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Bulk viscosity effects on ultrasonic thermoacoustic instability

JEFFREY LIN, Stanford University, CARLO SCALO, Purdue University, LAMBERTUS HESSELINK, Stanford University — We have carried out unstructured fully-compressible Navier–Stokes simulations of a minimal-unit traveling-wave ultrasonic thermoacoustic device in looped configuration. The model comprises a thermoacoustic stack with 85% porosity and a tapered area change to suppress the fundamental standing-wave mode. A bulk viscosity model, which accounts for vibrational and rotational molecular relaxation effects, is derived and implemented via direct modification of the viscous stress tensor, $\tau_{ij} \equiv 2\mu \left[S_{ij} + \frac{\lambda}{2\mu} \frac{\partial u_k}{\partial x_k} \delta_{ij} \right]$, where the bulk viscosity is defined by $\mu_b \equiv \lambda + \frac{2}{3}\mu$. The effective bulk viscosity coefficient accurately captures acoustic absorption from low to high ultrasonic frequencies and matches experimental wave attenuation rates across five decades. Using pressure-based similitude, the model was downscaled from total length $L = 2.58$ m to 0.0258 m, corresponding to the frequency range $f = 242 - 24200$ Hz, revealing the effects of bulk viscosity and direct modification of the thermodynamic pressure. Simulations are carried out to limit cycle and exhibit growth rates consistent with linear stability analyses, based on Rott's theory.

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