Inverse Problems in Aeroacoustics

C. Yu, M. Zhuang and Z. Zhou
Department of Mechanical Engineering
Michigan State University
East Lansing, MI 48824

Inverse aeroacoustic problems have been investigated with various objectives in the past [1-5]. In the current work, the far field noise generated by flows around airfoils is being studied using the acoustic intensity based inverse method [6]. It is well known that the hybrid method [7], which couples the CFD solver with the FW-H far field acoustic prediction, and experimental measurements are the primary approaches for the study of such a far field noise problem. Unfortunately, the hybrid method requires a complete flow field solution from CFD simulations that are computational intensive. The experimental measurement of the far field acoustic data is usually limited to a finite number of measurements in a restricted region. Therefore, it is extremely desirable for practical purposes to develop an inverse method so that a limited number of far field acoustic measurements can be used to reconstruct the entire acoustic far field. The recently developed acoustic intensity based inverse method is used here to reconstruct the far field acoustic solutions for the two model problems of flows around an airfoil. The first model is a two-dimensional mathematical model formulated as the vortex/trailing edge interaction problem (see Figure 1) and the second model is a general two-dimensional flow around an airfoil (see Figure 2). For the vortex/trailing edge interaction model, the acoustic wave from a single line vortex passing by a sharp edge of a semi-infinite plate is propagated to the far field. The problem was analytically solved by Crighton [8]. The reconstructed acoustic solution from the inverse method is compared with the analytical solution and the effectiveness of the inverse method is demonstrated. For the general two-dimensional model, a high fidelity CFD flow solver combined with the FW-H integral method [9] is considered for the calculation of the far acoustic field. The CFD solver is based on a cell-centered finite volume discretization, Roe's flux splitting, a least-squares linear reconstruction, and a differentiable limiter. The CFD calculation employs the $k-\varepsilon$ turbulence model. For the FW-H integral method, the quadruple source is neglected considering flows at low Mach number. Once the far field acoustic solution is calculated from the FW-H integral method, a finite number of the acoustic field data will be used as the input for the inverse method to reconstruct the unsteady pressures over an off-body permeable FW-H surface that enclosing the sound source in the near-field. The inverse method and its robustness and accuracy in aeroacoustic applications are discussed and analyzed.

References

1. Grace, S. P. and Atassi, H. M., "Inverse Aeroacoustic Problem for a Streamlined Body, Part 1: Basic Formulation," *AIAA J.* 1996, Vol.34, pp.2233-2240.
2. Yoon, S. H. and Nelson, "Reconstruction of Aeroacoustic Source Strength by Inverse Methods," 1998 AIAA-Paper No. 98-2339.
3. Li, X. D., and Zhou, S., "Spatial Transformation of the Discrete Sound Field from a Propeller," *AIAA J.* 1996, Vol.34, pp.1097-1102..
4. Li, X. D., Luo, J. and Yu, C., "An Inverse Aeroacoustic Problem on Gust Cascade Interaction", 2001 AIAA-Paper No. 2001-2122.

5. Luo, J. and Li, X. D., “An Inverse Aeroacoustic Problem on Rotor Wake/Stator Interaction”, *Journal of Sound and Vibration* 2002, Vol.254(2), pp.219-229.
6. C. Yu, Z. Zhou and M. Zhuang [2006] “Improved Inverse Acoustic Methods through Advances in Acoustic Intensity Measurement Techniques Two-dimensional acoustic reconstruction using simultaneous acoustic intensity and pressure measurement,” AIAA Paper No. 2007-3563.
7. Greschner, B., Yu, C., Zheng, S., Zhuang, M., Wang, Z. J. and Thiele, F. [2005] “Constrained Aeroacoustic Shape Optimization of An Airfoil,” *AIAA Paper* 2005-2968.
8. Crighton, D.G., “Radiation from vortex filament motion near a half plane,” *J. Fluid Mech.* 1972, Vol.51, Part 2, pp.357-362.
9. Lockard, D. P., “An Efficient, Two-Dimensional Implementation of the Ffowcs Williams and Hawkings Equation”, *Journal of Sound and Vibration*, 2000, Vol. 229 (4), pp. 897-911.

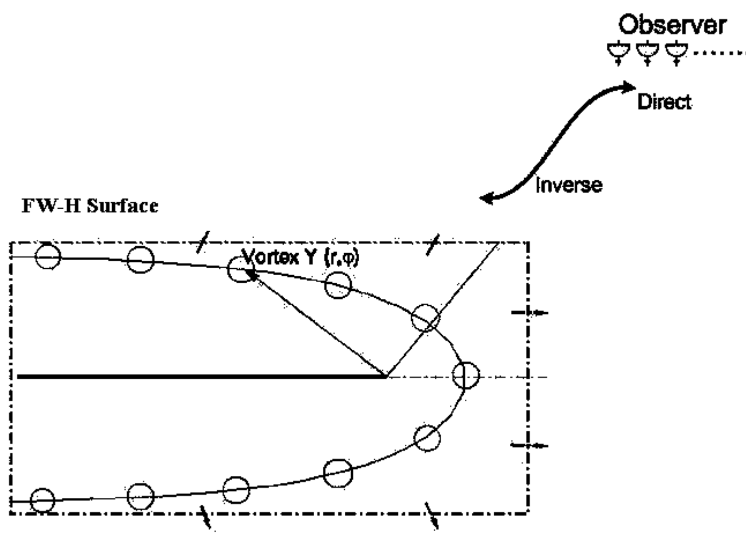

Figure 1. Schematic of the vortex/trailing edge interaction model.

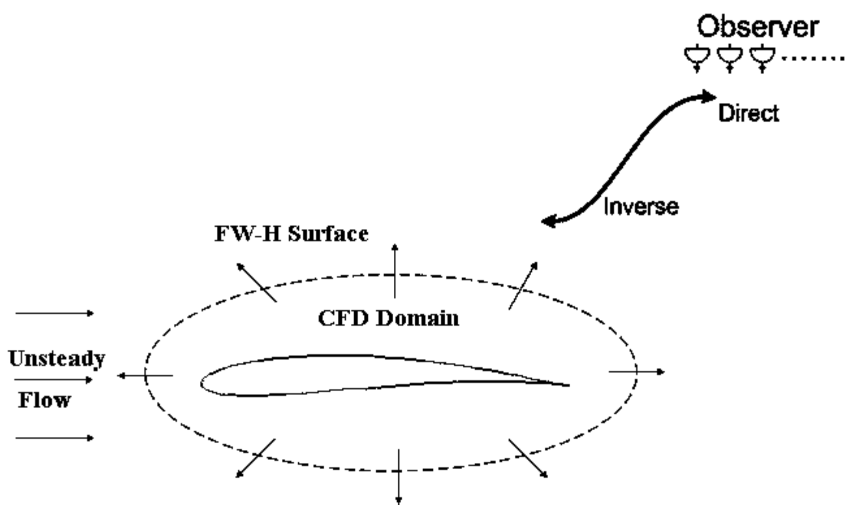

Figure 2. Schematic of a two-dimensional flow around an airfoil.