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Secondary noise sources in a vortical flow interacting with an undulated aerofoil

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Background & Introduction

Primary Source (S1)

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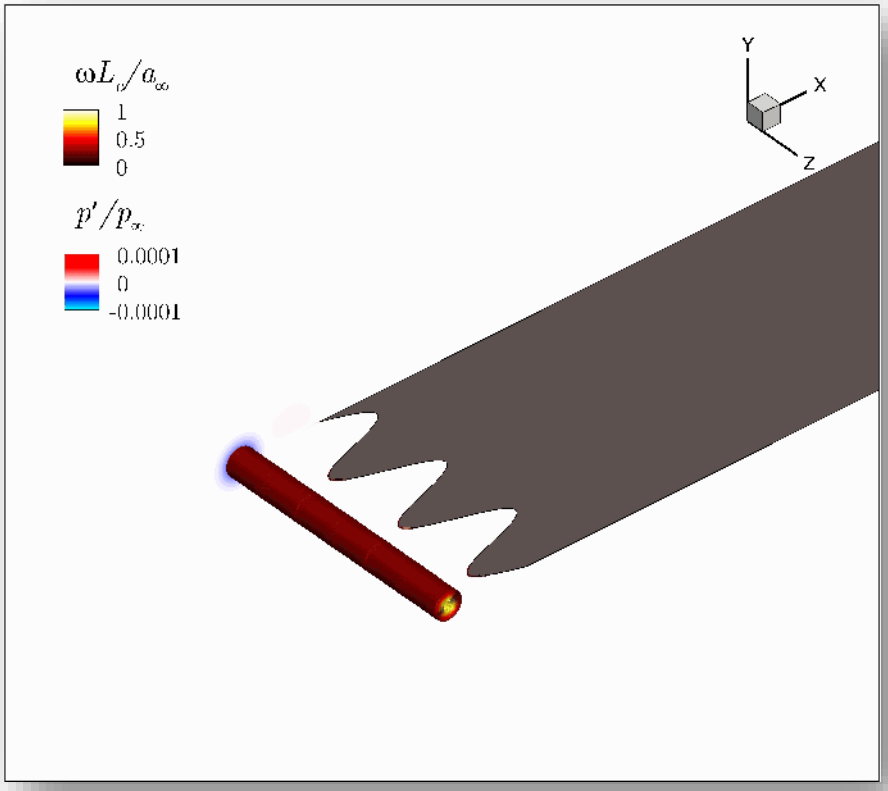
- LE vortical scattering (LEVS)
  - LEVS sound can be obtained by using an semi-infinite aerofoil.



Secondary Source (S2-TEVS)

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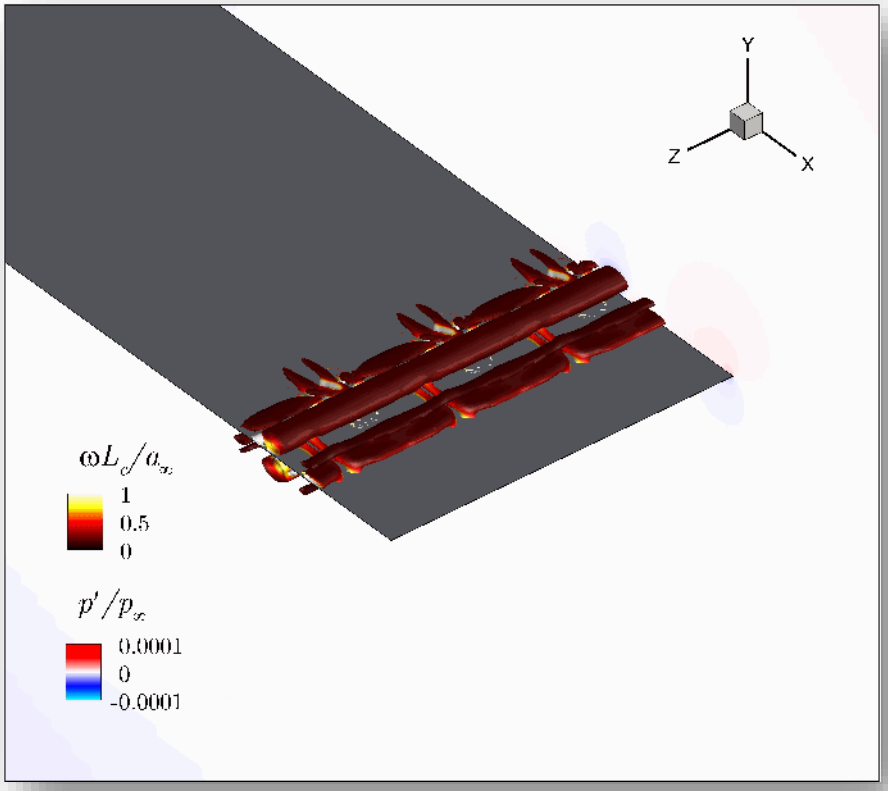
- Trailing-edge vortical scattering (TEVS)
  - The vortex has been bisected and distorted at LE before reaching TE.



Secondary Source (S2-ABS)

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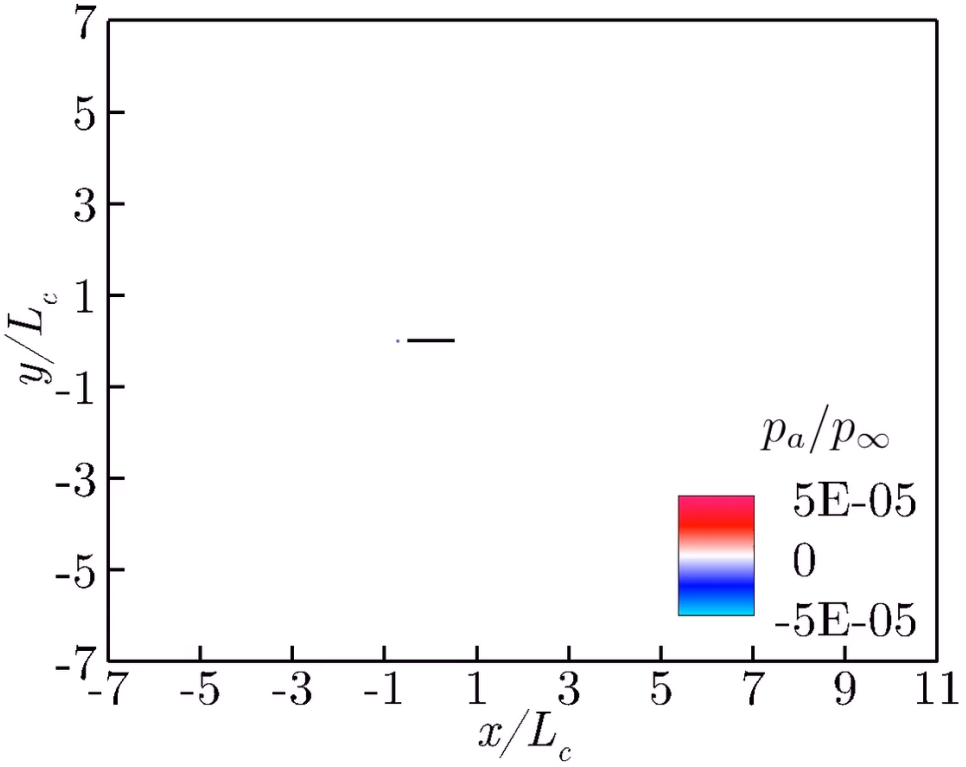
- Acoustic back-scattering (ABS)
  - Subsequent scattering and reflection of sound waves having been generated by the vortex at LE or TE.



Why on Secondary Sources?

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- Not much known, particularly, about the contribution of TEVS (and its ABS).
  - Even for SLE cases, let alone the WLE.
  - Amiet's theory (1975) covers LEVS and its ABS only.
- New results exhibit significant effects at high frequencies where the WLE geometry works.
- What implications do the secondary sources have in terms of the noise reduction by using WLE?

Results

The Presence of TE

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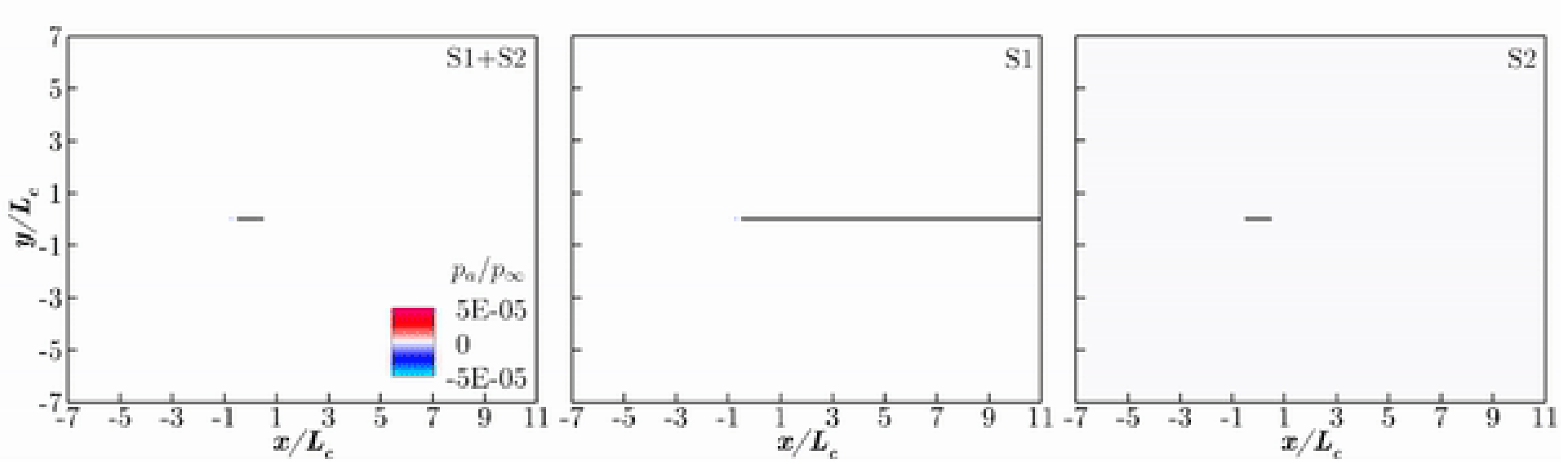
- S1+S2 = All sources combined (i.e. finite chord)
- S1 = Primary source = LEVS (i.e. semi-infinite chord)
- S2 = Secondary sources = TEVS + ABS



S2 Effects on Sound PSDs

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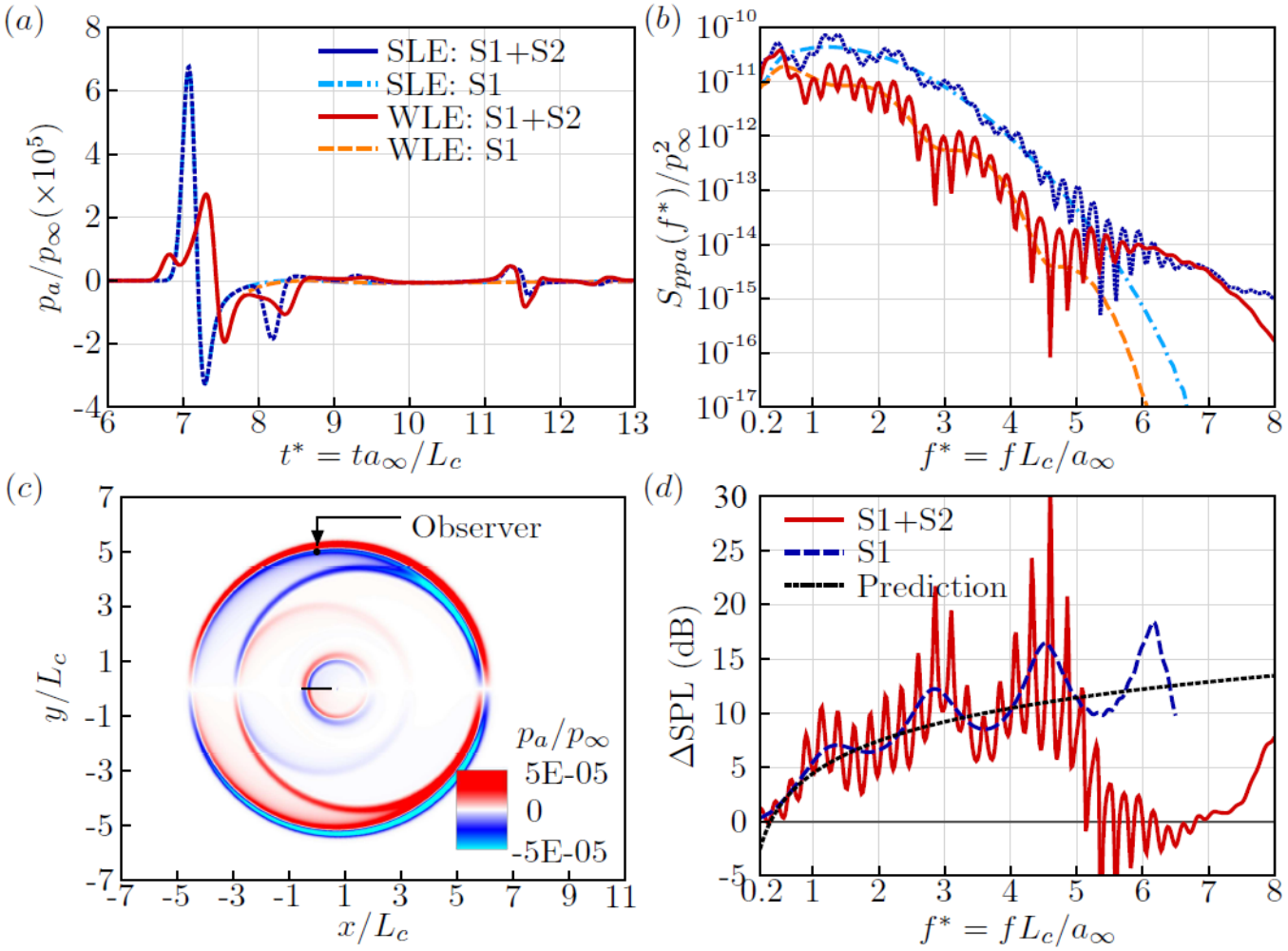
- Significant changes in the high-frequency range



Extracting S2 Solution

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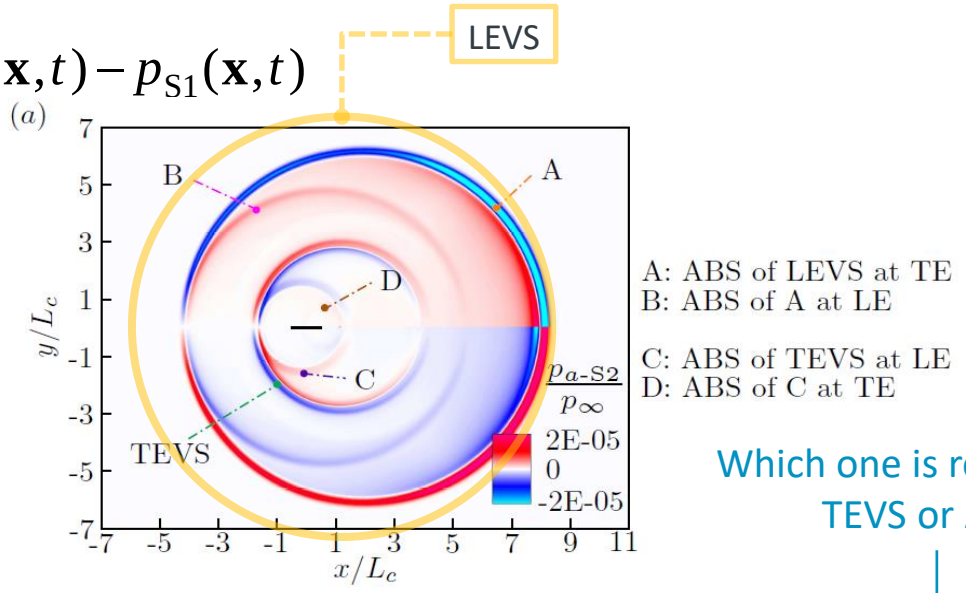
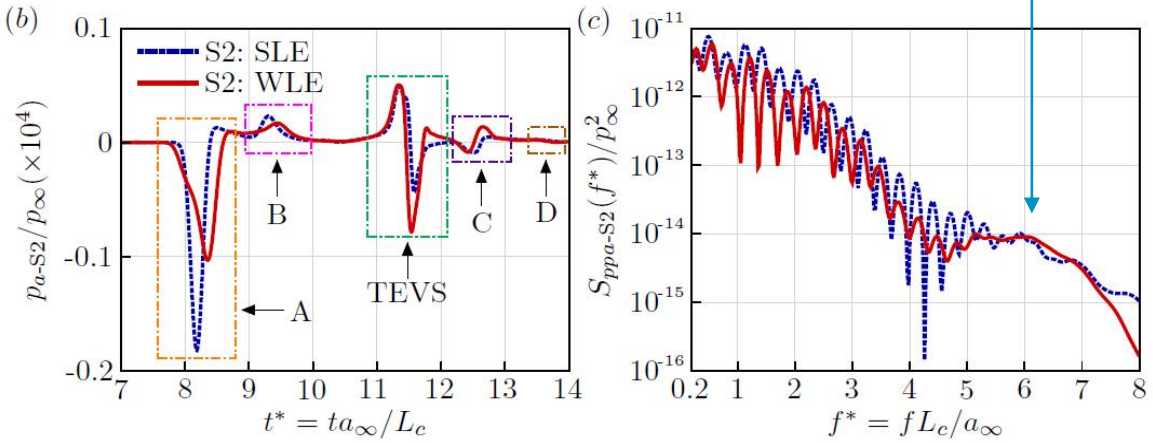
- Subtracting the SIC solution from the FC solution:

$$p_{S2}(\mathbf{x},t) = p(\mathbf{x},t) - p_{S1}(\mathbf{x},t)$$

$$\begin{cases} p(\mathbf{x},t) \\ p_{S1}(\mathbf{x},t \end{cases}$$



Which one is responsible, TEVS or ABS?



Extracting TEVS Solution

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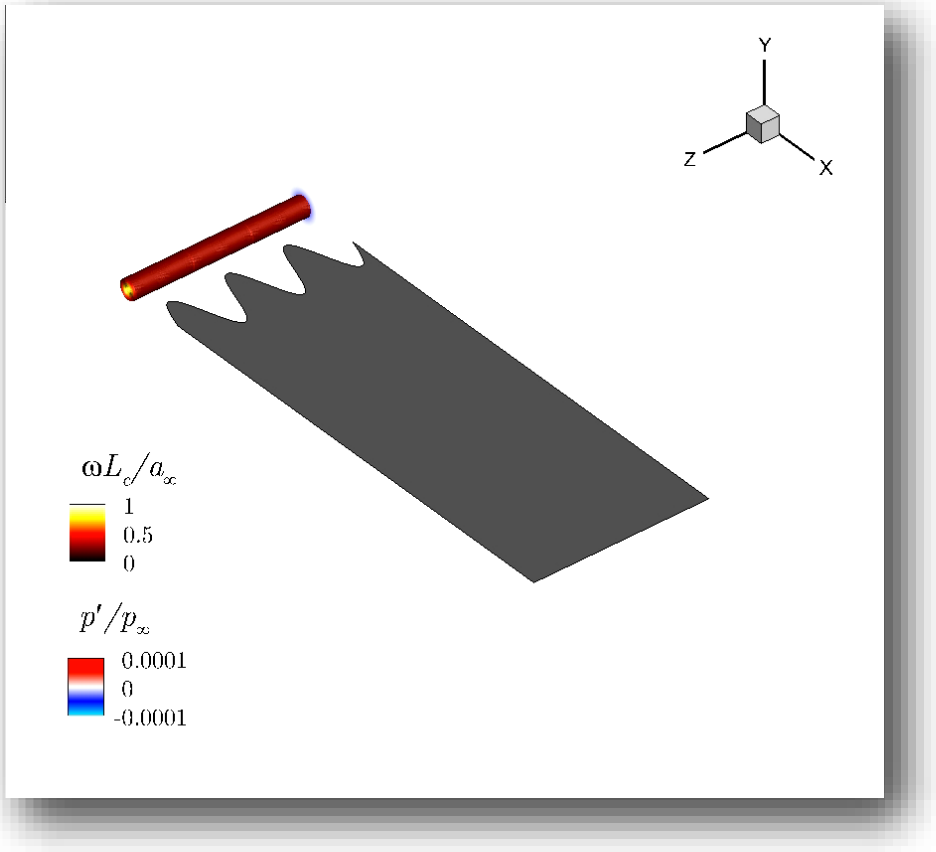

$p_{\mathrm{TEVS}}(\mathbf{x},t)$ $\Rightarrow$ $p_{\mathrm{ABS}}(\mathbf{x},t) = p_{\mathrm{S2}}(\mathbf{x},t) - p_{\mathrm{TEVS}}(\mathbf{x},t)$

TEVS vs ABS

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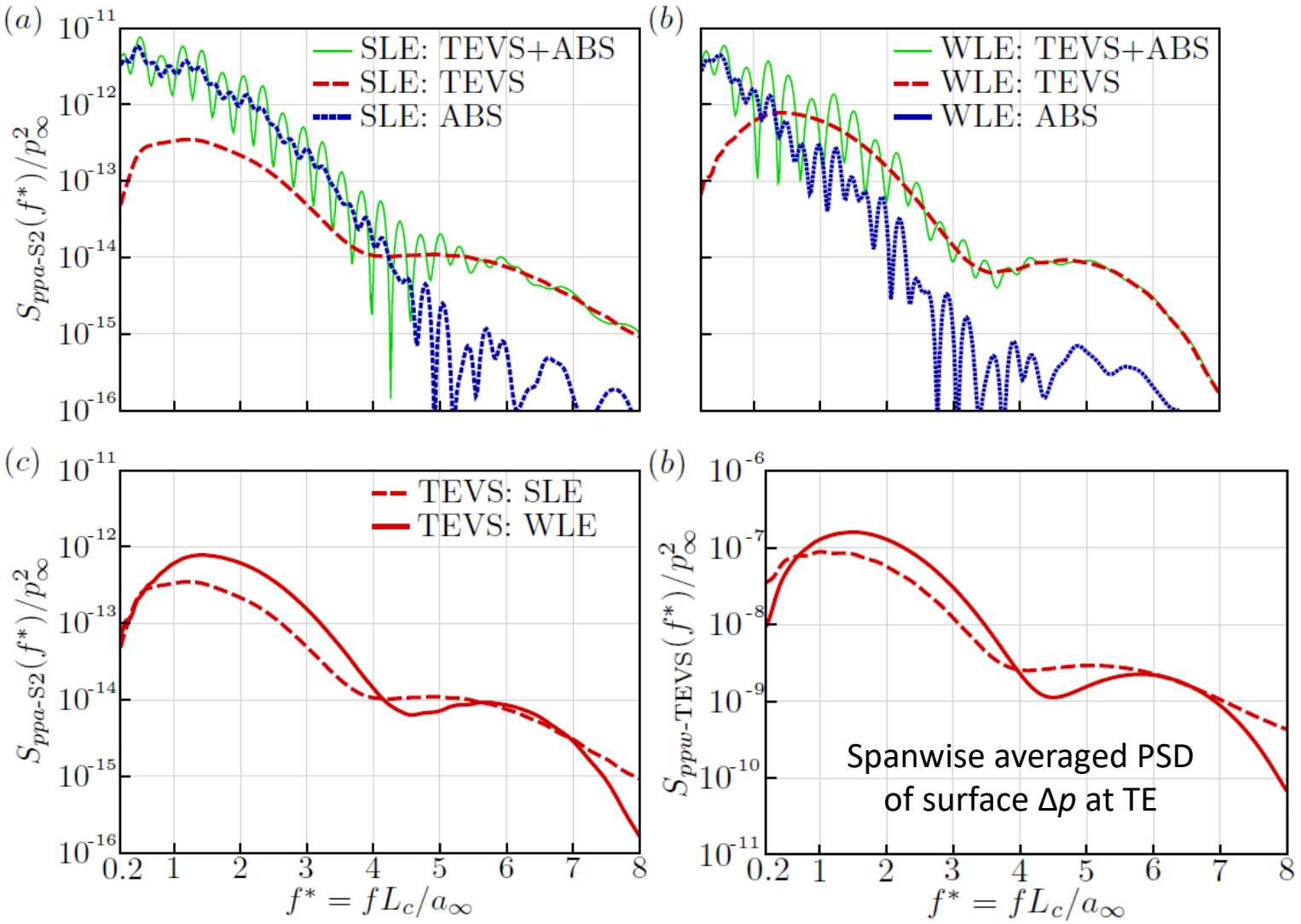

Overall SPL Directivity

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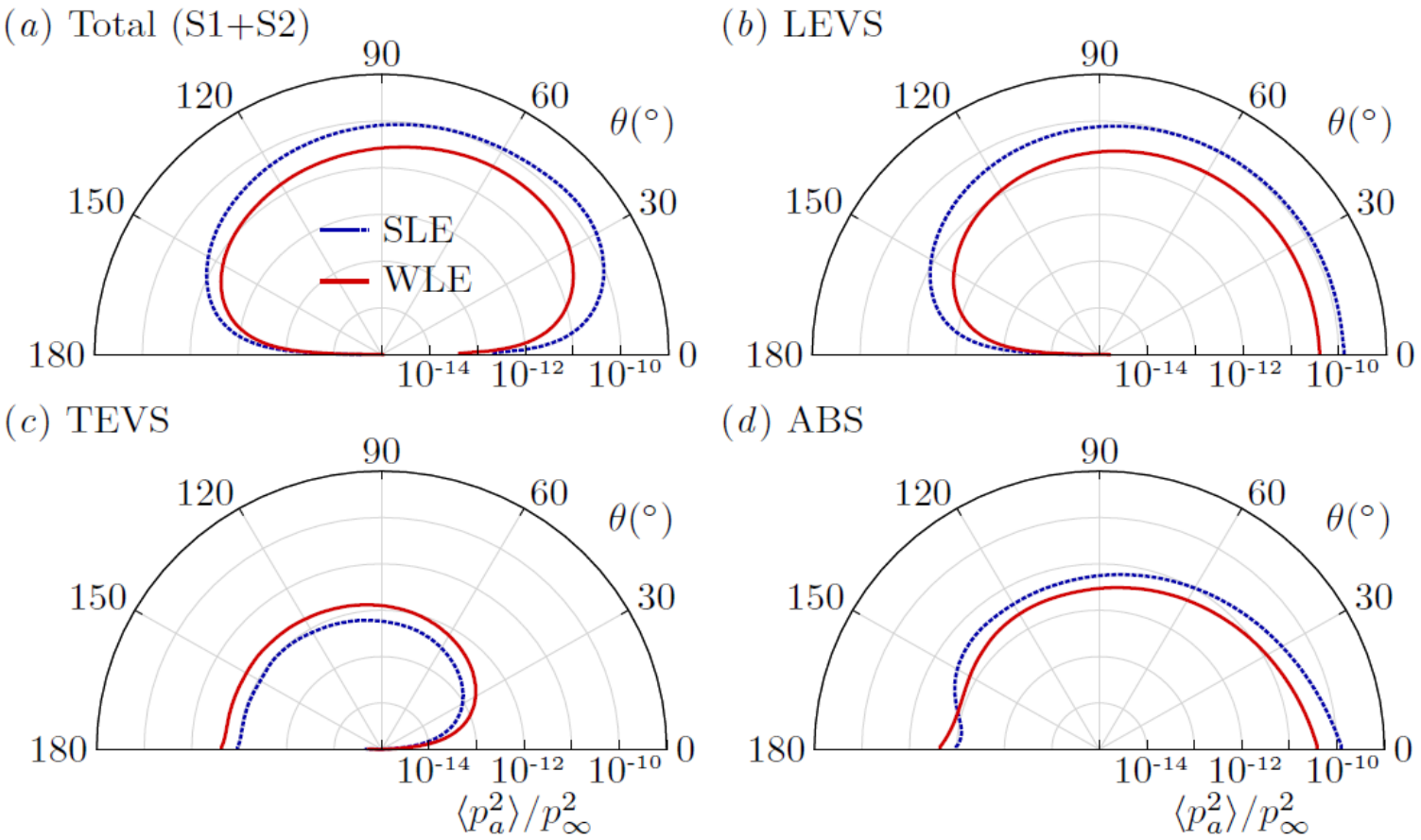
- For each source compared to all combined (log scale):



Low vs. High Frequencies

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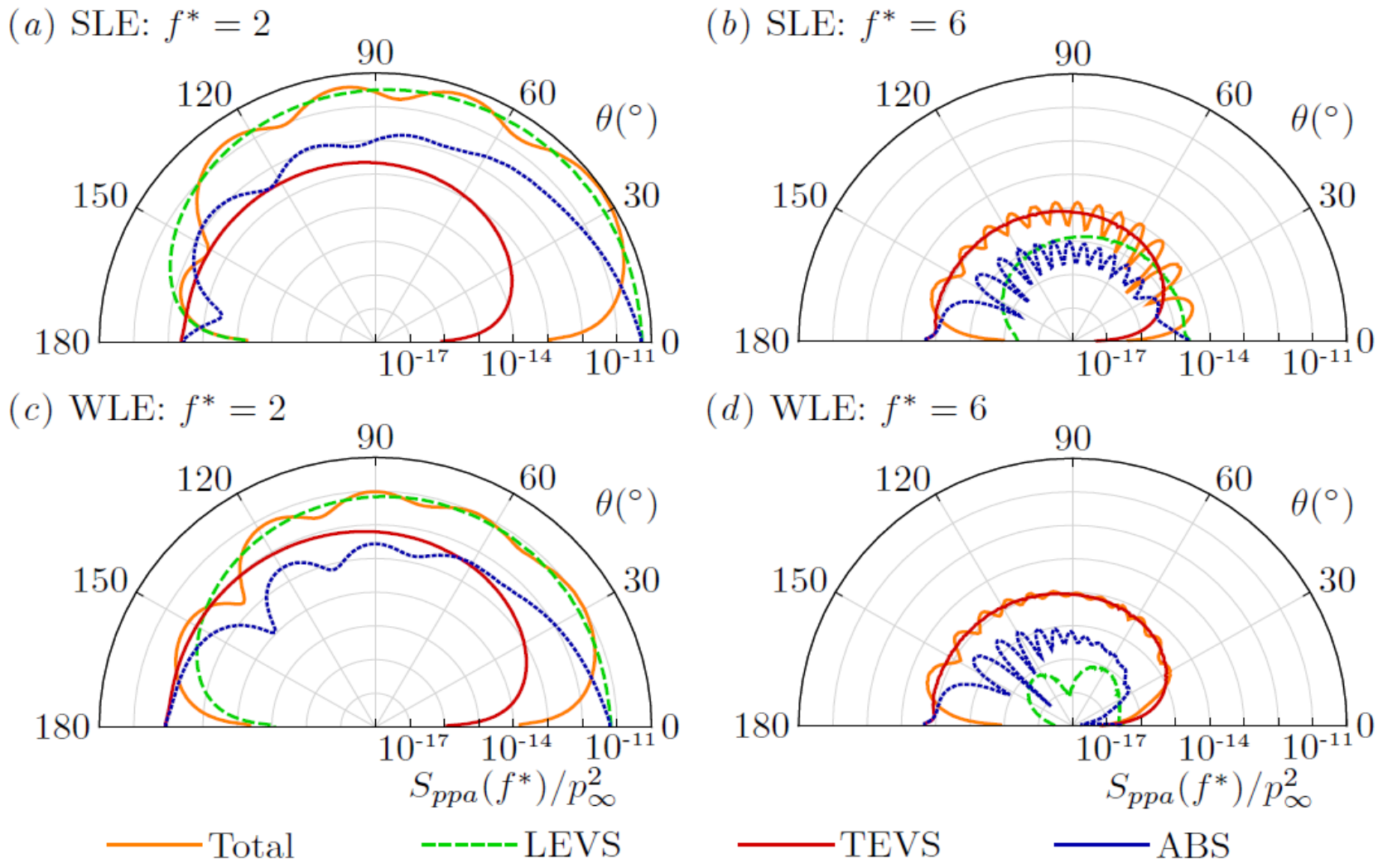

Noise Reduction by WLE (?)

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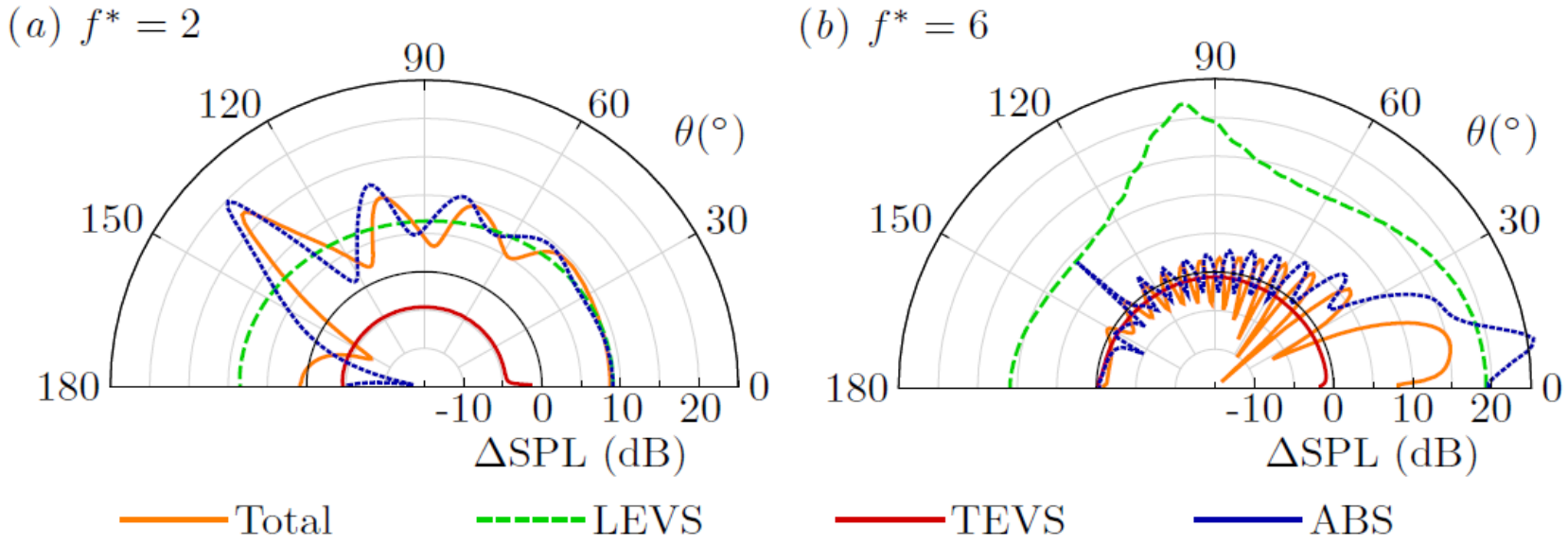
- Prediction of noise reduction based on the primary source (LEVS) becomes unreliable.



Analytic Prediction (2D/SLE)

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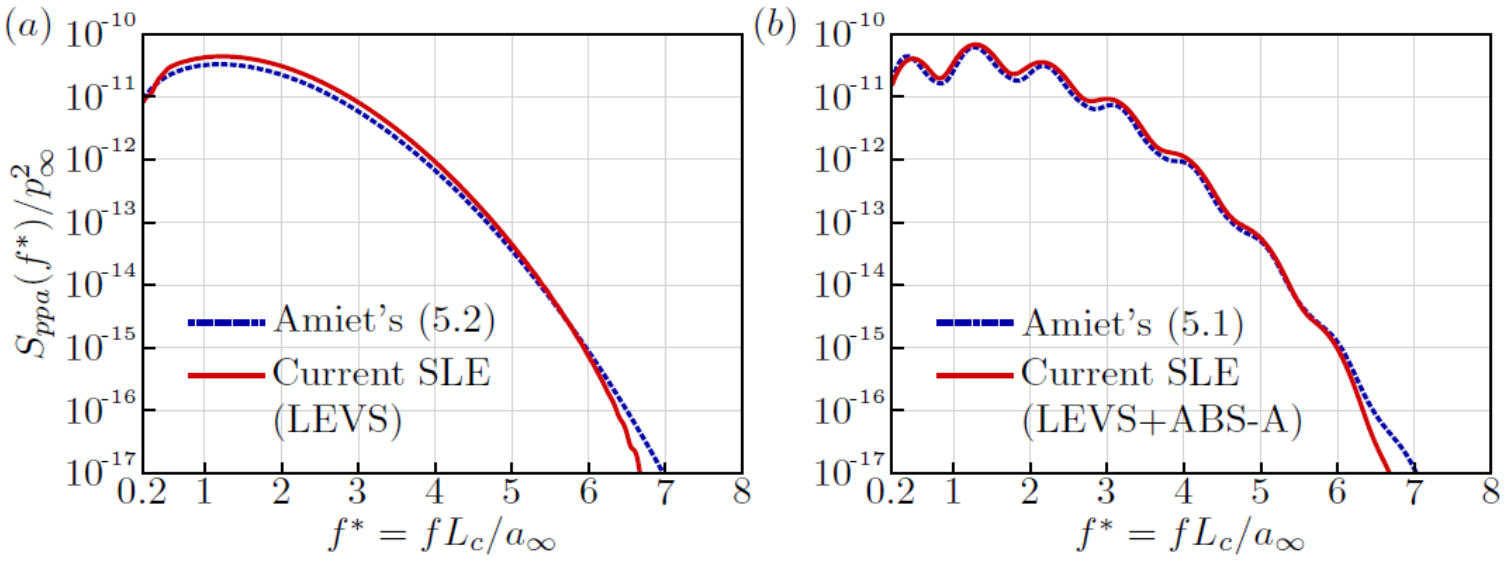
- Amiet's model for ATI noise (JSV 1975)



$$S_{ppa\text{-Amiet1}}(k_x) = \frac{\pi k_x M_\infty \rho_\infty^2 u_\infty^2 L_c^2 \sin^2\theta}{8 r_o A^3(\theta)} \Phi_{vv}(k_x) \left|\mathcal{L}(k_x)\right|^2$$

$$S_{ppa\text{-Amiet1-LEVS}}(k_x) = \frac{\rho_\infty^2 u_\infty^2 (1 - M_\infty) \sin^2\theta}{2\pi r_o k_x A(\theta)^2 [A(\theta) - \cos\theta]} \Phi_{vv}(k_x)$$

Analytic Prediction (2D/SLE)

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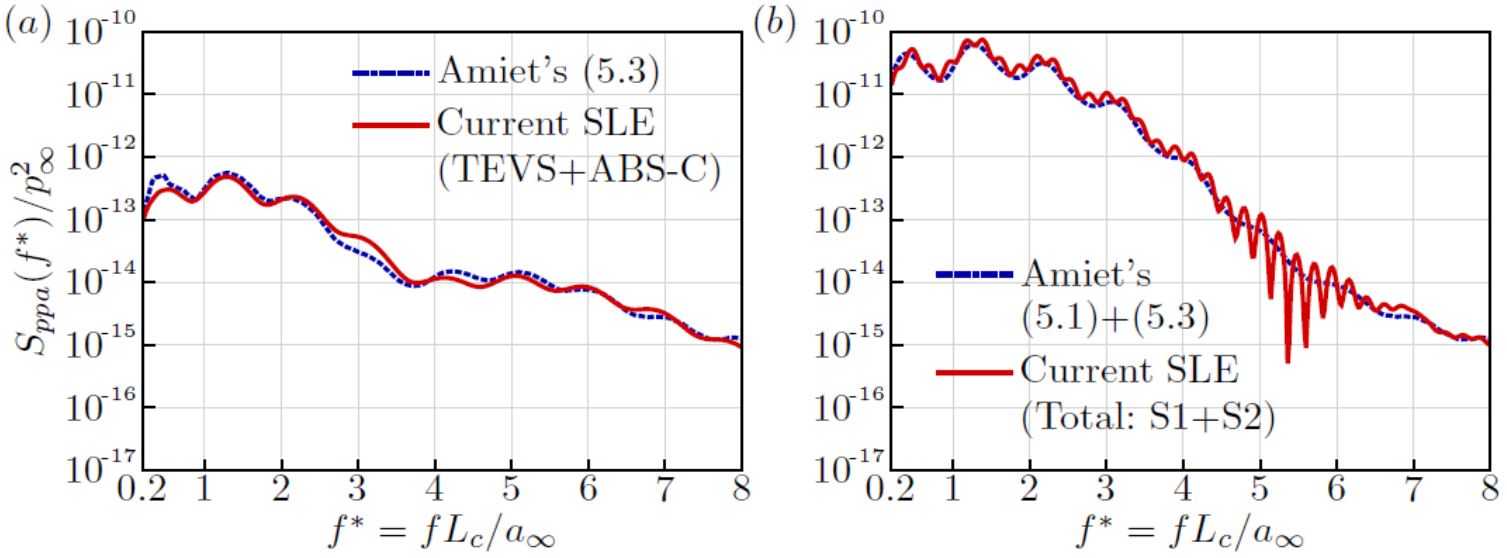
- Amiet's model for self-noise due to TBL at TE (JSV 1976):



$$S_{ppa\text{-Amiet2}}(k_x) = -\frac{\beta^2\mu_0^2}{16}(y_{\mathrm{TE}} - y_o)^2 \iint \frac{S_{QQ}(x_1, x_2, k_x)}{R(x_1)R(x_2)} \times H_1^{(2)}(S(x_1))H_1^{(1)}(S(x_2))\mathrm{d}x_1\mathrm{d}x_2$$

$$R(x) = \sqrt{(x - x_o)^2 + \beta^2(y_{\mathrm{TE}} - y_o)^2}, \quad S(x) = \mu_0[M_\infty(x - x_o) + R(x)]$$

Concluding Remarks

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- The dominance of TEVS at high frequencies:
  - effectively acts as the primary source in all directions.
  - limits the noise-reduction performance of WLE.
  - adverse effect at low frequencies (TEVS amplified by WLE).
- Perhaps false accusation on broadband self-noise?
- Narrow angle of sound measurement ($50° \leq \theta \leq 130°$) sound?
- Provisions for analytic prediction models for ATI noise:
  - to include the effect of TEVS.

Two-dimensional simulation

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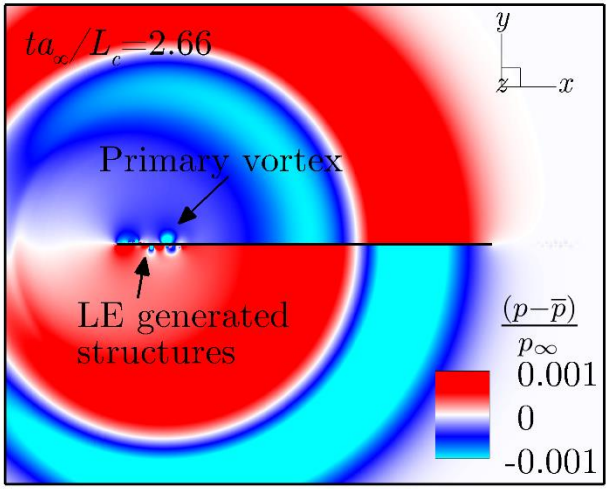
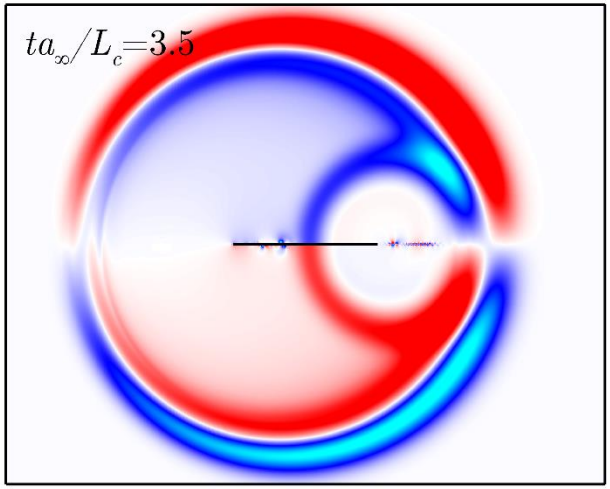
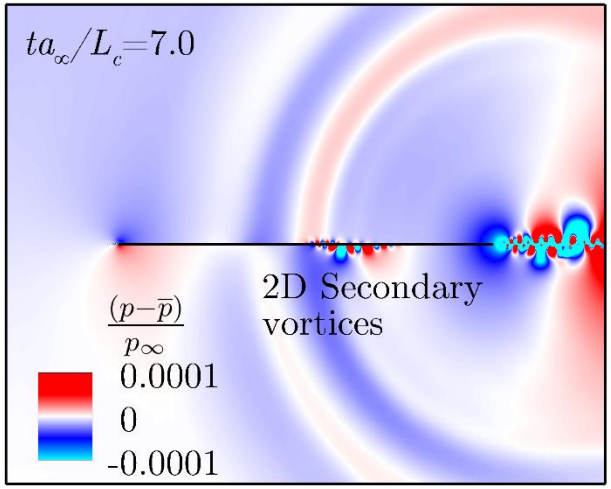
Leading-edge vortical scattering



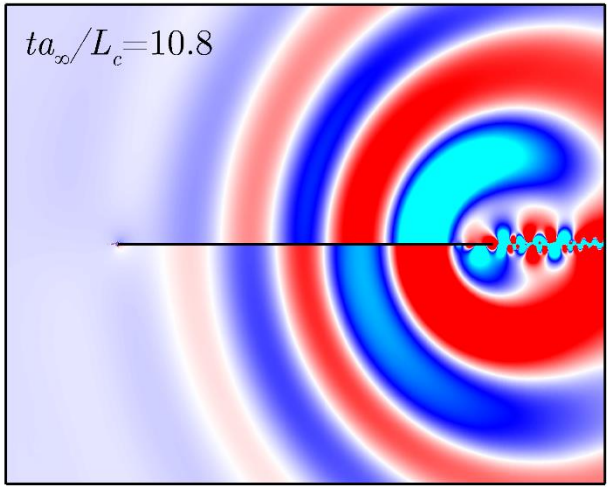
Acoustic backscattering



Trailing-edge vortical scattering (primary vortex)



Trailing-edge vortical scattering (secondary vortices)



Three-dimensional simulation

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- Three dimensional strong vortex interaction, $|u'| = 0.25U_\infty$

ta_∞/L_c=1.534