# REVIEW OF COMPUTATIONAL AEROACOUSTICS FOR APPLICATION IN ELECTRONICS COOLER NOISE

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## 1. INTRODUCTION

The acoustic performance of heat sink and fan combination cooling systems is important for computer manufacturers, in addition to thermal performance. These systems are usually tested experimentally, which can be very costly and time-consuming. In many applications, computational fluid dynamics (CFD) has replaced or supplemented experimental methods in order to shorten design and testing times and to reduce costs. In order to use CFD for acoustics, very detailed simulations are required because of the differences in scales between the flow and acoustic phenomena. Only recently has computational aeroacoustics (CAA) begun to penetrate into design strategies in applications, like electronics cooling, where acoustic performance matters. Numerical simulation of the flow inside and around heat sinks and fans can lead to a prediction of the emitted noise while they are still in the design phase. Research in determining the required level of detail in modeling the flow is ongoing.

## 2. COMPUTATIONAL AEROACOUSTICS

Computational aeroacoustics encompasses all numerical methods where the purpose is to predict the noise emissions from a simulated flow. There are four main methods: direct, acoustic analogy, vortex/boundary element methods (BEM), and broadband methods [1, 2, 3, 4].

Direct CAA is theoretically the best way to predict flow-based acoustic phenomena numerically, but is also the most costly and difficult to use. This method does not use any models; the idea is to simulate both bulk flow and acoustic phenomena everywhere from the source to the receiver. This is very computationally expensive due to the large differences in scales between acoustic and flow phenomena [1]. Computational resources are the most significant limitation to the use of direct CAA [1]. Extremely fine meshes and time steps are necessary, and the resolutions required are proportional to the highest frequency to be simulated. Given this, direct CAA is typically used only for low-frequency sound prediction [5]. A CFD solver such as Fluent [6] can be used to obtain the acoustic data. Despite the high cost of direct CAA, some studies [7] have been undertaken which use it for higher frequency phenomena.

Less computationally demanding alternatives to direct CAA are acoustic analogy methods [1]. These are typically based on Lighthill's theory [8, 9]. These methods work only when the propagation of the noise is towards free space [1]. Also, it is critical that the acoustic wave propagation does not influence the flow [8], as acoustic analogy methods separate the production and propagation of noise. The latter is analytically predicted using the wave equation [10]. Two prominent formulations of the theory are Kirchhoff's and Ffowcs-Williams and Hawkings' (FW-H) [11, 12, 13]. The Kirchhoff formulation is based on the wave equation and thus must be used only in linear regions of the flow [13]. The FW-H formulation also accounts for aerodynamic noise generated by moving surfaces [14]. Extensions of this method allow the surfaces to be arbitrary. Another method available is to compute the flow field solution and source terms using CFD and then export that data to an external program, such as SysNoise or ACTRAN/LA [1, 15]. ACTRAN/LA overcomes the free-space limitation, but is also more computationally demanding [15].

The boundary element method (BEM) offers low computational cost at the expense of some detail in the information provided. This method does not use a computational grid [3], but instead uses vortex-surface calculations to determine tonal noise.

Broadband methods offer the lowest computational effort of any CAA method [1]. These are the only methods which can use a steady CFD solution in order to determine noise levels. The disadvantage of broadband methods is that only the overall sound power level of a source can be predicted, and not with great accuracy [1]. This can be useful for quickly comparing several designs in order to determine the quietest of several alternatives [6].

## 3. COMPUTER COOLING SOLUTIONS

Axial fans are commonly used to increase the airflow and thus the heat transfer over heat sinks within computer cases. They are relatively quiet and inexpensive. Rotating blades cause tonal dipole noise, while turbulent intake and wakes cause broadband quadrupole noise [3].

Rotor-stator interactions can also cause dipole sound [10].

Recently, radial fans have begun appearing in computer cooling applications. They have higher air-moving potential, but this comes at the expense of greater noise emissions. Tonal noise can be more dominant with radial fans than it is for axial fans [16]. Some full 3D, unsteady CFD studies of radial fans have been performed [17].

The core of the vast majority of heat-dissipation systems in computers is the heat sink. Most CFD of heat sink flows has focused on thermal performance [18, 19]. Noise predictions are also important for these flows, however, as the channel exits create jets which are sources of quadrupole noise. Few studies exist that have attempted to use CFD for noise predictions from heat sink flows.

## 4. PREDICTION METHODS

In [16], the vortex surface or boundary element method is used to predict the noise generation of a centrifugal fan. This prediction method gives only the tonal components of the noise [16]. This method is also used in [3], where both axial and radial fans are considered. The direct CAA method was used to predict the acoustic emissions of a shrouded fan in [7].

In the modeling of heat sinks, thermal performance has been the focus rather than acoustics. The level of detail required in modeling in order to obtain accurate thermal predictions is examined in [18], but the results do not apply to acoustic predictions, which require greater levels of detail than flow predictions. Another study [19] goes even further and uses a porous block modeling techniques for heat sinks, which is completely inappropriate for noise prediction.

## 5. CONCLUSIONS REGARDING FUTURE RESEARCH

If the overall acoustic performance of fan and heat sink cooling solutions is to be predicted accurately, the simulations must be combined so that both components are present, in order to capture interaction effects. Acoustic analogy methods seem to be the best compromise of accuracy and computational cost. Very detailed source simulations in the fan and heat sink region coupled with the use of analogy methods could result in excellent simulation results with a reasonable computational effort.

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