Sound is generated by movement: the same way that whenever an object at the air-water interface is subject to unsteady movement, surface waves are generated and propagate away from its source, any unsteady movement in a real fluid gives rise to pressure waves which, although we cannot see, we can eventually hear — in which case we call them sound waves. When sound is generated in a homogeneous medium at rest by the movement or deformation of an ‘external’ body, the flow field, which comprises both the ‘accommodation’ movement close to the source and the medium wave-like reaction, which carries energy away, is indistinguishable from the sound field — they are one and the same thing. In this case, as fluctuations of pressure, density and velocity are typically small when compared to the average values of ambient pressure, density and sound speed, respectively, it is usually sufficient to describe the sound field using linearized equations. This means that all terms in the mass, momentum and energy equations involving products of fluctuation can be abandoned. Effectively, combining the linearized form of these three basic equations for a homogeneous medium at rest and neglecting gravity, viscosity and heat conduction (effects which cause negligible influence on the free field propagation of sound over ‘moderate’ distances) leads to the standard wave equation, also called the d’Alembert equation, as it was first obtained by Jean-le-Rond d’Alembert in 1747, for describing waves on a string.

Now, when sound is produced inside a moving fluid, like in the turbulent flow which exhales from a jet turbine, there is certainly a flow field which is, frequently, independent of the sound field while, far away from the flow, only the sound field remains. Although this picture suggests that the separation between flow and sound may be straightforward, this separation is far from simple. In fact, there is no unambiguous answer to this issue because, while there is not a well defined frontier through which sound is being imparted to the medium, both the ‘flow’ and the ‘propagation’ are described by the same set of basic equations, even if different hypotheses may be used in each case.

The first general approach to tackle this problem was proposed by Sir James Lighthill (1924–1998) in 1952 (Proc. Royal Soc. A, 211 (1107)). Lighthill rearranged the momentum equation so that the difference between the stresses due to the flow in the real situation and those that would exist due to the propagation of sound waves in a reference homogeneous medium at rest could be interpreted as ‘external’ (or ‘equivalent’) sources acting on such a reference medium. With this very elegant trick, the mass and momentum equations could be combined into an inhomogeneous d’Alembert equation for density fluctuations, known as the Lighthill equation. This is, in fact, valid for any continuous medium, with the appropriate stress tensor considered. A significant advantage is that the d’Alembert equation has a known, simple solution.

The approach introduced by Lighthill establishes an acoustic analogy by replacing the real problem by another considering a hypothetical homogeneous medium at rest. In this approach, all complications are transferred to the source term which, if known, provides the required input for obtaining the sound field. However, to adequately predict the acoustic field in the presence of a mean flow, an excessive amount of detail is required for the ‘source’ description, because the wave operator in Lighthill’s equation (the d’Alembert operator) “does not know” that there is flow and consequently, all details regarding the interaction of sound waves with the mean flow (and with turbulence as well) are left in the source function and have to be modeled. In the incompressible flow approximation, for instance, these details are lost.

The way to escape this is to consider a different rearrangement of the basic equations so that the new wave operator considers the existence of a mean flow. In doing this, however, the charming simplicity of Lighthill’s equation has to be abandoned. Two important approaches were developed which constitute different acoustic analogies: one by G. M. Lilley (1919–2015; given first in a 1971 Lockheed-Georgia Report) and another by M. S. Howe (J. Fluid Mech., 71(4), 1975). In Lilley’s approach, terms non-linear in the fluctuations are considered as equivalent sources while linear terms are seen as describing sound propagation. Thus, at the cost of a more complex equation (which considers a parallel mean flow with transverse shear and whose solution, except in specific limiting cases, has to be obtained numerically), a more detailed description is provided.

Lilley’s approach can be generalized for an arbitrary mean flow by considering the system of basic equations with all terms non-linear in the fluctuations regarded as equivalent sources at the respective equation (Béchara et al., AIAA J. 32(3), 1994; Goldstein, J. Fluid Mech. 488, 2003). Howe’s approach, on the other hand, considers as sources of sound, vorticity and entropy inhomogeneities, treating the propagation as an irrotational and homentropic process. In short, these approaches consider different reference situations and thus, different criteria to separate flow and sound. All of them have provided — and keep providing — quite important results. Each of these (and of other non-cited approaches as well) is more appropriate to specific situations and this is partially related to the type of approximation that is adequate to a given problem. If one wants to compute, for instance, effects of non-linear steepening on jet noise, a Lilley-type approach (based on linear equations) is unlikely to yield adequate predictions.

The Lighthill analogy is surely a masterpiece, which has been applied even to Cosmology (Lilley, IJA V 8(3), 2003). However, it is also, not infrequently, applied in ways which, given the approximations involved, the solution has limited applicability. It seems that, despite the numerous attempts made in this direction so far, no single aeroacoustic theory can be regarded as providing the optimal solution to all problems in the field. Whenever we have to introduce approximations (and we always have to do this) we have to check carefully which approach is more likely to give the desired results.