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NASA TM - 73,261

(NASA-TM-73261)	ACCURACY OF	THE KIRCHOFF	N77-30906
FORMULA IN DETERI	MINING ACOUST	CIC SHIELDING	
WITH THE USE OF 1	A FLAT PLATE	(NASA) 20 p HC	
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ACCURACY OF THE KIRCHOFF FORMULA IN

DETERMINING ACOUSTIC SHIELDING WITH

THE USE OF A FLAT PLATE

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August 1977



ACCURACY OF THE KIRCHOFF FORMULA IN DETERMINING ACOUSTIC SHIELDING WITH THE USE OF A FLAT PLATE

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Ames Research Center and Ames Directorate, USAAMRDL

INTRODUCTION

In recent years, the desire for reducing aircraft noise has begun to play an increasingly important role in the design of current and proposed commercial and military jet aircraft. The main source of noise on most jet aircraft is the jet engine exhaust. The interaction of this noise with the other surfaces of the aircraft, notably the wings, has a definite effect on the total acoustic signature produced. Numerous studies have suggested that if the jet engines of various aircraft were placed at appropriate locations above the wing instead of below it, the wing would provide a partial shielding of the noise generated by the engines relative to observers on the ground.

As a result of these findings, further experimental and analytical studies are being conducted in order to better understand and eventually predict this shielding in a given situation. The purpose of this study was to analytically predict the shielding effect of an idealized three-dimensional barrier in the presence of an idealized engine noise source by means of the well-known Kirchoff formula. In addition, the results were compared with experimental measurements (ref. 1).

The wing was represented in the analysis by a rectangular flat plate and the engine noise source by a point source. Calculations of the shielding effect were performed for various plate sizes, shapes, locations, and for several point source frequencies ranging from 100 Hz. to 20 kHz. The results are presented in terms of the difference in decibel (dB) level of the shielded versus unshielded situations.

On the following pages the method of analysis is described, the results presented, and conclusions drawn.

METHOD OF ANALYSIS

The acoustic shielding of a point source by a rectangular flat plate was calculated by means of the Kirchoff formula (ref. 2). This formula resulted from assuming that the values for the velocity potential and the

*Contractor

the normal velocity on a diffractor may be replaced by the free-field values induced by the source on the "illuminated" side, and by zero on the "shadow" side.

Basic Equations and Boundary Conditions

The problem under consideration is described by the wave equation

$$\Delta \phi = \frac{1}{c^2} \phi_{tt}$$

with suitable boundary conditions on the surface ∂S of the diffractor, and at infinity, where

 ϕ = velocity potential,

c = speed of sound in air,

t = time.

For a periodic acoustic wave, the velocity potential ϕ can be expressed by

$$\phi = ue^{-ikct}$$

where

 $k = wave constant 2\pi/\lambda$,

 λ = wave length of the acoustic waves,

and $\,u\,$ is independent of time. Substituting this expression for $\,\varphi\,$ into the wave equation gives

$$\nabla^2 \mathbf{u} + \mathbf{k}^2 \mathbf{u} = \mathbf{0}$$

which is the Helmholtz equation. For a given point source u_0 , it can be shown by Green's theorem that

$$u(P) = u_{0}(P) + \frac{1}{4\pi} \int_{\partial S} \left[u(Q) \frac{\partial}{\partial n} \frac{e^{ikr}}{r} - \frac{e^{ikr}}{r} \frac{\partial u(Q)}{\partial n} \right] dS(Q)$$
(1)

providing, of course, that u satisfies the Sommerfeld condition at infinity, where

 $\partial S = surface$ of the diffractor,

P = arbitrary point in the field,

 $n = inward normal to \partial S$,



r = |Q-P|,

Q = arbitrary point on the surface of the diffractor.

The acoustic shielding (Δ SPL) for a given point in space is defined to be the difference in dB level between the shielded and unshielded cases, i.e.,

$$\Delta SPL = 20 \log_{10} \left| \frac{u(P)}{u_o(P)} \right|$$
(2)

where the acoustic pressure p is defined as

$$p(P) = -ik\rho_0 U(P)$$

and

c = speed of sound in air,

 ρ_0 = reference density of air.

The Kirchoff Formula

By applying the Kirchoff assumptions discussed above, the Helmholtz-Huygens integral representation yields the formula

$$u(P) \approx u_{0}(P) + \frac{1}{4\pi} \int_{\partial S_{1}}^{0} \left\{ -u_{0}(Q) \frac{\partial}{\partial n} \frac{e^{ikr}}{r} + \frac{e^{ikr}}{r} \frac{\partial}{\partial n} \left[u_{0}(Q) \right] \right\} dS(Q)$$
(3)

where ∂S_i denotes the illuminated side of ∂S .

For the problem under consideration, the incident acoustic source is a point source, i.e.,

$$u_0(Q) = \frac{e^{ikr_1}}{r_1}$$

where $r_1 = |Q-R|$, and R is the location of the point source, and the diffractor is a rectangular flat plate of width W and length L. Hence, referring to the coordinate system of figure 1, equation (3) becomes

$$u(P) \approx \frac{e^{ikr_2}}{r_2} + \int_0^{\infty} \int_0^{\infty} \frac{e^{ik(r_1+r)}}{r_1r} \left[\frac{Z(R)}{r_1} \left(ik - \frac{1}{r_1} \right) - \frac{Z(P)}{r} \left(ik - \frac{1}{r} \right) \right] dy(Q) dx(0)$$
(4)

where

 $\mathbf{r}_2 = \mathbf{P} - \mathbf{R}$,

Z(Q) = 0.

Based upon the literature, it is rather difficult, if not impossible, to determine whether or not the Kirchoff formula would be of practical value for the problem in question. In fact, based upon the literature, it would be possible to present a credible argument either way. However, since its value has been argued for over fifty years, and its actual formulation even modified somewhat in recent years, one is motivated to try it. For this problem, Kirchoff's formula yielded good results based on experimental comparisons.

The calculations of acoustic shielding that are discussed in the remainder of this report were computed using equations (2) and (4). The integral in equation (4) was numerically evaluated using Simpson's rule. The density of the numerical integration mesh was chosen so that the results were less than 1% in error relative to the value of the integral obtained using a much finer mesh.

DISCUSSION OF RESULTS

Calculations of the acoustic shielding of a point source by a rectangular flat plate were made for the five different point source and rectangular plate configurations shown in figure 2. These calculations were performed at frequencies ranging from 100 Hz. to 20 kHz. The acoustic shielding ASPL was always evaluated at Z = -5.0 m along a line (called the traverse line) parallel to the x-axis (see figure 1) at the same y location as that of the point source. The traverse angle at these locations is defined as

$$\theta = \tan^{-1} \frac{X(P) - X(R)}{Z(R) - Z(P)}$$

Some samples of the results are shown in figures 3 through 10. These are representative of the results obtained for all five configurations. Most of the numerical results are compared with experimental measurements by Ahtye and McCulley (ref. 1). The comparisons with the experimental data indicate that the Kirchoff approximation provides good qualitative results for all five combinations at all frequencies and provides good quantitative agreement for all combinations at frequencies above 4 kHz.

In comparing the numerical and experimental results, it is important to realize that the periodic sharp peaks in shielding (locations of maximum negative ASPL) are very narrow at the higher frequencies and are difficult to compute or measure accurately. Numerically, the exact point of these peaks can only be found by trial and error which is prohibitively expensive.

Experimentally, these peaks cannot be measured accurately because the microphone that performs the measurement is a finite size much larger than the band width of the peak. Hence, only a spatial average of the pressure can be measured at these peaks.

At periodic locations of minimum shielding (locations of smallest negative ASPL) the band widths are not as narrow as for peaks of maximum shielding. Hence, these locations can be defined both numerically and experimentally with sufficient accuracy. Fortunately, it is the values of minimum shielding that are the most important in assessing the acoustic shielding in a given situation.

In general, the acoustic shielding provided by the various rectangular plates was most effective for the higher frequencies and at locations where the point source was hidden geometrically by the plate. The best shielding occurred with the rectangular plate placed closest to the point source and centered in front of it (configuration 1, fig. 3-6). The least shielding occurred with the rectangular plate placed forther away from the point source and furthest off-center (configuration _, tigs. 7-10).

CONCLUSIONS

Based on the good agreement between experimental measurements and the numerical results of the current study, it can be concluded that the Kirchoff approximation provides at least a good qualicative estimation of the acoustic shielding of a point source by a rectangular flat plate for measurements taken in the far field of the flat plate at frequencies ranging from 1 kHz. to 20 kHz. Furthermore, at frequencies greater than 4 kHz, the Kirchoff approximation provides reasonably accurate quantitative predictions of acoustic shielding. It appears to be a valuable tool for predicting far field acoustic shielding and, on that basis, can be of use in preliminary evaluations of noise reducing design considerations for future jet aircraft.

APPENDIX

COMPUTER PROGRAM USED TO PERFORM CALCULATIONS

The predictions of the acoustic shielding of a point source by a rectangular flat plate were performed using the computer program listed in figure 11. The program was written in standard USA Fortran IV and run on a CDC 7600 computer. A description of the user input and the program output is given below. Both the input and output parameters are consistent with the coordinate system of figure 1 and the definitions in the Method of Analysis and Conclusions.

User Input

Card No. 1 - Format(6F10.4)

X1, Y1, Z1, X2, Y2, Z2

where

X1,Y1,Z1 = Coordinates of the point source.

X2,Y2,Z2 = Coordinates of the initial evaluation point along the traverse line where the acoustic shielding is to be computed. The traverse line is always assumed to be parallel to the X-axis. The program automatically computes the velocity potential at a series of points along the traverse line. These points are defined by the parameters DELT and TM4X.

Card No. 2 - Format(I5)

NCASE

where

NCASE = Number of different frequencies at which the calculations are to be performed. Card No. 3 is repeated once for each different frequency.

Card No. 3 - Format(215,4F10.4)

N1,N2,F,DX,TMAX,DELT (One card for each frequency)

where

- N1 = Number of numerical integration grid points in the X-direction on the rectangular plate.
- N2 = Number of numerical integration grid points in the Y-direction on the rectangular plate.
- F = Frequency of the point source in Hertz.
- DX = Distance between the numerical integration grid points in either the X or Y direction.

- TMAX = Maximum traverse angle at which the acoustic shielding is to be evaluated (degrees). The traverse line extends from X2 to the X location whose traverse angle is TMAX.
- DELT = Incremental traverse angle between each successive evaluation point along the traverse line. The default value is 0.5 degrees.

Program Output

- T2 = Traverse angle at the point at which the acoustic shielding is being evaluated.
- V = Magnitude of the complex velocity potential at the traverse angle T2.
- TIME = Accumulated compute time in seconds used by the computer program.
- DSPL = Acoustic shielding (see Basic Equations and Boundary Conditions) at the traverse angle T2.
- VOP = Complex velocity potential (real and imaginary parts) induced by the point source alone at the traverse angle T2.
- X, Y, Z = Coordinates of the point source.
- Y2,Z2 = The Y and Z coordinates of the traverse line at which the acoustic shielding is computed.
- F = Frequency of the acoustic waves.

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- Baker, B. B.; and Copson, E. T.: "The Mathematical Theory of Huygens' Principle," Oxford University Press, London, 1950.
- 3. Bouwkamp, C. J.: "Diffraction Theory," Reports on Progress in Physics, vol. 17, London, 1954.







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Figure 2.- Configuration for which the acoustic shielding of a point source by a rectangular flat plate were computed.



Figure 3.- Acoustic shielding for configuration 1 at a frequency of 0.1 kHz along a traverse line at Z = -5.0 m.



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Figure 4.- Acoustic shielding for configuration 1 at a frequency of 1 kHz along a traverse line at $\rm Z$ = -5.0 m.



Figure 5.- Acoustic shielding for configuration 1 at a frequency of 8 kHz along a traverse line at Z = -5.0 m.

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Figure 6.- Acoustic shielding for configuration 1 at a frequency of 20 kHz along a traverse line at Z = -5.0 m.



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Figure 7.- Acoustic shielding for configuration 2 at a frequency of 0.1 kHz along a traverse line at Z = -5.0 m.

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TRAVERSE ANGLE, θ , deg

0

-20

-30 |_ -40

RVE









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PRICRAM #INC (INPUT, OUTPUT, TAPESEINPUT, TAPESECUTPUT)
    COMPLEX VOP. C2. C4. VOS. C5. DVOS. C7. RLE. CRLE, VSLMX, VSUMY, V
    CALL SECON (TIME)
    NELTE CHALMES TIME
    P1=3.10159205359
    P12=2.0+P1
    $14=2.0*Ft?
    RA =57,29577 1
    SEADIS, 900) . 1, 41, 71, X2, 42, 72.
900 FCHMATCHF10. ]
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    FK2012+F/CO
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102 FORMATCINI, 41HKIPCHCEF APPROXIMATION + ALF PLANE BARRIER//)
    ARTTE (6, 103) X1, Y1, Z1, Y2, Z2, F
103 FORMATCIMO, SHX# , F6. 3, 2x, 3HY# , F6. 3, 2x, 3HZ# , Fe. 3, 2x, 4HY2# , F6. 3,
   12X, 0+77= , F7.5,2X, 3HF= , E12.5/)
    *# [TF(m, 104)
104 FORMAT(140,4×,5+THETA,14×,1+V,12×,4+1IME,11×,4+5FL,12×,3+V(P/)
 10 CONTINUE
    R=SONT((22=21)++2+(x2+x1)++2+(Y2=Y1)++2)
    CIEFKER
    C2=CMPLX(0,.(1)
    VOP=CEXP(C2)/R
    VOPREPEAL (VOF)
    VOPTEATMAG(VUP)
    VOPMAGESORT(VOPR**P+VOPI**2)
    VSUMX=CMPLX( -.0.0.0)
    VRLD=CMPLX(0.0,0.0)
    VSDR=CMPLX(0.0,0.0)
    N1P1=N1+1
    N2P1=N2+1
    212=71+71
    222=22+22
    A x = 1 .
    OC P IstaNIPI
    XT=(I=1.]*DX
    IX#TX=STX
    AYZ1.
    VSUMY=CMPLX(C.0.0.0)
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Figure 11.- Listing of computer program used to determine the acoustic shielding of a point source by a rectangular flat plate.

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Figure 11.- Concluded.

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