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How opening a hole affects the sound of a flute

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Consider the wave equation in a thin three-dimensional tube. The "thin domains" methods easily show that this situation can be approximated by a one-dimensional wave equation. But what happens when a hole is open on the side of the tube? In the case of old flutes, the approximation by a simple 1D wave equation is inaccurate. In this talk, we use a work of J. Casado-Díaz, M. Luna-Laynez and F. Murat to mathematically derive a suitable model.