EMPIRICAL EXTROPLATION OF THE ACOUSTICALLY-INDUCED RANDOM VIBRATION LEVEL FROM A REFERENCE VEHICLE TO A NEW VEHICLE
Revision A

By Tom Irvine
Email: tomirvine@aol.com

September 11, 2009

Variables

f	Frequency
$G_{new}(f)$	Acceleration PSD of the new vehicle, extrapolated
$G_{ref}(f)$	Acceleration PSD of the reference vehicle, measured
w_{ref}	Average surface mass density of the reference vehicle
w_{new}	Average surface mass density of the new vehicle
$P_{new}(f)$	Acoustic pressure PSD of the new vehicle
$P_{ref}(f)$	Acoustic pressure PSD of the reference vehicle

The acceleration PSD unit is typically G^2/Hz. The pressure PSD unit is typically psi^2/Hz.

Scaling Formula

The following equation gives a method for scaling the acoustically-induced random vibration level of a reference vehicle to that of a new vehicle. The objective is to obtain base excitation levels for components, payloads, and structural members.

$$G_{new}(f) = G_{ref}(f)\left[\frac{w_{ref}}{w_{new}}\right]^2\left[\frac{P_{new}(f)}{P_{ref}(f)}\right] \quad (1)$$

Note that predictions can be obtained for any desired flight condition by extrapolating the measurements from the reference vehicle to that of the new vehicle. i.e. – the method may be used for both liftoff and aeroacoustics.

Equation (1) is taken from Reference 1, section 6.1. It is known as the Condos and Butler Method. The method gives the best results for the case where the two vehicles have similar designs.

The method may cause some error if the two vehicles have different diameters, in which case the corresponding ring frequencies would differ.

Furthermore, equation (1) does not account for differences in damping. There are many other potential details which may affect the vibration level of the new vehicle. So equation (1) must be used with caution.

Aeroacoustic Pressure Scaling

A simplified method is often substituted for the pressure scaling in equation (1). The scaling is based on the dynamic pressure and Mach numbers of the reference and new vehicles.

Let

p_{rms}	=	RMS pressure
q	=	dynamic pressure
M	=	Mach number

The scaling depends on the flow type at the station of interest.

For attached supersonic flow,

$$p_{rms} \propto q \tag{2}$$

Note that the pressure PSD terms in equation (1) are each proportional to p_{rms}^{2}.

Equation (1) would thus be modified for attached flow as

$$G_{new}(f) = G_{ref}(f)\left[\frac{w_{ref}}{w_{new}}\right]^2\left[\frac{q_{new}}{q_{ref}}\right]^2 \tag{3}$$

where each q value is the maximum dynamic pressure for the respective vehicle.

For an expansion corner, supersonic and transonic flow,

$$p_{rms} \propto \frac{q}{1+M^2} \tag{4}$$

Note that the maximum $\left[\frac{q}{1+M^2}\right]$ usually occurs at or near Mach one.

Additional flow types are considered in Reference 4.

Mass Loading

Consider the case where vibration predictions are desired at points where heavy components will be mounted.

Assume that the acceleration PSD for the new vehicle has been predicted, but that component weight was omitted in the calculation.

Reference 1, section 5.7.1, suggests the following correction factor:

$$G_{nc}(f) = \frac{W_n}{W_n + W_c} G_n(f) \tag{5}$$

where

$G_n(f)$	Acceleration PSD of the new vehicle structure without components
W_n	Weight of new vehicle in general region of interest without components
W_c	Weight of all attached component in general region of interest
$G_{nc}(f)$	Acceleration PSD of the new vehicle structure with components attached

Note that the weight terms in equation (5) should be squared in order for physical consistency with PSD values in units of G^2/Hz.

Additional methods are given in Reference 2.

Acoustic Pressure PSD of the New Vehicle

The acoustics pressure PSD of the New Vehicle can be predicted for liftoff and aeroacoustics by using the methods in References 3 and 4, respectively.

The methods in these references yield a one-third octave sound pressure level, which can be converted into a narrowband pressure PSD format.

References

1. NASA CR-1302, Summary of Random Vibration Prediction Procedures, 1969.
2. T. Irvine, Mass Loading Effects for Heavy Equipment and Payloads, Revision D, Vibrationdata, 2009.
3. Rocket Vehicle Liftoff Acoustics and Skin Vibration Acoustic Loads Generated by the Propulsion System, NASA SP-8072, Monograph N71-33195, 1971.
4. T. Irvine, Prediction of Sound Pressure Levels on Rocket Vehicles During Ascent, Revision D, Vibrationdata, 2007.