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Book Reviews

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Large-Eddy Simulation for Acoustics

Edited by C. Wagner, T. Hütll, and P. Sagaut, Cambridge University Press, New York, 2007, 441 pp., $125.00

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Aircraft noise has become increasingly more important in the last few decades. Public concern about excessive aircraft noise emissions has led to the adoption of strict regulations near heavily populated urban centers. Even when airplanes are cruising far from populated areas, jet engine noise is a serious issue for passenger comfort. For the military, noise has been a dangerous early warning for military flights. Beyond aircraft noise, aeroacoustics is important in automobiles, trains, personal computers, etc. Thus, there is a need to develop new tools that will allow the robust and accurate prediction of sound levels from aircraft airframes and engines. Therefore, a relatively new discipline, computational aeroacoustics (CAA), has emerged as a tool to complement theoretical and experimental approaches. CAA, unlike computational fluid dynamics (CFD), involves the accurate prediction of small-amplitude acoustic fluctuations and their correct propagation to the far field. In that respect, CAA poses significant challenges for researchers because the computational scheme should have high accuracy, good spectral resolution, and low dispersion and diffusion errors.

The current state of the art in CAA predictions of far-field noise are based on time-dependent simulations of the turbulent flows that generate noise coupled with acoustic methods for propagating the noise to the observer location. The highest level of flow simulation (based on the Navier–Stokes equations) is direct numerical simulation (DNS) in which the time-dependent motion of all the relevant length scales are captured, from the largest eddies in the flow to the Kolmogorov scales where energy is dissipated. No turbulence modeling is used; instead the turbulence is simulated directly from the Navier–Stokes equations. The difficulty with DNS is that the computational cost scales as Re^3 (Re is the Reynolds number), making computations infeasible for realistic Reynolds numbers. For high Reynolds number flows of practical engineering interest, the range of length scales is too large for DNS to be feasible. The limitations of DNS can be overcome to a certain extent by using large-eddy simulation (LES). With LES the large eddies in a turbulent flow are simulated directly whereas the effect of the small eddies is modeled using a subgrid-scale (SGS) model. Because the small scales of a turbulent flow are more universal in nature than the large scales, they are easier to model, and one can use a fairly simple SGS turbulence model. Because the small scales are not captured in an LES, coarser grids can be used than with DNS, making it more feasible to simulate high Reynolds number flows.

This book deals with the use of LES for aeroacoustics. Whereas acoustics as a discipline has been around for a while and aeroacoustics has been around since the 1950s (i.e., Lighthill's acoustic analogy), LES is a relatively recent method of doing turbulence simulation and evaluating aeroacoustic sources. Thus, the use of LES in aeroacoustics is fairly recent. This book reviews the current state-of-the-art and is divided to 7 chapters, which include the introduction, theoretical background on aeroacoustics, theoretical background on LES, use of hybrid RANS-LES (Reynolds-averaged Navier–Stokes large-eddy simulation) for acoustic source prediction, numerical methods (with subsections on discretization schemes, boundary conditions, and LES–CAA coupling), applications (with subsections on mixing layers, jets, cavities, aeroelastic noise, trailing edge noise, blunt bodies, internal flows, and industrial aeroacoustic analyses), and results of LES for acoustics and conclusions. As it is now the usual practice for monographs, different sections and chapters are written by different authors. There are 19 contributions from 30 authors.

The first chapter provides an introduction about the importance of acoustic research, CAA, and LES. In the acoustics introduction there is a discussion of health effects, activity effects, annoyance, technical noise sources, and political, social, and industrial reactions to noise. An introduction to CAA and an introduction to LES are also given.

The second chapter provides a primer for aeroacoustics. This chapter is self-contained, and I am thinking of using some of this material for my graduate level aeroacoustics course. Some material is not used in subsequent chapters, but this is fine. However, I would suggest adding a brief discussion of the permeable surface Ffowcs Williams-Hawkings formulation and the Kirchhoff method that are used in the applications discussed in Chapter 6.

The third chapter provides a primer for LES. This chapter is also self-contained and explains the basics of LES. It discusses the LES mathematical models, governing equations, basic numerical issues, and subgrid-scale modeling for incompressible and compressible flows including the MILES (monotonic implicit LES) concept.

Chapter four presents the hybrid RANS-LES approaches, a very important topic. Hybrid RANS-LES approaches could provide significant savings compared with pure LES, and their use is currently increasing. The chapter is divided into global hybrid approaches, including the approach of Speziale, detached eddy simulations, limited numerical scales, Menter et al., and nonlinear acoustic solvers, and zonal hybrid approaches, including the approaches of Quemere and Sagaut, Labourasse, and Sagaut. Examples and a summary are also included in this chapter. A well-written, thorough discussion of the various approaches is given.

Chapter five discusses numerical methods. It should be noted that the requirements for capturing acoustic waves are more stringent than usual CFD requirements, as pointed out in the book. There are sections for spatial and temporal discretization schemes, boundary conditions for LES and acoustics, as well as some concepts of LES and CAA coupling, where the CAA is based on acoustic perturbation equations. Maybe this last section should be expanded to review various CAA methods used later in Chapter 6 (e.g., Kirchhoff, Ffowcs Williams-Hawkings, and linearized Euler equations) as discussed in Section 1.2.4. The first two might be discussed in Chapter 2, as mentioned previously.

Chapter 6 discusses various applications including mixing layers, round jets, cavity noise, aeroelastic noise, trailing edge noise, blunt bodies (cylinder, cars), internal flows, and industrial applications. This is the longest chapter of the book (140 pages) and covers a wide range of applications. However, the coverage is somewhat uneven. Some sections provide many details and equations of the formulations, other sections do not. The trailing edge noise provides good examples of hybrid approaches (i.e., LES plus CAA). The last section provides some discussion of using RANS for aeroacoustics, a very important and interesting topic, but still technically outside the scope of the book, as the title indicates. Maybe this part should be expanded (e.g., adding some equations) and moved earlier in the methods sections of the book.

Finally, Chapter 7 offers some concluding remarks providing a well-written summary of the book contents.

The coverage of the material is good, and the book provides a good introduction to the subject. It should be noted that, in general, the level (and the subject) is somewhat advanced. Thus, a beginning graduate student with no background in the area will have some trouble following some parts. However, I think that the level is adequate for an advanced graduate student or researcher in the area. Adequate references are given to clarify things, if needed. Overall, I liked both the level and the breadth of the material covered. However, the there is still some unevenness in the coverage level (some sections have equations, some sections do not). In conclusion, this book is timely, well-written, and covers useful material for graduate students and researchers in this area.

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