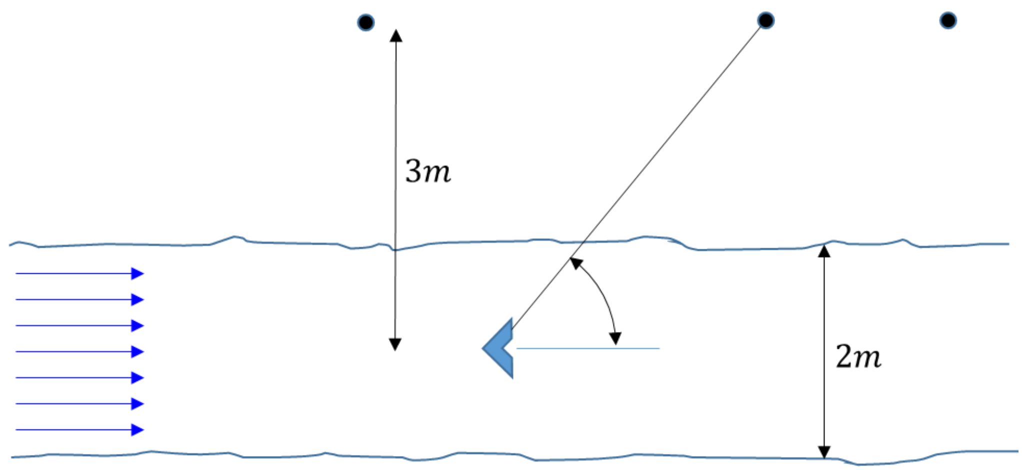
Chapter 10

10.1 The sound radiated by a model placed at the center of a 2-m wide open jet test section in a flow of Mach number 0.45 is recorded by 3 microphones placed outside the flow. The microphones are positioned on a line 3m from the test section centerlines at directivity angles that, when corrected for refraction, are 30, 60 and 100 degrees respectively. Determine the actual angles of the microphones θ_m. At 3kHz the microphones record sound pressure levels (based on the spectral density per Hz) of 80, 83, and 90dB respectively. Correct these SPLs for the presence of the shear layer. It is recommended that you write a



short Matlab code to determine the results. *Hint: Several inverse trigonometric functions in Matlab return answers between* $-\pi/2$ *and* $\pi/2$*. Be aware that this may not match the ranges of some angles in this problem.*

10.2 An in-flow microphone placed on a stand is being used to measure the sound produced by a model in a wind tunnel test section at standard sea level conditions.

(a) Write a list of items that the experimentalist should consider here in order to maximize the accuracy and signal to noise ratio of the measurement, both in terms of the hardware or hardware arrangement, and in terms of the data reduction.

The microphone is positioned 1-m directly upstream of the model which is a small bluff body. In the first test, the body sheds vortices producing an unsteady force on the flow at this point of amplitude $0.2\ N$ and direction aligned along the flow at a frequency of $10\ kHz$.

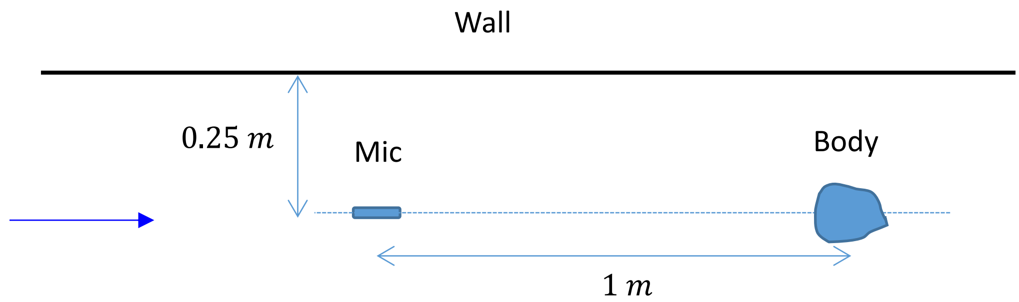
(b) Is the mic in the far-field of this acoustic source? Quantitatively justify your answer.
(c) How small does the microphone diaphragm need to be to be acoustically compact?

Assuming the tunnel walls are perfectly anechoic, and ignoring any scattering by the mic mount:

(d) Estimate the SPL at the microphone for the first test, ignoring convection by the flow

A hard-wall is placed in the test section parallel to the flow and 0.25-m from both the mic and the model, as shown

(e) Estimate the effect of the wall on your answer to part (d) above, giving the SPL at the microphone in this case



Worked example solution

Solution Problem 10.2

(a)

- Mic stand should be designed for low noise – e.g. with airfoil section that doesn't shed vorticity
- Mic should be mounted (on a streamwise sting) as far upstream of the stand as possible
- Mic should face upstream regardless of direction of sound
- Mic should be fitted with a nose cone
- Sound spectra will need to be corrected for the modified directivity at high frequencies that results from the nose cone

(b) $kr = \frac{2\pi f}{c_o} = \frac{20000\pi}{340} = 184 \gg 1$ therefore mic is easily in the far field

(c) $kd \ll 1$ so $d \ll \frac{c_o}{2\pi f} = \frac{1}{184}$ so the mic needs to be significantly less than 5.4mm in diameter.

(d) Using equation 4.4.7 we have,

$$p' = \frac{x_i}{4\pi|\mathbf{x}|^2 c_\infty}\frac{\partial F_i}{\partial t}$$

Now $F_1 = Re\{0.2e^{-i\omega t}\}$ Newtons, so

$$\partial F_1/\partial t = Re\{-i\omega 0.2e^{-i\omega t}\} = -2\pi \times 10{,}000 \times 0.2 \times \sin(\omega t) = -12566\sin(\omega t)$$

And therefore

$$p' = \frac{-1}{4\pi 340}12566\, sin(\omega t) = 2.94\, sin(\omega t)$$

So,

$$SPL = 20\log_{10}\left(\frac{2.94}{2\sqrt{2}\times 10^{-5}}\right) = 100.3dB$$

(e) Microphone will also hear sound from image source for which $\frac{x_i}{|\mathbf{x}|^2} = \frac{1}{1+0.5^2} = 0.8$. Also we have to account for the fact that $\frac{\partial F_i}{\partial t}$ in 4.4.7 is calculated at the retarded time, $t - r/c_o$. Thus there will be a phase lag between the source and its image of $\frac{\Delta r}{c_o} = \frac{\sqrt{1+0.5^2}-1}{340.3} = 0.00073$ secs. Thus, the sound at the microphone will be

$$p' = 2.94\, sin(\omega t) + 2.94 \times 0.8 \sin(\omega t - \omega 0.000347)$$

$$= 2.94\, sin(\omega t) + 2.94 \times 0.8\sin(\omega t)\cos(\omega 0.000347) - 2.94 \times 0.8\cos(\omega t)\sin(\omega 0.000347)$$

$$= (2.94 + 2.94 \times 0.8\cos(\omega 0.000347))\, sin(\omega t) - 2.94 \times 0.8\sin(\omega 0.000347)\cos(\omega t)$$

Which has an amplitude of $\sqrt{(2.94 + 2.94 \times 0.8\cos(\omega 0.000347))^2 + (2.94 \times 0.8)^2 \sin(\omega 0.000347)^2}$

$= \sqrt{0.402 + 0.214} = 0.784\, Pa$. So,

$$SPL = 20\log_{10}\left(\frac{0.784}{2\sqrt{2}\times 10^{-5}}\right) = 88.9dB$$