Toying with Acoustics Underflow: Nonreciprocal Sound Propagation in Fluid Flow

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Acoustic wave propagation in the presence of fluid flow is a well-known phenomenon that leads to nonreciprocal sound transmission, breaking time-reversal symmetry. This effect has been widely studied in classical acoustics and hydrodynamics, with foundational discussions available in texts such as *Fundamentals of Acoustics* by Kinsler et al. and *Acoustics: An Introduction to Its Physical Principles and Applications* by Pierce. In this presentation, I will discuss three distinct research directions explored by my group that leverage fluid flow to control and manipulate acoustic waves. To minimize turbulence, our experimental and theoretical setups consist of a quiescent fluid confined within a duct, which is sandwiched between two uniform half-spaces supporting parallel background flow. This configuration allows for a controlled study of nonreciprocal wave dynamics while maintaining analytical and experimental tractability.

As a first case study [1], I will present a theoretical investigation of an intriguing form of acoustic nonreciprocity that arises when the background flow is transverse to the direction of wave propagation. Unlike conventional convective nonreciprocity, which results from the Doppler effect in co- and counter-propagating waves, this scenario demonstrates a unique flow-induced asymmetric mode conversion mechanism. The results provide insight into how shear flows and transverse velocity gradients influence sound wave transmission, potentially offering new avenues for acoustic wave control in aerospace and underwater applications.

As a second example, I will discuss experimental results demonstrating acoustic isolation in a duct embedded within a randomly structured medium. By introducing disordered acoustic scatterers inside the duct, we enhance wave dispersion and reflection asymmetries, leading to highly directional energy transport. This approach exploits a combination of flow-induced biasing and multiple scattering effects, drawing connections to the broader fields of wave localization and nonreciprocal metamaterials.

Finally, I will discuss a theoretical framework for achieving sectorial one-way wave propagation in a two-dimensional system. This phenomenon occurs when the fluid flow in the upper and lower half-spaces is directed in different directions, inducing spatially varying nonreciprocity. We demonstrate that under appropriate conditions, acoustic waves can be confined and guided along specific angular sectors, effectively creating a tunable one-way sound corridor.

Reference:
[1] O. Silbiger, Y. Hadad, *One-way acoustic guiding under transverse fluid flow*, Physical Review Applied, 17 (6), 064058 (2022).