[8]Ericsson, L. E. and Reding, J. P., "Review of Vortex-Induced Asymmetric Loads—Part II," Zeitschrift für Flugwissenschaften und Weltraumforschung, Vol. 5, Heft 6, 1981, pp. 349-366.
[9]Ericsson, L. E. and Reding, J. P., "Steady and Unsteady Vortex-Induced Loads on Slender Vehicles," *Journal of Spacecraft and Rockets,* Vol. 18, March-April 1981, pp. 97-109.
[10]Ericsson, L. E. and Reding, J. P., "Dynamics of Forebody Flow Separation and Associated Vortices," AIAA Paper 83-2118, Aug. 1983 (to be published in *Journal of Aircraft*).
[11]Keener, E. R., Chapman, G. T., Cohen, L., and Teleghani, J., "Side Forces on Forebodies at High Angles of Attack at Mach Numbers from 0.1 to 0.7. Two Tangent Ogives, Paraboloid and Cone," NASA TMX-3438, Feb. 1977.
[12]Yanta, W. and Wardlaw, A., "Multi-Stable Vortex Patterns on Slender Circular Bodies at High Incidence," AIAA Paper 81-0006, Jan. 1981.
[13]Fidler, J. E., "Active Control of Asymmetric Vortex Effects," *Journal of Aircraft,* Vol. 18, April 1981, pp. 267-272.
[14]Ericsson, L. E., "Karman Vortex Shedding and the Effect of Body Motion," *AIAA Journal*, Vol. 18, Aug. 1980, pp. 334-344.
[15]Nguyen, L. T., Yip, L. P., and Chambers, J. R., "Self-Induced Wing Rock of Slender Delta Wings," AIAA Paper 81-1883, Aug. 1981.
[16]Ericsson, L. E., "The Fluid Mechanics of Slender Wing Rock," *Journal of Aircraft,* Vol. 21, May 1984, pp. 322-328.
[17]Chambers, J. R., Private communication of unpublished experimental results, July 16, 1982.
[18]Yoshinaga, T., Tate, A., and Inoue, K., "Coning Motion of Slender Bodies at High Angles of Attack in Low Speed Flow," AIAA Paper 81-1899, Aug. 1981.
[19]Orlik-Rückemann, K. J., Private communication of unpublished data, July 16, 1982.
[20]Orlik-Rückemann, K. J., "Aerodynamic Coupling between Lateral and Longitudinal Degrees of Freedom," *AIAA Journal*, Vol. 15, Dec. 1977, pp. 1792-1799.
[21]Keener, E. R., "Oil-Flow Separation Patterns on an Ogive Forebody," *AIAA Journal*, Vol. 21, April 1983, pp. 550-556.
[22]Ericsson, L. E. and Reding, J. P., "How to Cope with the Problems of Scaling and Support Interference in Dynamic Subscale Tests," AIAA Paper 84-0382, Jan. 1984.
[23]Ericsson, L. E., "Is the Free Flight/Wind Tunnel Equivalence Concept Valid for Unsteady Viscous Flow,?" AIAA Paper 85-0378, Jan. 1985.

A Composite Model of Aircraft Noise

Robert G. Melton*
The Pennsylvania State University
University Park, Pennsylvania

Nomenclature

$c_{1,i}, c_{2,i}$	= noise level coefficients for aircraft i
$c^*_{1,k}, c^*_{2,k}$	= composite noise level coefficients for trajectory k
i	= noise source index
k	= trajectory index
L^*	= sound level produced by a single source delivering the same power density as N_s sources
$L_{\text{d-n}}$	= average day-night noise level
L_i	= sound level from source i
L_{tot}	= sound level from N_s sources
N	= number of sound level samples taken in 24 h
N_s	= number of sound sources
N_t	= number of trajectories
r	= distant (slant range) from aircraft
t	= time index for sampling sound levels
w_i, w_t	= time-of-day weighting factor associated with human perception of noise levels, = 1 from 7 a.m. to 7 p.m., = 10 otherwise

Received Feb. 10, 1985. Copyright © American Institute of Aeronautics and Astronautics, Inc., 1985. All rights reserved.
*Assistant Professor, Department of Aerospace Engineering. Member AIAA.

Introduction

IN the analysis of aircraft noise effects on a community it has been found[1] that the separate calculation of noise levels from each aircraft contributes a significant portion of the overall computations (i.e., evaluations of noise levels and effects on the population). A method for reducing the amount of computation needed to determine these noise levels is presented. It is assumed that each aircraft can be assigned to one of several known flight paths (or that any deviations from these paths do not significantly alter the noise field on the ground).

Adding Sound Energy

The exact expression for the total sound level[2] (using any power-intensity related scale) contributed from N_s sources is

$$L_{\text{tot}} = 10 \log_{10} \sum_{i=1}^{N_s} 10^{L_i/10} \tag{1}$$

where L_i is the level produced by the ith source. Addition of the individual sound levels implicitly assumes incoherent interference of the acoustic waves, and is commonly referred to as "addition on an energy basis"; however, *power density addition* would be a more accurate characterization. Nevertheless, it provides a means for calculating the sound level from various aircraft operating in a community.

Under the assumption of isotropy in the far-field propagation of aircraft sound, the approximation for the level at distance r from the ith source is

$$L_i = c_{1,i} - c_{2,i} \log_{10} r \tag{2}$$

Using data obtained from the Integrated Noise Model,[3] values of c_1 and c_2 were calculated from least-square-error fits, and the results are shown in Table 1. A plot of sound level (in this case, the A-weighted level, L_A) vs r for Boeing 737-100/200 aircraft appears in Fig. 1.

The concept of "energy addition" is also employed in various other measures of noise, notably those that include some weighting of the incident power based upon the time of day and the resulting human perception of the sound level. For example, the average day-night level $L_{\text{d-n}}$ is defined as

$$L_{\text{d-n}} = 10 \log_{10} \sum_{t=1}^{N_t} w_t 10^{L_{A,t}/10} / N_t \tag{3}$$

Clearly, $L_{\text{d-n}}$ is based upon a weighted *average over time* of the incident power. The order of occurrence of the various sound level contributions is irrelevant, as long as the appropriate weighting is assigned to each.

This concept raises the possibility, for simulation purposes, of replacing a number of aircraft moving along a specified trajectory with a single "equivalent source" that delivers the same weighted average power distribution to points on the ground.

Composite Model

Using Eqs. (1) and (2), and continuing to use $L_{\text{d-n}}$ as the prototype, the equivalent level at distance r from all sources on the kth trajectory is

$$L^*_k(r) = 10 \log_{10} \sum_{i=1}^{N_s} w_i 10^{L_i(r)/10} \tag{4}$$

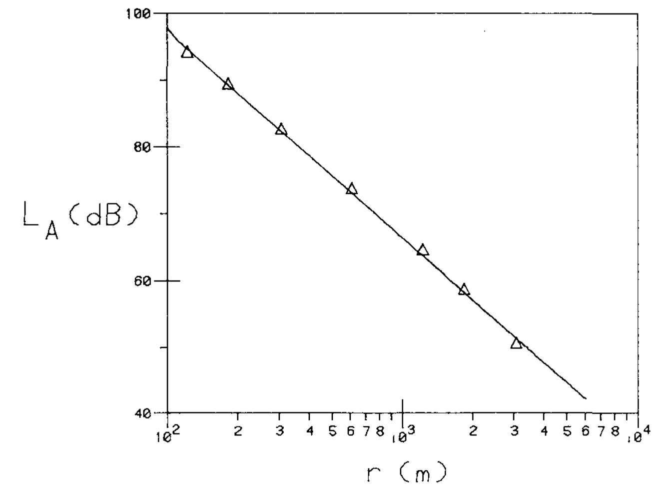

Fig. 1 Linear fit of sound levels for Boeing 737-100/200 aircraft.

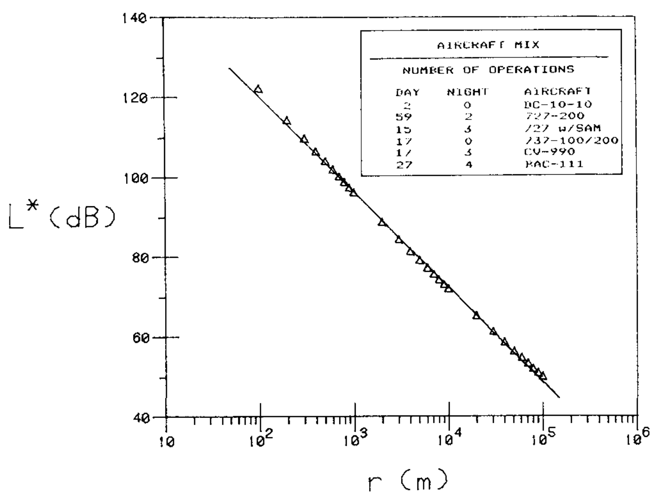

Fig. 2 Linear fit of sound levels from multiple aircraft.

It has been found that an excellent approximation for $L_k^*(r)$ is given by the same form as Eq. (2), i.e.,

$$L_k^*(r) = c_{1,k}^* - c_{2,k}^* \log_{10}(r) \tag{5}$$

where the composite coefficients $c_{1,k}^*$ and $c_{2,k}^*$ will depend upon the mixture of aircraft on trajectory k. The quantity $L^*(r)$ represents the sound level of an "equivalent source" at distance r, which delivers the same total weighted power density as the combination of individual sources at that distance. An example of the quality of the least-square-error fit is shown in Fig. 2.

With the coefficients $c_{1,k}^*$ and $c_{2,k}^*$ calculated for each trajectory, the equivalent level L^* at any point on the ground is found by summing over all the trajectories:

$$L^* = 10 \log_{10} \sum_{k=1}^{N_t} 10^{L_k^*/10} \tag{6}$$

Since the time-of-day weighting has already been included in L_k^* and, hence, L^*, the expression for $L_{\text{d-n}}$ becomes

$$L_{\text{d-n}} = 10 \log_{10} \sum_{t=1}^{N} 10^{L_t^*/10}/N \tag{7}$$

Calculation of $c_{1,k}^*$, $c_{2,k}^*$, and $L_{\text{d-n}}$ is relatively fast compared with summing the power densities of every source at each time sample to get $L_{\text{d-n}}$.

Table 1 Noise level coefficients for commercial aircraft[a]

Aircraft	c_1	c_2
DC-8-30	164.02	31.06
DC-9 w/SAM	146.76	26.13
DC-10-10	150.81	30.32
707 w/SAM	138.77	24.81
720	143.92	22.95
727-200	142.57	23.68
727 w/SAM	124.83	18.92
737-100/200	159.35	31.04
737 w/SAM	149.60	27.72
747-200	144.19	26.20
L-1011	140.75	25.75
A-300	179.76	41.60
BAC-111	154.88	28.44
VC-10	144.74	23.64
CV-990	164.17	29.42

[a]Computed for landing thrust levels, 3-deg glide slope.

Conclusion

The method of using composite noise coefficients reduces the number of calculations needed to determine $L_{\text{d-n}}$ at any point on the ground, as compared with more straightforward methods. For simulations of aircraft noise where many aircraft are involved, a considerable savings in computation time can be achieved. While the method has been demonstrated for the measure $L_{\text{d-n}}$, it is applicable to any measure that adds effects from separate sources via power density addition.

References

[1]Melton, R. G. and Jacobson, I. D., "Minimum Noise Impact Aircraft Trajectories," NASA CR-164719, Sept. 1981.

[2]Pearsons, K. S. and Bennett, R. L., "Handbook of Noise Ratings," NASA CR-2376, April 1974.

[3]"Integrated Noise Model Data Base," Ver. 2, Federal Aviation Administration, Washington, D.C., released July 31, 1979.

Airplane Designer's Checklist for Occupant Injury Prevention

Howard Wesley Smith*
The University of Kansas, Lawrence, Kansas

Introduction

ALTHOUGH the design techniques for injury protection are maturing, there are a large number of bewildering specification requirements that confront a designer of pilots' seats and cabins. Design engineers are educated and oriented toward vehicle construction and components. After graduation, they enter industry and acquire organizational assignments. Design engineers become responsible for some subset of the aircraft, such as structures, control systems or equipment, but not all of them. Each design group, together with their supporting analysts and staff groups, have improved their designs by research on operational usage. Gathering data on injuries is especially difficult because the operational usages are usually mishaps, crashes, and emergency egresses.

Presented as Paper 84-2520 at the AIAA/AHS/ASEE Aircraft Design Systems and Operations Meeting, San Diego, Calif., Oct. 31-Nov. 2, 1984; received Nov. 25, 1984; revision received Jan. 28, 1985.

Copyright © American Institute of Aeronautics and Astronautics, Inc., 1984. All rights reserved.

*Professor, Aerospace Engineering. Associate Fellow AIAA.