Acoustic Scattering of Point Sources by a Moving Prolate Spheroid

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Abstract

THIS paper contains a numerical prediction of body-scattering effects on aircraft flyover noise. A simple model consisting of a moving prolate spheroid with trailing acoustic point sources is used to represent the complicated physical system of a subsonic jet aircraft flyover. Classical theories of scattering and diffraction are used to predict sound pressure levels on an imaginary plane below the body.

This technique was developed for application in the study of installation effects for static and moving jets. Several approaches for calculating the scattered field of an acoustic point source near a stationary prolate spheroid are available, for example, Refs. 1 and 2. The method of geometric optics was selected because it provides solutions in a minimum amount of computer time and allows for sources off the axis of symmetry. Using the Lorentz transform described in Ref. 3, the scattered field of a moving body and source can be determined from an equivalent stationary problem.

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Consider an acoustic point source near the end of a slender prolate spheroid where source and body are moving at a constant forward speed, Fig. 1. The rectangular coordinate axes x and y fall on the major and minor axes of the body. An imaginary observer plane is below and parallel to the x-y plane. The intersection of the z axis with this observer plane is defined as a reference point; all sound pressure levels (SPL) presented herein are normalized with respect to the SPL at the reference point. Figure 1 also indicates the position of the geometric shadow region. Only diffracted rays contribute to the solution in this region, whereas incident and scattered rays dominate the solution elsewhere.

Geometric optics solutions are appropriate for high frequencies, that is, for frequencies whose wavelengths are considerably smaller than the dimensions of the body. The usual measure of normalized frequency is the product of the wave number ($k = 2\pi f/c$) and the semimajor axis length a. A ka value of 50 is considered high. A comparison of geometric optics solution with other experimental and numerical results in Ref. 2 shows that geometric optics is very reliable except in the shadow region. Fortunately, in the present study, SPL values in the shadow region are not as important as those values near the reference point.

Contouring of computed results demonstrate the significance of scattering and motion effects on flyover data. Normalized SPL are calculated for a grid of points on an observer plane, which is a distance of $20a$ below the body. A standard computer software routine is used to draw equal level contours for the data. Contours for a stationary point source are concentric circles with the highest SPL occurring at the reference point. When the prolate spheroidal body is added to the model, the circular contours are deformed. Further change occurs when body and source are set in motion.

Figure 2 illustrates how an SPL contour is affected by body scattering and forward motion. In the right-hand frame of the figure, the contours for a stationary point source with and without body are compared. In the next two frames, the stationary body and source contour is compared with contours for the body and source moving at Mach 0.3 and 0.6. As body and source move at higher Mach numbers, the SPLs in the forward half of the observer plane increase, while levels in the other half of the plane decrease.

Further information about the effects of motion is available through directivity plots. Sound pressure levels calculated at points on the centerline of the observer plane are plotted against emission angle, as illustrated in Fig. 3. Again, at higher Mach numbers, it is evident that SPL increases in the forward half-plane and decreases in the rear half-plane.

Figure 3 illustrates the effect of forward motion on directivity curves, but does not indicate the effects of scattering on these curves. To show the latter effect, directivity plots for moving sources with and without the scattering body

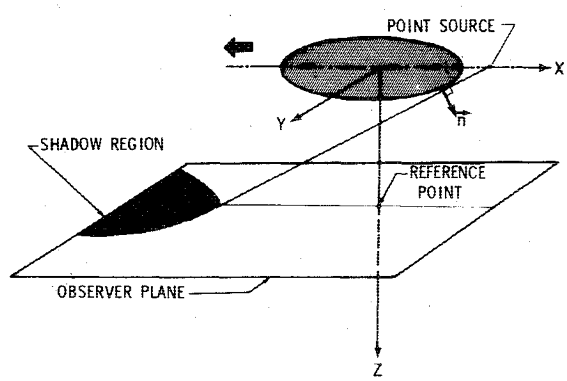

Fig. 1 Acoustic scattering configuration.

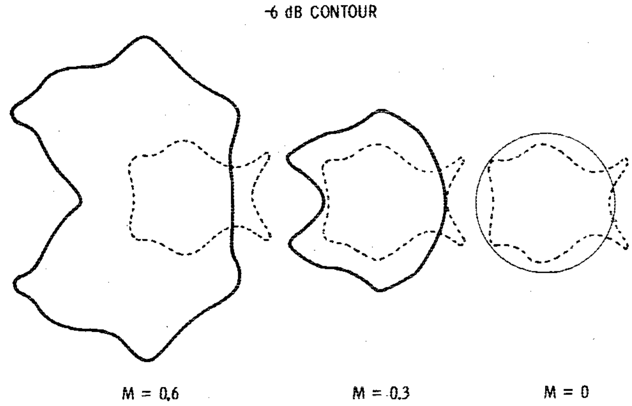

Fig. 2 Mach number effects on SPL in observer plane $z/a = 20$ ($ka = 1000$, $b/a = 0.1412$).

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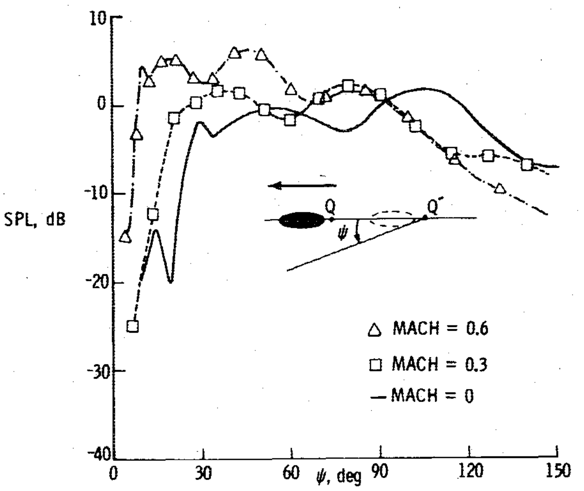

Fig. 3 SPL vs emission angle at $z/a=20$, $y/a=0$ for several Mach numbers ($ka=200$, $b/a=0.1412$).

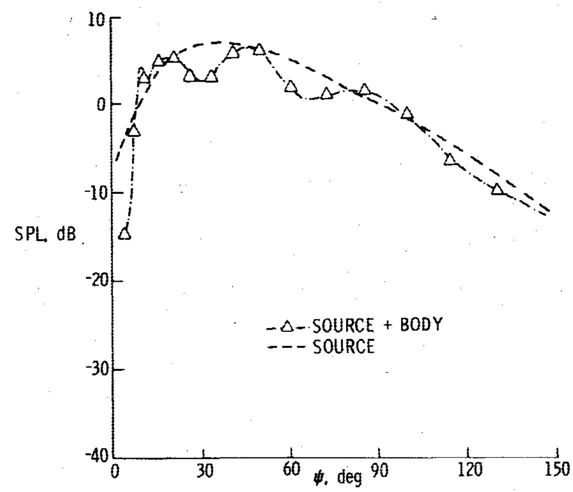

Fig. 4 Effects of body scattering at $M=0.6$ ($z/a=20$, $y/a=0$, $ka=200$, $b/a=0.1412$).

must be compared. Figure 4 is one such comparison. By studying many such plots at various frequencies and Mach numbers, a trend is apparent. When the Mach number is very small, the source and body curve oscillates around the source-only curve. However, as Mach number increases, the source and body curve shifts below the source-only curve. This indicates that sound from the point source is scattered away from the centerline of the observer plane as the Mach number increases. Thus, it is evident that the effect of body scattering is not a constant effect, but rather it changes with the forward velocity of body and source.

The application of these results to measured flyover data is not justified. Although the body shape, source frequencies, and forward motion reflect characteristic aircraft conditions, other variations, such as shear flow around the body and source distribution, are neglected. Even so, the fact that acoustic scattering is effected by motion suggests that installation effects may be significant and deserve further experimental and theoretical study.

References

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