FLUENT 6.1

Acoustics Module Manual

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Contents

Chapter 1. Aero-Noise Model Theory

This chapter presents an overview of the theory and the governing equations for the mathematical model for FLUENT's aero-noise prediction capabilities.

1.1 Introduction

In FLUENT's Aero-Noise Model, Lighthill's Acoustic Analogy is applied for aero-noise prediction. Based on transient flow simulation results (LES modeling is highly recommended for capturing wide band sound spectrum), time variation of acoustic pressure is calculated with the formulation of Lighthill's Acoustic Analogy.

1.2 Lighthill's Acoustic Analogy

Aerodynamic sound is generated from fluid flow, which is governed by the well-known mass conservation and Navier-Stokes momentum equations.

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0 \tag{1.2-1}$$

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_i u_j + p_{ij}) = 0 \tag{1.2-2}$$

where ρ is density, u_i and u_j are the velocity components, p_{ij} is the stress tensor

$$p_{ij} = -\sigma_{ij} + \delta_{ij} p \tag{1.2-3}$$

where p is the statistic pressure of the flow field, δ_{ij} the Kronecker delta, and σ_{ij} is the viscous stress tensor:

$$\sigma_{ij} = \mu\{\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}(\frac{\partial u_i}{\partial x_i})\delta_{ij}\} \tag{1.2-4}$$

Equations of sound propagation are derived by use of the above mass and momentum conservation equations as:

$$\frac{\partial^2 \rho}{\partial t^2} - a_0^2 \nabla^2 \rho = \frac{\partial^2}{\partial x_i \partial x_j} T_{ij} \tag{1.2-5}$$

$$T_{ij} = \rho u_i u_j + p_{ij} - a_0^2 \rho \delta_{ij} \tag{1.2-6}$$

Mathematically, Equation 1.2-5 is a hyperbolic partial differential equation, which describes a wave propagating at the speed of sound a_0 in a medium at rest, on which fluctuating forces are externally applied in the form described by the right hand side of equation (1.2-5).

Physically, this means that sound is generated by the fluid flow's fluctuating internal stresses acting on an acoustic medium at rest (without flow), and propagated at the speed of sound. Lighthill's analogy separates the analysis of aerodynamic acoustics into two steps. The first step is sound generation induced by fluid flow in any real continuous medium. The second step is sound propagation in a acoustic medium at rest, exerted by external fluctuating sources which are a function of T_{ij}, known from the first step.

The equation of sound propagation has been solved by Lighthill[2] and Curle[1] in the form

$$\begin{aligned} \rho'(\boldsymbol{x}, t) &= \rho(\boldsymbol{x}, t) - \rho_0 \\ &= \frac{1}{4\pi a_0^2} \frac{\partial^2}{\partial x_i \partial x_j} \int_V \frac{T_{ij}(\boldsymbol{y}, t - \frac{R}{a_0})}{R} dV(\boldsymbol{y}) + \frac{1}{4\pi a_0^2} \frac{\partial}{\partial x_i} \int_S \frac{l_j p_{ij}(\boldsymbol{y}, t - \frac{R}{a_0})}{R} dS(\boldsymbol{y}) \end{aligned} \tag{1.2-7}$$

where

$\boldsymbol{x}$	is the acoustic observation point where acoustic quantities are measured.
$\boldsymbol{y}$	is the point in the flow field where sound is generated.
$R = \lvert\boldsymbol{x} - \boldsymbol{y}\rvert$	is therefore the distance between the acoustic observation point and the point in the flow field where sound is generated. (Usually, it is assumed that $\lvert\boldsymbol{x}\rvert \gg \lvert\boldsymbol{y}\rvert$).
l_j	is the unit direction vector of the solid boundary, pointing toward the fluid.
t	is the current observation time measured at $\boldsymbol{x}$.

This equation relates fluctuating stresses in a flow field to the acoustic density oscillation with which conversion from the kinetic energy of fluctuating shearing motion in the flow to the acoustic energy of oscillating longitudinal sound wave can be calculated.

There are some assumptions to this formulation that limit its applicability. These are:

- The sound is radiated into free space.
- The sound induced by fluid flow is weak (i.e., the backward-interaction of acoustic phenomena on the fluid flow is negligible.)
- The fluid flow is not sensitive to the sound induced by the fluid flow.

Lighthill's acoustic analogy is therefore successfully applicable to the analysis of energy "escaped" from subsonic flows as sound, and not to the analysis of the change in character of generated sound which is often observed in transitions to supersonic flow due to high frequency emission associated with shock waves.

$\rho'(\boldsymbol{x})$ can be transformed into a simpler and numerically more tractable form:

$$\begin{aligned}\rho'(\boldsymbol{x},t) &= \rho(\boldsymbol{x},t)-\rho_0\\ &= \frac{1}{4\pi a_0^4}\int_V \frac{(x_i-y_i)(x_j-y_j)}{R^3}\frac{\partial^2}{\partial t'^2}T_{ij}(\boldsymbol{y},t')dV(\boldsymbol{y}) + \frac{1}{4\pi a_0^3}\int_S \frac{(x_i-y_i)l_i}{R^2}\frac{\partial p(\boldsymbol{y},t')}{\partial t'}dS(\boldsymbol{y})\\ &\quad+\frac{1}{4\pi a_0^2}\int_S \frac{(x_i-y_i)l_i}{R^3}p(\boldsymbol{y},t')dS(\boldsymbol{y}) \qquad (1.2\text{-}8)\end{aligned}$$

The first term is derived from the volume integrand in equation (1.2-7), neglecting short distance terms (proportional to inverse of R^4 and R^5). The remaining two terms are derived from the surface integrand in equation (1.2-7). When R is large, the third term is damped faster than the second term. Therefore the second and the third term are called the long and short distance terms respectively. Usually, the distance between the observer's location and the location at which sound generation occurs is large, and the short distance term will not appear in the following formulations.

Pressure variation can be derived by using the isentropic relation

$dp = a_0^2 d\rho$ as

$$\begin{aligned}p'(\boldsymbol{x},t) &= p(\boldsymbol{x},t)-p_0\\ &= \frac{1}{4\pi a_0^2}\int_V \frac{(x_i-y_i)(x_j-y_j)}{R^3}\frac{\partial^2}{\partial t'^2}T_{ij}(\boldsymbol{y},t')dV(\boldsymbol{y}) + \frac{1}{4\pi a_0}\int_S \frac{(x_i-y_i)l_i}{R^2}\frac{\partial p(\boldsymbol{y},t')}{\partial t'}dS(\boldsymbol{y})\end{aligned} \qquad (1.2\text{-}9)$$

where ρ_0 is constant atmospheric density.

1.3 Intensity and Spectral Density of The Sound

1.3.1 Intensity of Sound

Intensity of sound at an observation point is defined as:

$$\begin{aligned} I(\boldsymbol{x}) &= \frac{{a_0}^3}{\rho_0}\overline{(\rho(\boldsymbol{x})-\rho_0)^2} \\ &= \frac{1}{\rho_0 a_0}\overline{(p(\boldsymbol{x})-p_0)^2} = \frac{1}{\rho_0 a_0} < p'^2 > (\boldsymbol{x}) \end{aligned}$$

The units of I are W/m^2 or $J/s/m^2$. Intensity of sound $I(\boldsymbol{x})$ represents the acoustic energy received at point $\boldsymbol{x}$ in the unit time and per unit area. If $I(\boldsymbol{x})$ is integrated around a large sphere surface which includes the solid obstruction under observation, the total amount of acoustic power (W) radiated from the surface of the obstruction can be obtained.

It is clear that intensity of sound is related to the mean-square acoustic pressure $< p'^2 > (\boldsymbol{x})$, which can be defined from auto-correlation of the acoustic pressure as

$$C(\tau) = \lim_{T-\infty} \frac{1}{T}\int_{-T/2}^{T/2} p'(\boldsymbol{x},t)p'(\boldsymbol{x},t+\tau)dt =< p'^2 > (\boldsymbol{x},\tau) \qquad (1.3\text{-}1)$$

Letting $\tau = 0$, yields

$$< p'^2 > (\boldsymbol{x},0) =< p'^2 > (\boldsymbol{x}) \qquad (1.3\text{-}2)$$

Intensity of sound can be expressed as Sound Pressure Level relative to base sound pressure p_0 set at 2×10^{-5} (Pa) as follows:

$$SPL = 10\log_{10}\frac{I}{I_0} \qquad (dB) \qquad (1.3\text{-}3)$$

$$I_0 = \frac{{p_0}^2}{\rho_0 a_0} \qquad (W/m^2) \qquad (1.3\text{-}4)$$

$$SPL = 10\log_{10}\frac{< p'^2 >}{{p_0}^2} \qquad (dB) \qquad (1.3\text{-}5)$$

In Lighthill's and Curle's dimensional analysis of sound production, the intensity of sound generated by quadrupoles I_Q varies nearly as

$$I_Q \sim \rho_0 {U_0}^8 {a_0}^{-5} L^2 \tag{1.3-6}$$

where U_0 is a typical flow velocity in the flow field, and L is a typical dimension of the solid bodies.

The intensity of sound generated by the dipoles I_D is on the order of

$$I_D \sim \rho_0 {U_0}^6 {a_0}^{-3} L^2 \tag{1.3-7}$$

From equation (1.3-6) and (1.3-7), it follows that

$$\frac{I_Q}{I_D} \sim \left(\frac{U_0}{a_0}\right)^2 \tag{1.3-8}$$

Apparently, at low Mach numbers ($M = \frac{U_0}{a_0} < 1$), the contribution to the sound generation from dipoles dominates over that from quadrupoles.

1.3.2 Spectral Density and Power Spectral Density of Sound

Investigation of frequency components for a given acoustic pressure variation $p'(\boldsymbol{x})$ is necessary to analyze the characteristics of the sound generated in flows. The range of audible sound frequencies is about 20Hz-20kHz. To reduce the acoustic energy of noise within this frequency range is one of the major tasks of acoustics engineering. To accomplish this and other tasks in acoustics engineering, it is necessary to understand the mechanisms of how sound frequencies relate with fluctuating stresses in fluid flows.

For a given acoustic pressure oscillation $p'(\boldsymbol{x}, t)$, measured at point $\boldsymbol{x}$, a spectral density $P(f)$ can be defined as the Fourier transform pair with the acoustic pressure

$$p'(\boldsymbol{x}, t) = \int_{-\infty}^{\infty} P(f) e^{i2\pi f \tau} df \tag{1.3-9}$$

$$P(f) = \int_{-\infty}^{\infty} p'(\boldsymbol{x}, t) e^{-i2\pi f t} dt \tag{1.3-10}$$

where f is the frequency in Hz.

The auto-correlation of acoustic pressure is

$$< p'^2 > (\boldsymbol{x}, \tau) = \int_{-\infty}^{\infty} p'(\boldsymbol{x}, t) p'(\boldsymbol{x}, t + \tau) dt \tag{1.3-11}$$

The Fourier transform pair of the auto-correlation is

$$< p'^2 > (\boldsymbol{x}, \tau) = \int_{-\infty}^{\infty} \Phi_p(f) e^{i2\pi f \tau} df \qquad (1.3\text{-}12)$$

$$\Phi_p(f) = \int_{-\infty}^{\infty} < p'^2 > (\boldsymbol{x}, \tau) e^{-i2\pi f \tau} d\tau \qquad (1.3\text{-}13)$$

where $\Phi_p(f)$ is called power spectral density function. By using a correlation theorem, $\Phi_p(f)$ can be expressed as:

$$\Phi_p(f) = P(f)P^*(f) \qquad (1.3\text{-}14)$$

where $P^*(f)$ is the conjugate of $P(f)$.

Letting $\tau = 0$, the auto-correlation becomes the mean-square acoustic pressure which is expressed as:

$$\begin{aligned} < p'^2 > (\boldsymbol{x}) &= \int_{-\infty}^{\infty} \Phi_p(f) df \\ &= \int_{-\infty}^{\infty} P(f)P^*(f) df = \int_{-\infty}^{\infty} |P(f)|^2 df \end{aligned} \qquad (1.3\text{-}15)$$

This equation is known as Parseval's Theorem. It states that the energy in a waveform $p'(\boldsymbol{x}, t)$ obtained by integration over the entire time domain is equal to the energy of $P(f)$ obtained by integration over the entire frequency domain.

It is apparent that the power spectral density function $\Phi_p(f)$ expresses the contribution to the mean-square acoustic pressure from each frequency component of acoustic energy.

The following example illustrates the application of the derived equations for an acoustic pressure expressed as a single cosine mode with a frequency of f_0.

$$p'(t) = A \cos(2\pi f_0 t) \qquad (1.3\text{-}16)$$

where $f_0 = \frac{1}{T}$, and T is the length of sampling time of the surface pressure.

The Fourier transform of $p'(t)$ is

$$P(f) = \int_{-\infty}^{\infty} A \cos(2\pi f_0 t) e^{-i2\pi f t} dt = \frac{A}{2}\delta(f - f_0) + \frac{A}{2}\delta(f + f0) \qquad (1.3\text{-}17)$$

According to the Parseval Theorem (1.3-15), the power spectral density function $\Phi_p(f)$ can be expressed as

$$\Phi_p(f) = [P(f)]^2 = \left(\frac{A}{2}\right)^2 \delta(f - f_0) + \left(\frac{A}{2}\right)^2 \delta(f + f_0) \tag{1.3-18}$$

and the waveform energy in the time domain can be calculated from energy integration in the frequency domain:

$$< p'^2 >= \int_{-\infty}^{\infty} \Phi_p(f) df = 2\left(\frac{A}{2}\right)^2 = \frac{A^2}{2} \tag{1.3-19}$$

In engineering applications, it is common practice to only show the power spectral density function in the range of $f \geq 0$ with the part of $f \leq 0$ folded and superimposed on to the range of $f \geq 0$. Therefore, the plotted power spectral density function is expressed as

$$\Phi_p(f)_{fold} = 2\left(\frac{A}{2}\right)^2 \delta(f - f_0) = \frac{A^2}{2}\delta(f - f_0) \tag{1.3-20}$$

This equation states that waveform energy at frequency f_0 is equal to the waveform energy of the time domain. The waveform energy in the frequency domain can be further expressed in dB:

$$\Phi_p(f)_{fold} = 10 \log_{10} \frac{A^2}{2{p_0}^2}\delta(f - f_0) \qquad (dB) \tag{1.3-21}$$

1.4 Dipole Sound Strength Distribution on Surface

1.4.1 Surface Dipole Radiation

For flows at low Mach number, where the volume generated noise from quadrupoles is weak, the surface integral will dominate in equation (1.2-9). Furthermore, if the surfaces are stationary or in rigid steady motion, $u_n = 0$, giving

$$p'(\boldsymbol{x}, t) = \frac{1}{4\pi a_0} \int_S \frac{(x_i - y_i)l_i}{R^2} \frac{\partial p(\boldsymbol{y}, t')}{\partial t'} dS(\boldsymbol{y}) \tag{1.4-1}$$

The noise is then generated primarily from a dipole source on the surface. The dipole source is associated with stress fluctuations due to viscous shear stress and local surface pressure fluctuation p_s. In case that the viscous stress component σ_{ij} is small compared with p_s, acoustic pressure variation can be expressed by its relation with the fluctuating surface pressure:

$$p'(\boldsymbol{x},t) = \frac{1}{4\pi a_0}\int_S \frac{(x_i - y_i)l_i}{R^2}\frac{\partial p_s(\boldsymbol{y},t')}{\partial t'}dS(\boldsymbol{y}) \tag{1.4-2}$$

1.4.2 Surface Dipole Strength

If both sides of equation (1.4-2) are multiplied with acoustic pressure variation at a delayed time $t_\tau = t + \tau$, taking a time average yields auto-correlation of pressure:

$$\begin{aligned} &< p'(\boldsymbol{x},t)p'(\boldsymbol{x},t+\tau) >= \\ &= \frac{1}{4\pi a_0}\int_S \frac{(x_i - y_i)l_i}{R^2}\left\{\frac{1}{T}\int_{-T/2}^{T/2}\frac{\partial p_s(\boldsymbol{y},t')}{\partial t'}p'(\boldsymbol{x},t'+\tau+\frac{R}{a_0})dt'\right\}dS(\boldsymbol{y}) \\ &= \frac{1}{4\pi a_0}\int_S \frac{(x_i - y_i)l_i}{R^2} < \frac{\partial p_s(\boldsymbol{y},t')}{\partial t'}p'(\boldsymbol{x},t'+\tau+\frac{R}{a_0}) > dS(\boldsymbol{y}) \end{aligned} \tag{1.4-3}$$

For a stationary random process, the cross-correlation can be expressed as:

$$< p'(\boldsymbol{x})p'(\boldsymbol{x},\tau) >= \frac{-1}{4\pi a_0}\int_S \frac{(x_i - y_i)l_i}{R^2}\frac{\partial}{\partial \tau} < p_s p' > (\boldsymbol{y},\boldsymbol{x},\tau + \frac{R}{a_0})dS(\boldsymbol{y}) \tag{1.4-4}$$

Restricting attention to mean-square acoustic pressure ($\tau = 0$), yields

$$< p'^2(\boldsymbol{x}) >= \frac{-1}{4\pi a_0}\int_S \frac{(x_i - y_i)l_i}{R^2}\frac{\partial}{\partial \tau} < p_s p' > (\boldsymbol{y},\boldsymbol{x},\frac{R}{a_0})dS(\boldsymbol{y}) \tag{1.4-5}$$

Thus the fraction of $< p'^2(\boldsymbol{x}) >$ associated with unit surface area at the point where p_s was measured is

$$\frac{d < p'^2(\boldsymbol{x}) >}{dS} = \frac{(x_i - y_i)l_i}{4\pi a_0 R^2}\frac{\partial}{\partial \tau} < p_s p' > (\boldsymbol{y},\boldsymbol{x},\frac{R}{a_0}) \tag{1.4-6}$$

By measuring p_s at various points on the surface and the cross-correlation between $p_s(\boldsymbol{y},t)$ and acoustic pressure $p'(\boldsymbol{x},t)$, the complete distribution of surface dipole strength is obtained.

Chapter 2. Using the Aero-Noise Model

This chapter provides an overview of the setup and use of all options and parameters within the aero-noise model in FLUENT.

2.1 Introduction

In FLUENT's Aero-Noise Model, Lighthill's Acoustic Analogy is applied to the prediction of the flow induced noise. Two kinds of aero-noise are assumed in a fluid flow: the aero-noise from quadrupole sources induced from free shear layer, and that from dipole sources generated from pressure variation on the surface of obstructions in the fluid flow. In Lighthill and Curle's dimensional analysis of sound production, it is shown that, at low Mach number ($M < 1$), the contribution to the sound generation from dipoles dominates over that from quadrupoles.

In the current model, only Curle's formulation for the dipole sound generation is used. See Chapter 1 for details.

To precisely predict the aero-noise using Curle's formulation, the variation of the surface pressure needs to be calculated accurately. This is obtained by performing Large Eddy Simulation (LES) in FLUENT. The instantaneous surface pressure data on each cell face on the sound generation obstruction surface is stored in a data files by using DEFINE_ADJUST UDFs. The surface pressure data is then used for aero-noise calculation by means of an Execute On Demand UDF. Both UDFs should be used as compiled. When you expand the relevant file provided with this module (by tar or unzip depending on your platform) in your working directory, you will obtain the libudf directory containing the necessary libraries, and the lib directory containing the scheme file acoustic_par.scm.

2.2 Using the Aero-Noise Prediction Model

2.2.1 Installing the Aero-Noise Prediction Model

The aero-noise prediction model consists of a number of user-defined functions (UDFs) and scheme routines which need to be loaded and activated before calculations can be performed. These files are provided with your standard installation of FLUENT. They can be found in your installation area in a directory called addons/acoustics1.1. In order to load these files, you will need to either provide the complete path to your installation area when loading, or create a local copy of the files (or a link for UNIX platforms).

Installing the Aero-Noise Prediction Model on Unix/Linux Platforms

To install the aero-noise model on Unix and Linux platforms, it is recommended that you create links in your local working directory to the files you will need. This can be done with the commands:

```
ln -s <path>/addons/acoustics1.1/lib/acoustic_par.scm  acoustic_par.scm
ln -s <path>/addons/acoustics1.1 libudf
```

where <path> represents the location in the file system where FLUENT is installed.

Installing the Aero-Noise Prediction Model on NT/Windows Platforms

To install the aero-noise model on Windows platforms, you will need to create copies of the aero-noise model folder and the files you will need in your local working folder. From your installation area, you will have to copy the folder

```
<path>\addons\acoustics1.1
```

locally and rename it to libudf. Inside this folder are three different ports of the acoustics module, one for each type of parallel message passing supported (net, smpi and vmpi). You will need to select one of the folders; ntx86_net, ntx86_smpi, or ntx86_vmpi you wish to use and rename it as ntx86. If you are only running in serial mode, you can rename any of the folders.

You will also need to copy the files

```
<path>\addons\acoustics1.1\lib\acoustic_par.scm
```

locally. Note that <path> represents the location in the file system where FLUENT is installed.

2.2.2 Setup and Solution Procedure

Before you perform the aero-noise calculation, a LES flow field solution has to be run to a "dynamically steady state". In order to specify the time step size for both the initial LES calculation and the subsequent acoustic analysis, you must consider two factors. The time step size required to appropriately resolve the turbulent eddies in a LES computation, and the time step size required to appropriately capture the audible sound range. The smaller of the two time steps will dictate the time step required for the acoustic analysis. As far as the LES calculation is concerned, it is recommended to specify a time step size δt such that the Courant number for the flow is everywhere less than 1

$$\delta t = C\frac{\delta x}{u} \tag{2.2-1}$$

where $C < 1$ is the local Courant number, δx and u are the local cell size in the direction of the highest velocity component, and highest velocity component, respectively. The time step δt calculated using Equation 2.2-1 can be much smaller than is needed to resolve the high frequency end of the spectrum of audible sound (i.e., $\delta t << t = 1/f$, $f = 20kHz$). In a real-world engineering analysis a bigger time step may have to be specified to improve computational performance. The effect of a bigger time step is that a portion of the acoustic energy will be neglected in the higher frequency range. The time step should not be taken so large as to significantly affect the power spectrum of sound pressure. Note that numerical instability will not arise when using a time step corresponding to a Courant number greater than 1, because implicit temporal discretization is used. See section 10.7 of the User's Guide for more information about the LES model in FLUENT.

After a LES calculation for your flow field has been executed to a "dynamically steady state" (i.e., when statistics of flow variables don't change anymore), you can begin the setup to save the instantaneous pressure on the sound generation wall surface. A scheme file acoustic_par.scm which will generate the Acoustic Parameters panel needs to be loaded

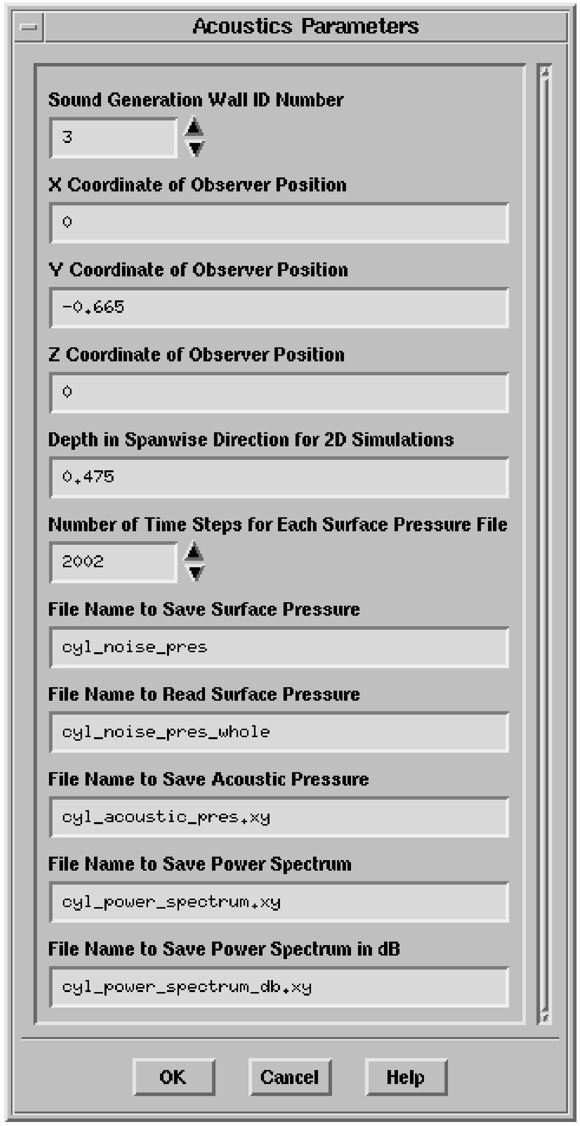
File ⟶ Read ⟶ Scheme...

In the File Selection dialog box, select acoustic_par.scm, normally located in the lib subdirectory.

Save Surface Pressure

Open the Acoustic Parameters panel

Define ⟶ User-Defined ⟶ Acoustic Parameters...



1. Set up the inputs for the aero-noise simulation according to the following guidelines

   Sound Generation Wall ID Number: Currently, all walls that generate sound need to be grouped up into a single zone with a single ID number. You can find out the ID number for a particular zone in the Define Boundary Conditions panel.

   X,Y,Z Coordinates of Observer Position: The position for the calculation of Acoustic Pressure and Sound Pressure Level.

Depth in Spanwise Direction for 2D Simulation: This value is only used for acoustic calculations, and does not change the default depth value in 2D flow simulation. The default value in the acoustic calculation is `1.0` m. In 3D acoustic calculations, this value will be ignored.

Number of Time Steps for Each Surface Pressure File: It is recommended to save the surface pressure data for a calculation with a large number of time steps into several separate files with smaller numbers of time steps.

File Name to Save Surface Pressure: Root name of the surface pressure files is required. The saved surface pressure file name will be the root name followed by a hyphen and a number which is the number of the last time step in that file.

2. Click OK to save your settings and close the panel.

You will return to the Acoustic Parameters panel at next step for aero-noise calculation.

To store the values of surface pressure that will be used for the aero-noise calculations, you need to allocate 1 user-defined memory location

Define ⟶ User-Defined ⟶ Memory...

Specify 1 for Number of User-Defined Memory Locations. The allocated user-defined memory will be used as an auxiliary array to save surface pressure in the save-pressure-adjust UDF and then be used later to save the distribution of Surface Dipole Strength on the sound generation wall surface in cal-sound UDF.

To activate the UDFs that will be used by the aero-noise model, you will use the User-Defined Function Hooks panel

Define ⟶ User-Defined ⟶ Function Hooks...

Under Adjust Function, select save-pressure-adjust and click OK to activate the UDF to save surface pressure values of all cell faces on the sound generating wall surface(s) at each time step. Data will be saved once the solution is started. Note that the above procedure will be the same for both serial and parallel calculations.

! There is a limit to the minimum number of time steps according to the sound calculation scheme. The minimum number of time steps needs to be larger than $n = T/dt$, where T is the sound transmission time through the distance L, which is roughly the length scale of the sound generating surface, and dt is the time step size applied in the unsteady flow simulation. If the number of time steps is smaller than the required minimum number, a warning will be displayed along with the indication of the minimum number of time steps required:

```
Warning: Number of Time Steps of The Input Surface
Pressure Data Must Be Larger Than: <n>.
```

Calculate Aero-Noise

Once the unsteady LES calculation is finished, you need to concatenate the separate surface pressure files into one single input file for the subsequent aero-noise calculation. Open the Acoustic Parameters panel again, and finish the input in this panel using the following directions:

File Name to Read Surface Pressure: A name of a single surface pressure file. If the surface pressure is saved in several separate files such as filename1, filename2, etc., you will need to concatenate the files into one. For example, on a Unix machine you can do so by typing: `cat filename1 filename2 > filename1+2`.

File Name to Save Acoustic Pressure: This file will be saved for XY-plots to display acoustic pressure.

File Name to Save Power Spectrum: This file will be saved for XY-plots of power spectrum of acoustic pressure in units of Pa^2.

File Name to Save Power Spectrum in dB Unit: This file will be saved for XY-plots of power spectrum of acoustic pressure in dB.

Remember to click OK to save your settings and close the panel.

Note that currently, while you can directly execute the cal-sound UDF in the serial version of FLUENT at this step, in the parallel version of the solver you still were able to use the DEFINE_ADJUST UDF to save surface pressure, but can not use the cal-sound Execute On Demand UDF to calculate aero noise.

In a parallel session of FLUENT save your case and data files, exit the parallel version of the solver, start a serial FLUENT session, read in the Scheme file for defining the Acoustic Parameters panel (acoustic_par.scm), and then read in the case and data files you just saved.

! All inputs in the Acoustic Parameters panel are also saved in the case file. Thus, for an existing case, you need to read in the Scheme file for defining the Acoustic Parameters panel before reading in case and data files, to avoid a segmentation error in FLUENT.

Define ⟶ User-Defined ⟶ Execute On Demand...

Select the cal-sound UDF and click Execute. The UDF will calculate Acoustic Pressure, Power Spectrum (in dB), Sound Pressure Level and Surface Dipole Strength.

2.3 Postprocessing an Aero-Noise Solution

You can perform postprocessing on an aero-noise solution using the postprocessing tools and options available in FLUENT. Some additional variables will be available for postprocessing as described below. This section highlights only some of the suggested procedures to display and plot the most relevant results obtained from an aero-noise simulation in FLUENT.

To inspect the Acoustic Pressure:

Plot ⟶File...

Click on Add, and select the relevant file name for the acoustic pressure. Click on Plot in the File XY Plot panel.

To inspect the Power Spectrum (both in units of Pa^2 and in dB):

Plot ⟶File...

Click on Add, and select the relevant file name for the power spectrum. Click on Plot in the File XY Plot panel.

To inspect the Sound Pressure Level:

This value will be printed in FLUENT's console window.

To inspect the Surface Dipole Strength:

Display ⟶Contours...

1. In the Contours Of drop-down list, select User-Defined-Memory and udm-0.
2. Under Surfaces, select the sound generating surface(s).
3. Turn on the Filled option, and turn off Node Values.
4. Click on Display.

Note that the Surface Dipole Strength values are stored in the first layer of cells on the sound generating wall, thus the use of cell values.

2.3.1 Limitations

Currently, only Curle's sound calculation formulation is implemented in FLUENT's aero-noise UDF-based model. The model is only applicable to aero-noise predictions for subsonic external flows such as the flow surrounding vehicles. It is not applicable to aero-noise predictions for internal flows such as flows in mufflers, or to the flows in rotating machinery such as the flows surrounding fans.

Bibliography

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