NAVWEPS REPORT 7347

CHARACTERIZATION OF SQUIB MK 1 MOD 0

Determination of the Statistical Model (U)

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U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

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CHARACTERIZATION OF SQUIB MK 1 MOD 0
Determination of the Statistical Model

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ABSTRACT: Nearly 8,000 Squibs Mk 1 Mod 0 were fired with a 4.00-microfarad capacitor in order to provide data to serve as a basis of deciding on a proper statistical distribution function to express the response of the squib to adiabatically delivered electrical energy pulses. The Log-Logistic Model (expressed in cumulative form by $\ln \{p/(1-p)\} = M \log_{10}D + B$) was found to be not completely satisfactory but considerably better than the Log-Gaussian Model. With the use of suitable tolerance intervals, the Log-Logistic Model can be made to include the observed data. A direction is indicated which future work might take in developing a more accurate statistical model.

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Explosions Research Department
U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

The work reported herein has been carried out as a part of the Naval Ordnance Laboratory's participation in the HERO (Hazards of Electromagnetic Radiation to Ordnance) program, Task NOL-443. The objective of the HERO effort at NOL is generally to characterize the response of electro-explosive devices to electrical energy. The work described in this report is a statistical study of Squib Mk 1 Mod 0 firing data with the purpose of developing methods of estimating very high and very low functioning levels.

This work should be of interest not only to the HERO project but also to the broad field of electro-explosive device design, development, manufacture, test, and utilization.

W. D. COLEMAN
Captain, USN
Commander

C J Aronson
C. J. ARONSON
By direction

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INTRODUCTION

1. Both safety and reliability considerations involving EED (Electro-Explosive Device) functioning probabilities require assumption of some statistical model which describes the response of the EED to different levels of input stimulus (firing signal). Various data collection and data reduction procedures exist for estimating the population 50% firing level (or perhaps some other specific response level) and usually some method for estimating some parameter, such as the standard deviation, indicative of the population variability.

2. The most obvious choice of statistical model is the Gaussian (normal) relationship between response and the input stimulus, with the stimulus taken as linearly related to the input energy. However, experience at this and other laboratories indicates that the input stimulus is better described by using the logarithmic transform as a normalizing function, i.e., log energy, log $\{1/\text{gap}\}$, log drop height. For individual cases, particularly when the sample size is small and the variability low, the choice of stimulus transformation function and of distribution function may make little difference in the estimate of the 50% firing level. On the other hand, even with a relatively large sample size, errors in estimates of extreme functioning levels (above 99% and below 1.0%) can be of major magnitude.

3. The choice of the proper intensity-to-stimulus transform and of the proper probability distribution function would ideally be made on the basis of the electrical-physical-chemical mechanisms which are operative in the response of the EED to the stimulus. Even though present knowledge is too meager to provide a complete theoretical basis for choice of a statistical model, there are considerations which point to the logarithmic intensity transform:

(a) The low probability asymptote of the probability function should approach a non-negative level of stimulus since a negative level of stimulus is physically meaningless. By virtue of the logarithmic transform the lower branch of the cumulative distribution function can be made to approach the zero stimulus level asymptotically. (If there is basis for deciding that some finite positive stimulus level should be the lower bound, then a log-log or log {x-a} transform might be indicated.)

(b) One of the requirements of a normally distributed system is that the magnitude of the standard deviation should be independent of the magnitude of the 50% firing level. Experience has shown, when the stimulus has been assumed proportional to the intensity, that the standard deviation has been more-or-less proportional to the 50% firing level. The logarithmic transform brings about the necessary independence of the two parameters.

4. In the absence of sufficient theoretical basis for establishing the statistical model, (the statistical model is here used to denote the intensity-stimulus transform in combination with the probability function) it is possible to derive a function empirically based on the data from a sufficiently massive and properly designed experimental firing program.

5. As part of the HERO (Hazards of Electromagnetic Radiation to Ordnance) program it was decided to attempt to collect enough firing data to determine the statistical model of the Squib Mk 1 Mod 0, Figure 1. Two production lots (10,000 units each) were made available for this and other experimental work.

EXPERIMENTAL PROCEDURE

6. The Bartlett firing plan[1] was used for data collection. This plan is a modified stair-step firing plan wherein firing is continued until two reversals are observed at a particular level. When the second reveral is observed, the level is abandoned and the next higher (if above the 50% firing level) or the next lower (if below the 50% firing level) is chosen. This collection plan is designed

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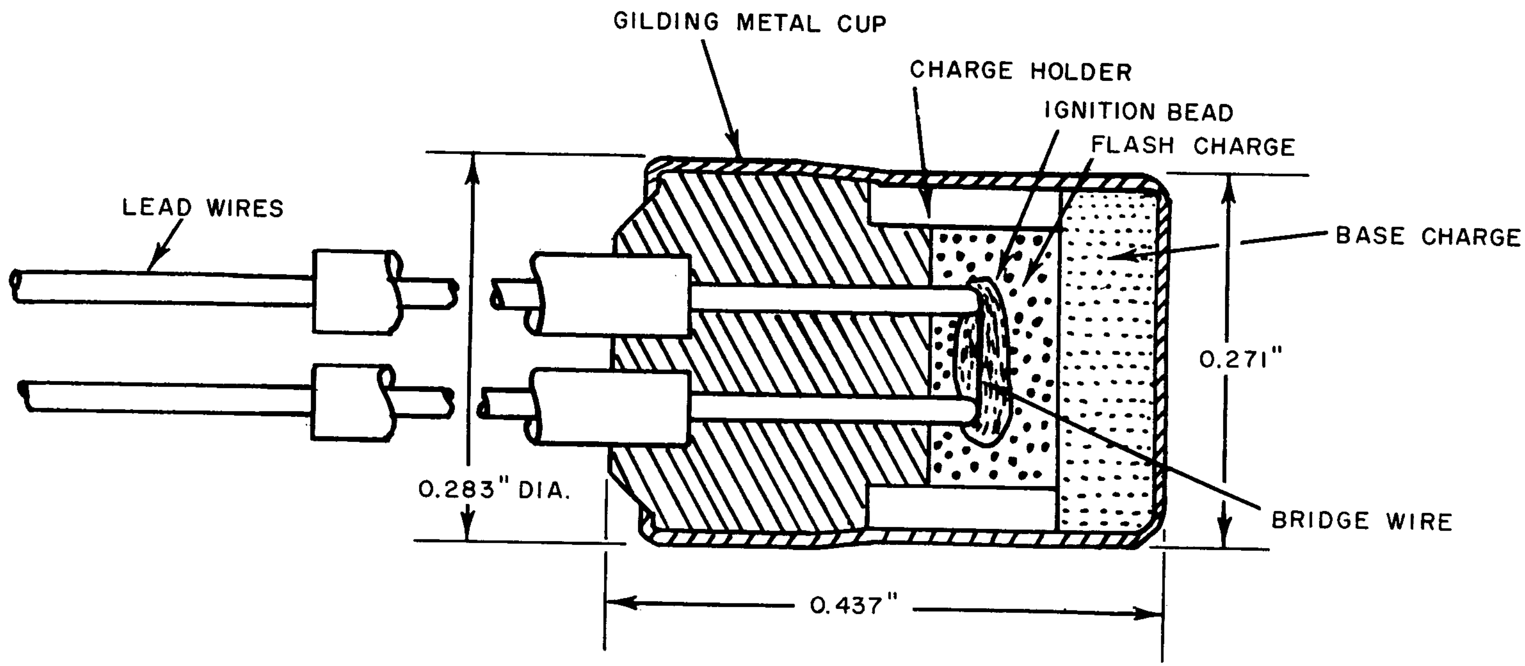
(1) Carl Hammer, "Statistical Methods in Initiator Evaluation", Franklin Institute Initiator Laboratories Interim Report No. I-1804-1, Prepared for Picatinny Arsenal Samuel Feltman Ammunition Laboratory, May 1, 1955.



NOTES:

1. IGNITION BEAD - APPROX. 5 MG DDNP/$KClO_3$
2. FLASH CHARGE - APPROX. 45 MG BLACK POWDER
3. BASE CHARGE - APPROX. 45 MG BLACK POWDER
4. BRIDGE WIRE - 0.001" PLATINUM-IRIDIUM 0.060" LONG

FIG. I SQUIB MK I MOD O

to allocate the number of shots at each level in such a manner that the statistical weighting is more-or-less the same at the different levels from the center to the extremes of the distribution. As can be seen from the final results, this firing plan calls for an enormous number of firings at the extremes.

7. While it is highly desirable to have some random sampling method for allocating individual units to the firing sequence, it was decided that the logistics of reorganizing 10,000 units in a new, random array involved a degree of manpower, bookkeeping, and explosive handling not compatible with the available manpower and time scale.

8. The energy delivered by the test equipment[(2)] was known to ± 2%. Each firing was monitored by cathode ray oscillography, the pulse wave-form being checked for distortion and amplitude. All data were discarded for which the oscillograms were found to indicate a faulty wave-form. In order to check on possible aging effects on the instrumentation and on the EEDs, three pilot test runs were made; one before, one during, and one after the Bartlett run. In the data tabulation (Tables 1, 2, and 3) the results of the three runs have been combined, since the individual runs do not differ by more than would be expected on the basis of experimental error.

9. At the more extreme levels, where hundreds of shots were made at a single level, it was decided to alternate high and low levels in blocks of 60 or 120 trials at a level. This was done to give more assurance that the instrumentation was operating properly and also to help guard against operator errors due to monotony. At this point it is appropriate to say that from the outset it was evident that this program would require the utmost in reliability of instrumentation and accuracy of operators. An overall reliability of 99.99% would be barely good enough to permit the statement that the observed results are independent of measurement error.

RESULTS

10. The objectives of the program were twofold:

(a) Obtain data to serve as a basis for determining the statistical model of the EED response to stimulus.

(b) Study the relationship between small-sample estimates of the sensitivity distribution parameters and the parameters empirically determined from the large sample used to determine the statistical model.

(2) J. N. Ayres, "Characterization of Squib Mk 1 Mod 0; Capacitor Discharge Sensitivity, Instrumentation", NavWeps Report 7308, 10 January, 1961.

Table 1

Capacitor Discharge Firing Data, Observations

Index	Charge Potential (volts)	Stored Energy (milli-joules)	Delivered Energy (milli-joules)	OBSERVED RESPONSE Bartlett Plan Fires	Bartlett Plan Fails	Accumulated Pilot Tests * Fires	Accumulated Pilot Tests * Fails
a	33.59	2.257	1.790	2,486	2	--	--
b	32.87	2.161	1.714	617	2	--	--
c	32.16	2.069	1.641	460	2	--	--
d	31.48	1.982	1.572	819	2	--	--
e	30.81	1.899	1.506	61	2	--	--
f	30.17	1.820	1.444	118	2	--	--
g	29.53	1.744	1.383	37	2	--	--
h	28.92	1.673	1.327	34	2	--	--
i	28.32	1.604	1.272	86	2	--	--
j	27.74	1.539	1.221	14	2	--	--
k	27.68	1.532	1.215	--	--	53	9
l	27.15	1.474	1.169	9	2	--	--
m	26.62	1.417	1.124	5	2	--	--
n	26.36	1.390	1.102	--	--	125	53
o	25.13	1.263	1.002	--	--	67	124
p	25.06	1.256	0.996	--	--	2	3
q	24.57	1.207	0.957	2	23	--	--
r	24.09	1.161	0.921	2	31	--	--
s	23.97	1.149	0.911	--	--	1	46
t	23.62	1.116	0.885	2	281	--	--
u	23.17	1.074	0.852	2	344	--	--
v	22.74	1.034	0.820	2	234	--	--
w	22.31	0.996	0.790	2	441	--	--
x	21.90	0.959	0.761	1	1270	--	--

* The results of Pilot Tests A, B, and C have been collected together and reported as "Accumulated Pilot Tests".

Table 2

Capacitor Discharge Firing Data, Probability Estimates

Index	Charge Potential (volts)	Delivered Energy (Log-milli-joules)	Functioning Probability Observed %	90% Tolerance Interval	
a	33.59	0.25285	99.920	99.992	99.78
b	32.87	0.23401	99.677	99.91	99.14
c	32.16	0.21511	99.577	99.88	98.85
d	31.48	0.19645	99.756	99.94	99.35
e	30.81	0.17782	96.83	99.15	91.78
f	30.17	0.15957	98.33	99.56	95.62
g	29.53	0.14082	94.87	98.63	86.90
h	28.92	0.12287	94.44	98.51	85.90
i	28.32	0.10449	97.73	99.39	94.06
j	27.74	0.08636	87.50	96.63	70.00
k	27.68	0.08458	85.48	91.07	78.06
l	27.15	0.06781	81.82	95.05	58.48
m	26.62	0.05077	71.43	92.13	40.39
n	26.36	0.04218	70.22	74.97	65.30
o	25.13	0.00087	35.08	40.28	30.01
p	25.06	-0.01578	40.00	75.31	11.24
q	24.57	-0.01909	8.00	20.03	2.15
r	24.09	-0.03574	6.06	15.32	1.62
s	23.97	-0.04048	2.13	8.00	0.22
t	23.62	-0.05306	0.71	1.88	0.188
u	23.17	-0.06956	0.58	1.55	0.154
v	22.74	-0.08619	0.85	2.26	0.226
w	22.31	-0.10237	0.45	1.20	0.120
x	21.90	-0.11861	0.787	0.36	0.008

Table 3

Capacitor Discharge Firing Data, Probability Estimates

Index	Delivered Energy (Log-milli-joules)	Logit Coordinates			Normit Coordinates		
		Observed Response	90% Tolerance Interval		Observed Response	90% Tolerance Interval	
a	0.25285	7.13	9.43	6.12	3.15	3.76	2.85
b	0.23401	5.72	7.01	4.75	2.72	3.13	2.38
c	0.21511	5.44	6.72	4.45	2.63	3.04	2.27
d	0.19645	6.01	7.42	5.03	2.81	3.24	2.48
e	0.17782	3.43	4.76	2.41	1.85	2.39	1.39
f	0.15957	4.08	5.42	3.08	2.13	2.62	1.71
g	0.14082	2.92	4.28	1.89	1.63	2.21	1.12
h	0.12287	2.77	4.19	1.81	1.59	2.17	1.08
i	0.10449	3.76	5.27	2.76	2.00	2.51	1.56
j	0.08636	1.95	3.36	0.85	1.15	1.83	0.52
k	0.08458	1.77	2.32	1.27	1.06	1.35	0.77
l	0.06781	1.50	2.95	0.34	0.91	1.65	0.21
m	0.05077	0.92	2.46	-0.39	0.57	1.41	-0.24
n	0.04218	0.96	1.10	+0.63	0.53	0.67	+0.39
o	0.00087	-0.62	-0.39	-0.85	-0.38	-0.25	-0.52
p	0.01578	-0.41	+1.02	-2.07	-0.253	+0.68	-1.21
q	0.01909	-2.44	-1.39	-3.82	-1.40	-0.84	-2.02
r	0.03574	-2.67	-1.71	-4.11	-1.55	-1.02	-2.14
s	0.04048	-3.83	-2.44	-6.12	-2.02	-1.40	-2.85
t	0.05306	-4.94	-3.96	-6.28	-2.45	-2.08	-2.90
u	0.06956	-5.15	-4.15	-6.47	-2.52	-2.16	-2.96
v	0.08619	-4.75	-3.77	-6.09	-2.39	-2.00	-2.84-
w	0.10237	-5.40	-4.41	-6.72	-2.61	-2.26	-3.04
x	0.11861	-7.15	-5.62	-9.43	-3.16	-2.69	-3.77

The experiments and data processing procedures were designed to meet these objectives and also to provide internal consistency checks between various sectors of the data in order to give an indication of the "quality control" of the experimental techniques.

11. The individual pilot tests were designated as A, B, and C. Tests A and B were analyzed using the Bruceton(1) computational scheme. Test C was analyzed using the Probit[3] method. The means of the three tests were essentially the same. The standard deviations appeared more variable. A cross classification table was constructed which listed the individual levels and the observed responses for each of the three pilot tests at these levels. The assumption was made that any differences observed between the three tests was due only to random variation. A Chi-Square test of the assumption indicated that at 95% confidence, the assumption could not be denied. It is therefore held that there is no significant difference, one from the other, and that they represent equally valid samples drawn from the same population. From this can be deduced that neither the squibs nor the instrumentation had significantly changed characteristics throughout the test program (a period of about one year). This also is sufficient basis for combining all the pilot test data into one composite group.

12. Tables 1, 2, and 3 list all data obtained relevant to the present study and lists as well the Gaussian and Logistic coordinates of each observed probability. Also included are the 95% upper and 95% lower confidence limits which were computed about each observed probability point as well as the Gaussian and Logistic coordinates of each of these points. These upper and lower confidence limits form a 90% tolerance interval which represents the zone of estimate of the population response, the estimate being made at a 90% confidence.

COMPARISON OF LOG-GAUSSIAN AND LOG-LOGISTIC MODELS

13. The data in Tables 1, 2, and 3 have been plotted in the Log Gaussian (log-normal) probability space in Figure 2 and in the Log-Logistic probability space in Figure 3.

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(3) D. J. Finney, "Probit Analysis, A Statistical Treatment of the Sigmoid Response Curve", (Cambridge University Press, Cambridge, 1952.)

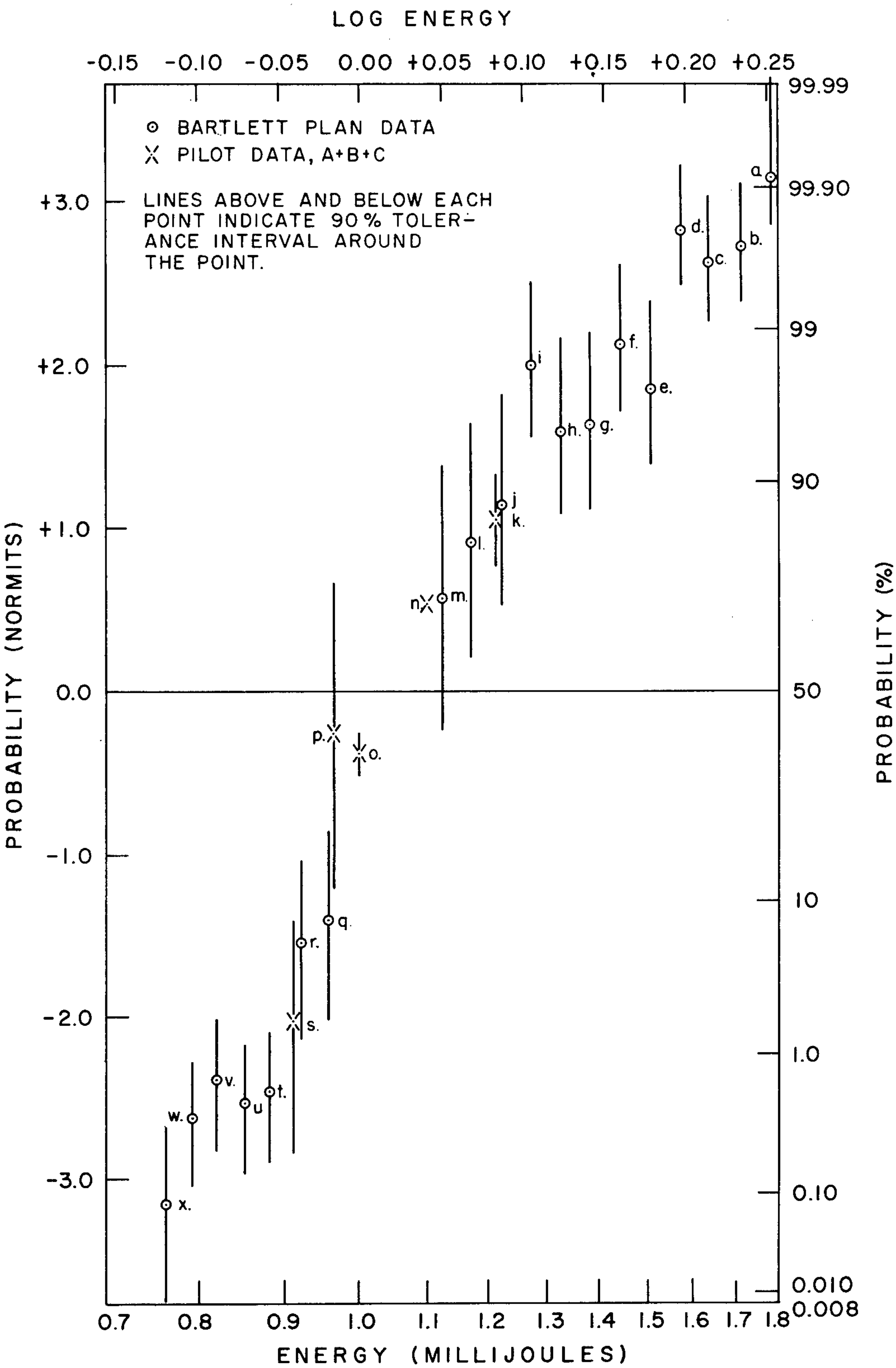

FIG.2 LOG-GAUSSIAN PLOT OF FIRING DATA

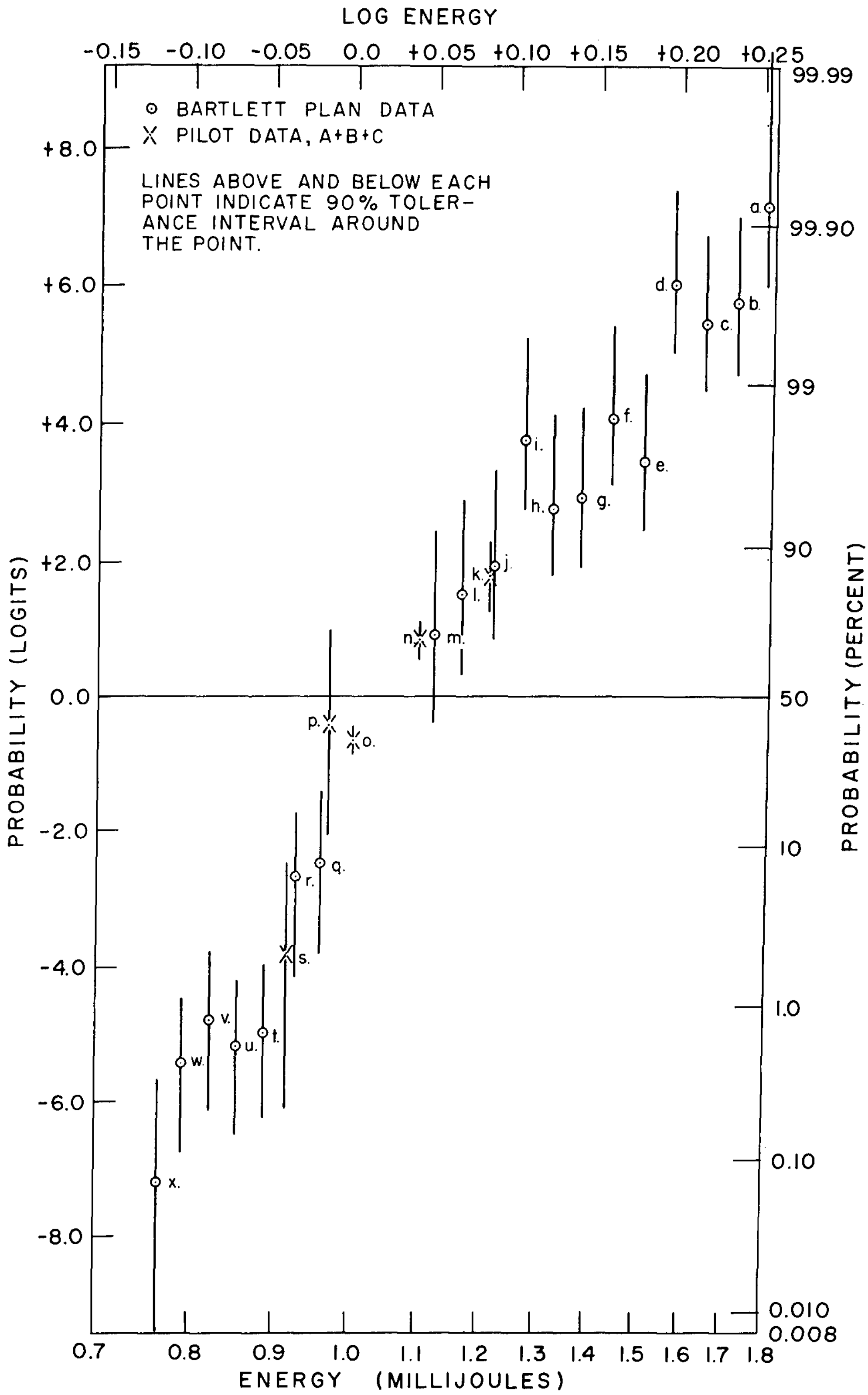

FIG. 3 LOG-LOGISTIC PLOT OF FIRING DATA

14. The Logistic distribution function is not as well known or as frequently encountered as the Gaussian. It is in some ways much easier to use than the Gaussian, and may be a more satisfactory statistical model on the basis of a previous work. The Logit coordinate of a probability can be computed in a number of ways:

$$L = \ln(p/q),$$

or $L = \ln p/(1-p)$,

and since $p = s/n$,

and $q = f/n$,

$L = \ln(s/f)$.

Also $L = 2.3026 \log_{10} p/(1-p)$,

where p is functioning probability

q is failure probability

s is number of successes

f is number of failures

n is number of trials, and

L is the Logit coordinate.

By assuming that the data are from a logistically distributed population, the response to stimulus can be given as:

$$L = MX + B$$

where M and B are parameters of the logistic transform and X is the stimulus.

The stimulus is assumed to be proportional to the logarithm of the delivered energy, D_α , where D_α is expressed in

$$X = \log D_\alpha .$$

These equations can be combined to give the cumulative distribution function:

$$\ln p/(1-p) = M \log_{10} D_{\alpha} + B.$$

15. An analysis was performed on the Bartlett data using the standard Probit Technique(3). The Probit fit is shown in Figure 4. A Chi-Square test of the goodness of fit of the data to the Gaussian curve indicated a very poor fit (99.9% of the time one would expect a better fit than was observed). A Logit analysis was performed on the same data using the technique developed by Berkson.(4)

16. Inspection of the Logit fit of the data indicate that the fit is not altogether satisfactory. The central Bartlett data (points h, i, j, l, m) and the Pilot Test data points (k, n, o, p, s) do not seem to be consistent with the data at the extremes (points a, b, c, d, e, f, g, q, r, t, u, v, w, x). Three possible explanations were considered:

(a) The data are still skewed, even in the Log-Logistic model.

(b) The central data (which were in large part collected early in the program) may not be from the same population or may have been tested differently from the data at the extremes.

(c) One or two points (point i, in particular) may have been in error due to faulty observation.

17. Fits of the data, omitting point i, showed considerable improvement for both models. Point i, however, was found to be consistent with the combined Pilot Test data and with the central Bartlett data. There is fairly clear evidence then that point i is a valid point and should not be discarded. Separate Log-Logit fits of the Bartlett central data and of the data at the extremes are shown in Figures 5A and 5B as well as the logit fit of all Bartlett data. The discrepancy that appears to exist between the central Bartlett and extreme Bartlett data can be explained by either of two hypothesis:

(a) One Log-Logistic function describes the distribution of response vs. stimulus for stimuli near the 50% firing level and another describes the distribution at extreme levels.

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(4) Joseph Berkson, "A Statistically Precise and Relatively Simple Method of Estimating the Bio-assay with Quantal Response Based on the Logistic Function", J. Am. Stat. Assn. 48, 565-599 (1953).

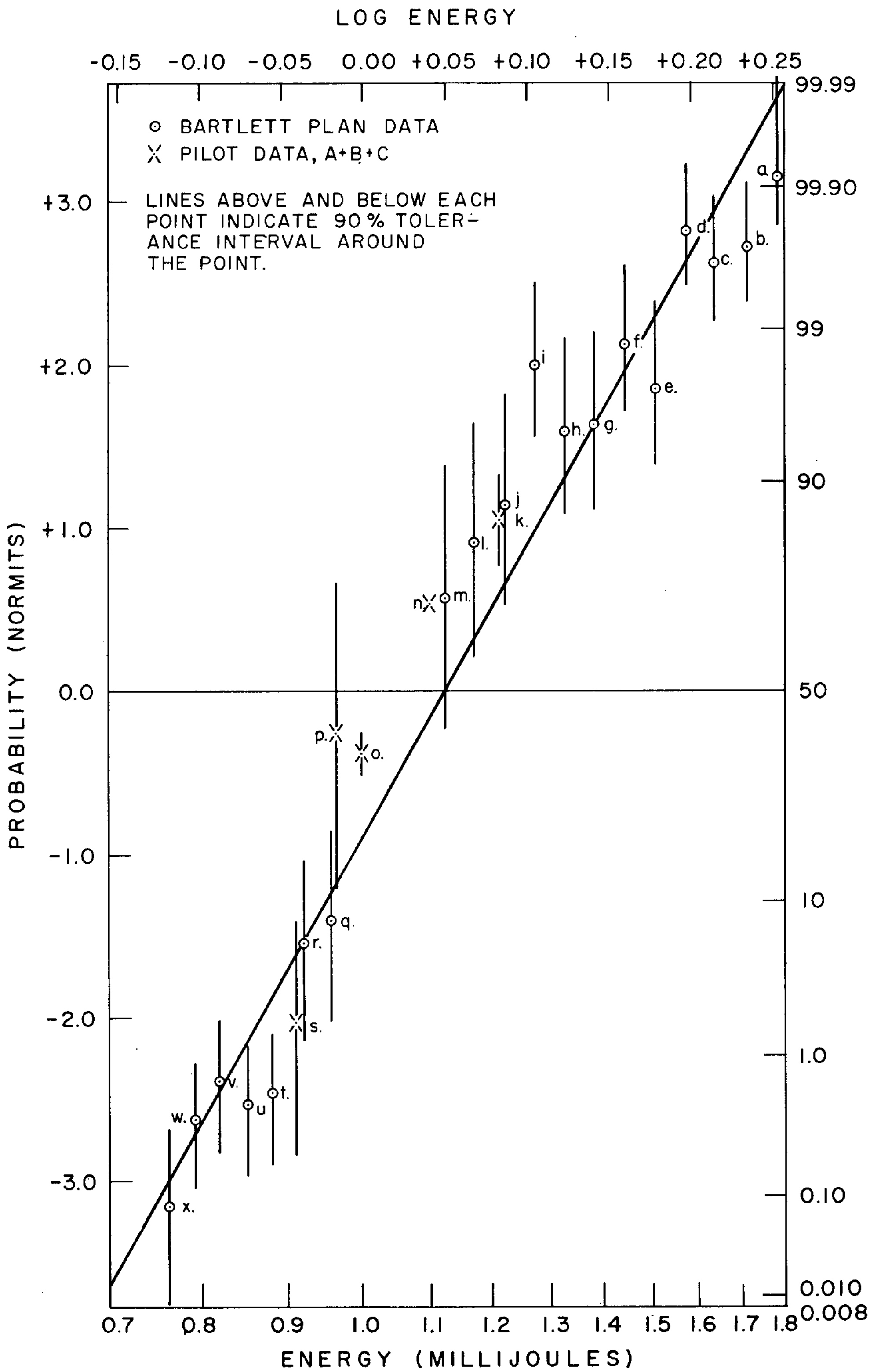

FIG. 4 LOG-GAUSSIAN FIT OF BARTLETT DATA

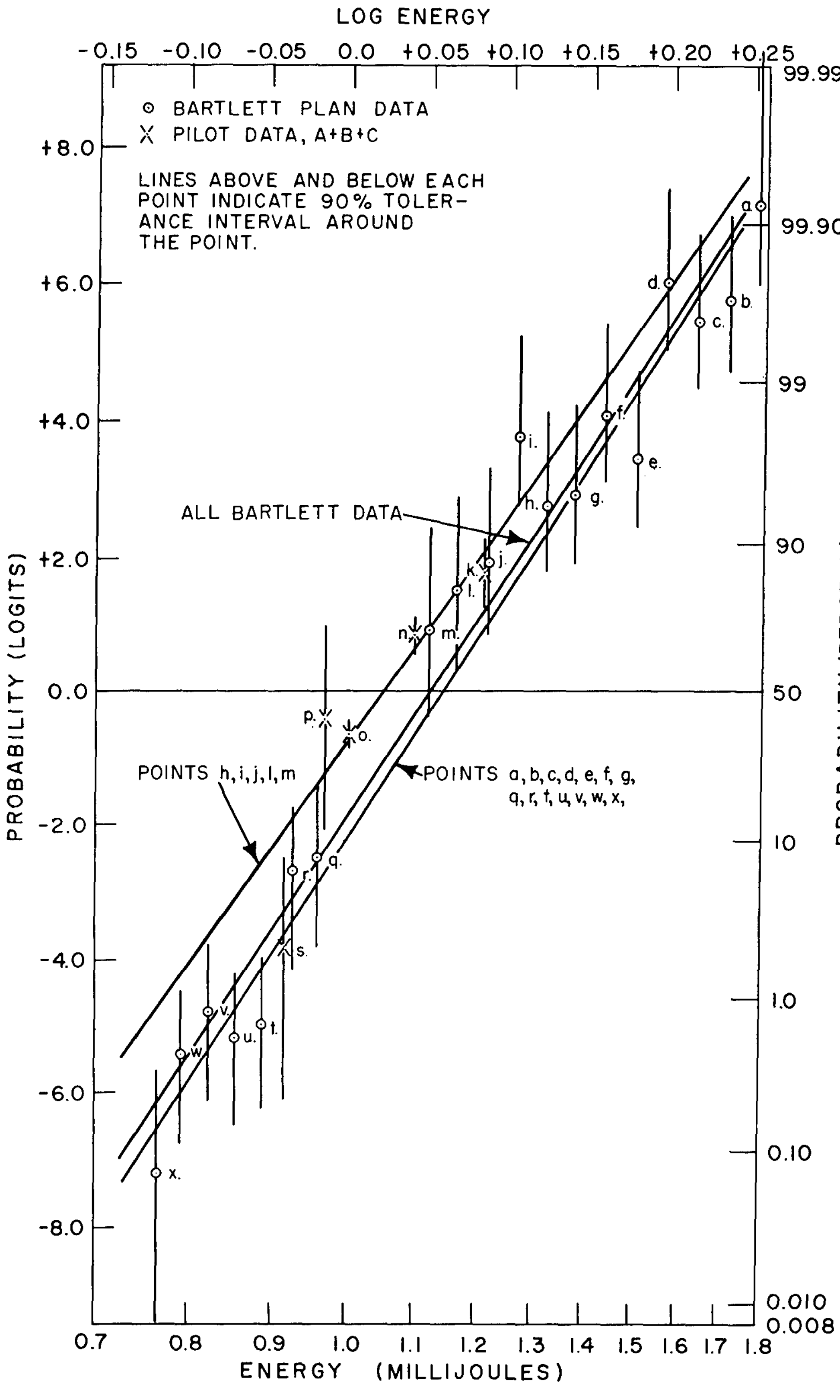

FIG. 5A LOGIT FIT OF BARTLETT PLAN DATA

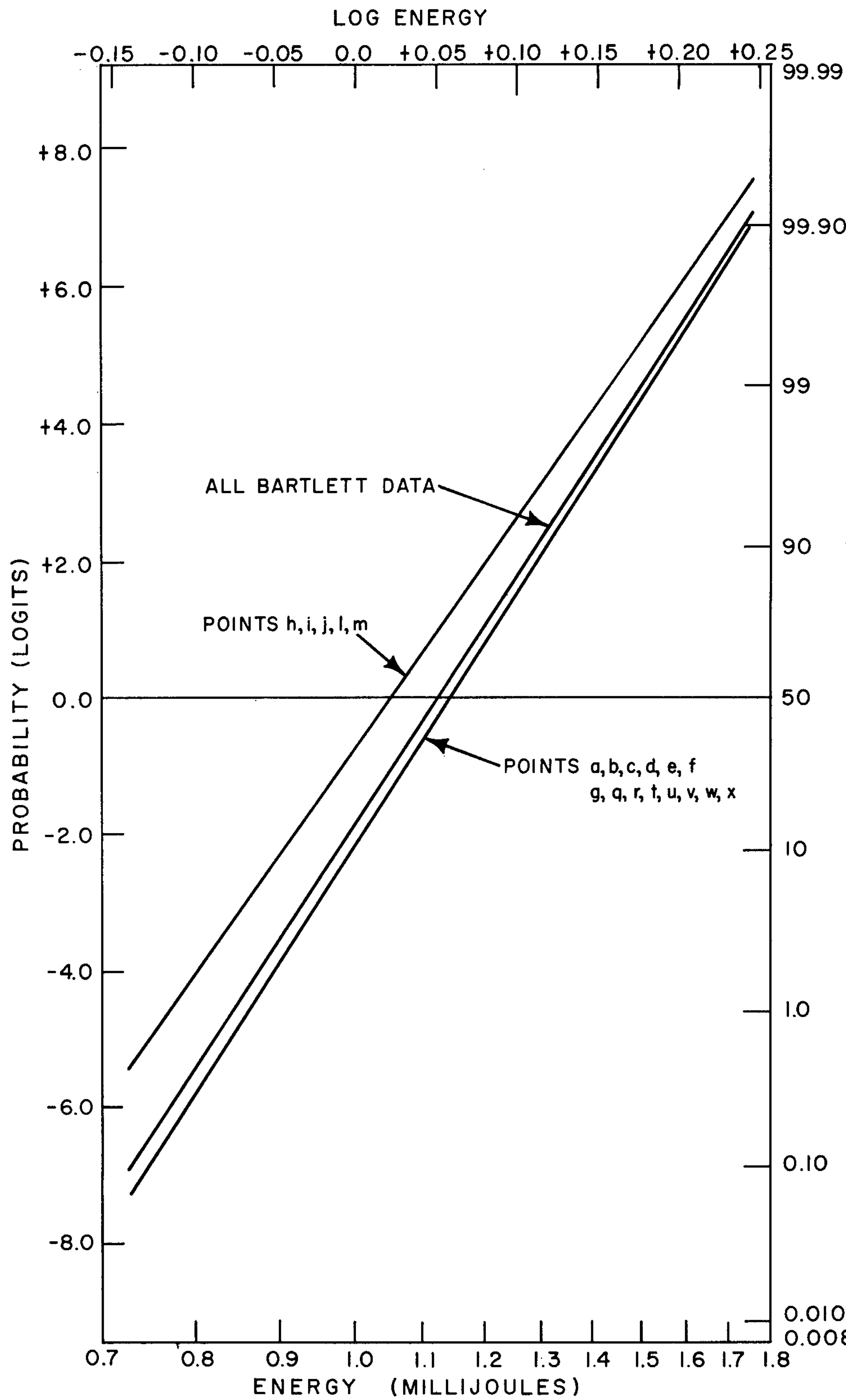

FIG.5B LOGIT FIT OF BARTLETT PLAN DATA

b. There still remains a skewness in the distribution function which cannot be described by the Log-Logistic model.

The former hypothesis is discarded because there is no physical (theoretical) basis for requiring such an arrangement.

18. The Log-Logistic model is better than the Log-Gaussian. Further investigations should be directed toward a more suitable model. Work by Ash and Lacugna (5) was done employing a distribution function,

$$f(X) = \frac{A}{\sigma} exp\left\{-B\left(\frac{|X-\mu|}{|\sigma|}\right)^{1/2}\right\},$$

where f (X) = the distribution function

X = the stimulus

A and B = arbitrary constants

σ = a measure of the population variability

μ = a measure of the population mean,

which seems to very promising for the present problem.

SMALL-SAMPLE ESTIMATES

19. The Pilot Tests A, B, and C represent the most information that one normally can hope for to serve as a basis for estimating extremely high or extremely low functioning levels. Two of the runs (A and B) contained 200 shots and run C was somewhat smaller in sample size. Even these runs are considerably larger than would be expected in usual circumstances. As can be seen from Figs. 6A & 6B, none of the small sample tests nor the composite test made a good estimate of the Gaussian fit to the data which in itself was not good. All of the estimates tend to underestimate the stimulus needed to obtain high functioning reliabilities. While the estimates are somewhat better on the low functioning end of the distribution curve, they do not give sufficiently conservative estimates for safety considerations.

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(5) M. Ash and C. Lacugna, "The Cumulative Probability Function of Fire for a Donor-Barrier-Acceptor Explosive System", NavOrd Report 5746, Proceedings of the Gilbert B. L. Smith Memorial Conference on Explosive Sensitivity, R. McGill and P. Holt, Eds., 2 June 1958, Confidential.

20. The Log-Logistic small-sample estimates (Figures 7A and 7B) are better than the Log-Gaussian. By the use of the appropriate confidence limits computed in the Log-Logistic domain it is possible to introduce enough conservatism to include the observed data points. Computations in this manner are shown in Figures 8A and 8B for Pilot Test C.

CONCLUSIONS

21. On the basis of this work the following opinions are held:

(a) The Log-Logistic model is much better than the Log-Gaussian for the description of the relationship between the response of the Squib Mk 1 Mod 0 to adiabatic firing pulses derived from a 4.0-microfarad capacitor.

(b) The Log-Logistic model revised for skewness, or some other distribution function may give an even better description of the sensitivity of the squib.

(c) The Log-Logistic model with appropriate confidence limits should provide an adequate basis for estimating the sensitivity of the squib to a specific stimulus.

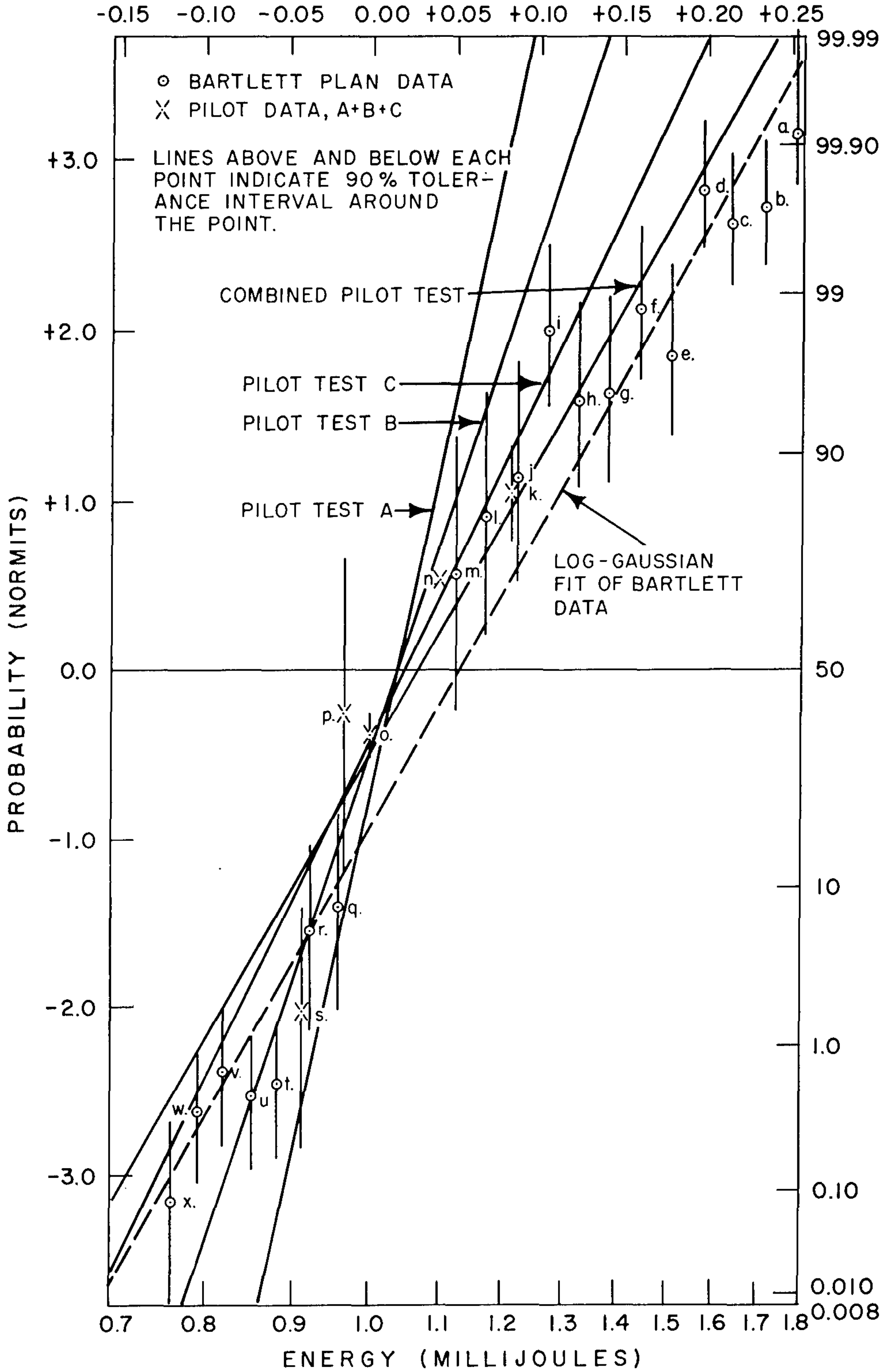

FIG.6A SMALL-SAMPLE ESTIMATES, LOG-GAUSSIAN MODEL

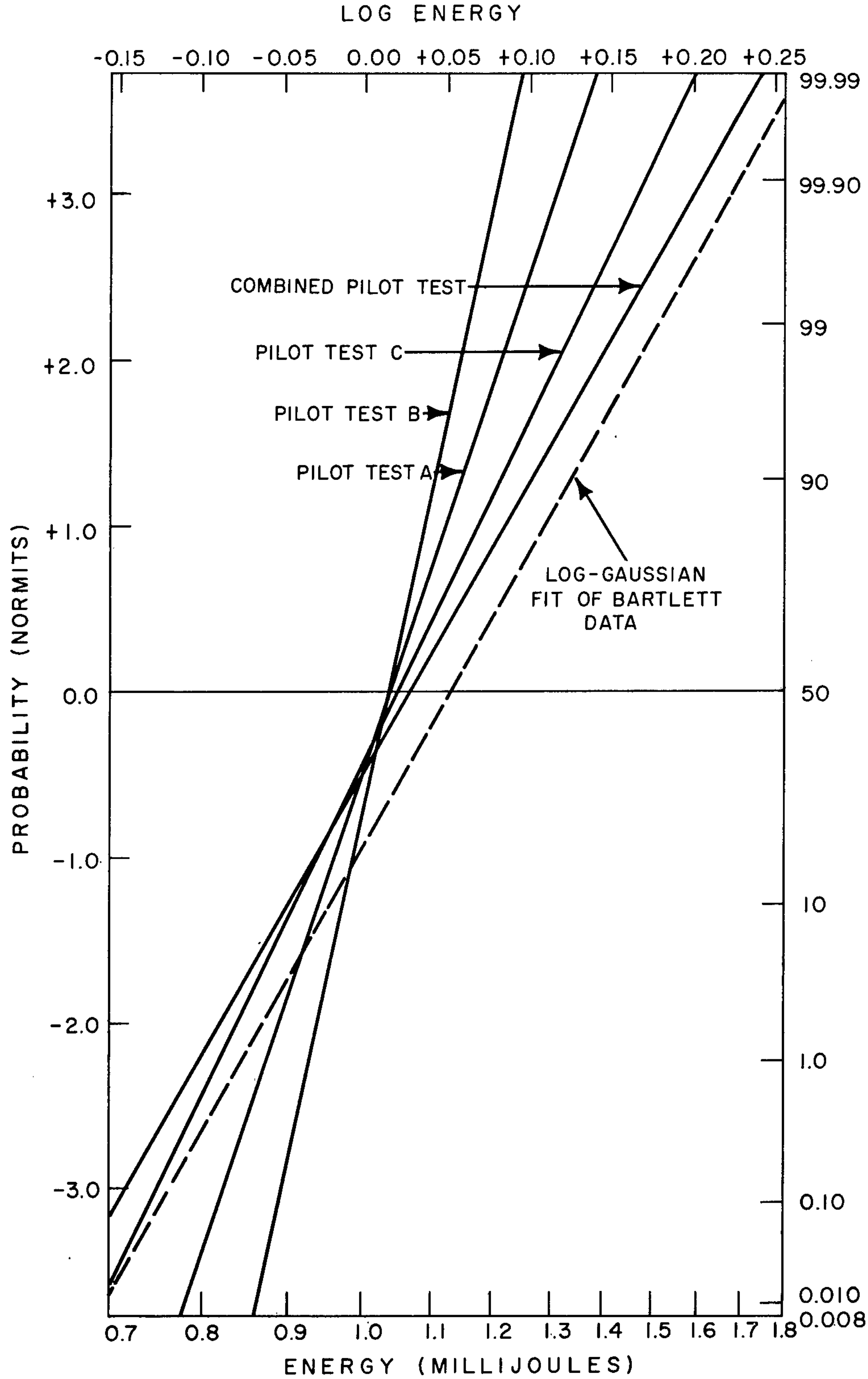

FIG. 6B SMALL-SAMPLE ESTIMATES, LOG-GAUSSIAN MODEL

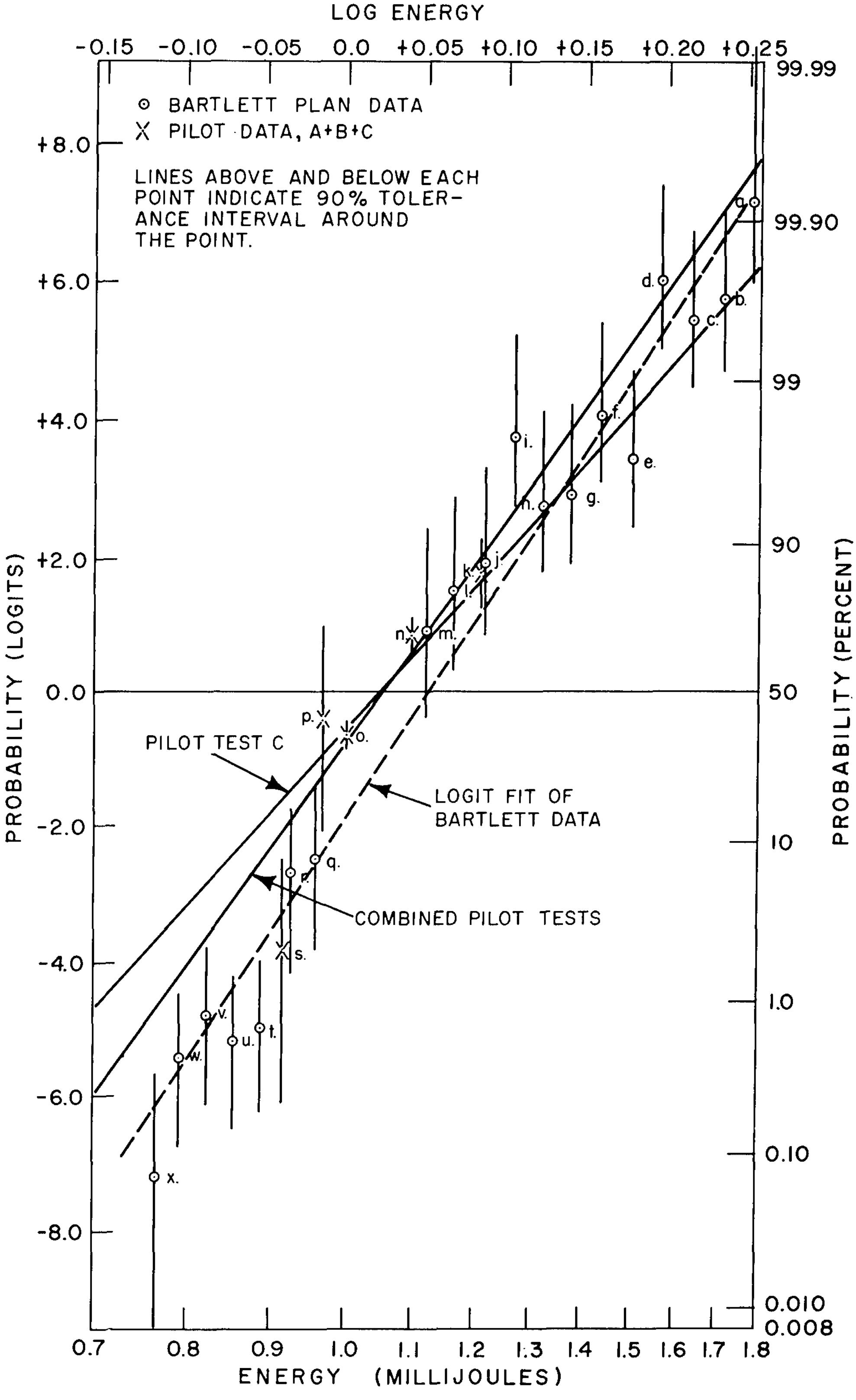

FIG. 7A SMALL-SAMPLE ESTIMATES, LOG-LOGISTIC MODEL

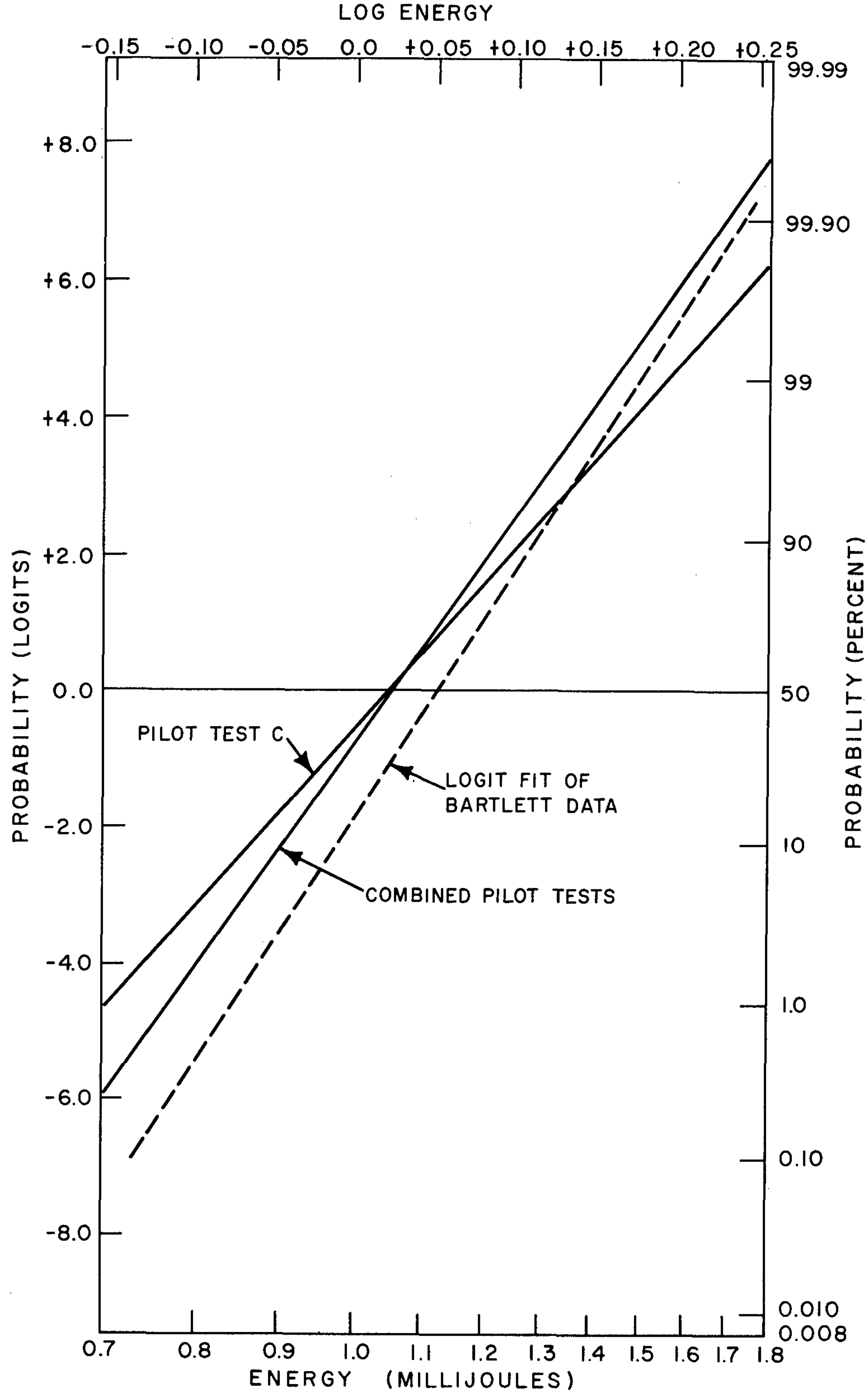

FIG.7B SMALL SAMPLE ESTIMATES, LOG-LOGISTIC MODEL

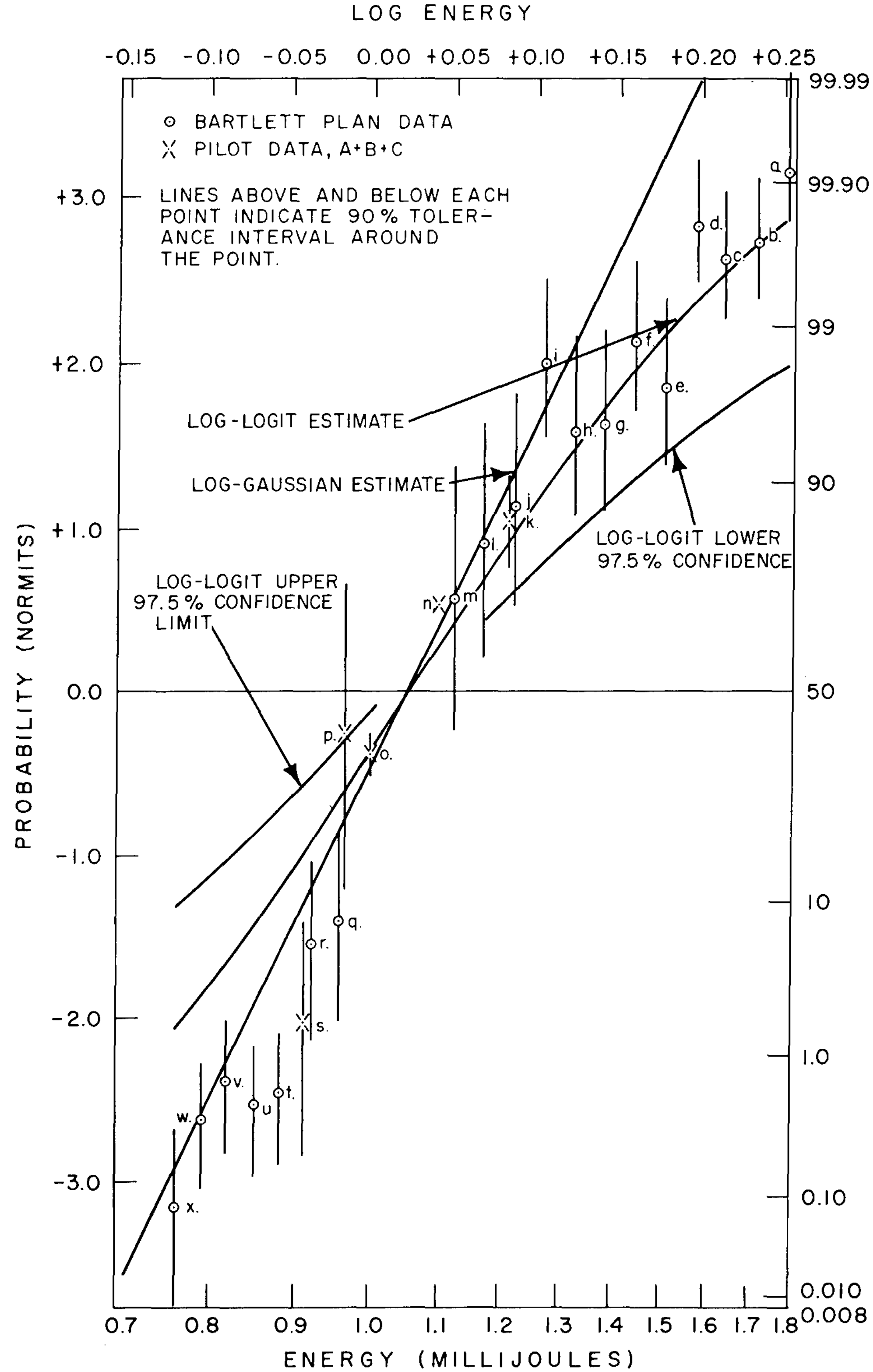

FIG.8A TREATMENT OF PILOT TEST C DATA

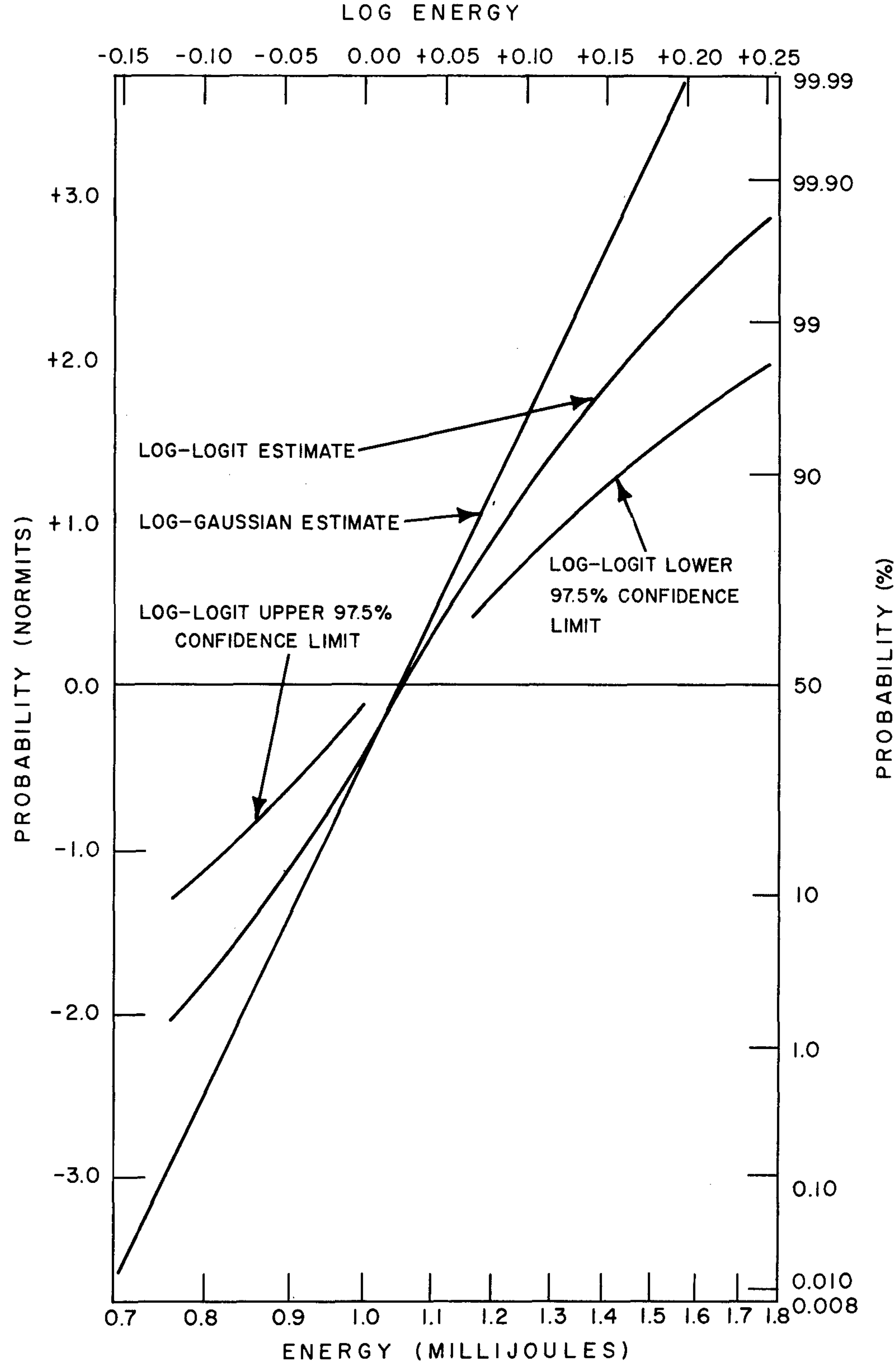

FIG. 8B TREATMENT OF PILOT TEST C DATA

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UNCLASSIFIED

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Abstract card is unclassified (over)

1. Squibs - Mark 1 mod 0
2. Squibs - Firing
3. Squibs - Sensitivity

I. Title
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III. Ayres, James N., jt. author
IV. Project

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