ROCKET VEHICLE LIFTOFF ACOUSTICS
Part III: Acoustic Attenuation

By Tom Irvine
Email: tomirvine@aol.com

October 18, 2000

Introduction

Rocket motors generate tremendous acoustic energy at liftoff.

This energy is attenuated as it propagates from the nozzle exit plane to the upper stages and nosecone fairing. Ideally, the attenuation would follow the free field "inverse square law." The attenuation is less than free field estimates, however.

Lyon (Reference 1) wrote the following regarding measured acoustic spectra from Atlas, Titan, Saturn and other rocket vehicles:

> More recent data on Saturn launch vehicles tend to confirm the general features of the latter estimates, except that (a) the levels do not diminish as quickly as anticipated as one proceeds from the booster to the payload sections and (b) the spectrum does not undergo, in the same progression, as large a shift to lower frequencies as anticipated.

Barrett (References 2 and 3) gives empirical graphs expressing acoustic pressure versus distance for seven rocket engines. This is presumably the same data set from which Lyon drew his conclusions.

The purpose of this report is to derive a distance attenuation formula from Barrett's data.

Analysis

The Barrett acoustic pressure data for seven rocket engines is given in Figures 1 through 7. The data is given for the overall pressure level. The attenuation within individual frequency bands is not considered.

The curves for the overall pressure P as a function of distance x can be modeled as

$$P(x) = a + \left[\frac{b}{x^{c} + d} \right] \tag{1}$$

where a, b, c and d are empirical constants.

Equation (1) can be differentiated to obtain the attenuation slope equation.

$$\frac{dP}{dx} = \frac{-bc\ x^{c-1}}{\left(x^{c} + d\right)^{2}} \tag{2}$$

The empirical coefficients can be obtained via a trial-and-error curve fitting method. The values are given in Table 1.

Table 1. Distance Attenuation for Rocket Vehicles Noise

Engine	a	b	c	d
165K H-1	-0.00476	5.07	0.681	10.8
188K H-1	-0.00440	6.79	0.714	14.5
RL-10	-7.49e-04	3.97	0.796	24.1
AGENA B	-0.732e-04	3.93	0.805	26.2
F-1	-0.0108	8.58	0.635	14.3
J-2	-0.00694	5.68	0.650	14.0
M-1	-0.0507	4.12	0.443	2.86
Average	-	5.45	0.67	15.25

Integrate equation (2) and apply an integration constant. The pressure (psi) as a function of distance x (inches) is

$$P(x) = P_{o} - \left[\frac{b}{{x_{o}}^{c} + d}\right] + \left[\frac{b}{x^{c} + d}\right] \tag{3}$$

where

P_o is the acoustic pressure at the nozzle exit plane.

x_o is the distance at which the source pressure is measured, typically 10 inches.

Simplify the expression and apply the average values from Table 1.

$$P(x) = P_o + b\left\{\left[\frac{-1}{x_o{}^c + d}\right] + \left[\frac{1}{x^c + d}\right]\right\} \tag{4}$$

$$P(x) = P_o + 5.45\left\{\left[\frac{-1}{x_o{}^{0.67} + 15.25}\right] + \left[\frac{1}{x^{0.67} + 15.25}\right]\right\} \tag{5}$$

Again, the pressure terms are in units of psi. The distance term is in units of inches.

Peacekeeper Example

Consider a launch vehicle with a Peacekeeper booster. The acoustic pressure is P_o = 0.26 psi rms at x_o = 10 inches. Estimate the overall pressure at the external fairing skin at the payload station, 900 inches from the nozzle exit plane.

The resulting pressure is 0.36 psi rms at 900 inches, per equation (5). A complete attenuation graph is given in Figure 8.

The overall level thus decreases from 159 dB at the nozzle exit plane to 142 dB at the external payload skin location. The reference value is 20 micro Pascal.

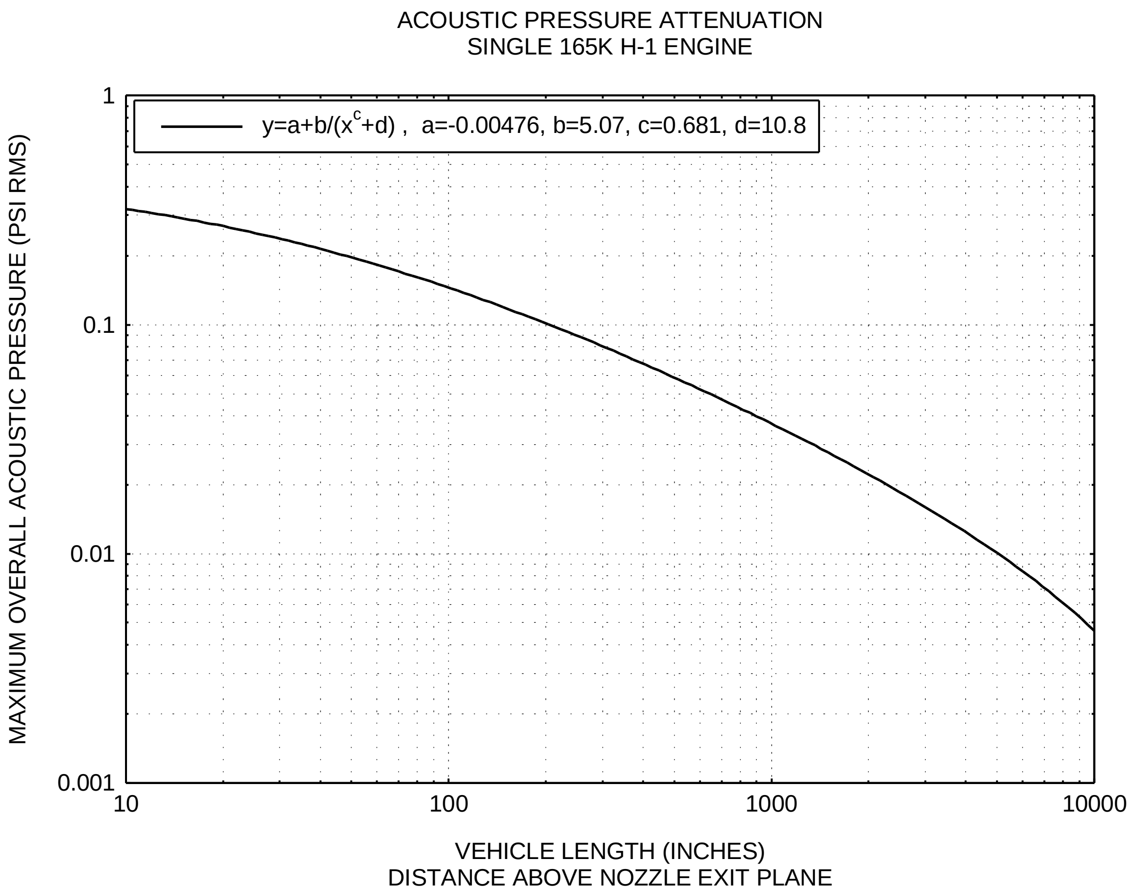

ACOUSTIC PRESSURE ATTENUATION
SINGLE 165K H-1 ENGINE
y=a+b/(x^c+d) , a=-0.00476, b=5.07, c=0.681, d=10.8
MAXIMUM OVERALL ACOUSTIC PRESSURE (PSI RMS)
1
0.1
0.01
0.001
10
100
1000
10000
VEHICLE LENGTH (INCHES)
DISTANCE ABOVE NOZZLE EXIT PLANE

Figure 1.

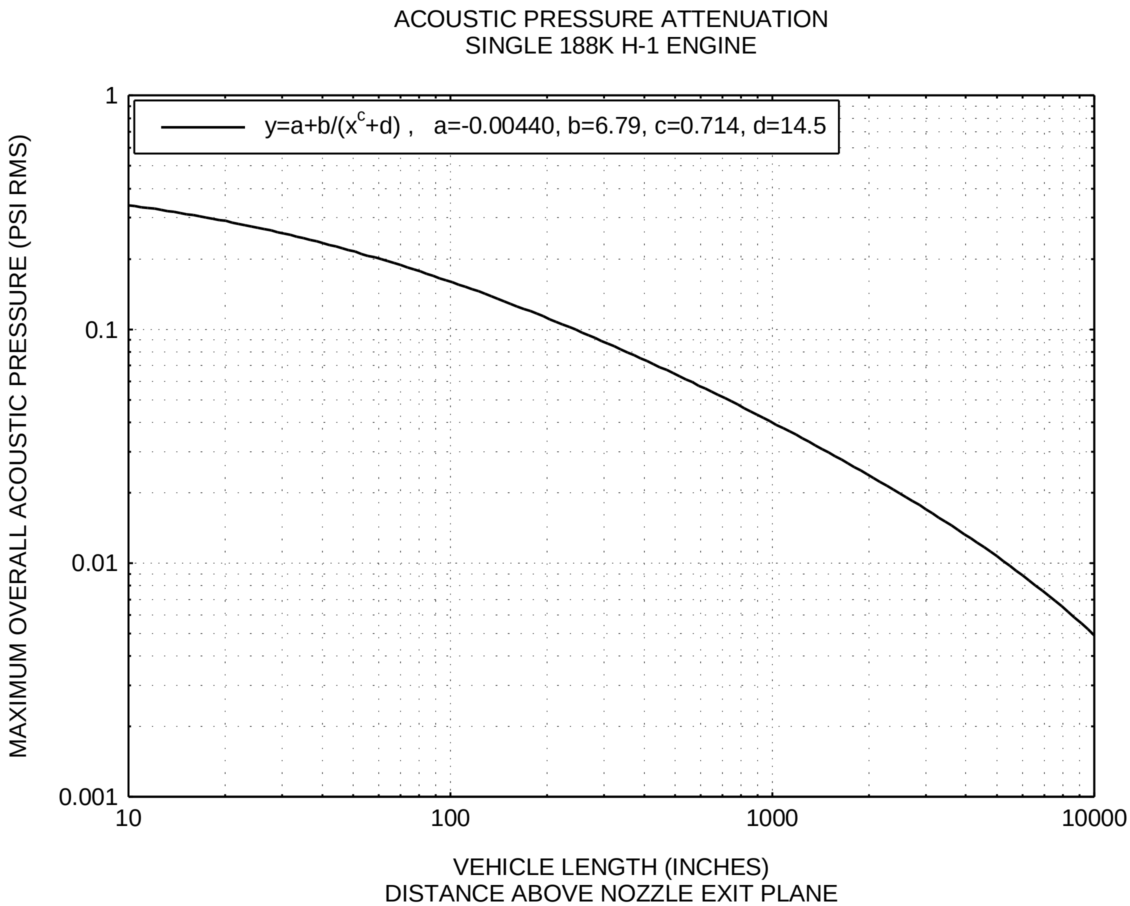
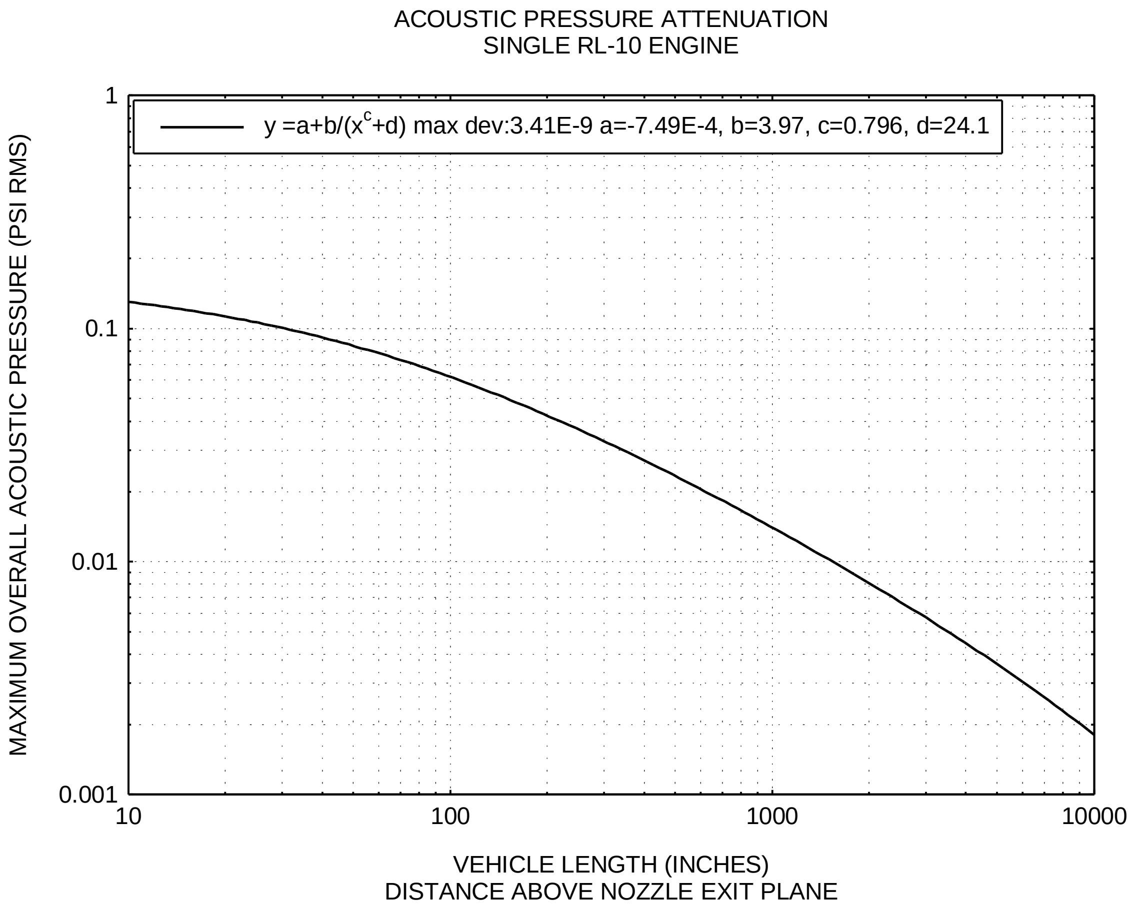

ACOUSTIC PRESSURE ATTENUATION
SINGLE 188K H-1 ENGINE
y=a+b/(x^c+d) , a=-0.00440, b=6.79, c=0.714, d=14.5
MAXIMUM OVERALL ACOUSTIC PRESSURE (PSI RMS)
1
0.1
0.01
0.001
10
100
1000
10000
VEHICLE LENGTH (INCHES)
DISTANCE ABOVE NOZZLE EXIT PLANE

Figure 2.



ACOUSTIC PRESSURE ATTENUATION
SINGLE RL-10 ENGINE
y =a+b/(x^c+d) max dev:3.41E-9 a=-7.49E-4, b=3.97, c=0.796, d=24.1
MAXIMUM OVERALL ACOUSTIC PRESSURE (PSI RMS)
1
0.1
0.01
0.001
10
100
1000
10000
VEHICLE LENGTH (INCHES)
DISTANCE ABOVE NOZZLE EXIT PLANE

Figure 3.

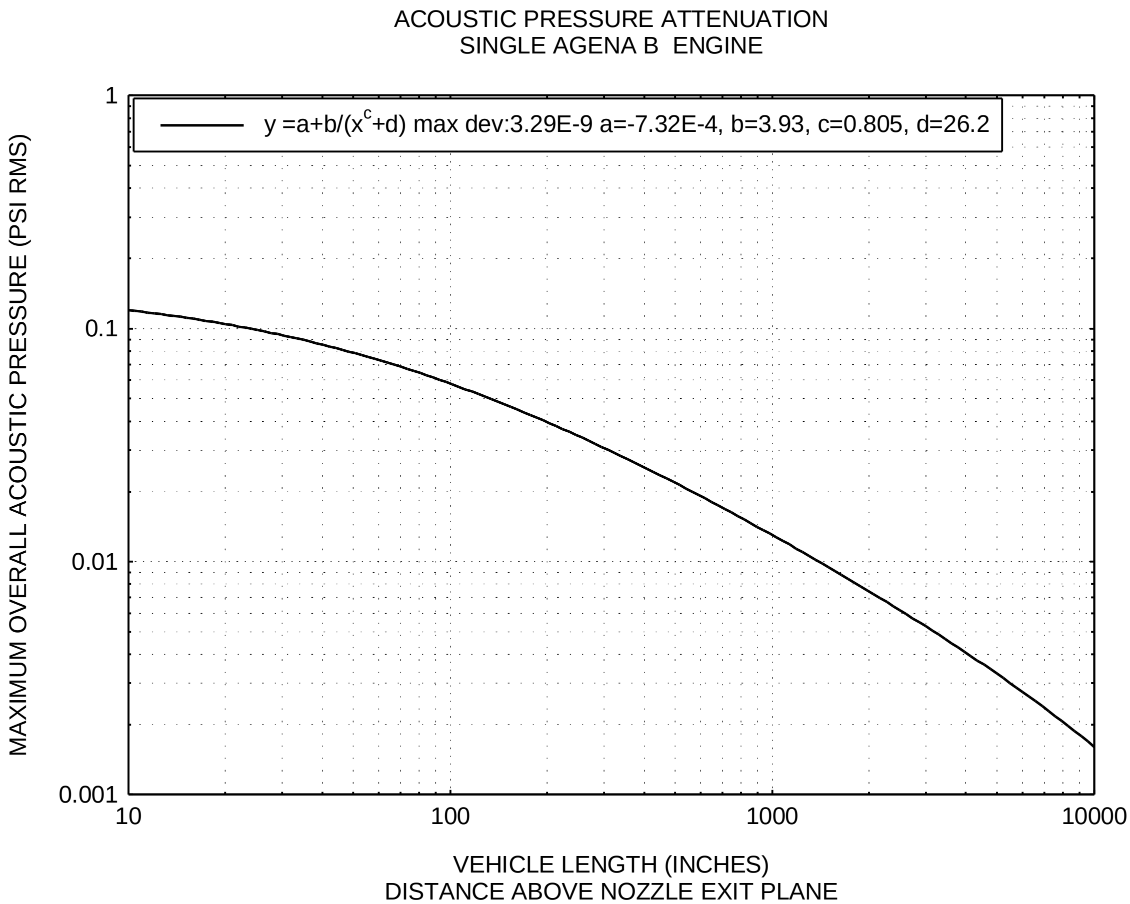

ACOUSTIC PRESSURE ATTENUATION
SINGLE AGENA B ENGINE
y =a+b/(x^c+d) max dev:3.29E-9 a=-7.32E-4, b=3.93, c=0.805, d=26.2
MAXIMUM OVERALL ACOUSTIC PRESSURE (PSI RMS)
1
0.1
0.01
0.001
10
100
1000
10000
VEHICLE LENGTH (INCHES)
DISTANCE ABOVE NOZZLE EXIT PLANE

Figure 4.

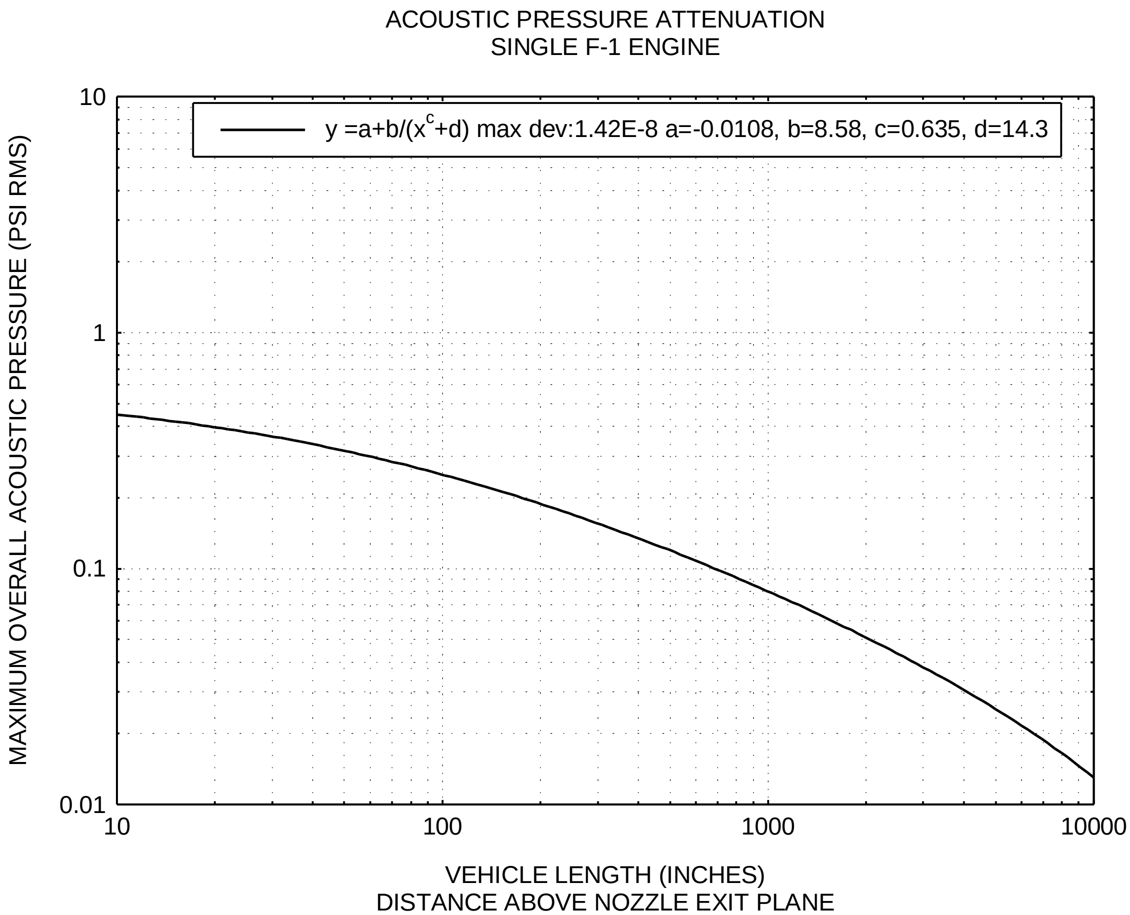
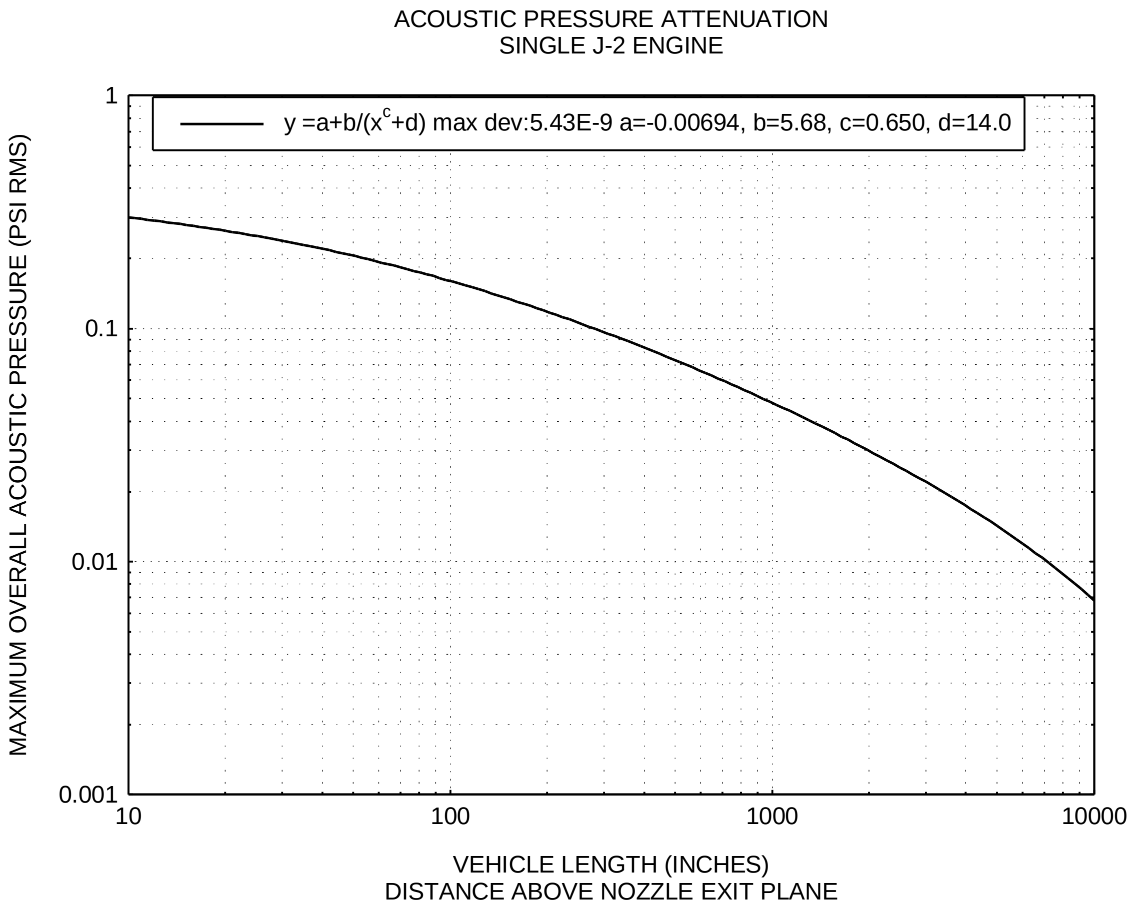

ACOUSTIC PRESSURE ATTENUATION
SINGLE F-1 ENGINE
y =a+b/(x^c+d) max dev:1.42E-8 a=-0.0108, b=8.58, c=0.635, d=14.3
MAXIMUM OVERALL ACOUSTIC PRESSURE (PSI RMS)
10
1
0.1
0.01
10
100
1000
10000
VEHICLE LENGTH (INCHES)
DISTANCE ABOVE NOZZLE EXIT PLANE

Figure 5.



ACOUSTIC PRESSURE ATTENUATION
SINGLE J-2 ENGINE
y =a+b/(x^c+d) max dev:5.43E-9 a=-0.00694, b=5.68, c=0.650, d=14.0
MAXIMUM OVERALL ACOUSTIC PRESSURE (PSI RMS)
1
0.1
0.01
0.001
10
100
1000
10000
VEHICLE LENGTH (INCHES)
DISTANCE ABOVE NOZZLE EXIT PLANE

Figure 6.

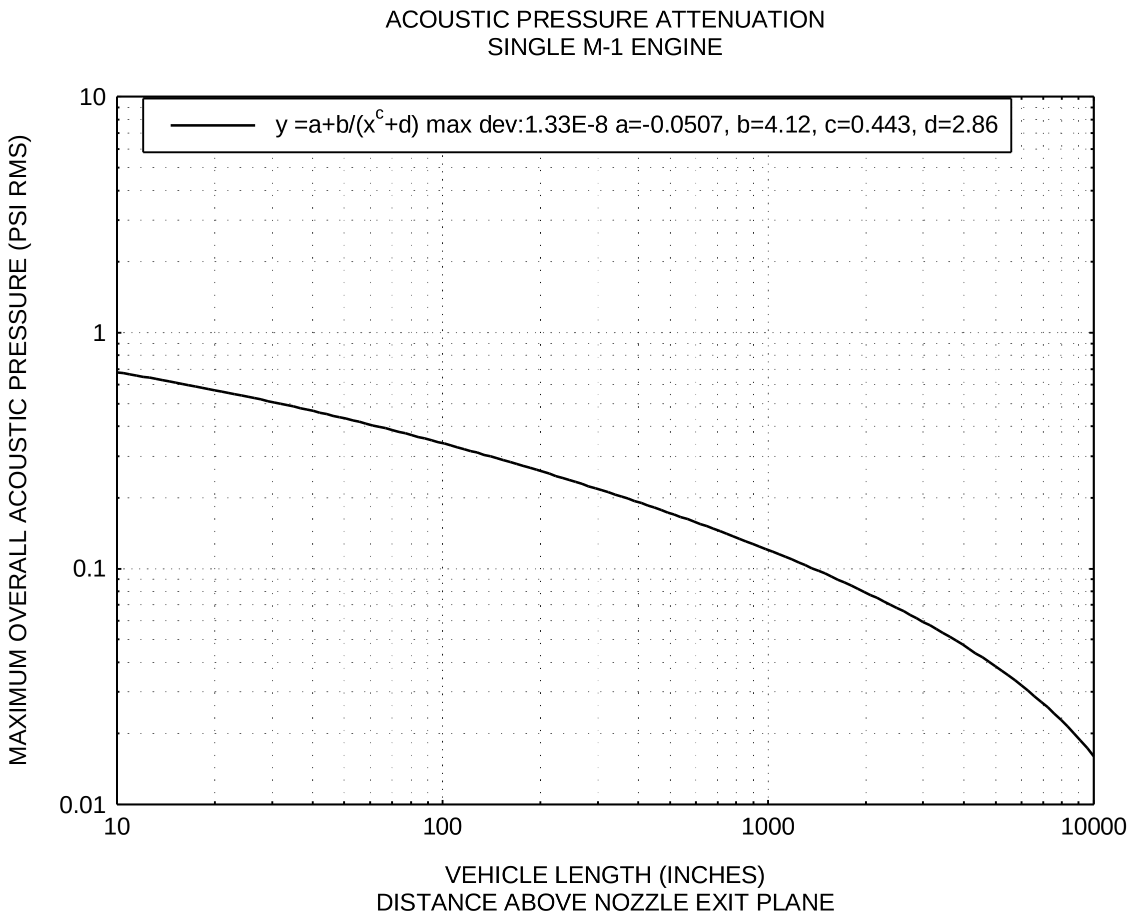

ACOUSTIC PRESSURE ATTENUATION
SINGLE M-1 ENGINE
y =a+b/(x^c+d) max dev:1.33E-8 a=-0.0507, b=4.12, c=0.443, d=2.86
MAXIMUM OVERALL ACOUSTIC PRESSURE (PSI RMS)
10
1
0.1
0.01
10
100
1000
10000
VEHICLE LENGTH (INCHES)
DISTANCE ABOVE NOZZLE EXIT PLANE

Figure 7.

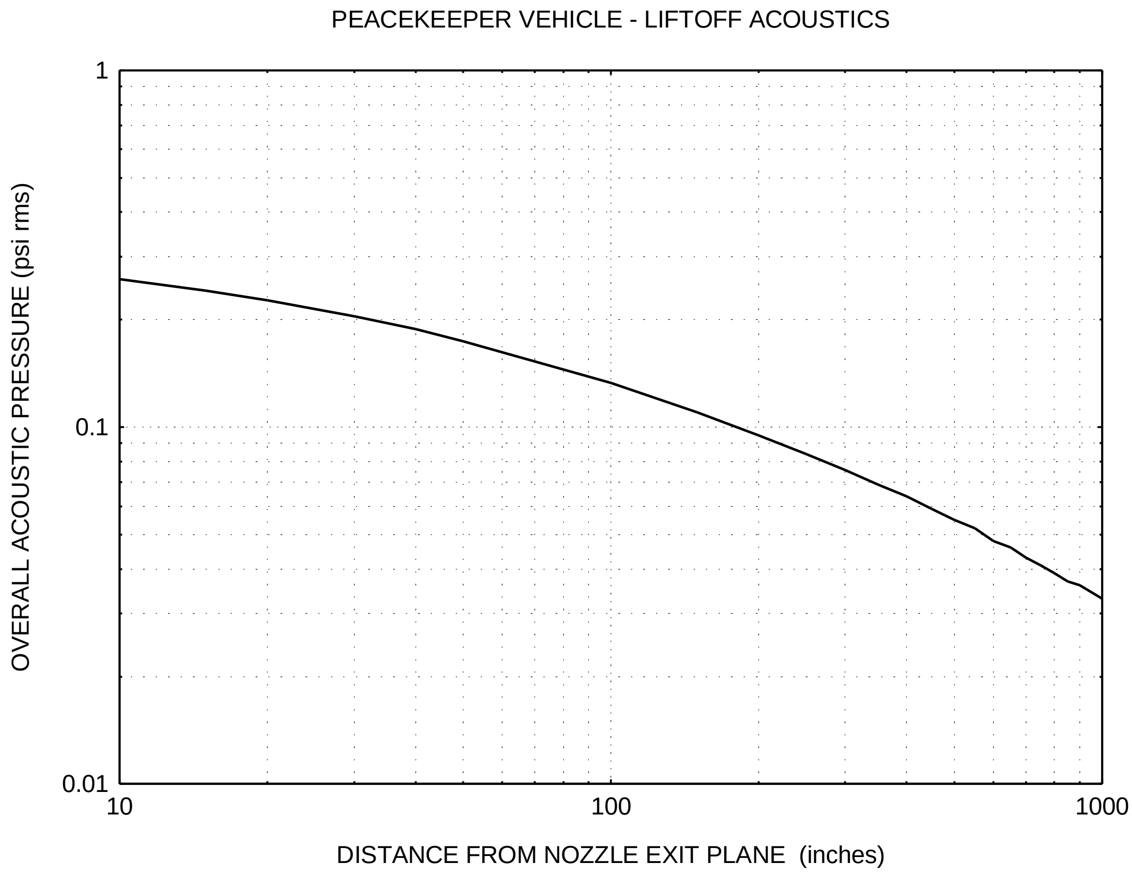

PEACEKEEPER VEHICLE - LIFTOFF ACOUSTICS
OVERALL ACOUSTIC PRESSURE (psi rms)
1
0.1
0.01
10
100
1000
DISTANCE FROM NOZZLE EXIT PLANE (inches)

Figure 8.

References

1. R. Lyon, Random Noise and Vibration in Space Vehicles, SVM-1, The Shock and Vibration Information Center, United States Department of Defense, 1967.
2. Barrett, Techniques for Predicting Localized Vibratory Environments of Rocket Vehicles, NASA Technical Note D-1836, 1963.
3. Summary of Random Vibration Prediction Procedures, NASA CR-1302, 1969.