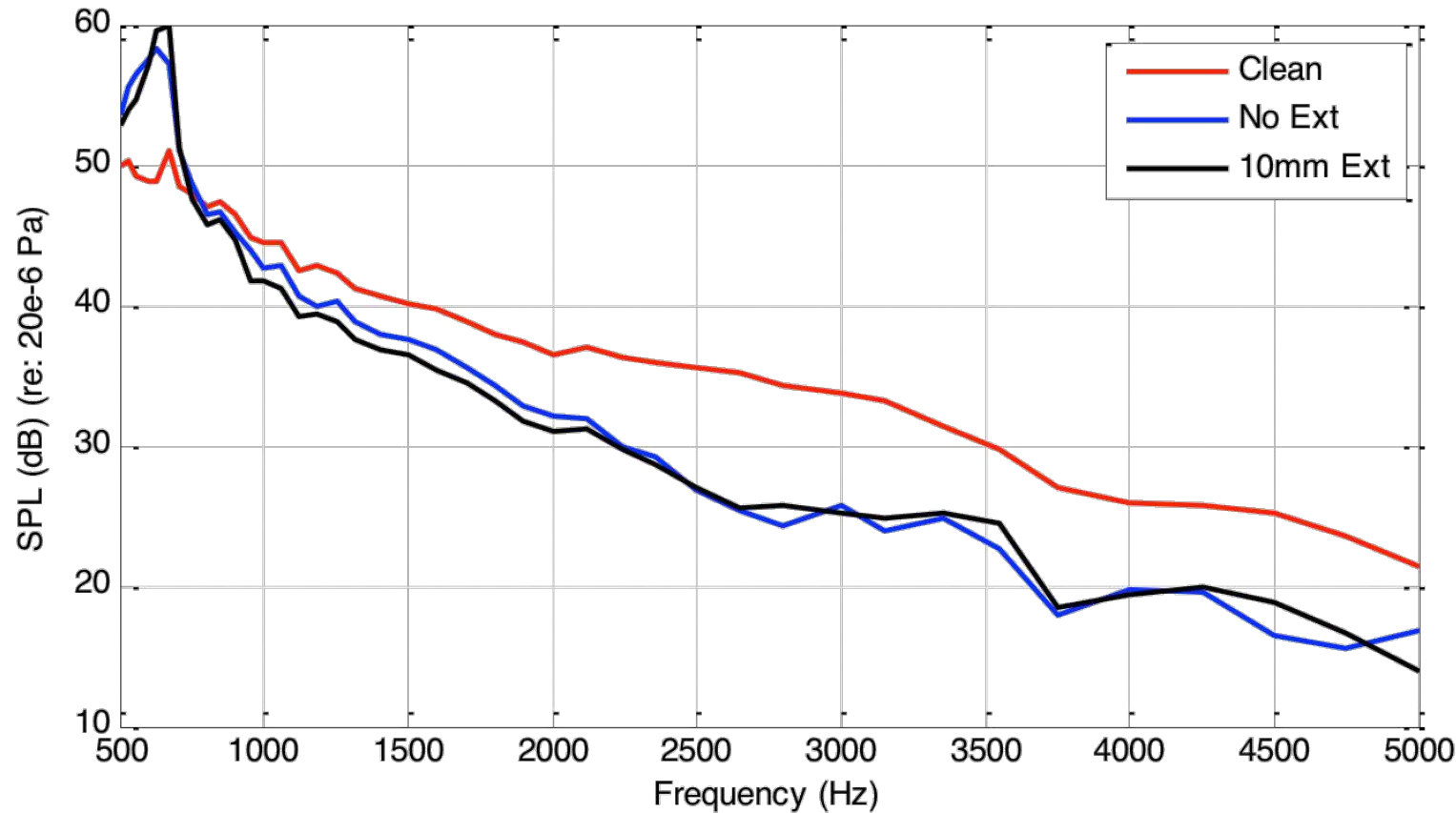
Thickness – 0.5mm  
Spacing – 4mm  
Height – 4, 8mm  
10mm Extension

6.9°

# Finlets – Effect of Extension

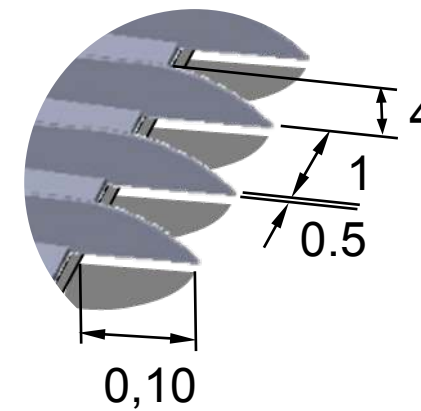


## Integrated Spectra

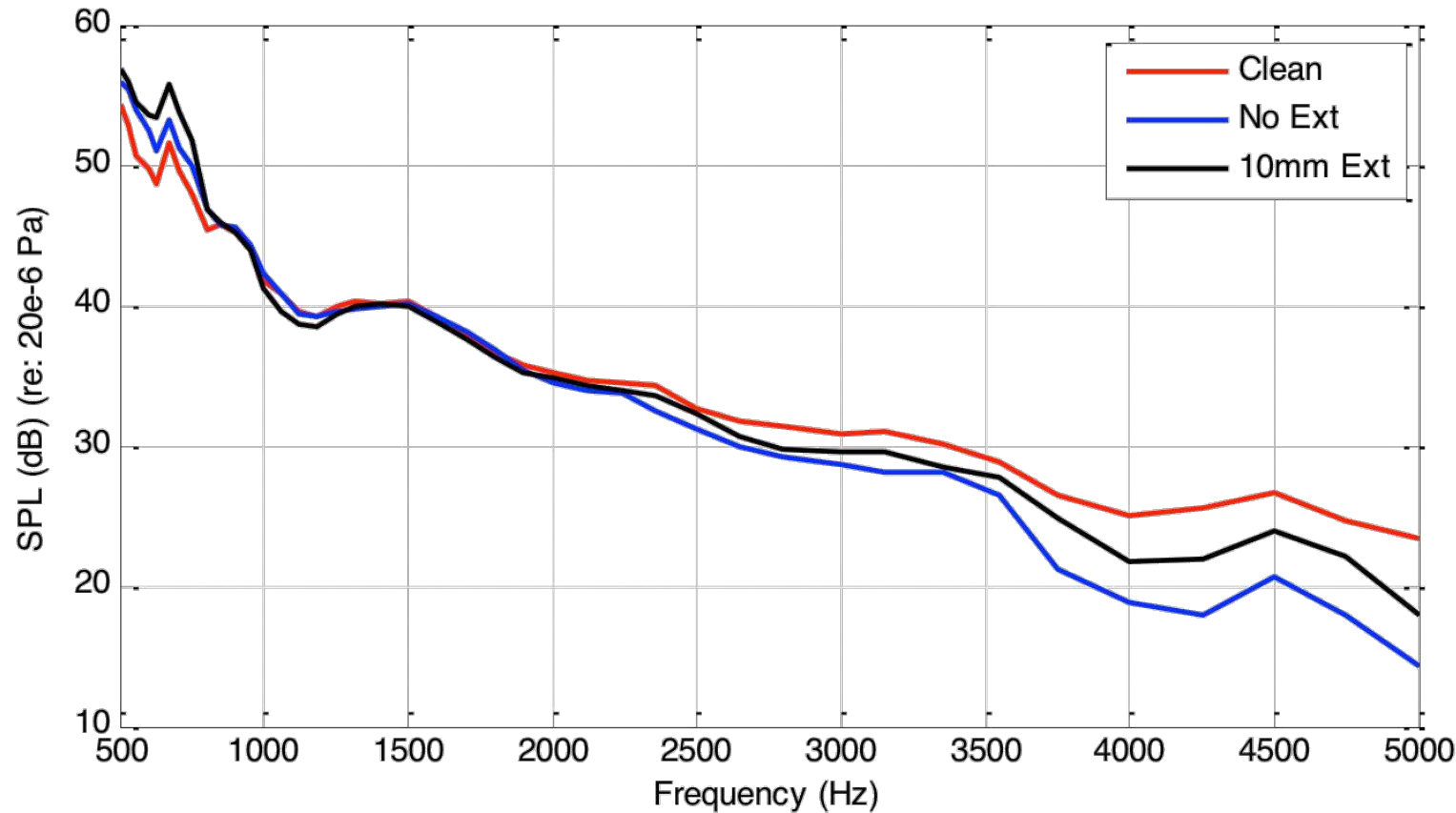


Thickness – 0.5mm  
Spacing – 1mm  
Height – 4mm  
0, 10mm Extension

# Finlets – Effect of Extension



## Integrated Spectra

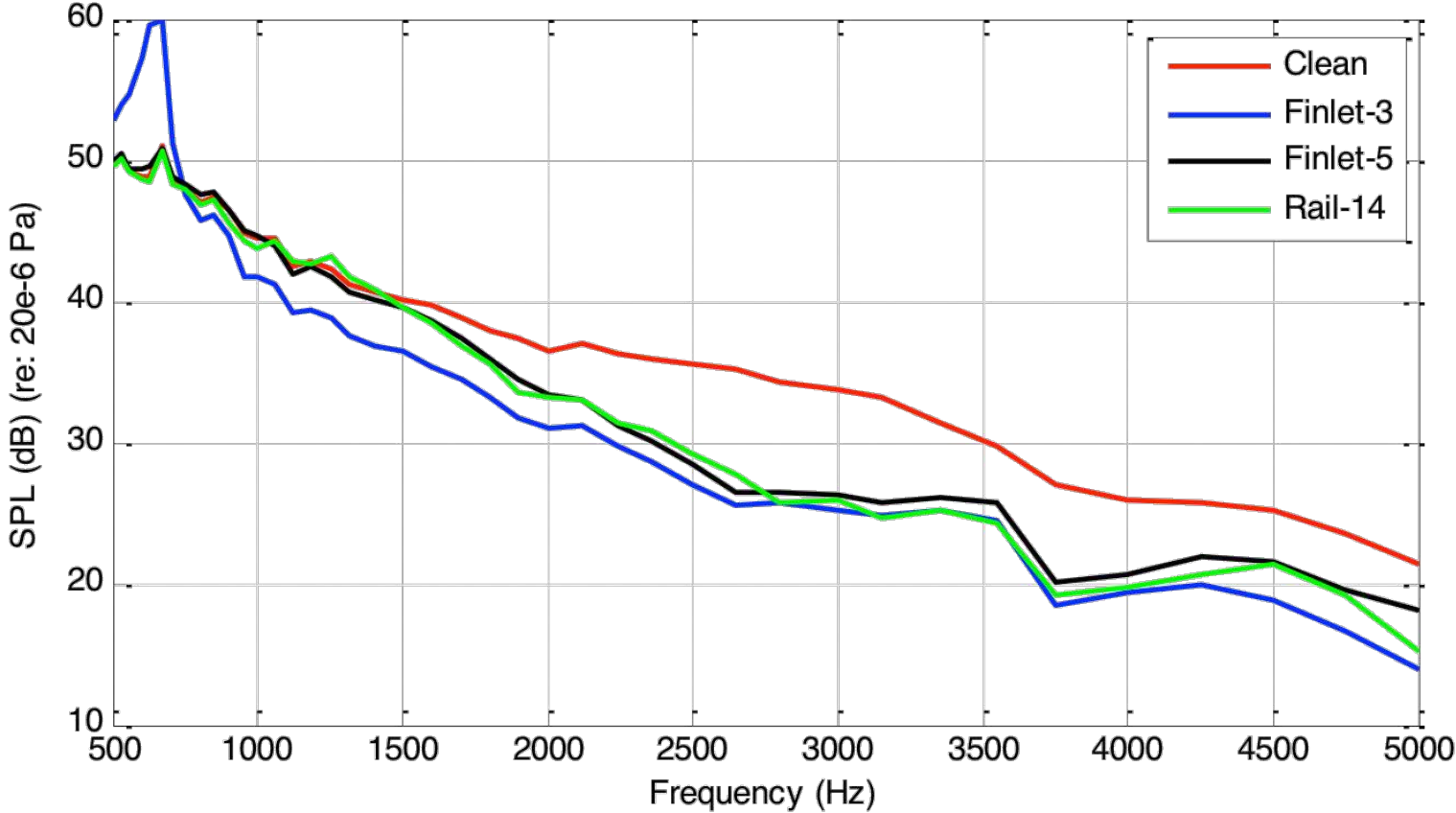
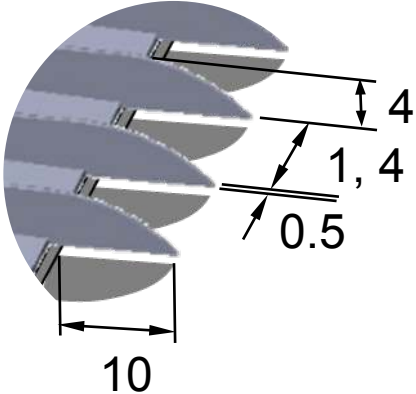
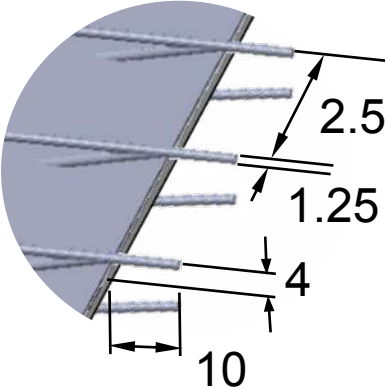


Thickness – 0.5mm  
Spacing – 1mm  
Height – 4mm  
0, 10mm Extension

# Rails vs Finlets



## Integrated Spectra



-0.5°