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Virginia Tech Center for Renewable Energy and Aerodynamic Testing

Bio-Inspired Trailing Edge Noise Control

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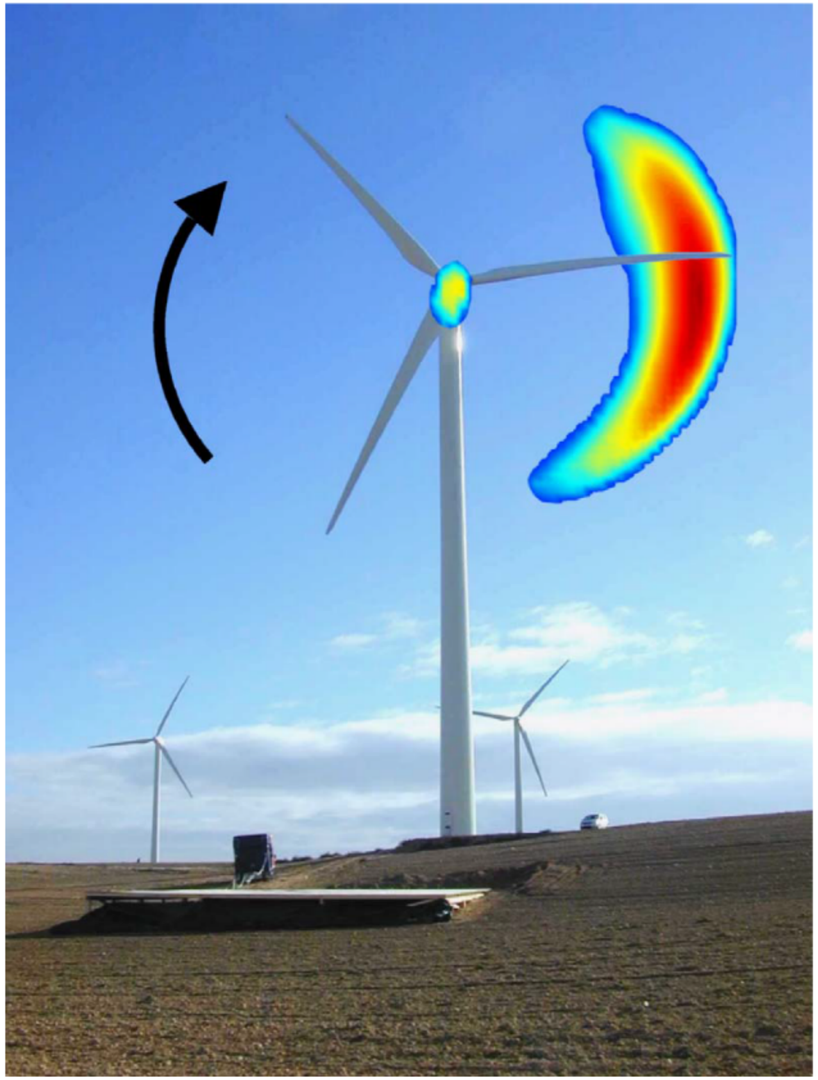
Motivation

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).



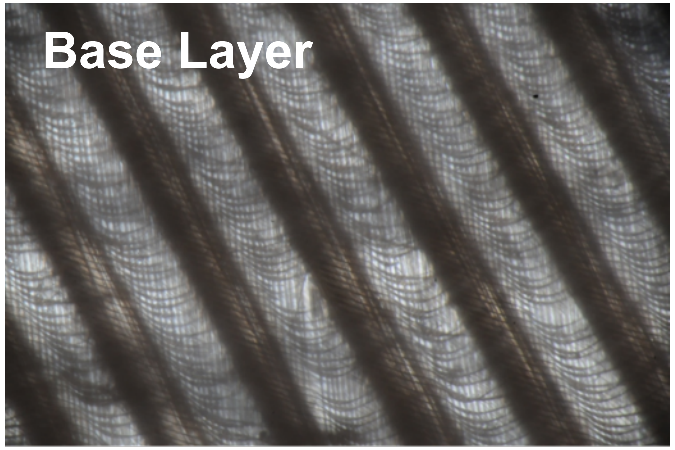
Credit: Oerlemans, S., et al. (2007). "Location and quantification of noise sources on a wind turbine." Journal of Sound and Vibration **299**(4-5): 869-883.

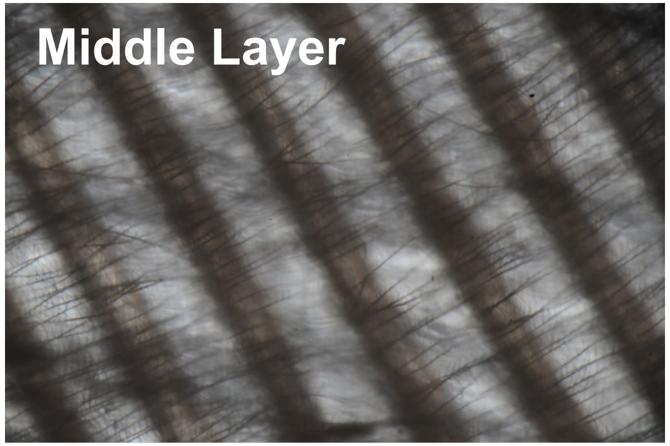
Inspiration

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.

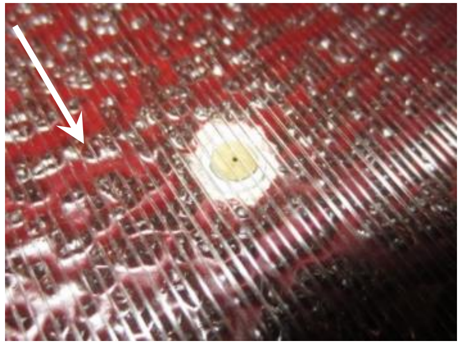
A similar structure has been shown to attenuate pressure fluctuations at the underlying surface.

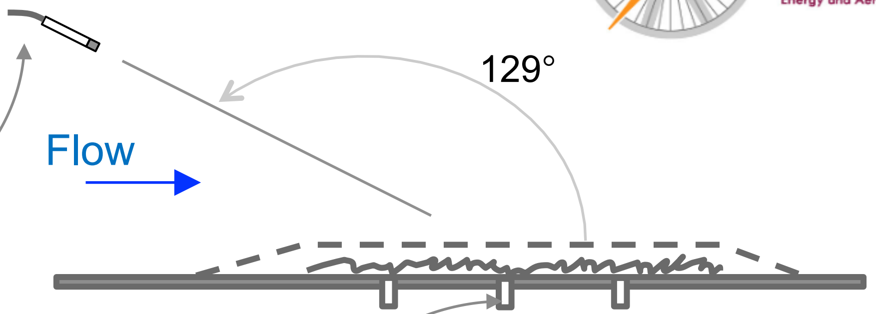


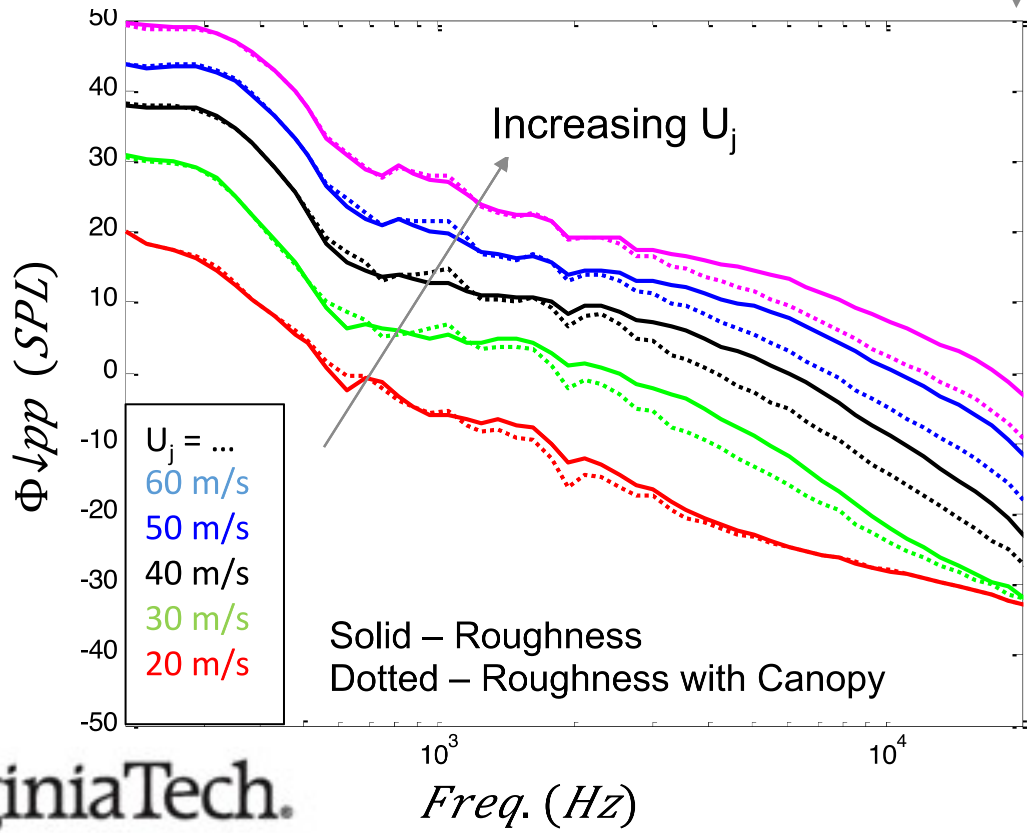


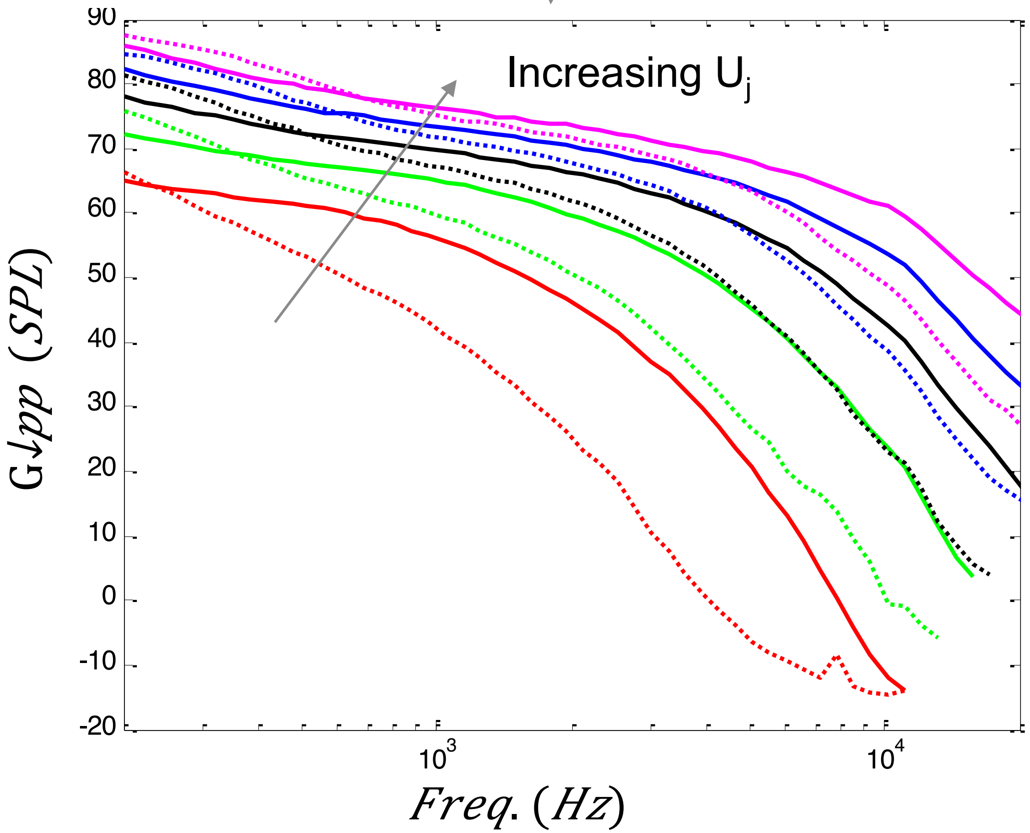
Canopy height ≅ 0.5mm
Individual hair Re ≅ 7
Canopy open area ratio ≅ 70%

Unidirectional Fabric Canopy







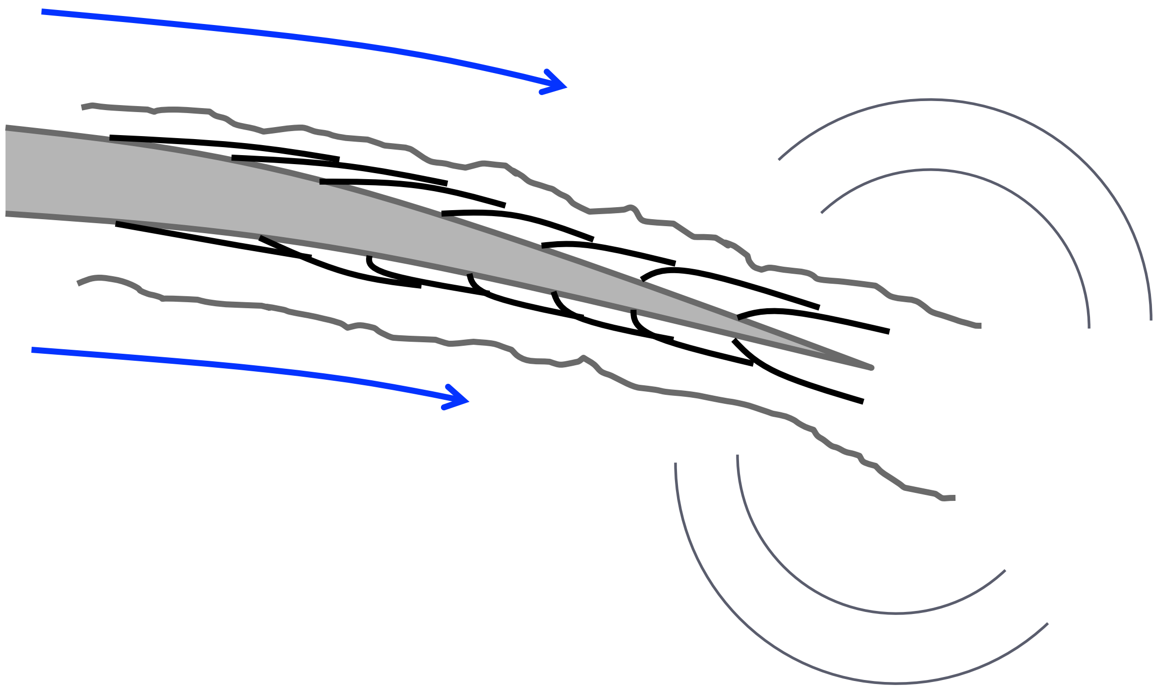


The Idea

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

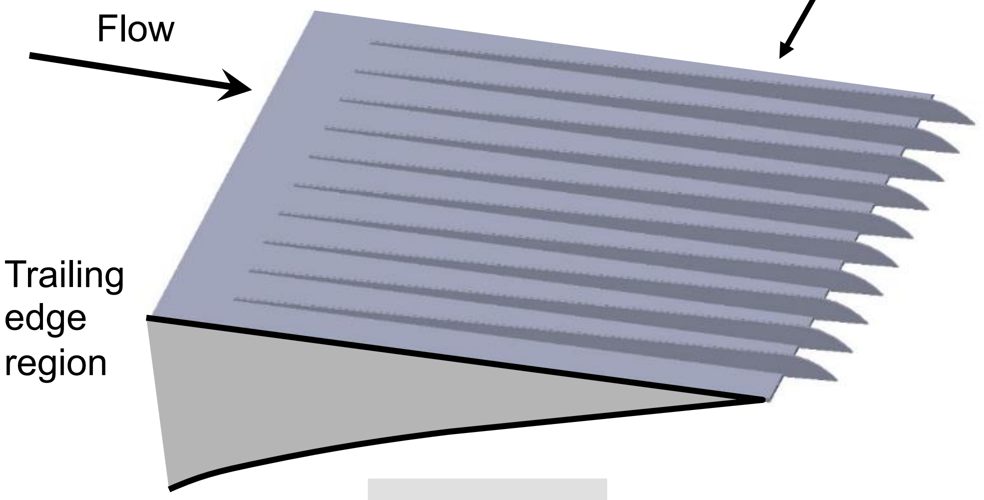
How could a canopy be applied to an airfoil?

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

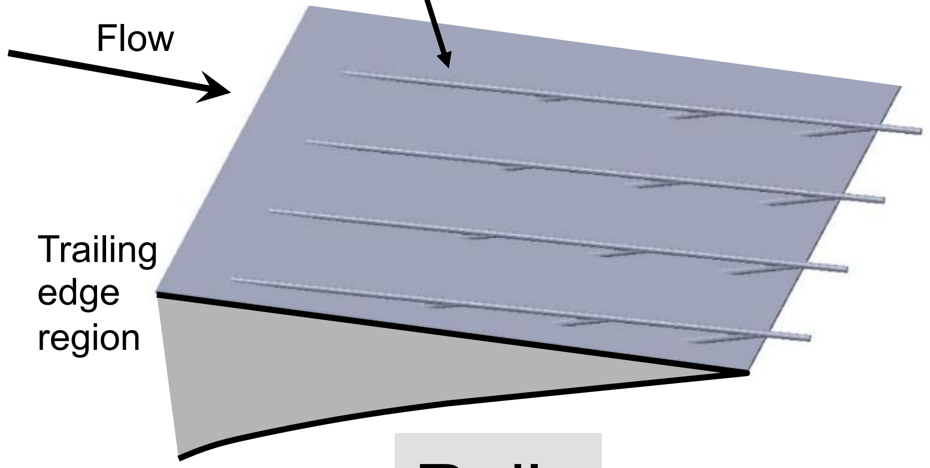


Two Practical Concepts

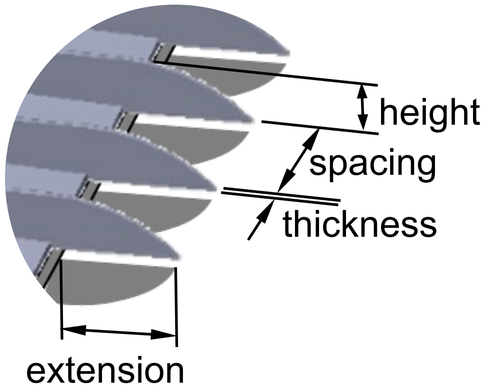
Flow-aligned elements on top and bottom surfaces manipulate boundary layers ahead of the trailing edge.

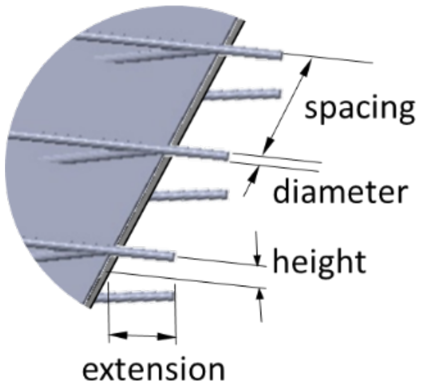


Finlets

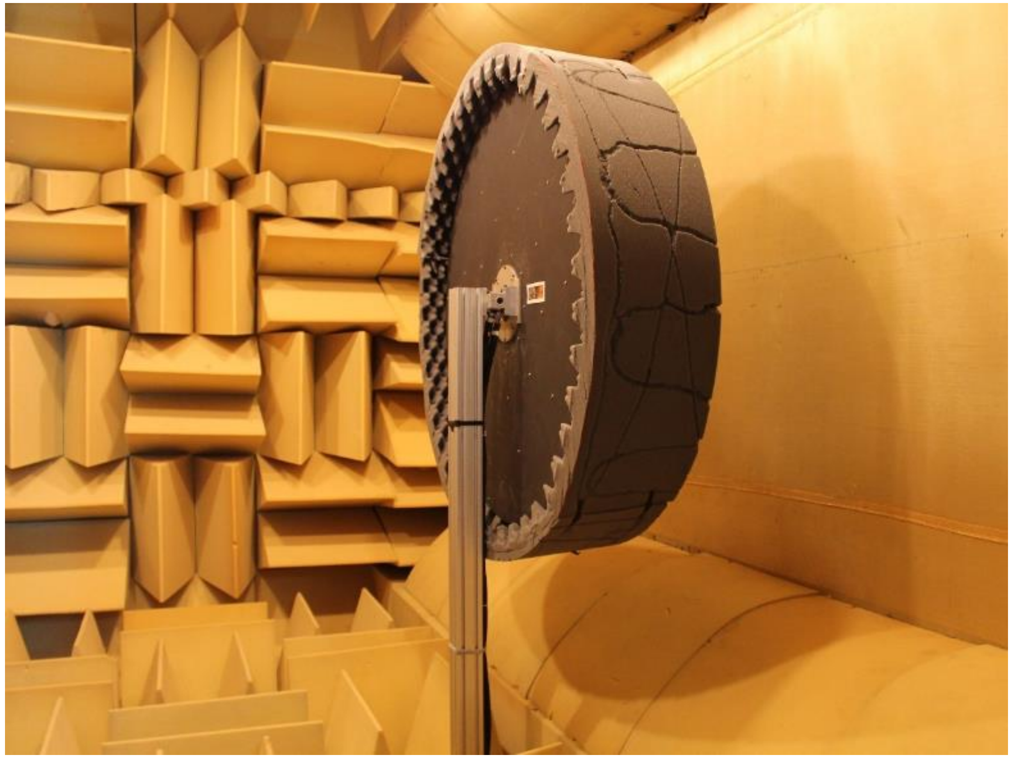


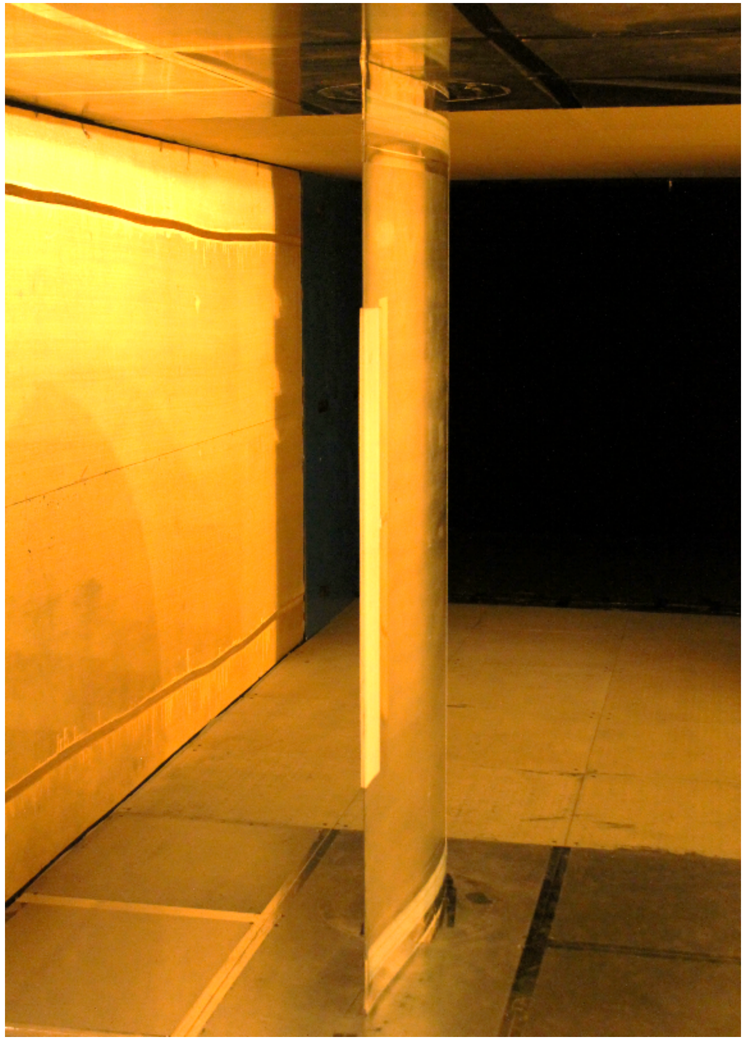
Rails





The Experiment





- 117 microphone phase array for far field acoustics
- Surface pressure taps for C_p 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 ($Re \approx 2.5\mathrm{M}, 3\mathrm{M}$)
- α from $-4°$ to $15°$, $\alpha_{zero\ lift} = -2.5°$

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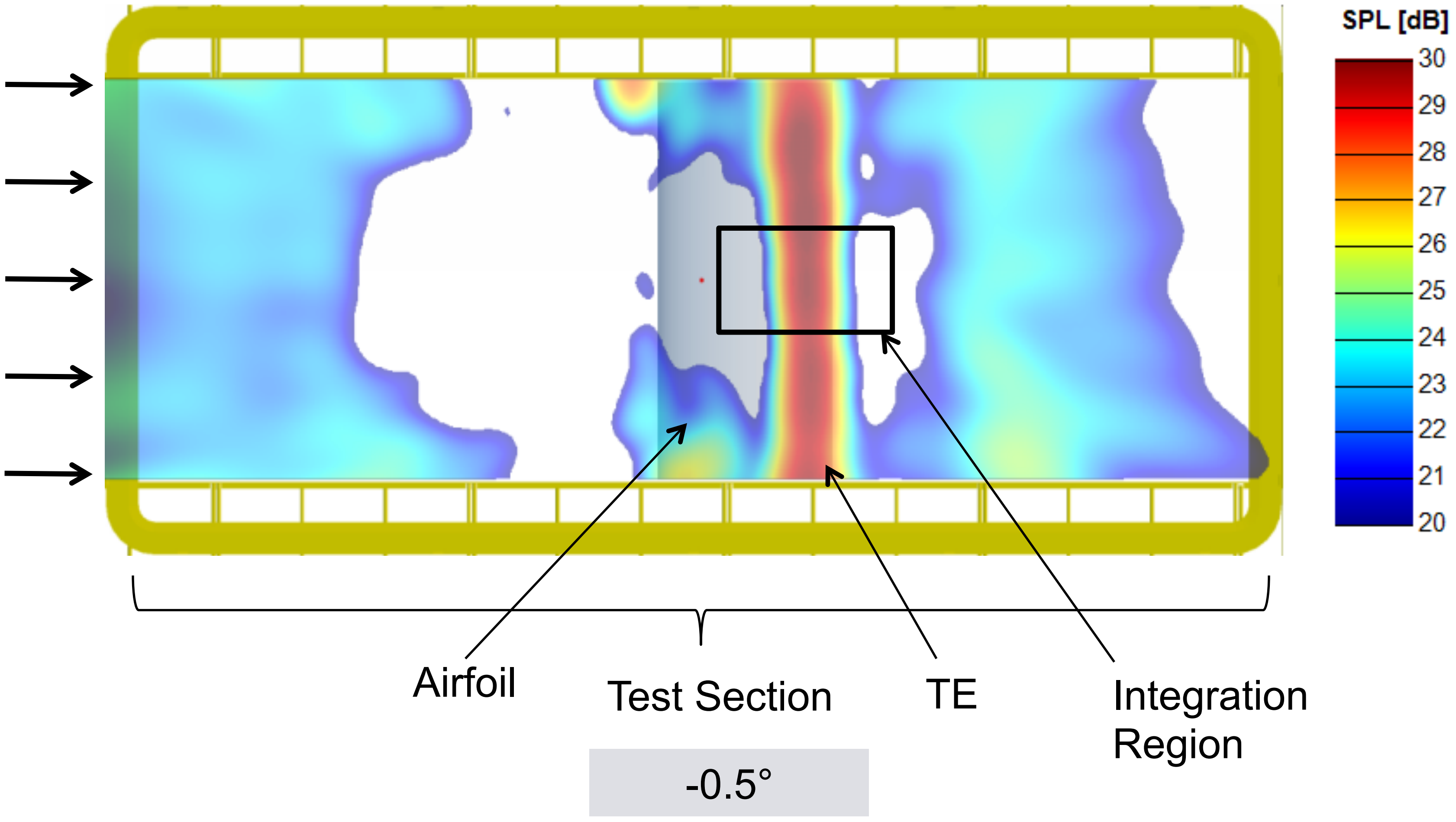
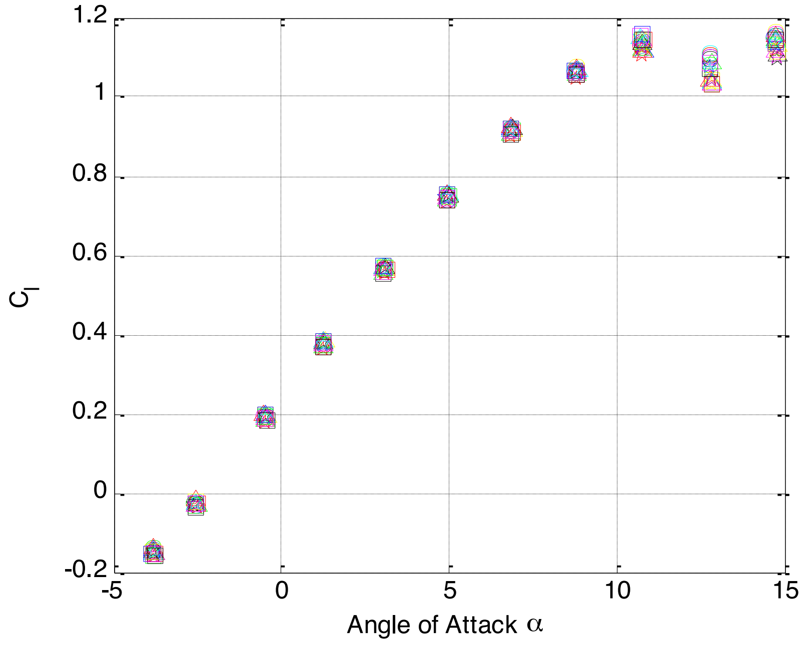
Clean Airfoil

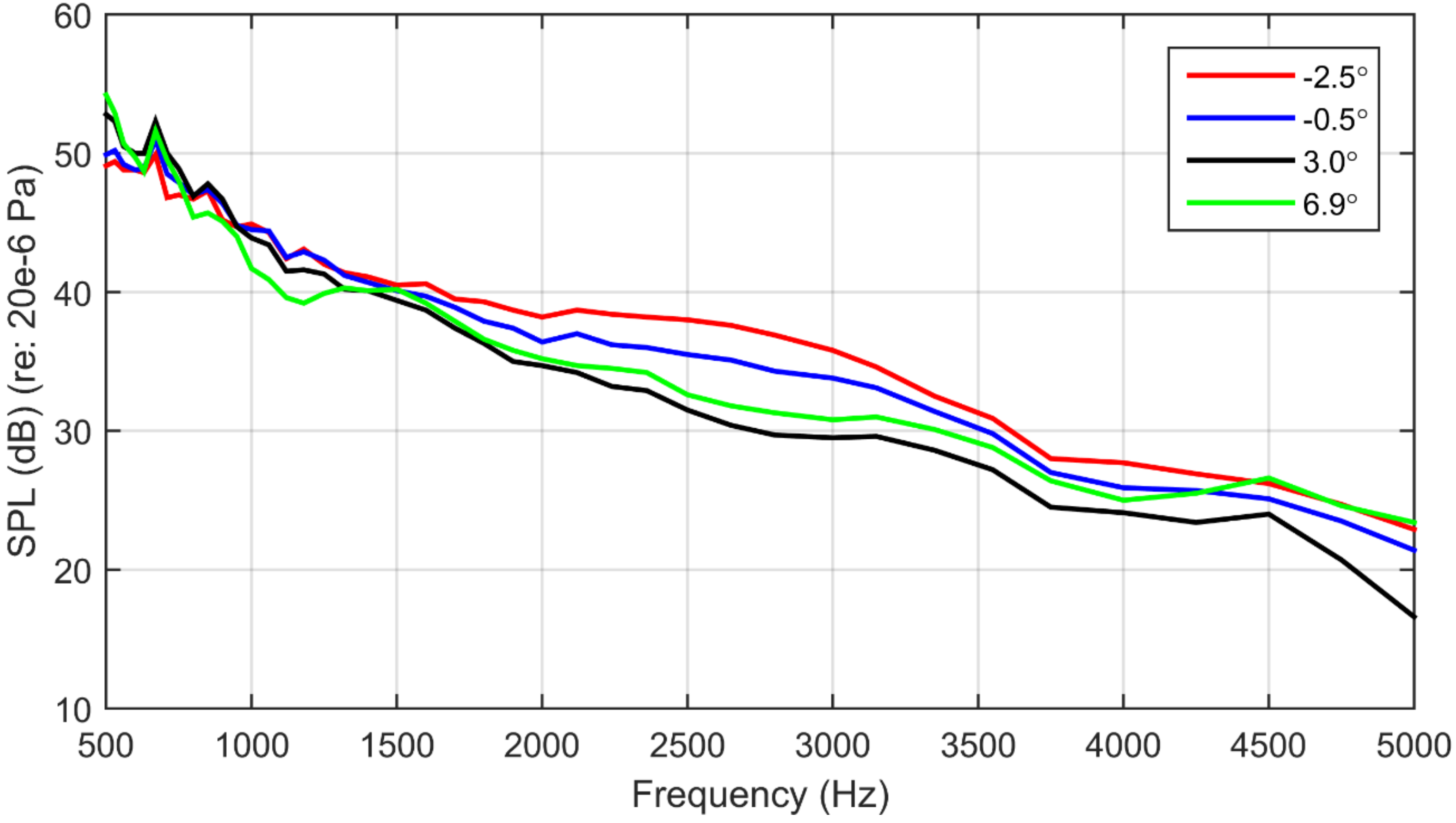
Re = 3M, Tripped, 3000 Hz



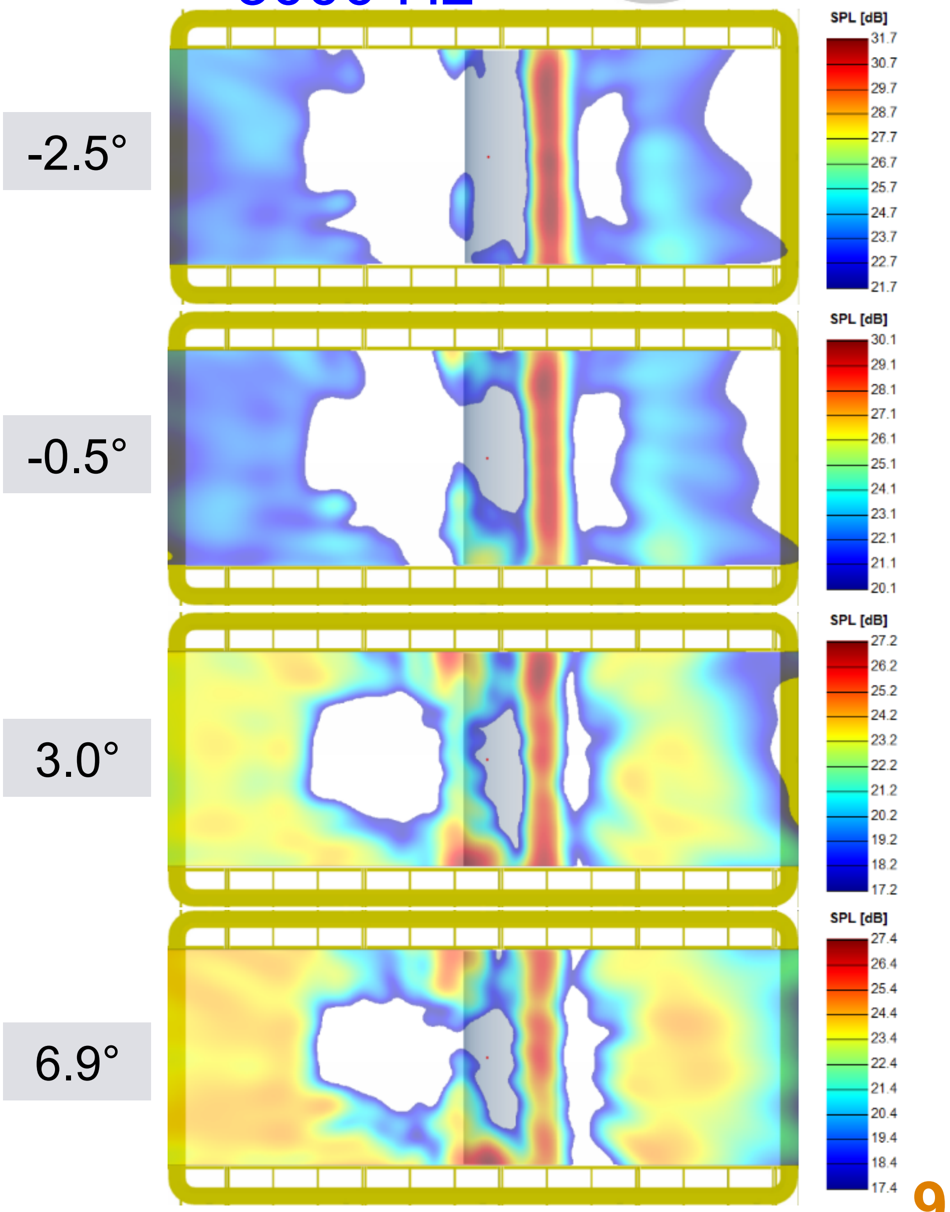


Clean Airfoil

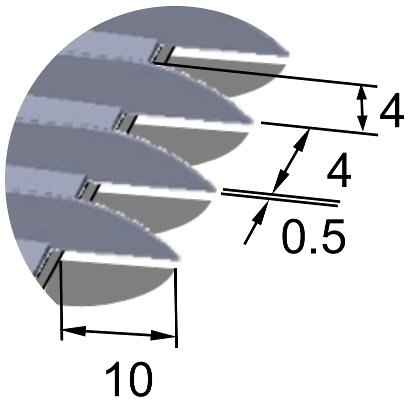
Integrated Spectra



3000 Hz

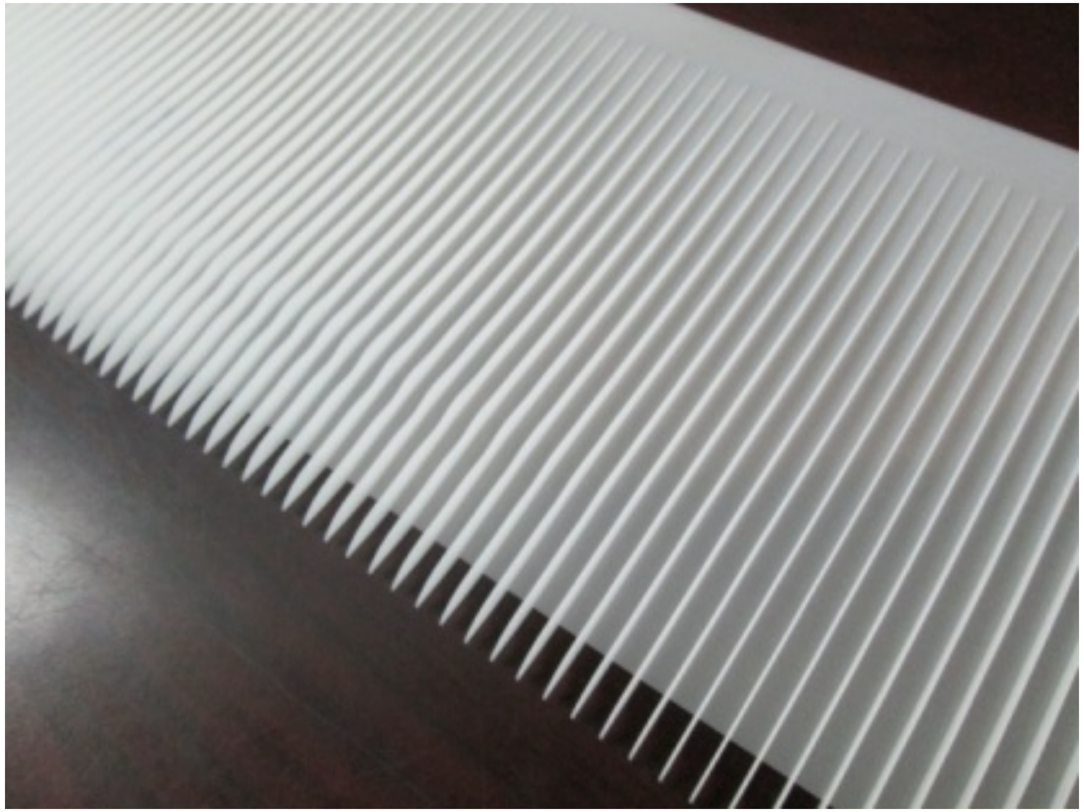


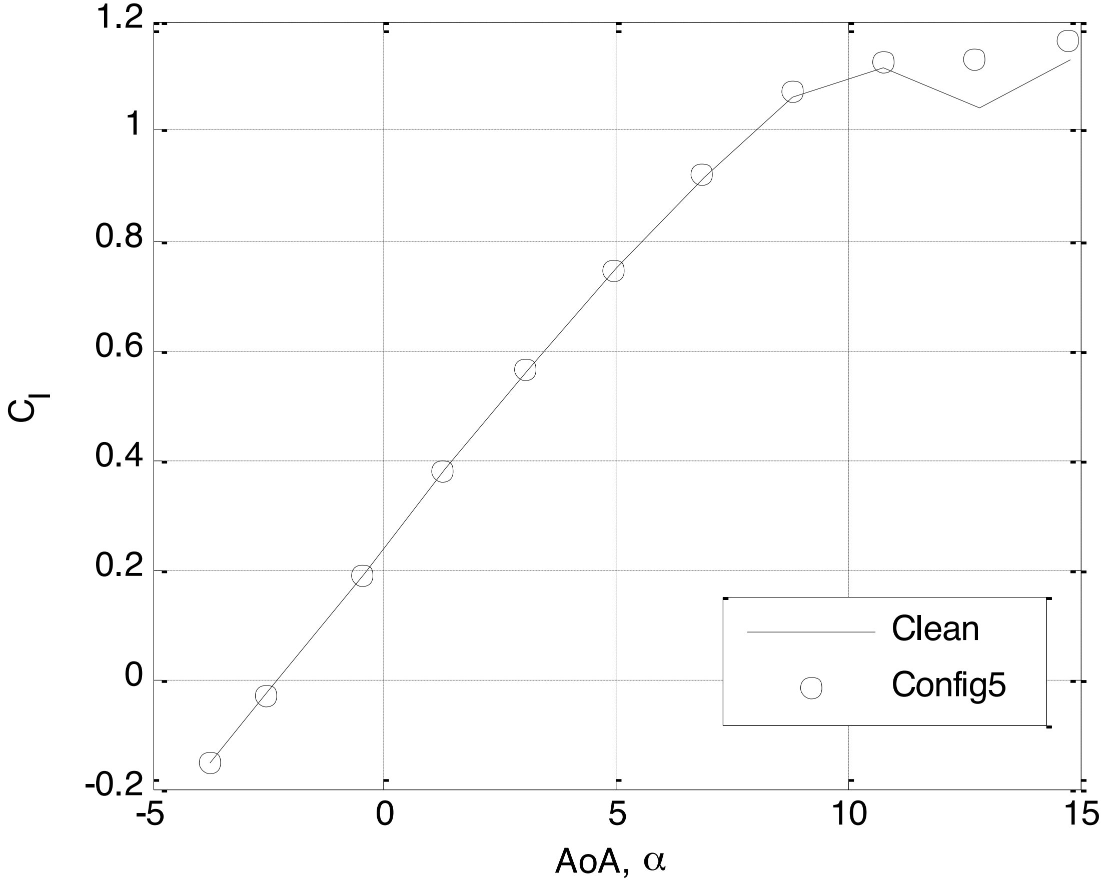
Finlets – Configuration 5



Thickness – 0.5mm
Spacing – 4mm

Height – 4mm
10mm Extension





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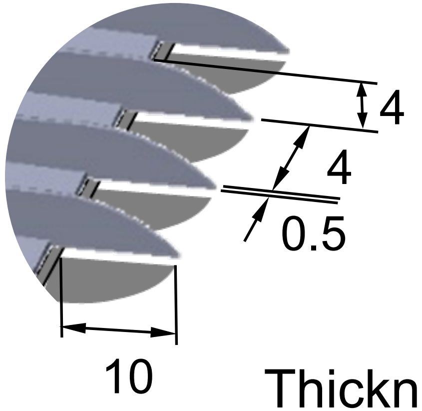
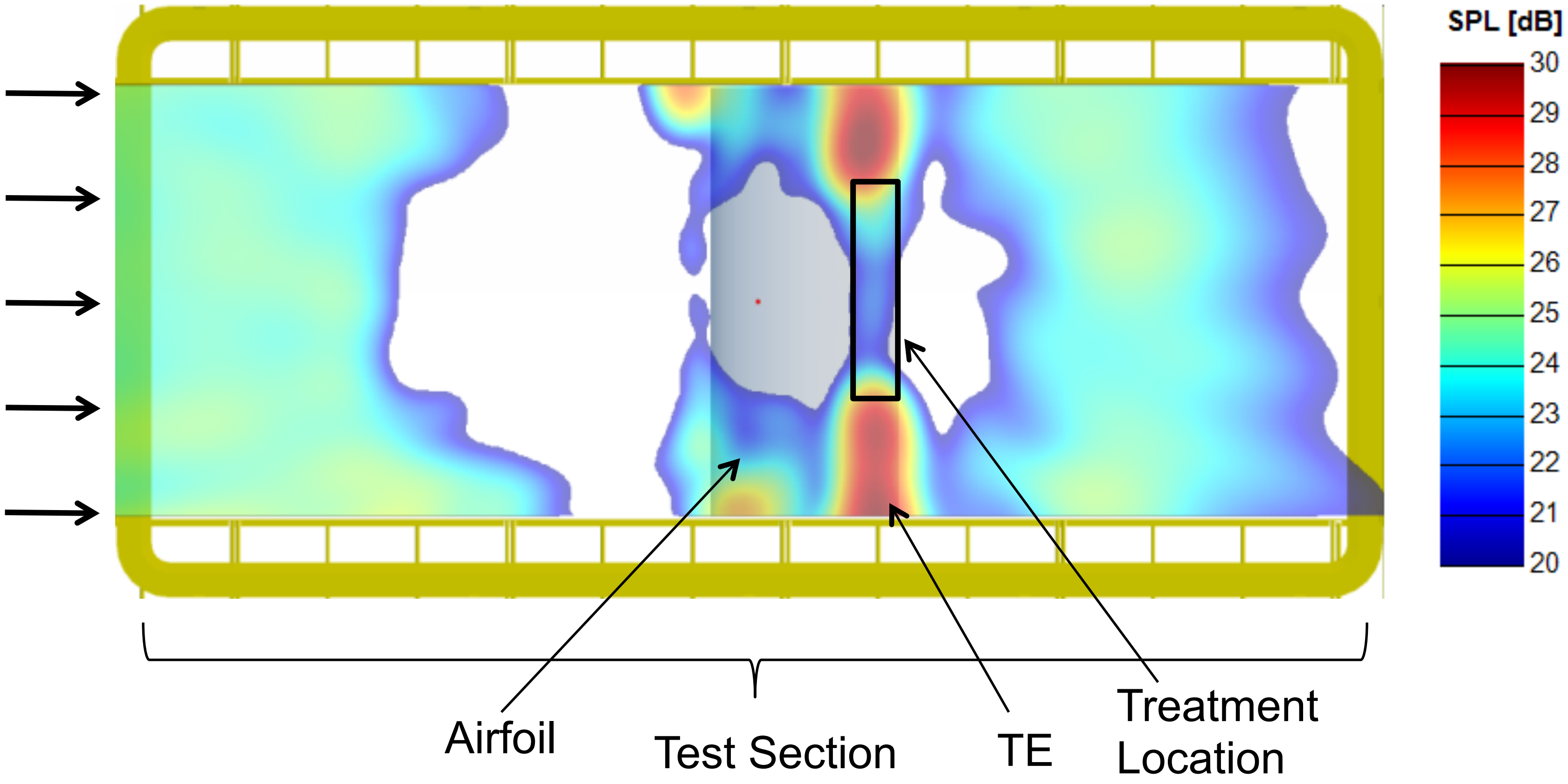


Thickness – 0.5mm
Spacing – 4mm
Height – 4mm
10mm Extension
($\delta \approx$ 20mm)

Re = 3M, Tripped, 3000 Hz



-0.5°

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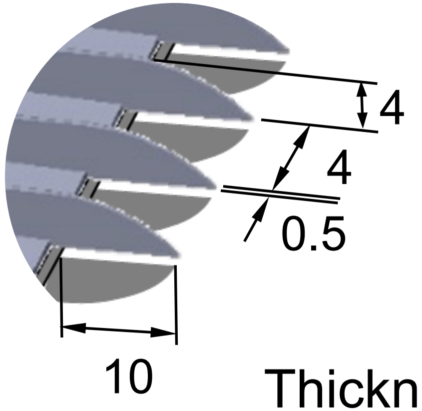
Finlets – Configuration 5



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

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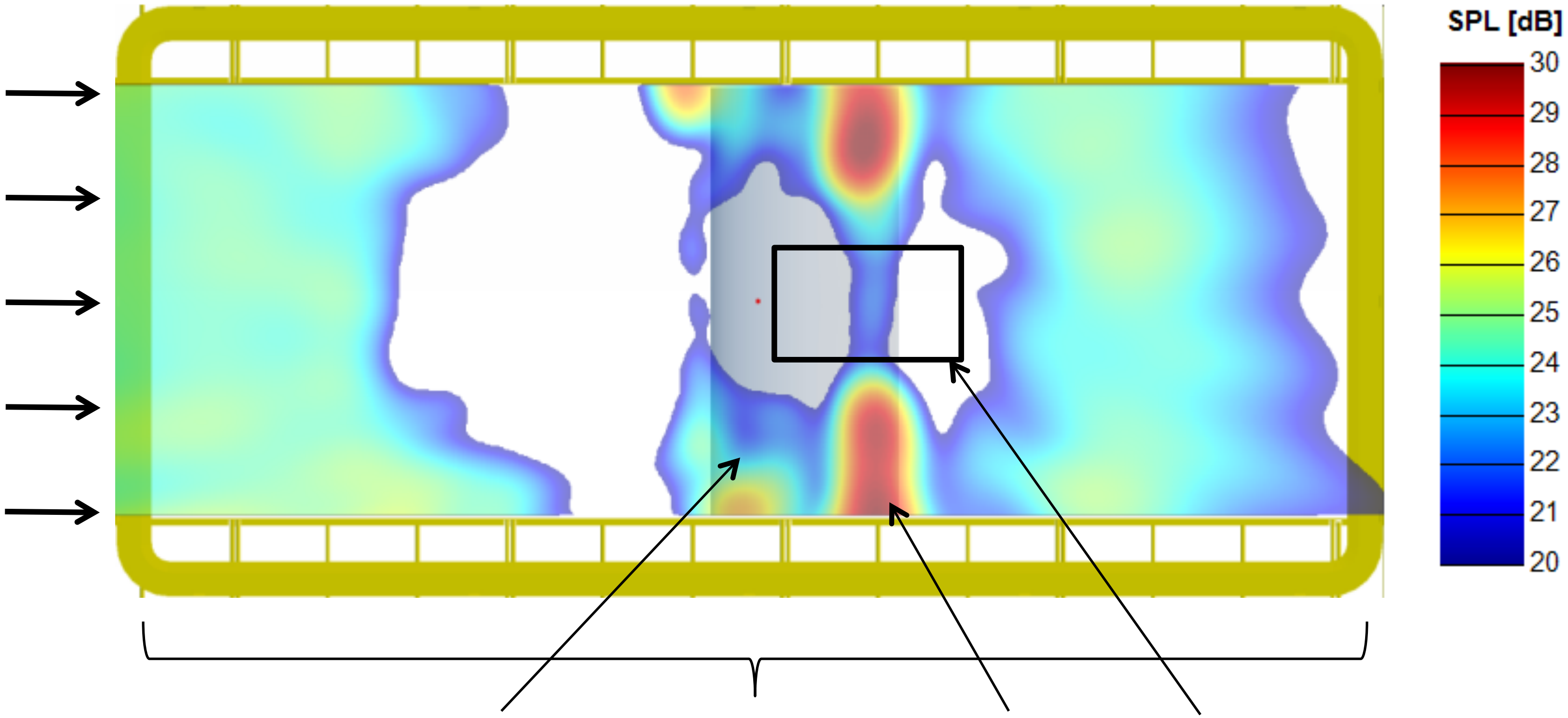
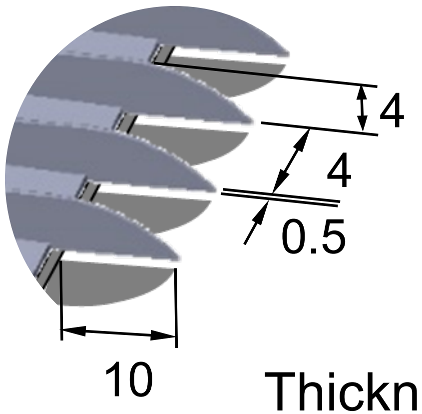
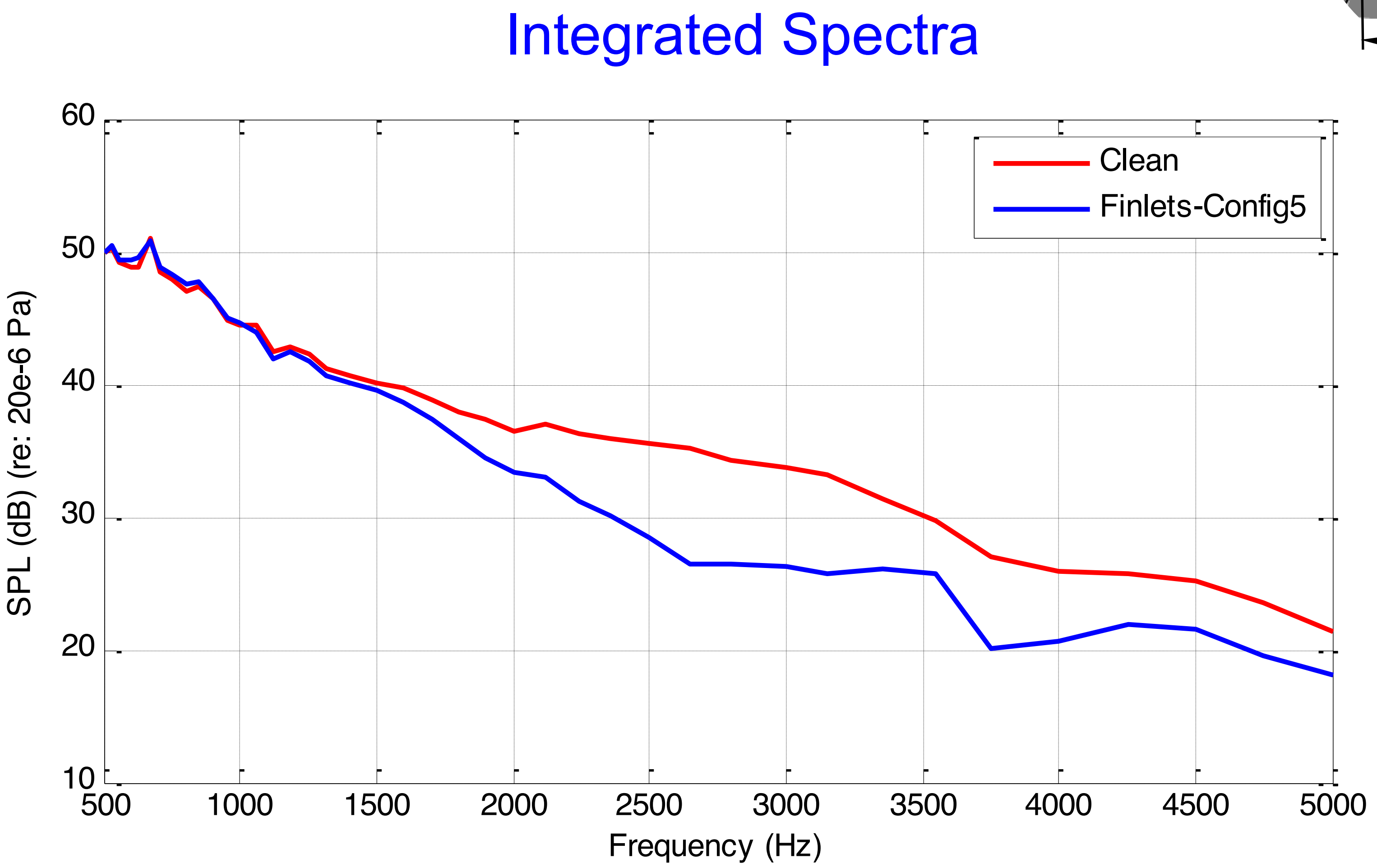


-0.5°

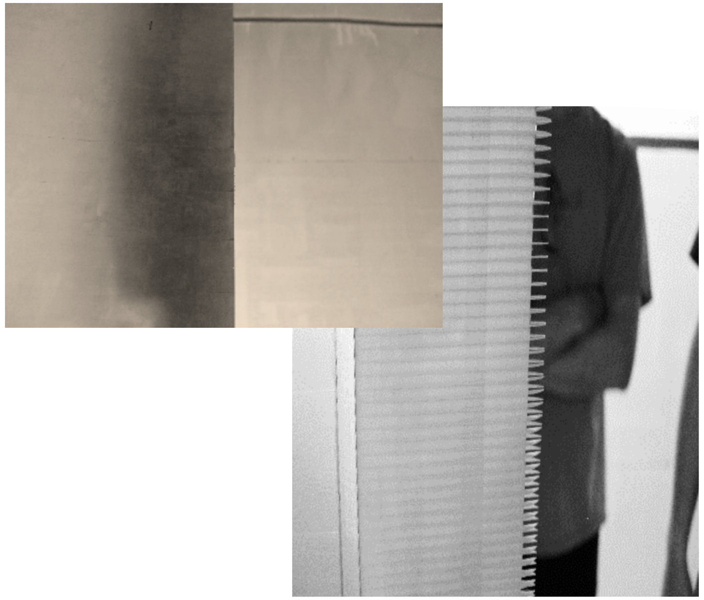
Effect of Configuration 5 Finlet



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



-0.5°



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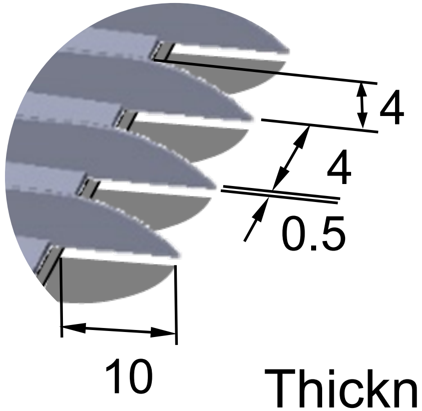
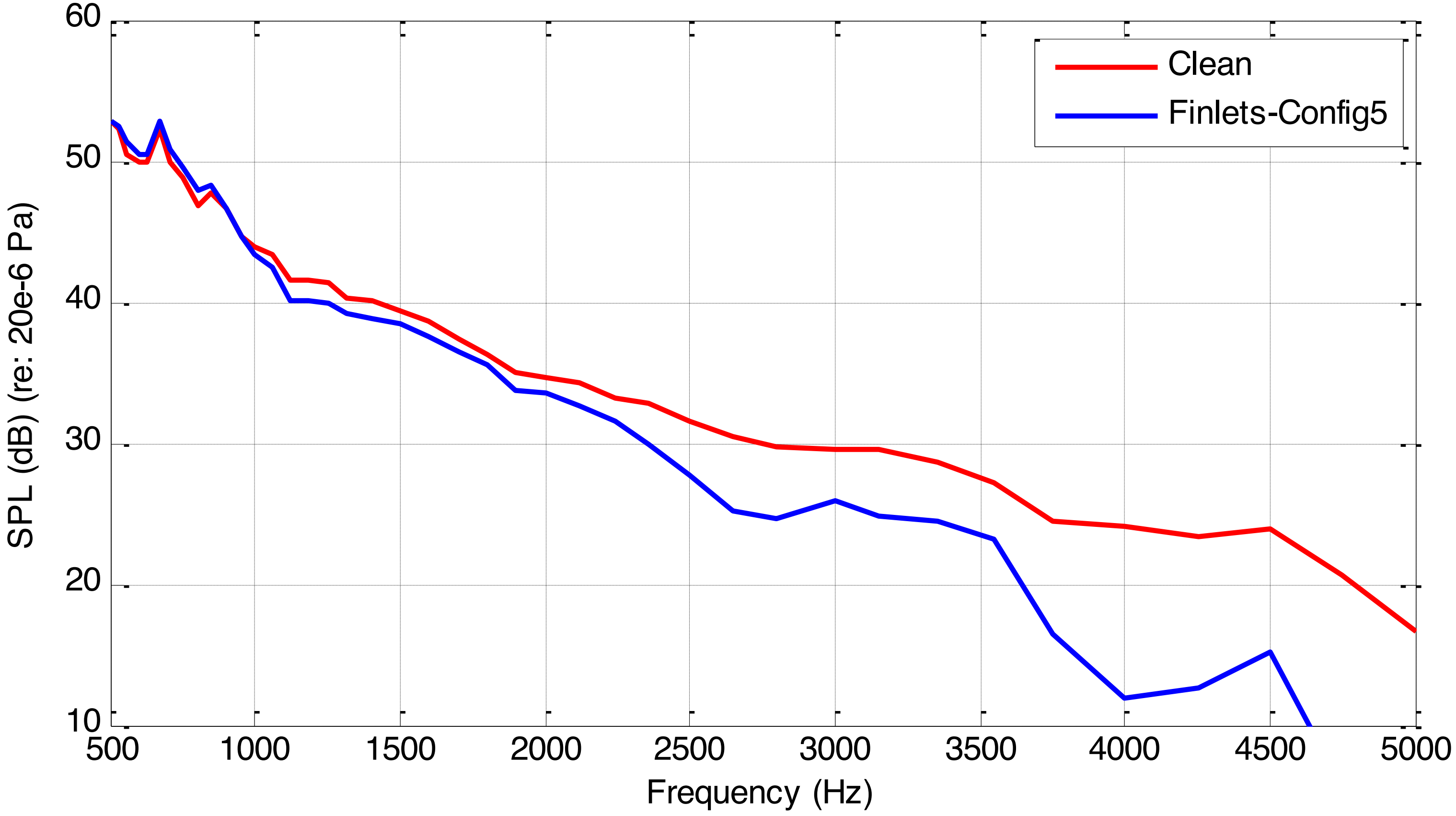
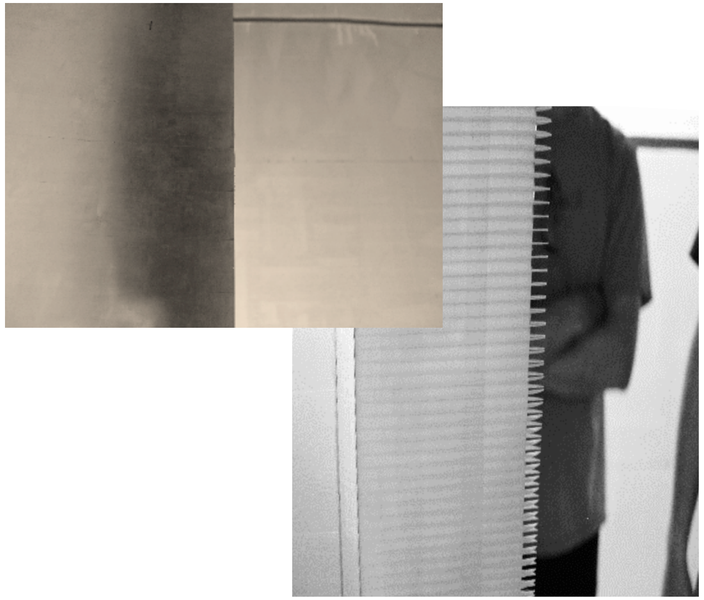


Integrated Spectra

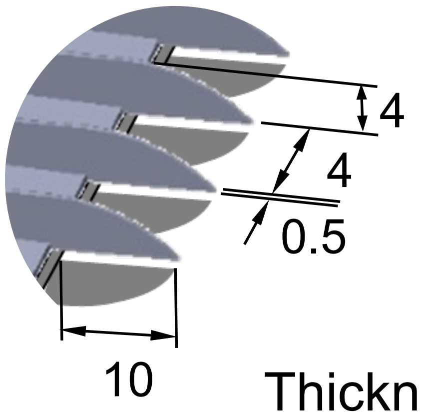


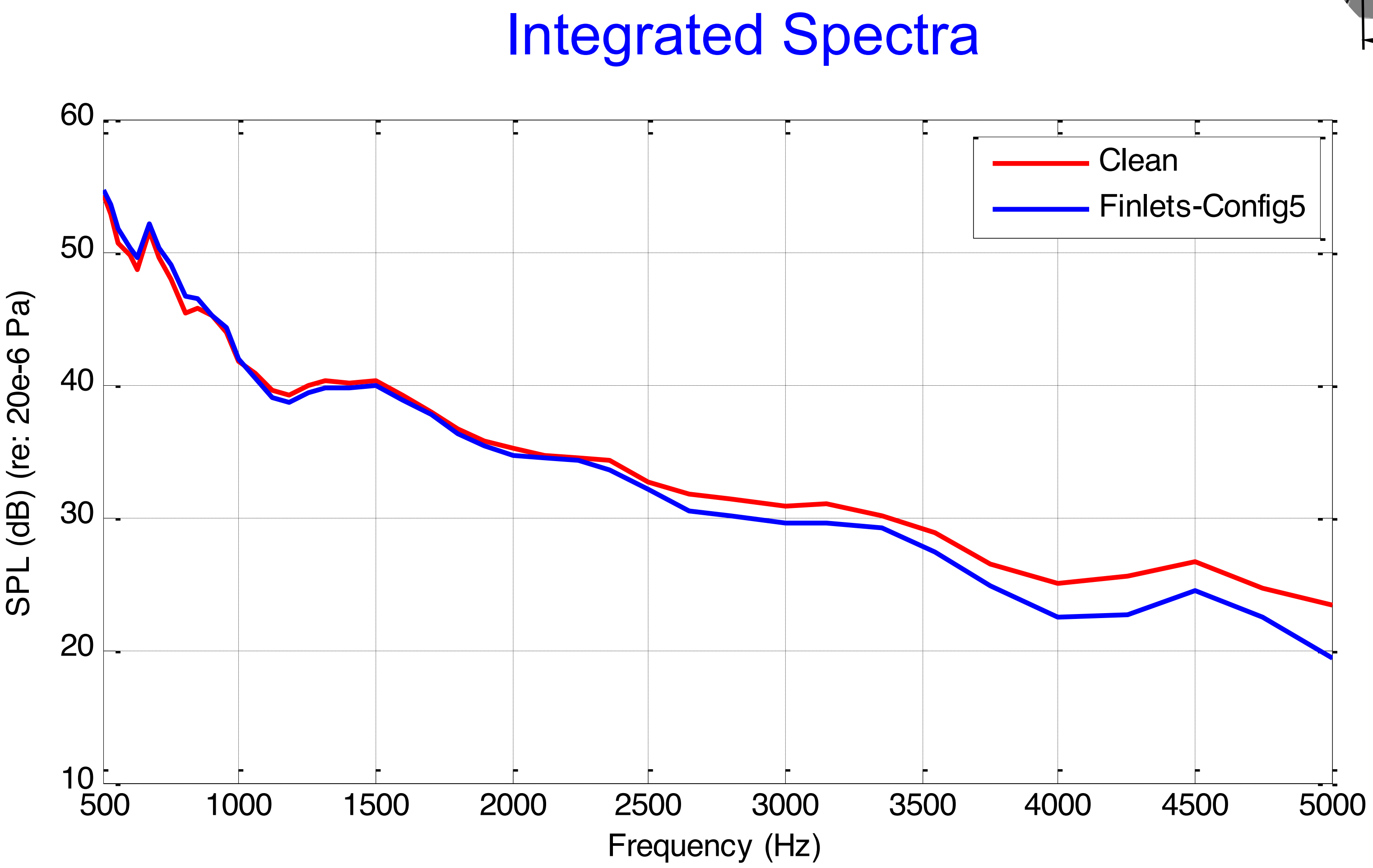
Thickness – 0.5mm
Spacing – 4mm
Height – 4mm
10mm Extension
($\delta \approx$ 30mm)



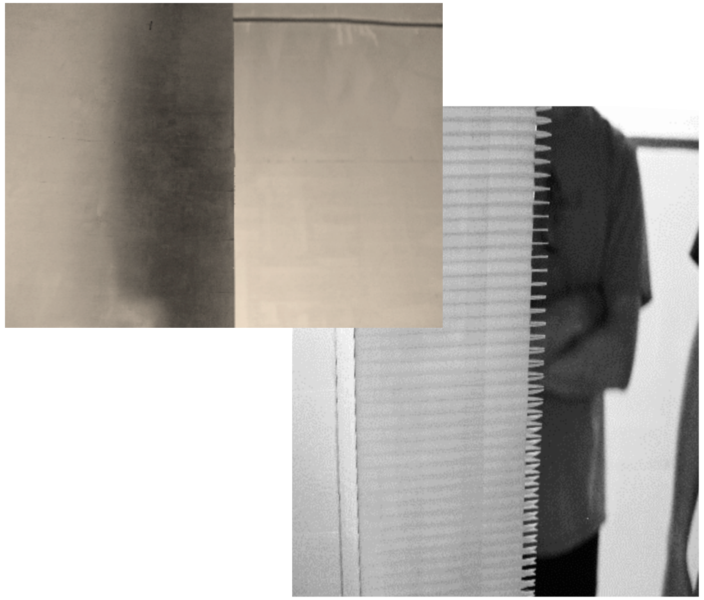
3.0°

Effect of Configuration 5 Finlet





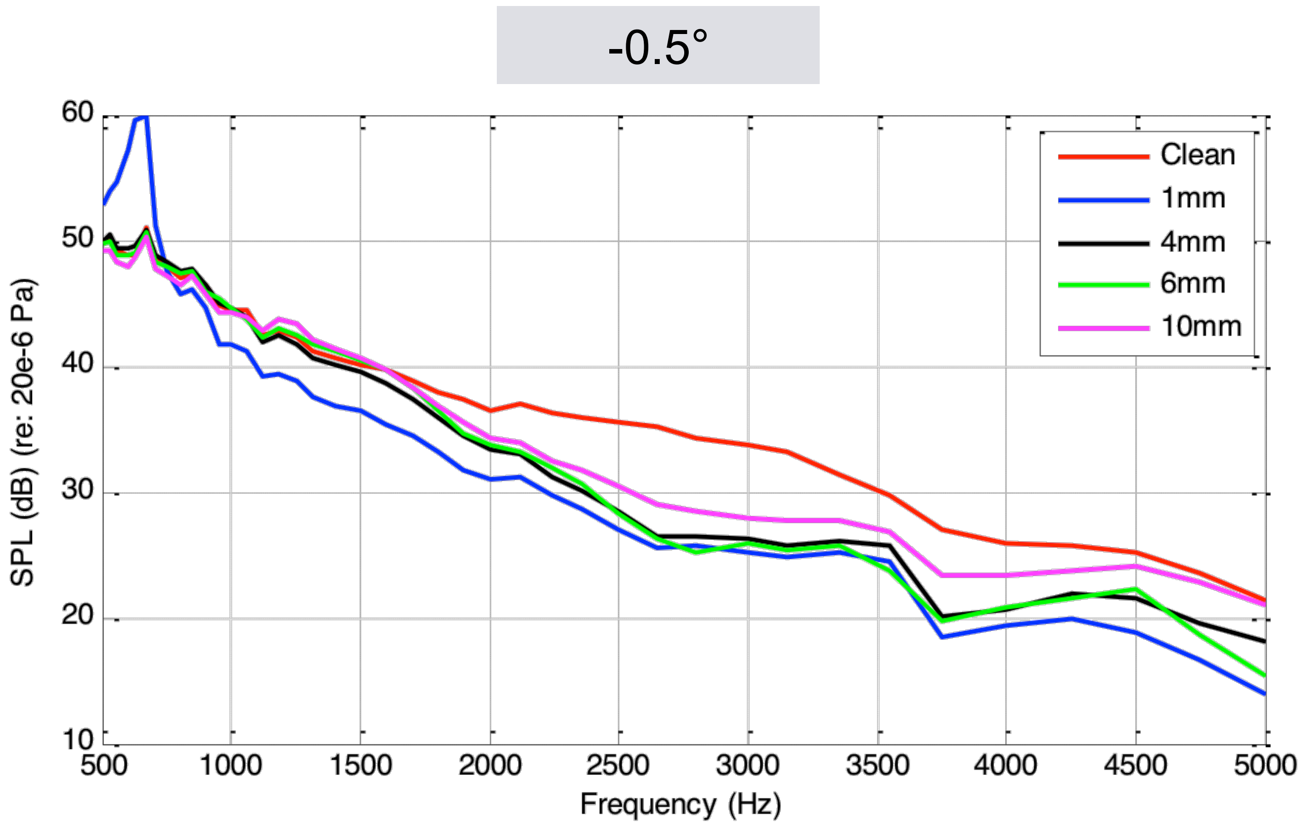
Thickness – 0.5mm
Spacing – 4mm
Height – 4mm
10mm Extension
($\delta \approx$ 40mm)



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



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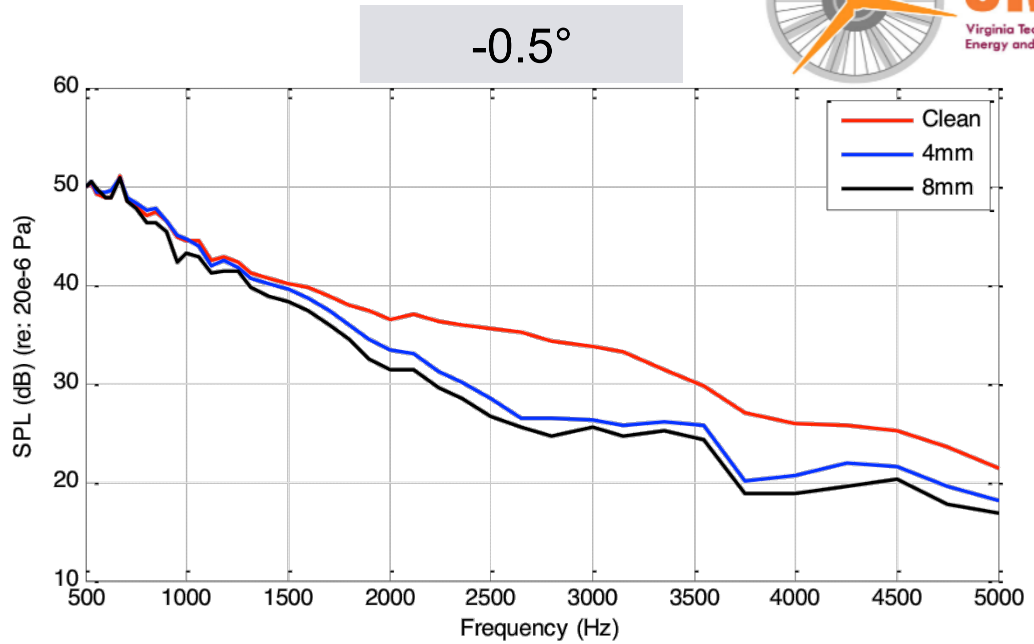

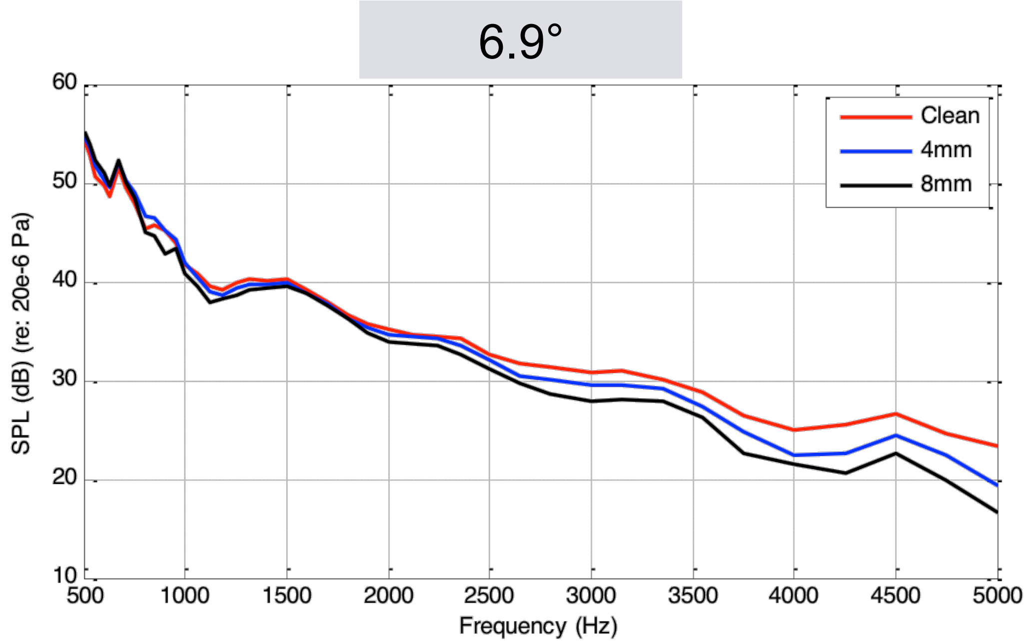

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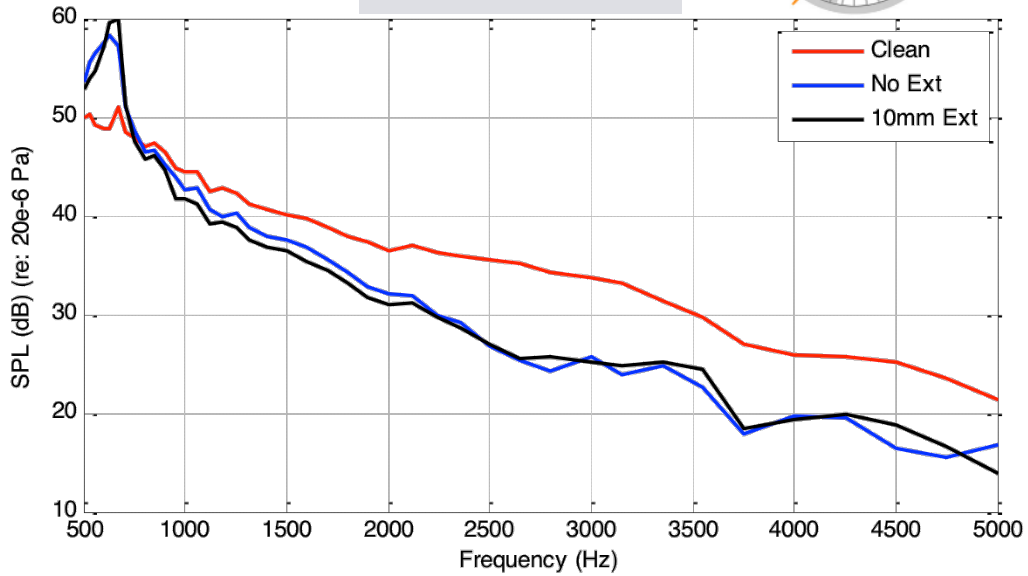
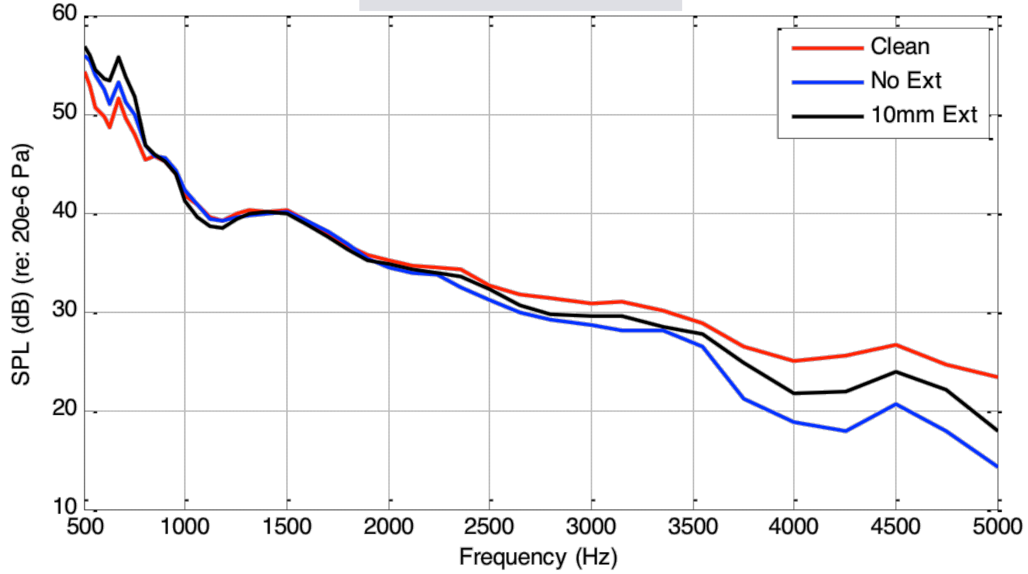
-0.5°



6.9°



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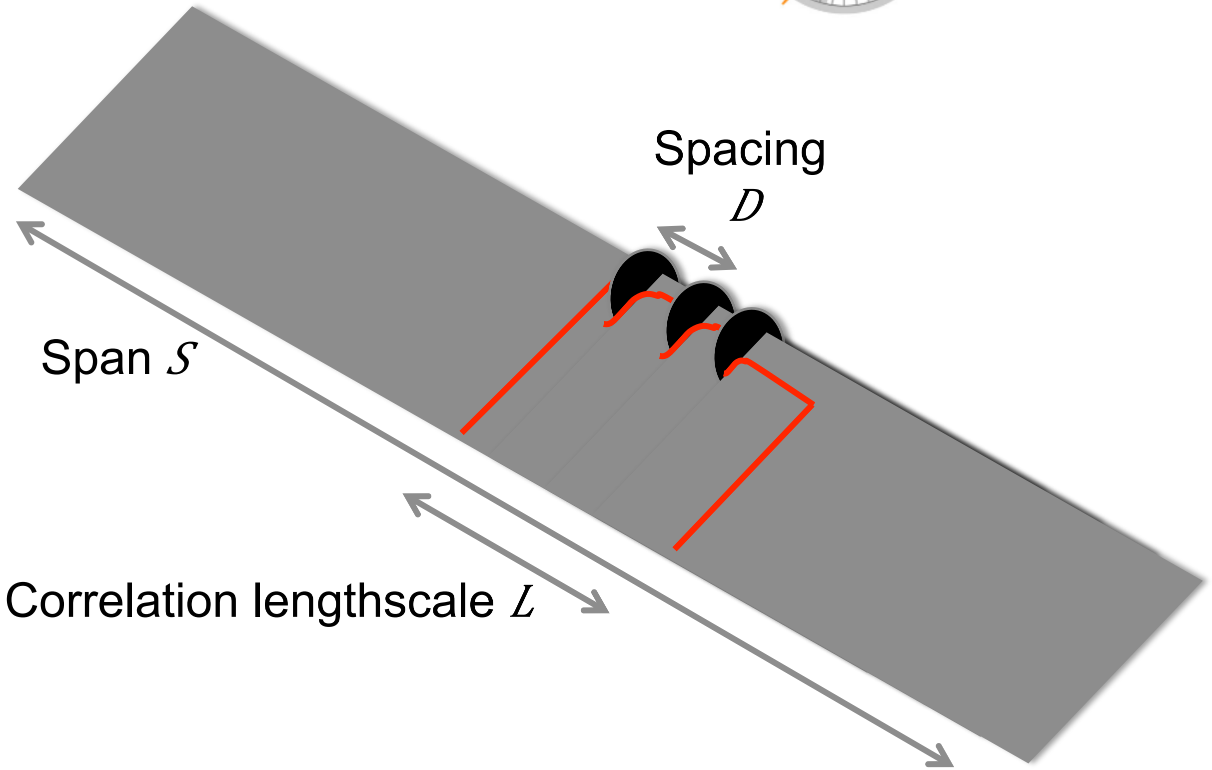
What physical mechanisms are we exploiting?

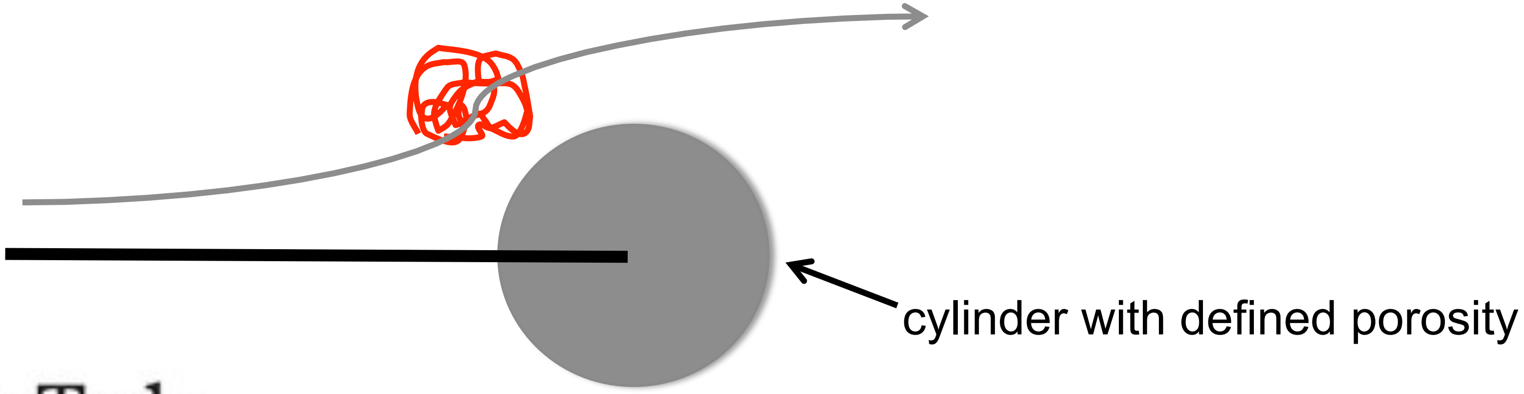
Break up of the boundary layer eddies?

Displacing those structures away from the surface/edge?

Shear sheltering of the edge?

Suppression of trailing edge shedding?



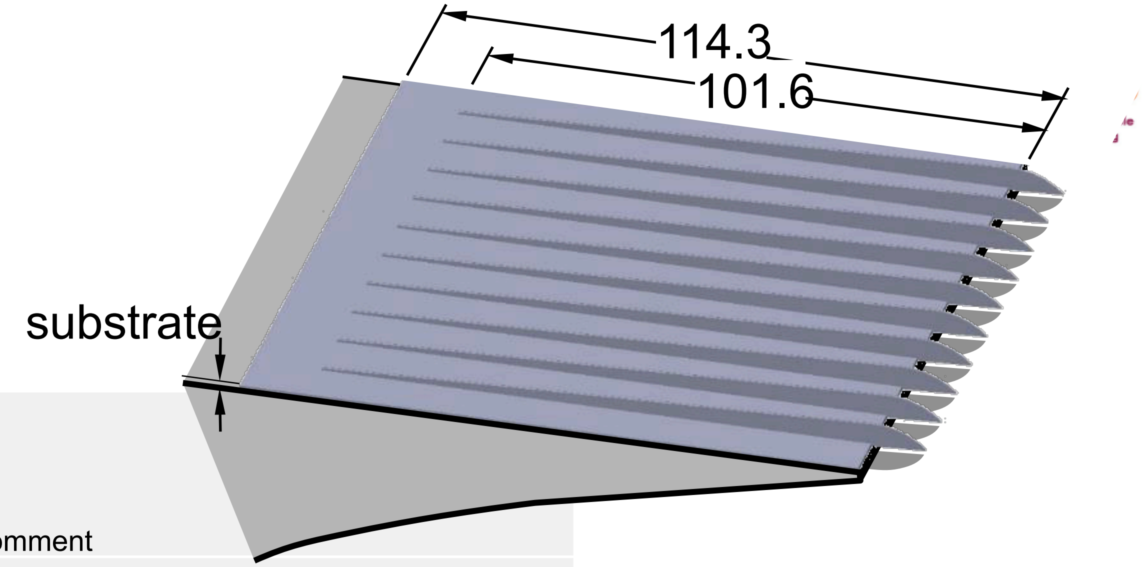


Conclusions

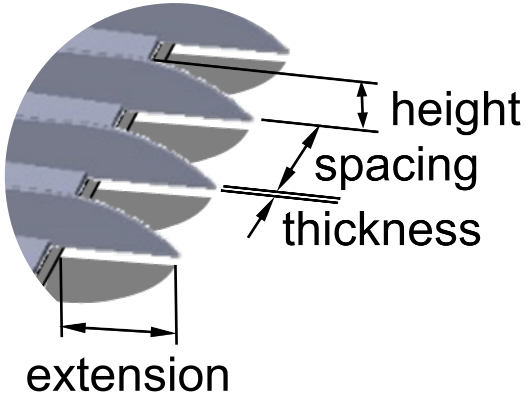
1. A new, bio-inspired surface treatment for the suppression of trailing edge noise has been demonstrated.
2. The treatment could be combined with existing trailing edge modifications (serrations, etc.) to maximize noise control.
3. The treatment is effective throughout a wide parameter range and is 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

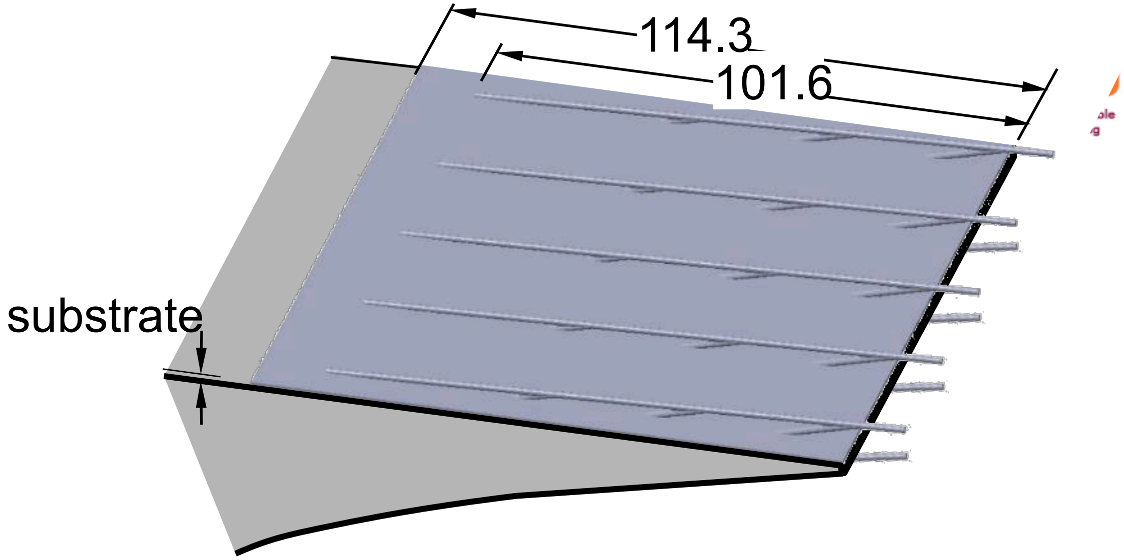
Configurations - Finlets



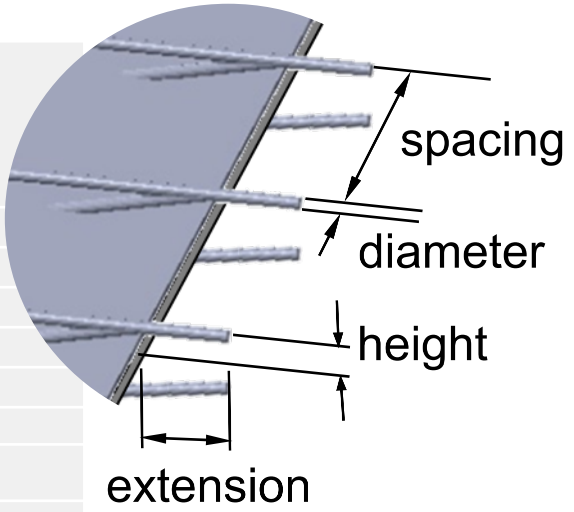
Config#	Runs	Type	Height	Spacing	Thickness	TE extension	Substrate	Suction only	Cp/lift	Drag	Acoustics	Comment
0	All	-	-	-	-	-	-	-	Y	Y	Y	
2	133-154	Blank	-	-	-	-	0.5	-	Y	Y	Y	Control cases
10	683-704	Blank	-	-	-	-	0.75	-	Y	-	Y	
3	463-484	Fin	4	1	0.5	10	0.5	-	Y	-	Y	Fin anchor case
1	419-440	Fin	4	1	0.5	0	0.5	-	Y	-	Y	Effect of extension w. C3
5	243-264	Fin	4	4	0.5	10	0.5	-	Y	-	Y	
13	804-825	Fin	4	6	0.5	10	0.75	-	Y	-	Y	Effects of fin spacing w. C3
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



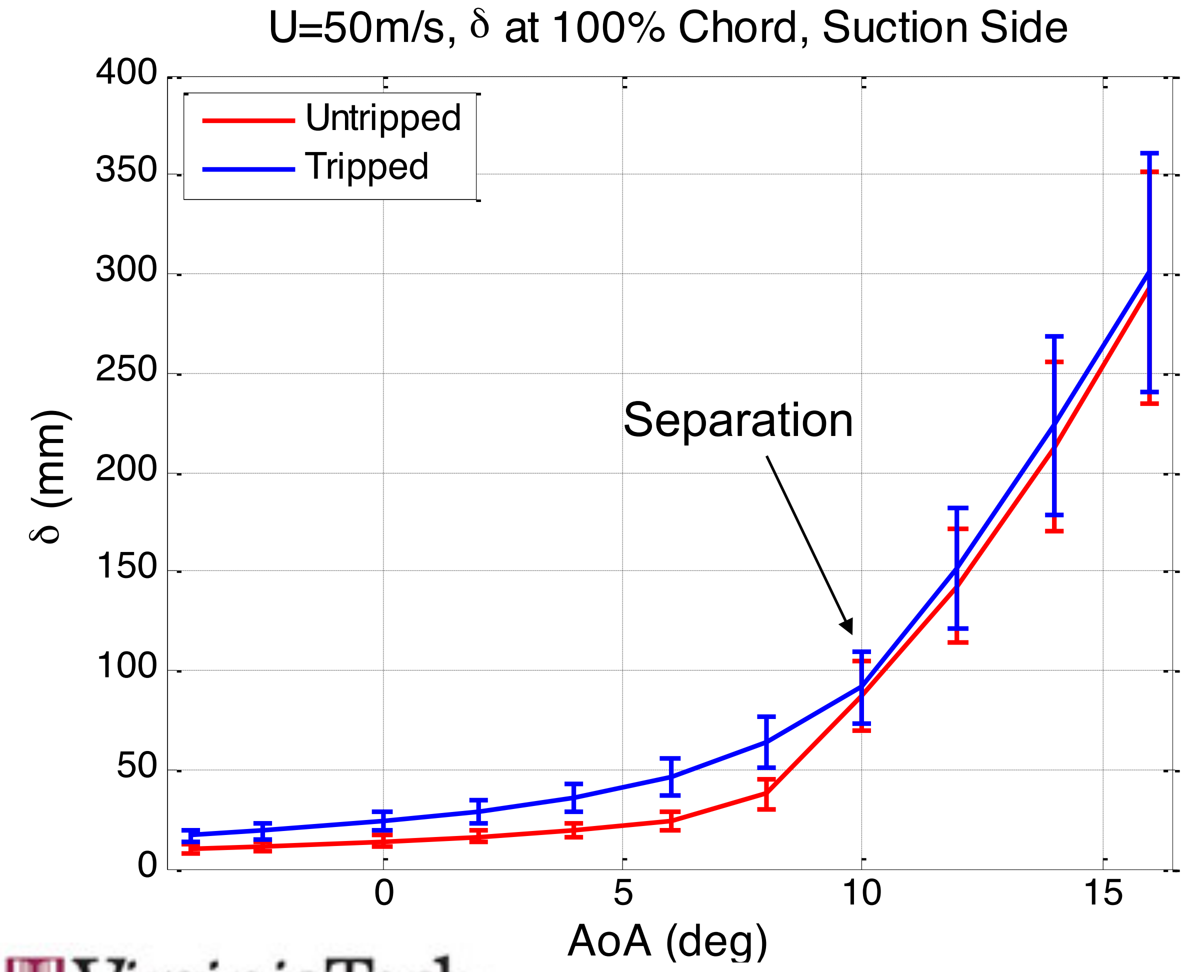
Configurations - Rails

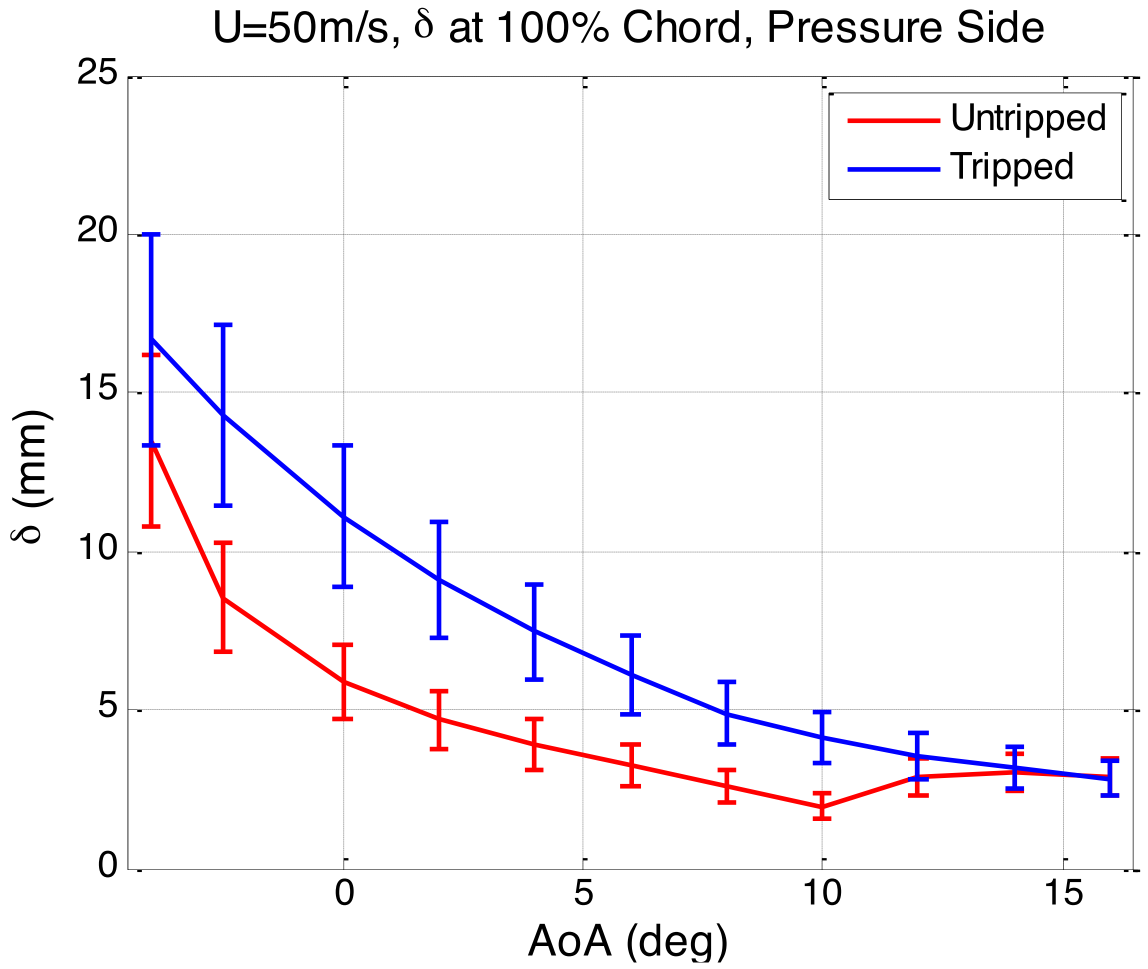


Config#	Runs	Type	Height	Spacing	Diameter	TE extension	Substrate	Suction only	Cp/lift	Drag	Acoustics		Comment
14	848-869	Rail	4	2.5	1.25	10	0.75		Y	-	Y		Rod anchor case
15	936-957	Rail	4	2.5	1.25	0	0.75	-	Y	-	Y		Effect of extension w. C14
17	1024-1045	Rail	8	2.5	1.25	10	0.75	-	Y	-	Y		Effect of height 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





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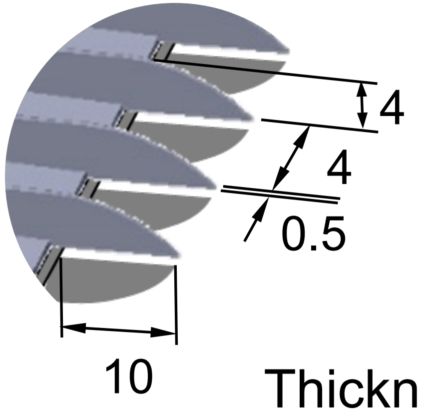
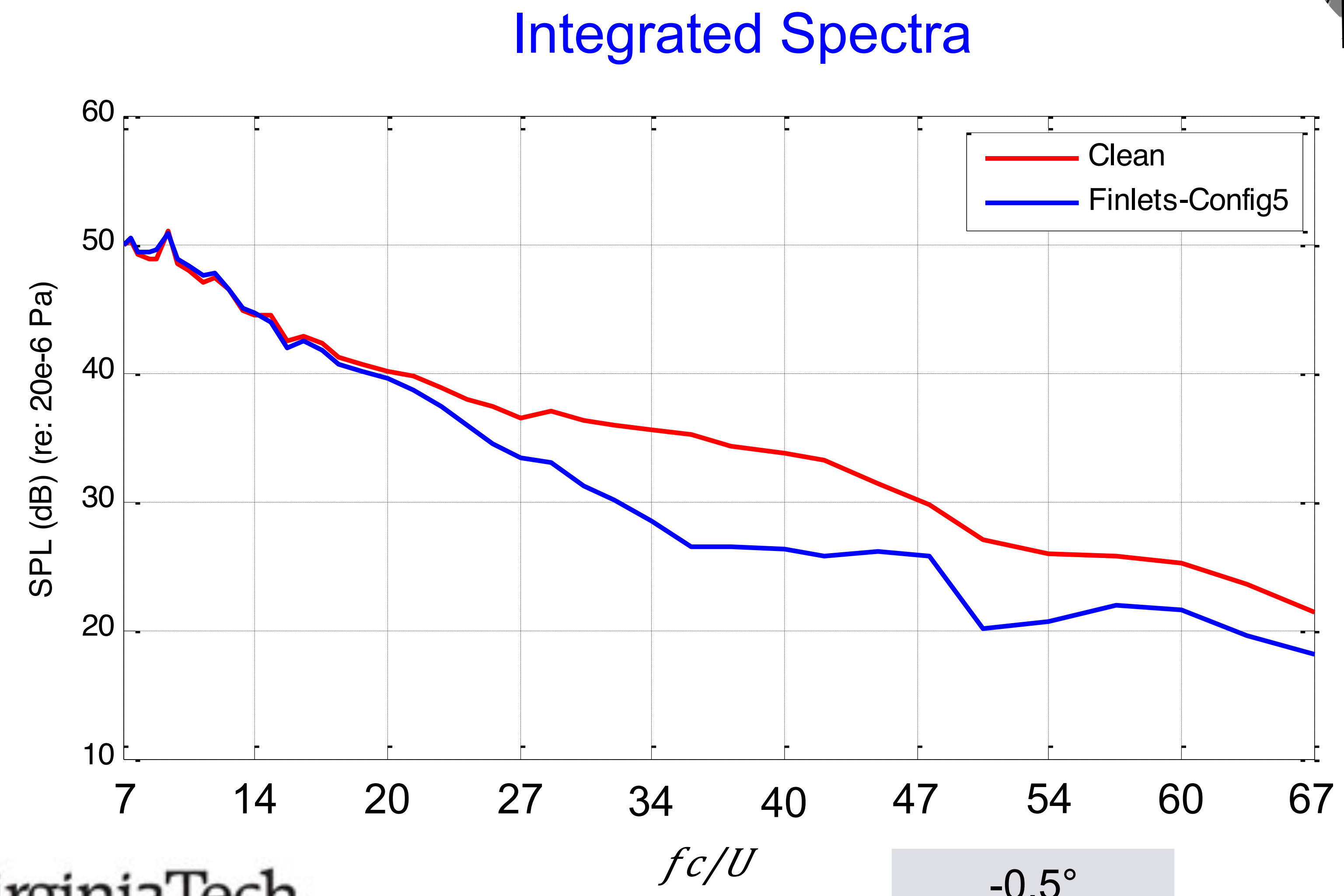
Effect of Configuration 5 Finlet

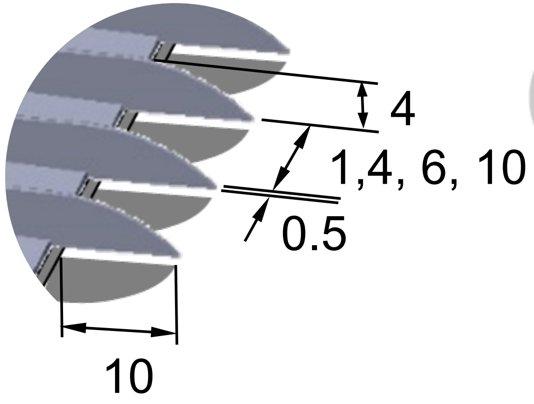


Thickness – 0.5mm
Spacing – 4mm
Height – 4mm
10mm Extension
($\delta \approx$ 15mm)

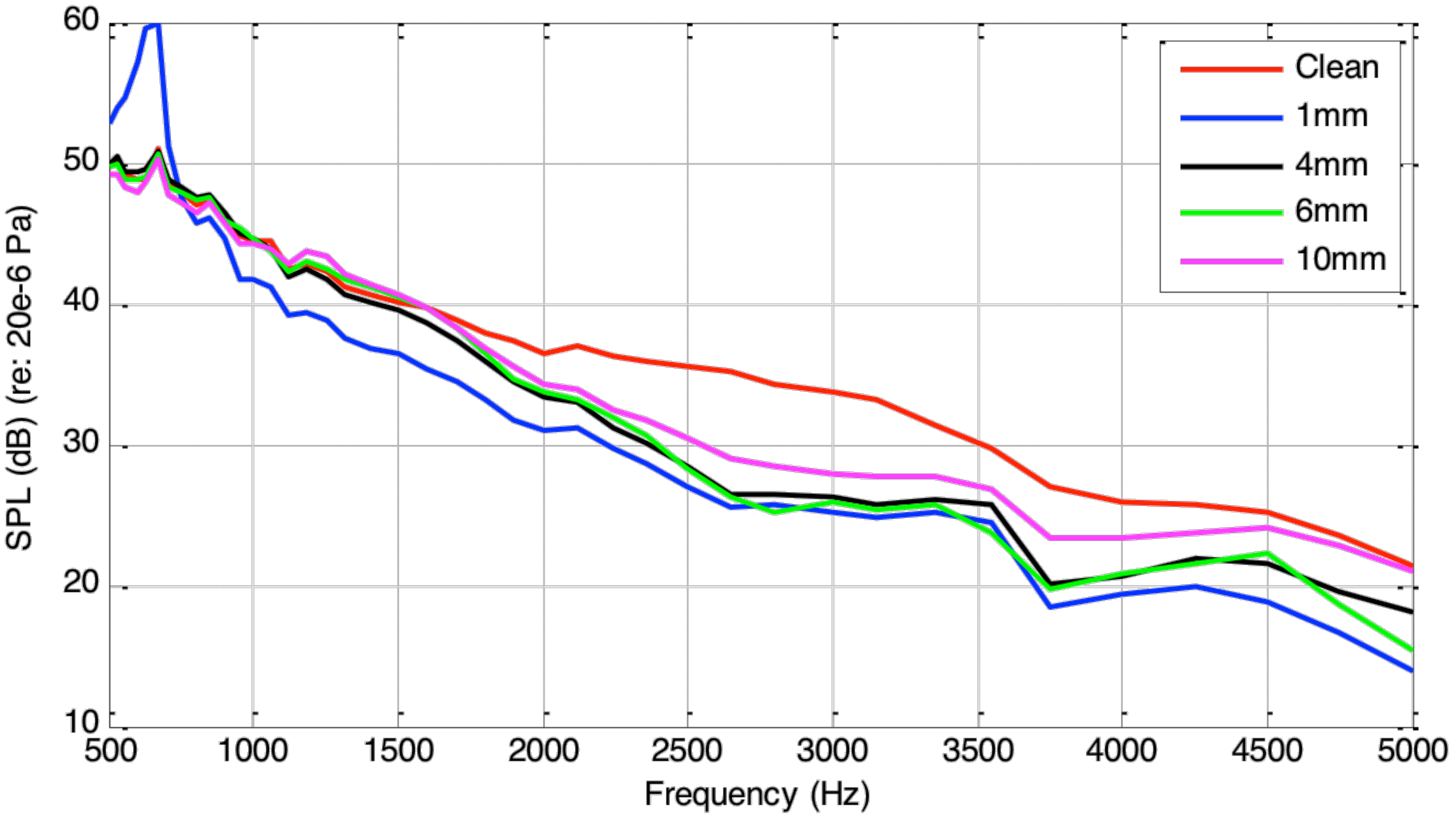


-0.5°

Finlets – Effect of Spacing



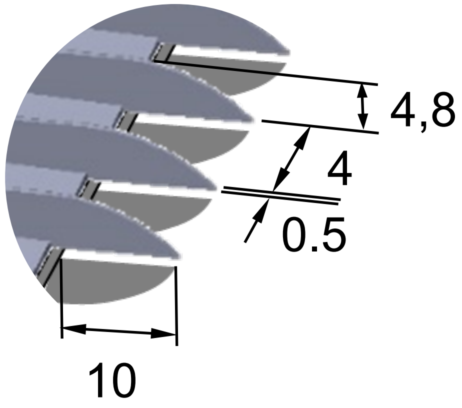
Integrated Spectra



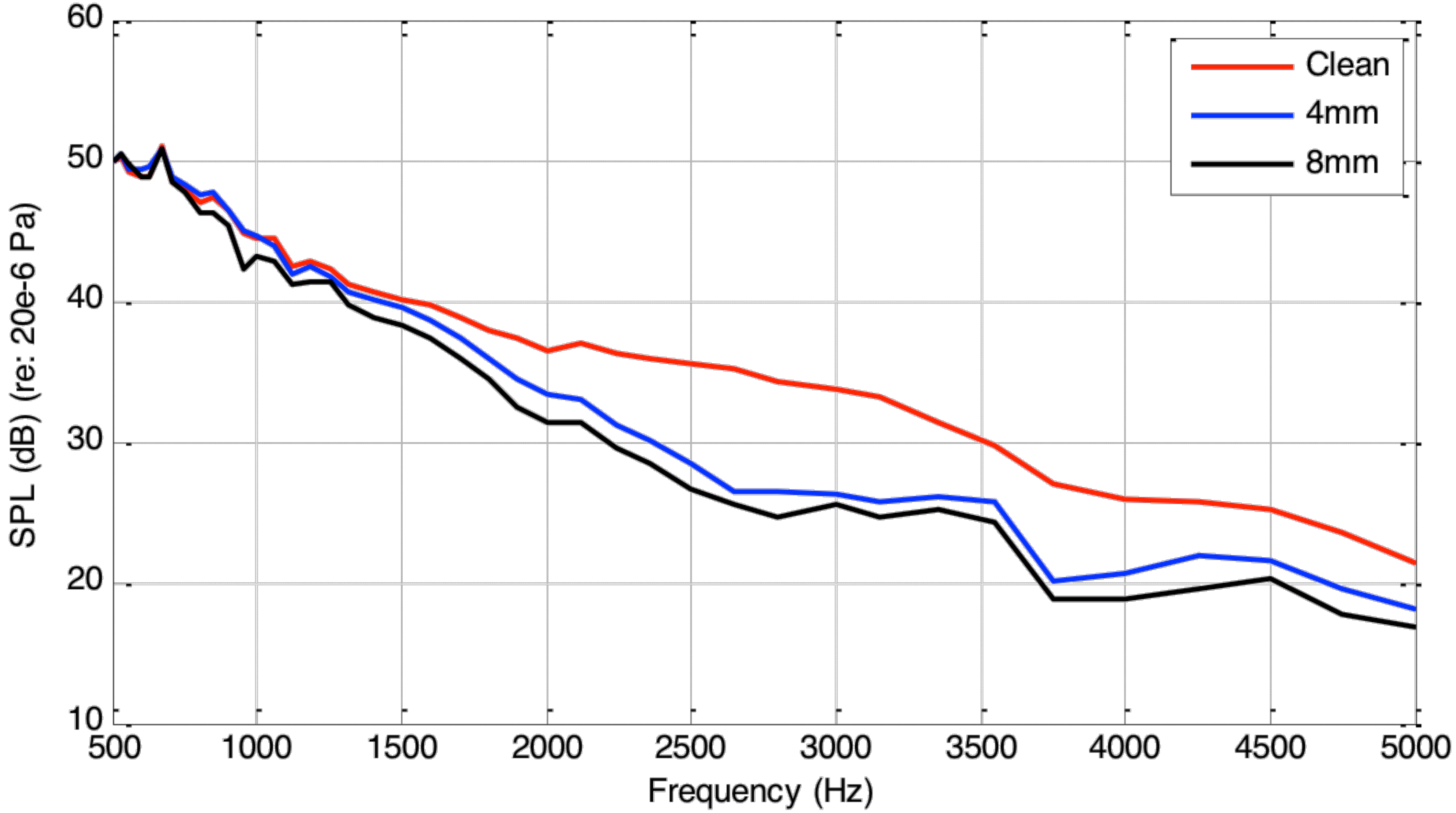
-0.5°

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

Finlets – Effect of Height



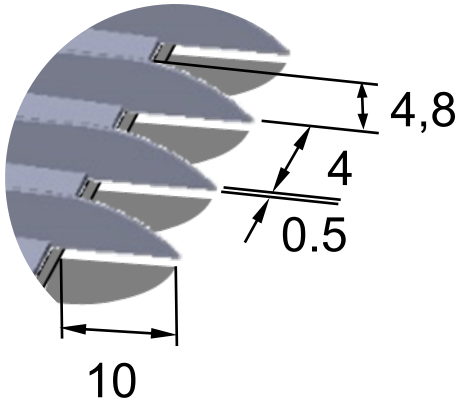
Integrated Spectra

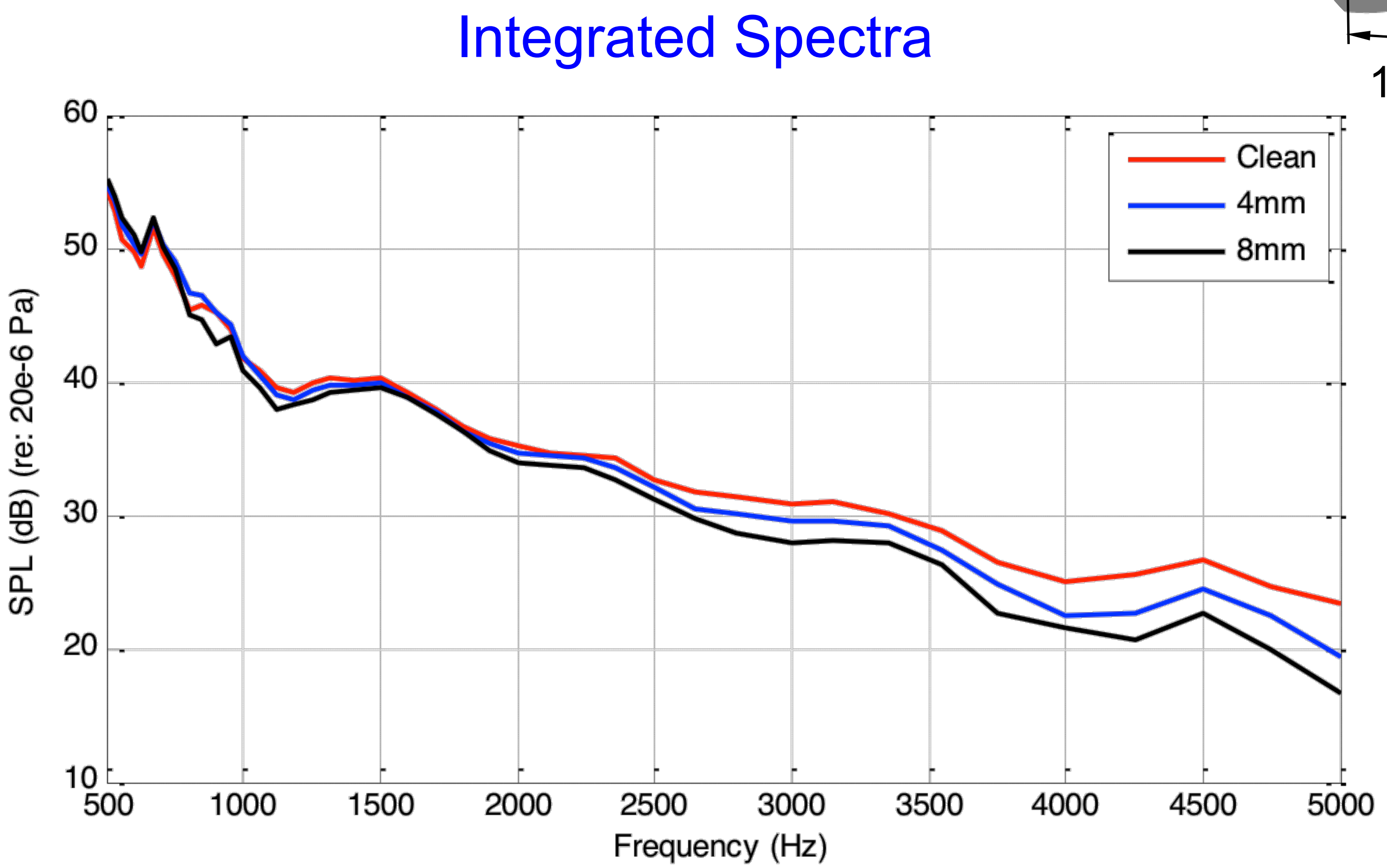


Thickness – 0.5mm
Spacing – 4mm
Height – 4, 8mm
10mm Extension

-0.5°

Finlets – Effect of Height

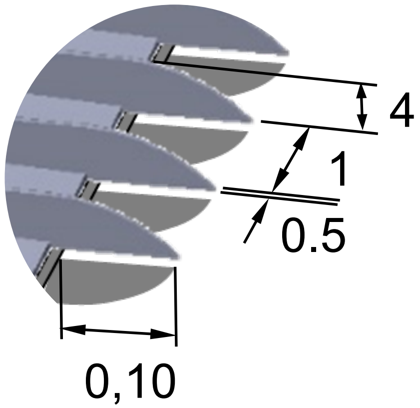




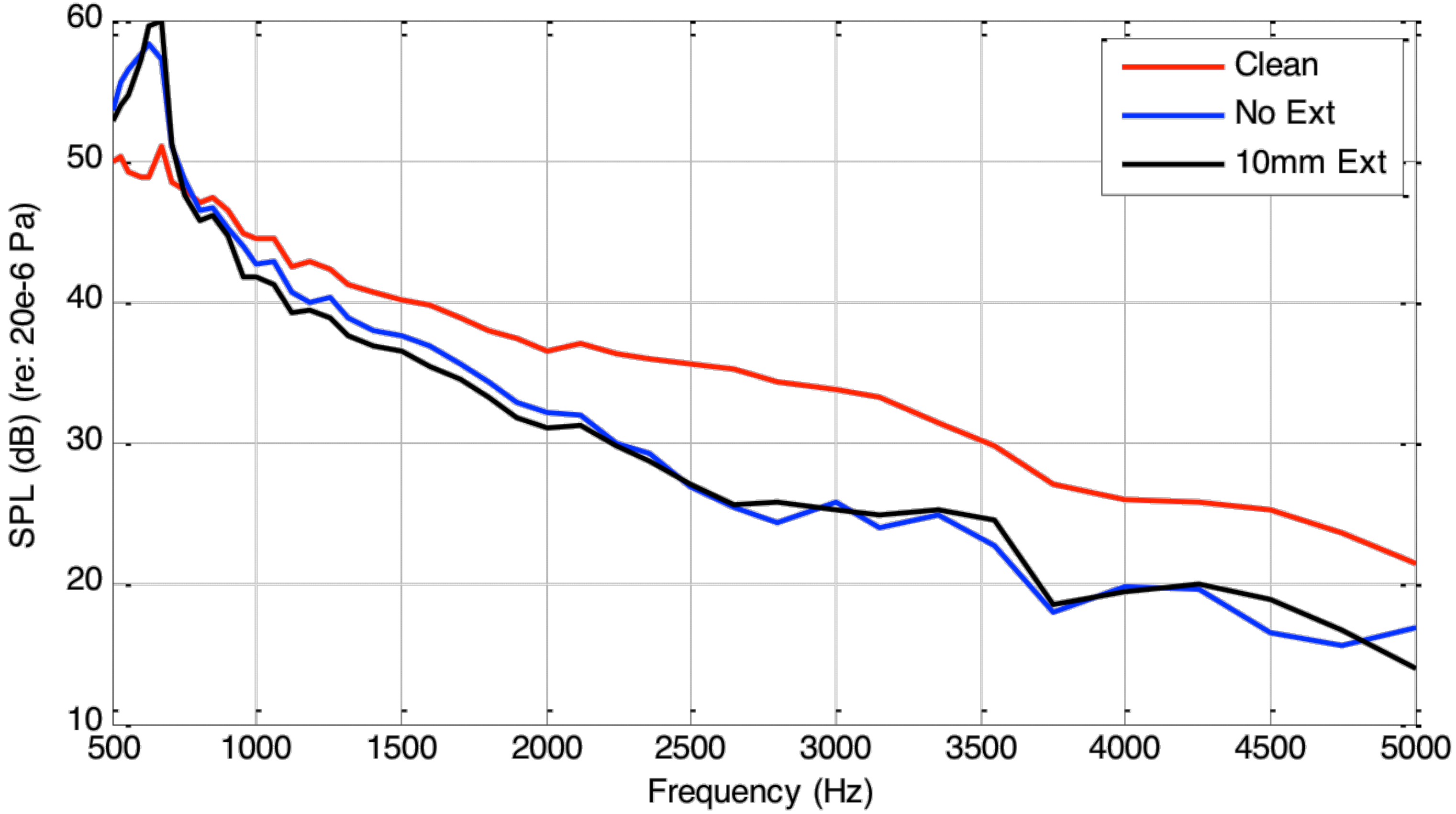
Thickness – 0.5mm
Spacing – 4mm
Height – 4, 8mm
10mm Extension

6.9°

Finlets – Effect of Extension



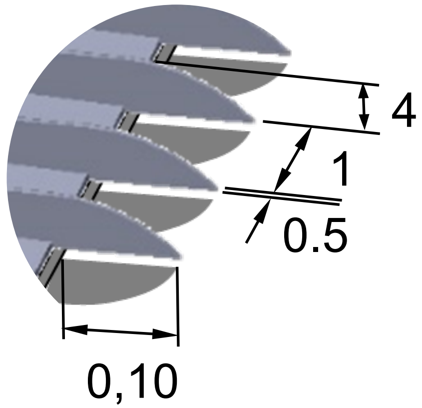
Integrated Spectra

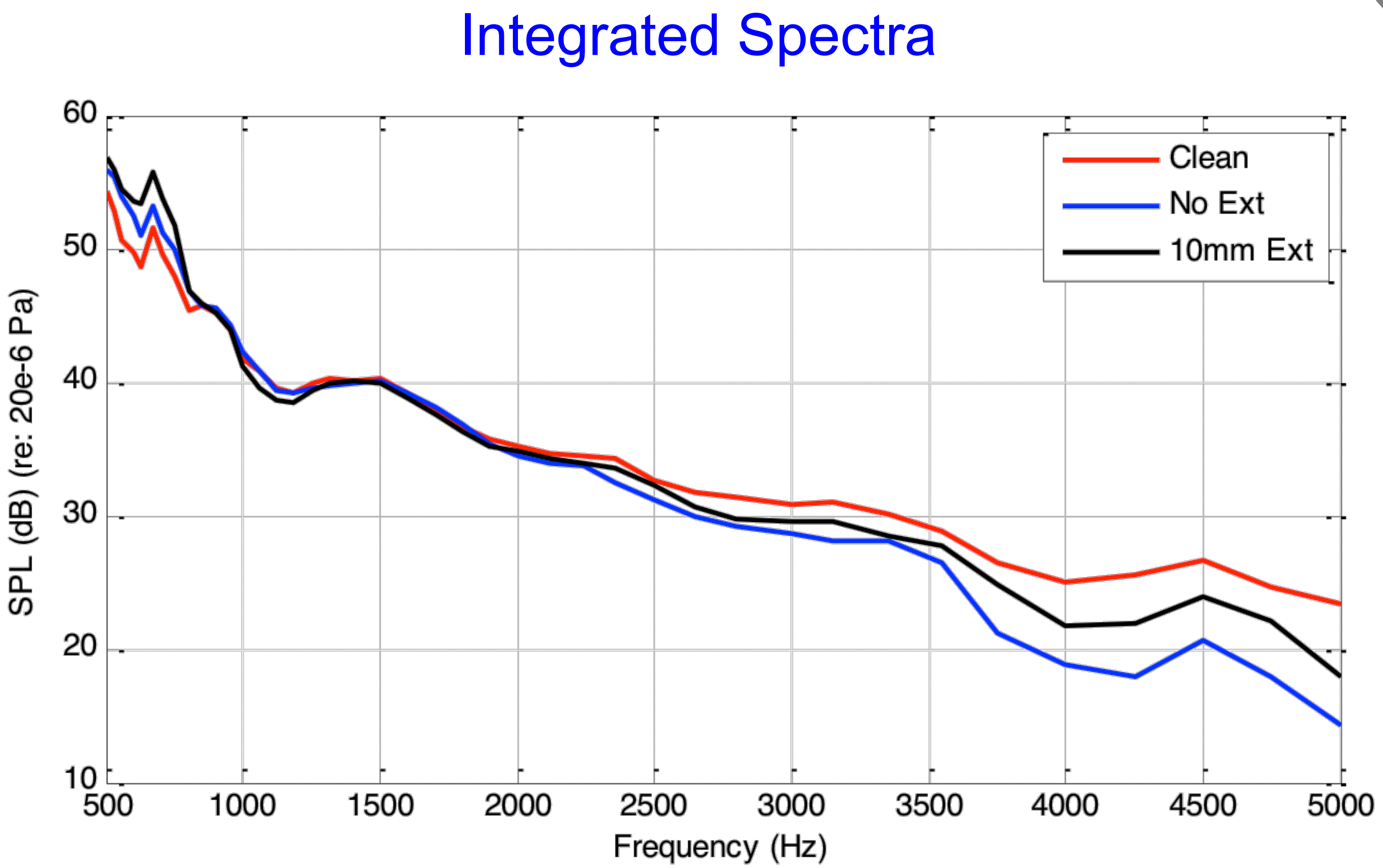


Thickness – 0.5mm
Spacing – 1mm
Height – 4mm
0, 10mm Extension

-0.5°

Finlets – Effect of Extension

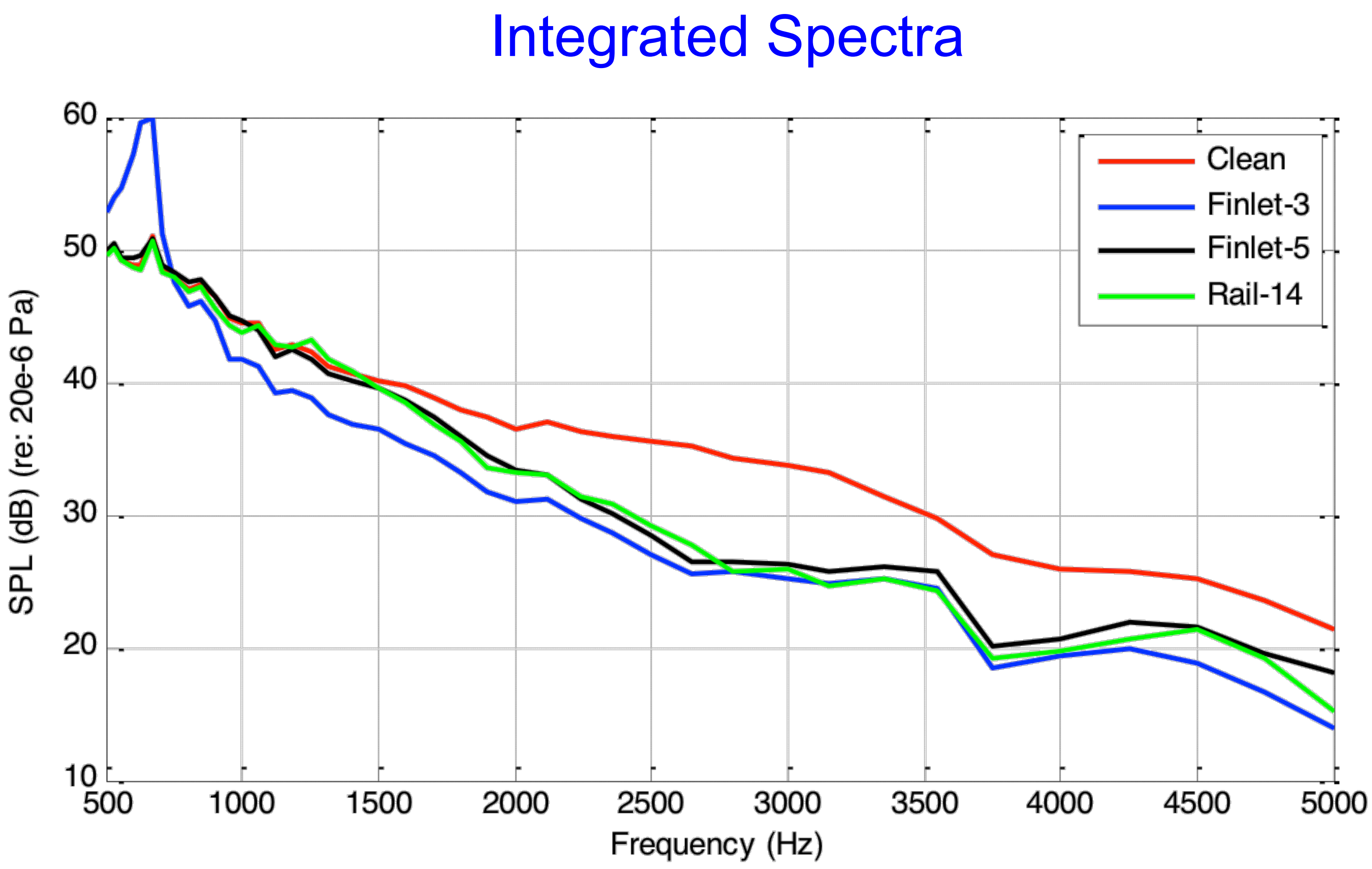


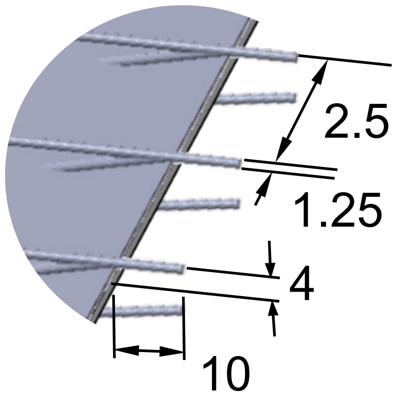


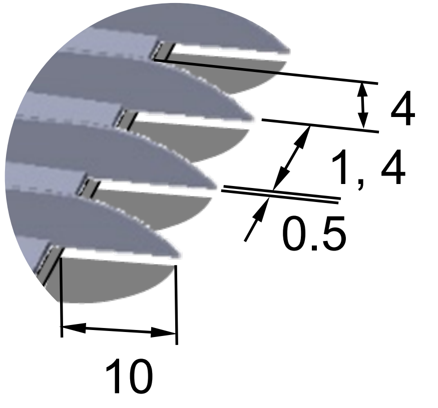
Thickness – 0.5mm
Spacing – 1mm
Height – 4mm
0, 10mm Extension

6.9°

Rails vs Finlets







-0.5°