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COUNTING ACCELEROMETERS

(An Error Analysis)

GARY F. WALKER

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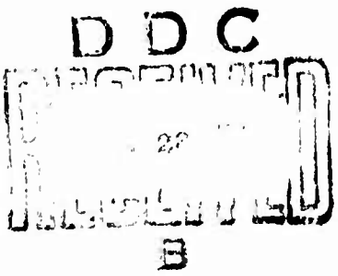

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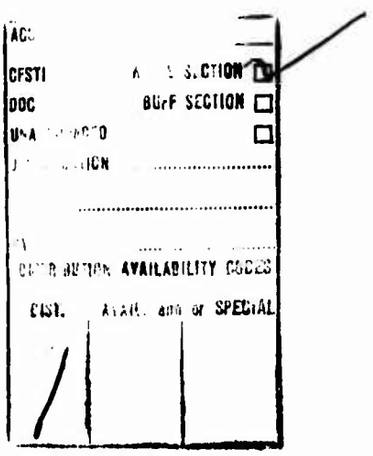

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GARY F. WALKER

FOREWORD

This report was prepared by Deputy For Engineering, Directorate Of Airframe Subsystems Engineering, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. The report represents the "in-house" research effort under System No. 327B, "F/RF-4 Aircraft." The manuscript was submitted by the author May 1970.

The author prepared this final report to document the results of a study undertaken to evaluate the error associated with Counting Accelerometers used on the F/RF-4 aircraft.

This technical report has been reviewed and is approved.

G.F. PURKEY
Chief, Structures Division
Directorate of Airframe Subsystems
Engineering

ABSTRACT

Counting accelerometers are used on F/RF-4 aircraft as a part of the Aircraft Structural Integrity Program. The device counts and records the number of times four acceleration levels have been exceeded. The data are used with a fatigue analysis to determine fatigue damage on individual aircraft. This report presents the results of an error analysis of the counting accelerometer data and the fatigue analysis.

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ABBREVIATIONS AND SYMBOLS

SYMBOL	DEFINITION
G	(Maneuver acceleration in the normal direction Ft/S^2)/32.2Ft/S^2)
n	Number of occurrences of N_z
Σn	Exceedances of N_z (i.e. - Number of occurrences equal to or greater than N_z)
n/1000	Number of occurrences of N_z per 1000 flight hours
$\Sigma n/1000$	Number of exceedances of N_z per 1000 flight hours
N_c	Number of cycles to fatigue failure for combat data
N_{nc}	Number of cycles to fatigue failure for non-combat data
N_z	(Maneuver acceleration in the normal direction Ft/S^2)/32.2Ft/S^2
N_{ze}	N_z x(Gross weight at the time N_z was pulled)/ (Design gross weight)
$\overline{N}_z$	Mid-point of the nominal N_z range
$(n/N_c)/1000$	Fatigue damage for combat data, for an N_z level, per 1000 flight hours
$(n/N_{nc})/1000$	Fatigue damage for non-combat data, for an N_z level, per 1000 flight hours
$\Sigma(n/N)/1000$	Total fatigue damage, for all N_z levels, per 1000 flight hours
VGH	Flight loads data consisting of Velocity, G, Height, and time
Δ	Difference between total fatigue damage for the individual set of levels and the total fatigue damage for the ideal set of levels.
% Diff	Δ expressed as a percent of the ideal fatigue damage

SECTION I
INTRODUCTION

At the present, there are about 1200 counting accelerometer systems installed on F/RF-4 aircraft. Additional units are being procured for those F/RF-4's that do not presently have the system. The counting accelerometers are procured under the Reference 1 Military Specification, and are composed of an indicator (Type MS 25448), and a transducer (Type MS 25447-4). The system is designed to count the number of times four load factor levels are exceeded. The levels are 3.0, 4.0, 5.0, and 6.0 G's. The acceptable test tolerance associated with each of the four levels is ±0.2G for a dynamic input (i.e. - the acceptable error bands are 3.0 ±.2, 4.0 ±.2, 5.0 ±.2, and 6.0 ±.2G's). The data obtained from these systems are used with the fatigue analysis (References 2 and 3) to calculate individual aircraft fatigue damage. It is the purpose of this report to evaluate the counter, its error, and the counter-analysis interface error. This goal was accomplished by two steps:

a. Determining the effect of ±.02G tolerances,

b. Determining the effect of the counting accelerometer fatigue analysis (as compared to the VGH fatigue analysis).

SECTION II

EFFECT OF TOLERANCES

The primary task to be accomplished in this chapter was to ascertain what error was introduced if the four G levels were set low and what error would be introduced if the four levels were set high. An exceedance spectrum was obtained from Reference 4. This spectra is for all US Air Force F-4C/D/E aircraft, and represents 885,000 hours of data, and is as follows:

N_z Level	3	4	5	6	7*
Exceedances of N_z/1000 Hrs	6890	2366	1004	357.3	71.5

*Estimated - See text below

These data are also plotted in Figure 1. Consistent with the requirements of the fatigue analysis, the number of exceedances of 7 G's is estimated as 20% of the number of exceedances of 6 G's. Thus, the number of exceedances of 7 G's is (357.3)(.2) = 71.5 per 1000 hours.

Five sets of ranges were selected: the upper and lower tolerance limits, the ideal case, and two intermediate points. These levels were chosen as they encompass the allowable error in acceptable instruments, and are enumerated below:

Lower Limit	Lower Intermediate	Nominal or Ideal	Upper Intermediate	Upper Limit
2.8 - 3.8	2.9 - 3.9	3 - 4	3.1 - 4.1	3.2 - 4.2
3.8 - 4.8	3.9 - 4.9	4 - 5	4.1 - 5.1	4.2 - 5.2
4.8 - 5.8	4.9 - 5.9	5 - 6	5.1 - 6.1	5.2 - 6.2
5.8 - 6.8	5.9 - 6.9	6 - 7	6.1 - 7.1	6.2 - 7.2
6.8 - 7.8	6.9 - 7.9	7 - 8	7.1 - 8.1	7.2 - 8.2

The next step was to estimate the number of exceedances (and thus occurrences) of each set of G levels of interest. To do this the points plotted in Figure 1 were assumed to represent a continuous curve, and a smooth curve was plotted through these points. The discrete points of interest may then be read directly from the curve. This is accomplished in Table I for the five sets of levels given above. It should be noted that all occurrences of the 7G level are estimated as 20% of the exceedances of the 6G level.

The data are now in the discrete acceleration bands required by the fatigue analysis. This analysis assumes that all occurrences of a load factor level are at the mid-point of that level (i.e. - a load factor greater than 3G's and less than 4G's is assumed to have occurred at 3.5G's). This plus further assumptions concerning airspeed, altitude, and weight results in the number of cycles to failure, for both combat

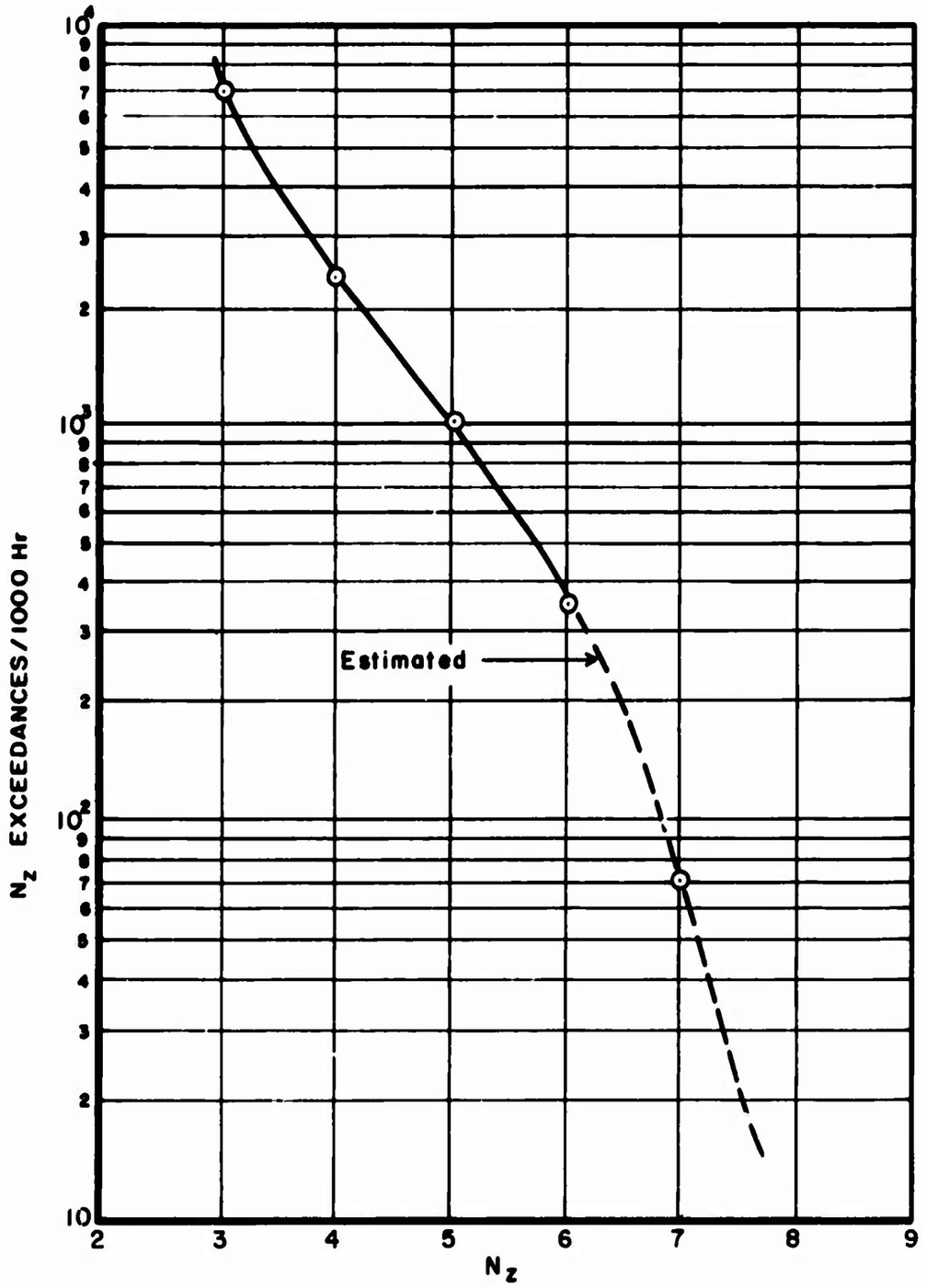

Figure 1. C. A. Exceedance Spectrum

From Mc Donnell Memo 237-53
Revision 1 26 January 1970

and non-combat conditions. These values are given in Reference 2, and are repeated below:

Nominal Level	Combat (N_c)	Non-Combat (N_{nc})
3.5	700,000	3,000,000
4.5	53,000	76,000
5.5	13,000	20,000
6.5	5,000	7,000
7.5	1,800	2,800

To calculate fatigue damage, the number of occurrences of the various G levels (from Table I) are divided by the number of cycles to failure (given above) for the corresponding G level. This is accomplished in Table IIA through IIE for the five sets of levels of interest. An important point to note here is that in Table II all fatigue damage is calculated at the mid-point of the nominal ranges (3.5, 4.5, 5.5, 6.5, and 7.5). The reason for this is that when operational data are received, the true calibration of the counting accelerometer system is not known - it must be assumed that the levels are at their nominal or "ideal" values. Thus in Table IIA "N_Z" (load factor) corresponds to the nominal value, and "$\bar{N}_Z$" is the nominal mid-point. Further, "n/1000" is the number of cycles per 1000 Hrs of nominal N_Z minus .2G (taken from Table I). This is the number of cycles that the system would have recorded at levels set .2G low (2.8, 3.8, 4.8, and 5.8). N_c and N_{nc} are the number of cycles to failure for combat and non-combat operations respectively, as shown in the above text, for the nominal mid-point. "$(n/N_c)/1000$" and "$(n/N_{nc})/1000$" are the fatigue damage per 1000 Hrs for each "G" level for Combat and Non-Combat, respectively. Finally, $(n/N_c)/1000$ and

TABLE I

C.A. EXCEEDANCE SPECTRA

N_z	*Σn/1000 Hr	n/1000 Hr					
		Nominal -0.2	Nominal -0.1	Nominal 0.0	Nominal 0.1	Nominal 0.2	Nominal N_z Level
2.8	9200	6350					
2.9	7900		5300				
3.0	6890			4524			
3.1	6000				3820		3
3.2	5200					3200	
3.8	2850	1670					
3.9	2600		1530				
4.0	2366			1362			
4.1	2180				1285		4
4.2	2000					1185	
4.8	1180	730					
4.9	1070		665				
5.0	1004			646.7			5
5.1	895				577		
5.2	815					535	
5.8	450	360					
5.9	405		324				
6.0	357.3			285.8			6
6.1	318				254.4		
6.2	280					224.0	
6.8	90.0	90					
6.9	81.0		81				
7.0	71.5			71.5			
7.1	63.6				63.6		7
7.2	56.0					56.0	

* From Figure 1

Nominal -0.2 = Lower Limit
Nominal -0.1 = Lower Intermediate
Nominal 0.0 = Ideal
Nominal +0.1 = Upper Intermediate
Nominal +0.2 = Upper Limit

TABLE II
DAMAGE CALCULATIONS

II A (Nominal - 0.2 G)

N_z	3 - 4	4 - 5	5 - 6	6-7	7-8	
$\overline{N}_z$	3.5	4.5	5.5	6.5	7.5	
n/1000*	6350	1670	730	360	90	
N_c+	700,000	53,000	13,000	5000	1800	
N_{nc}+	3,000,000	76,000	20,000	7000	2800	TOTAL Σ(n/N)/1000Hrs
$(n/N_c)/1000$	.0091	.0315	.0562	.0720	.0500	.2188
$(n/N_{nc})/1000$	.0021	.0220	.0365	.0514	.0321	.1441

II B (Nominal - 0.1 G)

N_z	3 - 4	4 - 5	5 - 6	6 - 7	7-8	
$\overline{N}_z$	3.5	4.5	5.5	6.5	7.5	
n/1000	5300	1530	665	324	81	
N_c	700,000	53,000	13,000	5000	1800	
N_{nc}	3,000,000	76,000	20,000	7000	2800	TOTAL Σ(n/N)/1000Hrs
$(n/N_c)/1000$	.0076	.0289	.0512	.0648	.0450	.1975
$(n/N_{nc})/1000$	.0018	.0201	.0333	.0463	.0289	.1304

* From Table I

\+ From Reference 2

TABLE II (Contd)

II C (Nominal + 0.0 G)

N_z	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	
$\overline{N}_z$	3.5	4.5	5.5	6.5	7.5	
n / 1000	4524	1362	646.7	285.8	71.5	
N_c	700,000	53,000	13,000	5000	1800	
N_{nc}	3,000,000	76,000	20,000	7000	2800	TOTAL Σ(n/N)/1000 Hrs
$(n/N_c)/1000$	.0065	.0257	.0497	.0572	.0397	.1788
$(n/N_{nc})/1000$	.0015	.0179	.0323	.0408	.0255	.1180

II D (Nominal + 0.1 G)

N_z	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	
$\overline{N}_z$	3.5	4.5	5.5	6.5	7.5	
n / 1000	3820	1285	577	254.4	63.6	
N_c	700,000	53,000	13,000	5000	1800	
N_{nc}	3,000,000	76,000	20,000	7000	2800	TOTAL Σ(n/N)/1000 Hrs
$(n/N_c)/1000$	.0055	.0242	.0444	.0509	.0353	.1603
$(n/N_{nc})/1000$	.0013	.0169	.0289	.0363	.0227	.1061

TABLE II (Contd)

II.E (Nominal + 0.2 G)

N_z	3-4	4-5	5-6	6-7	7-8	
$\overline{N}_z$	3.5	4.5	5.5	6.5	7.5	
n/1000	3200	1185	535	224.0	56	
N_c	700,000	53,000	13,000	5000	1800	
N_{nc}	3,000,000	76,000	20,000	7000	2800	TOTAL Σ(n/N)/1000 Hrs
$(n/N_c)/1000$	.0046	.0224	.0412	.0448	.0311	.1441
$(n/N_{nc})/1000$	.0011	.0156	.0268	.0320	.0200	.0955

$(n/N_{nc})/1000$ are summed to give the fatigue damage for all "G" levels. This process is iterated for each of the four remaining sets of levels in Tables IIB through IIE.

The results of Table II are summarized and compared in Table IIIA for combat data, and in IIIB for non-combat data. In Table III, "$\Sigma(n/N_c)/1000$" is the total fatigue damage, given for each of the five sets of ranges, "Δ" is the difference between the total fatigue damage for the individual set of levels and the total fatigue damage for the ideal set of levels. "% Diff" is "Δ" expressed as a percent of the ideal fatigue damage. These data are also plotted in Figure 2. As is shown, the error due to the $\pm$.2G tolerance ranges from about +22% for -.2G to about -19% for +.2G, and is of the same magnitude regardless of whether the data are combat or non-combat.

TABLE III

ERROR SUMMARY

III A (Combat)

	Nominal				
	-0.2	-0.1	0.0	+0.1	+0.2
$\Sigma (n/N_c)/1000$	.2188	.1975	.1788	.1603	.1441
Δ	+.0400	+.0187	0	-.0185	-.0347
% Diff	22.4	10.6	0	-10.3	-19.4

III B (Non-Combat)

	Nominal				
	-0.2	-0.1	0.0	+0.1	+0.2
$\Sigma (n/N_{nc})/1000$	.1441	.1304	.1180	.1061	.0955
Δ	+.0261	+.0124	0	-.0119	-.0225
% Diff	+22.1	+10.5	0	-10.1	-19.1

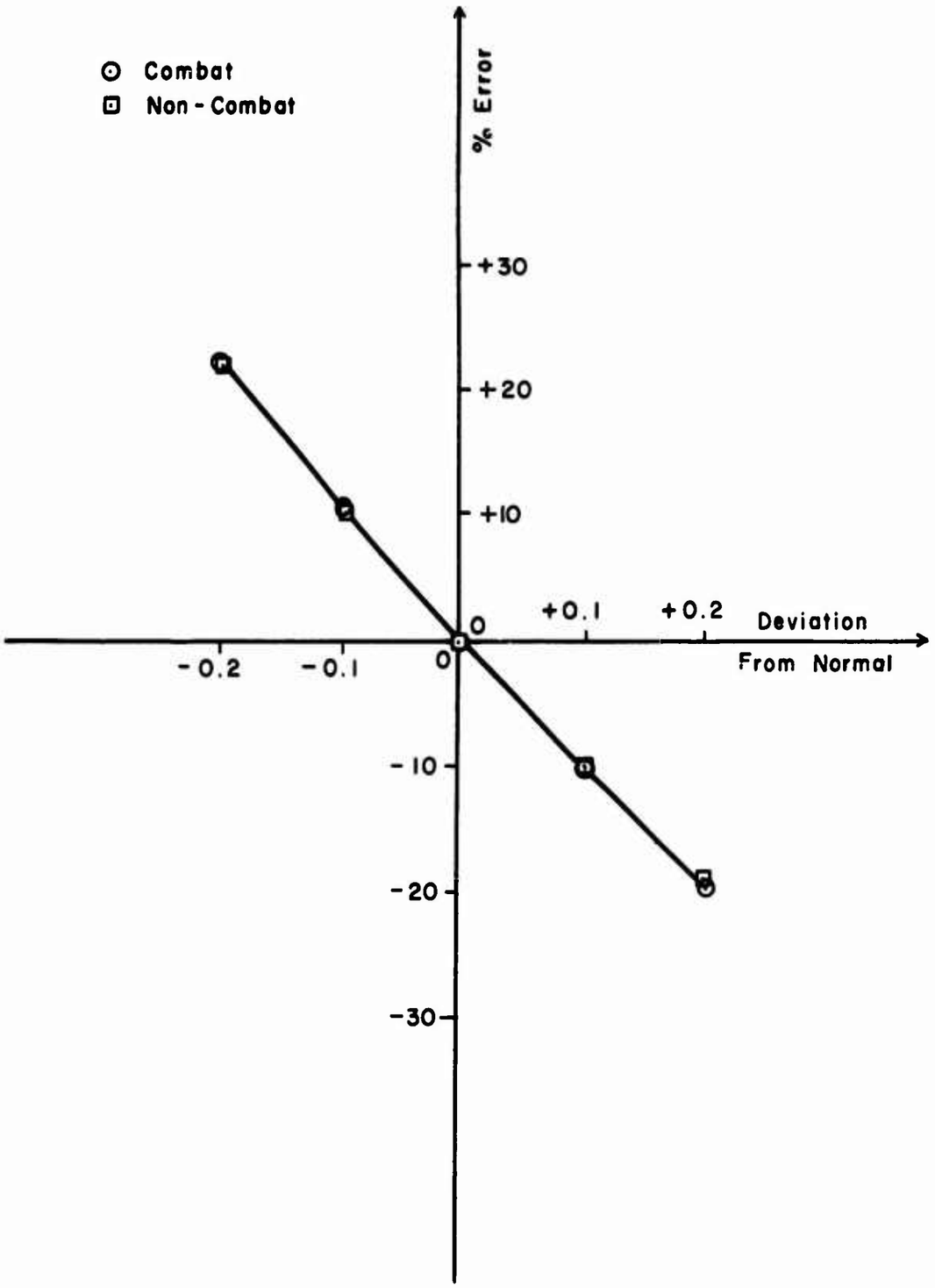

Figure 2. C. A. Tolerance Error

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SECTION III
EFFECT OF ANALYSIS

The purpose of this section is to evaluate the effect, on fatigue damage, of the counting accelerometer fatigue analysis, as compared to the VGH fatigue analysis. The approach taken was to collect some VGH data, run it through the VGH analysis, and then run it through the counting accelerometer analysis, as it is used by McDonnell Aircraft Company.

The counting accelerometer fatigue analysis is derived directly from the VGH fatigue analysis. In the VGH analysis, all occurrences of load factors are distributed in a three dimensional matrix of airspeed, altitude, and gross weight. The counter analysis assumes that all occurrences of load factors are at one point in the matrix - an airspeed of 450 knots, an altitude of 5,000 ft, and a gross weight of 42,000 pounds for combat, and 40,000 pounds for non-combat.

The data selected (Reference 5, Table 12) for use in the evaluation consists of 600 hours of air-to-ground combat data, from F-4D/E aircraft, collected during late summer and fall of 1969. The analysis (Reference 6) uses as an input N_{ze} versus Airspeed by Altitude and Mission. The data mentioned above was in precisely this format. The data were run through the fatigue analysis, point by point. Because of the sheer bulk of these calculations, they are not included in this report, but are summarized as follows:

Time	Damage
599.9 Hours	.15541365 or
1000.0 Hours	.25910875

The next step was to run the data through the counting accelerometer fatigue analysis. However, as this requires N_z data as an input, instead of N_{ze}, Table 6 of Reference 5 was used. It should be noted that this represents the same data used above, only with a different format. The data are presented in Table IV, and are plotted in Figure 3. As can be seen in Table IV, the N_z ranges from the VGH data are not directly compatible with the counting accelerometer ranges. For this reason, it was necessary to again assume that these data points represented a smooth curve and plot it as such. The discrete data ranges for the counting accelerometer analysis are then read directly from Figure 3. This is accomplished in Table V. The data is now in the discrete load factor range format required by the analysis. Fatigue damage is calculated in Table VI, using the same methods used in the previous chapter. The results are summarized below:

	$\Sigma(n/N)/1000$	Δ	% Diff
VGH Analysis	.25910875		
Counter Analysis	.20838115	-.0572760	-19.6

TABLE IV

VGH EXCEEDANCE SPECTRUM

N_z*	n/599.9*	n/1000	Σ n/1000
7.8	4	6.7	6.7
6.6	43	71.7	78.4
5.4	501	835.1	913.5
4.6	710	1183.5	2097.0
3.8	938	1563.6	3660.6
3.0	2038	3397.2	7057.8
2.6	1964	3273.9	10331.7
2.2	2583	4305.7	14637.4
TIME	599.9	1000.0	1000.0

* From Table VI, Reference 5

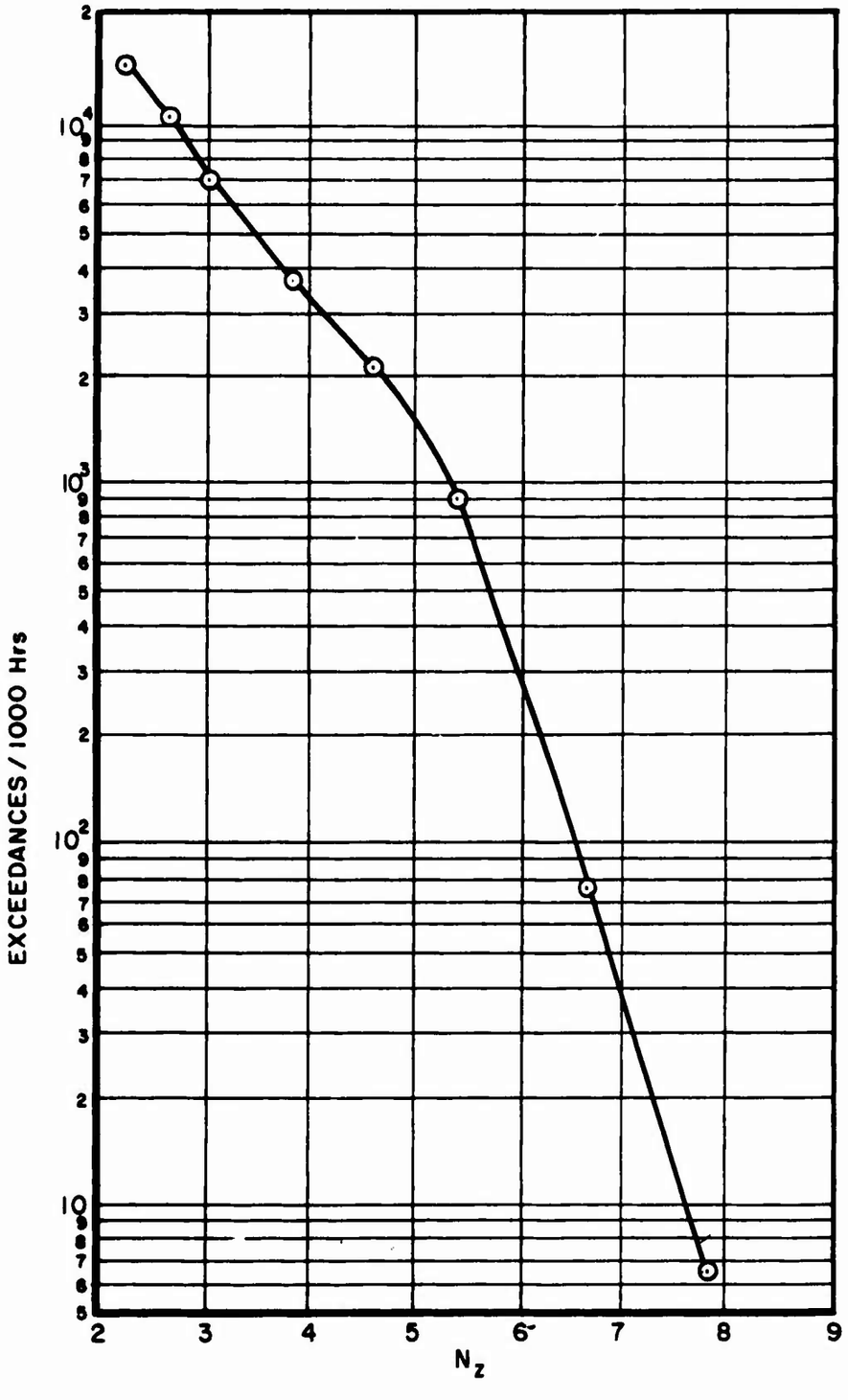

Figure 3. VGH Exceedance Spectrum

TABLE V

C. A. SPECTRUM

N_z	$\Sigma n/1000$ **	n/1000
7.0*	63	63
6.0	315	252
5.0	1410	1095
4.0	3170	1760
3.0	7050	3880

* Est (315)(20%) = 63
** From Figure 3

TABLE VI

DAMAGE CALCULATIONS

N_z	3.0	4.0	5.0	6.0	7.0
n/1000	3880	1760	1095	252	63
N_c	700,000	53,000	13,000	5000	1800
$(n/1000/N_c)(1000)$	5.54285	33.20754	84.23076	50.40000	35.00000

* From Table V

$$\Sigma \frac{(n/1000)}{N_c} \quad (1000) = 208.38115$$

SECTION IV
CONCLUSIONS

1. The error in fatigue life estimates introduced by the ±.2G tolerance of the counting accelerometers is -19% for +.2G and +22% for -. .. The error is of the same magnitude, regardless of whether the data are combat or non-combat.

2. The error in fatigue life estimates introduced by the analysis itself is about -20%.

3. The error spreads are as summarized below:

Source	Fatigue
Analysis	-20%
Transducer +.2	-19%
-.2	+22%
Expected Spread	+2% to -39%

REFERENCES

1. MIL-A-22145B, Amendment 1, 15 December 1967 "Military Specification - Accelerometer Group, Counting Type Designation MS 25447 and MS 25448"

2. McDonnell Aircraft Company Memo No. 237-120, 24 March 1970 "Air Force F-4 Fatigue Damage Computer Program."

3. McDonnell Aircraft Company Report F-707, 18 April 1967, Fatigue Evaluation - F/RF-4C, F-4D/E.

4. McDonnell Aircraft Company Memo No. 237-53 Rev 1, 26 January 1970 "Quarterly Summary - F/RF-4C/D/E Counting Accelerometer Data (through September 1969).

5. F-4 Aircraft First Quarterly Report, unpublished, USAF Contract F33657-70-C-0408.

6. McDonnell Aircraft Company letter, dated 8 January 1968, "Life History Recorder Program - F-4 Series Aircraft."

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13 ABSTRACT

Counting accelerometers are used on F/RF-4 aircraft as a part of the Aircraft Structural Integrity Program. The device counts and records the number of times four acceleration levels have been exceeded. The data are used with a fatigue analysis to determine fatigue damage on individual aircraft. This report presents the results of an error analysis of the counting accelerometer data and the fatigue analysis.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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