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ASD-TR-70-21

COUNTING ACCELEROMETERS

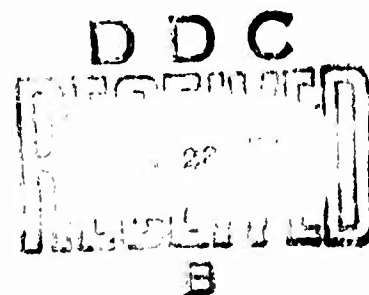
(An Error Analysis)

GARY F. WALKER

TECHNICAL REPORT ASD-TR-70-21

AUGUST 1970

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AERONAUTICAL SYSTEMS DIVISION
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ACC	
CFSTI	A. 1. SECTION ☒
DOC	B. 2. SECTION ☐
UNA	C. 3. SECTION ☐
D. 4. SECTION	
E. 5. SECTION	
F. 6. SECTION	
G. 7. SECTION	
H. 8. SECTION	
I. 9. SECTION	
J. 10. SECTION	
K. 11. SECTION	
L. 12. SECTION	
M. 13. SECTION	
N. 14. SECTION	
O. 15. SECTION	
P. 16. SECTION	
Q. 17. SECTION	
R. 18. SECTION	
S. 19. SECTION	
T. 20. SECTION	
U. 21. SECTION	
V. 22. SECTION	
W. 23. SECTION	
X. 24. SECTION	
Y. 25. SECTION	
Z. 26. SECTION	
AA. 27. SECTION	
AB. 28. SECTION	
AC. 29. SECTION	
AD. 30. SECTION	
AE. 31. SECTION	
AF. 32. SECTION	
AG. 33. SECTION	
AH. 34. SECTION	
AI. 35. SECTION	
AJ. 36. SECTION	
AK. 37. SECTION	
AL. 38. SECTION	
AM. 39. SECTION	
AN. 40. SECTION	
AO. 41. SECTION	
AP. 42. SECTION	
AQ. 43. SECTION	
AR. 44. SECTION	
AS. 45. SECTION	
AT. 46. SECTION	
AU. 47. SECTION	
AV. 48. SECTION	
AW. 49. SECTION	
AX. 50. SECTION	
AY. 51. SECTION	
AZ. 52. SECTION	
BA. 53. SECTION	
BB. 54. SECTION	
BC. 55. SECTION	
BD. 56. SECTION	
BE. 57. SECTION	
BF. 58. SECTION	
BG. 59. SECTION	
BH. 60. SECTION	
BI. 61. SECTION	
BJ. 62. SECTION	
BK. 63. SECTION	
BL. 64. SECTION	
BM. 65. SECTION	
BN. 66. SECTION	
BO. 67. SECTION	
BP. 68. SECTION	
BQ. 69. SECTION	
BR. 70. SECTION	
BS. 71. SECTION	
BT. 72. SECTION	
BU. 73. SECTION	
BV. 74. SECTION	
BW. 75. SECTION	
BX. 76. SECTION	
BY. 77. SECTION	
BZ. 78. SECTION	
CA. 79. SECTION	
CB. 80. SECTION	
CC. 81. SECTION	
CD. 82. SECTION	
CE. 83. SECTION	
CF. 84. SECTION	
CG. 85. SECTION	
CH. 86. SECTION	
CI. 87. SECTION	
CJ. 88. SECTION	
CK. 89. SECTION	
CL. 90. SECTION	
CM. 91. SECTION	
CN. 92. SECTION	
CO. 93. SECTION	
CP. 94. SECTION	
CQ. 95. SECTION	
CR. 96. SECTION	
CS. 97. SECTION	
CT. 98. SECTION	
CU. 99. SECTION	
CV. 100. SECTION	
CW. 101. SECTION	
CX. 102. SECTION	
CY. 103. SECTION	
CZ. 104. SECTION	
DA. 105. SECTION	
DB. 106. SECTION	
DC. 107. SECTION	
DD. 108. SECTION	
DE. 109. SECTION	
DF. 110. SECTION	
DG. 111. SECTION	
DH. 112. SECTION	
DI. 113. SECTION	
DJ. 114. SECTION	
DK. 115. SECTION	
DL. 116. SECTION	
DM. 117. SECTION	
DN. 118. SECTION	
DO. 119. SECTION	
DP. 120. SECTION	
DQ. 121. SECTION	
DR. 122. SECTION	
DS. 123. SECTION	
DT. 124. SECTION	
DU. 125. SECTION	
DV. 126. SECTION	
DW. 127. SECTION	
DX. 128. SECTION	
DY. 129. SECTION	
DZ. 130. SECTION	
EA. 131. SECTION	
EB. 132. SECTION	
EC. 133. SECTION	
ED. 134. SECTION	
EE. 135. SECTION	
EF. 136. SECTION	
EG. 137. SECTION	
EH. 138. SECTION	
EI. 139. SECTION	
EJ. 140. SECTION	
EK. 141. SECTION	
EL. 142. SECTION	
EM. 143. SECTION	
EN. 144. SECTION	
EO. 145. SECTION	
EP. 146. SECTION	
EQ. 147. SECTION	
ER. 148. SECTION	
ES. 149. SECTION	
ET. 150. SECTION	
EU. 151. SECTION	
EV. 152. SECTION	
EW. 153. SECTION	
EX. 154. SECTION	
EY. 155. SECTION	
EZ. 156. SECTION	
FA. 157. SECTION	
FB. 158. SECTION	
FC. 159. SECTION	
FD. 160. SECTION	
FE. 161. SECTION	
FF. 162. SECTION	
FG. 163. SECTION	
FH. 164. SECTION	
FI. 165. SECTION	
FJ. 166. SECTION	
FK. 167. SECTION	
FL. 168. SECTION	
FM. 169. SECTION	
FN. 170. SECTION	
FO. 171. SECTION	
FP. 172. SECTION	
FQ. 173. SECTION	
FR. 174. SECTION	
FS. 175. SECTION	
FT. 176. SECTION	
FU. 177. SECTION	
FV. 178. SECTION	
FW. 179. SECTION	
FX. 180. SECTION	
FY. 181. SECTION	
FZ. 182. SECTION	
GA. 183. SECTION	
GB. 184. SECTION	
GC. 185. SECTION	
GD. 186. SECTION	
GE. 187. SECTION	
GF. 188. SECTION	
GG. 189. SECTION	
GH. 190. SECTION	
GI. 191. SECTION	
GJ. 192. SECTION	
GK. 193. SECTION	
GL. 194. SECTION	
GM. 195. SECTION	
GN. 196. SECTION	
GO. 197. SECTION	
GP. 198. SECTION	
GQ. 199. SECTION	
GR. 200. SECTION	
GS. 201. SECTION	
GT. 202. SECTION	
GU. 203. SECTION	
GV. 204. SECTION	
GW. 205. SECTION	
GX. 206. SECTION	
GY. 207. SECTION	
GZ. 208. SECTION	
HA. 209. SECTION	
HB. 210. SECTION	
HC. 211. SECTION	
HD. 212. SECTION	
HE. 213. SECTION	
HF. 214. SECTION	
HG. 215. SECTION	
HH. 216. SECTION	
HI. 217. SECTION	
HJ. 218. SECTION	
HK. 219. SECTION	
HL. 220. SECTION	
HM. 221. SECTION	
HN. 222. SECTION	
HO. 223. SECTION	
HP. 224. SECTION	
HQ. 225. SECTION	
HR. 226. SECTION	
HS. 227. SECTION	
HT. 228. SECTION	
HU. 229. SECTION	
HV. 230. SECTION	
HW. 231. SECTION	
HX. 232. SECTION	
HY. 233. SECTION	
HZ. 234. SECTION	
IA. 235. SECTION	
IB. 236. SECTION	
IC. 237. SECTION	
ID. 238. SECTION	
IE. 239. SECTION	
IF. 240. SECTION	
IG. 241. SECTION	
IH. 242. SECTION	
II. 243. SECTION	
IJ. 244. SECTION	
IK. 245. SECTION	
IL. 246. SECTION	
IM. 247. SECTION	
IN. 248. SECTION	
IO. 249. SECTION	
IP. 250. SECTION	
IQ. 251. SECTION	
IR. 252. SECTION	
IS. 253. SECTION	
IT. 254. SECTION	
IU. 255. SECTION	
IV. 256. SECTION	
IW. 257. SECTION	
IX. 258. SECTION	
IY. 259. SECTION	
IZ. 260. SECTION	
JA. 261. SECTION	
JB. 262. SECTION	
JC. 263. SECTION	
JD. 264. SECTION	
JE. 265. SECTION	
JF. 266. SECTION	
JG. 267. SECTION	
JH. 268. SECTION	
JI. 269. SECTION	
JJ. 270. SECTION	
JK. 271. SECTION	
JL. 272. SECTION	
JM. 273. SECTION	
JN. 274. SECTION	
JO. 275. SECTION	
JP. 276. SECTION	
JQ. 277. SECTION	
JR. 278. SECTION	
JS. 279. SECTION	
JT. 280. SECTION	
JU. 281. SECTION	
JV. 282. SECTION	
JW. 283. SECTION	
JX. 284. SECTION	
JY. 285. SECTION	
JZ. 286. SECTION	
KA. 287. SECTION	
KB. 288. SECTION	
KC. 289. SECTION	
KD. 290. SECTION	
KE. 291. SECTION	
KF. 292. SECTION	
KG. 293. SECTION	
KH. 294. SECTION	
KI. 295. SECTION	
KJ. 296. SECTION	
KK. 297. SECTION	
KL. 298. SECTION	
KM. 299. SECTION	
KN. 300. SECTION	
KO. 301. SECTION	
KP. 302. SECTION	
KQ. 303. SECTION	
KR. 304. SECTION	
KS. 305. SECTION	
KT. 306. SECTION	
KU. 307. SECTION	
KV. 308. SECTION	
KW. 309. SECTION	
KX. 310. SECTION	
KY. 311. SECTION	
KZ. 312. SECTION	
LA. 313. SECTION	
LB. 314. SECTION	
LC. 315. SECTION	
LD. 316. SECTION	
LE. 317. SECTION	
LF. 318. SECTION	
LG. 319. SECTION	
LH. 320. SECTION	
LI. 321. SECTION	
LJ. 322. SECTION	
LK. 323. SECTION	
LL. 324. SECTION	
LM. 325. SECTION	
LN. 326. SECTION	
LO. 327. SECTION	
LP. 328. SECTION	
LQ. 329. SECTION	
LR. 330. SECTION	
LS. 331. SECTION	
LT. 332. SECTION	
LU. 333. SECTION	
LV. 334. SECTION	
LW. 335. SECTION	
LX. 336. SECTION	
LY. 337. SECTION	
LZ. 338. SECTION	
MA. 339. SECTION	
MB. 340. SECTION	
MC. 341. SECTION	
MD. 342. SECTION	
ME. 343. SECTION	
MF. 344. SECTION	
MG. 345. SECTION	
MH. 346. SECTION	
MI. 347. SECTION	
MJ. 348. SECTION	
MK. 349. SECTION	
ML. 350. SECTION	
MM. 351. SECTION	
MN. 352. SECTION	
MO. 353. SECTION	
MP. 354. SECTION	
MQ. 355. SECTION	
MR. 356. SECTION	
MS. 357. SECTION	
MT. 358. SECTION	
MU. 359. SECTION	
MV. 360. SECTION	
MW. 361. SECTION	
MX. 362. SECTION	
MY. 363. SECTION	
MZ. 364. SECTION	
NA. 365. SECTION	
NB. 366. SECTION	
NC. 367. SECTION	
ND. 368. SECTION	
NE. 369. SECTION	
NF. 370. SECTION	
NG. 371. SECTION	
NH. 372. SECTION	
NI. 373. SECTION	
NJ. 374. SECTION	
NK. 375. SECTION	
NL. 376. SECTION	
NM. 377. SECTION	
NN. 378. SECTION	
NO. 379. SECTION	
NP. 380. SECTION	
NQ. 381. SECTION	
NR. 382. SECTION	
NS. 383. SECTION	
NT. 384. SECTION	
NU. 385. SECTION	
NV. 386. SECTION	
NW. 387. SECTION	
NX. 388. SECTION	
NY. 389. SECTION	
NZ. 390. SECTION	
OA. 391. SECTION	
OB. 392. SECTION	
OC. 393. SECTION	
OD. 394. SECTION	
OE. 395. SECTION	
OF. 396. SECTION	
OG. 397. SECTION	
OH. 398. SECTION	
OI. 399. SECTION	
OJ. 400. SECTION	
OK. 401. SECTION	
OL. 402. SECTION	
OM. 403. SECTION	
ON. 404. SECTION	
OO. 405. SECTION	
OP. 406. SECTION	
OQ. 407. SECTION	
OR. 408. SECTION	
OS. 409. SECTION	
OT. 410. SECTION	
OU. 411. SECTION	
OV. 412. SECTION	
OW. 413. SECTION	
OX. 414. SECTION	
OY. 415. SECTION	
OZ. 416. SECTION	
PA. 417. SECTION	
PB. 418. SECTION	
PC. 419. SECTION	
PD. 420. SECTION	
PE. 421. SECTION	
PF. 422. SECTION	
PG. 423. SECTION	
PH. 424. SECTION	
PI. 425. SECTION	
PJ. 426. SECTION	
PK. 427. SECTION	
PL. 428. SECTION	
PM. 429. SECTION	
PN. 430. SECTION	
PO. 431. SECTION	
PP. 432. SECTION	
PQ. 433. SECTION	
PR. 434. SECTION	
PS. 435. SECTION	
PT. 436. SECTION	
PU. 437. SECTION	
PV. 438. SECTION	
PW. 439. SECTION	
PX. 440. SECTION	
PY. 441. SECTION	
PZ. 442. SECTION	
QA. 443. SECTION	
QB. 444. SECTION	
QC. 445. SECTION	
QD. 446. SECTION	
QE. 447. SECTION	
QF. 448. SECTION	
QG. 449. SECTION	
QH. 450. SECTION	
QI. 451. SECTION	
QJ. 452. SECTION	
QK. 453. SECTION	
QL. 454. SECTION	
QM. 455. SECTION	
QN. 456. SECTION	
QO. 457. SECTION	
QP. 458. SECTION	
QQ. 459. SECTION	
QR. 460. SECTION	
QS. 461. SECTION	
QT. 462. SECTION	
QU. 463. SECTION	
QV. 464. SECTION	
QW. 465. SECTION	
QX. 466. SECTION	
QY. 467. SECTION	
QZ. 468. SECTION	
RA. 469. SECTION	
RB. 470. SECTION	
RC. 471. SECTION	
RD. 472. SECTION	
RE. 473. SECTION	
RF. 474. SECTION	
RG. 475. SECTION	
RH. 476. SECTION	
RI. 477. SECTION	
RJ. 478. SECTION	
RK. 479. SECTION	
RL. 480. SECTION	
RM. 481. SECTION	
RN. 482. SECTION	
RO. 483. SECTION	
RP. 484. SECTION	
RQ. 485. SECTION	
RR. 486. SECTION	
RS. 487. SECTION	
RT. 488. SECTION	
RU. 489. SECTION	
RV. 490. SECTION	
RW. 491. SECTION	
RX. 492. SECTION	
RY. 493. SECTION	
RZ. 494. SECTION	
SA. 495. SECTION	
SB. 496. SECTION	
SC. 497. SECTION	
SD. 498. SECTION	
SE. 499. SECTION	
SF. 500. SECTION	
SG. 501. SECTION	
SH. 502. SECTION	
SI. 503. SECTION	
SJ. 504. SECTION	
SK. 505. SECTION	
SL. 506. SECTION	
SM. 507. SECTION	

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COUNTING ACCELEROMETERS
(An Error Analysis)

GARY F. WALKER

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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.

TABLE OF CONTENTS

SECTION	PAGE
I INTRODUCTION	1
II EFFECT OF TOLERANCES	2
III EFFECT OF ANALYSIS	13
IV CONCLUSIONS	18
REFERENCES	19

ILLUSTRATIONS

FIGURE		PAGE
1.	C. A. Exceedance Spectrum	4
2.	C. A. Tolerance Error	11
3.	VGH Exceedance Spectrum	16

TABLES

TABLE		PAGE
I	C. A. Exceedance Spectra	6
II	Damage Calculations	7
III	Error Summary	10
IV	VGH Exceedance Spectrum	15
V	C. A. Spectrum	17
VI	Damage Calculations	17

ABBREVIATIONS AND SYMBOLS

SYMBOL	DEFINITION
G	(Maneuver acceleration in the normal direction Ft/S^2)/32.2 Ft/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)/32.2 Ft/S^2)
N_{ze}	$N_z \times (\text{Gross weight at the time } N_z \text{ was pulled}) / (\text{Design gross weight})$
$\bar{N}_z$	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 $\pm 0.2G$ for a dynamic input (i.e. - the acceptable error bands are $3.0 \pm .2$, $4.0 \pm .2$, $5.0 \pm .2$, and $6.0 \pm .2G$'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 $\pm 0.2G$ 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 ₂ Level	3	4	5	6	7*
Exceedances of N ₂ /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

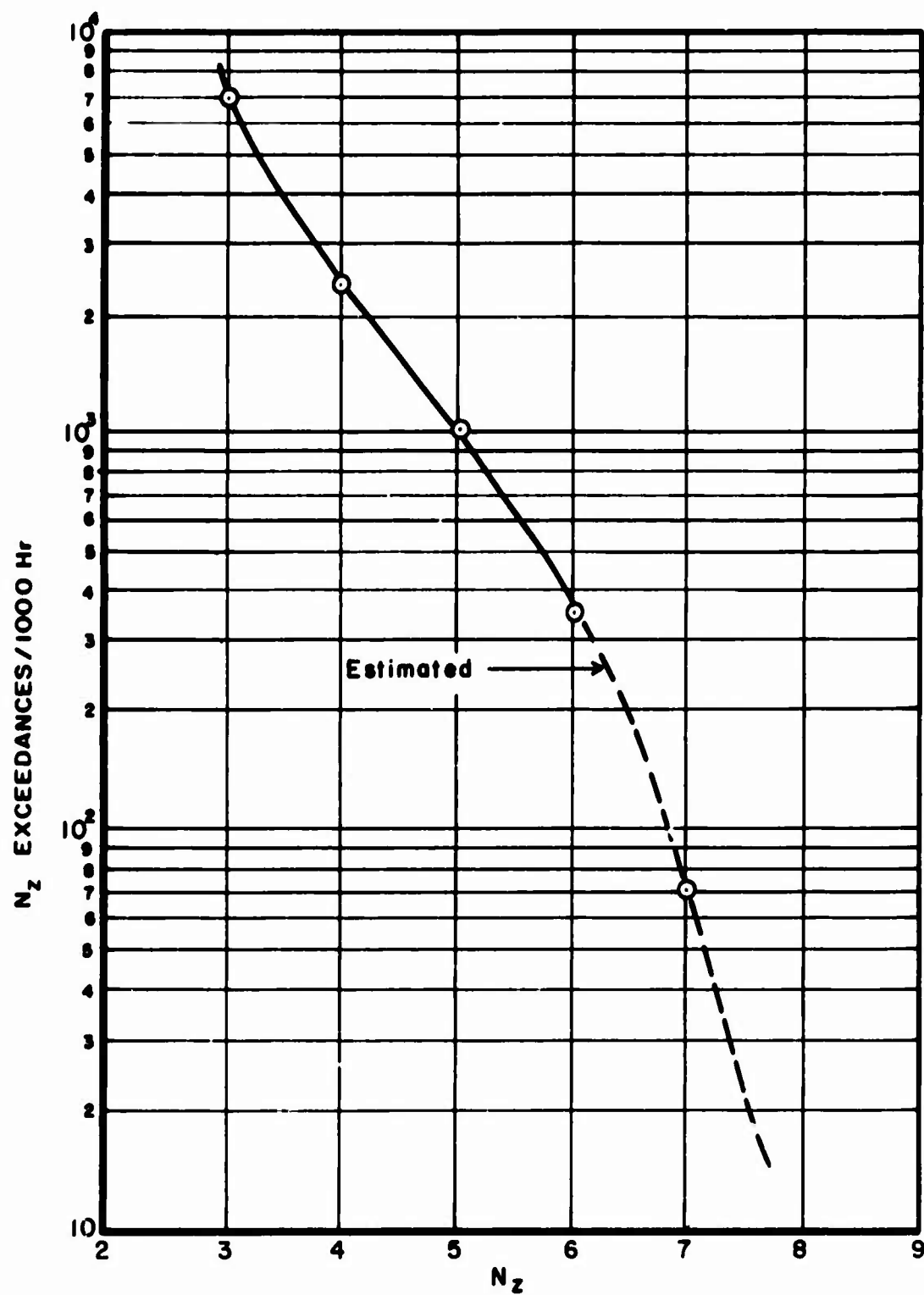


Figure 1. C. A. Exceedance Spectrum

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:

<u>Nominal Level</u>	<u>Combat (N_c)</u>	<u>Non-Combat (N_{nc})</u>
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	$*\Sigma n/1000 \text{ Hr}$	$n/1000 \text{ Hr}$					
		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 $\Sigma(n/N)/1000Hrs$
$(n/N_c)/1000$	.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 $\Sigma(n/N)/1000Hrs$
$(n/N_c)/1000$	.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	
$\bar{N}_z$	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 $\Sigma(n/N)/1000$ 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	
$\bar{N}_z$	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 $\Sigma(n/N)/1000$ 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	
$\bar{N}_z$	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 $\sum(n/N)/1000$ 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, " $\sum(n/N_c)/1000$ " 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 $\pm 0.2G$ tolerance ranges from about +22% for $-0.2G$ to about -19% for $+0.2G$, and is of the same magnitude regardless of whether the data are combat or non-combat.

TABLE III
ERROR SUMMARY

III A (Combat)

	- 0.2	Nominal - 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)

	- 0.2	Nominal - 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

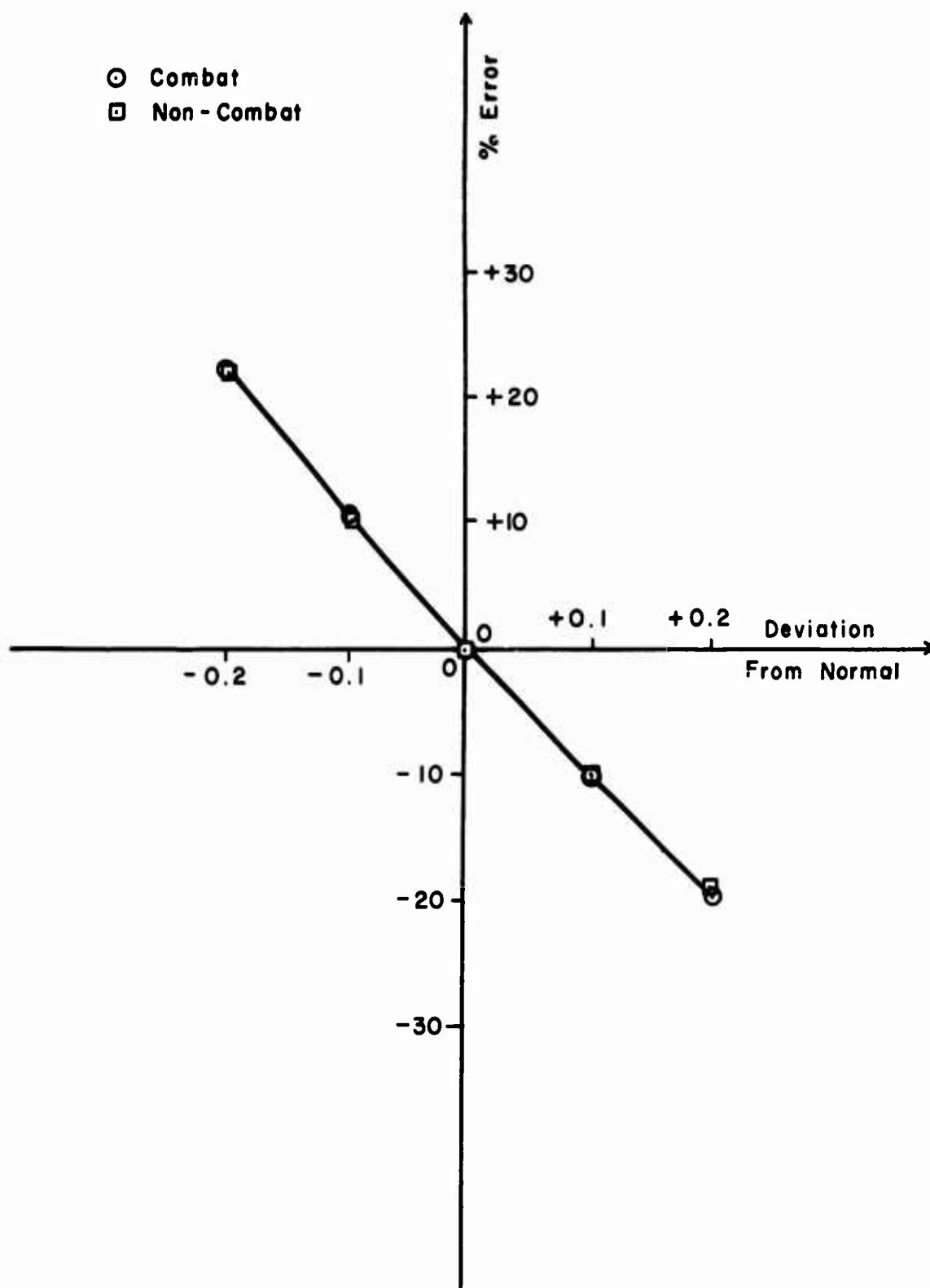


Figure 2. C. A. Tolerance Error

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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:

<u>Time</u>	<u>Damage</u>
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:

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

TABLE IV
VGH EXCEEDANCE SPECTRUM

N_z^*	$n/599.9^*$	$n/1000$	$\Sigma n/1000$
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

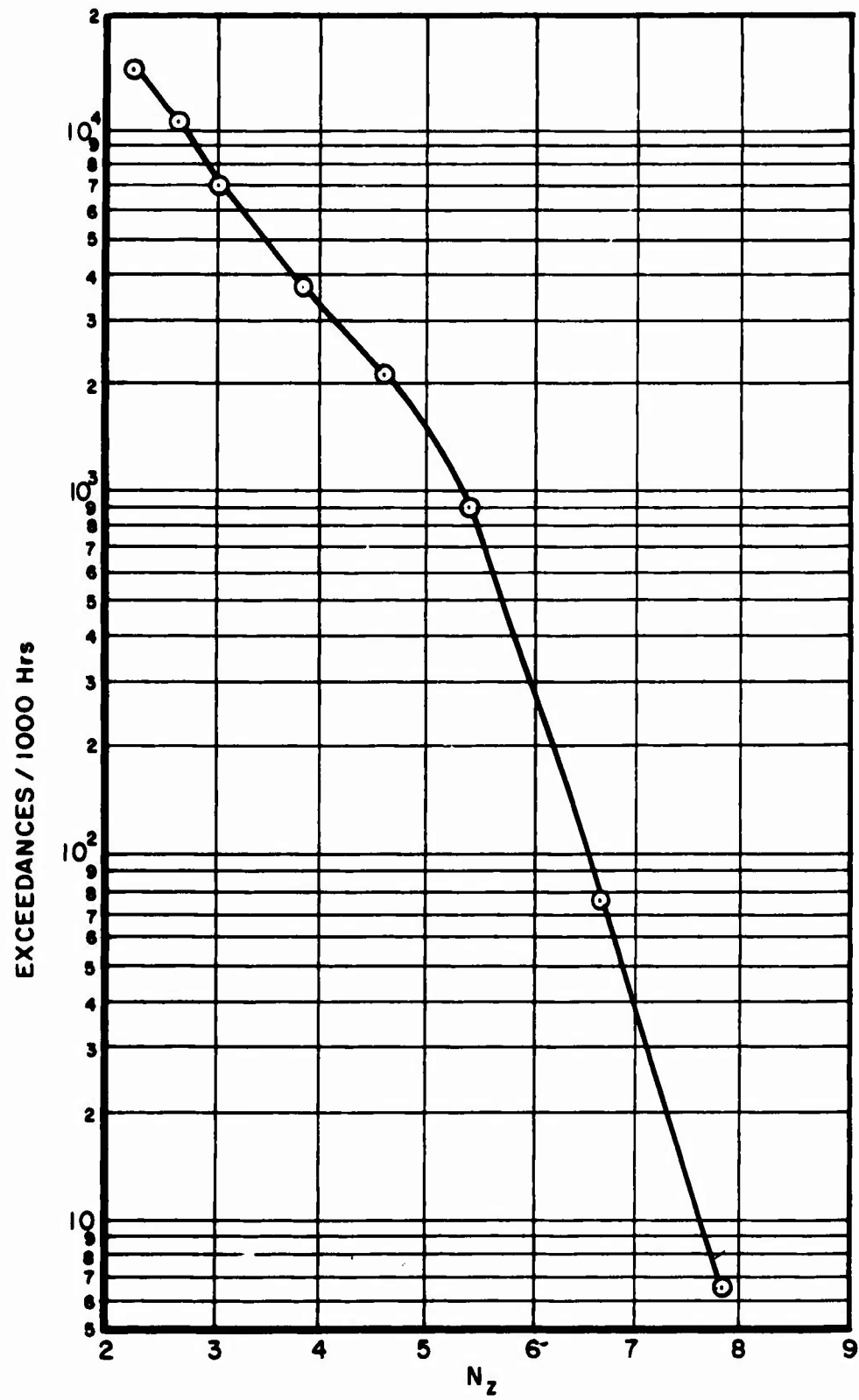


Figure 3. VGH Exceedance Spectrum

TABLE V
C. A. SPECTRUM

N_z	$\sum n/1000^{**}$	$n/1000$
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

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

SECTION IV CONCLUSIONS

1. The error in fatigue life estimates introduced by the $\pm .2G$ 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:

<u>Source</u>	<u>Fatigue</u>
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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