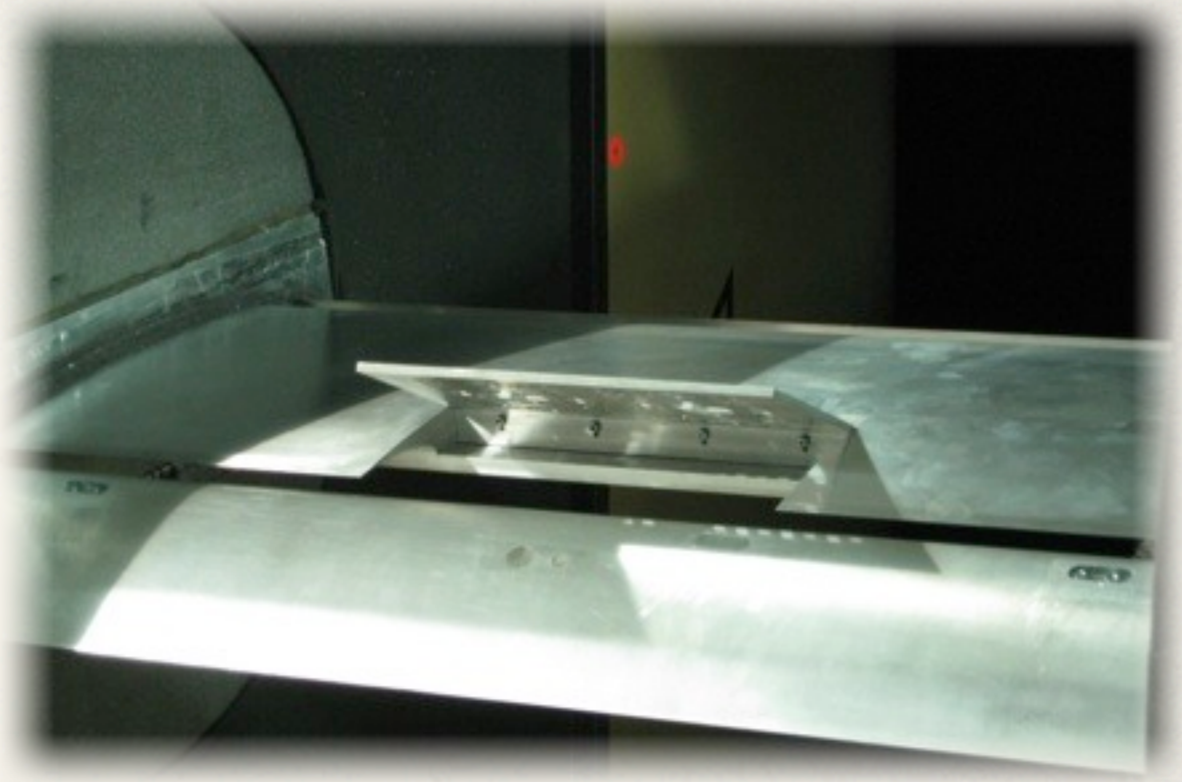
Aero-acoustic performance of fractal spoilers



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The Aim

- **To reduce the noise generated by the outboard spoilers on an A320 aircraft, through means of large-scale fractal porosity, whilst maintaining the lift and drag characteristics**

Spoiler Noise

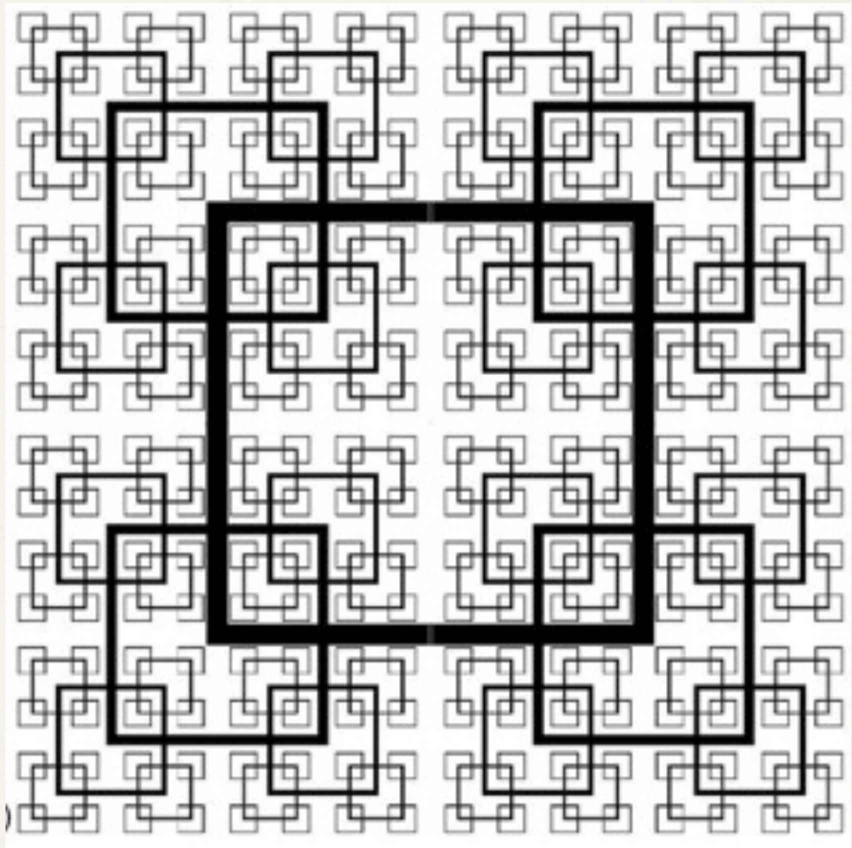
- **Spoilers generate a large area of re-circulating flow behind them**
  - This large, oscillating body is the main source of the low frequency noise that the spoilers generate
- **By introducing bleed air, the hope is to remove this low pressure area and hence its noise**

Theory

- By introducing bleed air through a plate, the air can either displace, decrease or remove the re-circulation bubble entirely depending on the blockage ratio (Castro 1971).
- At a porosity/blockage of 30%/70%, Castro found that the re-circulation region disappears entirely.
- This was looked at from an acoustic point of view by Sakalyski et. al (2007), where they created porous spoilers and found that the low frequency noise generated by the spoilers was reduced.
- For the same blockage ratio, the bleed air from a fractal grid would have a higher turbulence intensity, (u_{rms}/U_0), and fluctuating momentum.
- Hence, it should be able to interact even more with the re-circulation region and the wake, reducing the noise further.

Fractal Grids and Turbulence

- **Fractal grids designed by J.C. Vassilicos from Imperial College London**
- **Main property of space-filling fractal square grids :**
  - Produce higher turbulence intensity than regular grid with same blockage ratio
  - Large region of turbulence production
  - Independent control of pressure drop and turbulence intensity
  - By increasing the thickness ratio, t_r, we are able to increase the turbulence intensity



tr = 17 grid used in Hurst and Vassilicos experiments

Hurst D. and Vassilicos J. C. (2007)
"Scaling and decay of fractal-generated turbulence",
Phys. Fluids 19, 035103 (2007)

Fractal Spoilers

- **Spoilers based on report by Sakaliyski et al. 2007**
  - Porous plate
    75% blockage
    Plate normal to flow
- **A total of seven fractal spoilers were made**
  - Varying thickness ratio,
    $t_r = t_{max}/t_{min}$
  - Blockage
  - Frame size
- **Limitation to fractal design**
  - Design fills space
  - Max blockage between 50-60%
  - Had to introduce a frame to increase the blockage

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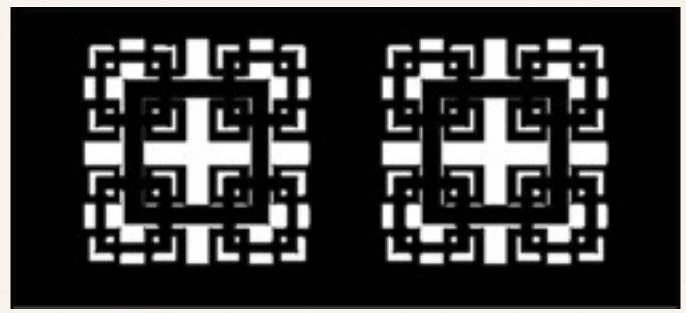

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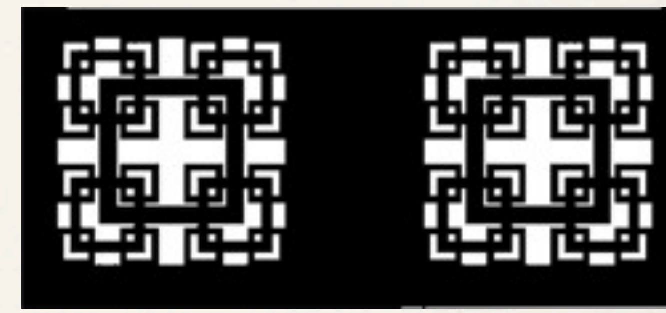

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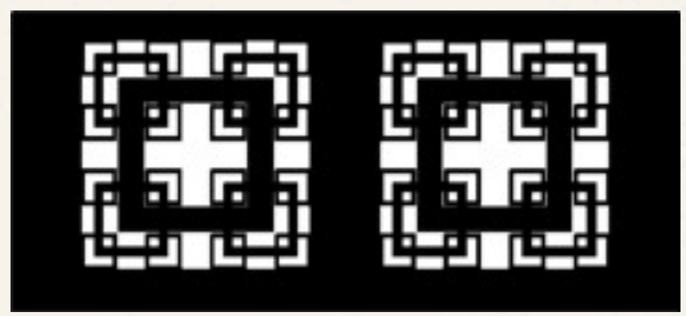

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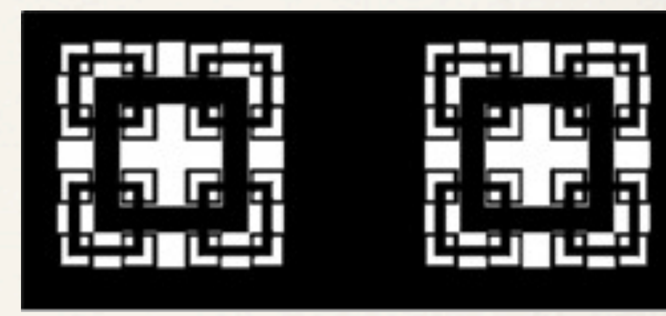

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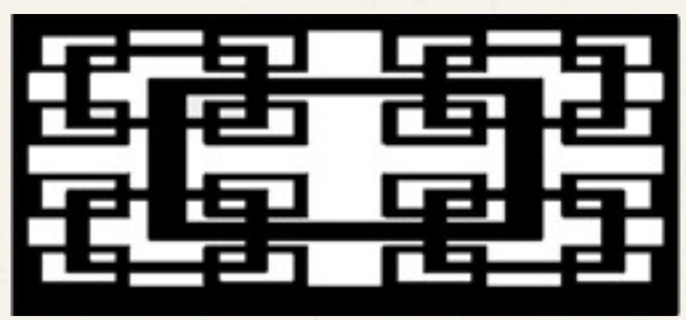

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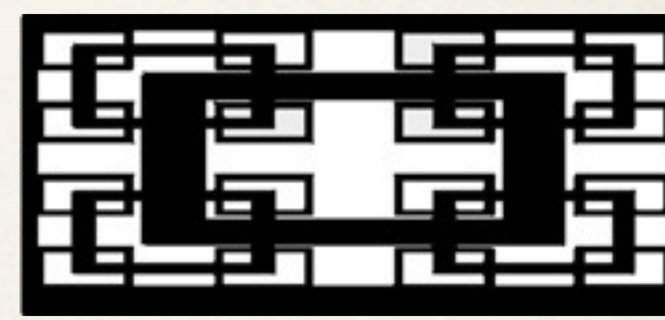

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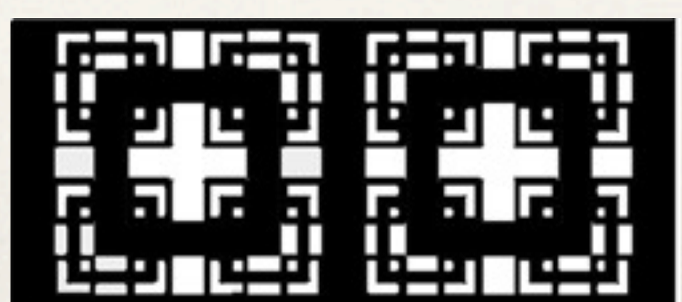

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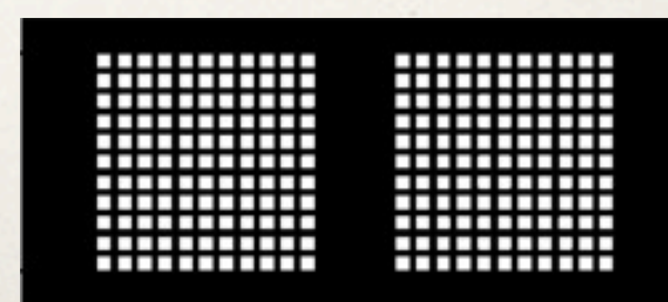
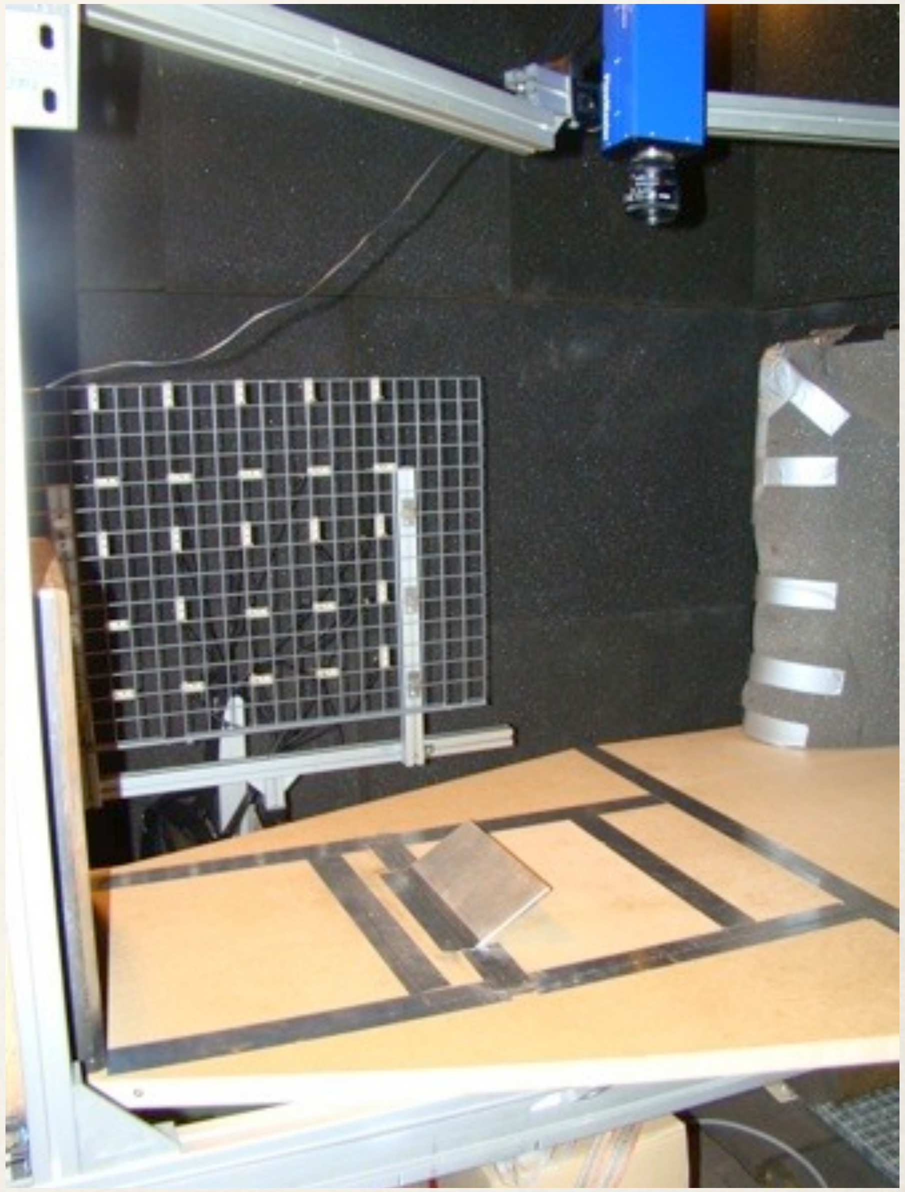


The Experiments

- **Two sets of experiments were done:**
- The preliminary measurements had the spoiler mounted on a flat plate and inclined by 30 degrees
- Acoustic, flow visualisation and force measurements were taken to select two spoilers
- The two chosen spoilers were then tested on a three-element wing system, with acoustic and force measurements taken simultaneously

Preliminary Experiments

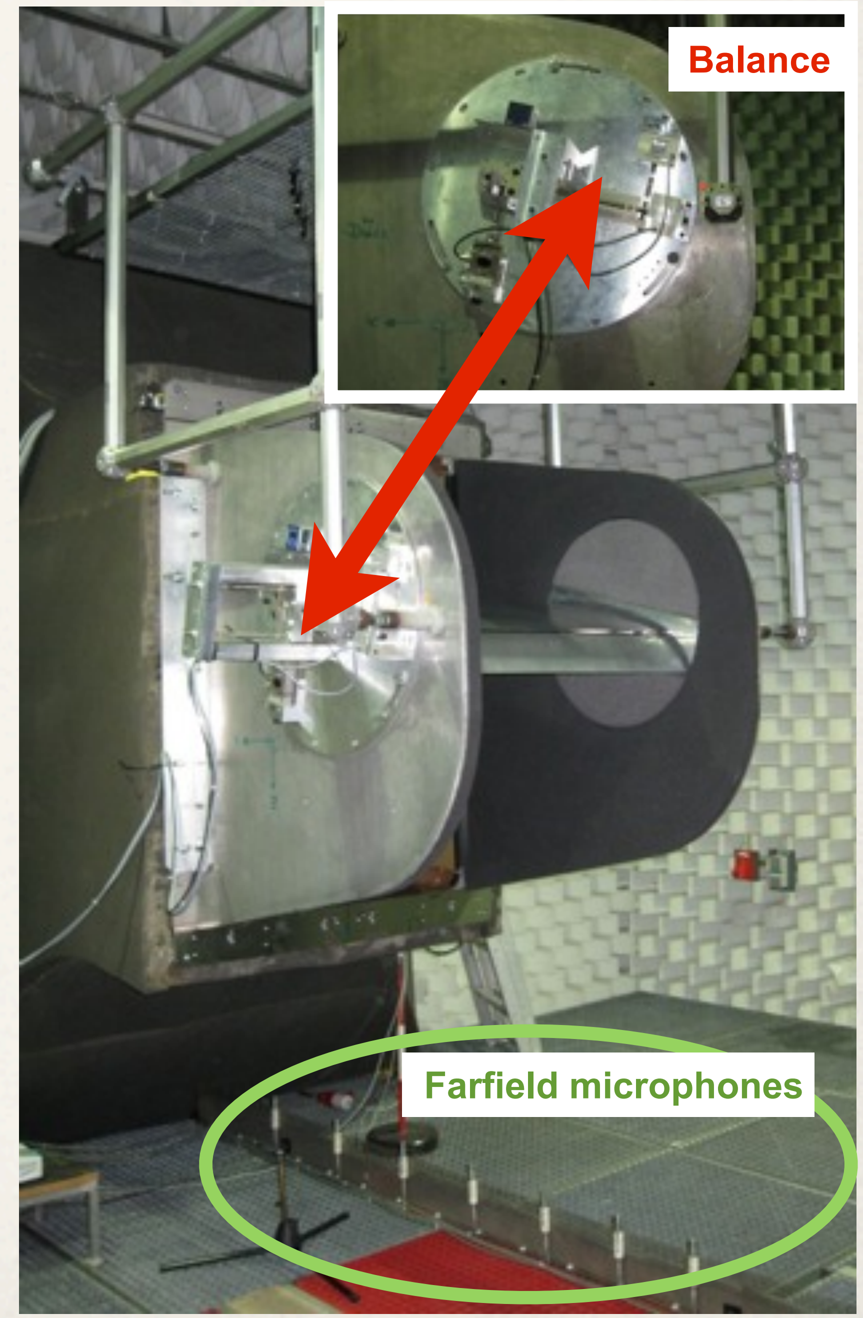
- **PIV and acoustic measurements take at EOLE, Poitiers**
  - Free-stream of 30 and 40 m/s
    Along the centre-line of the fractal squares and 4mm from the wall
    PIV plane covered 182.41mm x 145.70mm area
  - 4 x 4 microphone array used
    Placed 1m to the side and 1m above the spoiler
    Sampled at 44kHz and 20 seconds
    Free-stream velocity at 40, 45 and 50m/s



Picture showing the combined experimental set-up at EOLE Anechoic Chamber, University of Poitiers

Combined Aero-acoustic Measurements

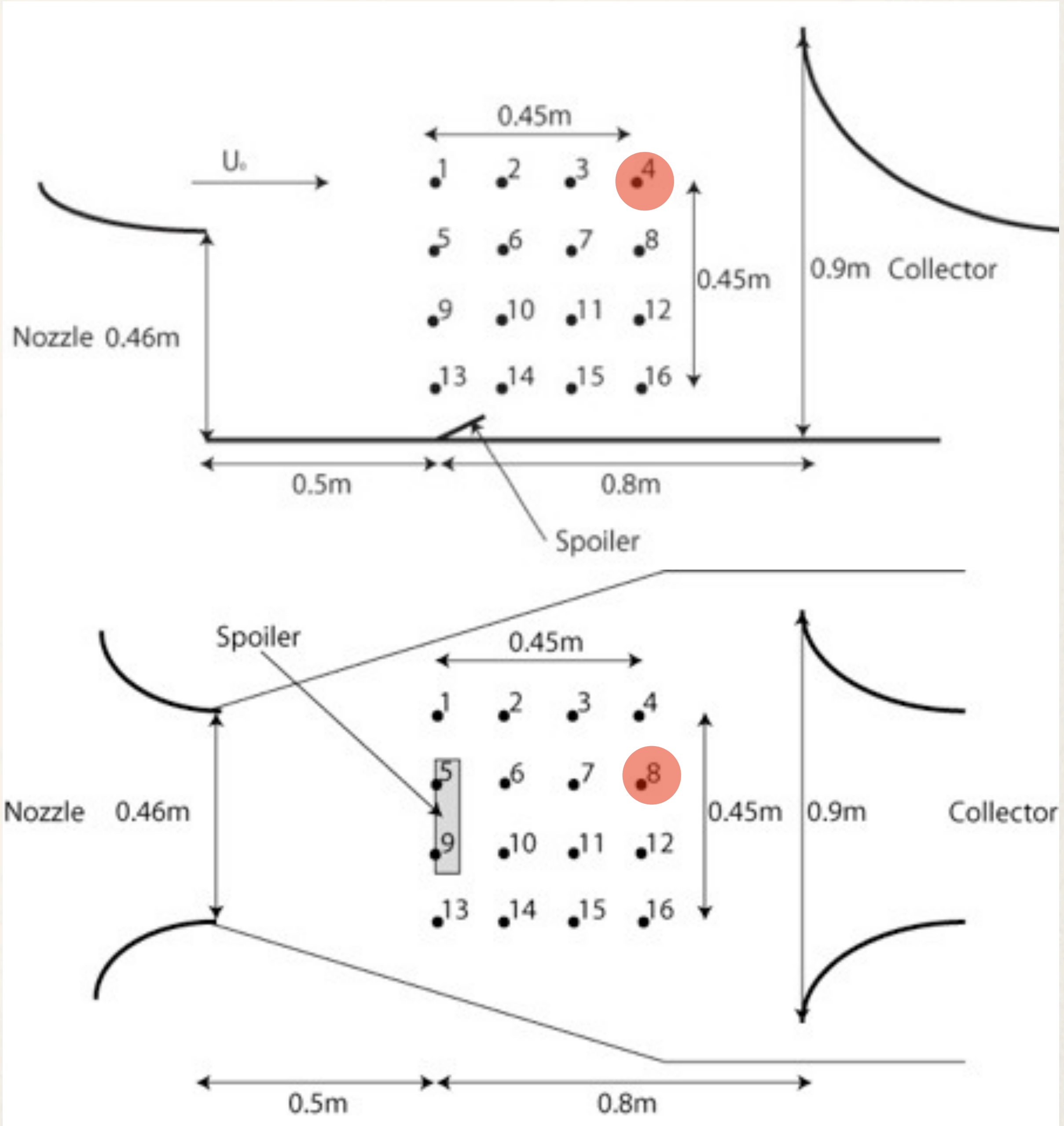
- **Combined aero-acoustic measurements taken in AWB at DLR, Braunschweig**
- **Three-element wing system comprised of:**
  - Leading edge slat deflected at 25°
    Main wing section
    Trailing edge flap deflected at 35°
  - Three wing angles used: 9°, 12° and 15°
- **Far-field microphones**
  - Located below the wing configuration
  - Polar angle range of 60° to 120° (first and last microphone not used)
- **Balance used to obtain aerodynamic forces**
- **Free-stream set to U = 40, 50 and 60 ms^{-1}**



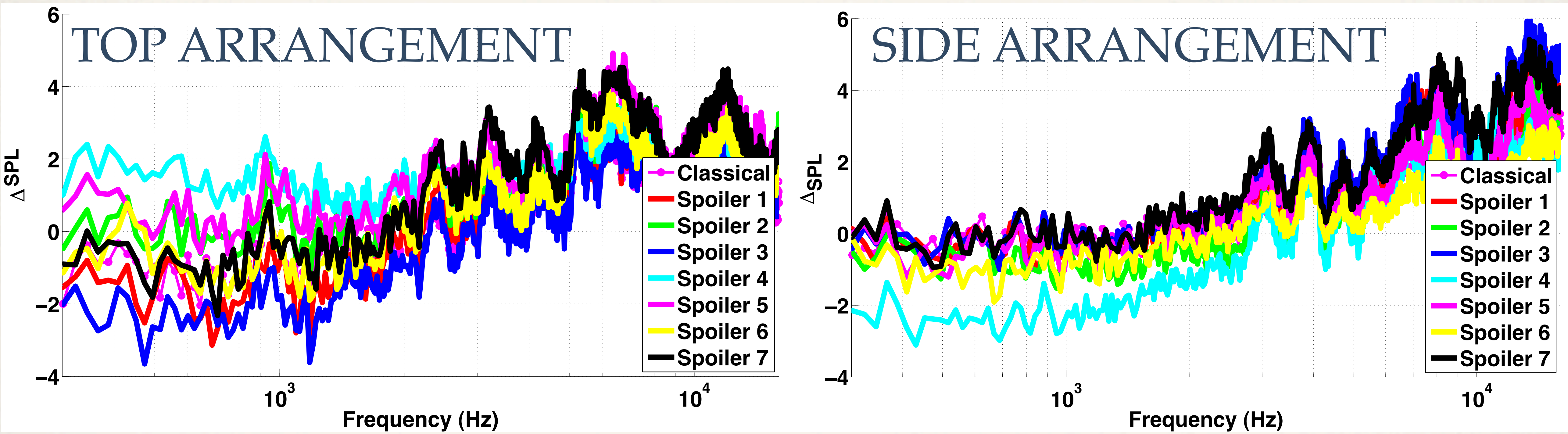
Preliminary Measurements on a Flat Plate

Acoustic Tests

- Carried out in EOLE Tunnel at the University of Poitiers
- Used a microphone array placed 1m to side and 1m above
- Sample Frequency= 44kHz
- Sample Time = 20s
- Tunnel has an acoustic range of 300Hz - 16,000Hz
- Able to get a quick indication of the acoustic performance
- Far-field radiation study using microphones 8 for the side arrangement and microphone 4 for the top arrangement

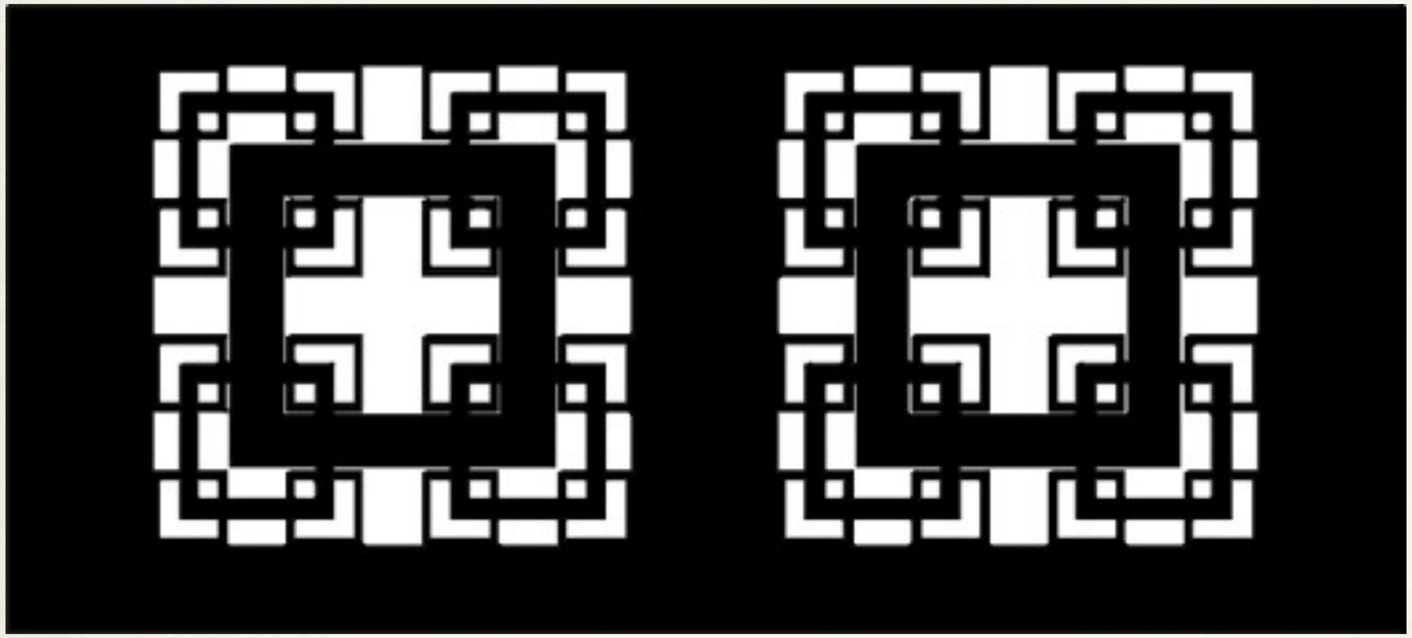


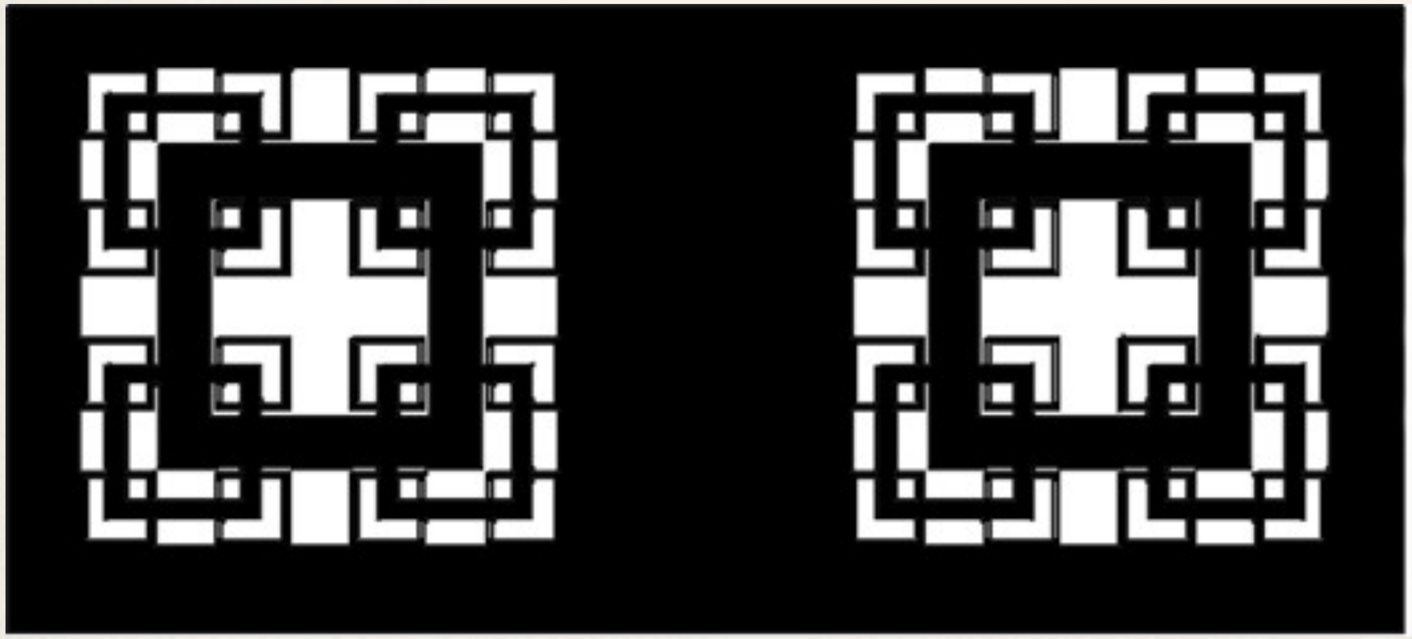
Acoustic Tests



- Performance based on change in Sound Pressure Level (SPL) compared to solid spoiler: ***Delta SPL = SPL$_{spoiler}$ - SPL$_{solid}$***
- Clear difference in performance depending upon location of microphones
- Far-field radiation suggests that Spoilers 3 and 4 produce the biggest reduction in SPL

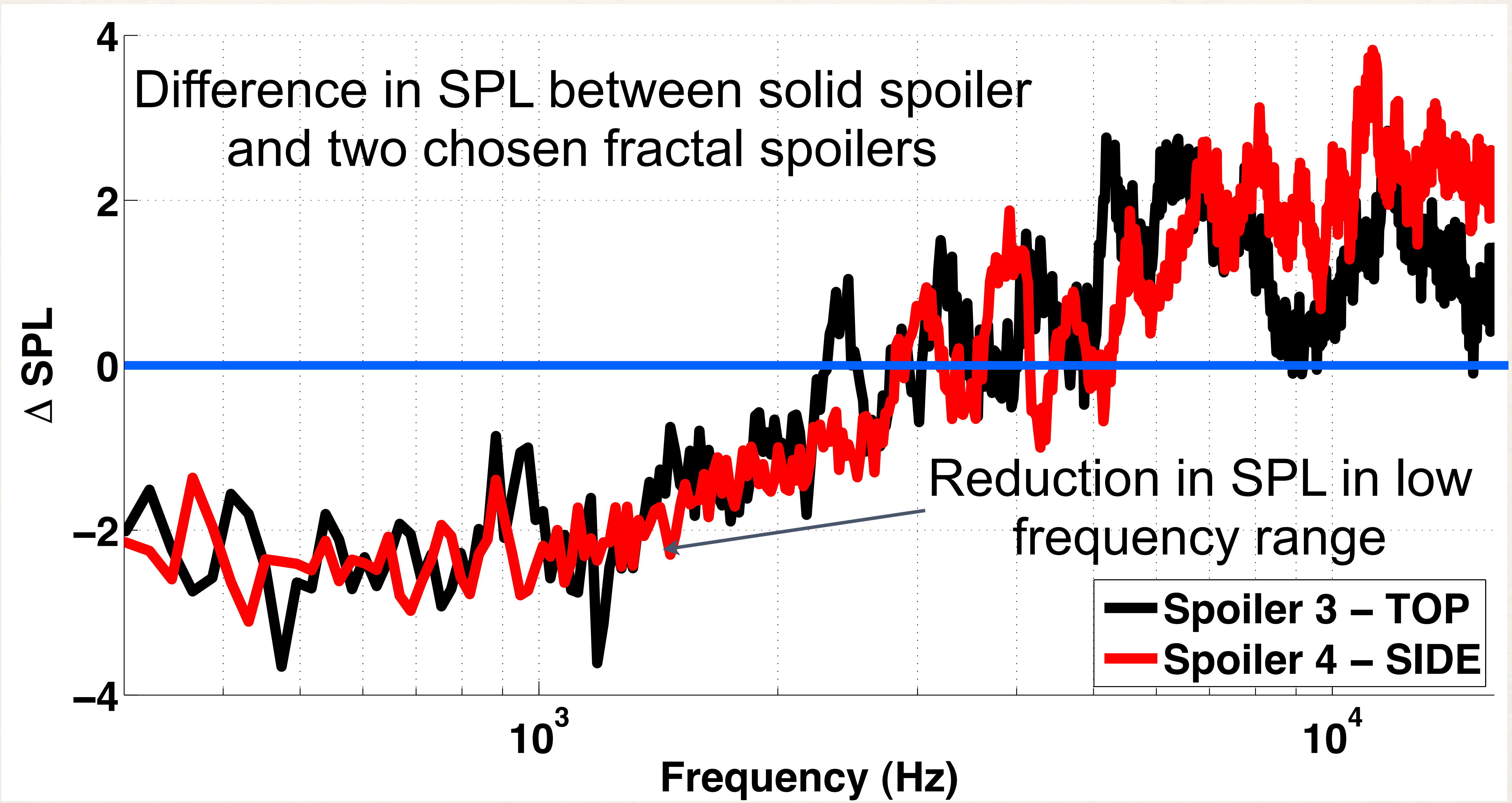
Acoustic Tests - Chosen Spoilers





- **SPOILER 3**
  - $t_r = 9$
  - Equal spacing between fractal grids
  - Blockage Ratio = 0.75
- **SPOILER 4**
  - $t_r = 9$
  - Unequal spacing, which leads to smaller side frame
  - Blockage Ratio = 0.75

Acoustic Tests - Chosen Spoilers

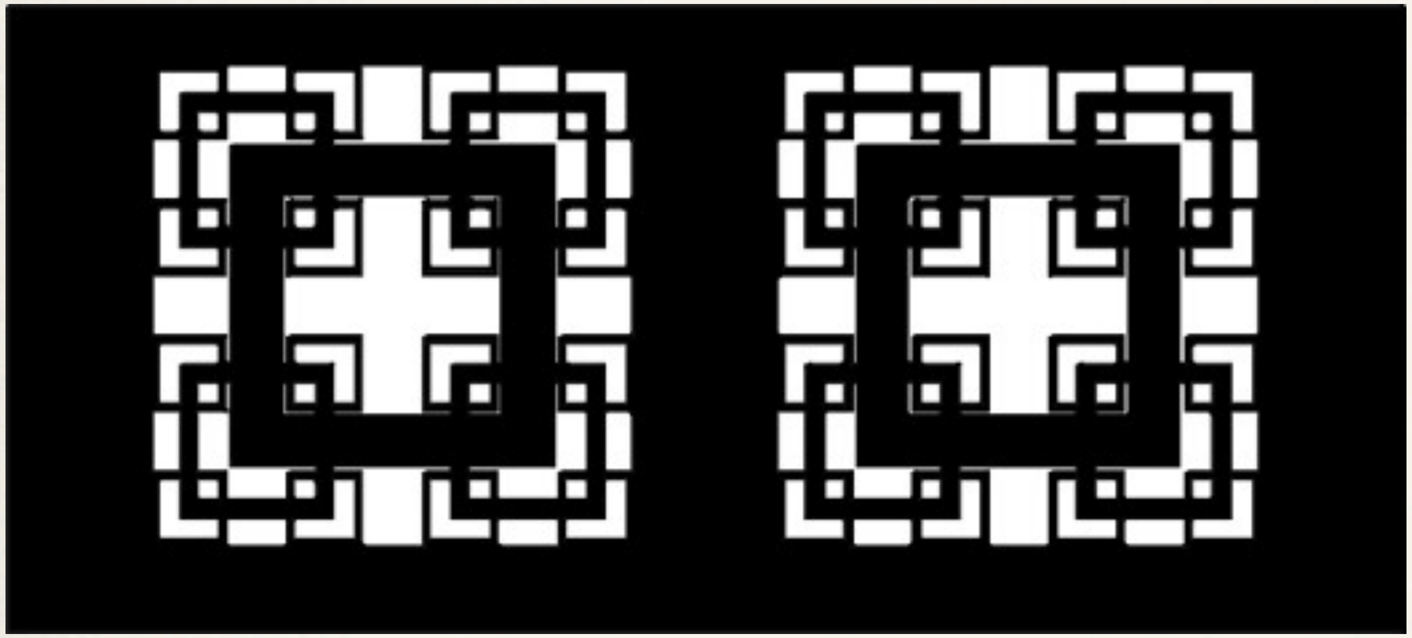


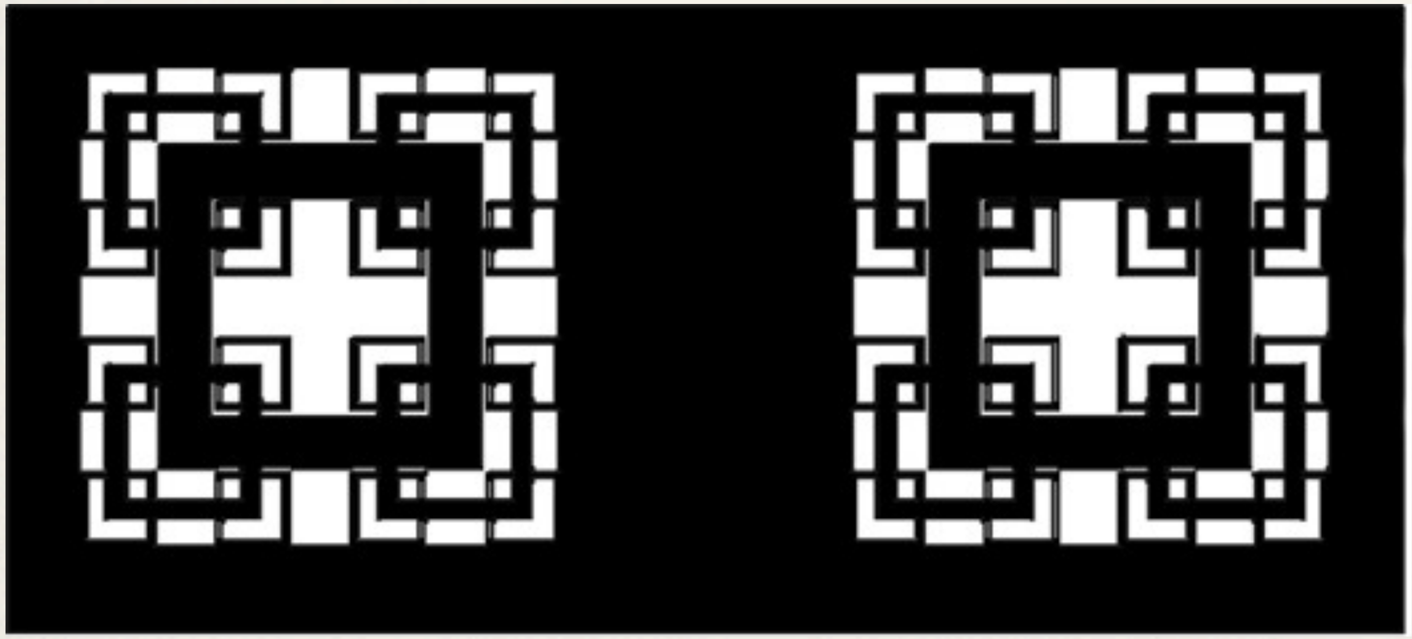
Acoustic Tests

- **What affect do increasing the thickness ratio have on the SPL?**
- Used results from top arrangement as this mimics a downstream (rear-arc) radiation.
- Compared results from Spoiler 3 and Spoiler 1
- Delta SPL = $SPL_{spoiler1}$ - $SPL_{spoiler3}$

- **What affect does decreasing the central frame have on the SPL?**
- Used results from top arrangement as this mimics a downstream (rear-arc) radiation.
- Compared results from Spoiler 3 and Spoiler 4
- Delta SPL = $SPL_{spoiler4}$ - $SPL_{spoiler3}$

Acoustic Tests - Chosen Spoilers





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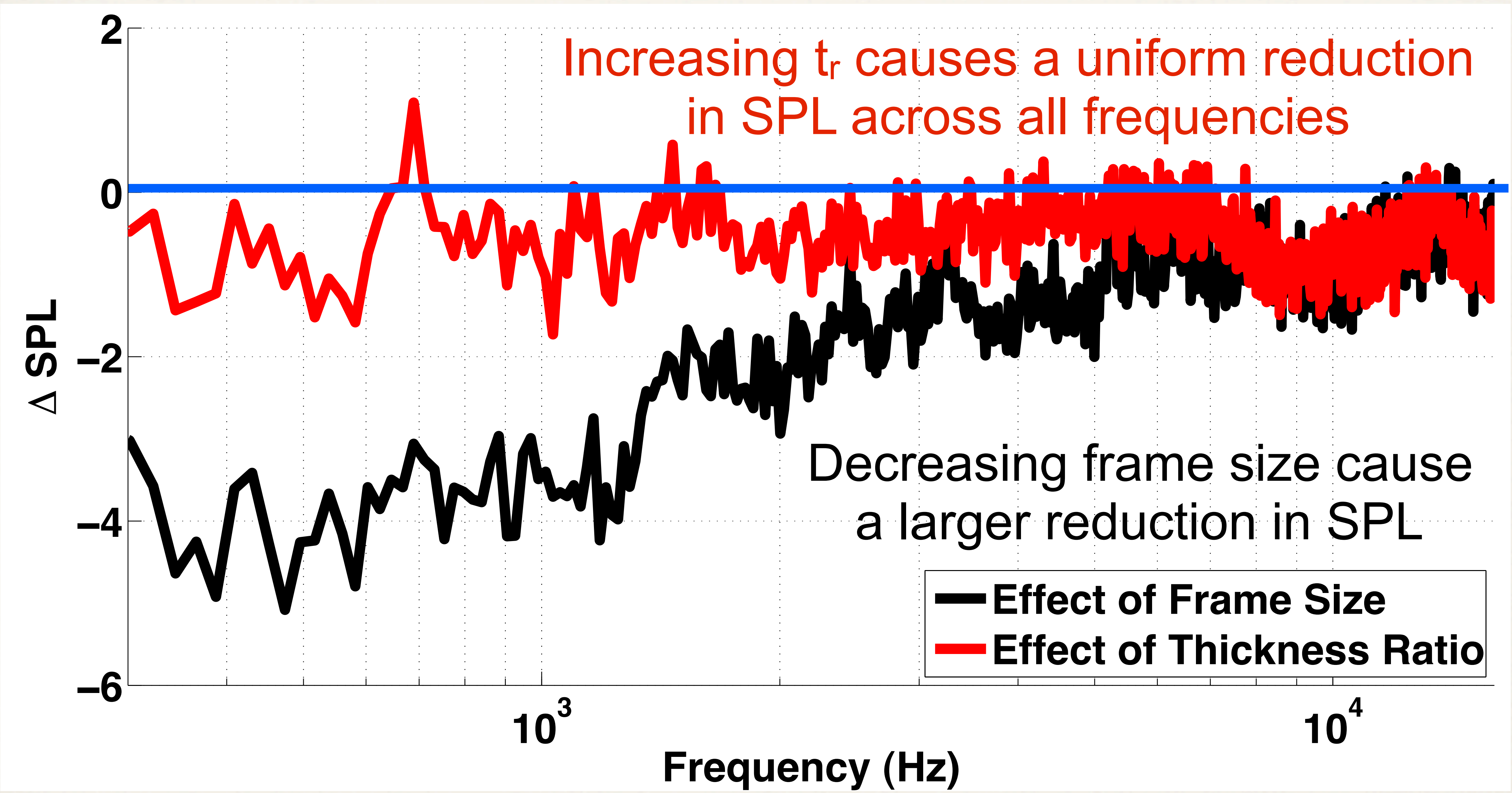
Acoustic Tests



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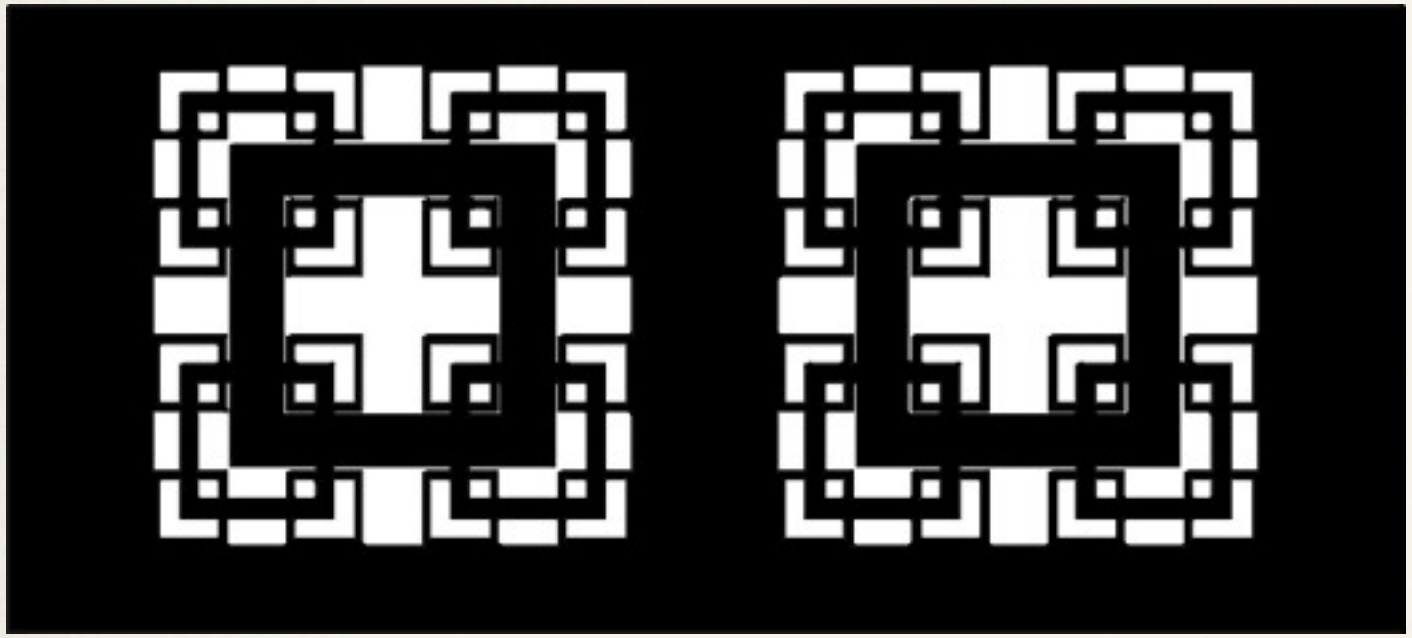

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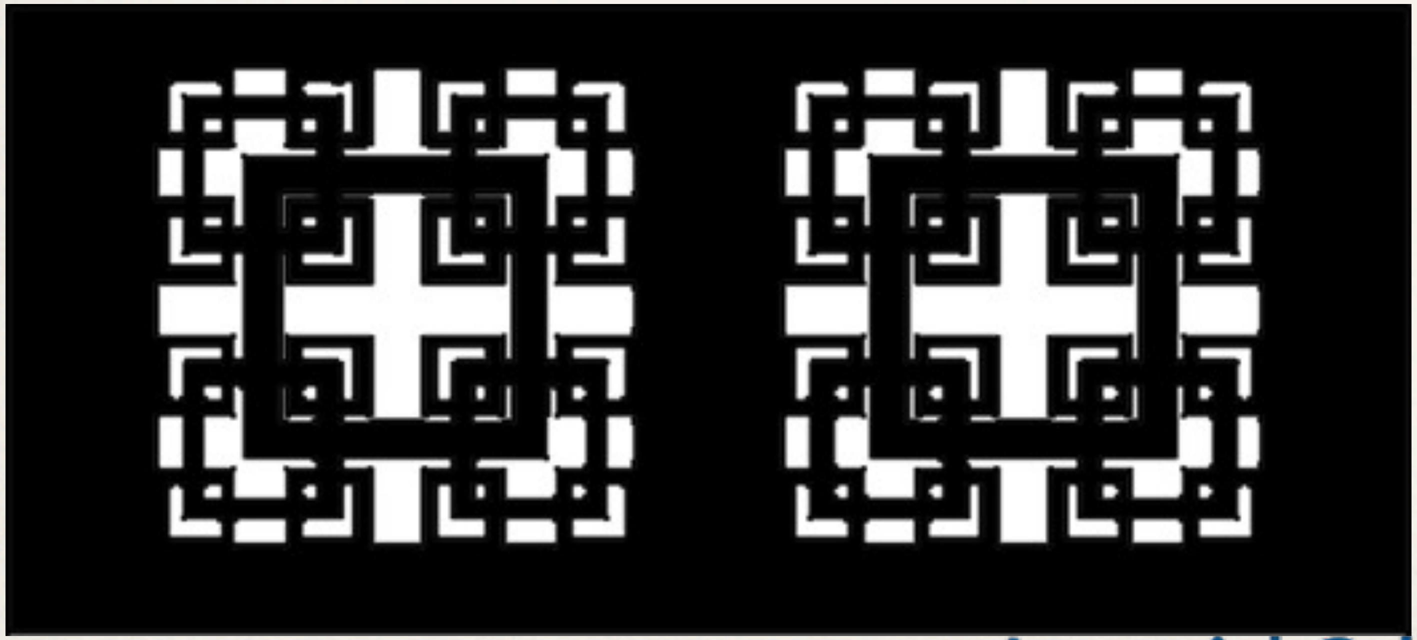
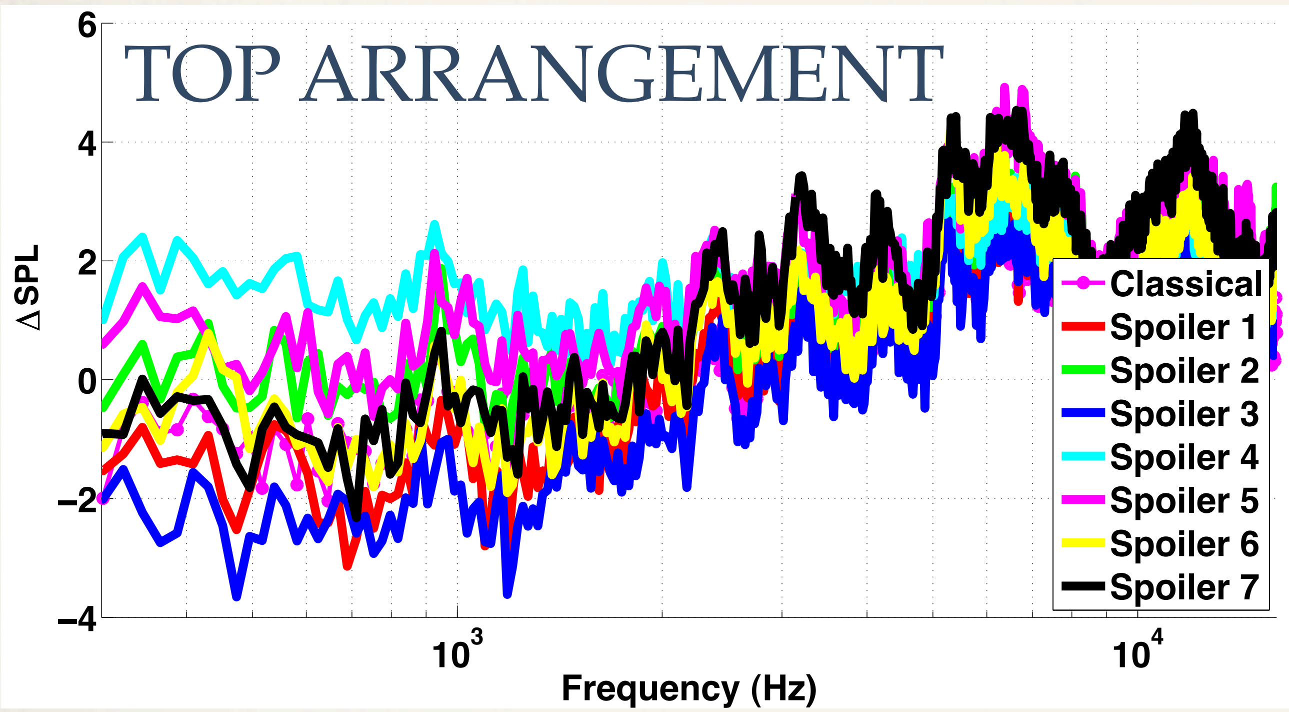


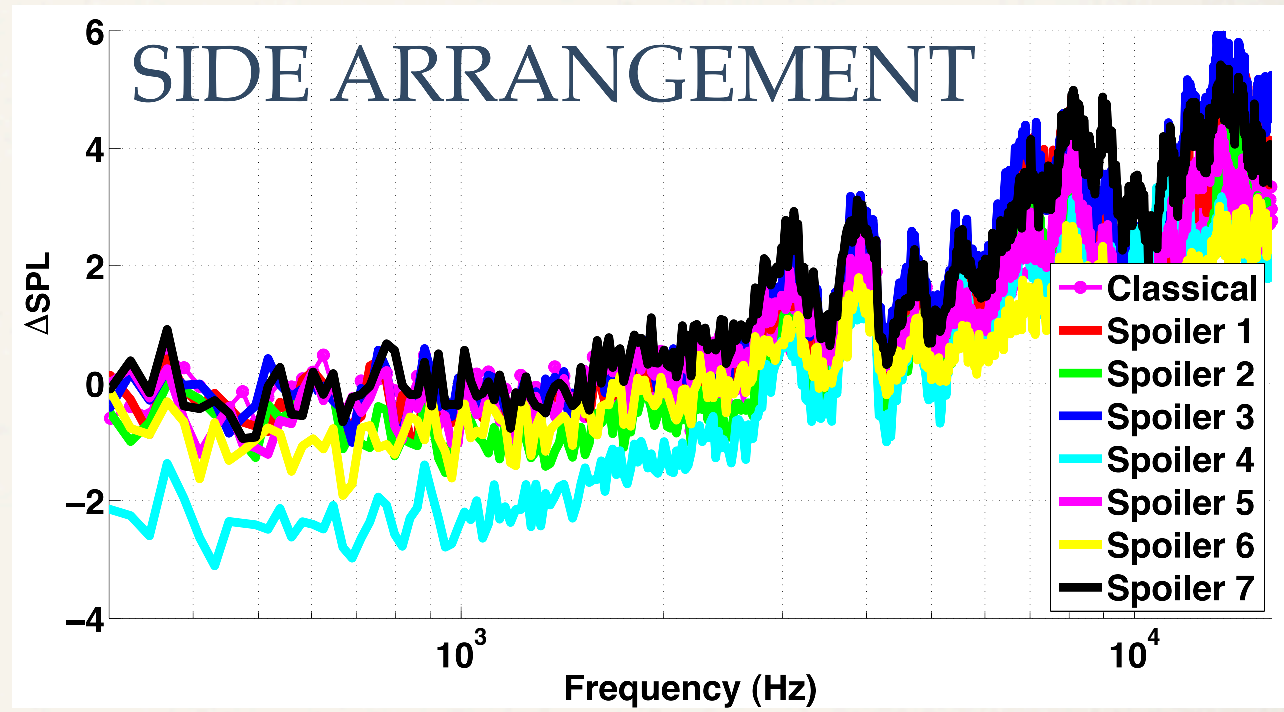
- **SPOILER 1**
- $t_r = 3$
- Blockage Ratio = 0.75

Acoustic Tests

- Results suggest that a higher thickness ratio would give a better reduction in SPL
- Location of microphones, combined with spoiler configuration suggest that a smaller frame would be beneficial in terms of SPL reduction
  - **Spoiler 3** - highest t_r, smaller central frame, larger side frame - best result for top, worse for side
  - **Spoiler 4** - highest t_r, smaller side frame, bigger central frame - worst result for top, best for side
- Ideal spoiler would have small edge frames, grids as close as possible and highest possible t_r
  - This is why spoiler 7 was designed
  - However, blockage had to be reduced to 60% to have t_r = 11

Acoustic Tests





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- Clear difference in performance depending upon location of microphones
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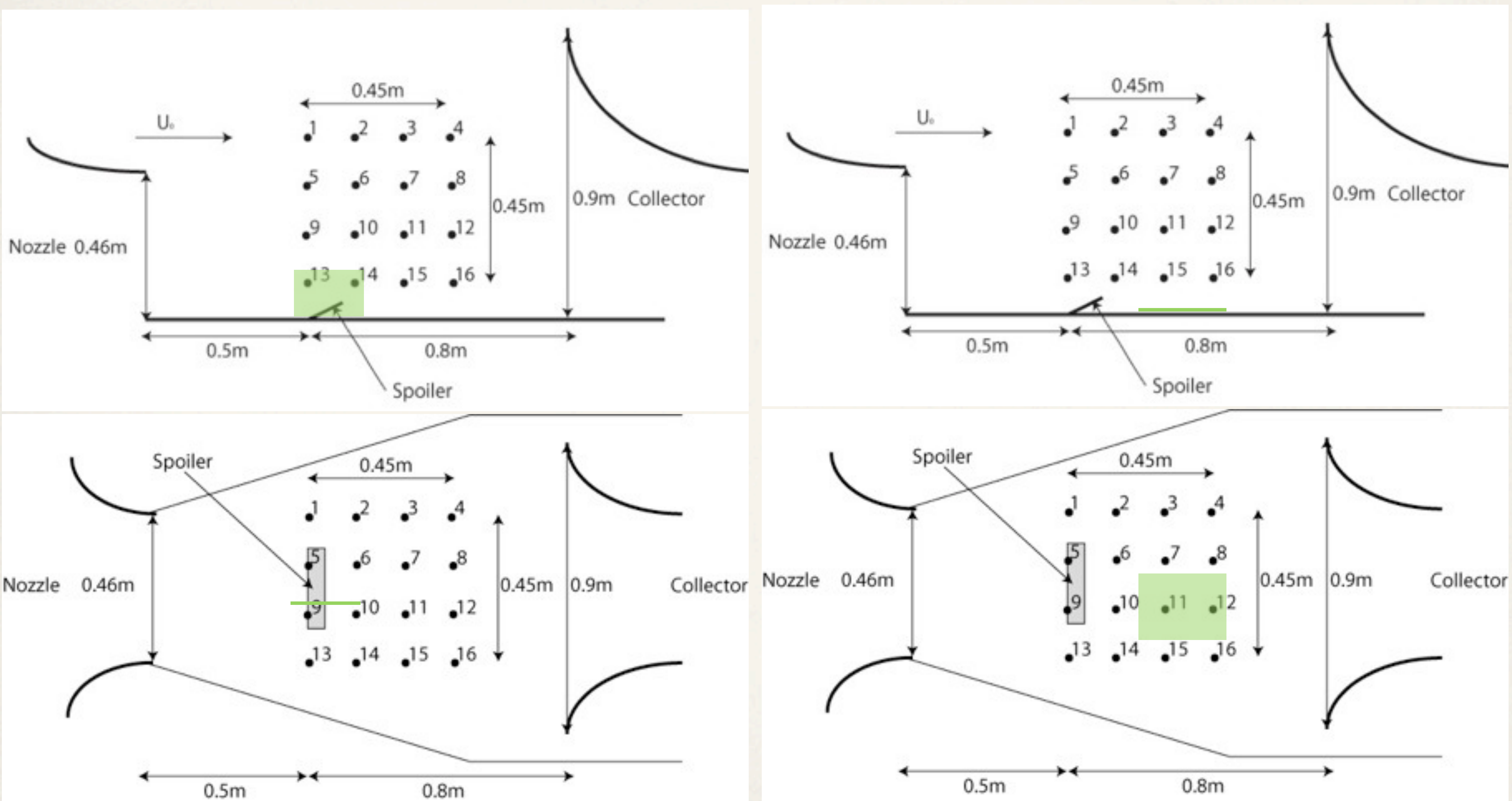
Acoustic Tests

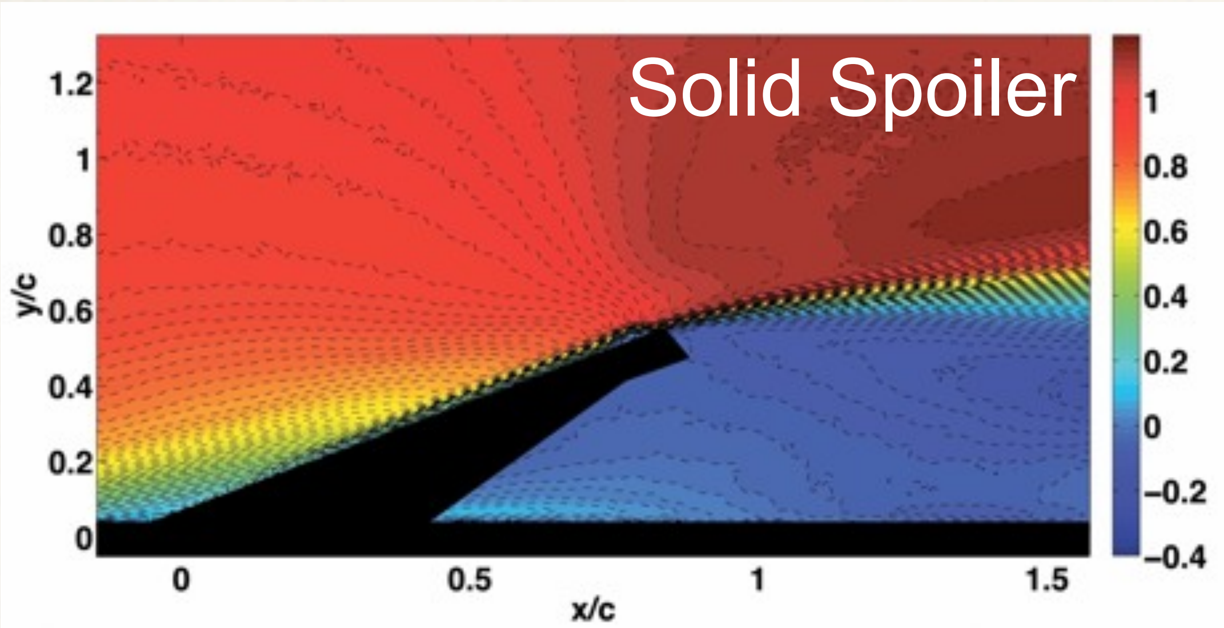
- Spoiler 7, however, doesn't produce the desired results
- In theory, this should remove the bubble entirely
- Clearly there is an optimum design between the two blockages (60-75%)
- It is believed that one should not think in terms of blockage ratios, but should instead ask how intense should the bleed air be to remove the bubble?
- Spoiler 7 would introduce very intense bleed air, with a lot of fluctuating momentum, that impacts the flat plate:
  - **THIS WILL GIVE OFF ITS OWN LOW FREQUENCY NOISE SIGNATURE**

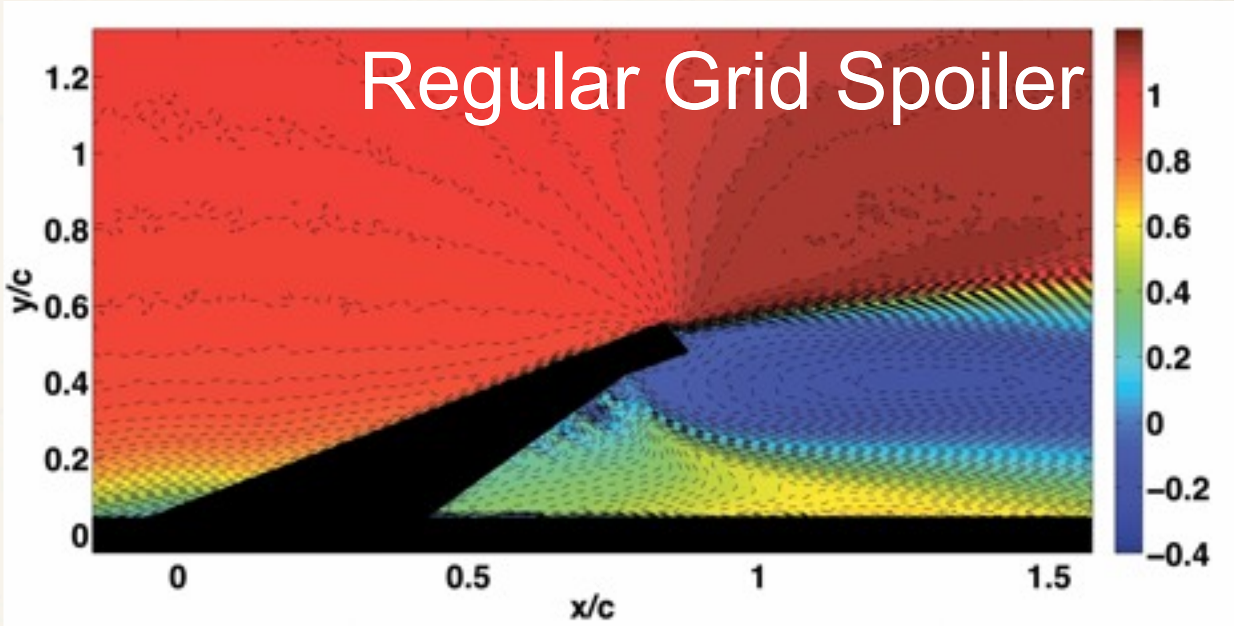
PIV Planes

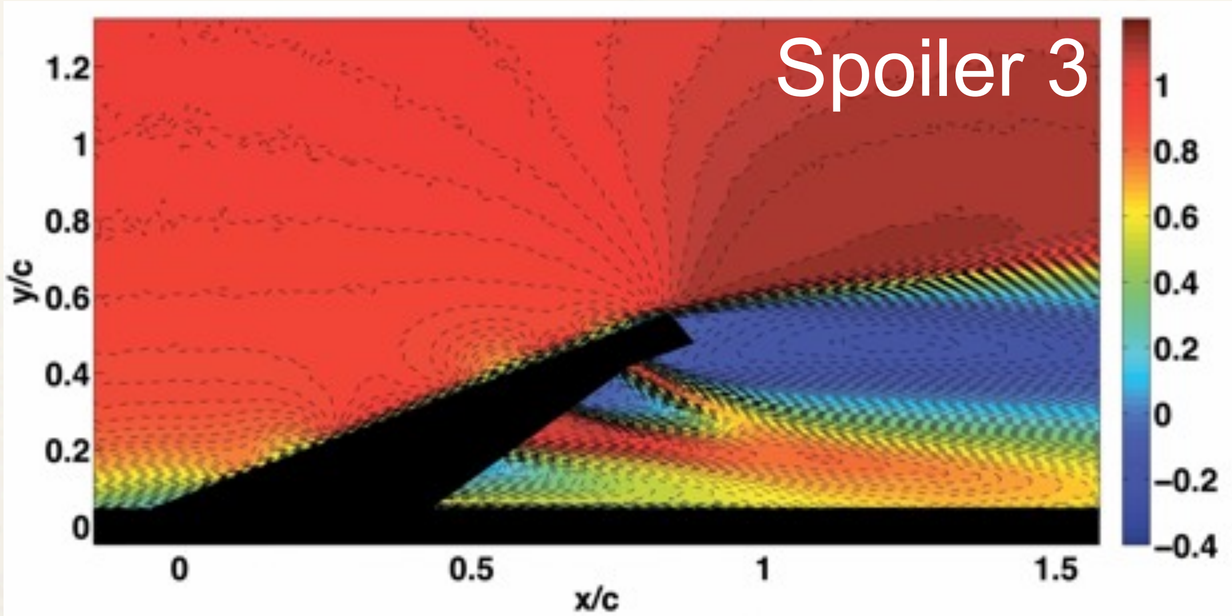


0.45m
U₀
1 2 3 4
5 6 7 8
9 10 11 12
13 14 15 16
0.45m
0.9m Collector
Nozzle 0.46m
0.5m
0.8m
Spoiler

XY PIV Results Mean Flow



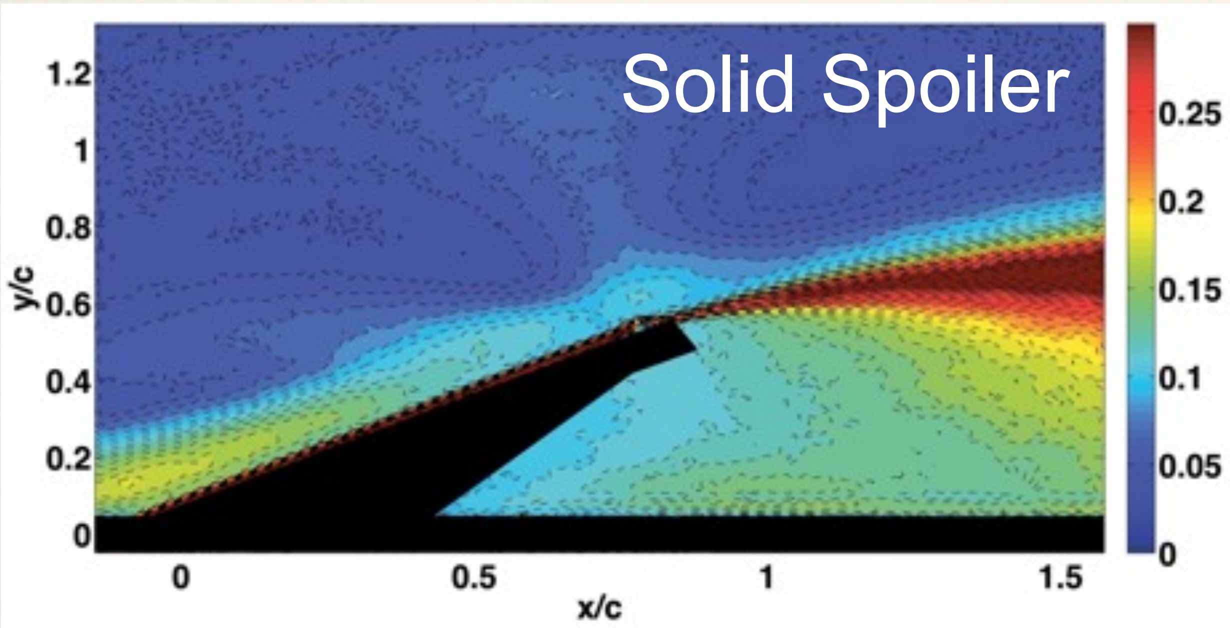


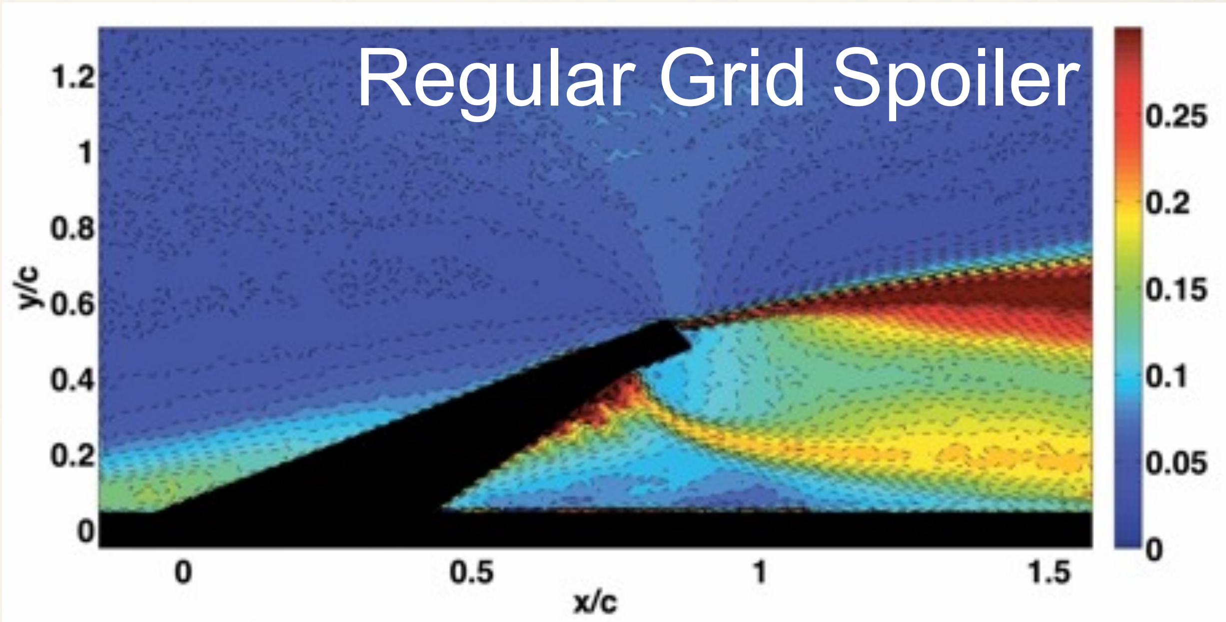


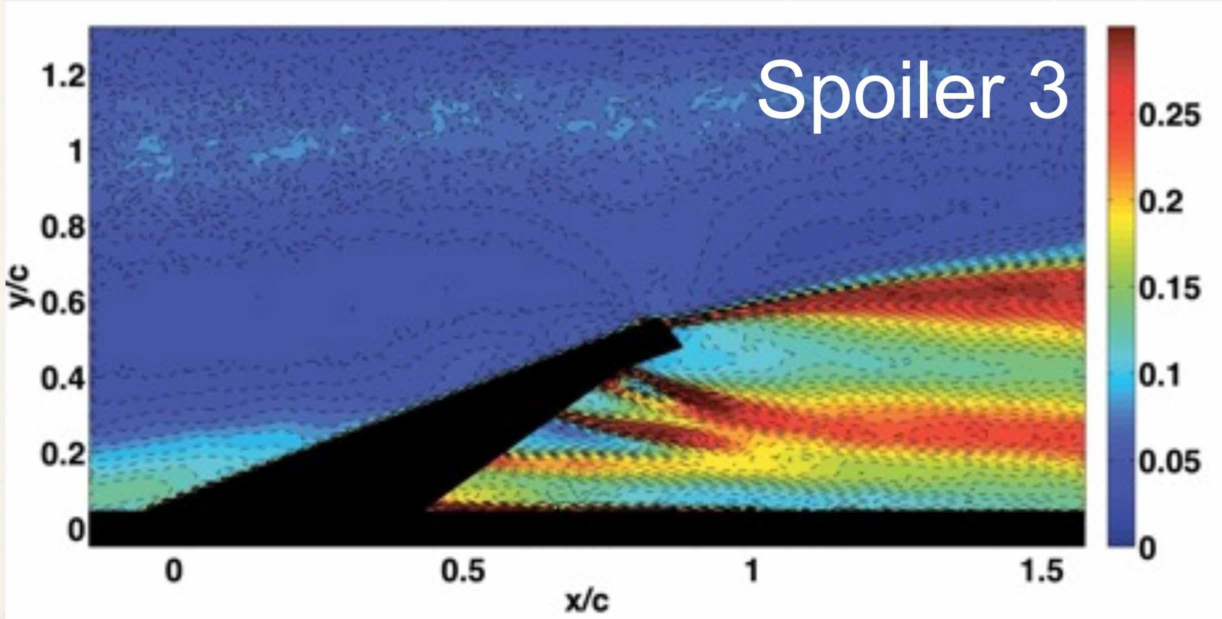
- Normalised U Mean Velocity (U/U_0)

- Black Shading indicates area where laser sheet created a shadow

XY PIV Results Turbulence Intensity



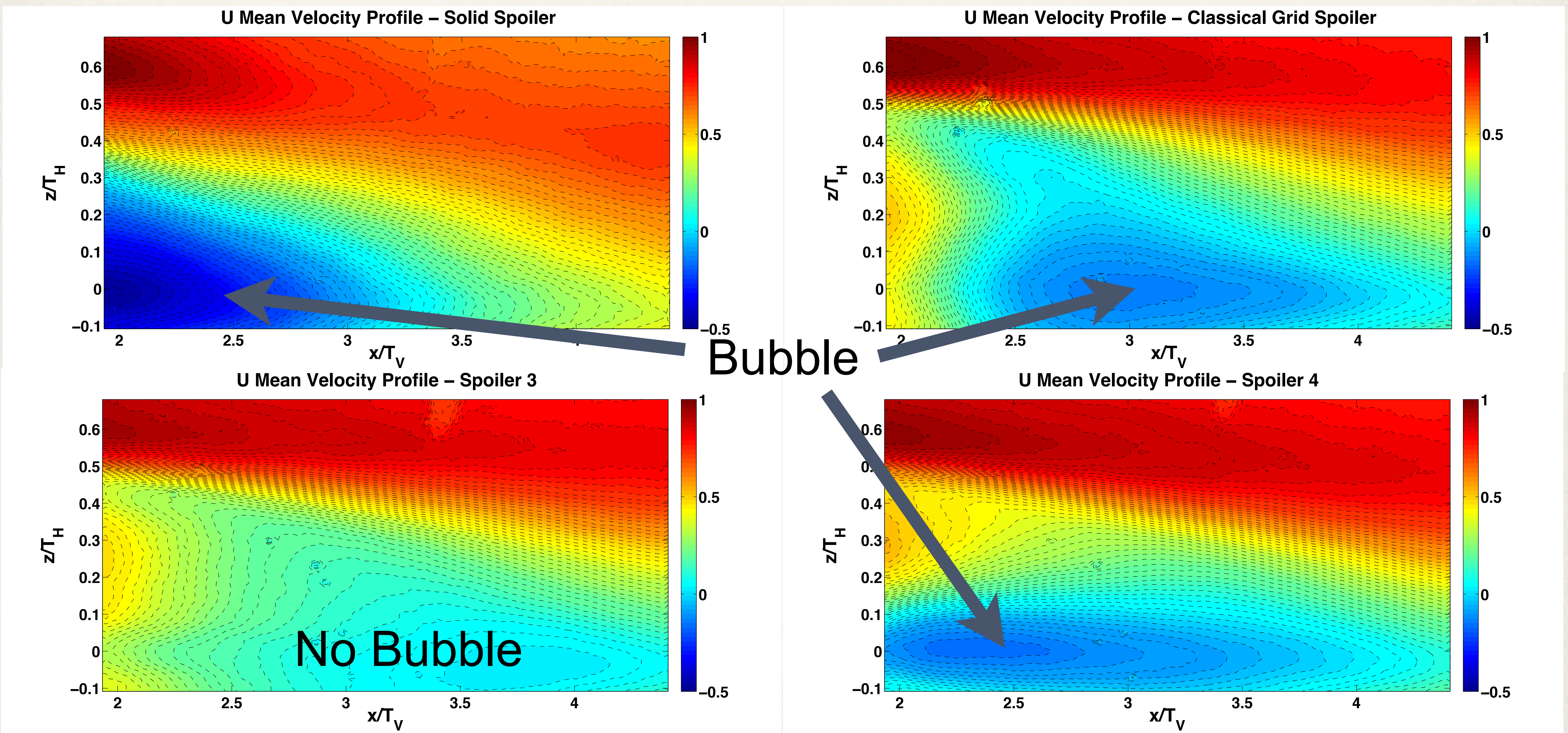




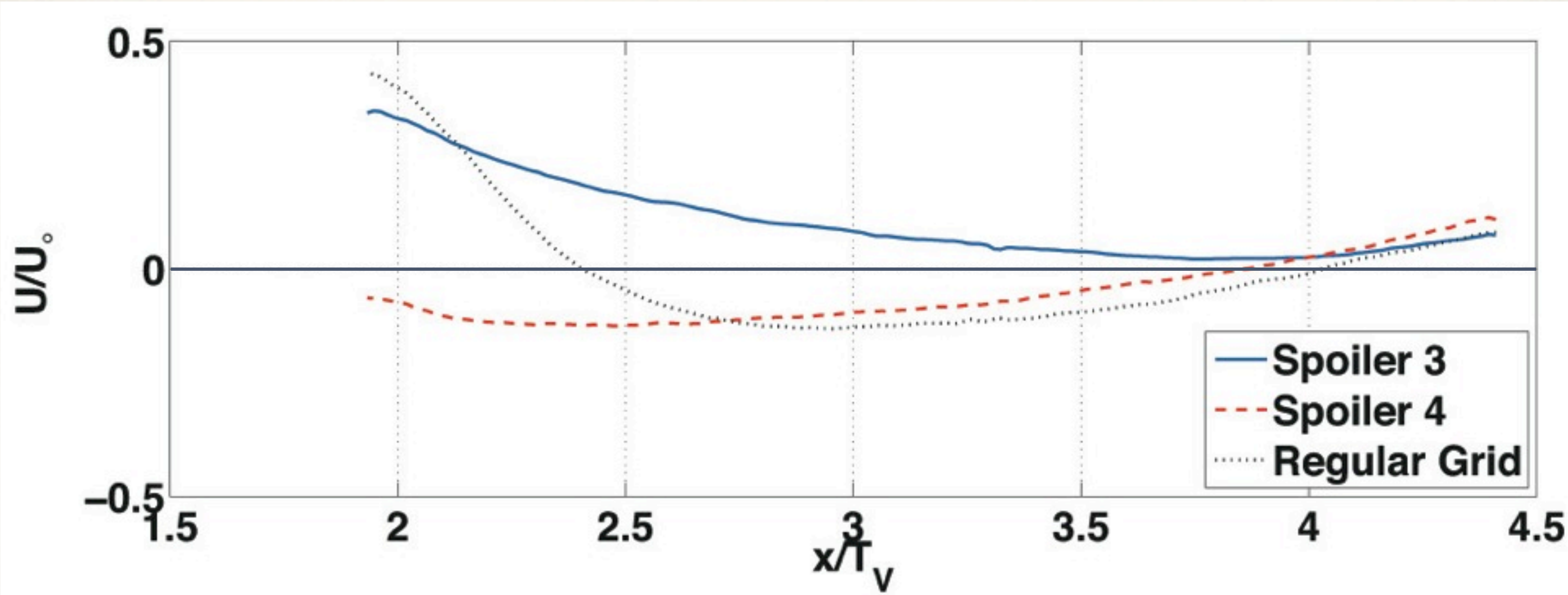
- Turbulence Intensity (u_{rms}/U_0)

- Black Shading indicates area where laser sheet created a shadow

XZ PIV Results
Mean Flow

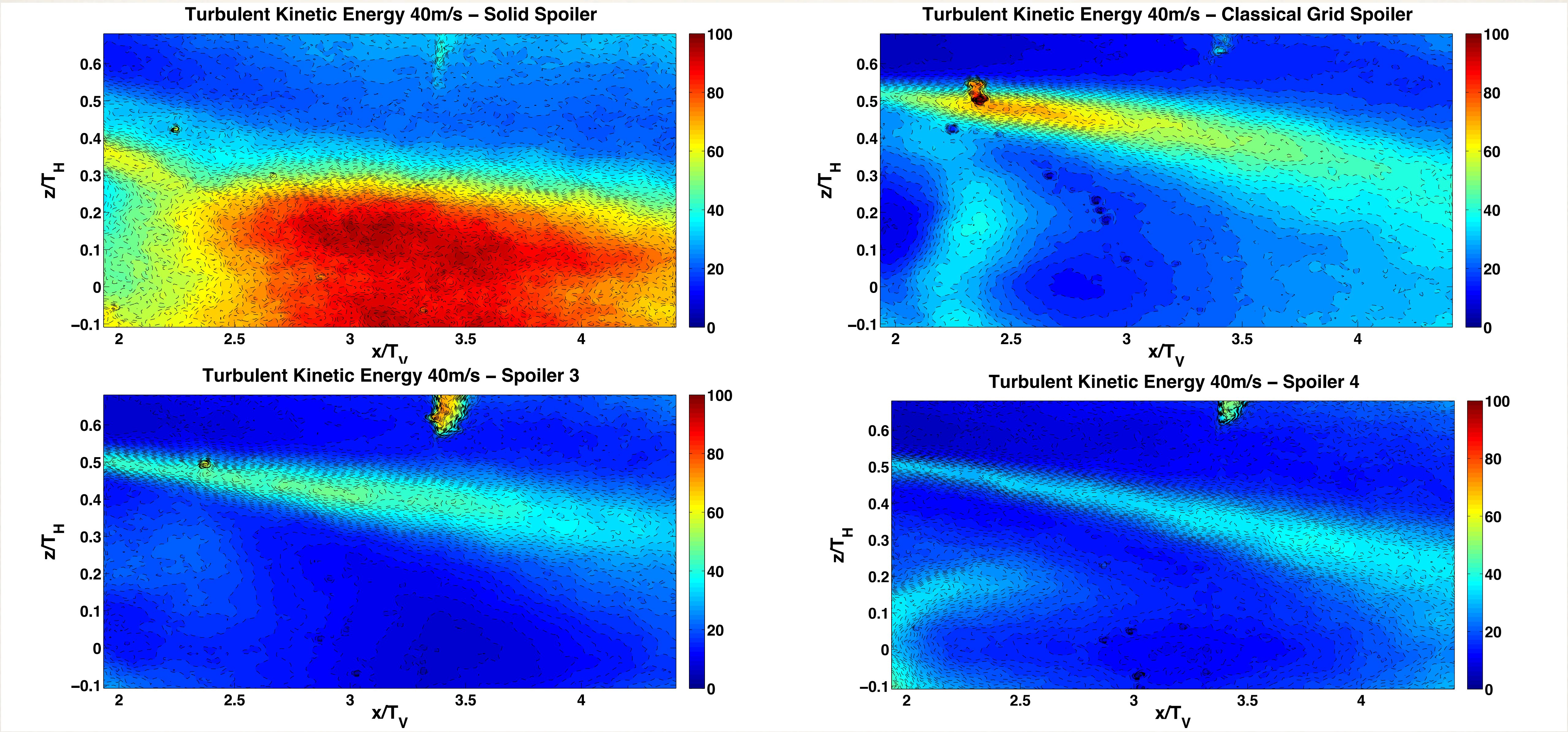


XZ PIV Results
Mean Flow



- No re-circulating flow seen for Spoiler 3 along the centre line
- Bubble seen for both Spoiler 4 and Regular Grid Spoiler

XZ PIV Results
Turbulent Kinetic Energy

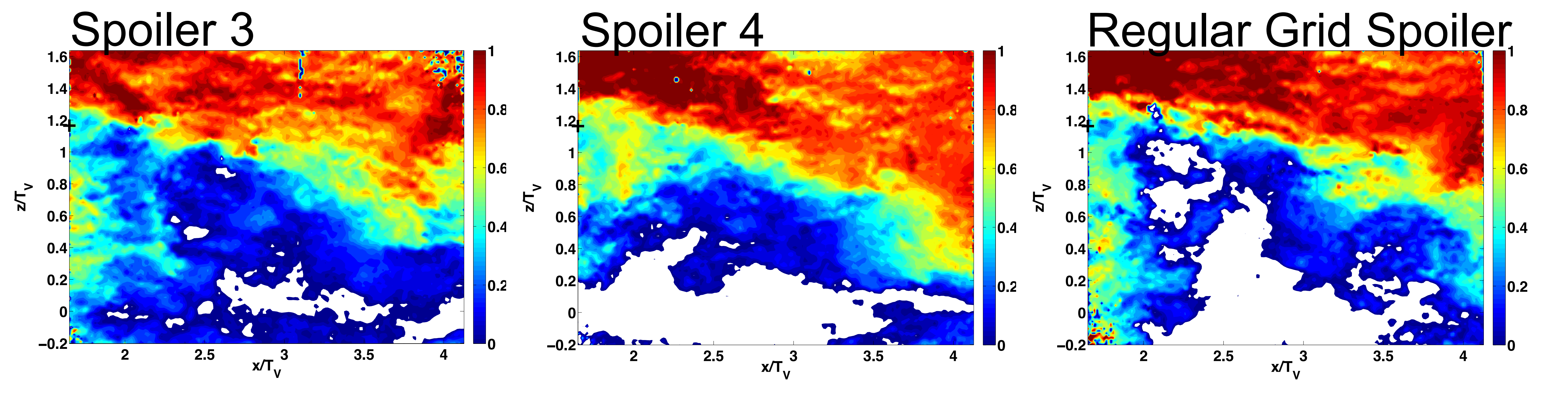


- $TKE = 0.5(u_{rms}^2 + w_{rms}^2)$

PIV Results

- **Recirculation Region moved further downstream when porosity is added**
- **NO recirculation region seen for Spoiler 3**
- **Turbulence intensity highest for Fractal Spoilers**
- **Turbulence kinetic energy is lower in the shear layer for Spoiler 4 than Spoiler 3**
- **This is true for mean values only, instantaneous data will show a different picture**

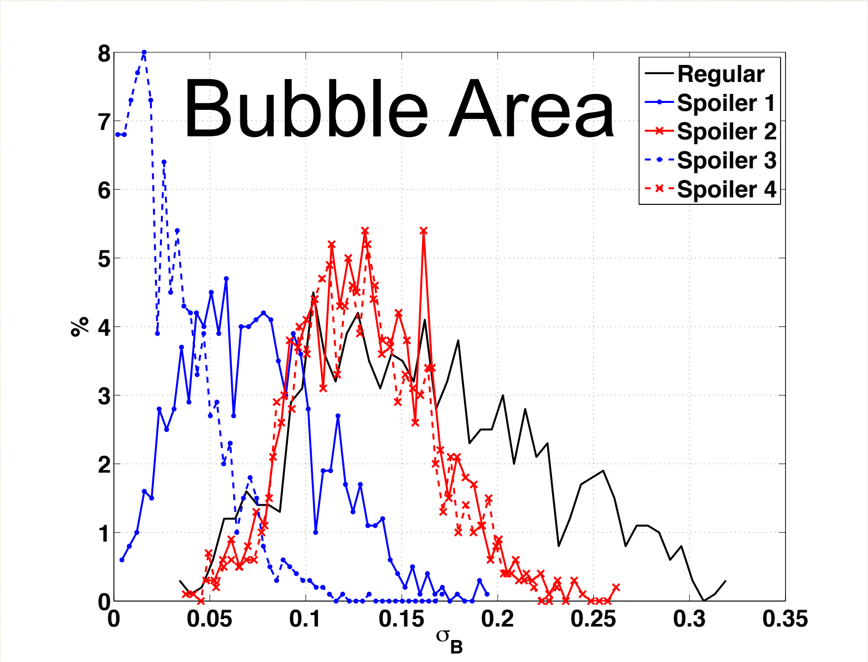
XZ PIV Results Instantaneous Flow

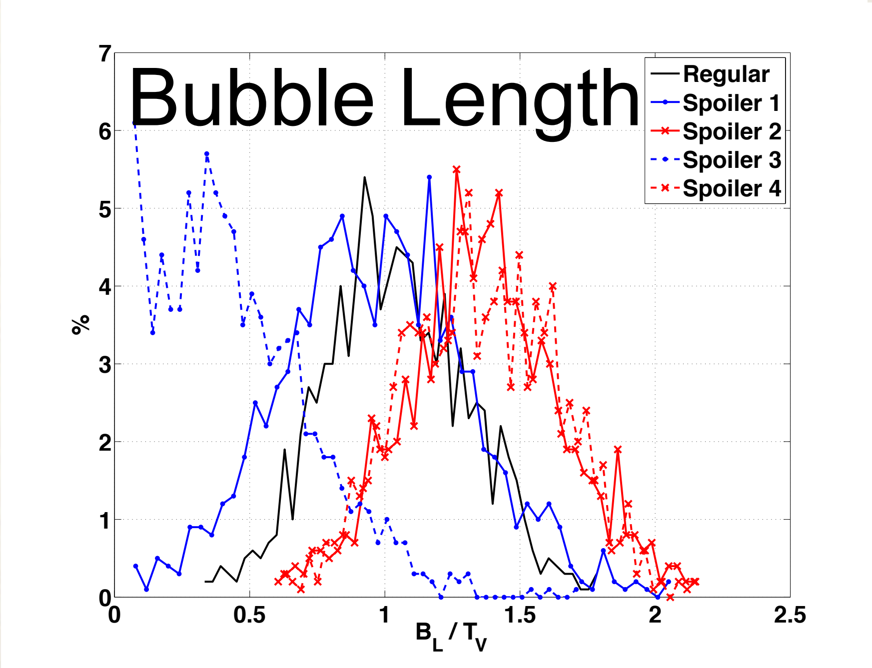


- Limit set to $0 \leq \frac{u}{U_\infty} \leq 1$ meaning white regions indicate recirculating flow
- All three spoilers show that at some point, there is a bubble present, but the size differs greatly between the three
- From an acoustic point of view, it would be interesting to see how these regions fluctuate

PDF of Bubble Characteristics

- **Two parameters are important, the area of the bubble and the length**
- **The first PDF shows the variation of normalised bubble area**
  - Modal area of Spoilers 2, 4 and Regular Grid spoiler are similar
  - Spoiler 3 shows that the bubble fluctuates between existing and not existing
- **Second PDF is of mean bubble length, taken from the centre-line outwards**
  - Again no real difference between Spoilers 2 and 4
  - Modal mean length of regular grid spoiler is lower, hence its bubble must be wider
  - Spoiler 3 has very small length, so when the bubble does exist, it is very small and thin





PIV Results

- The PIV data has shown that the bubble does exist for all the spoilers
- However, when the bubble does exist for Spoiler 3, it is small and the effect it would have on the SPL is less than the other spoilers
- As for the sound radiating to the side, it appears that a bubble might be preferential in order to stop the side shear layer fluctuating. More research would have to be carried out on this to understand it further

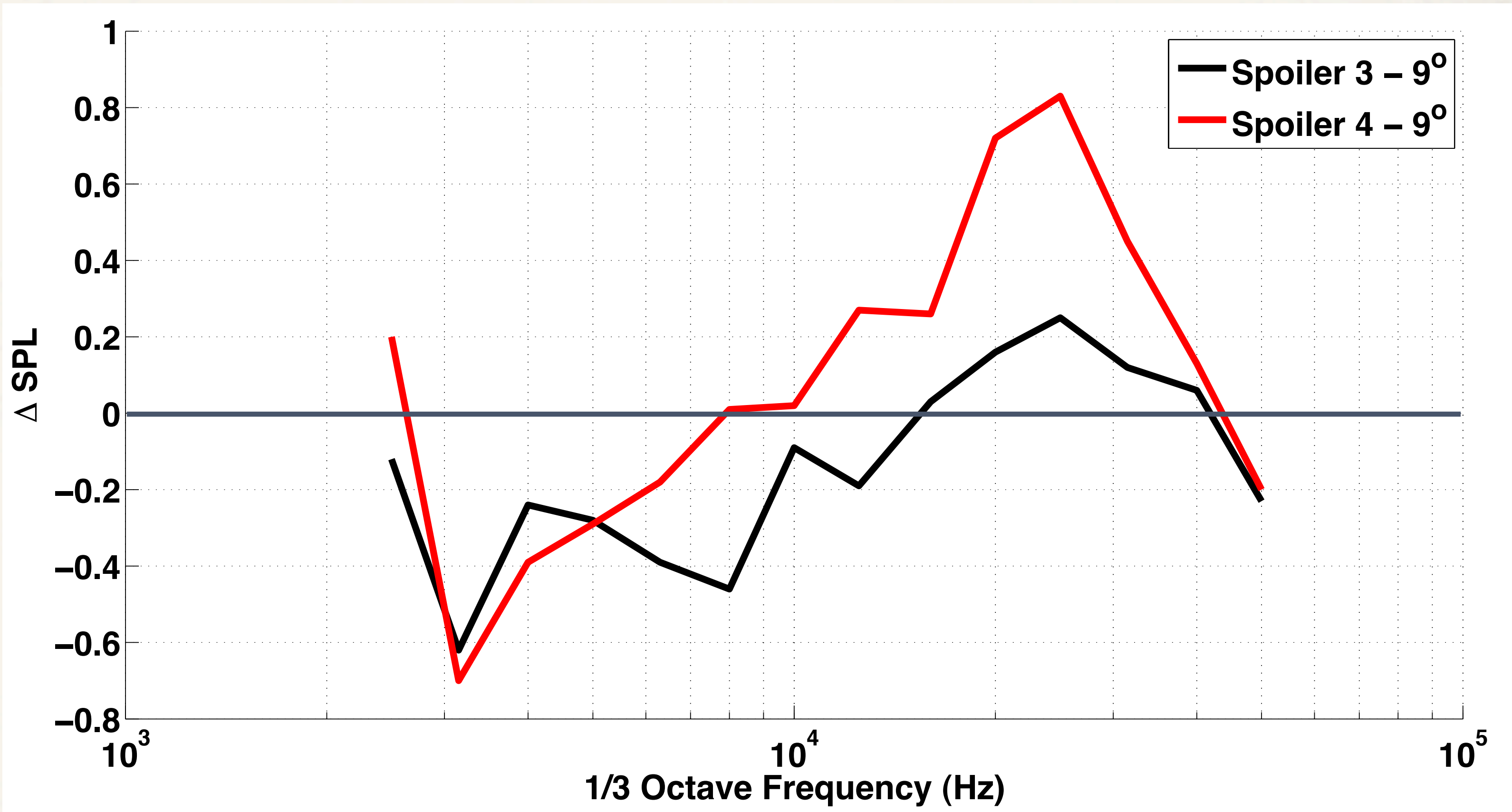
Conclusion from Preliminary Tests

- A reduction of roughly 2.5dB is observed
- Two spoilers were selected for tests at DLR: Spoilers 3 and 4, which have the same blockage and thickness ratio, but different frame sizes
- Small changes to the design of the spoiler, such as the thickness ratio, create a noticeable change in the acoustic performance
- Results also suggest that at 30^{o}, the fractal spoilers have an increased drag whilst creating a small change in the lift
- **NB This is true for the flat plate only not for a wing section**

Combined Aero-Acoustic Study

Combined Aero-Acoustic Study

- Acoustic performance based on difference in SPL compared to solid spoiler
- Third-octave spectra is used
- A smaller reduction in SPL observed compared to flat plate experiments: ~0.5dB
- Spoiler 3 performed better than Spoiler 4
- Coincides with flat plate experiments for ‘top’ microphone arrangement
- Same seen for other angles of attack



$$\phi = 90^\circ$$
$$U_\infty = 60ms^{-1}$$
$$\alpha = 9^\circ$$

Combined Aero-Acoustic Study

- The ideal replacement spoiler would have lift and drag forces **<u>similar</u>** to that of the solid spoiler.
- With the fractal spoilers integrated onto the wing system, there is <u>negligible</u> change to the lift and drag forces

Spoiler	P_L(%)	P_D(%)	C_L	C_D
Solid	714.74N	212.94N	1.04	0.31
3	0.03	-4.70	1.04	0.30
4	-0.53	-5.27	1.04	0.30

$U_\infty = 60ms^{-1}$
$\alpha = 9^\circ$

Conclusions

- Clearly there is a difference in how a spoiler behaves on a flat plate compared to the wing section
- Scale of spoiler gave limitations to fractal design, both machining and mathematical
- Despite this, both sets of experiments showed that fractals can be used to reduce the noise generated by spoilers
- It is believed that by scaling up the spoilers, there would be more freedom in terms of design and the capability of producing a wider range of bleed flows, which, it is believed, would reduce the noise further whilst not affecting the aerodynamics

Conclusion

- This is only an initial study, a **proof of concept**, where we looked at the possibility of using fractal grids
- The current design is by no means the final design
- More experiments would have to be carried out to get a better understanding of the flow properties behind the spoiler and how the various parameters change the acoustic performance, as well as the lift and drag characterisitcs

Acknowledgements

- **The authors are grateful to:**
- Werner Dobrzynski and Michael Pott-Polenske from the DLR Institut at Braunschweig for their input and use of AWB for the combined aero-acoustic study of the spoilers.
- Also to Jean-Paul Bonnet for bringing the Imperial and Poitiers team together on this project
- The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under OPENAIR, grant agreement number 234313.