Study on the effect of surface impedance to reduce aerodynamic sound from a circular cylinder

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This thesis describes a mathematical implementation, numerical simulation and a wind tunnel experiment about the aero-acoustical effect on the presence of finite surface impedance with a low Mach number flow around a circular cylinder. Surface impedance is defined as the ratio of complex pressure amplitude to complex normal velocity amplitude at the body boundary when assuming harmonic oscillation of the flow field. Modification of the surface acoustical properties of the source area is said to result in the reduction of radiated sound pressure level.

First, this thesis discusses a mathematical derivation of the ideal surface impedance that eliminates the pressure fluctuation on the body surface, utilizing the Compact Green's function.

Large Eddy Simulation (LES) is conducted using two different approaches of finite impedance models on the surface with a Smagorinsky Subgrid-Scale model. The governing equations are solved on a co-located grid for generalized coordinate system with a second-order accuracy finite difference method. Fractional step method is used as the algorithm. Time integration is performed with a second-order Adams-Bashforth scheme for the convection term and Crank-Nicholson scheme for the diffusion term. Second-order central difference is used for space discretization. Sixth-order explicit filtering is utilized as the filtering method.

A microstructure array of Helmholtz resonators and a perforated shell structure with a backspace on the surface is modeled to correspond with the appropriate surface impedance. The introduction of the finite impedance yields the reduced amplitude of the pressure fluctuation on the surface, which leads to the reduced level of far field sound pressure. The Reynolds Number is assumed to be 3000-6000, which corresponds to a flow velocity of 5-10[m/s], a cylinder diameter of 10[mm], and Karman vortex frequency of 88-176[Hz].
Three boundary conditions (BC) of surface impedance are supposed;
1) Rigid (i.e. infinite impedance),
2) Uniform impedance of 900[kg/m^{2}s],
3) Optimized impedance with a minimum value of 700[kg/m^{2}s].
The third condition caused reduction of the far field pressure level by 5[dB] and the second one by 2[dB], compared with the first condition.

In order to verify the surface impedance distributions that assigned as the boundary conditions to the numerical simulation, acoustical impedance is measured for similar materials using the two-microphone transfer function method on an impedance tube. This measurement was also a preparatory experimental stage for the wind tunnel tests.

A wind tunnel experiment is conducted under three types of BC. Tests are carried out in a wind tunnel in an anechoic room using a smooth flow over three types of cylindrical models. Three cylindrical models are developed according to the three types of BC. They have an outer diameter of 10[mm] and a span of 200[mm] each. In order to induce normal velocity at the periphery of the cylinders, under the cases of uniform and optimized impedance BC, an array of holes is bored over the entire surface in micrometer scale utilizing laser-boring techniques for hollow cylinders with 0.25[mm] thickness, making the model like a perforated shell. For the optimized case, holes are made with diameters of 50, 55, 60, and 65 micrometers with a distribution of circumferential and span-wise direction, with a span of two consecutive holes of ten times the particular hole diameter. Holes with a fixed diameter of 60 micrometers each are made for the uniform case. An inner cylinder with diameter of 8[mm] is assembled in order to have a shell with a backspace-like structure with end plates on each impedance BC model.

A comparison of the results from numerical simulation and wind tunnel experiment shows very good agreement. These results support the conclusion that this method of surface impedance optimization is appropriate for reducing aerodynamic sound radiated from compact solid bodies significantly.