AIRFRAME NOISE MODELING BY ACOUSTIC ANALOGY

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Abstract

This lecture discusses the application of the acoustic analogy to airframe noise modeling and prediction. The characteristics of airframe noise, including its composition, spectral features and directivity patterns, and its source mechanisms are reviewed to highlight the unique features and challenges of airframe noise modeling. Discussed are three approaches that have seen significant progresses in recent years. These are the Ffowcs Williams/Hawkings equation with numerical simulation for the unsteady source flows, the acoustic analogy with statistical modeling of the noise source mechanisms, and the development of simple models from the acoustic analogy. Examples are given for all three approaches to demonstrate their features and their practical applications with emphasis on their respective unique aspects. Each of the approaches has seen successes in dealing with individual aspects of airframe noise research, ranging from revealing the source mechanisms to providing tools for practical predictions. Together, these approaches have greatly facilitated the progresses made in recent years in airframe noise research.

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1 Introduction

Unless it is pure empirical prediction based on brute-force data collapsing and curve fitting, methods of airframe noise modeling and prediction all follow the general principles of the acoustic analogy, originated more than half a century ago by Lighthill (1952) through some simple and elegant mathematical manipulations of the fundamental governing equations of fluid dynamics. It is a methodology to set up practical problems in a way that useful prediction can be made on how unsteady flows generate noise without complete information on the flows themselves. The use of the acoustic analogy in airframe noise modeling and prediction is not only a convenience, but also a necessity because it is simply not feasible and practical to solve the complete flow-noise problem exactly. In the acoustic analogy approach, the unsteady flows around the airframe structures are assumed to be unaffected by the sound they radiate, thus making the sound generation and propagation decoupled from each other. Because the flows that generate airframe noise are usually of low Mach number and high Reynolds number in unbounded space, it is rare to have strong acoustic-aerodynamic feedback integrations, as rigorously analyzed by Crow (1970). This decoupling of the source flows from the back reaction of the sound they generate allows the unsteady flows to be formulated as sources and to be modeled and/or simulated by utilizing appropriate methods to extract and derive useful information about the source mechanisms, which has been the research focus for airframe noise in the past two decades or so.

There are many methods to model and simulate the source flows, ranging from simple dimensional analysis and correlation studies, to statistic models utilizing ensemble averages of turbulence properties, to sophisticated numerical methods such as Large Eddy Simulation (LES). None of these methods individually gives a complete description of the source mechanisms, but they supplement each other, and as a whole, offer a rich suite of tools that, together with experimental studies, have greatly enhanced the understanding of airframe noise generation in recent years. Needless to say, it is very difficult to review and summarize all the progresses in a lecture. Thus, the emphasis here will be the discussions on the general features