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Aircraft Noise

by

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NOMENCLATURE

C	Tone Correction Factor
d	Time interval during which $PNLT(k)$ is greater than $PNLTM - h$
D	Duration Correction Factor
$EPNL$	Effective Perceived Noise Level
F	Difference between Original and final Background Sound Pressure Level
h	The level to be subtracted from $PNLTM$ that defines the duration of noise.
i	Frequency band indicator
k	Time indicator
n	Annoyance value
N	Combined Annoyance value over Frequency
P	Sound Pressure
P_{ref}	Reference Sound Pressure
PNL	Perceived Noise Level
$PNLT$	Tone Corrected Perceived Noise Level
$PNLTM$	Maximum Tone Corrected Perceived Noise Level
s and s'	Sound Pressure Level differences between frequency bands
$\bar{s}$	Average differences in Sound Pressure Levels
SPL	Sound Pressure Level

SPL' and SPL''	Average Sound Pressure Levels
t	Time
dt	Length of time increments
T	Normalizing time constant

ACRONYMS AND ABBREVIATIONS

ANOPP	Aircraft Noise Prediction Program
ACSYNT	Aircraft Synthesis Program
DOT	Department of Transportation
FAA	Federal Aviation Agency
FAR	Federal Aviation Regulations
FLOPS	Flight Optimization System
FOOTPR	Aircraft noise prediction program by Bruce Clark
HSCT	High Speed Civil Transport
ICAO	International Commercial Aviation Organization
NASA	National Aeronautics and Space Administration

1. INTRODUCTION

The rapid spread of civil aviation, from the early elite of the 1960s to the tourists of today has exposed communities to a noise intrusion with unsociable levels and frequencies. With the introduction of the bypass and turbofan engines in the 1960s and 1970s and the subsequent evolution of these two engine technologies, aircraft have become progressively quieter, although the reduction in noise levels has not sufficiently offset the increase in operations or their psychological impact.

It is the purpose of this paper to derive and explain the procedure of obtaining a single indicator of this psychological effect, however, with the realization that not all factors can be included. Each person reacts differently to noise exposure depending on his or her tolerance level. This is furthermore only for a single noise event, studies have shown that the number of events can have even greater impact than the loudness of the noise itself.

Allowable levels of noise exposure and certification schemes are then outlined as dictated by the Federal Aviation Agency.

This is a partial fulfillment of a research effort on the community noise problem for HSCT aircraft.

2. Noise Calculations

The certification criteria in FAR part 36 consists of meeting specified noise levels at certain reference points. The noise evaluation is designated *EPNL* (Effective Perceived Noise Level) and is measured in units of EPNLdB. This is a single number indicator of the subjective effects of airplane noise on human beings.

2.1 Basic Properties

Noise, or undesirable sound, is a physical phenomenon detected by humans as sound waves, which are only minute fluctuations in atmospheric pressure. This pressure is usually reported as *SPL* or sound pressure level, and since human hearing has adopted to million fold differences in sound pressure it is measured in units of decibels, which is a logarithmic scale. If the sound pressure is given in other units, it can be transformed to decibels using the following equation:

$$SPL = 20 \log_{10}\left(\frac{P}{P_{ref}}\right) \text{dB} \qquad [2.1]$$

where P_{ref} is equal to 20 μPa or the equivalent in other units, the threshold of hearing.

SPL needs to be measured or predicted in the frequency range from 50 to 10,000 Hz; where noise lower than 50 Hz is usually not generated by aircraft and imposes little or none annoyance on people relative to other frequencies (See Figure 2.1), and noise higher than 1,000 Hz dissipates very quickly in the atmosphere and is thus dismissed as having any weight. This frequency range constitutes for 8 octave bands and by FAA definition dividing each band into 3 provides for a satisfactory resolution, resulting in a total of 24 1/3 octave bands. The measurements should preferably be made at the midrange frequency of each 1/3 octave band.

2.2 Calculation Procedures

There are four major steps to deriving the final value of the *EPNL*. Note that this is a spatial function as well as a function of time and that these procedures need to be repeated for every point of interest.

2.2.1 Annoyance Correction

The 24 1/3 octave bands of sound pressure levels are converted to perceived noisiness by means of a noy table (See Appendix A). This is to account for the annoyance response of the human hearing system as a function of frequency. The following graph shows this response. This graph is for a noy value of 1, with respect to the 1,000 Hz midrange frequency. What this graph shows is the relative annoyance to humans over the frequency spectrum from 50 to 10,000 Hz. For instance, a sound

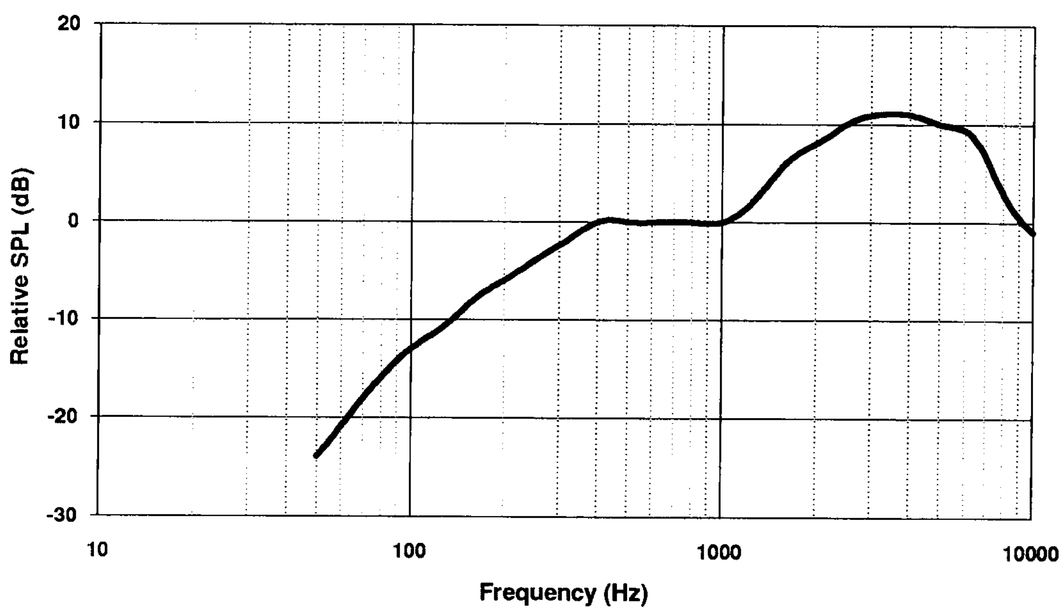

Figure 2.1 A graph of relative annoyance with respect to noise frequency.

pressure of 29 dB at 4,000 Hz has the same adverse effect or annoyance on a person as a sound pressure of 53 dB at 100 Hz.

The noy values for each band are then combined and converted to instantaneous perceived noise levels, *PNL(k)*. The following formula is used to combine the noy values:

$$\begin{aligned} N(k) &= n(k) + 0.15\left[\left[\sum_{i=1}^{24} n(i,k)\right] - n(k)\right] \\ &= 0.85\, n(k) + 0.15 \sum_{i=1}^{24} n(i,k) \end{aligned} \qquad [2.2]$$

where $n(k)$ is the largest of the 24 values of $n(i,k)$, $N(k)$ is the total perceived noisiness, i indicating the frequency band and k the time instant; whereas convention dictates that k indicates frequency. To calculate the perceived noise level or *PNL(k)*, the following formula is used:

$$PNL(k) = 40.0 + \frac{10}{\log 2} \log N(k) \qquad [2.3]$$

This formula is an approximation to the SPL-Noy relation at the 1,000 Hz frequency (See Appendix A). That is: First transform the sound pressure levels in each frequency band into Noys, combine them and then transform that value back into an equivalent sound pressure level at the 1,000 Hz frequency, and designate as the perceived noise level.

2.2.2 Tone Correction

A tone correction factor, *C(k)* is calculated for each spectrum to account for the subjective response to the presence of spectral irregularities. This is a rather lengthy procedure consisting of ten steps.

Step 1. Starting with the annoyance corrected sound pressure level in the 80 Hz 1/3 octave band (band number 3), calculate the changes in sound pressure level (or slopes) in the remainder of the 1/3 octave bands as follows:

$$
\begin{aligned}
&s(3,k) = \text{no value} \\
&s(4,k) = SPL(4,k) - SPL(3,k) \\
&\vdots \\
&s(i,k) = SPL(i,k) - SPL(i\text{-}1,k) \qquad [2.4] \\
&\vdots \\
&s(24,k) = SPL(24,k) - SPL(23,k)
\end{aligned}
$$

Step 2. Encircle the value of the slope, $s(i,k)$, where the absolute value of the change in slope is greater than five; that is, where

$$|\Delta s(i,k)| \;=\; |s(i,k) \;-\; s)i-1,k)| \rangle 5 \qquad [2.5]$$

Step 3.

i) If the encircled value of the slope $s(i,k)$ is positive and algebraically greater than the slope $s(i\text{-}1,k)$ encircle $SPL(i,k)$.

ii) If the encircled value of the slope $s(i,k)$ is zero or negative and the slope$s(i\text{-}1,k)$ is positive, encircle $SPL(i\text{-}1,k)$.

iii) For all other cases, no sound pressure level value is to be encircled.

Step 4. Compute new adjusted sound pressure levels $SPL'(i,k)$ as follows:

i) For non-encircled sound pressure levels, let the new sound pressure levels equal the original sound pressure levels, $SPL'(i,k) = SPL(i,k)$.

ii) For encircled sound pressure levels in bands 1 to 23 inclusive, let the new sound pressure level equal the arithmetic average of the preceding and following sound pressure levels:

$$SPL'(i,k) \;=\; ½\big[SPL(i-1,k) \;+\; SPL(i+1,k)\big] \qquad [2.6]$$

iii) If the sound pressure level in the highest frequency band (i=24) is encircled, set the new sound pressure level in that band equal to:

$$SPL'(24,k) = SPL(23,k) + s(23,k) \qquad [2.7]$$

Step 5. Recompute new slopes $s'(i,k)$, including one for an imaginary 25-th band, as follows:

$$s'(3,k) = s'(4,k)$$

$$s'(4,k) = SPL'(4,k) - SPL'(3,k)$$

$$\vdots$$

$$s'(i,k) = SPL'(i,k) - SPL'(i\text{-}1,k) \qquad [2.8]$$

$$\vdots$$

$$s'(24,k) = SPL'(24,k) - SPL'(23,k)$$

$$s'(25,k) = s'(24,k)$$

Step 6. For i from 3 to 23 compute the arithmetic average of the three adjacent slopes as follows:

$$\bar{s}(i,k) = \tfrac{1}{3}\left[s'(i,k) + s'(i+1,k) + s'(i+2,k)\right] \qquad [2.9]$$

Step 7. Compute final 1/3 octave band sound pressure levels, $SPL''(i,k)$, by beginning with band number 3 and proceeding to band number 24 as follows:

$$SPL''(3,k) = SPL(3,k)$$

$$SPL''(4,k) = SPL''(3,k) + \bar{s}(3,k)$$

$$\vdots$$

$$SPL''(i,k) = SPL''(i-1,k) + \bar{s}(i-1,k) \qquad [2.10]$$

$$\vdots$$

$$SPL''(24,k) = SPL''(23,k) + \bar{s}(23,k)$$

Step 8. Calculate the differences, $F(i,k)$ between the original sound pressure level and the final background sound pressure level as follows:

$$F(i,k) = SPL(i,k) - SPL''(i,k) \qquad [2.11]$$

and note only values equal to or greater than one and a half.

Step 9. For each of the relevant 1/3 octave bands (3 to 24), determine tone correction factors from the sound pressure level differences $F(i,k)$ and Table 2.1.

Step 10. Designate the largest of the tone correction factors, determined in *Step 9*, as $C(k)$. This tone correction factor is added to the perceived noise level to obtain tone corrected perceived noise level, $PNLT(k)$, using this simple formula:

$$PNLT(k) = PNL(k) + C(k) \qquad [2.12]$$

The maximum value of the tone corrected perceived noise level, $PNLTM$, is then determined from the time history; $PNLTM = PNLT(k)|_{MAX}$

2.2.3 Duration Correction

A duration correction factor, D, is computed by integration under the curve of tone corrected perceived noise level versus time, according to the following formula:

$$D = 10 \log \left[\left(\frac{1}{T} \right) \int_{t(1)}^{t(2)} \text{antilog} \frac{PNLT}{10} \right] dt - PNLTM \qquad [2.13]$$

where T is a normalizing time constant, $PNLTM$ is the maximum value of $PNLT$, and $t(1)$ and $t(2)$ are the limits of the significant noise time history.

Since $PNLT$ is calculated from measured or predicted values of SPL, there will be in general no obvious equation for PNLT as a function of time. Consequently, the equation shall be rewritten with a summation sign instead of an integral sign as follows:

Table 2.1 Tone Correction Factor

Frequency f (Hz)	Level Difference F (dB)	Tone Correction C (dB)
$50 \le f \le 500$	$1.5 \le F < 3$	$F/3 - 0.5$
	$3 \le F < 20$	$F/6$
	$20 \le F$	$3\frac{1}{3}$
$500 \le f \le 5{,}000$	$1.5 \le F < 3$	$2\ F/3\ -1$
	$3 \le F < 20$	$F/3$
	$20 \le F$	$6\frac{2}{3}$
$5{,}000 \le f \le 10{,}000$	$1.5 \le F < 3$	$F/3 - 0.5$
	$3 \le F < 20$	$F/6$
	$20 \le F$	$3\frac{1}{3}$

$$D = 10 \log\left[\left(\frac{1}{T}\right)\sum_{k=0}^{d/\Delta t} \Delta t \cdot \text{antilog}\frac{PNLT(k)}{10}\right] - PNLTM \qquad [2.14]$$

This equation can be further simplified by taking the Δt and T outside the summation, resulting in:

$$D = 10 \log\left[\sum_{k=0}^{d/\Delta t} \text{antilog}\frac{PNLT(k)}{10}\right] - PNLTM + 10 \log\left(\frac{\Delta t}{T}\right) \qquad [2.15]$$

where Δt is the length of the equal increments of time for which $PNLT(k)$ is calculated and d is the time interval to the nearest second during which $PNLT(k)$ is within a specified value, h, of $PNLTM$. This is depicted in Figure 2.2.

To obtain a satisfactory time history of the perceived noise level, Δt should be set to 500 ms, or a shorter approved limit. Other constants are

$T = 10$ s
$h = 10$ dB

Using these values the equation for D becomes:

$$D = 10 \log\left[\sum_{k=0}^{2d} \text{antilog}\frac{PNLT(k)}{10}\right] - PNLTM - 13 \qquad [2.16]$$

2.2.4 Final Objective

The effective perceived noise level, *EPNL*, is determined by the algebraic sum of the maximum tone corrected perceived noise level and the duration correction factor:

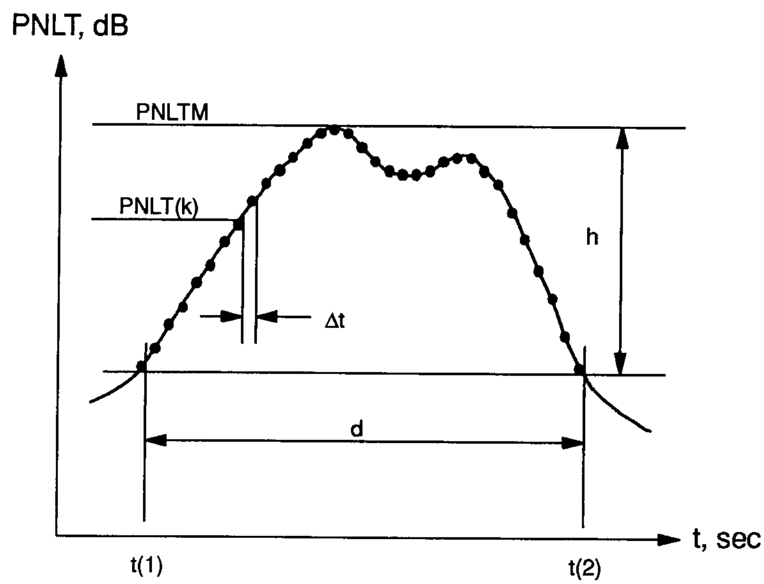

Figure 2.2. The noise time history and the related terms.

$$EPNL = PNLTM + D \qquad [2.17]$$

and represents the total subjective effects of an airplane flyover.

3. FAR Noise Certification Requirements

Noise limits for supersonic transport category airplanes are specified in section §36.301 of FAR part 36 [Ref. 2]. The specifications are short, the noise levels should be "...reduced to the lowest levels that are economically reasonable, technologically practicable, and appropriate..."[Ref. 2]. However, FAA has stated that future HSCT aircraft will be required to adhere to Stage 3 limits, which are currently required of all new subsonic airplanes.

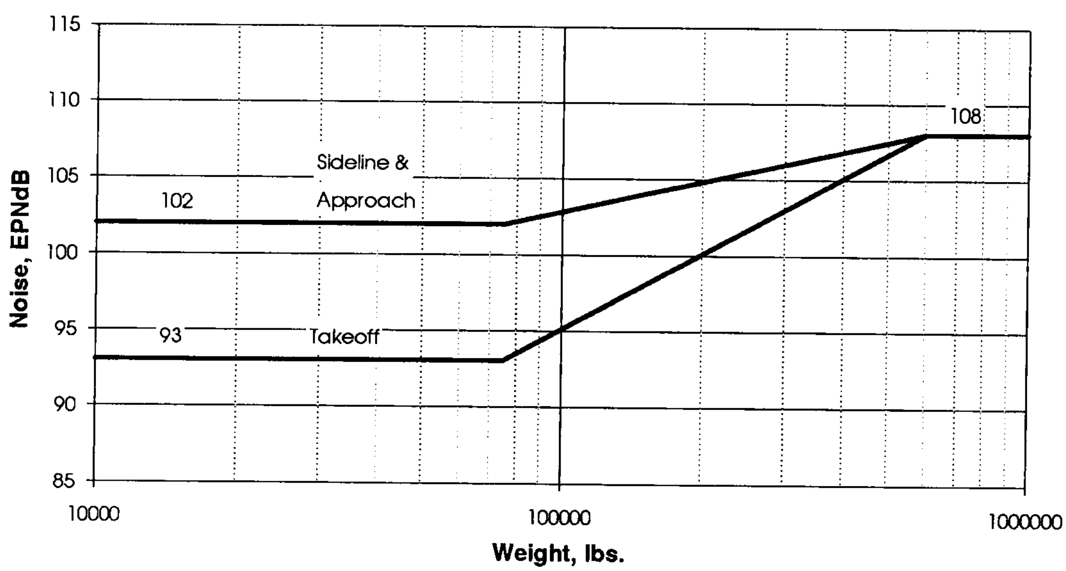

Figure 3.1 Stage 2 certification requirements.

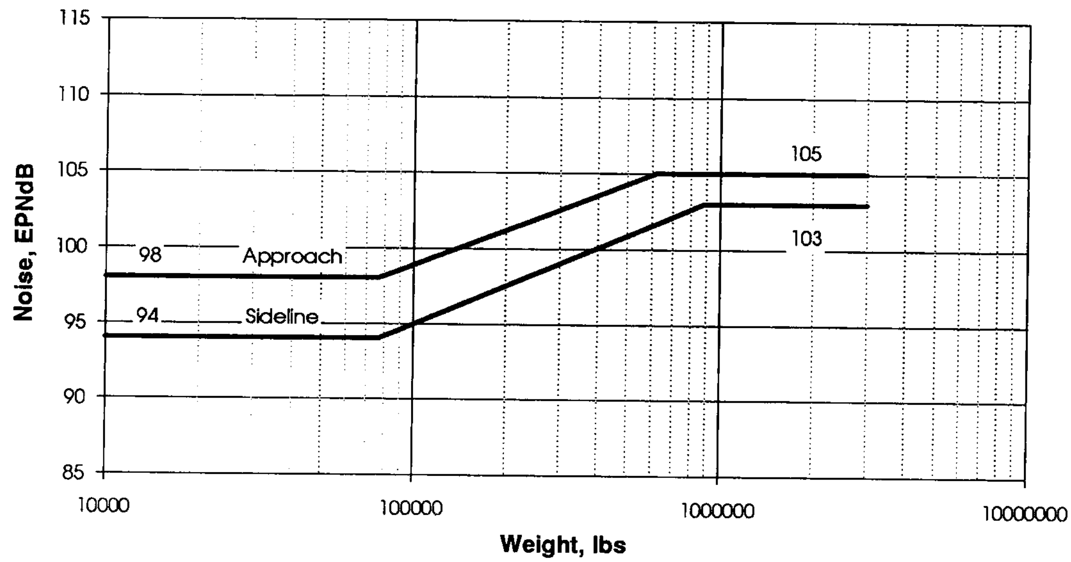

Figure 3.2 Stage 3 certification requirements for sideline and approach.

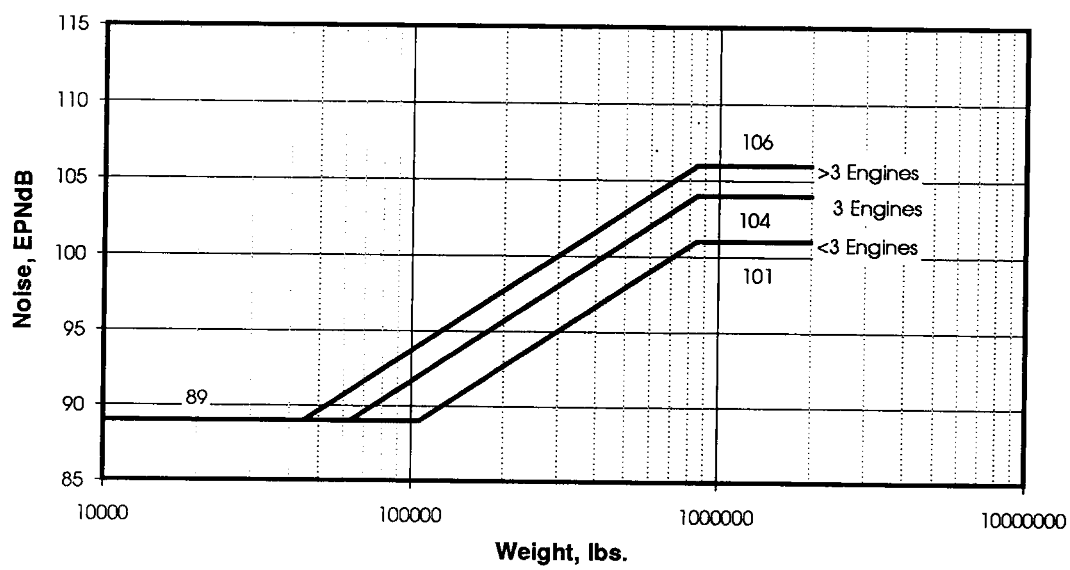

Figure 3.3 Stage 3 certification requirements for takeoff.

Figure 3.4 shows the reference points for approach, takeoff and sideline measurements. These points are the same for all stages. The points are located as follows:

- For takeoff, at a point 6,500 meters from the start of the takeoff roll on the extended centerline of the runway.
- For approach, at a point 2,000 meters from the threshold on the extended centerline of the runway
- For sideline, at the point on a line parallel to and 450 meters from the extended centerline of the runway, where the noise level after liftoff is greatest.

3.2 Stages

Figures 3.1 through 3.3 show stage 2 and stage 3 requirements versus weight, for takeoff, sideline and approach. See Appendix B for more specifics. Stage 1, the original limits, are not included since they are no longer applicable. These requirements are not all that strict though, since tradeoffs are allowed. The noise level limits at one or two of the measuring points may be exceeded, if:

- The sum of the exceedances is not greater than 3 EPNdB,
- No exceedance is greater than 2 EPNdB, and
- The exceedances are completely offset by reductions at the other points.

FAA is also considering lessening the restrictions on supersonic transports in terms of takeoff requirements [Ref. 4] ,which are more restrictive than FAR pt. 25 for the purpose of noise certification. Noise reduction through advanced takeoff procedures has been studied [Ref. 3], and shown to be somewhat effective. This study used the ANOPP noise prediction program along with the FLOPS flight optimization system.

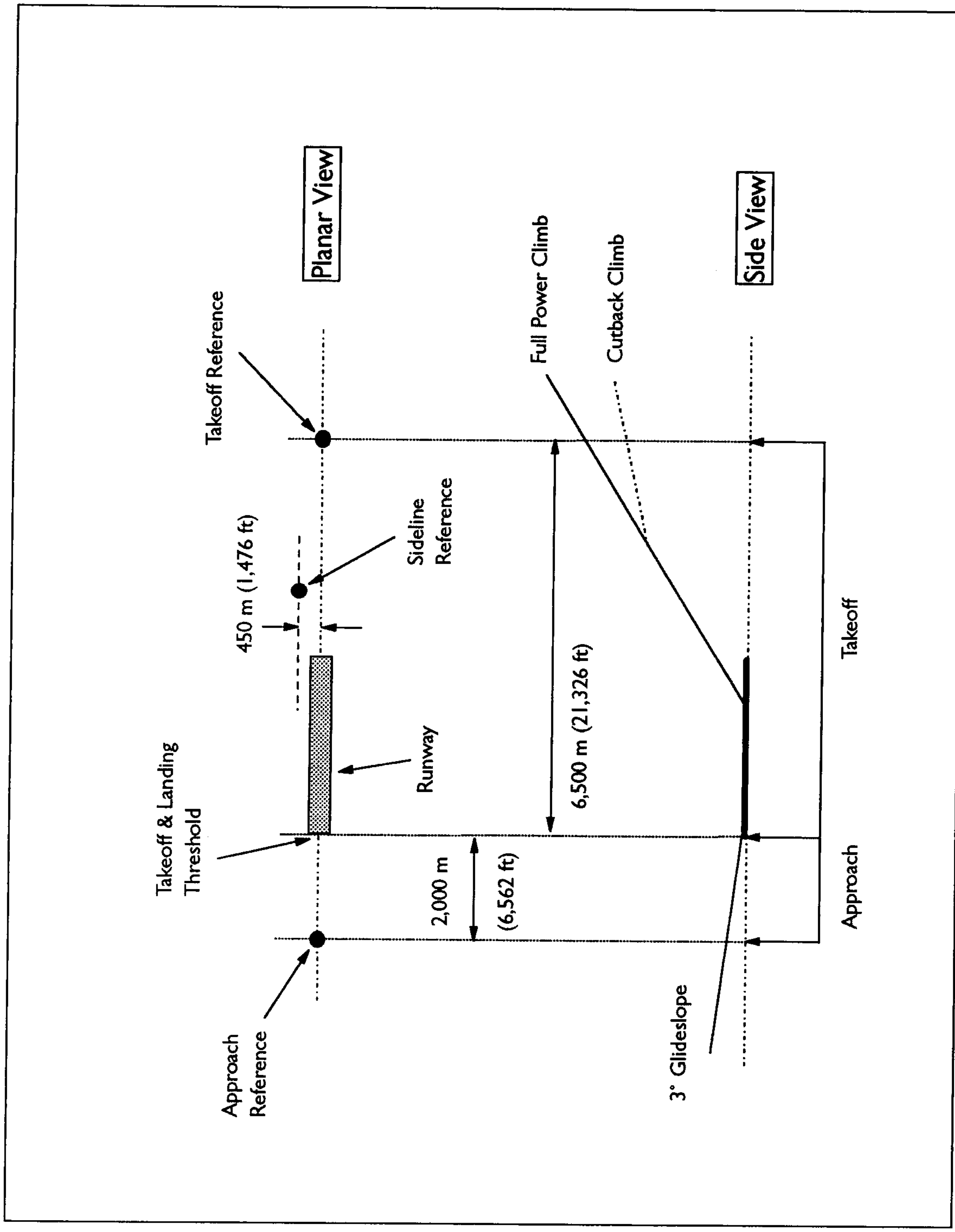

Figure 3.1 The FAR part 36 reference points.

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2. DOT/FAA Noise Standards: Aircraft Type and Airworthiness Certification, FAR Part 36, January 1, 1990.

3. **E.D. Olson**, Advanced Takeoff Procedures for High-Speed Civil Transport Community Noise Reduction, SAE Technical Paper Series, No. 921939, 1992.

4. Civil Supersonic Aircraft Noise Type Certification Standards and Operation Rules; Notice of Proposed Rulemaking. Federal Register Vol. 55, No. 104, Wednesday, May 30, 1990. [J1 A2]

APPENDIX A

This appendix contains a table of the annoyance values for a range of frequency and sound pressure level.

Frequency, Hz

SPL, dB	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
4																			0.1					
5																		0.1	0.11	0.1				
6																		0.11	0.12	0.11	0.1			
7																		0.12	0.14	0.13	0.11			
8																		0.14	0.16	0.14	0.13			
9																	0.1	0.16	0.17	0.16	0.14			
10																	0.11	0.17	0.19	0.18	0.16	0.1		
11																	0.13	0.19	0.22	0.21	0.18	0.12		
12																0.1	0.14	0.22	0.24	0.24	0.21	0.14		
13																0.11	0.16	0.24	0.27	0.27	0.24	0.16		
14																0.13	0.18	0.27	0.3	0.3	0.27	0.19		
15															0.1	0.14	0.21	0.3	0.33	0.33	0.3	0.22		
16										0.1	0.1	0.1	0.1	0.1	0.11	0.16	0.24	0.33	0.35	0.35	0.33	0.26		
17										0.11	0.11	0.11	0.11	0.11	0.13	0.18	0.27	0.35	0.38	0.38	0.35	0.3	0.1	
18									0.1	0.13	0.13	0.13	0.13	0.13	0.15	0.21	0.3	0.38	0.41	0.41	0.38	0.33	0.12	
19									0.11	0.14	0.14	0.14	0.14	0.14	0.17	0.24	0.33	0.41	0.45	0.45	0.41	0.36	0.14	
20									0.13	0.16	0.16	0.16	0.16	0.16	0.2	0.27	0.36	0.45	0.49	0.49	0.45	0.39	0.17	
21								0.1	0.14	0.18	0.18	0.18	0.18	0.18	0.23	0.3	0.39	0.49	0.53	0.53	0.49	0.42	0.21	0.1
22								0.11	0.16	0.21	0.21	0.21	0.21	0.21	0.26	0.33	0.42	0.53	0.57	0.57	0.53	0.46	0.25	0.11
23								0.13	0.18	0.24	0.24	0.24	0.24	0.24	0.3	0.36	0.46	0.57	0.62	0.62	0.57	0.5	0.3	0.13
24							0.1	0.14	0.21	0.27	0.27	0.27	0.27	0.27	0.33	0.4	0.5	0.62	0.67	0.67	0.62	0.55	0.33	0.15
25							0.11	0.16	0.24	0.3	0.3	0.3	0.3	0.3	0.35	0.43	0.55	0.67	0.73	0.73	0.67	0.6	0.36	0.17
26							0.13	0.18	0.27	0.33	0.33	0.33	0.33	0.33	0.38	0.48	0.6	0.73	0.79	0.79	0.73	0.65	0.39	0.2
27						0.1	0.14	0.21	0.3	0.35	0.35	0.35	0.35	0.35	0.41	0.52	0.65	0.79	0.85	0.85	0.79	0.71	0.42	0.23
28						0.11	0.16	0.24	0.33	0.38	0.38	0.38	0.38	0.38	0.45	0.57	0.71	0.85	0.92	0.92	0.85	0.77	0.46	0.26
29						0.13	0.18	0.27	0.35	0.41	0.41	0.41	0.41	0.41	0.49	0.63	0.77	0.92	1	1	0.92	0.84	0.5	0.3
30					0.1	0.14	0.21	0.3	0.38	0.45	0.45	0.45	0.45	0.45	0.53	0.69	0.84	1	1.07	1.07	1	0.92	0.55	0.33
31					0.11	0.16	0.24	0.33	0.41	0.49	0.49	0.49	0.49	0.49	0.57	0.76	0.93	1.07	1.15	1.15	1.07	1	0.6	0.37
32					0.13	0.18	0.27	0.36	0.45	0.53	0.53	0.53	0.53	0.53	0.62	0.83	1	1.15	1.23	1.23	1.15	1.07	0.65	0.41
33					0.14	0.21	0.3	0.39	0.49	0.57	0.57	0.57	0.57	0.57	0.67	0.91	1.07	1.23	1.32	1.32	1.23	1.15	0.71	0.45
34				0.1	0.16	0.24	0.33	0.42	0.53	0.62	0.62	0.62	0.62	0.62	0.73	1	1.15	1.32	1.41	1.41	1.32	1.23	0.77	0.5
35				0.11	0.18	0.27	0.36	0.46	0.57	0.67	0.67	0.67	0.67	0.67	0.79	1.07	1.23	1.41	1.51	1.51	1.41	1.32	0.84	0.55
36				0.13	0.21	0.3	0.4	0.5	0.62	0.73	0.73	0.73	0.73	0.73	0.85	1.15	1.32	1.51	1.62	1.62	1.51	1.41	0.92	0.55
37				0.15	0.24	0.33	0.43	0.55	0.67	0.79	0.79	0.79	0.79	0.79	0.92	1.23	1.41	1.62	1.74	1.74	1.62	1.51	1	0.67
38				0.17	0.27	0.37	0.48	0.6	0.73	0.85	0.85	0.85	0.85	0.85	1	1.32	1.51	1.74	1.86	1.86	1.74	1.62	1.1	0.74
39			0.1	0.2	0.3	0.41	0.52	0.65	0.79	0.92	0.92	0.92	0.92	0.92	1.07	1.41	1.62	1.86	1.99	1.99	1.86	1.74	1.21	0.82
40			0.12	0.23	0.33	0.45	0.57	0.71	0.85	1	1	1	1	1	1.15	1.51	1.74	1.99	2.14	2.14	1.99	1.86	1.34	0.9
41			0.14	0.26	0.37	0.5	0.63	0.77	0.92	1.07	1.07	1.07	1.07	1.07	1.23	1.62	1.86	2.14	2.29	2.29	2.14	1.99	1.48	1
42			0.16	0.3	0.41	0.55	0.69	0.84	1	1.15	1.15	1.15	1.15	1.15	1.32	1.74	1.99	2.29	2.45	2.45	2.29	2.14	1.63	1.1
43			0.19	0.33	0.45	0.61	0.76	0.92	1.07	1.23	1.23	1.23	1.23	1.23	1.41	1.86	2.14	2.45	2.63	2.63	2.45	2.29	1.79	1.21
44		0.1	0.22	0.37	0.5	0.67	0.83	1	1.15	1.32	1.32	1.32	1.32	1.32	1.52	1.99	2.29	2.63	2.81	2.81	2.63	2.45	1.99	1.34

Frequency, Hz

SPL, dB	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
45		0.12	0.26	0.42	0.55	0.74	0.91	1.08	1.24	1.41	1.41	1.41	1.41	1.41	1.62	2.14	2.45	2.81	3.02	3.02	2.81	2.63	2.14	1.48
46		0.14	0.3	0.46	0.61	0.82	1	1.16	1.33	1.52	1.52	1.52	1.52	1.52	1.74	2.29	2.63	3.02	3.23	3.23	3.02	2.81	2.29	1.63
47		0.16	0.34	0.52	0.67	0.9	1.08	1.25	1.42	1.62	1.62	1.62	1.62	1.62	1.87	2.45	2.81	3.23	3.46	3.46	3.23	3.02	2.45	1.79
48		0.19	0.38	0.58	0.74	1	1.17	1.34	1.53	1.74	1.74	1.74	1.74	1.74	2	2.63	3.02	3.46	3.71	3.71	3.46	3.23	2.63	1.98
49	0.1	0.22	0.43	0.65	0.82	1.08	1.26	1.45	1.64	1.87	1.87	1.87	1.87	1.87	2.14	2.81	3.23	3.71	3.97	3.97	3.71	3.46	2.81	2.18
50	0.12	0.26	0.49	0.72	0.9	1.17	1.36	1.56	1.76	2	2	2	2	2	2.3	3.02	3.46	3.97	4.26	4.26	3.97	3.71	3.02	2.4
51	0.14	0.3	0.55	0.8	1	1.26	1.47	1.68	1.89	2.14	2.14	2.14	2.14	2.14	2.46	3.23	3.71	4.26	4.56	4.56	4.26	3.97	3.23	2.63
52	0.17	0.34	0.62	0.9	1.08	1.36	1.58	1.8	2.03	2.3	2.3	2.3	2.3	2.3	2.64	3.46	3.97	4.56	4.89	4.89	4.56	4.26	3.46	2.81
53	0.21	0.39	0.7	1	1.18	1.47	1.71	1.94	2.17	2.46	2.46	2.46	2.46	2.46	2.83	3.71	4.26	4.89	5.24	5.24	4.89	4.56	3.71	3.02
54	0.25	0.45	0.79	1.09	1.28	1.58	1.85	2.09	2.33	2.64	2.64	2.64	2.64	2.64	3.03	3.97	4.56	5.24	5.61	5.61	5.24	4.89	3.97	3.23
55	0.3	0.51	0.89	1.15	1.35	1.71	2	2.25	2.5	2.83	2.83	2.83	2.83	2.83	3.25	4.26	4.89	5.61	6.01	6.01	5.61	5.24	4.26	3.46
56	0.34	0.59	1	1.29	1.5	1.85	2.15	2.42	2.69	3.03	3.03	3.03	3.03	3.03	3.48	4.56	5.24	6.01	6.44	6.44	6.01	5.61	4.56	3.71
57	0.39	0.67	1.09	1.4	1.63	2	2.33	2.61	2.88	3.25	3.25	3.25	3.25	3.25	3.73	4.89	5.61	6.44	6.9	6.9	6.44	6.01	4.89	3.97
58	0.45	0.77	1.18	1.53	1.77	2.15	2.51	2.81	3.1	3.48	3.48	3.48	3.48	3.48	4	5.24	6.01	6.9	7.39	7.39	6.9	6.44	5.24	4.26
59	0.51	0.87	1.29	1.66	1.92	2.33	2.71	3.03	3.32	3.73	3.73	3.73	3.73	3.73	4.29	5.61	6.44	7.39	7.92	7.92	7.39	6.9	5.61	4.56
60	0.59	1	1.4	1.81	2.08	2.51	2.93	3.26	3.57	4	4	4	4	4	4.59	6.01	6.9	7.92	8.49	8.49	7.92	7.39	6.01	4.89
61	0.67	1.1	1.53	1.97	2.26	2.71	3.16	3.51	3.83	4.29	4.29	4.29	4.29	4.29	4.92	6.44	7.39	8.49	9.09	9.09	8.49	7.92	6.44	5.24
62	0.77	1.21	1.66	2.15	2.45	2.93	3.41	3.78	4.11	4.59	4.59	4.59	4.59	4.59	5.28	6.9	7.92	9.09	9.74	9.74	9.09	8.49	6.9	5.61
63	0.87	1.32	1.81	2.34	2.65	3.16	3.69	4.06	4.41	4.92	4.92	4.92	4.92	4.92	5.66	7.39	8.49	9.74	10.4	10.4	9.74	9.09	7.39	6.01
64	1	1.45	1.97	2.54	2.88	3.41	3.98	4.38	4.73	5.28	5.28	5.28	5.28	5.28	6.06	7.92	9.09	10.4	11.2	11.2	10.4	9.74	7.92	6.44
65	1.11	1.6	2.15	2.77	3.12	3.69	4.3	4.71	5.08	5.66	5.66	5.66	5.66	5.66	6.5	8.49	9.74	11.2	12	12	11.2	10.4	8.49	6.9
66	1.22	1.75	2.34	3.01	3.39	3.99	4.64	5.07	5.45	6.06	6.06	6.06	6.06	6.06	6.96	9.09	10.4	12	12.8	12.8	12	11.2	9.09	7.39
67	1.35	1.92	2.54	3.28	3.68	4.3	5.01	5.46	5.85	6.5	6.5	6.5	6.5	6.5	7.46	9.74	11.2	12.8	13.8	13.8	12.8	12	9.74	7.92
68	1.49	2.11	2.77	3.57	3.99	4.64	5.41	5.88	6.27	6.96	6.96	6.96	6.96	6.96	8	10.4	12	13.8	14.7	14.7	13.8	12.8	10.4	8.49
69	1.65	2.32	3.01	3.88	4.33	5.01	5.84	6.33	6.73	7.46	7.46	7.46	7.46	7.46	8.57	11.2	12.8	14.7	15.8	15.8	14.7	13.8	11.2	9.09
70	1.82	2.55	3.28	4.23	4.69	5.41	6.31	6.81	7.23	8	8	8	8	8	9.19	12	13.8	15.8	16.9	16.9	15.8	14.7	12	9.74
71	2.02	2.79	3.57	4.6	5.09	5.84	6.81	7.33	7.75	8.57	8.57	8.57	8.57	8.57	9.85	12.8	14.7	16.9	18.1	18.1	16.9	15.8	12.8	10.4
72	2.23	3.07	3.88	5.01	5.52	6.31	7.36	7.9	8.32	9.19	9.19	9.19	9.19	9.19	10.6	13.8	15.8	18.1	19.4	19.4	18.1	16.9	13.8	11.2
73	2.46	3.37	4.23	5.45	5.99	6.81	7.94	8.5	8.93	9.85	9.85	9.85	9.85	9.85	11.3	14.7	16.9	19.4	20.8	20.8	19.4	18.1	14.7	12
74	2.72	3.7	4.6	5.94	6.5	7.36	8.57	9.15	9.59	10.6	10.6	10.6	10.6	10.6	12.1	15.8	18.1	20.8	22.3	22.3	20.8	19.4	15.8	12.8
75	3.01	4.06	5.01	6.46	7.05	7.94	9.19	9.85	10.3	11.3	11.3	11.3	11.3	11.3	13	16.9	19.4	22.3	23.9	23.9	22.3	20.8	16.9	13.8
76	3.32	4.46	5.45	7.03	7.65	8.57	9.85	10.6	11	12.1	12.1	12.1	12.1	12.1	13.9	18.1	20.8	23.9	25.6	25.6	23.9	22.3	18.1	14.7
77	3.67	4.89	5.94	7.66	8.29	9.19	10.6	11.3	11.8	13	13	13	13	13	14.9	19.4	22.3	25.6	27.4	27.4	25.6	23.9	19.4	15.8
78	4.06	5.37	6.46	8.33	9	9.85	11.3	12.1	12.7	13.9	13.9	13.9	13.9	13.9	16	20.8	23.9	27.4	29.4	29.4	27.4	25.6	20.8	16.9
79	4.49	5.9	7.03	9.07	9.76	10.6	12.1	13	13.6	14.9	14.9	14.9	14.9	14.9	17.1	22.3	25.6	29.4	31.5	31.5	29.4	27.4	22.3	18.1
80	4.96	6.48	7.66	9.85	10.6	11.3	13	13.9	14.6	16	16	16	16	16	16.4	23.9	27.4	31.5	33.7	33.7	31.5	29.4	23.9	19.4
81	5.48	7.11	8.33	10.6	11.3	12.1	13.9	14.9	15.7	17.1	17.1	17.1	17.1	17.1	19.7	25.6	29.4	33.7	36.1	36.1	33.7	31.5	25.6	20.8
82	6.06	7.81	9.07	11.3	12.1	13	14.9	16	16.9	18.4	18.4	18.4	18.4	18.4	21.1	27.4	31.5	36.1	38.7	38.7	36.1	33.7	27.4	22.3
83	6.7	8.57	9.87	12.1	13	13.9	16	17.1	18.1	19.7	19.7	19.7	19.7	19.7	22.6	29.4	33.7	38.7	41.5	41.5	38.7	36.1	29.4	23.9
84	7.41	9.41	10.7	13	13.9	14.9	17.1	18.4	19.4	21.1	21.1	21.1	21.1	21.1	24.3	31.5	36.1	41.5	44.4	44.4	41.5	38.7	31.5	25.6
85	8.19	10.3	11.7	13.9	14.9	16	18.4	19.7	20.8	22.6	22.6	22.6	22.6	22.6	26	33.7	38.7	44.4	47.6	47.6	44.4	41.5	33.7	27.4
86	9.05	11.3	12.7	14.9	16	17.1	19.7	21.1	22.4	24.3	24.3	24.3	24.3	24.3	27.9	36.1	41.5	47.6	51	51	47.6	44.4	36.1	29.4

Frequency, Hz

SPL, dB	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
87	10	12.1	13.9	16	17.1	18.4	21.1	22.6	24	26	26	26	26	26	29.9	38.7	44.4	51	54.7	54.7	51	47.6	38.7	31.5
88	11.1	13	14.9	17.1	18.4	19.7	22.6	24.3	25.8	27.9	27.9	27.9	27.9	27.9	32	41.5	47.6	54.7	58.6	58.6	54.7	51	41.5	33.7
89	12.2	13.9	16	18.4	19.7	21.1	24.3	26	27.7	29.9	29.9	29.9	29.9	29.9	34.3	44.4	51	58.6	62.7	62.7	58.6	54.7	44.4	36.1
90	13.5	14.9	17.1	19.7	21.1	22.6	26	27.9	29.7	32	32	32	32	32	36.8	47.6	54.7	62.7	67.2	67.2	62.7	58.6	47.6	38.7
91	14.9	16	18.4	21.1	22.6	24.3	27.9	29.9	31.8	34.3	34.3	34.3	34.3	34.3	39.4	51	58.6	67.2	72	72	67.2	62.7	51	41.5
92	16	17.1	19.7	22.6	24.3	26	29.9	32	34.2	36.8	36.8	36.8	36.8	36.8	42.2	54.7	62.7	72	77.2	77.2	72	67.2	54.7	44.4
93	17.1	18.4	21.1	24.3	26	27.9	32	34.3	36.7	39.4	39.4	39.4	39.4	39.4	45.3	58.6	67.2	77.2	82.7	82.7	77.2	72	58.6	47.6
94	18.4	19.7	22.6	26	27.9	29.9	34.3	36.8	39.4	42.2	42.2	42.2	42.2	42.2	48.5	62.7	72	82.7	88.6	88.6	82.7	77.2	62.7	51
95	19.7	21.1	24.3	27.9	29.9	32	36.8	39.4	42.2	45.3	45.3	45.3	45.3	45.3	52	67.2	77.2	88.6	94.9	94.9	88.6	82.7	67.2	54.7
96	21.1	22.6	26	29.9	32	34.3	39.4	42.2	45.3	48.5	48.5	48.5	48.5	48.5	55.7	72	82.7	94.9	102	102	94.9	88.6	72	58.6
97	22.6	24.3	27.9	32	34.3	36.8	42.2	45.3	48.5	52	52	52	52	52	59.7	77.2	88.6	102	109	109	102	94.9	77.2	62.7
98	24.3	26	29.9	34.3	36.8	39.4	45.3	48.5	52	55.7	55.7	55.7	55.7	55.7	64	82.7	94.9	109	117	117	109	102	82.7	67.2
99	26	27.9	32	36.8	39.4	42.2	48.5	52	55.7	59.7	59.7	59.7	59.7	59.7	68.6	88.6	102	117	125	125	117	109	88.6	72
100	27.9	29.9	34.3	39.4	42.2	45.3	52	55.7	59.7	64	64	64	64	64	73.5	94.9	109	125	134	134	125	117	94.9	77.2
101	29.9	32	36.8	42.2	45.3	48.5	55.7	59.7	64	68.6	68.6	68.6	68.6	68.6	78.8	102	117	134	144	144	134	125	102	82.7
102	32	34.3	39.4	45.3	48.5	52	59.7	64	68.6	73.5	73.5	73.5	73.5	73.5	84.4	109	125	144	154	154	144	134	109	88.6
103	34.3	36.8	42.2	48.5	52	55.7	64	68.6	73.5	78.8	78.8	78.8	78.8	78.8	90.5	117	134	154	165	165	154	144	117	94.9
104	36.8	39.4	45.3	52	55.7	59.7	68.6	73.5	78.8	84.4	84.4	84.4	84.4	84.4	97	125	144	165	177	177	165	154	125	102
105	39.4	42.2	48.5	55.7	59.7	64	73.5	78.8	84.4	90.5	90.5	90.5	90.5	90.5	104	134	154	177	189	189	177	165	134	109
106	42.2	45.3	52	59.7	64	68.6	78.8	84.4	90.5	97	97	97	97	97	111	144	165	189	203	203	189	177	144	117
107	45.3	46.5	55.7	64	68.6	73.5	84.4	90.5	97	104	104	104	104	104	119	154	177	203	217	217	203	189	154	125
108	48.5	52	59.7	68.6	73.5	78.8	90.5	97	104	111	111	111	111	111	128	165	189	217	233	233	217	203	165	134
109	52	55.7	64	73.5	78.8	84.4	97	104	111	119	119	119	119	119	137	177	203	133	249	249	133	217	177	144
110	55.7	59.7	68.6	78.8	84.4	90.5	104	111	119	128	128	128	128	128	147	189	217	249	267	267	249	133	189	154
111	59.7	64	73.5	84.4	90.5	97	111	119	128	137	137	137	137	137	158	203	233	267	286	286	267	249	203	165
112	64	68.6	78.8	90.5	97	104	119	128	137	147	147	147	147	147	169	217	249	286	307	307	286	267	217	177
113	68.6	73.5	84.4	97	104	111	128	137	147	158	158	158	158	158	181	233	267	307	329	329	307	286	133	189
114	73.5	78.8	90.5	104	111	119	137	147	158	169	169	169	169	169	194	249	286	329	352	352	329	307	249	203
115	78.8	84.4	97	111	119	128	147	158	169	181	181	181	181	181	208	267	307	352	377	377	352	329	267	217
116	84.4	90.5	104	119	128	137	158	169	181	194	194	194	194	194	223	286	329	377	404	404	377	352	286	133
117	90.5	97	111	128	137	147	169	181	194	208	208	208	208	208	239	307	352	404	433	433	404	377	307	249
118	97	104	119	137	147	158	181	194	208	223	223	223	223	223	256	329	377	433	464	464	433	404	329	267
119	104	111	128	147	158	169	194	208	223	239	239	239	239	239	274	352	404	464	497	497	464	433	352	286
120	111	119	137	158	169	181	208	223	239	256	256	256	256	256	294	377	433	497	533	533	497	464	377	307
121	119	128	147	169	181	194	223	239	256	274	274	274	274	274	315	404	464	533	571	571	533	497	404	329
122	128	137	158	181	194	208	239	256	274	294	294	294	294	294	338	433	497	571	611	611	571	533	433	352
123	137	147	169	194	208	223	256	274	294	315	315	315	315	315	362	464	533	611	655	655	611	571	464	377
124	147	158	181	208	223	239	274	294	315	338	338	338	338	338	388	497	571	655	702	702	655	611	497	404
125	158	169	194	223	239	256	294	315	338	362	362	362	362	362	416	533	611	702	752	752	702	655	533	433
126	169	181	208	239	256	274	315	338	362	388	388	388	388	388	446	571	655	752	806	806	752	702	571	464
127	181	194	223	256	274	294	338	362	388	416	416	416	416	416	478	611	702	806	863	863	806	752	611	497
128	194	208	239	274	294	315	362	388	416	446	446	446	446	446	512	655	752	863	925	925	863	806	655	533

Frequency, Hz

SPL, dB	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
129	208	223	256	294	315	338	388	416	446	478	478	478	478	478	549	702	806	925	991	991	925	863	702	571
130	223	239	274	315	338	362	416	446	478	512	512	512	512	512	588	752	863	991	1062	1062	991	925	752	611
131	239	256	294	338	362	388	446	478	512	549	549	549	549	549	630	806	925	1062	1137	1137	1062	991	806	655
132	256	274	315	362	388	416	478	512	549	588	588	588	588	588	676	863	991	1137	1219	1219	1137	1062	863	702
133	274	294	338	388	416	446	512	549	588	630	630	630	630	630	724	925	1062	1219	1306	1306	1219	1137	925	752
134	294	315	362	416	446	478	549	588	630	676	676	676	676	676	776	991	1137	1306	1399	1399	1306	1219	991	806
135	315	338	388	446	478	512	588	630	676	724	724	724	724	724	832	1062	1219	1399	1499	1499	1399	1306	1062	863
136	338	362	416	478	512	549	630	676	724	776	776	776	776	776	891	1137	1306	1499	1606	1606	1499	1399	1137	925
137	362	388	446	512	549	588	676	724	776	832	832	832	832	832	955	1219	1399	1606	1721	1721	1606	1499	1219	991
138	388	416	478	549	588	630	724	776	832	891	891	891	891	891	1024	1306	1499	1721	1844	1844	1721	1606	1306	1062
139	416	446	512	588	630	676	776	832	891	955	955	955	955	955	1098	1399	1606	1844	1975	1975	1844	1721	1399	1137
140	446	478	549	630	676	724	832	891	955	1024	1024	1024	1024	1024	1176	1499	1721	1975			1975	1844	1499	1219
141	478	512	588	676	724	776	891	955	1024	1098	1098	1098	1098	1098	1261	1606	1844					1975	1606	1306
142	512	549	630	724	776	832	955	1024	1098	1176	1176	1176	1176	1176	1351	1721	1975						1721	1399
143	549	588	676	776	832	891	1024	1098	1176	1261	1261	1261	1261	1261	1448	1844							1844	1499
144	588	630	724	832	891	955	1098	1176	1261	1351	1351	1351	1351	1351	1552	1975							1975	1606
145	630	676	776	891	955	1024	1176	1261	1351	1448	1448	1448	1448	1448	1664									1721
146	676	724	832	955	1024	1098	1261	1351	1448	1552	1552	1552	1552	1552	1783									1844
147	724	776	891	1024	1098	1176	1351	1448	1552	1664	1664	1664	1664	1664	1911									1975
148	776	832	955	1098	1176	1261	1448	1552	1664	1783	1783	1783	1783	1783	2048									
149	832	891	1024	1176	1261	1351	1552	1664	1783	1911	1911	1911	1911	1911										
150	891	955	1098	1261	1351	1448	1664	1783	1911	2048	2048	2048	2048	2048										

APPENDIX B

This appendix derives and explains how to obtain the FAR 36 noise limits for aircraft which weights are in the nonlinear range of the FAR 36 specifications. Figures 3.1 through 3.3 are presented using a logarithmic scale, which makes it hard to read off values. Let's first look at how FAA presents the requirements. As an example, the stage 2 requirements for takeoff reads as follows:

> "...108 EPNdB for maximum weights of 600,000 pounds or more, reduced by 5 EPNdB per halving of the 600,000 pounds maximum weight down to 93 EPNdB for maximum weights of 75,000 pounds and less."
>
> [Reference 2]

Essentially, what is given is a starting and ending point. In between is a non-linear region defined by a single constant: reduction in noise per halving of the weight. This is in effect a half-life constant, T, as for radioactive materials. Recall that the instantenaeous rate of decay of a radioactive substance is proportianal to the amount present, or

$$\frac{dy}{dt} = rt \qquad [B.1]$$

where y is the mass, t is time and r is a neagtive constant. The genaral soution is,

$$y = Cb^{rt} \qquad [B.2]$$

where C and b are positive constants. By introducing the half-life of a substance, T, this equation becomes,

$$y = C\left(\frac{1}{2}\right)^{t/T} \qquad [B.3]$$

which for aircraft noise translates into,

$$W = C\left(\frac{1}{2}\right)^{-(EPNL/T)} = C(2)^{EPNL/T} \qquad [B.4]$$

where W is the weight of the aircraft and $EPNL$ is the noise certification level required for that aircraft. Note that the negative sign on the exponent comes from the fact that $EPNL$ is a positive constant representing a reduction in noise levels.

Since the noise level is what we want, equation B.4 can be rewritten as,

$$EPNL = \frac{ln\left(\frac{W}{C}\right)\cdot T}{ln 2} \qquad [B.4]$$

where the constants required in the equation can be looked up in the following table, along with the region that the equation is valid in, represented by W_o and $W\infty$. , as well as the relevant noise level at that weight.

Table B.1 Constants for Noise Requirement Calculations

			C	T	Wo	W∞
	Appr. & Sidel.		$3.33*10^{-11}$	2	75,000@102	600,000@10
Stage 2	Takeoff		$1.89*10^{-01}$	5	75,000@93	600,000@10
		>3 Eng.	$8.96*10^{-03}$	4	44,673@89	850,000@10
Stage 3	Takeoff	=3 Eng.	$1.27*10^{-02}$	4	63,177@89	850,000@10
		<3 Eng.	$2.13*20^{-02}$	4	106,250@89	850,000@10
	Sideline		$6.82*10^{-07}$	2.56	77,200@94	882,000@10
	Approach		$1.68*10^{-08}$	2.33	77,200@98	617,300@10