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W_Z RATING OF RIDE QUALITY IMPLEMENTATION FOR FRA/AMTRAK PROGRAMS

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BACKGROUND

In 1941, Helberg and Sperling [1] developed a procedure for appraising the running qualities of railroad cars. A series of experiments was conducted to establish the relationship between vibrations and the response of an individual to those vibrations. Tests were conducted in a seated position on a vibrating table at frequencies between 1 and 12 Hz and at amplitudes up to one inch. Participants in the experiments were limited to employees of the railroad who had experience in vehicle vibrations. A total of 1,800 tests were conducted.

A formula for computing W_z was derived from these experimental results. W_z was defined as a function of both acceleration level and frequency. There are several points to be noted. First, no distinction was seen between vertical and horizontal vibrations in the frequency domain. This conclusion was drawn as a result of testing, as tests were conducted in both vertical and lateral directions. Second, for a given frequency, W_z only increases by 23% when the acceleration level doubles in amplitude. Third, on a five point scale, where 1 is an excellent ride and 5 a dangerous one, 3 was selected as the upper limit for passenger cars.

In 1968, Sperling [2] wrote a paper which updates the W_z method with respect to automatic computation on a railway vehicle using more modern methods. He describes how the method is used by the German Federal Railway.

The rating scheme for W_z is as follows:

W_z	Condition of Ride
1	Excellent
2	Good
3	Satisfactory
4	Car in Working Order
5	Dangerous

One advantage to the W_z rating process is that a single number can be applied which can describe the quality of the ride. Another advantage is that the W_z method is weighted in the frequency domain and takes into account experimental studies involving actual passenger reactions.

There are slight differences between the W_z and ISO criteria. In the W_z method, the frequency band of greatest passenger discomfort occurs at 5 Hz for both lateral and vertical accelerations. In the ISO standard, the frequency band of greatest passenger discomfort occurs at 1-2 Hz for lateral accelerations and at 4-8 Hz for vertical accelerations.

IMPLEMENTATION

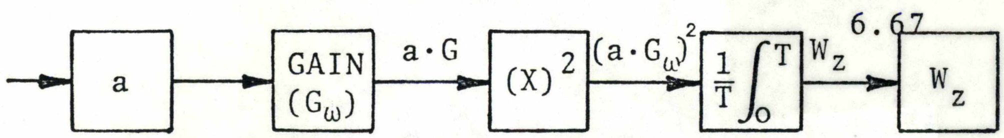
The following parameters were used to implement the W_z method into the computer program VIBES:

In recent times, several articles have been written concerning the W_z method. Pribnow [3] states that the method is useful but somewhat coarse. Andrew [4] feels the method is outdated and that poor experimental procedures were used in developing the method. However, he does feel that modifications to the method (weighing factors and integration over the entire frequency range) have improved the method.

DESCRIPTION

The W_z method of rating the ride of a rail vehicle has been widely used in recent decades. This method applies a single number to describe the quality of the ride. The instantaneous acceleration is measured and weighted in the frequency domain. This value is squared, averaged over time and the 6.67th root is taken. This final number is the W_z rating. Figure 1 shows a flowchart of the process. The working units are cm/sec^2 for acceleration.

Figure 1. Flowchart of W_z Method



07.06
Tol (Passengers)
Tolerable
Ride
Quality

In general

$$W_z = 6.67\sqrt{\frac{.896}{T}\int_0^T (G_\omega \cdot A)^2 \, dt}$$

where

W_z = criteria number

T = total time of data sampled

G_ω = weighting function

A = acceleration level

$G(I)$	=	an array of (where I = I^{th} frequency band)
$G_L(I)$	=	weighted gain (lateral)
$G_V(I)$	=	weighted gain (vertical)
Δf	=	bandwidth (0.25 hz) of present RQ software
$PSD(I)$	=	an array of power spectral density values (in dB WRT 1 g^2rms/hz)
$PD(I)$	=	conversion of PSD values to acceleration as a function of $(cm/sec^2)^2/hz$ (since the data is recorded in g's)
WZ_V	=	WZ rating in vertical direction
WZ_L	=	WZ rating in lateral direction
$G_L(I)$	=	an array of 120 points (see Table 1)
$G_V(I)$	=	$.8333 * G_L(I)$

G_L can be approximated as follows:

f(hz)	G_L
.25	.25
.50	.43
.75	.54
$1.0 \le f \le 8.0$	$[-(f-5)^2/40]+1$
$8.0 < f \le 30.0$	$.948^f$

This approximation can be used only if the $G_L(I)$ array is not compatible with available core space.

Then:

$$PD(I) = (980.7)^2 * \text{PSD Level } (g^2/Hz) \text{ for both vertical and lateral}$$

$$SUM_V = .896(\Delta f)\sum_{j=1}^{120} G_V(I) * PD_V(I)$$

$$SUM_L = .896(\Delta f)\sum_{j=1}^{120} G_L(I) * PD_L(I)$$

$$WZ_V = SUM_V ** 0.15$$

$$WZ_L = SUM_L ** 0.15$$

The ride can then be rated as follows:

W_z	Rating
1.0	Excellent
1.5	Nearly Excellent
2.0	Good
2.5	Nearly Good
3.0	Satisfactory (Upper limit/passenger cars)
3.5	Barely Satisfactory
4.0	Operable (Upper limit/freight cars)
5.0	Dangerous

TABLE 1 $G_L(I)$

I	Freq. (hz)	$G_L(I)$	I	f	$G_L(I)$	I	f	$G_L(I)$
1	.25	.25	28	7.0	.90	55	13.75	.45
2	.5	.43	29	7.25	.87	56	14.0	.45
3	.75	.54	30	7.5	.85	57	14.25	.44
4	1.00	.62	31	7.75	.82	58	14.5	.43
5	1.25	.68	32	8.0	.80	59	14.75	.42
6	1.50	.73	33	8.25	.77	60	15.0	.41
7	1.75	.77	34	8.5	.75	61	15.25	.41
8	2.00	.80	35	8.75	.72	62	15.5	.40
9	2.25	.83	36	9.0	.70	63	15.75	.40
10	2.50	.86	37	9.25	.69	64	16.0	.39
11	2.75	.89	38	9.5	.67	65	16.25	.39
12	3.00	.90	39	9.75	.65	66	16.5	.38
13	3.25	.93	40	10.0	.64	67	16.75	.37
14	3.50	.95	41	10.25	.62	68	17.0	.36
15	3.75	.96	42	10.5	.61	69	17.25	.36
16	4.00	.98	43	10.75	.60	70	17.5	.35
17	4.25	.99	44	11.0	.58	71	17.75	.35
18	4.50	.99	45	11.25	.57	72	18.0	.34
19	4.75	1.0	46	11.5	.56	73	18.25	.34
20	5.00	1.0	47	11.75	.55	74	18.50	.33
21	5.25	.99	48	12.0	.54	75	18.75	.33
22	5.50	.98	49	12.25	.53	76	19.0	.32
23	5.75	.97	50	12.5	.51	77	19.25	.32
24	6.00	.96	51	12.75	.50	78	19.50	.31
25	6.25	.95	52	13.0	.48	79	19.75	.31
26	6.50	.93	53	13.25	.47	80	20.0	.30
27	6.75	.92	54	13.5	.46	81	20.25	.30

I	f	G_L	I	f	G_L
82	20.5	.30	109	27.25	.21
83	20.75	.29	110	27.5	.21
84	21.0	.29	111	27.75	.21
85	21.25	.28	112	28.0	.21
86	21.5	.28	113	28.25	.20
87	21.75	.27	114	28.5	.20
88	22.0	.27	115	28.75	.20
89	22.25	.27	116	29.0	.20
90	22.5	.26	117	29.25	.19
91	22.75	.26	118	29.50	.19
92	23.0	.26	119	29.75	.19
93	23.25	.25	120	30.0	.19
94	23.5	.25			
95	23.75	.24			
96	24.0	.24			
97	24.25	.24			
98	24.5	.23			
99	24.75	.23			
100	25.0	.23			
101	25.25	.23			
102	25.5	.23			
103	25.75	.23			
104	26.0	.22			
105	26.25	.22			
106	26.5	.22			
107	26.75	.22			
108	27.0	.21			

Fig. 2 COMPARISON BETWEEN LATERAL AND VERTICAL ISO WEIGHTING FUNCTION

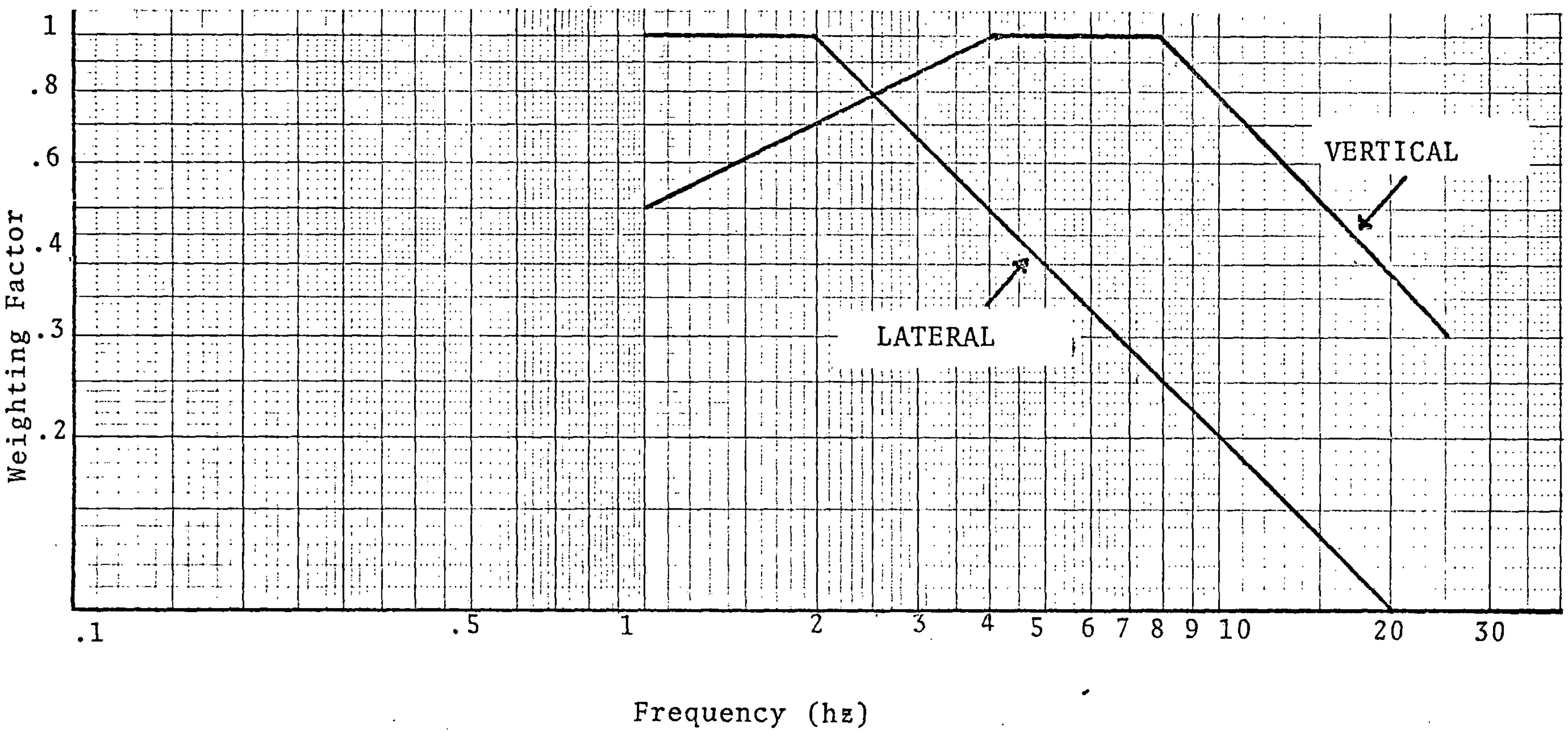


Fig. 3 COMPARISON BETWEEN LATERAL AND VERTICAL WZ WEIGHTING FUNCTION - VERTICAL

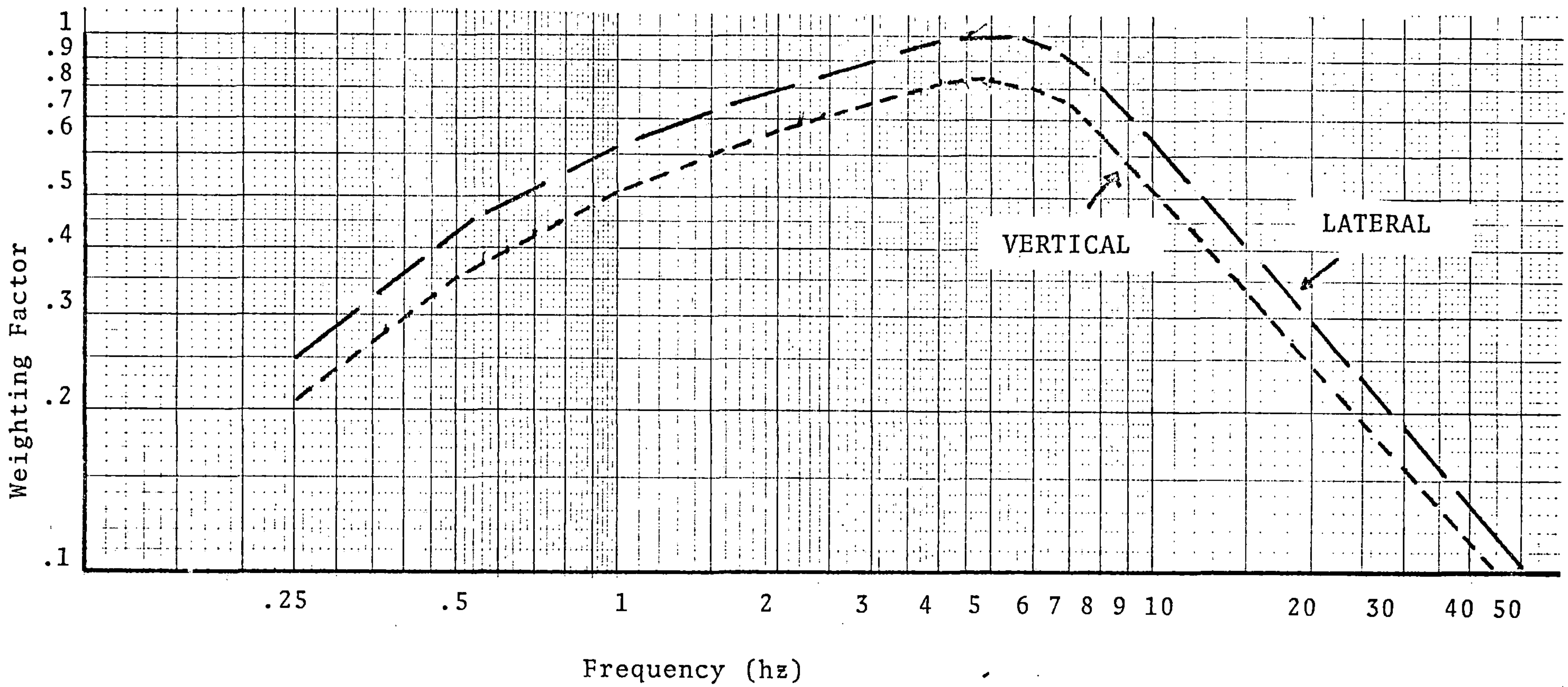


Fig. 4 COMPARISON BETWEEN ISO AND WZ WEIGHTING FUNCTION - VERTICAL

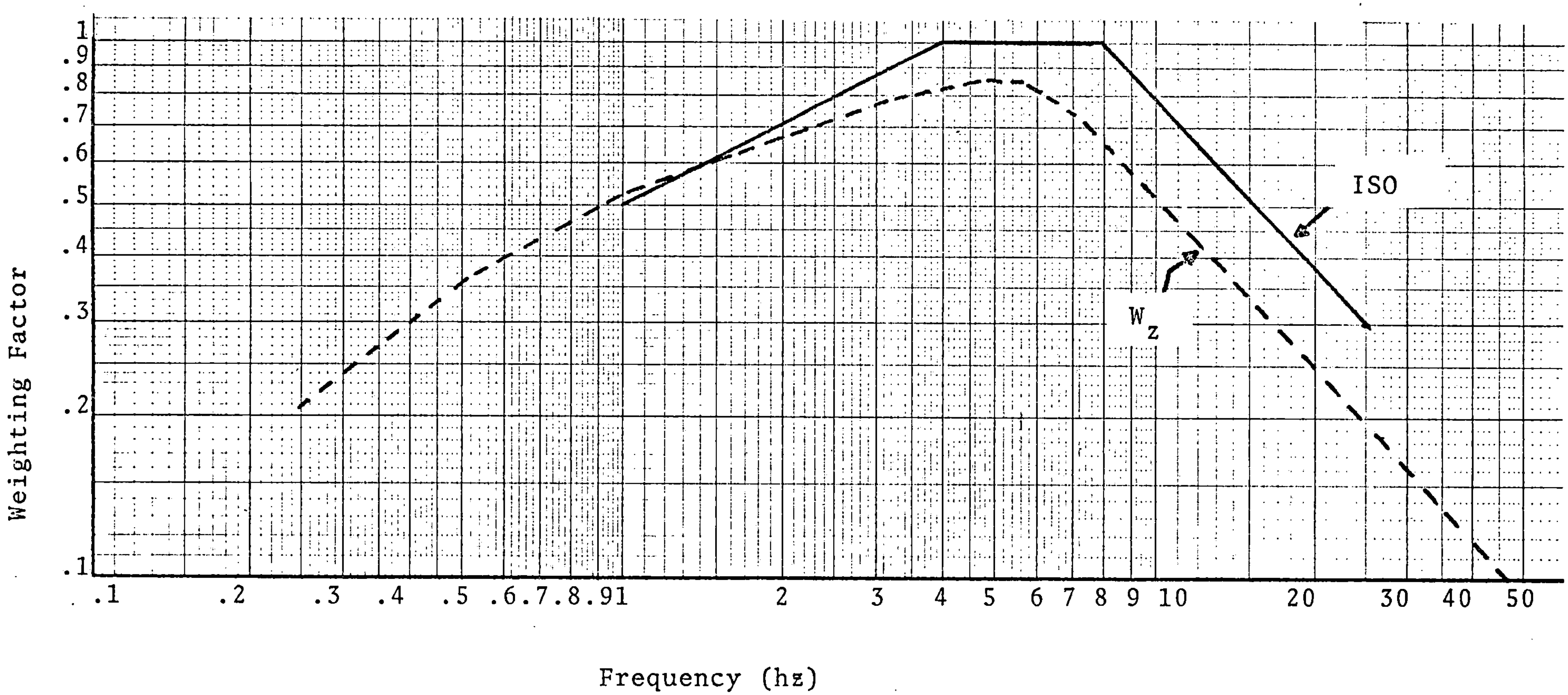
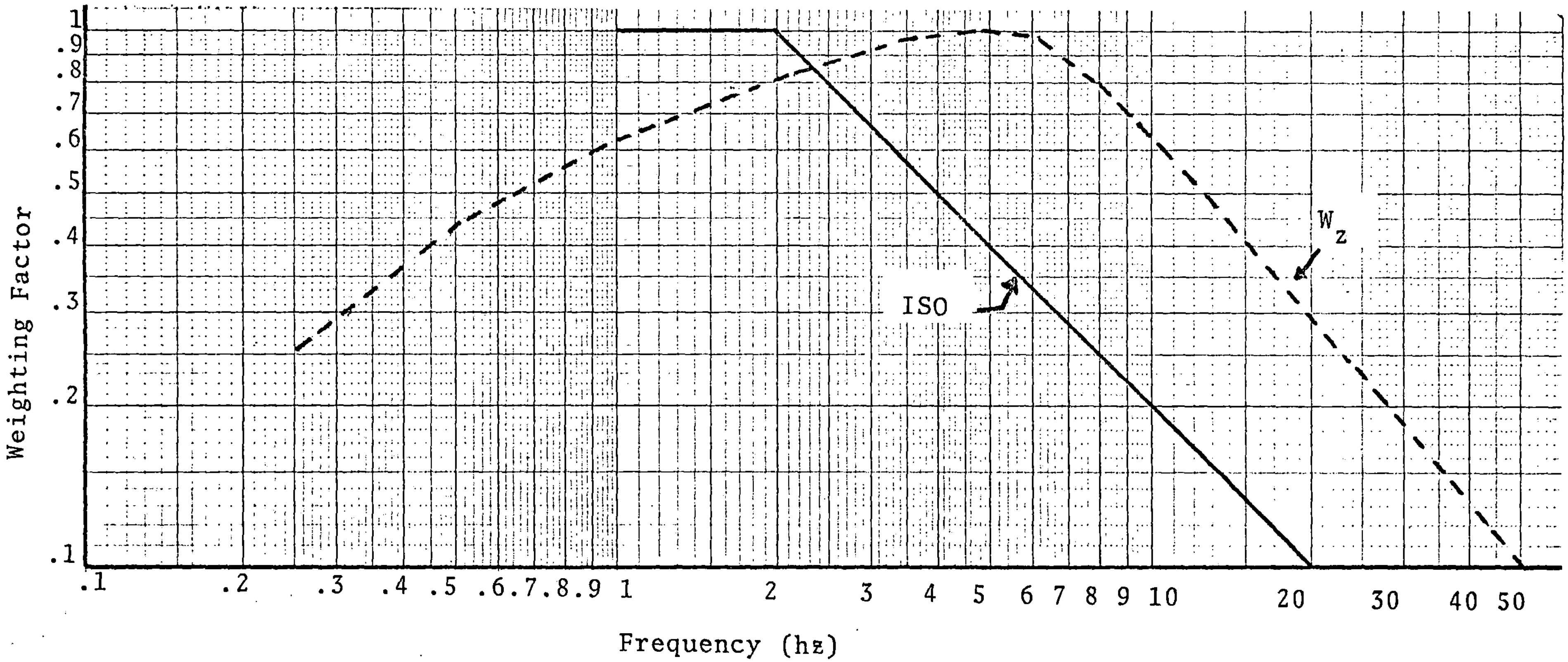


Fig. 5 COMPARISON BETWEEN ISO AND WZ WEIGHTING FUNCTION - LATERAL



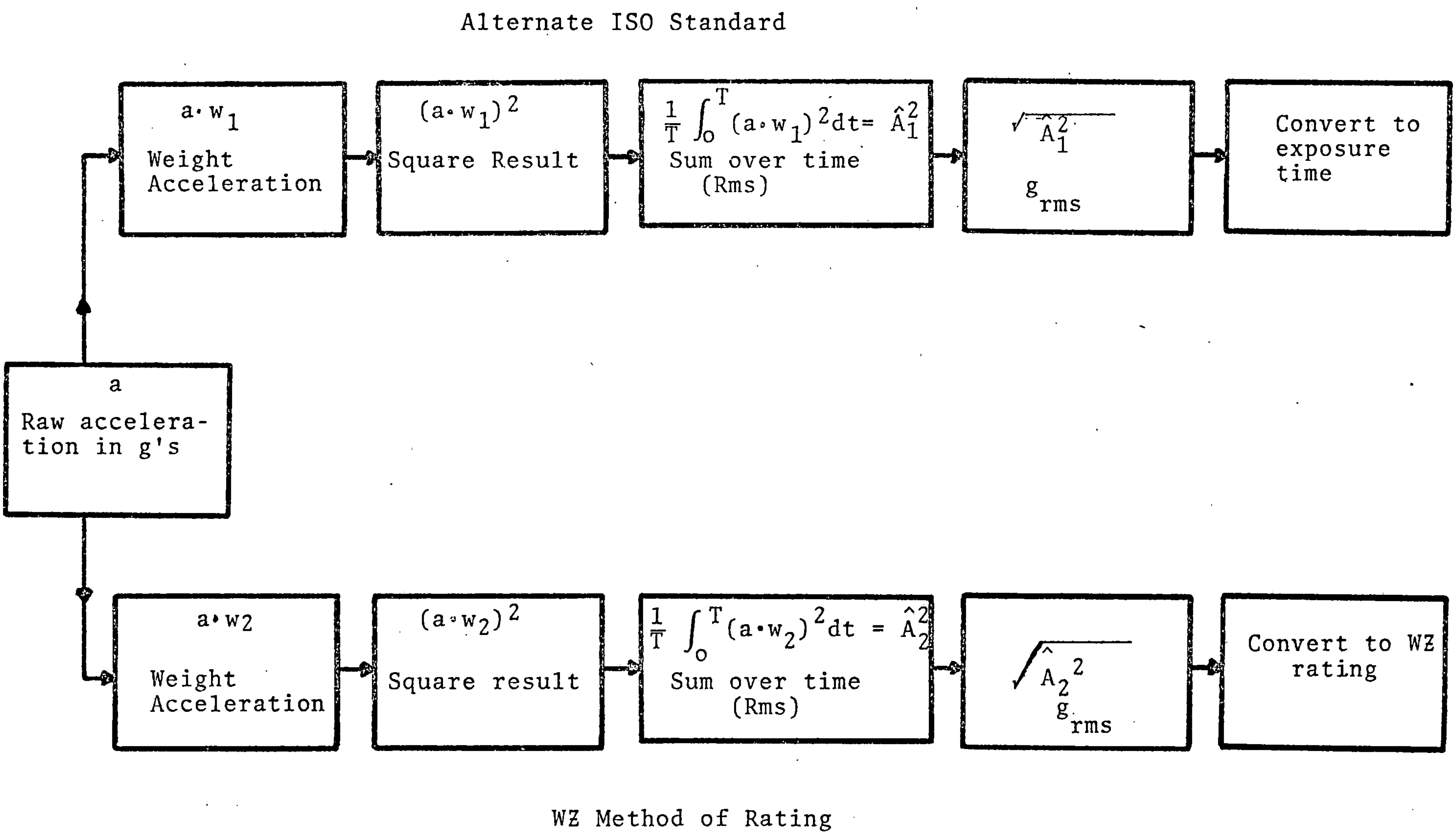


Figure 6. Comparison Between the WZ and Alternate ISO Standards

ISO EXPOSURE TIME AND W_z RATING

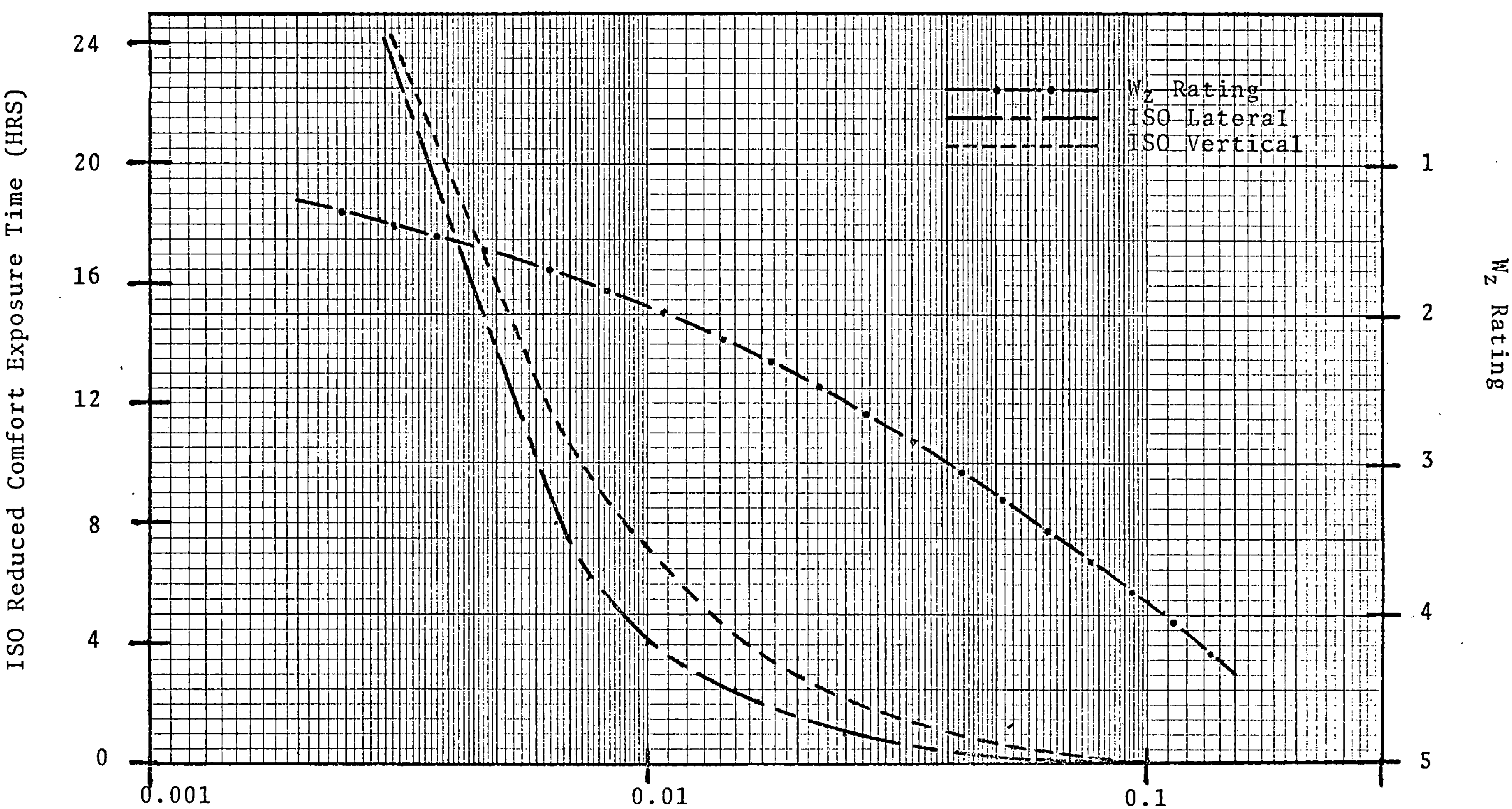


Figure 7. ACCELERATION LEVEL (g's)

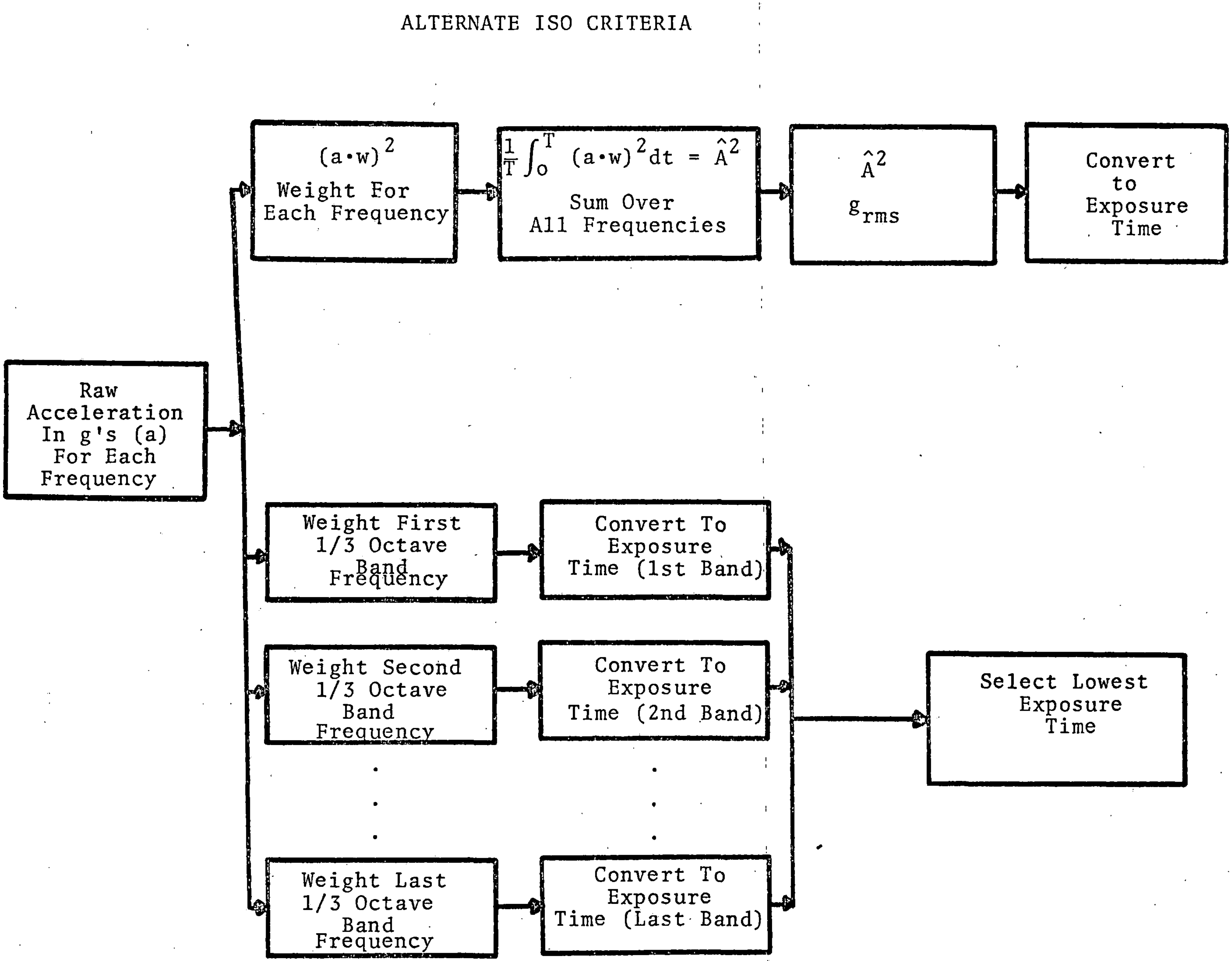


Figure 8. ISO CRITERIA

REFERENCES

[1] Helberg, W. and Sperling, "Verfahren zur Beurteilung der Laufeigenschaften von Eisenbahnwagen." Organ fur die Fortschutte des Eisenbahnwesens, 96(12): 177-187, June 15, 1941. English translation, "A Procedure for Appraising Running Qualities of Railroad Cars", translated from the German by Leon Narshak, Research Information Service, Chicago, IL.

[2] Sperling, Dr.-ING, E. "Stand der Laufgutebestimmungen, Messund und Auswertung," Eisenbahntechnik, 1968. English translation, "Position of Ride Quality Analysis, Measurement and Computation," 1968, Eisenbahntechnik, translation by University of New Hampshire, Center for Industrial and Institutional Development.

[3] Pribnow, Hans-Hermann, "A Simplified Method for Comparitive Evaluation of Ride Quality of Rail Vehicles."

[4] Andrew, Ian, "Ride Index Obsolete," Rail International August 1975, p 319.