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# SUMMARY OF CENTER-OF-GRAVITY ACCELERATIONS EXPERIENCED BY COMMERCIAL TRANSPORT AIRPLANES IN LANDING IMPACT AND GROUND OPERATIONS

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16. Abstract

Data are presented on incremental normal accelerations due to landing impacts and to ground operations associated with taxi, takeoff, and landing. NASA VGH recorders, installed in a total of 38 turbine-powered airplanes of both foreign and domestic airlines, were used to obtain the data. Limited data on longitudinal deceleration during landing are also presented.

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# SUMMARY OF CENTER-OF-GRAVITY ACCELERATIONS EXPERIENCED BY COMMERCIAL TRANSPORT AIRPLANES IN LANDING IMPACT AND GROUND OPERATIONS

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## SUMMARY

A summary of landing impact accelerations has shown that for 24 operations (airline-airplane combination) representing a total of 22 464 landings, the initial positive incremental landing impact accelerations expected to be exceeded once in 10 000 landings range from about 0.79g to about 1.67g (1g = 9.81 m/sec$^2$). These differences among the landing impact acceleration experiences of the various operations apparently reflect the combined effects of differences among the airplane characteristics and landing approach techniques used by the various airlines. These data were extrapolated by means of mathematically fitted Pearson curves.

In ground operations, only small differences in overall normal acceleration experience during taxi, takeoff, and landing exist for the seven operations investigated. Landing rollout contributed most heavily, and taxi contributed the least, to the overall ground acceleration experience. The maximum incremental accelerations recorded ranged from 0.5g to 0.7g.

Longitudinal decelerations measured during 556 landings indicated that maximum values ranged from about 0.12g to 0.42g.

## INTRODUCTION

The structural loads experienced by commercial transport airplanes during ground operations (taxiing, takeoff, and landing) have an important bearing on the design strength and fatigue requirements. Also, a knowledge of the loads imposed by the airplane on runways and taxiways is necessary for the proper design of these surfaces, particularly when novel design features such as trestles and bridge-type construction are employed. Inasmuch as statistical data on the loads are difficult to acquire, recourse often has been made in the past to deducing the loads from measurements of the center-of-gravity accelerations experienced by airplanes during routine operations. Information regarding landing impact accelerations has been published in references 1 and 7 and small samples of acceleration data during taxi, takeoff, and landing for piston and turboprop transports are given in references 8 and 3, respectively. A somewhat larger sample of ground acceleration data is given in reference 7 for a turbojet transport.

As part of a continuing program to define the operational experiences and loads of turbine-powered transports, statistical ground load data have been collected on several additional types of airplanes operated by United States and foreign airlines. The data pertain to the normal accelerations of the center of gravity during landing impact, taxiing, takeoff, and landing rollout and to the longitudinal decelerations during landing rollout. The frequency distributions of the measured accelerations and some analyses of the data are presented in this paper. In order to provide a convenient summary of all the ground loads data collected on turbine-powered airplanes, some of the previously published data are also included herein.

## AIRPLANES AND SCOPE OF DATA

Some of the characteristics of the airplanes from which the data were collected are given in table I. The units are given in both the International System of Units (SI) and U.S. Customary Units. Factors relating the two systems are given in reference 9. The measurements and calculations were made in U.S. Customary Units. The basic airplane types are designated by a Roman numeral and different models of a basic type are denoted by letter suffixes. The suffix F is used to indicate turbofan-powered versions of two models of airplane type I. As shown in table I, data were collected from 18 airplane models encompassing 12 basic airplane types. The airplanes included two-, three-, and four-engine models and ranged in maximum design takeoff weight from 166 808 to 1 459 017 newtons (37 500 to 328 000 lbf).

The scope of the data is shown in table II for each of the airline operations from which the data were obtained and the sample sizes evaluated for accelerations experienced during landing impact and ground operations. For purposes of this paper, an airline operation is considered to be one or more airplanes of a given model flown by a single airline. The airline operations are denoted by a letter designation of the airline preceding the Roman numeral and letter suffix designation of the airplane model. Samples of landing impact acceleration were obtained from 24 airline operations involving a total of 38 individual airplanes. The sizes of the data samples range from 556 to 2445 landings and in total represent 22 464 landings. Normal accelerations experienced during taxi, takeoff, and landing runout were obtained from seven airline operations. The individual data samples represent from 158 to 827 flights. Data on the decelerations during landing were obtained from 556 landings of a four-engine turbofan airplane flown in commercial cargo operations by one airline.

## INSTRUMENTATION

The data were collected through the use of NASA VGH recorders (ref. 10) which provide time-history records of indicated airspeed, normal acceleration, and pressure altitude on 61-meter (200-foot) rolls of photographic paper. A film transport speed of 0.203 millimeter (0.008 inch) per second was used to record landing impact accelerations and longitudinal decelerations, and a speed of 0.787 millimeter (0.031 inch) per second was used to record data during taxi, takeoff, and landing rollout. The remote acceleration sensor was located as close as practicable to the airplane center of gravity. In the most extreme instance, the acceleration sensor was located 1.2 meters (4 feet) aft of the position equivalent to the 25-percent mean-geometric-chord location. The electrical signal from the acceleration sensor is transmitted to a galvanometer in the recorder base.

Two types of galvanometers having different response characteristics have been used in the recording program. The response of the accelerometer in combination with each type of galvanometer is shown in figure 1. As shown in the figure, the frequency response of the recorder with galvanometer A is essentially flat up to frequencies of about 6 hertz, whereas that of the recorder with galvanometer B is flat up to about 10 hertz. Above these frequencies, both recorders progressively attenuate the response with increasing frequency. The center-of-gravity normal acceleration at landing impact generally consists of a low-frequency component associated with the airplane rigid body response and superimposed high-frequency responses due to the structural modes. From special investigations of landing impact responses of several types of airplanes, it has been observed that the structural mode responses generally have frequencies between about $1\frac{1}{2}$ hertz to 10 hertz. Also, the magnitude of these responses generally range between 25 to 50 percent of the low-frequency rigid body response. Inasmuch as the slow film speed used in the present investigations does not permit separation of the structural responses from the rigid body responses, the normal acceleration data obtained represent the peak values of the combined responses. Because two types of recorders having different response characteristics (fig. 1) have been used, there is a possibility that structural responses higher than about 6 hertz may not be reflected to the same extent in the data collected with the two recorders. This aspect of the data will be discussed further in the section entitled "Results and Discussion."

## EVALUATION OF RECORDS

The evaluation of the records for the landing impact data consisted in reading the maximum positive normal acceleration increment (from the 1.0g trace position) due to each initial landing impact. Subsequent accelerations, which may have occurred after the initial landing impact, were not included in the landing impact data but were included in the landing rollout data.

The records of normal acceleration during ground operations were edited to denote the portions of the records corresponding to preflight taxiing, takeoff, landing rollout, and postflight taxiing. These classifications are defined as follows:

Preflight taxi – from initiation of taxiing to beginning of takeoff roll
Takeoff – from beginning of takeoff roll to lift-off
Landing rollout – from immediately after initial landing impact until airplane was slowed to taxi speed
Postflight taxi – from end of landing rollout to termination of taxiing

The 1.0g position of the acceleration trace was used as a reference from which to read the incremental normal acceleration peaks which equaled or exceeded selected threshold values. Only the maximum incremental value of the acceleration was read for each crossing of the reference. An incremental threshold value of ±0.1g was used for two of the operations, and a value of ±0.2g was used for the other five operations. The data were tabulated according to the four classifications previously discussed. Also, the data during the takeoff and landing rollout were further categorized according to intervals of airspeed.

The time histories of deceleration during landing rollout generally exhibited a variation similar to one of the three characteristics curves shown in figure 2. For each landing rollout, the maximum deceleration was read in the manner indicated in the figure in terms of inches of trace deflection. The trace deflections were converted to acceleration units and tabulated in acceleration intervals of 0.01g. The data were also sorted according to whether they came from an operational flight or from an airplane- or pilot-check flight.

## RESULTS AND DISCUSSION

### Landing Impact Accelerations

The frequency distributions of initial positive incremental landing impact accelerations are given in table III for the 24 operations. For each operation, the number of landings represented, the number of airplanes involved in each operation, and the references for those data which have been previously published are given. In addition, the mean value and the value of acceleration expected to be exceeded, on the average, once in 10 000 landings based on extrapolation by use of Pearson curves are also given. The number 10 000 was arbitrarily chosen as representative of the large amplitudes expected during extended operations.

Effect of galvanometer.- As was discussed in the section entitled "Instrumentation," there is some question concerning possible disparity between the acceleration data obtained by the recorders using the type A galvanometers and those obtained by using the type B galvanometers. In this connection, the data given in table III for operation AIAF are particularly of interest inasmuch as part of these were obtained with the type A recorder and the remainder with the type B recorder. To determine whether there were any effects of recorder type, the data were sorted according to the type of recorder, and the two samples are shown in figure 3(a) in terms of the probability of equaling or exceeding a given value of acceleration during a landing. The results apparently show an increase in acceleration of about 20 percent by the use of the type B recorder. Because only two rather small samples representing only one operation are involved, the evidence is not considered conclusive, however. For further analysis, two other large data samples – one from an operation using galvanometer type A and one from an operation using galvanometer type B – were randomly divided into a number of smaller samples, comparable in size to those shown in figure 3(a). These small samples, presented in figure 3(b), show a variation in probability of exceeding a given landing impact acceleration, say for instance 0.5g, of the same order for either operation as that shown in figure 3(a). Consequently, the results of figure 3(a) are believed to be attributable to sample size; it is concluded that galvanometer type had no appreciable affect on the accelerations measured.

Data extrapolation.- In past presentations of landing impact acceleration probability data, the data points have either been connected by straight-line segments or, where some extrapolation was desired, have been arbitrarily fitted with a Pearson type III curve using the method of reference 11. For the present data, a brief study was undertaken to find a curve-fitting method that would predict more reliably the probability of occurrence of a given high value of incremental landing impact acceleration. Methods such as least squares and several variations of extreme value theory were examined; however, the method of fitting Pearson curves given in reference 12 was chosen. This method utilizes the first four moments of the experimental frequency data to compute parameters leading to the choice of the particular type of Pearson curve which best fits the data.

The frequency distributions given in table III were formed into distributions representing probability of exceeding given values of landing impact acceleration and are plotted in figure 4 for each operation. Each distribution has been fitted with a Pearson curve using the method of reference 12, and the type of Pearson curve chosen for the fit is labeled in the figure.

Comparison of landing experience by airplane type.- A gross comparison of the landing impact acceleration experience of the various operators and airplanes is provided by the mean values of the accelerations and the estimated acceleration values which would be exceeded on the average once in 10 000 landings, given in table III for each of the data samples. These data show that the mean values of the distributions for the individual operations range from about 0.22g to 0.41g and that the estimated landing impact accelerations expected to be exceeded once in 10 000 landings range from about 0.79g to 1.67g. These differences among the landing impact acceleration experiences of the various operations apparently reflect the combined effects of differences among the airplane characteristics and landing approach techniques used by the various airlines. The maximum value recorded during these 22 464 landings was 1.8g.

The Pearson curves of figure 4 representing the landing impact acceleration probability distributions have been grouped to facilitate comparison of landing impact experience. Figure 5(a) provides a comparison for the type I airplanes. As is indicated in table I, type I includes models of varying sizes and weights. In general, however, the major classifications within type I may be considered as the small series consisting of models IA and IAF and the large series consisting of models IC, ICF, and ID. The differences between these series are so large that they may be considered to be different airplanes so far as landing experience is concerned. In two of the three operations, the curves of figure 5 show the landing experience for the larger series of the type I airplane to be more severe than that of the small series above about 0.8g. Operation EIC is not only an exception in that the experience for that operation is the least extreme of the type I airplanes but, as is indicated in table III, has the lowest value of acceleration expected to be exceeded (0.79g) for one landing in 10 000 of any of the 24 operations sampled. The values of acceleration expected to be exceeded as given in table III are 0.95g and 1.16g for the type IA airplanes and 1.34g and 1.35g for the larger type I airplanes.

The probability distributions for type II airplanes shown in figure 5(b) generally exhibit about the same variation in acceleration values at a given probability as did those of the type IA airplanes. The exception is the distribution for operation CIIB which included one landing at 1.8g incremental. Table III indicates that the acceleration expected to be exceeded for one landing in 10 000 is 1.67g for operation CIIB and ranges from 0.97g to 1.18g for the remaining operations.

Distributions representing landing impact experience for several other four-engine types and one type of three-engine jet airplane are shown in figure 5(c). The accelerations expected to be exceeded for one landing in 10 000 are 1.31g and 1.27g for operations IIIIA and AVIIA, respectively, and range from 0.96g to 1.35g for the three operations involving the type IXA airplane. Two of the operations for the type IXA airplane exhibit similar and rather mild landing impact experience but the third operation was more severe. Examination of the frequency of occurrence for the three operations of the type IXA airplane in table III shows that operation UIXA experienced fewer of the small accelerations (0 to 0.2g) and more of the larger accelerations (0.3g and larger) than did operations AIXA or WIXA; consequently, the mean value is higher for operation UIXA.

Landing impact probability distributions for four types of two-engine jet transports are shown in figure 5(d). Three of these are reasonably similar and mild, but the distribution for the fourth operation (JXVIB) is one of the most severe of the distributions presented in this paper. The acceleration expected to be exceeded for one landing in 10 000 for this operation is 1.54g and the mean value is 0.384g. The accelerations expected to be exceeded for one landing in 10 000 are 1.04g, 0.93g, and 1.05g, respectively, for operations GVIIIB, SXIIIA, and IXIVA.

Figure 5(e) shows the probability of exceeding given landing impact accelerations for three types of turboprop transport airplanes. Three of the operations – AIVA, JVA, and DVIA – show about the same value of acceleration expected to be exceeded in one landing in 10 000, but the accelerations expected to be exceeded at intermediate probabilities differ considerably. The shape of the probability curve for operation DVIA is unusual compared to others and is a result of the combination of a low mean value and a few points located at the "tail" of the distribution. While they all have the same shape, the curves for the three operations of the type IVA airplane result in quite different values of acceleration expected to be exceeded in one landing in 10 000: 1.07g, 0.97g, and 1.36g for airlines A, B, and C, respectively.

Effect of airline on landing experience.- Although not plotted by airline, the data have been examined to determine if there were any trends by airline. Airline A was involved in five operations, airline E in three, and airlines C, G, I, and J in two each. No apparent trends by airline were noted. The two operations for airline G – operations GIIA/B and GVIIIB – showed relatively little variation in acceleration expected to be exceeded for one landing in 10 000 (1.04g to 1.13g), but the two operations for airline J and the five operations of airline A both showed relatively large variations in the accelerations expected to be exceeded for one landing in 10 000. However, airline G has had a procedure of setting up landing conditions (gear, flaps, and power) at a point farther from touchdown than is usual with other airlines and this procedure may be responsible for the small variation in acceleration noted previously.

Significance of extreme value landing impact.- Statistically, an acceleration as large as the 1.8g shown in figure 4(g) would be expected to occur only once in a sample many times larger than the 1512 landings obtained for operation CIIB. For example, operation JVA with 2445 landings had a maximum incremental acceleration of only 1.0g to 1.1g, and operation AVIIA with 1504 landings had a maximum of 1.1g to 1.2g. (See table III.) The 1.8g acceleration was experienced during a check-and-training flight for which airplane gross weights are generally low. Unfortunately, the number of check flights which occur during a typical VGH data collection period is too small to provide a statistically reliable sample of the landing impact accelerations experienced for check flights alone.

In order to ascertain the effect of one extreme point in a distribution, the 1.8g point was deleted from the data of operation CIIB and a new probability distribution was formed. The probability distributions, together with the Pearson faired curves, for operation CIIB with and without the 1.8g point are shown in figure 6. Inspection will show that the faired curve for the modified distribution is similar to the other distributions for type II airplanes shown in figure 5(b). The curves of figure 6 lead to the speculation that the tail of the distribution should flatten somewhat to account for the occasional hard landing. Unfortunately, insufficient data exist to confirm the speculation or to provide a guide for the flattening.

Effect of landing gear characteristics.- Landing gear characteristics can materially affect the amplitudes of center-of-gravity accelerations recorded during landing impacts and during operations on the ground. For two operations, JVA (ref. 3) and SXIIIA (ref. 6), modifications made to the airplane landing gear during the recording program resulted in significant reductions in the acceleration amplitudes. As indicated in the respective references, the modification in one case consisted of a change in oleo stroke and orifice and in the other case consisted of adding weights to the gear. The landing impact accelerations presented in this paper and the accelerations recorded during taxi, takeoff, and landing rollout in the next section for these two operations are those recorded subsequent to the respective landing gear modifications. It is possible that the relatively severe results shown in figures 4(x) and 5(d) for operation JXVIB may be attributed to landing gear characteristics rather than airplane operation.

## Taxi, Takeoff, and Landing Rollout Accelerations

The frequency distributions of positive and negative accelerations for preflight taxi, takeoff, landing rollout, and postflight taxi conditions are presented in table IV for seven operations. The total frequency distributions of positive and of negative accelerations for each operation and the number of flights represented by each frequency distribution are also presented. For takeoff and landing rollout, the frequency distributions are given for each of three speed intervals.

In order to compare the accelerations experienced during preflight taxi, takeoff, landing rollout, and postflight taxi, the data given in table IV for each category of ground operation are plotted in figure 7. The results show the average number of times per flight that given values of acceleration were exceeded in each of the categories. Accelerations of a given magnitude occurred most frequently during the landing rollout for most of the operations and least frequently during taxi. The accelerations were from 2 to 150 times more frequent during landing rollout that during taxi. This, in part, is a reflection of the method of evaluation whereby accelerations subsequent to the initial positive landing impact are evaluated in the landing rollout category. The maximum acceleration occurred during landing rollout for four of the operations but occurred for preflight taxi for operation SXIIIA. Equally high accelerations were recorded for takeoff and landing rollout for operation EIC and for preflight taxi and landing rollout for operation JVA.

In order to compare the acceleration experience for the seven operators, the positive and negative portions of the total distribution for each operation given in table IV were combined without regard to sign and are shown in figure 8 in terms of the cumulative frequency of occurrence per flight. The results show that the ground acceleration experiences for the seven operations are similar over most of the range of the data. For example, the results show that there is about a 3 to 1 difference among the frequencies of exceeding an incremental acceleration of ±0.2g for the seven operations. For a value of ±0.4g, the frequencies differ by a factor of about 4 to 1. The maximum incremental accelerations recorded ranged from 0.5g to 0.7g.

## Longitudinal Deceleration During Landings

Frequency distributions of maximum longitudinal decelerations during landing for one airplane during operational flights, check flights, and for combined operational and check flights are given in table V. The values of deceleration presented include aerodynamic drag, wheel braking, and reverse thrust; but the contribution of each of the three sources to the total deceleration is not known. The distributions are presented in figure 9 in terms of the probability that the maximum deceleration during a landing will exceed given values. The results show that a deceleration of 0.2g was exceeded on approximately 60 percent of the flights (Probability = 0.6) and that a value of 0.3g was exceeded on about 4 percent of the flights (Probability = 0.04). The maximum decelerations recorded in the 556 landings ranged from about 0.12g to 0.42g.

## CONCLUDING REMARKS

A summary of landing impact accelerations has shown that for 24 operations (airline-airplane combination) representing a total of 22 464 landings, the initial positive incremental landing impact accelerations expected to be exceeded once in 10 000 landings range from about 0.79g to about 1.67g. These differences among the landing impact acceleration experiences of the various operations apparently reflect the combined effects of differences among the airplane characteristics and landing approach techniques used by the various airlines. In order to permit reliable extrapolation of the landing impact accelerations, the data were mathematically fitted with a Pearson curve of the type appropriate to each set of data.

Only small differences in overall normal acceleration experience during taxi, takeoff, and landing rollout exist for the seven operations investigated. Landing rollout contributed most heavily, and taxi contributed the least, to the overall ground acceleration experience. The maximum incremental accelerations recorded ranged from 0.5g to 0.7g.

For one operation, longitudinal decelerations measured during 556 landings indicated that maximum value ranged from about 0.12g to 0.42g.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Virginia, February 2, 1971.

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TABLE I.- AIRPLANE CHARACTERISTICS

| Airplane type | Engines | | Wing area, sq m (sq ft) | Maximum design weight at – | |
|---|---|---|---|---|---|
| | Number | Type | | Takeoff, N (lbf) | Landing, N (lbf) |
| IA | 4 | Turbojet | 226.0 (2433) | 1 103 159 (248 000) | 778 439 (175 000) |
| IAF | 4 | Turbofan | 233.2 (2510) | 1 143 193 (257 000) | 822 921 (185 000) |
| IC | 4 | Turbojet | 268.7 (2892) | 1 387 845 (312 000) | 920 782 (207 000) |
| ICF | 4 | Turbofan | 279.6 (3010) | 1 459 017 (328 000) | 1 099 711 (247 000) |
| ID | 4 | Turbofan | 268.7 (2892) | 1 387 845 (312 000) | 920 782 (207 000) |
| IIA | 4 | Turbojet | 257.6 (2773) | 1 214 365 (273 000) | 858 507 (193 000) |
| IIB | 4 | Turbojet | 257.6 (2773) | 1 227 709 (276 000) | 887 420 (199 500) |
| IIC | 4 | Turbojet | 257.6 (2773) | 1 401 190 (315 000) | 920 782 (207 000) |
| IIIA | 4 | Turbojet | 199.7 (2150) | 820 697 (184 500) | 644 992 (145 000) |
| IVA | 4 | Turboprop | 120.8 (1300) | 502 649 (113 000) | 425 472 ( 95 650) |
| VA | 2 | Turboprop | 70.0 ( 754) | 166 808 ( 37 500) | 158 802 ( 35 700) |
| VIA | 4 | Turboprop | 89.5 ( 963) | 280 238 ( 63 000) | 240 204 ( 54 000) |
| VIIA | 4 | Turbofan | 232.3 (2500) | 1 086 256 (244 200) | 898 541 (202 000) |
| VIIIB | 2 | Turbojet | 146.7 (1579) | 490 328 (110 230) | 467 019 (104 990) |
| IXA | 3 | Turbojet | 157.9 (1700) | 676 130 (152 000) | 582 717 (131 000) |
| XIIIA | 2 | Turbofan | 91.0 ( 980) | 331 393 ( 74 500) | 293 583 ( 66 000) |
| XIVA | 2 | Turbofan | 85.9 ( 925) | 383 882 ( 86 300) | 363 420 ( 81 700) |
| XVIB | 2 | Turbofan | 89.6 ( 964) | 448 381 (100 800) | 399 005 ( 89 700) |

TABLE II.- SCOPE OF DATA

| Operation | Type of operation | Number of flights evaluated for – | | |
|---|---|---|---|---|
| | | Landing impact accelerations | Ground accelerations | |
| | | | Normal | Longitudinal |
| EIA | U.S. international | 809 | ---- | --- |
| AIAF | U.S. domestic long haul | 648 | ---- | --- |
| EIC | U.S. internationl | 573 | $\approx$562 | --- |
| AICF | U.S. domestic long haul | 556 | ---- | 556 |
| KID | Foreign international | 582 | $\approx$751 | --- |
| GIIA/B | U.S. domestic long haul | 924 | ---- | --- |
| CIIB | U.S. domestic long haul | 1512 | ---- | --- |
| EIIC | U.S. international | 687 | $\approx$827 | --- |
| HIIC | U.S. international | 722 | ---- | --- |
| LIIC | Foreign international | 1035 | ---- | --- |
| IIIIA | U.S. domestic medium haul | 1207 | $\approx$666 | --- |
| AIVA | U.S. domestic short haul | 878 | $\approx$762 | --- |
| BIVA | U.S. domestic short haul | 735 | ---- | --- |
| CIVA | U.S. domestic short haul | 694 | ---- | --- |
| JVA | U.S. domestic feederline | 2445 | 158 | --- |
| DVIA | U.S. domestic short haul | 799 | ---- | --- |
| AVIIA | U.S. domestic medium haul | 1504 | ---- | --- |
| GVIIIB | U.S. domestic short haul | 1122 | ---- | --- |
| AIXA | U.S. domestic short haul | 1090 | ---- | --- |
| UIXA | European domestic short haul | 811 | ---- | --- |
| WIXA | Australian domestic short haul | 817 | ---- | --- |
| SXIIIA | U.S. domestic short haul | 1043 | 705 | --- |
| IXIVA | U.S. domestic short haul | 556 | ---- | --- |
| JXVIB | U.S. domestic short haul | 715 | ---- | --- |

TABLE III.- FREQUENCY DISTRIBUTIONS OF INITIAL POSITIVE INCREMENTAL LANDING IMPACT ACCELERATIONS FOR 24 OPERATIONS

| Normal acceleration, g units | Frequency of occurrence for airline operation – | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | EIA | AIAF | EIC | AICF | KID | GIIA/B | CIIB (ref. 5) | EIIC | HIIC (ref. 5) | LIIC | IIIA (ref. 7) | AIVA | BIVA | CIVA | JVA (refs. 1 to 3) | DVIA (ref. 1) | AVIIA | GVIIIB | AIXA | UIXA | WIXA | SXIIIA (refs. 4 & 6) | IXIVA | JXIVB |
| 0 to 0.1 | 36 | 25 | 13 | 43 | 5 | 29 | 35 | 35 | 13 | 11 | 26 | 19 | 5 | 2 | 51 | 60 | 10 | 62 | 40 | 5 | 36 | 6 | 0 | 5 |
| 0.1 to 0.2 | 189 | 168 | 179 | 179 | 87 | 236 | 273 | 195 | 150 | 176 | 304 | 158 | 135 | 43 | 380 | 301 | 218 | 407 | 363 | 113 | 275 | 218 | 28 | 88 |
| 0.2 to 0.3 | 242 | 245 | 219 | 141 | 203 | 300 | 430 | 213 | 216 | 360 | 456 | 239 | 207 | 147 | 608 | 297 | 484 | 367 | 427 | 330 | 291 | 438 | 151 | 150 |
| 0.3 to 0.4 | 162 | 121 | 110 | 114 | 135 | 172 | 398 | 138 | 178 | 231 | 244 | 212 | 175 | 182 | 563 | 106 | 367 | 185 | 169 | 242 | 144 | 263 | 202 | 182 |
| 0.4 to 0.5 | 103 | 55 | 38 | 38 | 91 | 126 | 219 | 55 | 101 | 174 | 115 | 133 | 133 | 138 | 400 | 22 | 216 | 66 | 59 | 65 | 42 | 86 | 109 | 145 |
| 0.5 to 0.6 | 44 | 26 | 11 | 25 | 44 | 44 | 93 | 28 | 36 | 64 | 40 | 81 | 52 | 93 | 232 | 8 | 116 | 22 | 21 | 37 | 21 | 23 | 43 | 71 |
| 0.6 to 0.7 | 22 | 4 | 3 | 11 | 8 | 11 | 32 | 14 | 12 | 12 | 12 | 23 | 22 | 45 | 138 | 2 | 45 | 7 | 8 | 8 | 7 | 5 | 15 | 42 |
| 0.7 to 0.8 | 6 | 4 | | 1 | 2 | 3 | 24 | 7 | 8 | 3 | 4 | 9 | 4 | 30 | 48 | 1 | 28 | 4 | 2 | 6 | 0 | 4 | 6 | 14 |
| 0.8 to 0.9 | 2 | | | 2 | 2 | 1 | 5 | 2 | 8 | 4 | 3 | 3 | 1 | 7 | 21 | 2 | 13 | 2 | 0 | 1 | 1 | | 2 | 8 |
| 0.9 to 1.0 | 3 | | | 1 | 4 | 1 | 2 | | | | 1 | 0 | 1 | 3 | 2 | | 5 | | 1 | 3 | | | | 3 |
| 1.0 to 1.1 | | | | 0 | 0 | 1 | 0 | | | | 1 | 1 | | 3 | 2 | | 1 | | | 0 | | | | 3 |
| 1.1 to 1.2 | | | | 1 | 1 | | 0 | | | | 0 | | | 0 | | | 1 | | | 0 | | | | 1 |
| 1.2 to 1.3 | | | | | | | 0 | | | | 1 | | | 1 | | | | | | 1 | | | | 2 |
| 1.3 to 1.4 | | | | | | | 0 | | | | | | | | | | | | | | | | | 1 |
| 1.4 to 1.5 | | | | | | | 0 | | | | | | | | | | | | | | | | | |
| 1.5 to 1.6 | | | | | | | 0 | | | | | | | | | | | | | | | | | |
| 1.6 to 1.7 | | | | | | | 0 | | | | | | | | | | | | | | | | | |
| 1.7 to 1.8 | | | | | | | 0 | | | | | | | | | | | | | | | | | |
| 1.8 to 1.9 | | | | | | | 1 | | | | | | | | | | | | | | | | | |
| Total | 809 | 648 | 573 | 556 | 582 | 924 | 1512 | 687 | 722 | 1035 | 1207 | 878 | 735 | 694 | 2445 | 799 | 1504 | 1122 | 1090 | 811 | 817 | 1043 | 556 | 715 |
| No. of airplanes . . | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 1 | 2 | 1 | 1 |
| Mean . . . . . . . . | 0.298 | 0.270 | 0.255 | 0.264 | 0.326 | 0.287 | 0.321 | 0.275 | 0.312 | 0.314 | 0.279 | 0.328 | 0.328 | 0.411 | 0.353 | 0.222 | 0.340 | 0.242 | 0.246 | 0.307 | 0.247 | 0.280 | 0.362 | 0.384 |
| Acceleration, g* . . | 1.16 | 0.95 | 0.79 | 1.34 | 1.35 | 1.13 | 1.67 | 1.07 | 1.18 | 0.97 | 1.31 | 1.07 | 0.97 | 1.36 | 1.07 | 1.08 | 1.27 | 1.04 | 1.05 | 1.35 | 0.96 | 0.93 | 1.05 | 1.54 |

*Acceleration expected to be exceeded, on the average, once in 10 000 landings based on extrapolation of data by use of Pearson curves.

TABLE IV.- FREQUENCY DISTRIBUTIONS OF ACCELERATIONS COLLECTED DURING GROUND OPERATIONS

(a) Operation EIC

| Incremental acceleration, g units | Frequency of occurrence for – | | | | | | | | Total frequency of occurrence |
|---|---|---|---|---|---|---|---|---|---|
| | Preflight taxi | Takeoff | | | Landing rollout | | | Postflight taxi | |
| | | 0 to 80 knots | 80 to 120 knots | 120 to 160 knots | 120 to 160 knots | 80 to 120 knots | 0 to 80 knots | | |
| -0.5 to -0.6 | | 1 | | 4 | | 3 | | | 8 |
| -0.4 to -0.5 | | 10 | 2 | 6 | 6 | 14 | 4 | | 42 |
| -0.3 to -0.2 | 2 | 34 | 26 | 36 | 98 | 298 | 27 | 4 | 525 |
| -0.2 to -0.3 | 203 | 353 | 445 | 297 | 708 | 2571 | 663 | 90 | 5 330 |
| Negative total | 205 | 398 | 473 | 343 | 812 | 2886 | 694 | 94 | 5 905 |
| 0.2 to 0.3 | 274 | 451 | 592 | 350 | 711 | 2377 | 629 | 91 | 5 475 |
| 0.3 to 0.4 | 11 | 49 | 38 | 23 | 94 | 183 | 27 | 6 | 431 |
| 0.4 to 0.5 | | 11 | 2 | 3 | 11 | 14 | 3 | | 44 |
| 0.5 to 0.6 | — | 2 | 1 | 4 | 4 | 1 | 1 | — | 13 |
| Positive total | 285 | 513 | 633 | 380 | 820 | 2575 | 660 | 97 | 5 963 |
| Positive and negative total | 490 | 911 | 1106 | 723 | 1632 | 5461 | 1354 | 191 | 11 868 |
| No. of flights . . . | 645 | 561 | 561 | 561 | 558 | 558 | 558 | 558 | *562 |

*Weighted average.

TABLE IV.- FREQUENCY DISTRIBUTIONS OF ACCELERATIONS COLLECTED DURING GROUND OPERATIONS – Continued

(b) Operation KID

| Incremental acceleration, g units | Frequency of occurrence for – | | | | | | | | Total frequency of occurrence |
|---|---|---|---|---|---|---|---|---|---|
| | Preflight taxi | Takeoff | | | Landing rollout | | | Postflight taxi | |
| | | 0 to 80 knots | 80 to 120 knots | 120 to 160 knots | 120 to 160 knots | 80 to 120 knots | 0 to 80 knots | | |
| -0.5 to -0.6 | | | | | 2 | | | | 2 |
| -0.4 to -0.5 | | 1 | 3 | | 12 | | 1 | | 17 |
| -0.3 to -0.4 | | 6 | 10 | 3 | 121 | 90 | 21 | 1 | 252 |
| -0.2 to -0.3 | 37 | 101 | 226 | 84 | 1437 | 2302 | 523 | 99 | 4809 |
| Negative total | 37 | 108 | 239 | 87 | 1572 | 2392 | 545 | 100 | 5080 |
| 0.2 to 0.3 | 48 | 118 | 233 | 105 | 1270 | 1935 | 419 | 108 | 4236 |
| 0.3 to 0.4 | | 6 | 20 | 4 | 187 | 90 | 21 | 14 | 342 |
| 0.4 to 0.5 | | | | | 36 | 7 | | | 43 |
| 0.5 to 0.6 | — | — | — | — | 6 | — | — | — | 6 |
| Positive total | 48 | 124 | 253 | 109 | 1499 | 2032 | 440 | 122 | 4627 |
| Positive and negative total | 85 | 232 | 492 | 196 | 3071 | 4424 | 985 | 222 | 9707 |
| No. of flights . . . | 751 | 750 | 750 | 750 | 752 | 752 | 752 | 724 | *751 |

*Weighted average.

TABLE IV.- FREQUENCY DISTRIBUTIONS OF ACCELERATIONS COLLECTED DURING GROUND OPERATIONS – Continued

(c) Operation EIIC

| Incremental acceleration, g units | Frequency of occurrence for – | | | | | | | | Total frequency of occurrence |
|---|---|---|---|---|---|---|---|---|---|
| | Preflight taxi | Takeoff | | | Landing rollout | | | Postflight taxi | |
| | | 0 to 80 knots | 80 to 120 knots | 120 to 160 knots | 120 to 160 knots | 80 to 120 knots | 0 to 80 knots | | |
| -0.7 to -0.8 | | | | | 2 | 7 | | | 9 |
| -0.6 to -0.7 | | | | | | 5 | | | 5 |
| -0.5 to -0.6 | | | | 1 | 2 | 14 | | | 17 |
| -0.4 to -0.5 | | | | 2 | 13 | 29 | | | 44 |
| -0.3 to -0.4 | 3 | | | 16 | 72 | 123 | 4 | 3 | 221 |
| -0.2 to -0.3 | 83 | 20 | 47 | 189 | 476 | 1 023 | 87 | 97 | 2 022 |
| -0.1 to -0.2 | 9 180 | 2146 | 2611 | 2887 | 1492 | 7 883 | 5 244 | 7 125 | 38 568 |
| Negative total | 9 266 | 2166 | 2658 | 3095 | 2057 | 9 084 | 5 335 | 7 225 | 40 886 |
| 0.1 to 0.2 | 9 641 | 2354 | 2647 | 1911 | 924 | 6 841 | 5 423 | 7 624 | 37 365 |
| 0.2 to 0.3 | 324 | 72 | 80 | 161 | 432 | 1 185 | 170 | 238 | 2 662 |
| 0.3 to 0.4 | 51 | 3 | | 20 | 111 | 251 | 13 | 28 | 477 |
| 0.4 to 0.5 | 2 | | | 1 | 27 | 46 | | 2 | 78 |
| 0.5 to 0.6 | | | | | 5 | 14 | | | 19 |
| 0.6 to 0.7 | | | | | 5 | 1 | | | 6 |
| 0.7 to 0.8 | | | | | 1 | 2 | | | 3 |
| Positive total | 10 018 | 2429 | 2727 | 2093 | 1505 | 8 340 | 5 606 | 7 892 | 40 610 |
| Positive and negative total | 19 284 | 4595 | 5385 | 5188 | 3562 | 17 424 | 10 941 | 15 117 | 81 496 |
| No. of flights . . . | 848 | 837 | 837 | 837 | 802 | 802 | 802 | 841 | *827 |

*Weighted average.

TABLE IV.- FREQUENCY DISTRIBUTIONS OF ACCELERATIONS COLLECTED DURING GROUND OPERATIONS – Continued

(d) Operation IIIA

| Incremental acceleration, g units | Frequency of occurrence for – | | | | | | | | Total frequency of occurrence |
|---|---|---|---|---|---|---|---|---|---|
| | Preflight taxi | Takeoff | | | Landing rollout | | | Postflight taxi | |
| | | 0 to 80 knots | 80 to 120 knots | 120 to 140 knots | 120 to 140 knots | 80 to 120 knots | 0 to 80 knots | | |
| -0.5 to -0.6 | | | | | 2 | 2 | | | 4 |
| -0.4 to -0.5 | | | 1 | 2 | 34 | 4 | | | 41 |
| -0.3 to -0.4 | 1 | | 7 | 47 | 201 | 49 | 4 | | 309 |
| -0.2 to -0.3 | 49 | 36 | 202 | 426 | 1271 | 590 | 161 | 38 | 2773 |
| Negative total | 50 | 36 | 210 | 475 | 1508 | 645 | 165 | 38 | 3127 |
| 0.2 to 0.3 | 85 | 94 | 272 | 366 | 967 | 430 | 127 | 39 | 2380 |
| 0.3 to 0.4 | 3 | 6 | 11 | 12 | 197 | 31 | 2 | 3 | 265 |
| 0.4 to 0.5 | 1 | | | 3 | 55 | 3 | 1 | | 63 |
| 0.5 to 0.6 | — | — | — | — | 7 | 1 | — | — | 8 |
| Positive total | 89 | 100 | 283 | 381 | 1226 | 465 | 130 | 42 | 2716 |
| Negative and positive total | 139 | 136 | 493 | 856 | 2734 | 1110 | 295 | 80 | 5843 |
| No. of flights . . . | 662 | 670 | 670 | 670 | 667 | 667 | 667 | 519 | *666 |

*Weighted average.

TABLE IV.- FREQUENCY DISTRIBUTIONS OF ACCELERATIONS COLLECTED DURING GROUND OPERATIONS – Continued

(e) Operation AIVA

| Incremental acceleration, g units | Frequency of occurrence for – | | | | | | | | Total frequency of occurrence |
|---|---|---|---|---|---|---|---|---|---|
| | Preflight taxi | Takeoff | | | Landing rollout | | | Postflight taxi | |
| | | 0 to 40 knots | 40 to 80 knots | 80 to 120 knots | 80 to 120 knots | 40 to 80 knots | 0 to 40 knots | | |
| -0.5 to -0.6 | | | | | | 2 | | | 2 |
| -0.4 to -0.5 | | | | | 9 | 4 | | | 13 |
| -0.3 to -0.4 | | | | 4 | 101 | 15 | | 5 | 125 |
| -0.2 to -0.3 | 85 | 2 | 19 | 213 | 1407 | 354 | 67 | 142 | 2289 |
| Negative total | 85 | 2 | 19 | 217 | 1517 | 375 | 67 | 147 | 2429 |
| 0.2 to 0.3 | 124 | 5 | 16 | 291 | 1510 | 343 | 35 | 224 | 2548 |
| 0.3 to 0.4 | 2 | | | 6 | 277 | 20 | | 33 | 338 |
| 0.4 to 0.5 | | | | 1 | 74 | 10 | | | 85 |
| 0.5 to 0.6 | | | | | 11 | | | | 11 |
| Positive total | 126 | 5 | 16 | 298 | 1872 | 373 | 35 | 257 | 2982 |
| Negative and positive total | 211 | 7 | 35 | 515 | 3389 | 748 | 102 | 404 | 5411 |
| No. of flights . . . | 802 | 757 | 757 | 757 | 761 | 761 | 761 | 761 | *762 |

*Weighted average.

TABLE IV.- FREQUENCY DISTRIBUTIONS OF ACCELERATIONS COLLECTED DURING GROUND OPERATIONS – Continued

(f) Operation JVA

| Incremental acceleration, g units | Frequency of occurrence for – | | | | | | | | Total frequency of occurrence |
|---|---|---|---|---|---|---|---|---|---|
| | Preflight taxi | Takeoff | | | Landing rollout | | | Postflight taxi | |
| | | 0 to 40 knots | 40 to 80 knots | 80 to 105 knots | 80 to 105 knots | 40 to 80 knots | 0 to 40 knots | | |
| -0.5 to -0.6 | 1 | | | | | | | | 1 |
| -0.4 to -0.5 | 0 | | | | 5 | 5 | | | 10 |
| -0.3 to -0.4 | 3 | | | 6 | 24 | 43 | | | 76 |
| -0.2 to -0.3 | 25 | | 18 | 77 | 160 | 225 | 2 | 8 | 515 |
| -0.1 to -0.2 | 749 | 190 | 707 | 617 | 400 | 1161 | 210 | 420 | 4 454 |
| Negative total | 778 | 190 | 725 | 700 | 589 | 1434 | 212 | 428 | 5 056 |
| 0.1 to 0.2 | 783 | 219 | 997 | 635 | 282 | 1097 | 225 | 478 | 4 716 |
| 0.2 to 0.3 | 21 | | 11 | 69 | 161 | 250 | 7 | 8 | 527 |
| 0.3 to 0.4 | 5 | | | 3 | 58 | 43 | | | 109 |
| 0.4 to 0.5 | 0 | | | | 21 | 15 | | | 36 |
| 0.5 to 0.6 | 1 | | | | 8 | 2 | | | 11 |
| Positive total | 810 | 219 | 1008 | 707 | 530 | 1407 | 232 | 486 | 5 399 |
| Positive and negative total | 1588 | 409 | 1733 | 1407 | 1119 | 2841 | 444 | 914 | 10 455 |
| No. of flights . . . | 158 | 158 | 158 | 158 | 158 | 158 | 158 | 158 | 158 |

TABLE IV.- FREQUENCY DISTRIBUTIONS OF ACCELERATIONS COLLECTED DURING GROUND OPERATIONS – Concluded

(g) Operation SXIIIA

| Incremental acceleration, g units | Frequency of occurrence for – | | | | | | | | Total frequency of occurrence |
|---|---|---|---|---|---|---|---|---|---|
| | Preflight taxi | Takeoff | | | Landing rollout | | | Postflight taxi | |
| | | 0 to 80 knots | 80 to 120 knots | 120 to 140 knots | 120 to 140 knots | 80 to 120 knots | 0 to 80 knots | | |
| -0.6 to -0.7 | | | | | | | | | |
| -0.5 to -0.6 | | | 1 | | | | 1 | | 2 |
| -0.4 to -0.5 | 7 | 1 | 13 | 4 | | 4 | 3 | 7 | 39 |
| -0.3 to -0.4 | 34 | 9 | 32 | 10 | | 71 | 40 | 20 | 216 |
| -0.2 to -0.3 | 542 | 208 | 685 | 125 | 2 | 1351 | 1122 | 346 | 4381 |
| Negative total | 583 | 218 | 731 | 139 | 2 | 1426 | 1166 | 373 | 4638 |
| 0.2 to 0.3 | 506 | 186 | 645 | 101 | 2 | 1194 | 786 | 331 | 3751 |
| 0.3 to 0.4 | 56 | 7 | 57 | 20 | | 122 | 25 | 31 | 318 |
| 0.4 to 0.5 | 6 | 1 | 6 | 2 | | 6 | | 5 | 26 |
| 0.5 to 0.6 | 3 | | | | | 3 | | 2 | 8 |
| 0.6 to 0.7 | 1 | | | | | | | | 1 |
| Positive total | 572 | 194 | 708 | 123 | 2 | 1325 | 811 | 369 | 4104 |
| Positive and negative total | 1155 | 412 | 1439 | 262 | 4 | 2751 | 1977 | 742 | 8742 |
| No. of flights . . . | 705 | 705 | 705 | 705 | 705 | 705 | 705 | 705 | 705 |

TABLE V.- LONGITUDINAL DECELERATIONS DURING LANDING FOR OPERATION AICF

| Longitudinal deceleration, g units | Frequency of occurrence for – | | |
|---|---|---|---|
| | Operational flights | Check flights | Combined operational and check flights |
| 0.12 to 0.13 | 1 | 3 | 4 |
| 0.13 to 0.14 | 6 | 3 | 9 |
| 0.14 to 0.15 | 0 | 0 | 0 |
| 0.15 to 0.16 | 30 | 10 | 40 |
| 0.16 to 0.17 | 42 | 14 | 56 |
| 0.17 to 0.18 | 0 | 0 | 0 |
| 0.18 to 0.19 | 64 | 25 | 89 |
| 0.19 to 0.20 | 71 | 24 | 95 |
| 0.20 to 0.21 | 0 | 0 | 0 |
| 0.21 to 0.22 | 75 | 15 | 90 |
| 0.22 to 0.23 | 52 | 2 | 54 |
| 0.23 to 0.24 | 0 | 0 | 0 |
| 0.24 to 0.25 | 44 | 4 | 48 |
| 0.25 to 0.26 | 10 | 1 | 11 |
| 0.26 to 0.27 | 13 | 0 | 13 |
| 0.27 to 0.28 | 19 | 1 | 20 |
| 0.28 to 0.29 | 4 | 1 | 5 |
| 0.29 to 0.30 | 2 | 1 | 3 |
| 0.30 to 0.31 | 6 | 0 | 6 |
| 0.31 to 0.32 | 2 | 0 | 2 |
| 0.32 to 0.33 | 0 | 0 | 0 |
| 0.33 to 0.34 | 2 | 0 | 2 |
| 0.34 to 0.35 | 2 | 0 | 2 |
| 0.35 to 0.36 | 0 | 1 | 1 |
| 0.36 to 0.37 | 1 | 0 | 1 |
| 0.37 to 0.38 | 1 | 0 | 1 |
| 0.38 to 0.39 | 2 | 0 | 2 |
| 0.39 to 0.40 | 1 | 0 | 1 |
| 0.40 to 0.41 | 0 | 0 | 0 |
| 0.41 to 0.42 | 0 | 0 | 0 |
| 0.42 to 0.43 | 1 | 0 | 1 |
| Total | 451 | 105 | 556 |

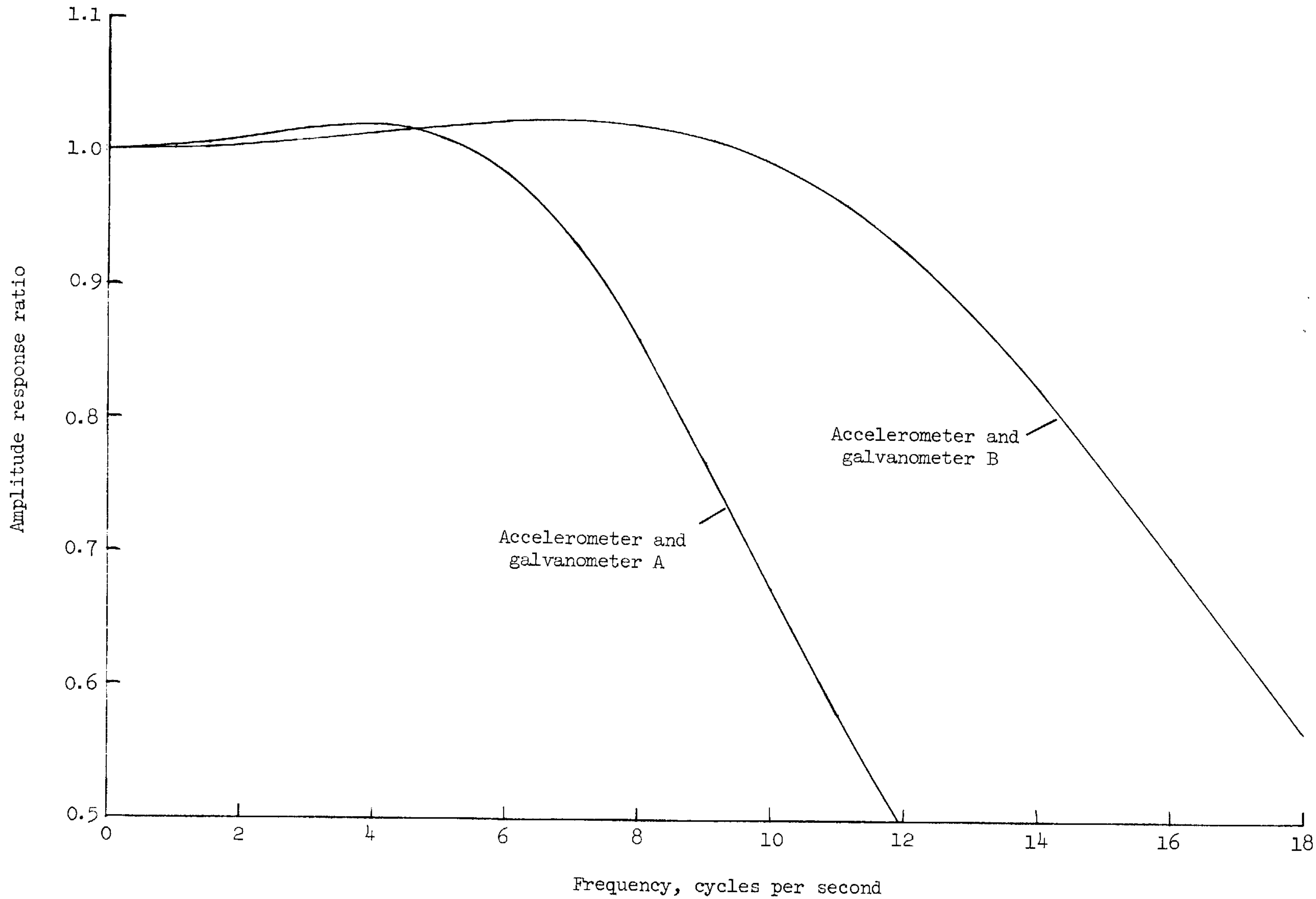



Figure 1.- Response of two acceleration sensing systems employed in NASA VGH recorder.

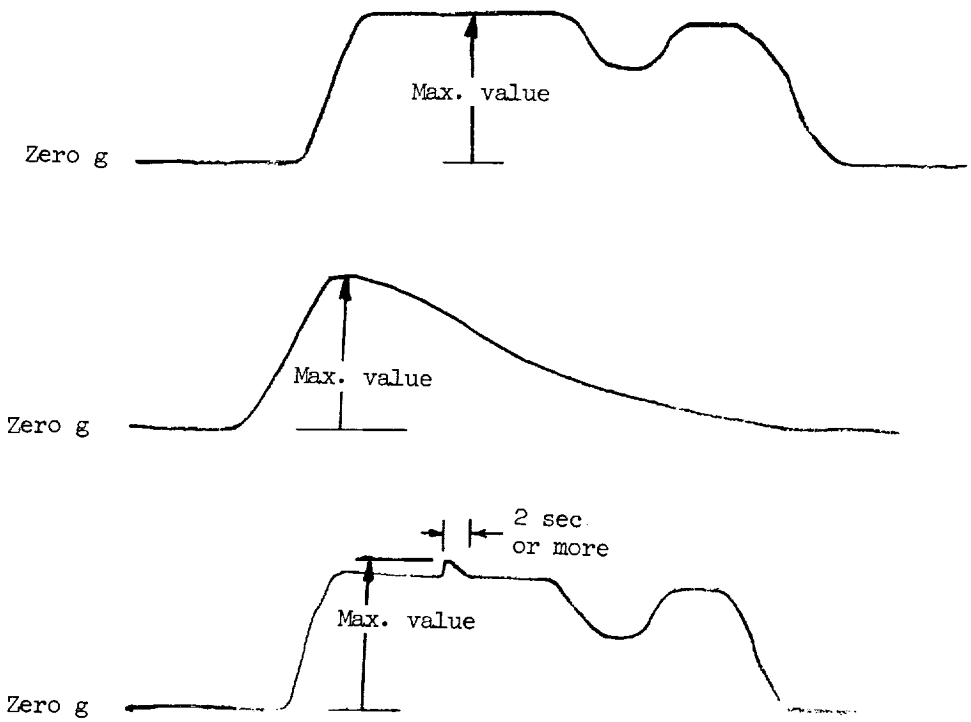
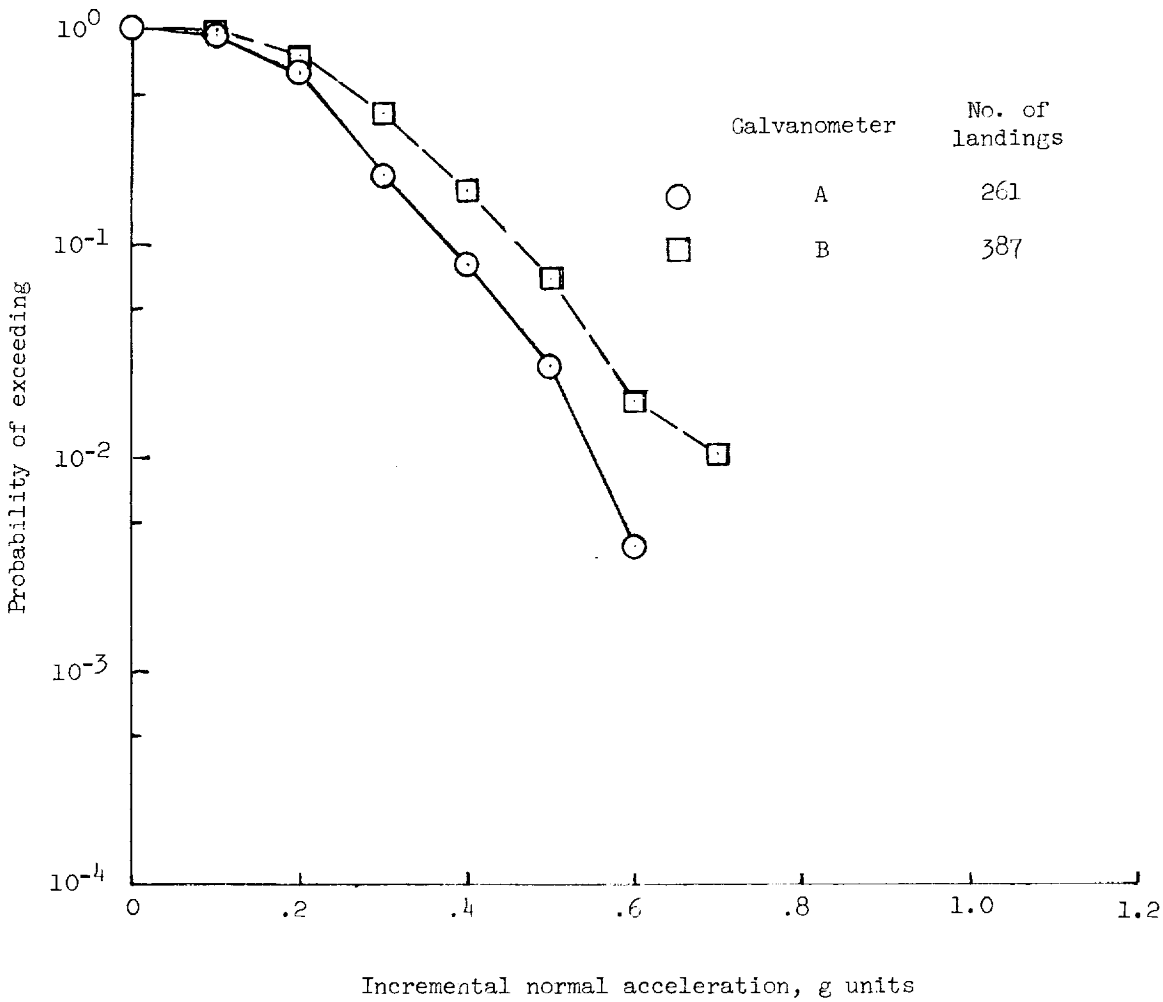
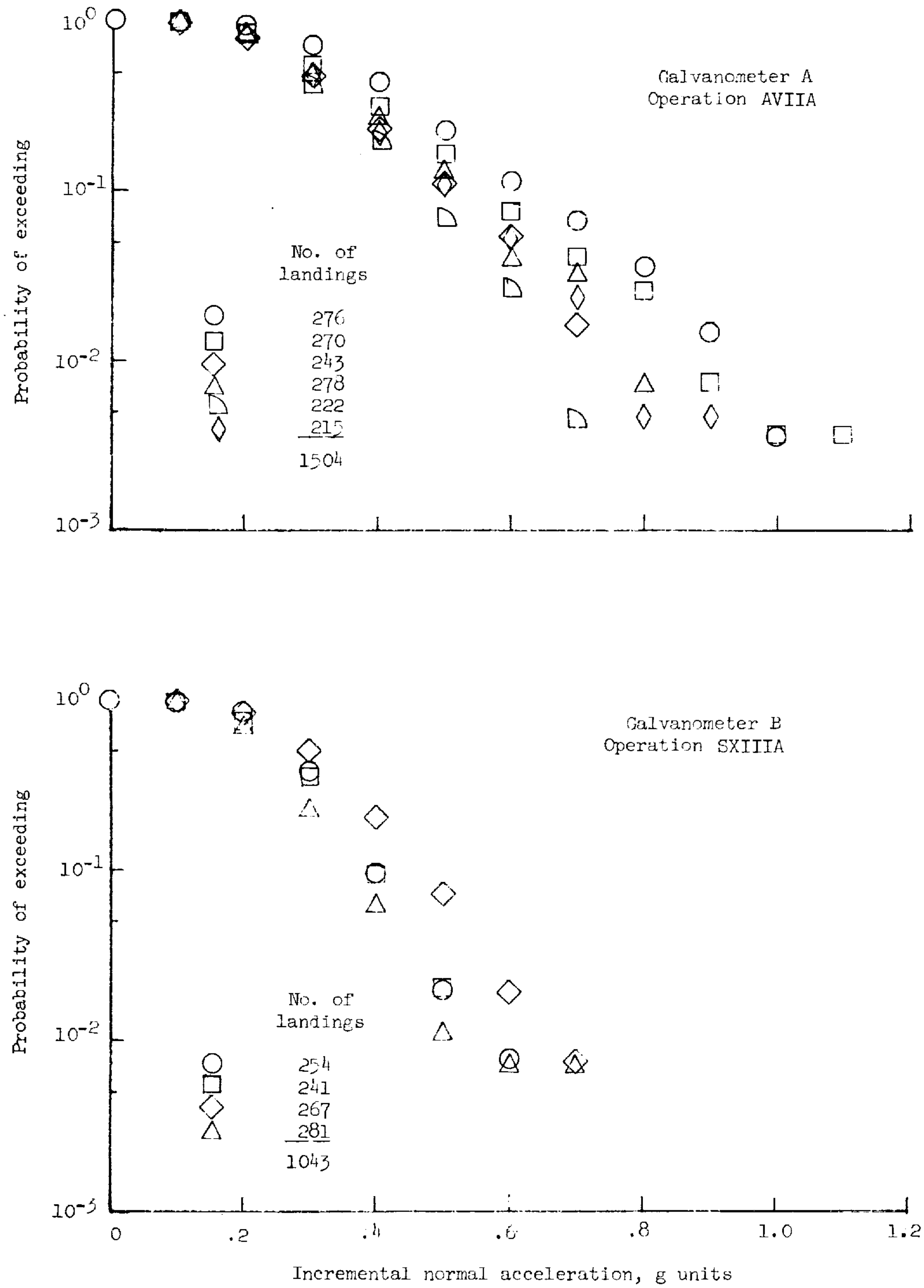



Figure 2.- Time histories of longitudinal deceleration during landing rollout.



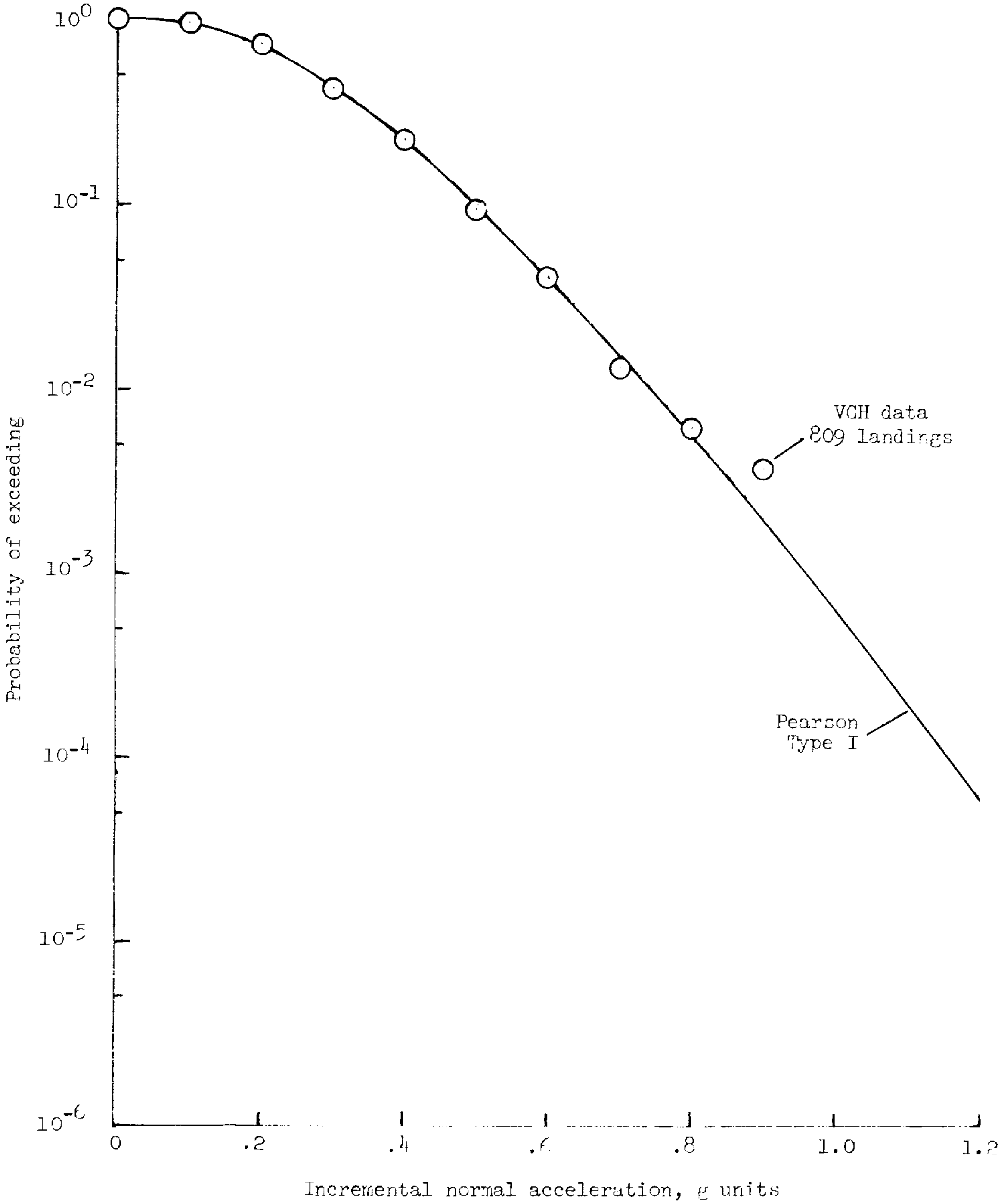

(a) Data from one operation.

Figure 3.- Comparison of normal acceleration data samples collected with two types of galvanometers having different frequency-response characteristics.



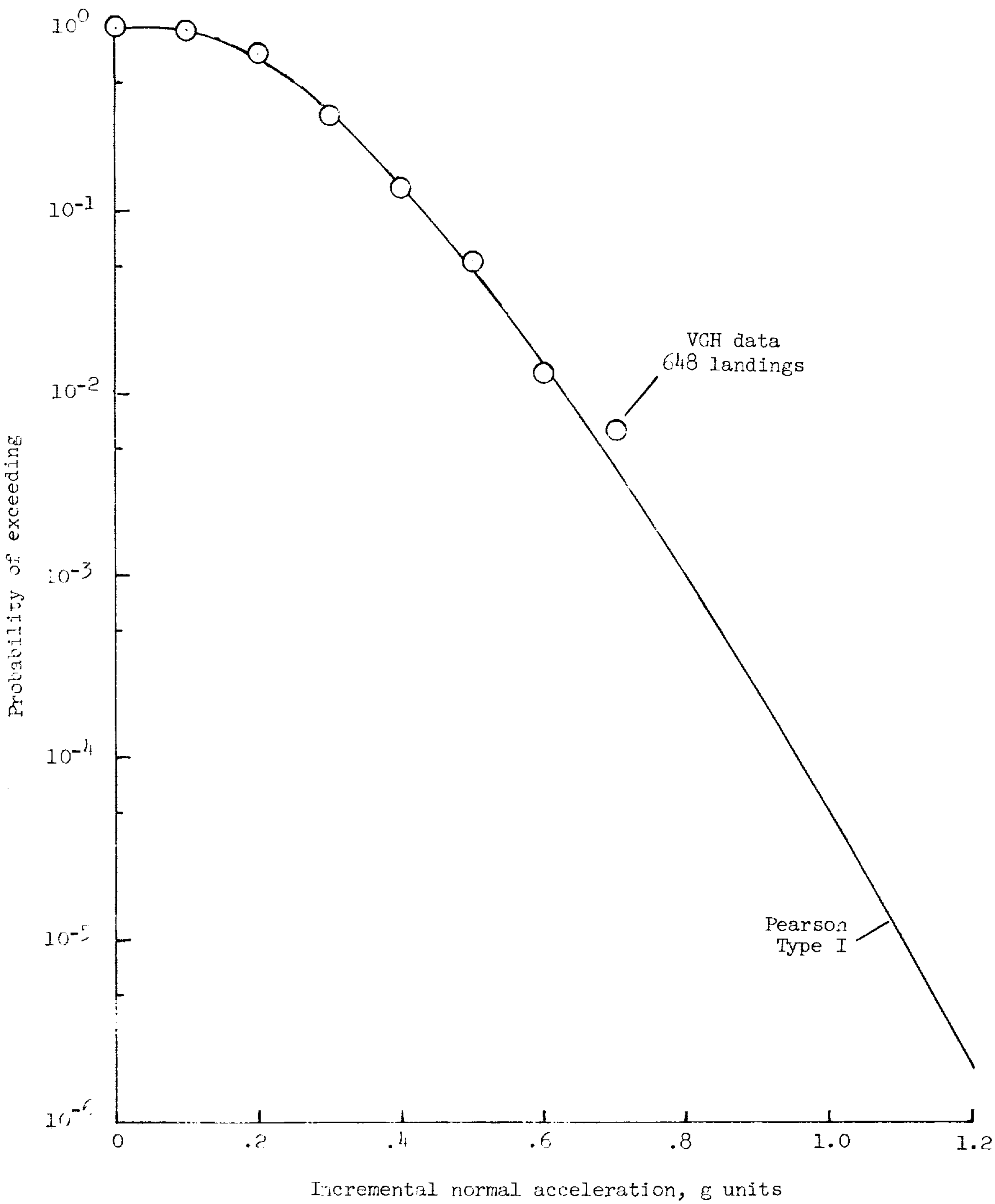

(b) Data from two large samples randomly divided into a number of smaller samples.

Figure 3.- Concluded.



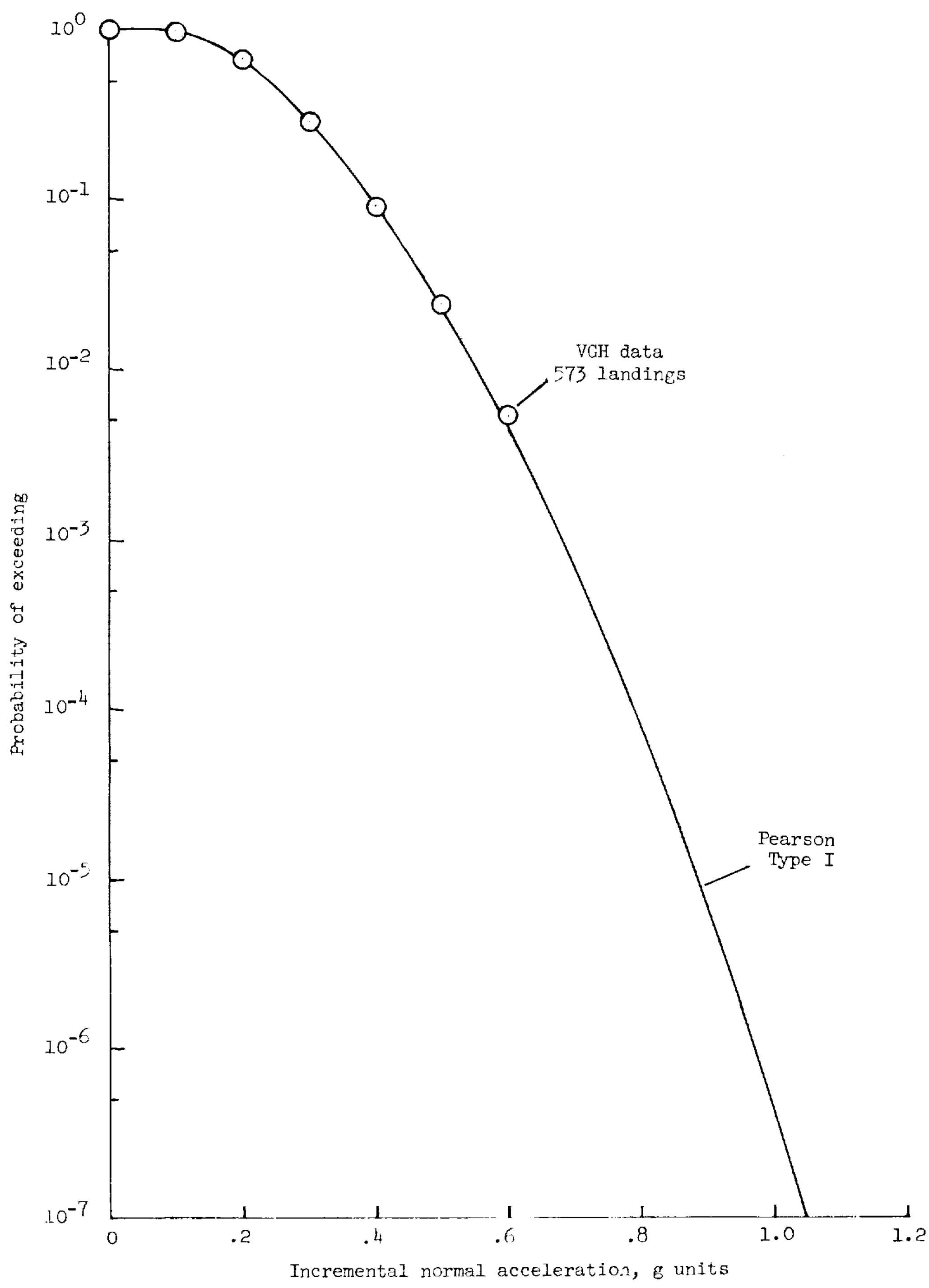

(a) Operation EIA.

Figure 4.- Probability of exceeding given values of landing impact incremental normal acceleration for individual operations.



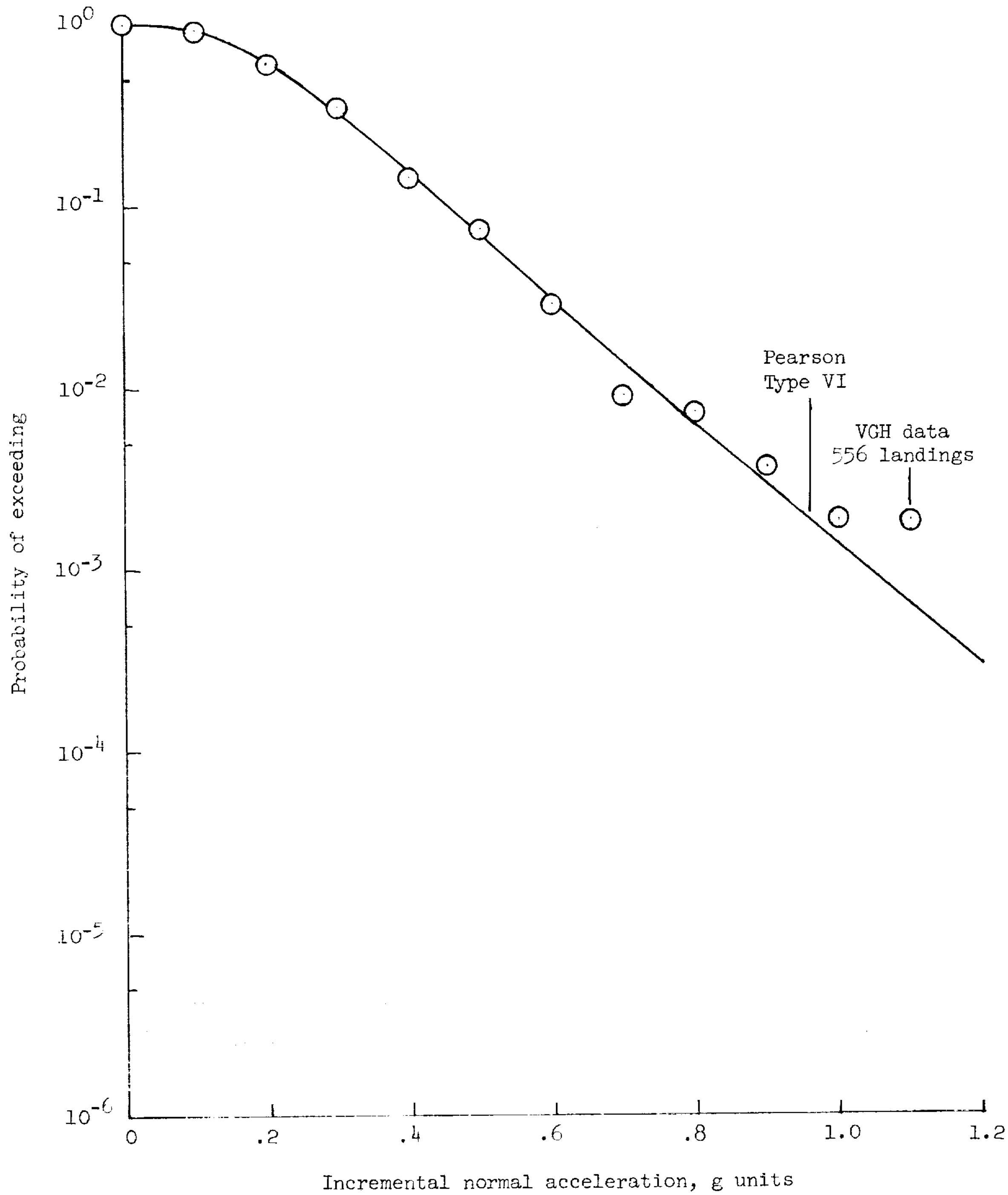

(b) Operation AIAF.

Figure 4.- Continued.



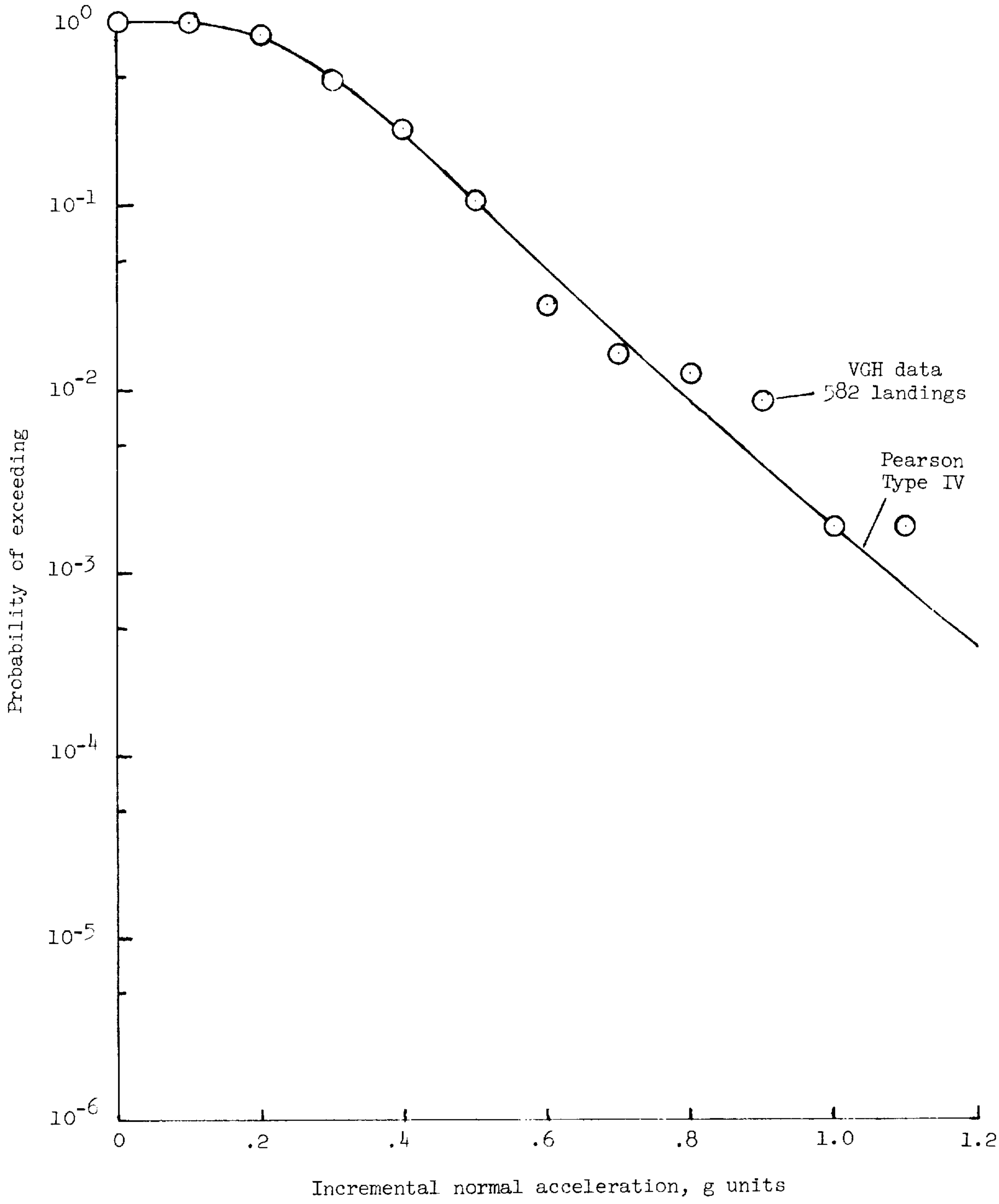

(c) Operation EIC.

Figure 4.- Continued.



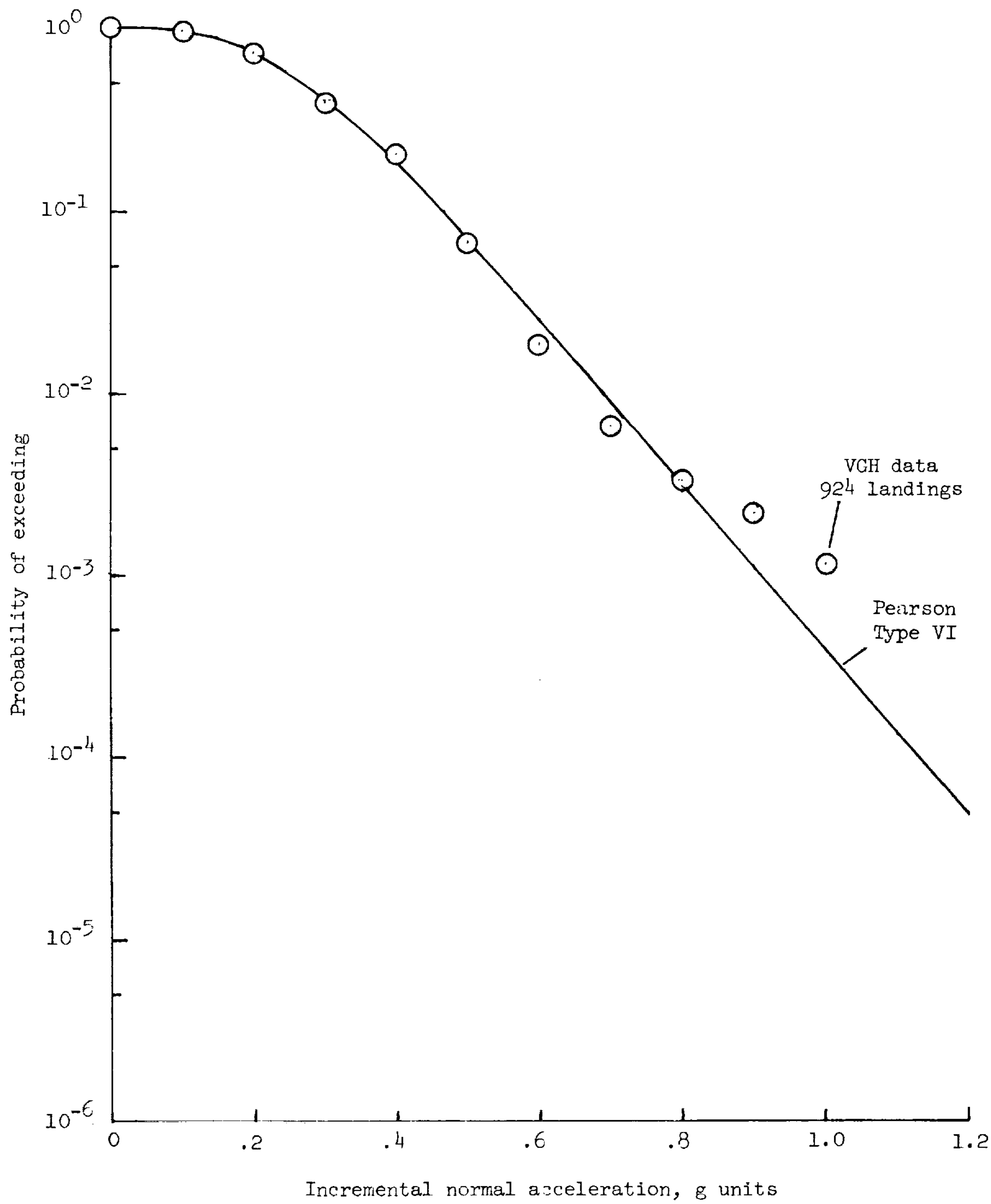

(d) Operation AICF.

Figure 4.- Continued.



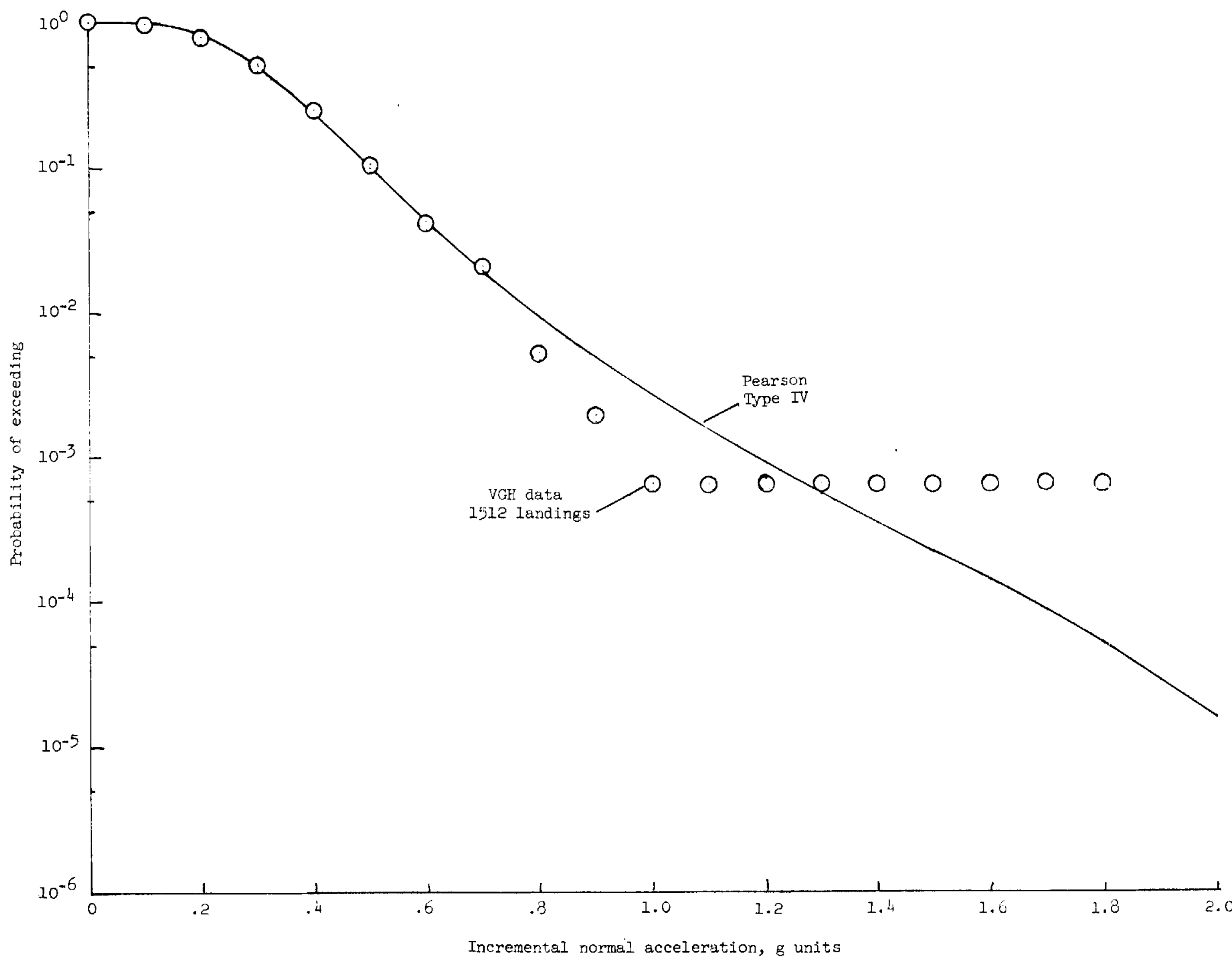

(e) Operation KID.

Figure 4.- Continued.



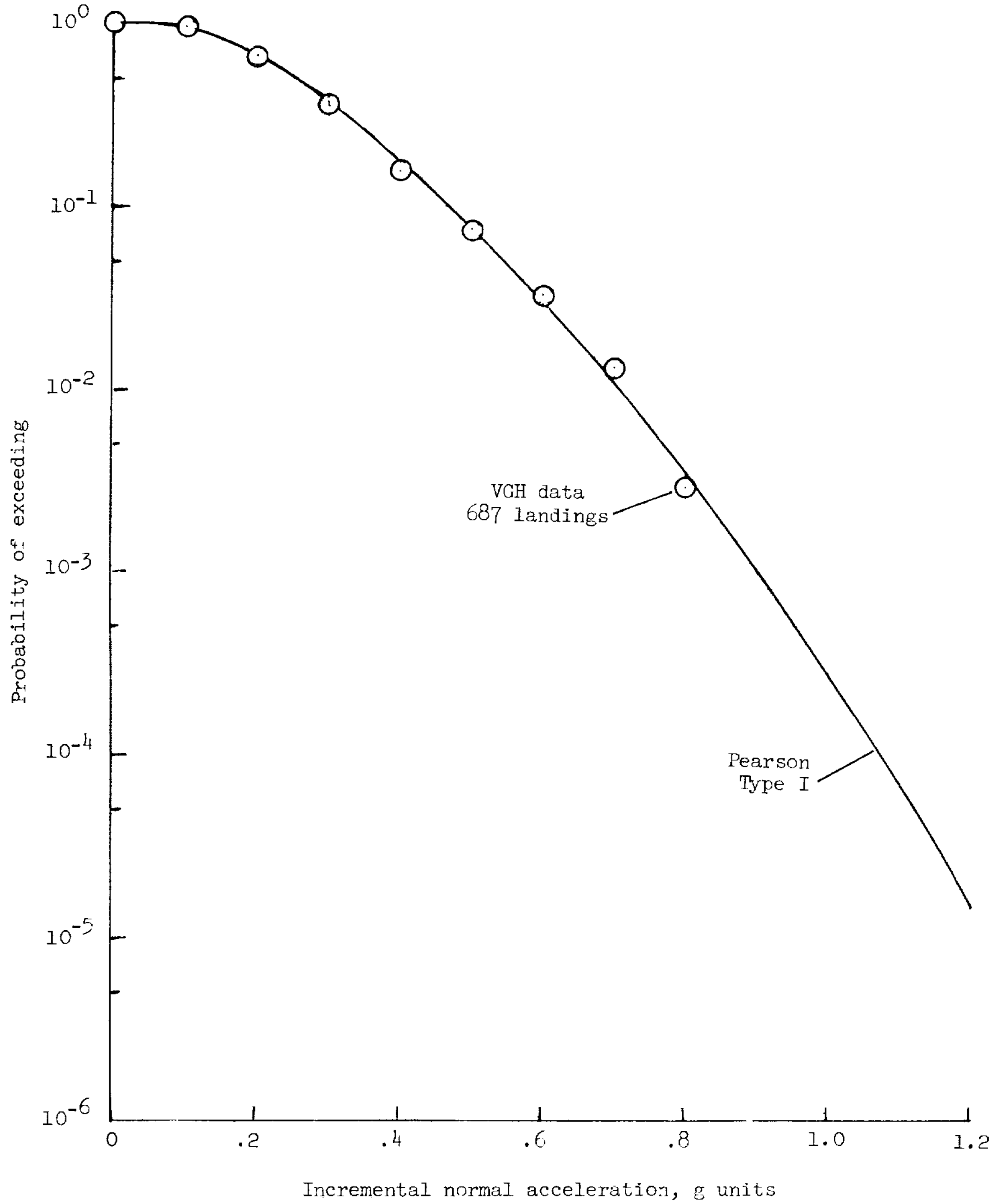

(f) Operation GIIA/B.

Figure 4.- Continued.



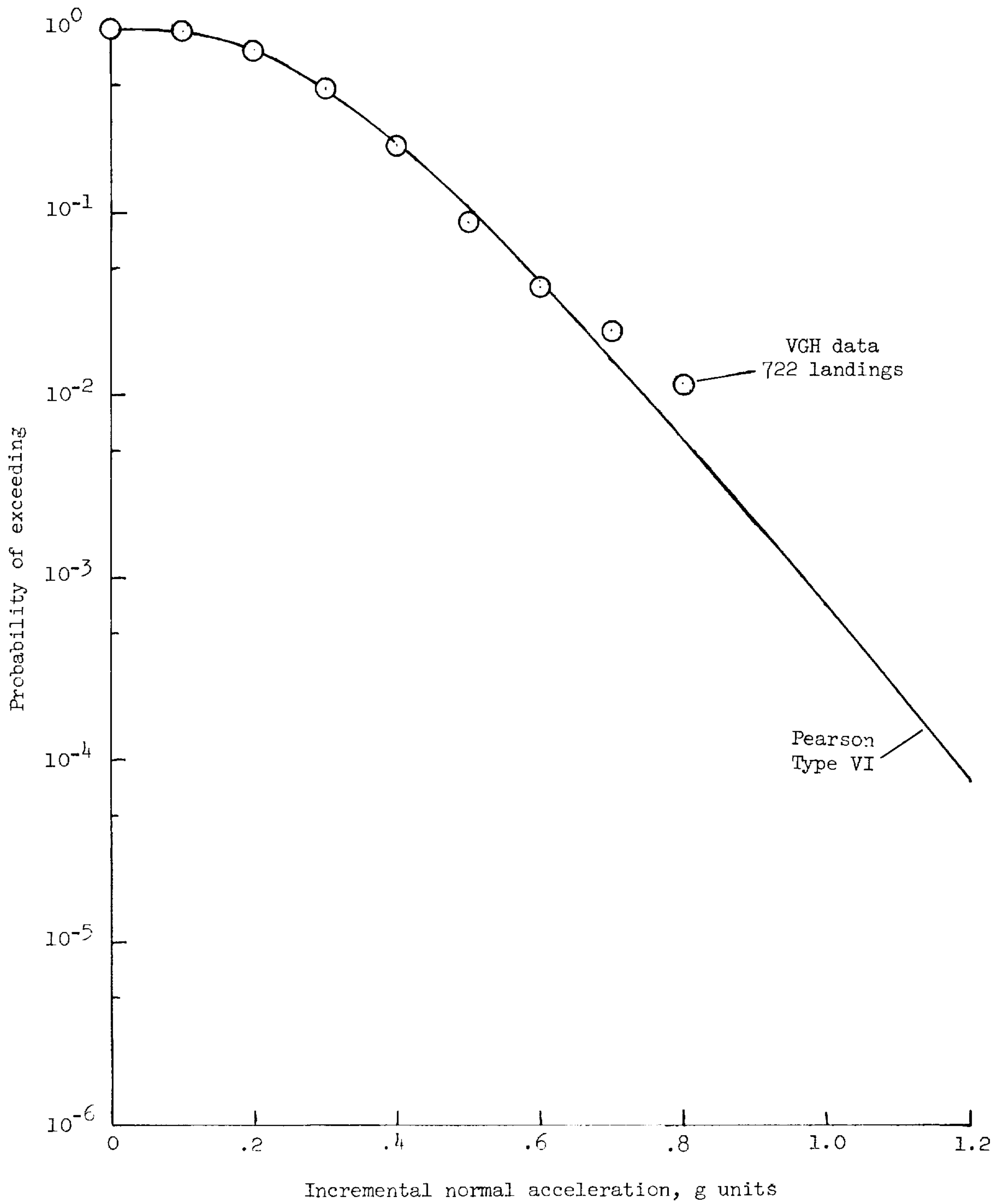

(g) Operation CIIB.

Figure 4.- Continued.



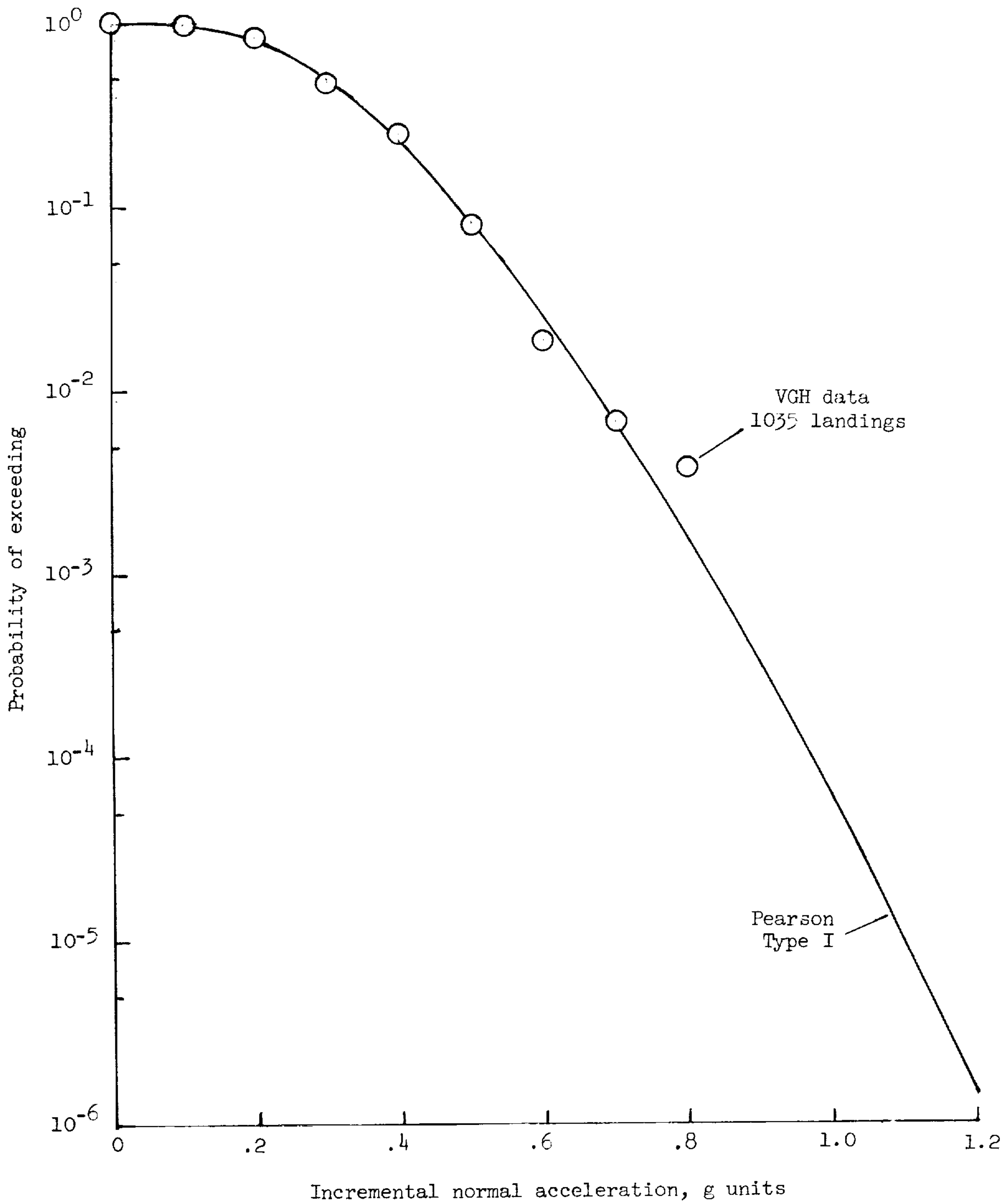

(h) Operation EIIC.

Figure 4.- Continued.



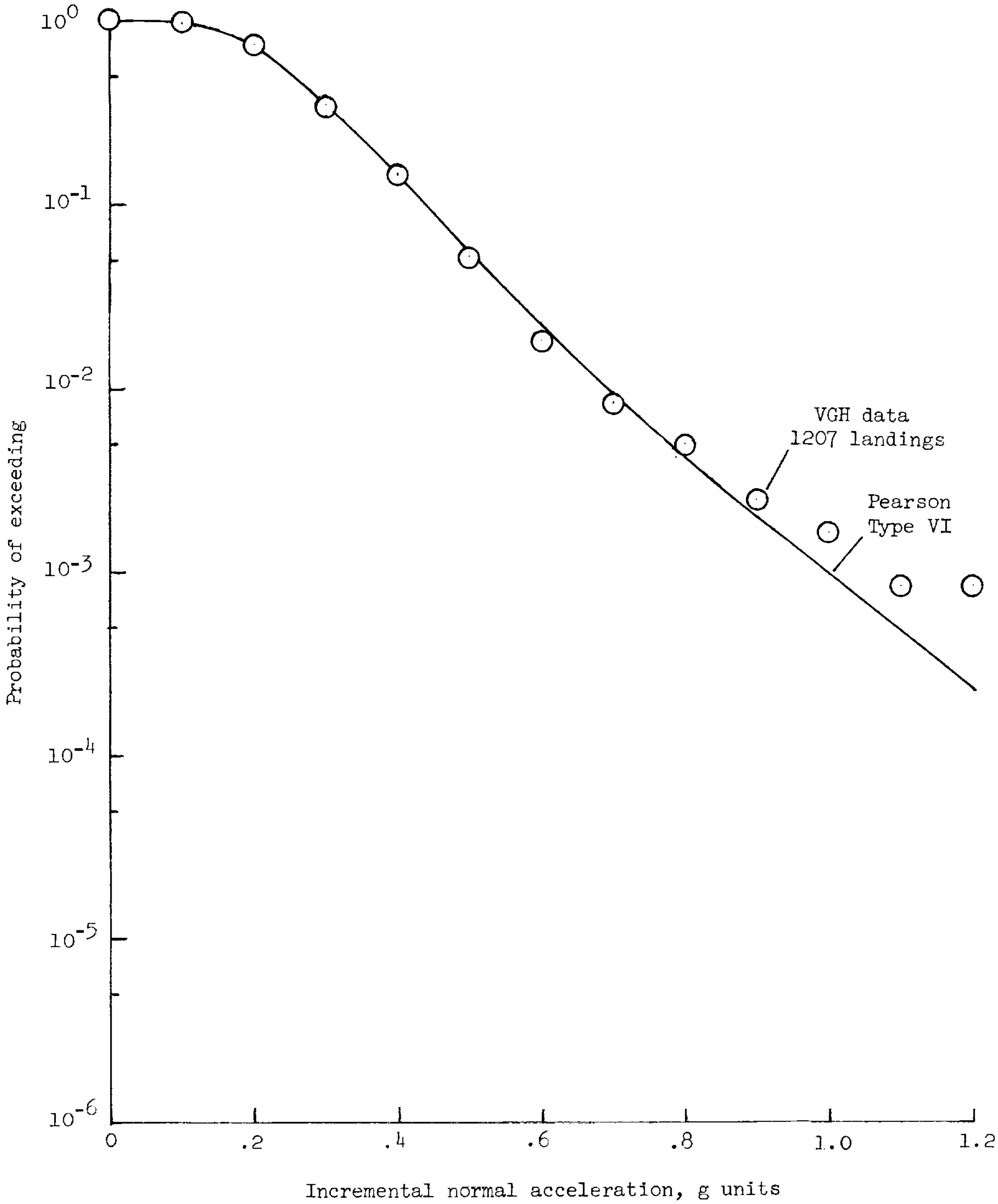

(i) Operation HIIC.

Figure 4.- Continued.



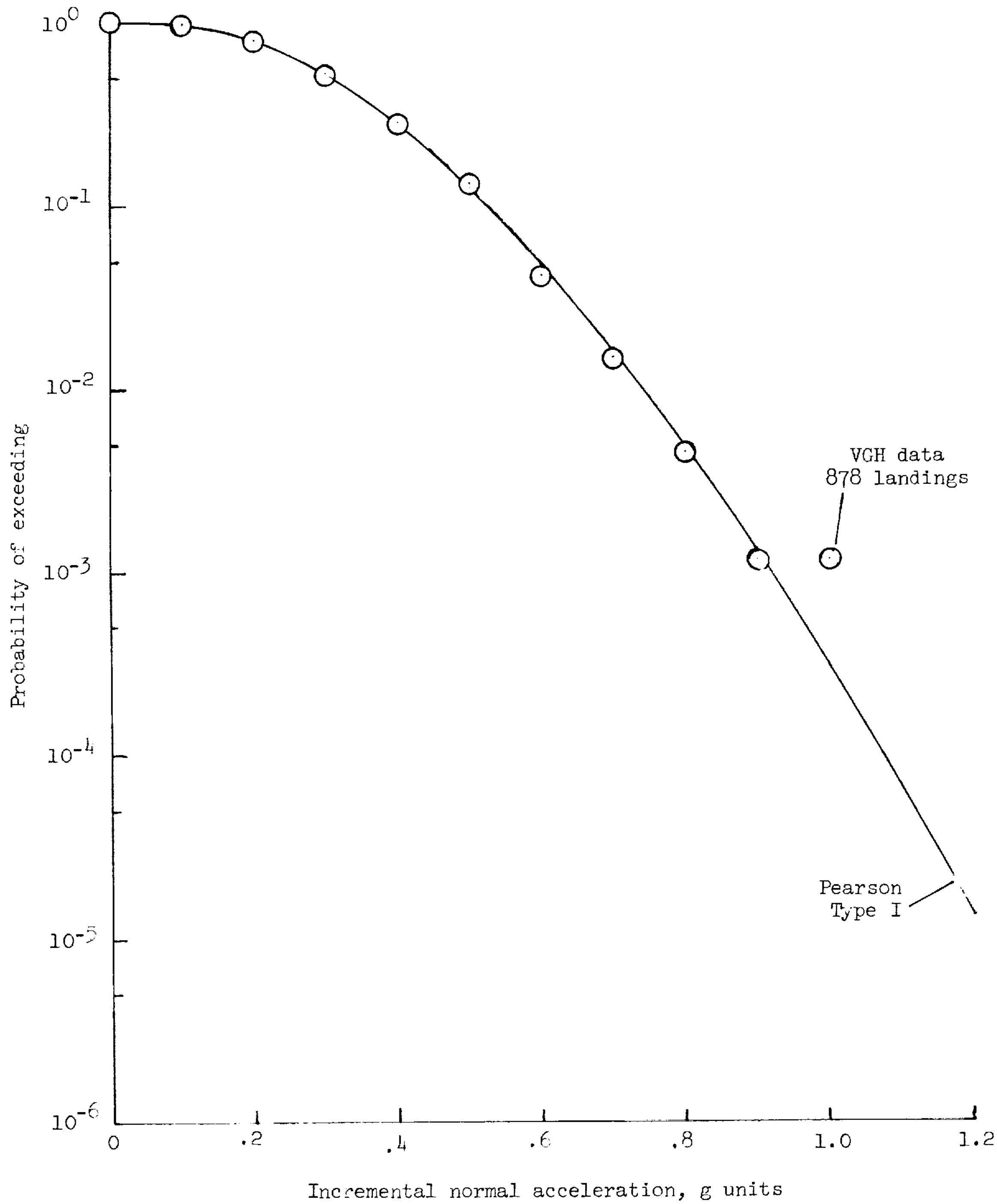

(j) Operation LIIC.

Figure 4.- Continued.



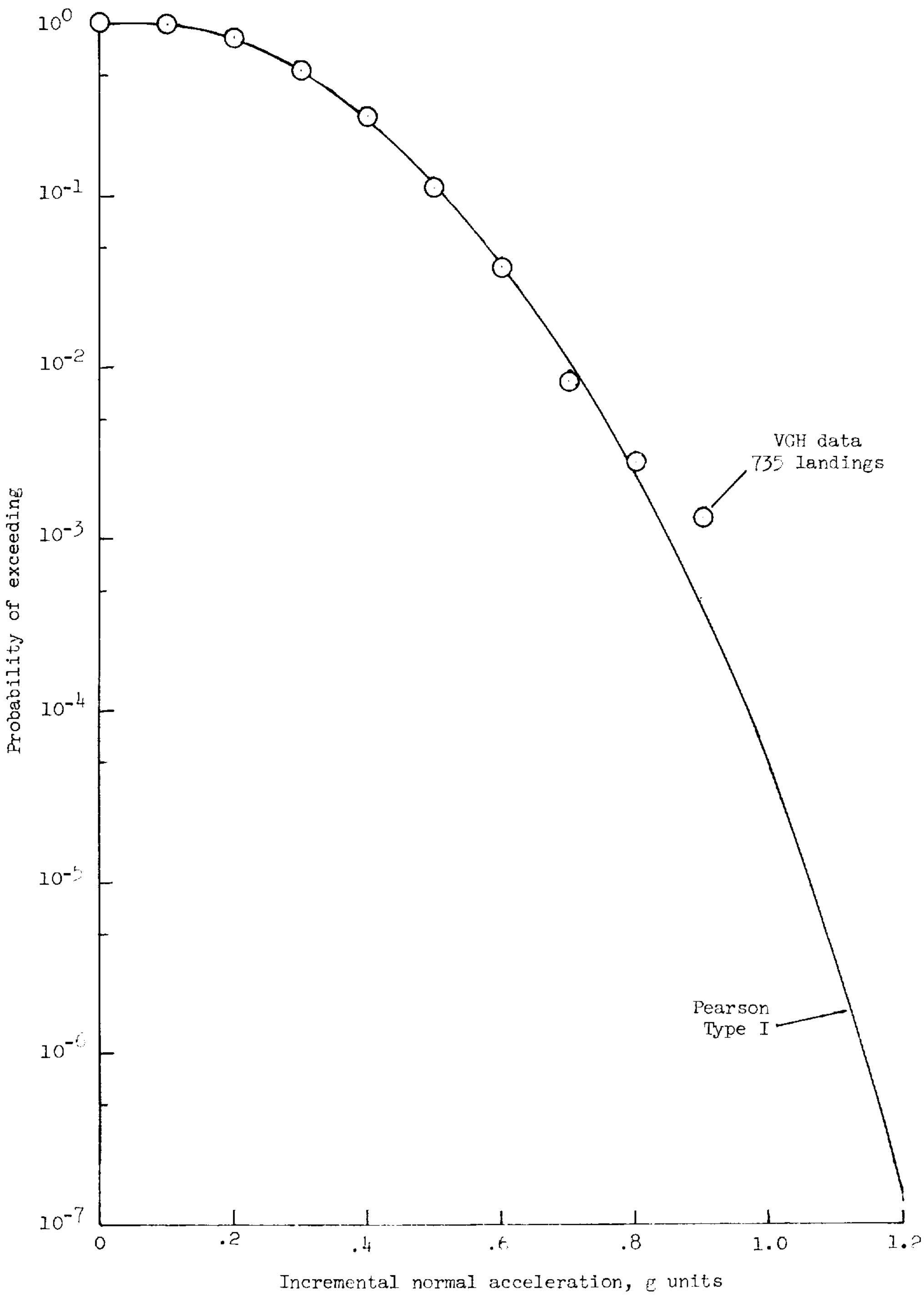

(k) Operation IIIIA.

Figure 4.- Continued.



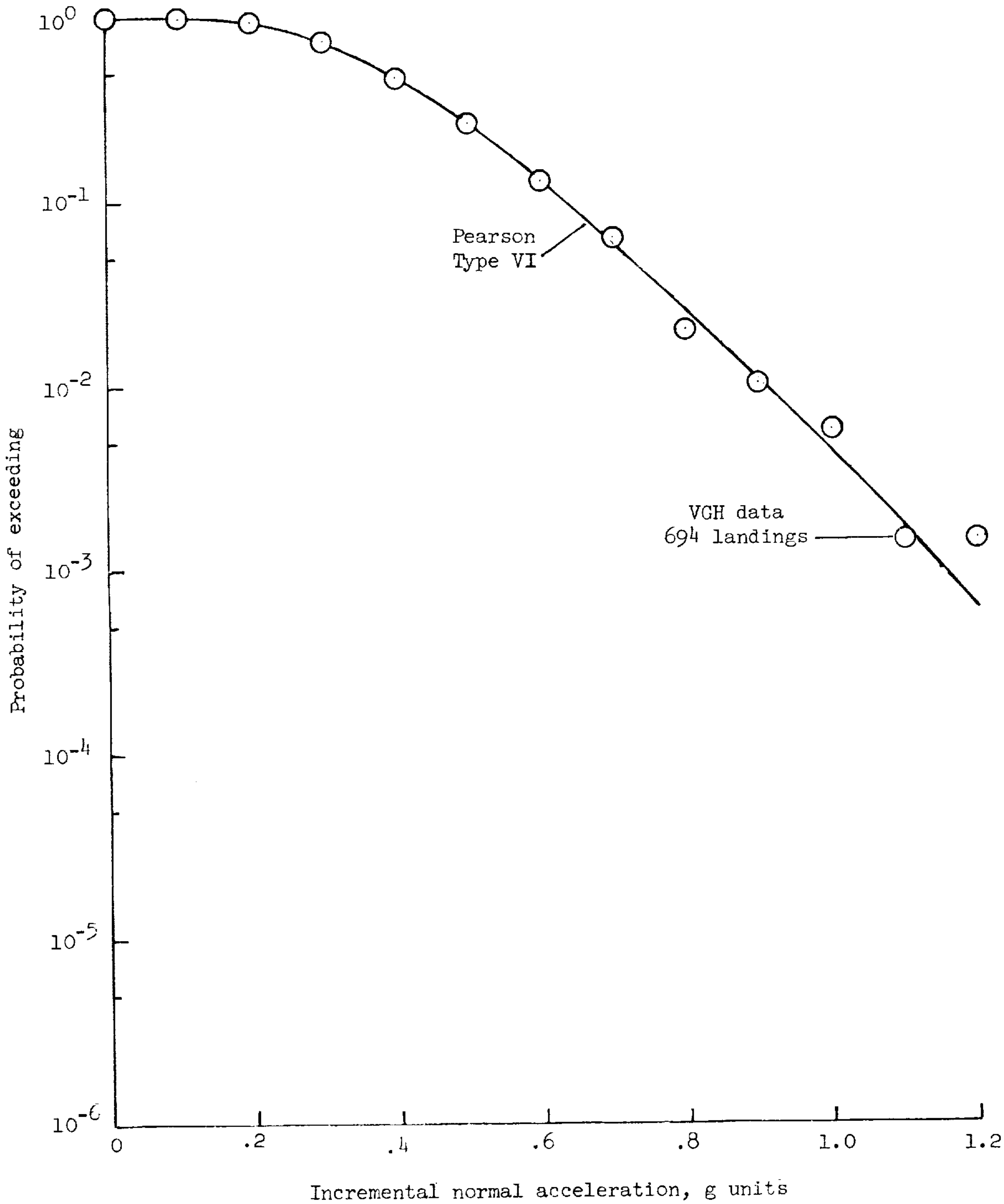

(l) Operation AIVA.

Figure 4.- Continued.



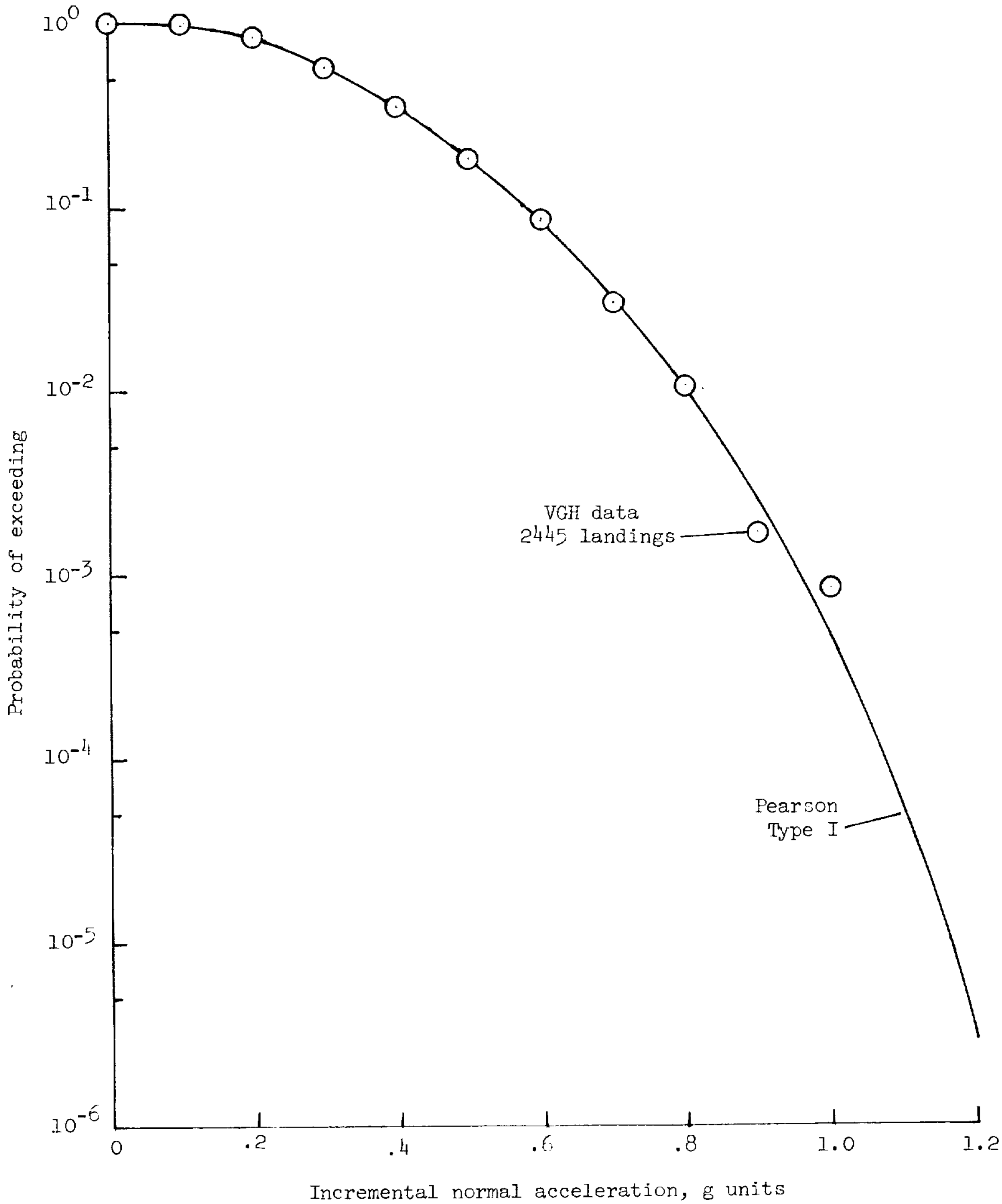

(m) Operation BIVA.

Figure 4.- Continued.



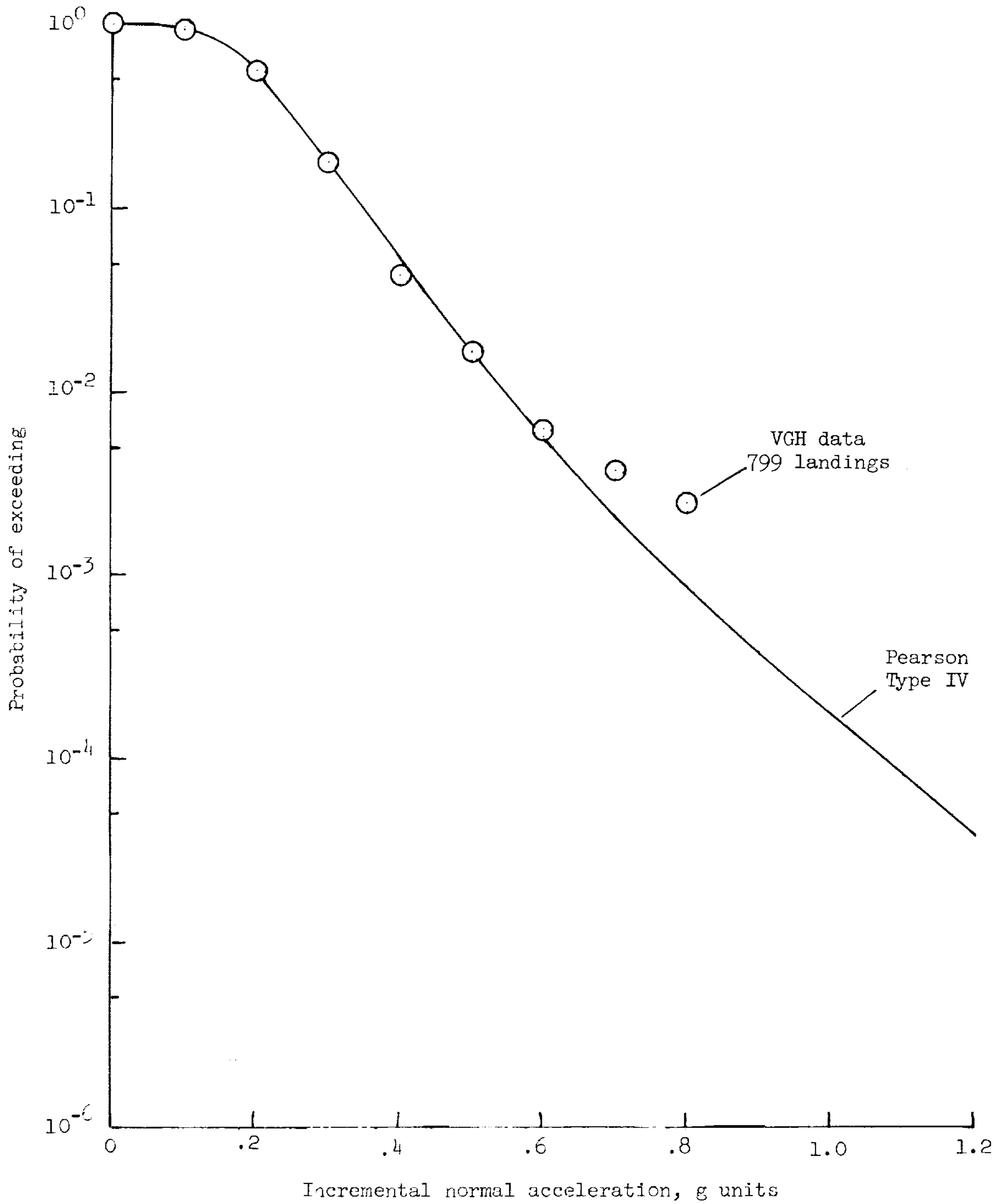

(n) Operation CIVA.

Figure 4.- Continued.



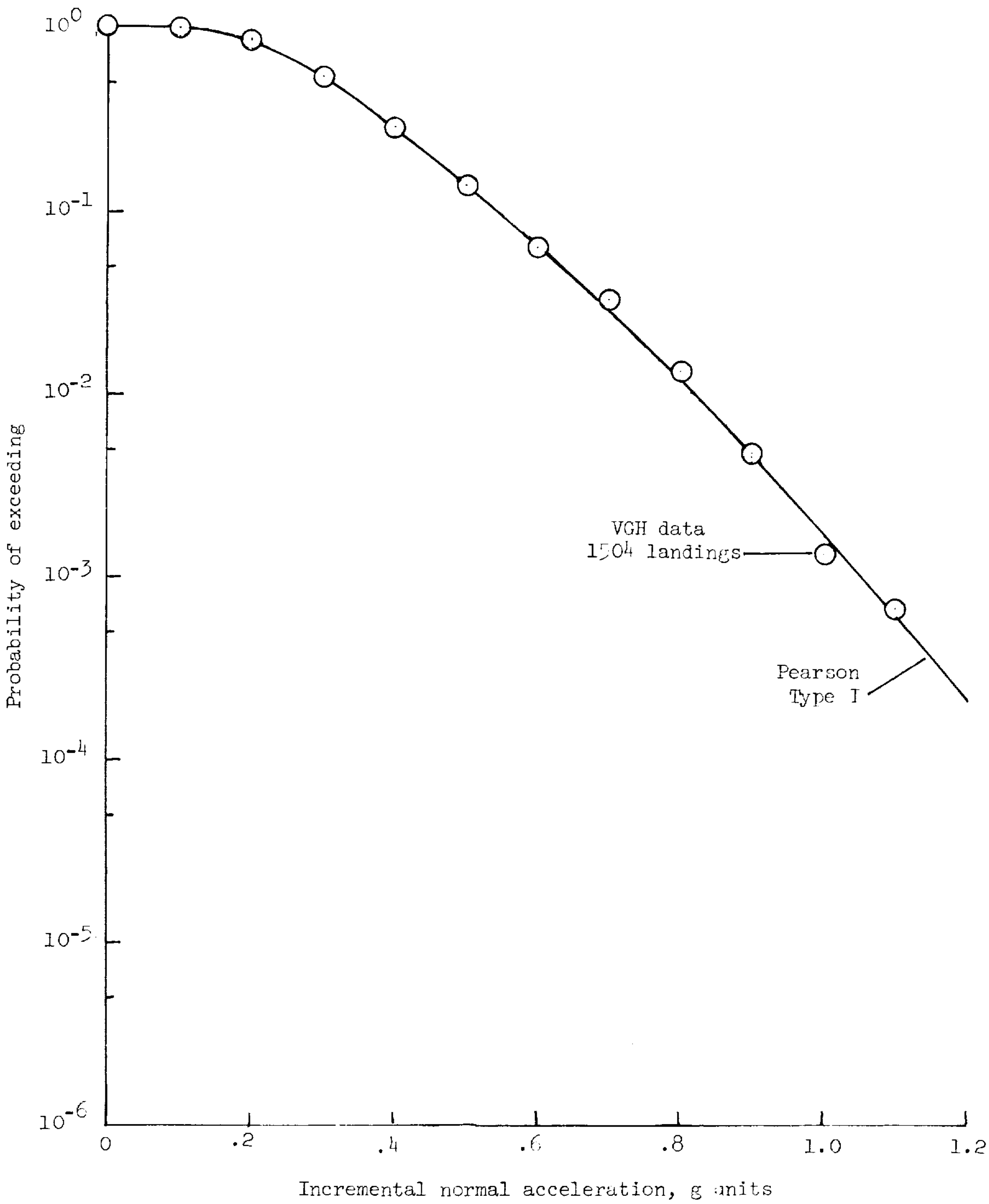

(o) Operation JVA.

Figure 4.- Continued.



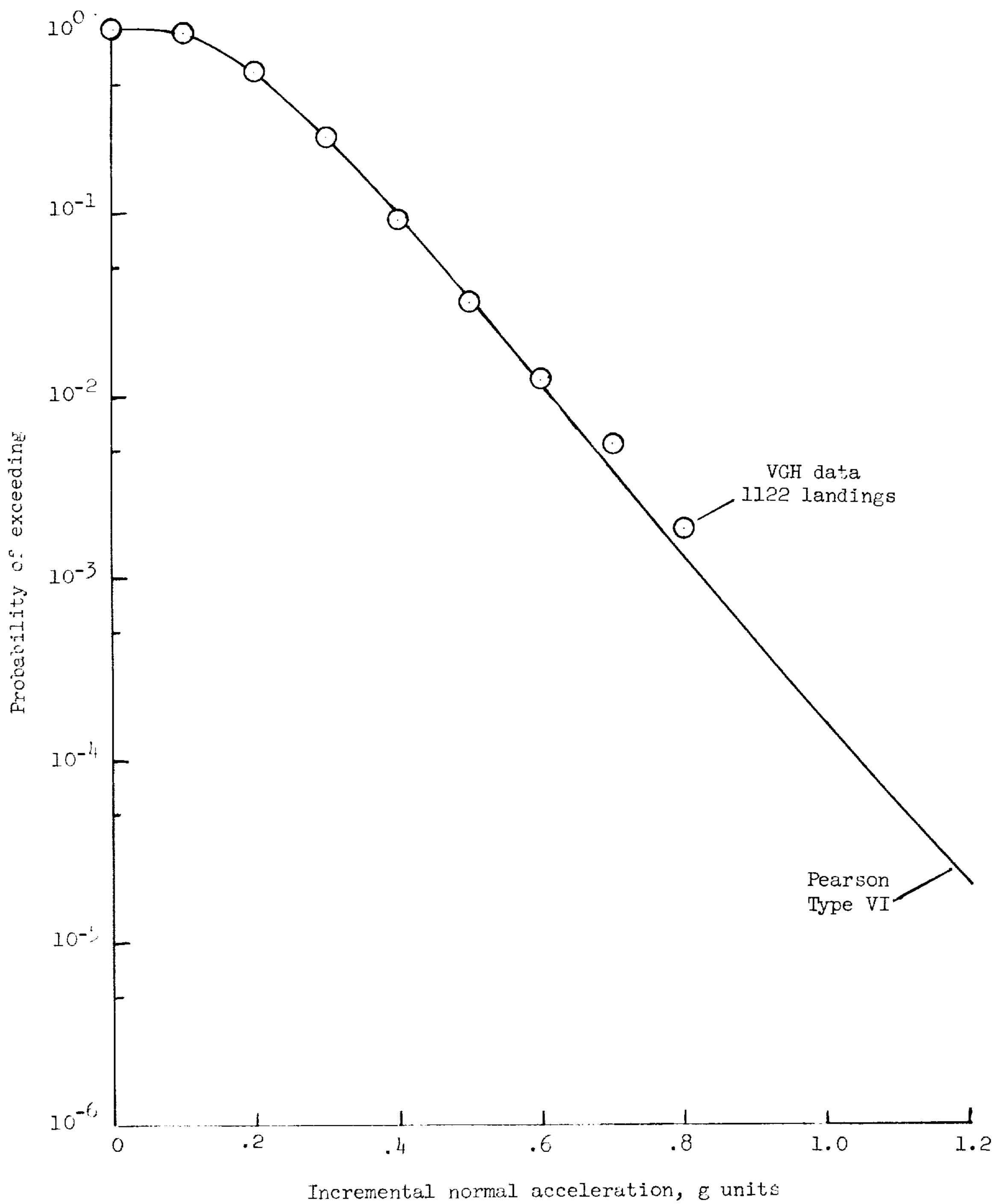

(p) Operation DVIA.

Figure 4.- Continued.



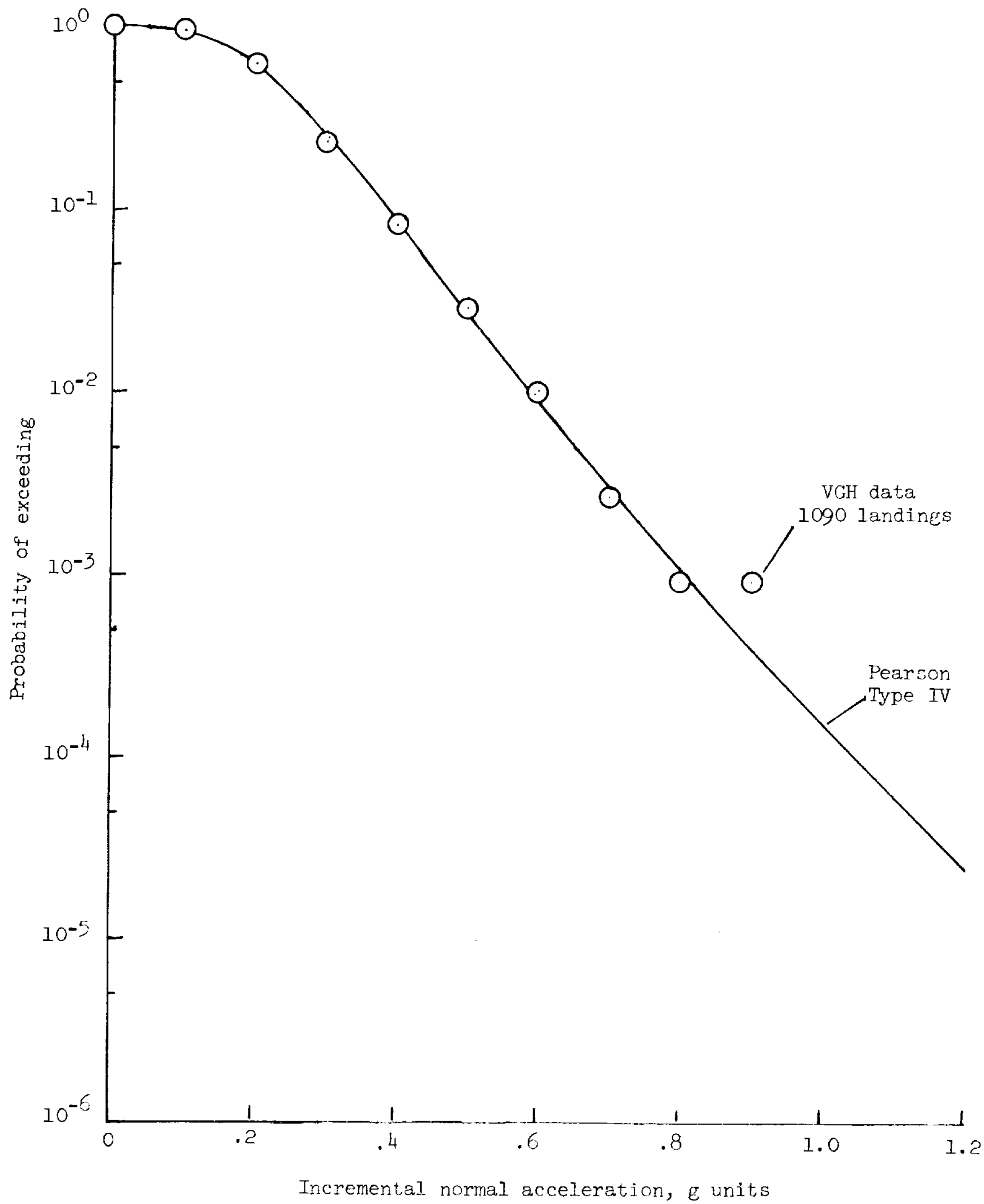

(q) Operation AVIIA.

Figure 4.- Continued.



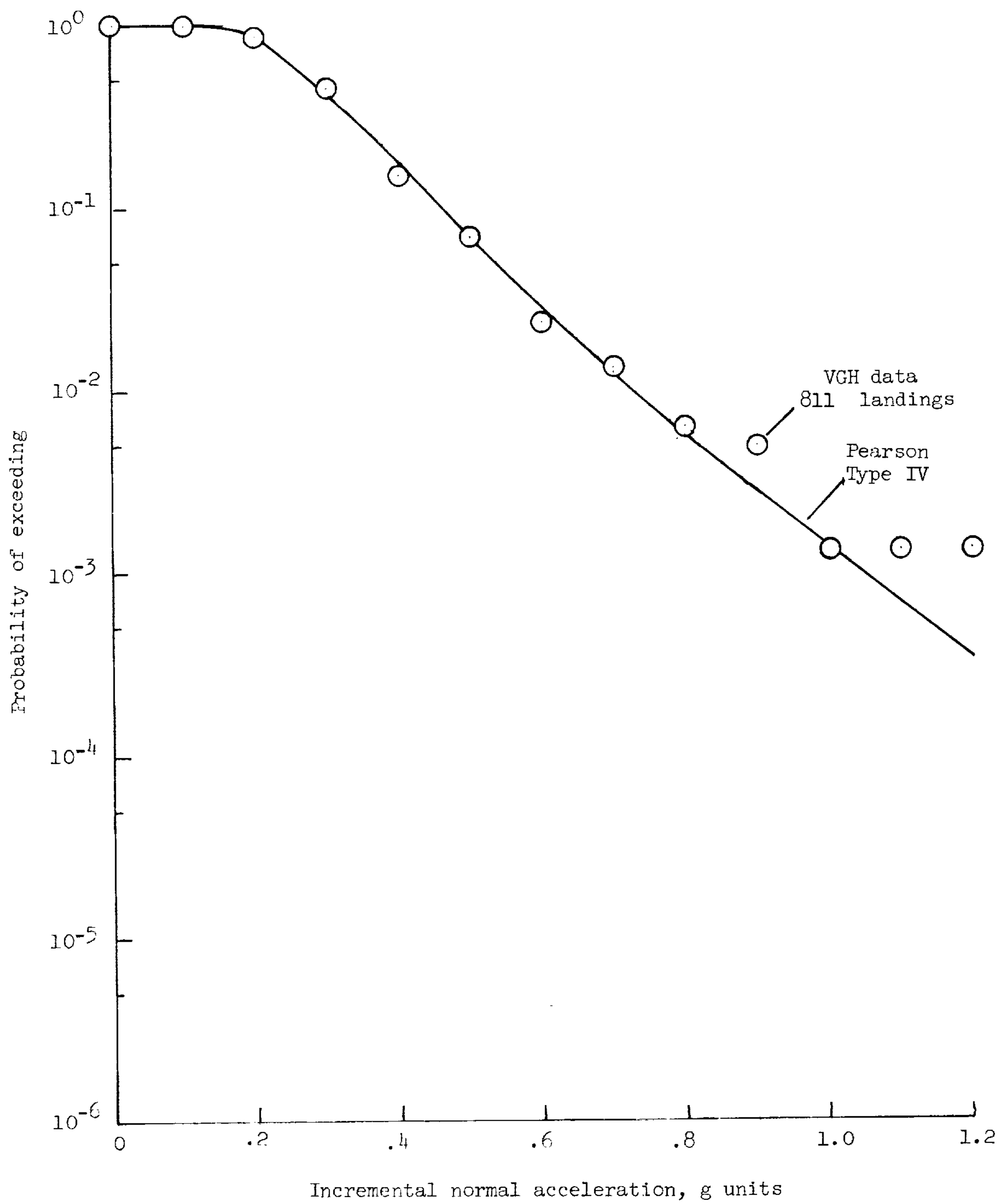

(r) Operation GVIIIB.

Figure 4.- Continued.



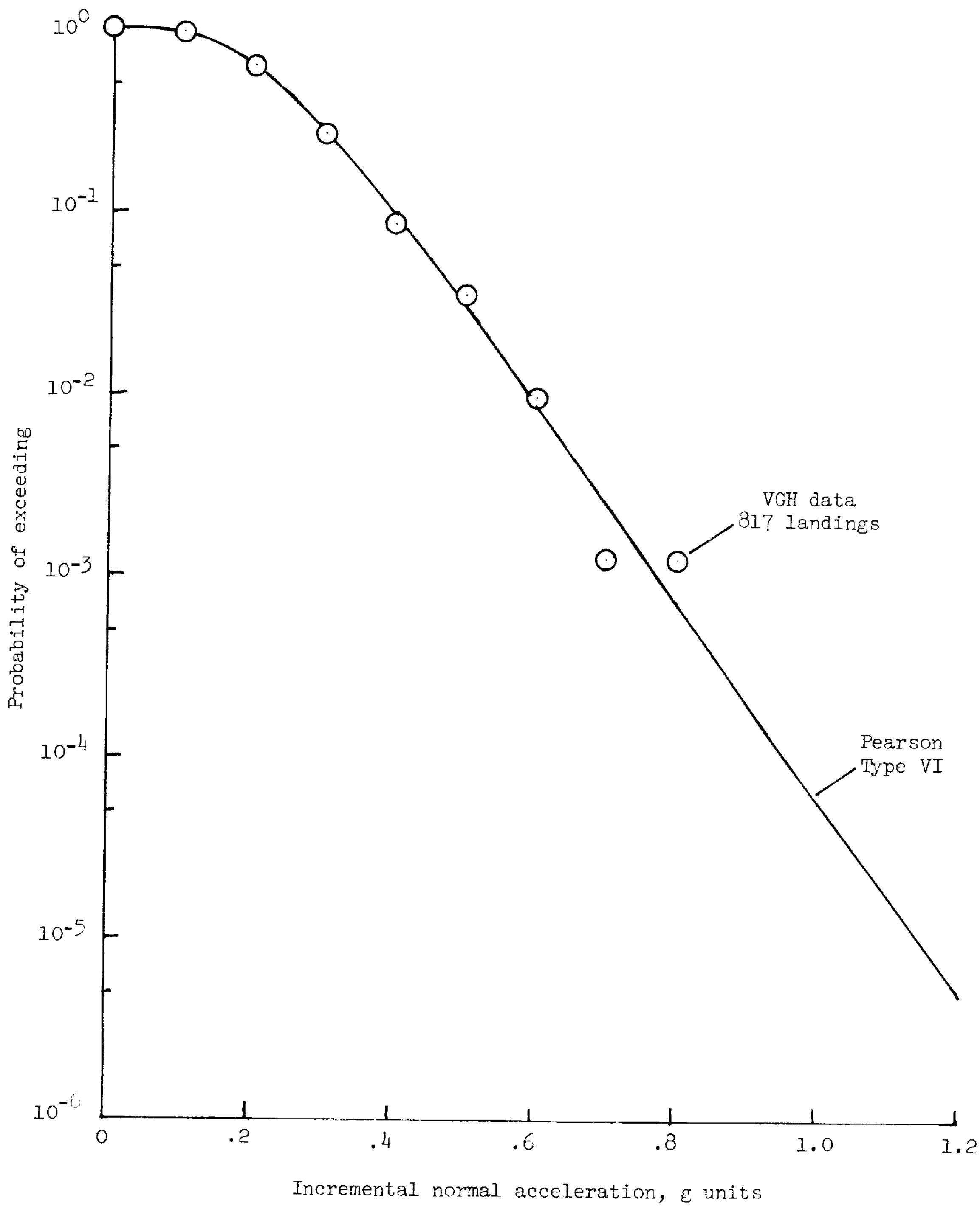

(s) Operation AIXA.

Figure 4.- Continued.



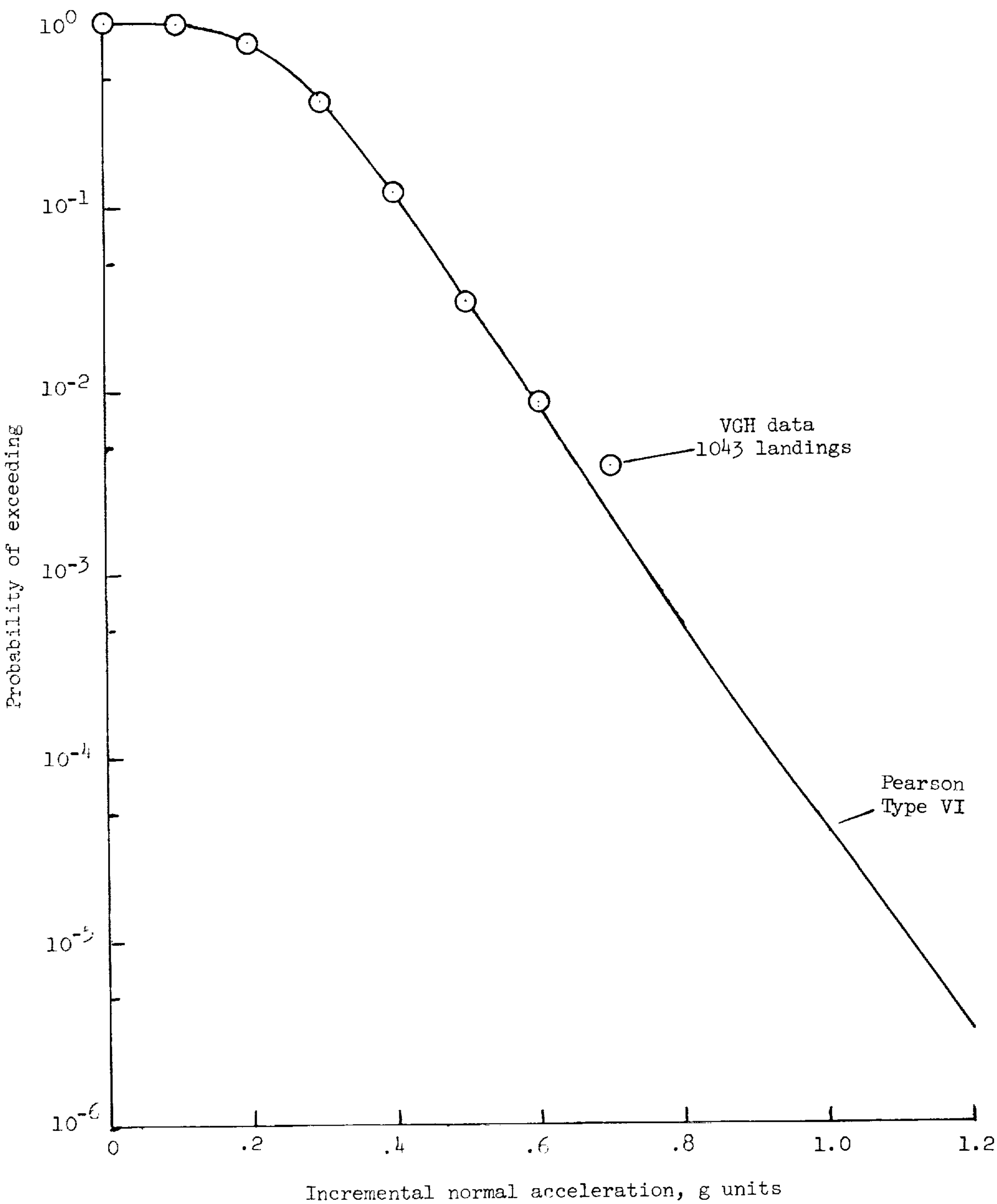

(t) Operation UIXA.

Figure 4.- Continued.



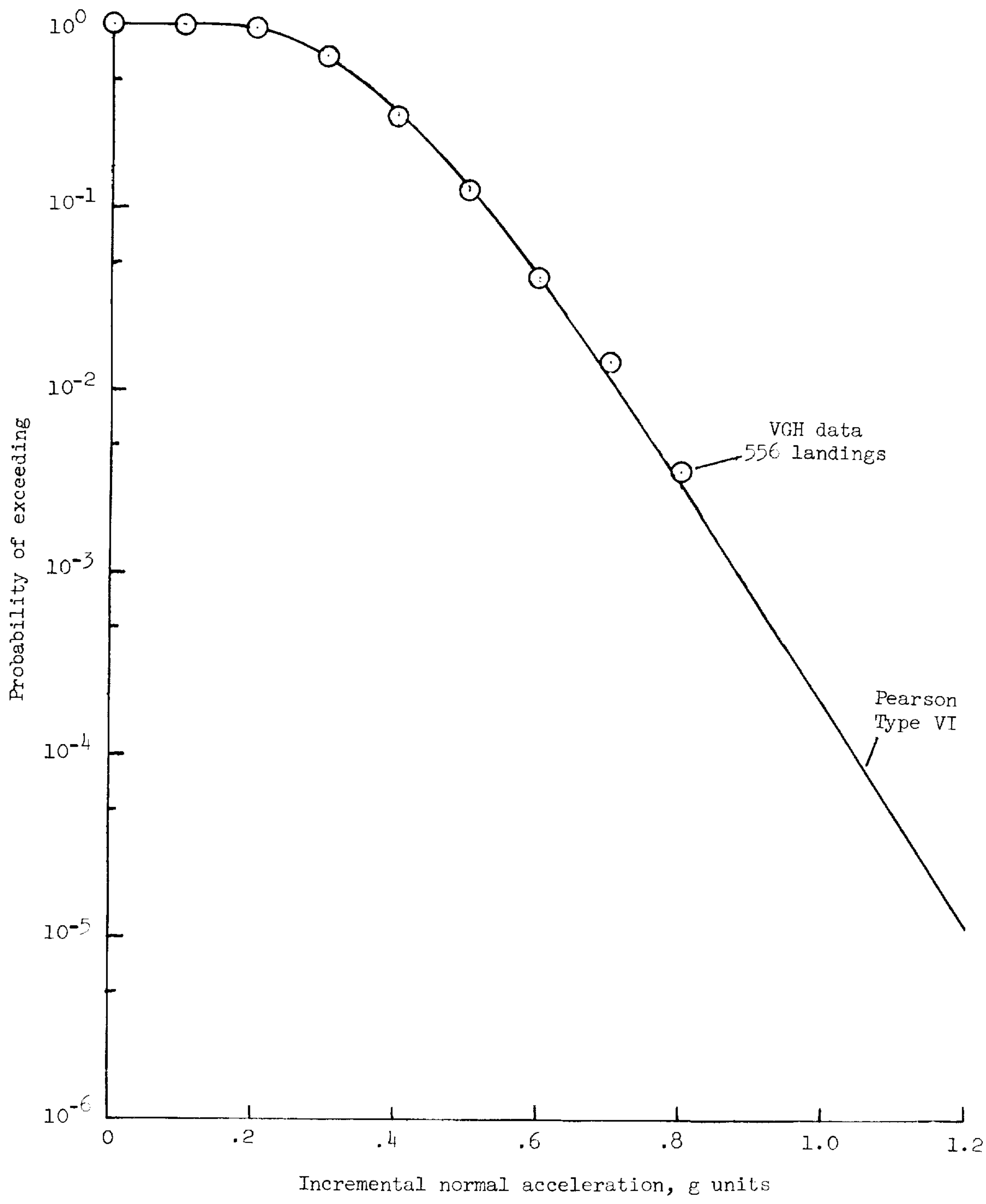

(u) Operation WIXA.

Figure 4.- Continued.



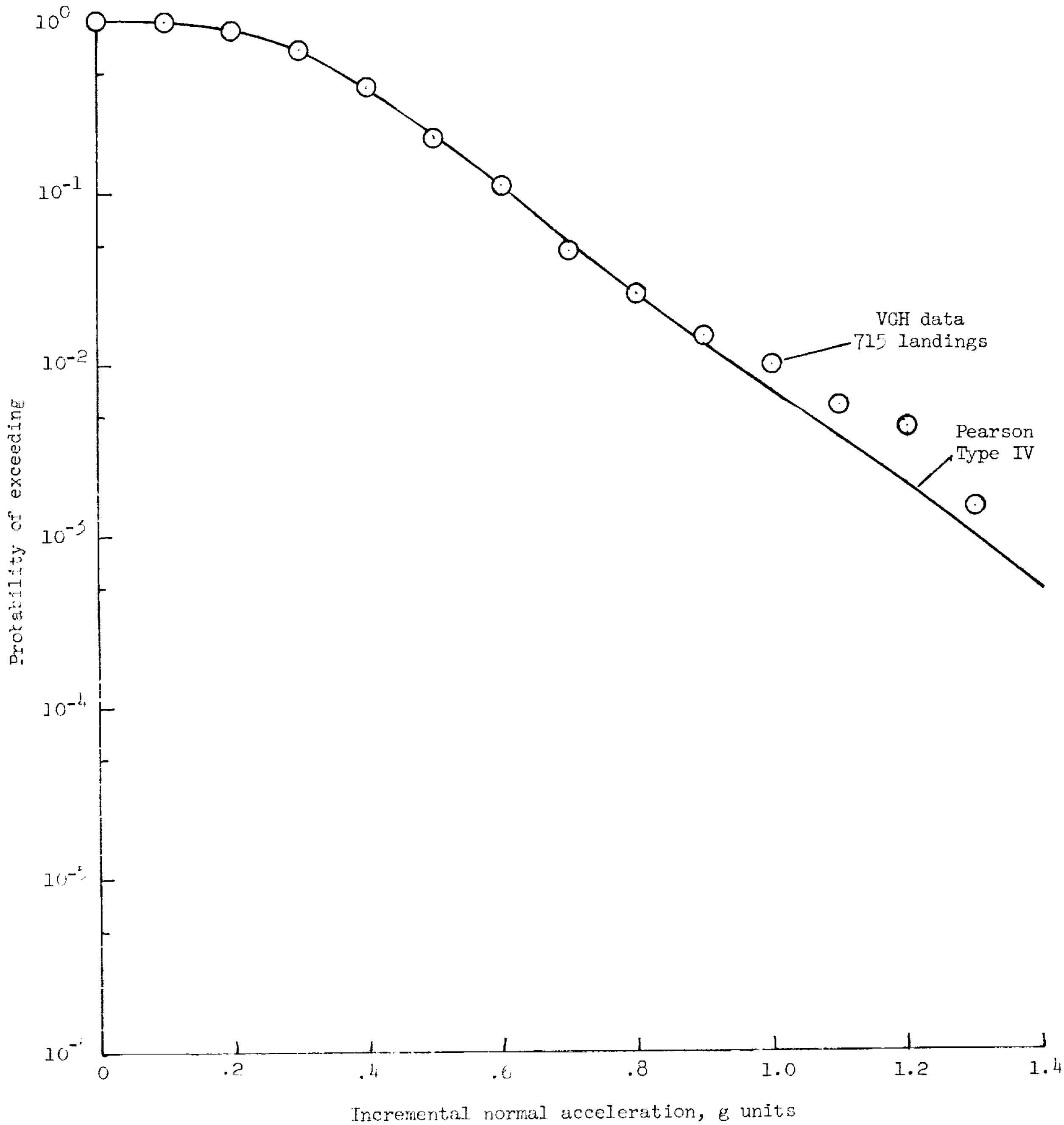

(v) Operation SXIIIA.

Figure 4.- Continued.



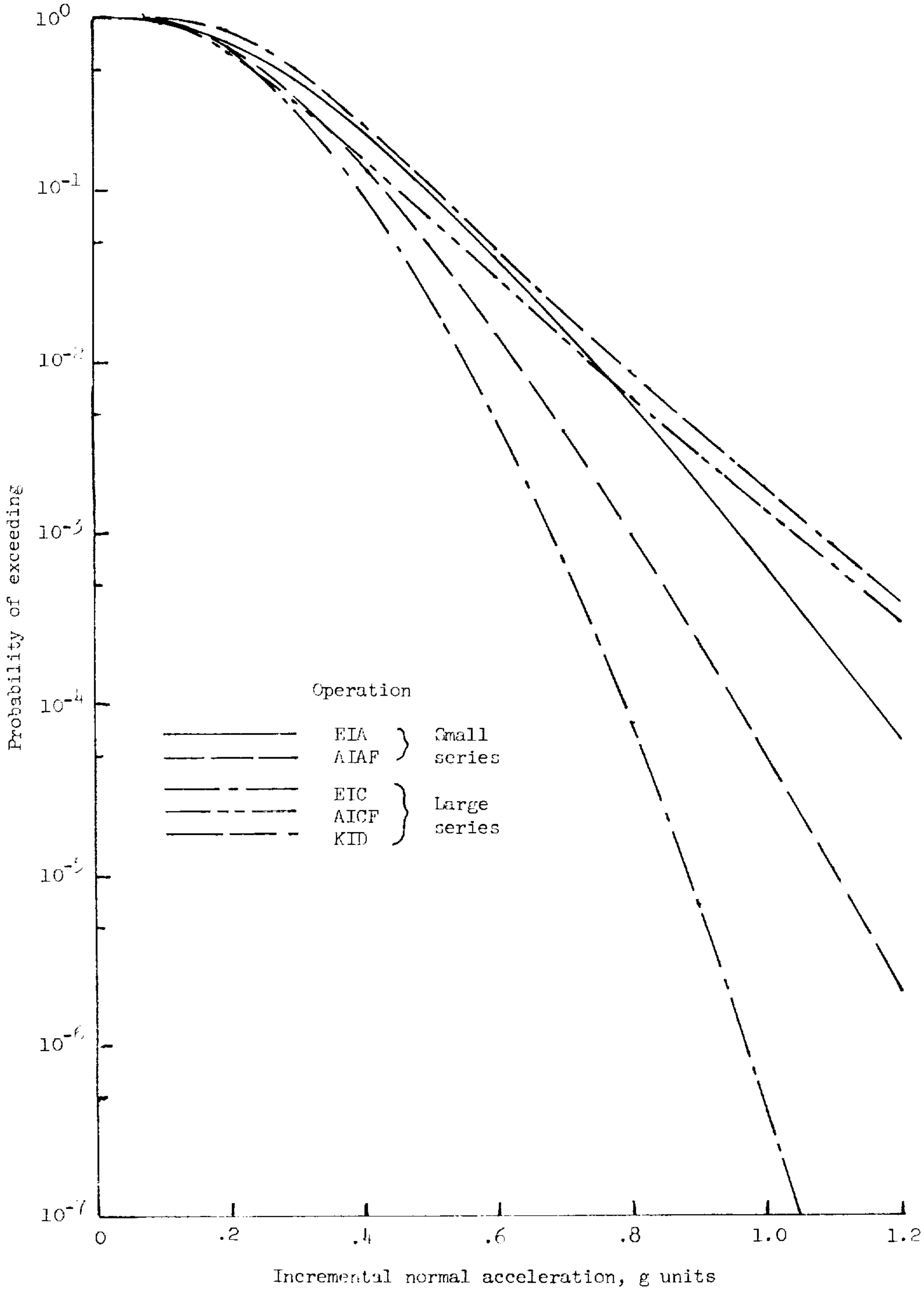

(w) Operation IXIVA.

Figure 4.- Continued.



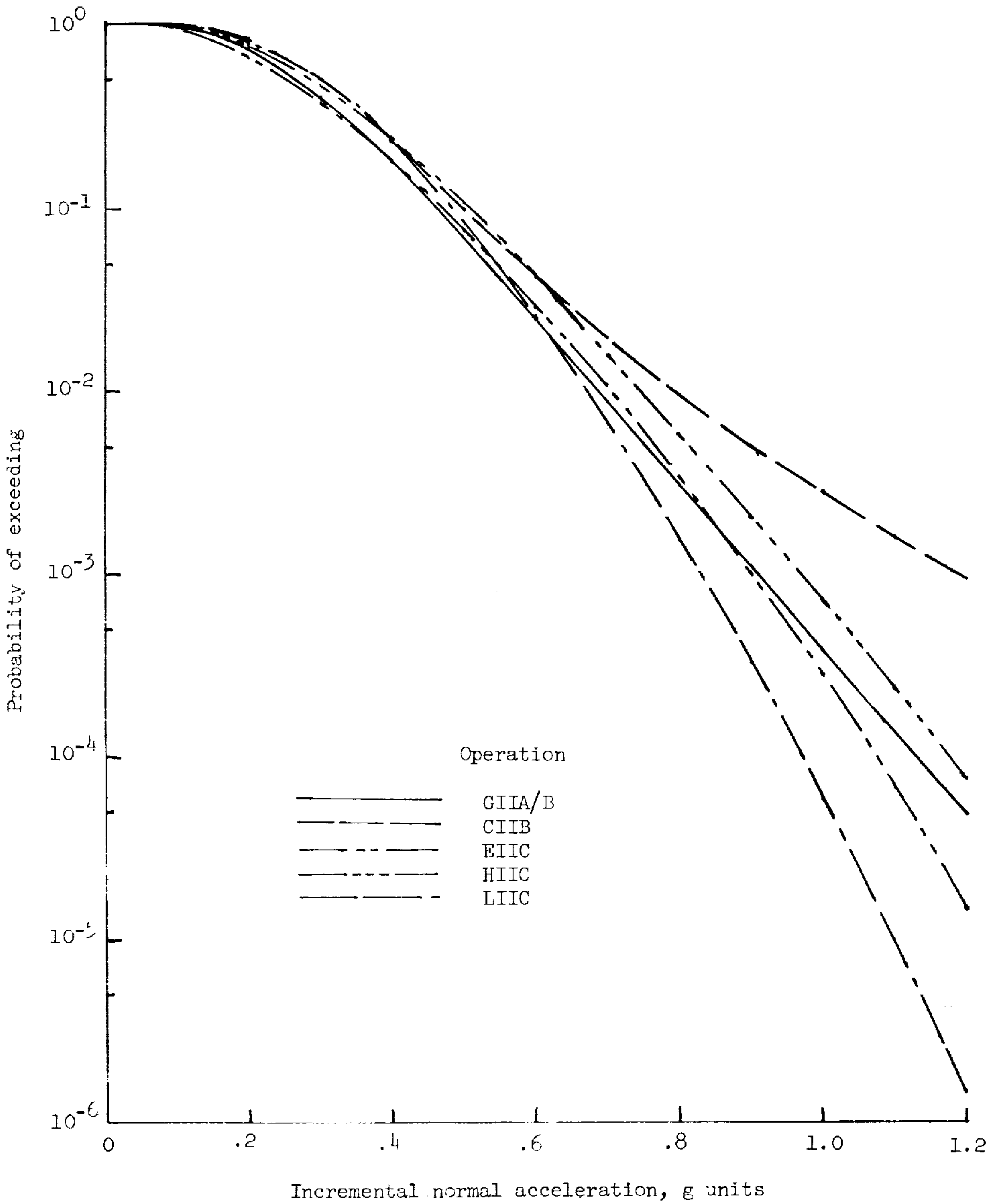

(x) Operation JXVIB.

Figure 4.- Concluded.



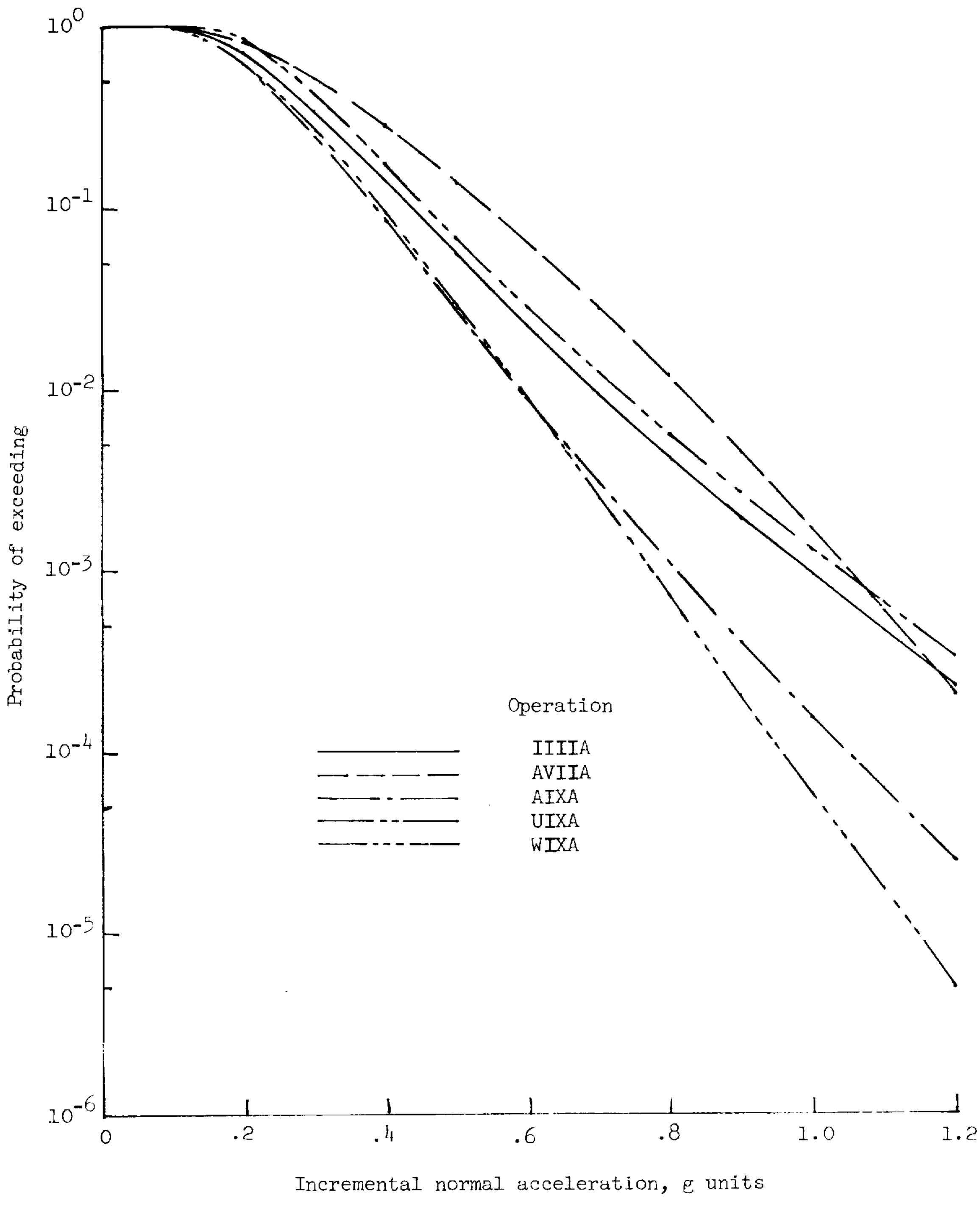

(a) Large four-engine jet transport (type I).

Figure 5.- Probability of exceeding given values of landing impact incremental normal acceleration by airplane types.



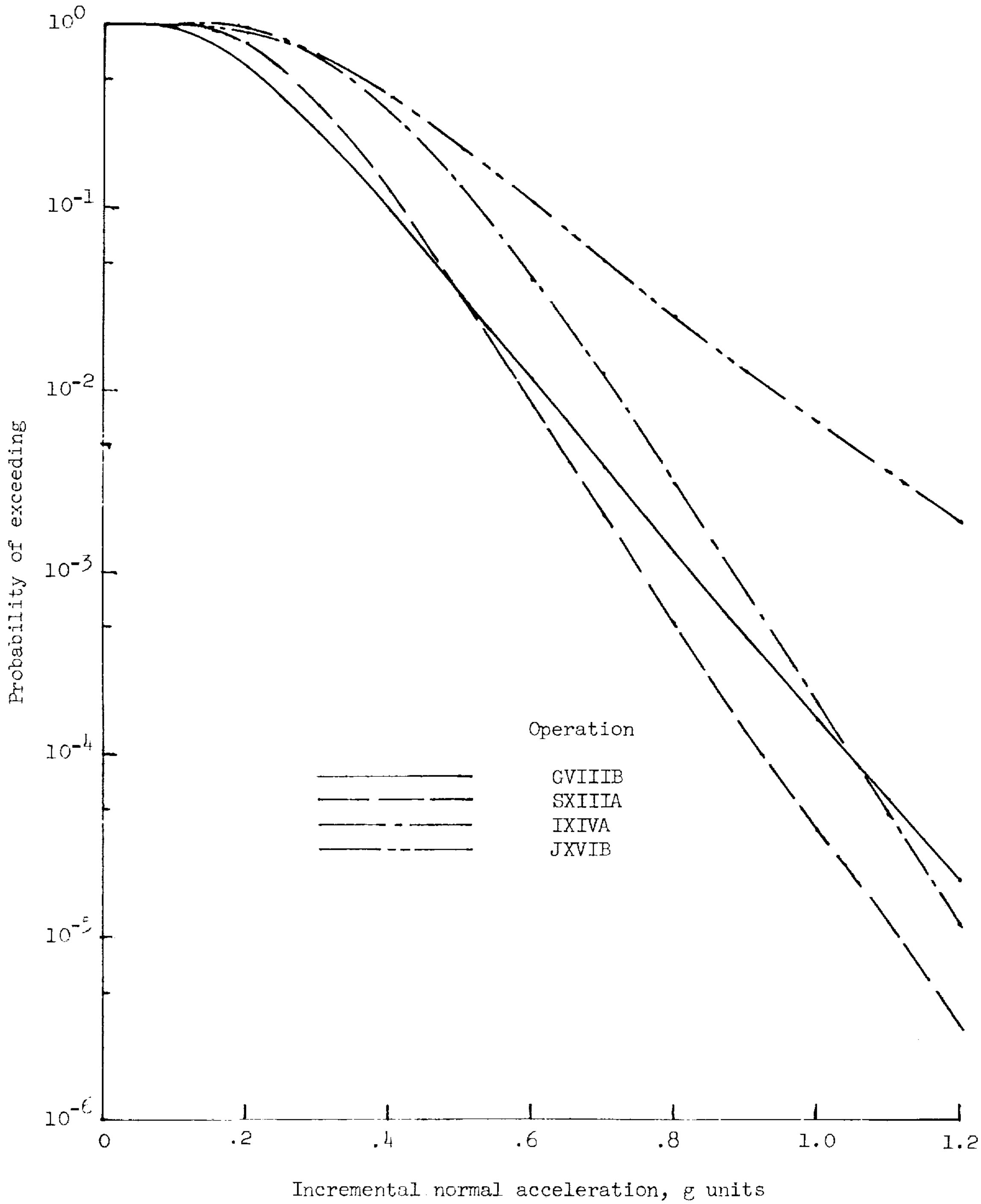

(b) Large four-engine jet transport (type II).

Figure 5.- Continued.



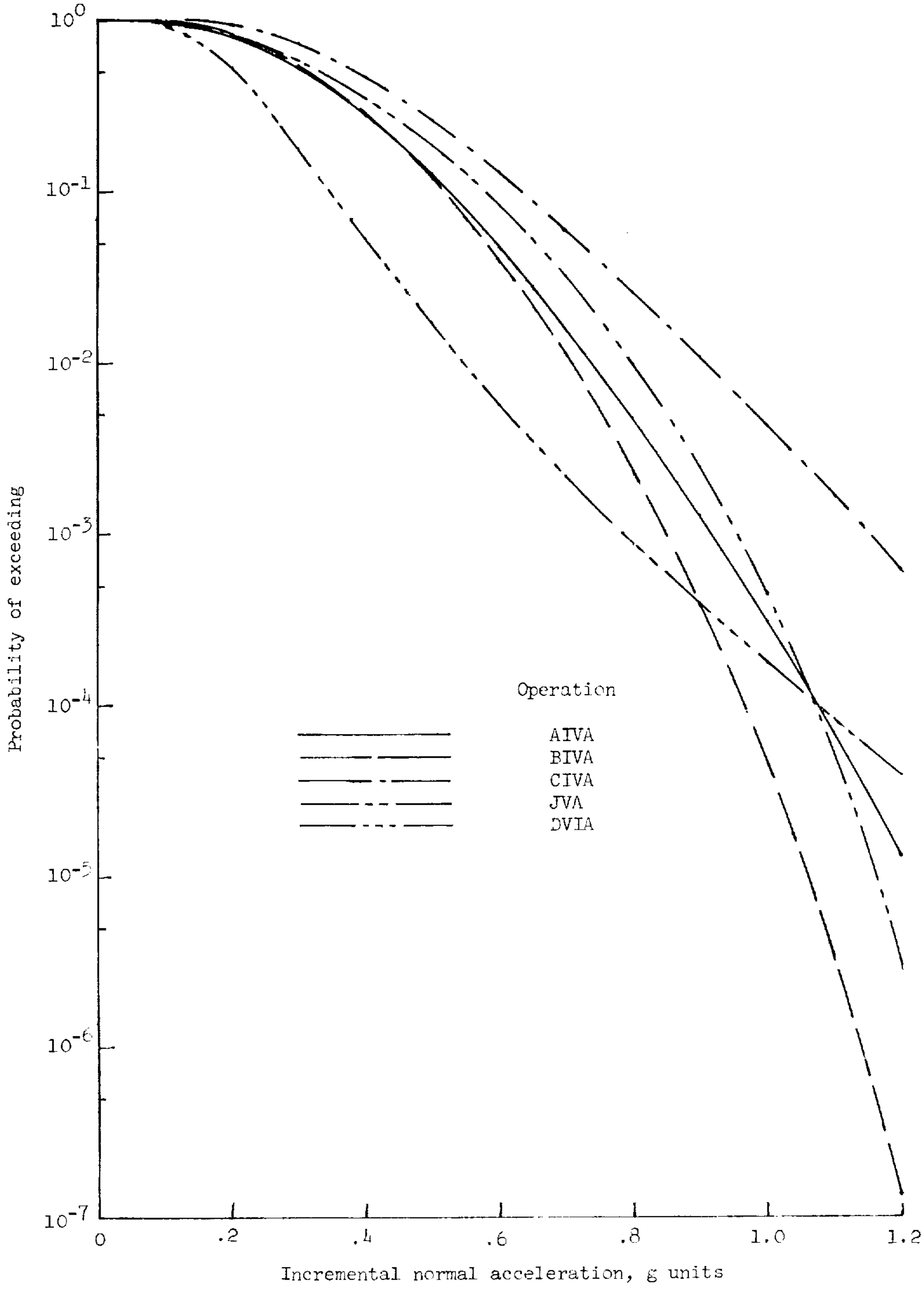

(c) Three-engine and other four-engine jet transports.

Figure 5.- Continued.




(d) Two-engine jet transports.

Figure 5.- Continued.




(e) Turboprop transports.

Figure 5.- Concluded.