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ANALYSIS OF THE SENSITIVITY OF EXPLOSIVE
MATERIALS TO INITIATION BY IMPACT,
VARIOUS STATISTICAL METHODS

by

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INTRODUCTION

The characterization of impact sensitivity of explosive materials using, for example, the Picatinny Arsenal impact testing machine involves some decisions on how to deal with data provided by the machine. The raw data normally consists of the number of samples which have fired, and the number of "no-fires" for a given sample size N at each drop height. In order to reduce this data for the purpose of comparing two differing materials or to decide whether or not a particular material has changed its performance (with respect to impact measurements) after some treatment, it is necessary to choose a particular statistical method. The choice of method will, in turn, have an effect on the size of sample used and on the number of heights at which tests are made. It would be very convenient to have one standard method that would enable easy comparison of the results of different workers, or of measurements made at different times and places; however, this is not possible. Test procedures which are appropriate to the detailed comparison of only two materials may not be suitable where it is necessary to characterize samples with respect to a large number of variables, or where limited quantities of material are available.

The need for statistical methods in the reduction of impact data comes not only from a general lack of reproducibility of testing techniques, but from the following considerations: If one considers a number of tests on a sample at one drop height, the question occurs as to why one drop results in a fire and another in a no-fire, since one is supposedly dealing with the same material and reasonable precautions have been taken to make the test conditions the same. The same question arises when one finds that a test on one sample results in a fire at one drop height and a second test results in a no-fire at a greater drop height (where the energy input to the sample is undoubtedly higher). One can only conclude that individual samples of the material are not in fact the same, but differ in some respect which will result in differing impact behavior.

This report is not concerned with the physical or chemical reasons for these differences (one plausible physical model is given, for example, in the paper by Levy et al. Reference 1). It is merely accepted that there exist, within a sample of any given size, variations in sensitivity. Figure 1 shows a distribution of sensitivities for a particular material such that a test on a sample at a drop height such as h in Figure 1 would result in a fire if the sample belonged to the part of the distribution to the left of the vertical line at h (i.e., if its critical height were less than the test drop height) and result in a no-fire if it belonged to the larger part of the distribution to the right of that line. Tests on a sufficiently large number of samples at a large number of heights would result in the typical cumulative curve shown in Figure 2.

The methods given below for the analysis of impact data, whether they involve trials at only one or at more than one height, or whether the heights are chosen depending on the results of the testing as it proceeds (as in the Bruceton test), are eventually designed to give information about the distribution of critical heights. The demonstration of differences between materials or of changes in a material as a result of some treatment depends on showing that there are differences between critical height distributions.

In order to categorize different materials it is possible to use properties of the critical height distribution quite arbitrarily: If trials are made at only one height, the estimate of the percentage of the distribution of critical heights which lies at heights smaller than the test height might be used as some measure of sensitivity. If more is known about the distribution from trials at a variety of heights, the mean of the distribution might be used as a measure of "sensitivity" and some measure of the width of the distribution (e.g., its variance) as a measure of "predictability" of the samples.

In the discussion of methods that follows, these assumptions have been made:

1. It is assumed that the main purpose of the testing is to detect possible differences between materials, and that the categorizing of materials with regard to their relative impact sensitivities is of only secondary importance.

2. It is assumed that errors or uncertainties in the testing procedure will have less effect on the uncertainties in the results than those arising from small sample sizes and from the generally broad critical height distributions.

3. It is sometimes assumed that the important parameter in impact testing is energy input to the sample, and that drop heights may be changed without affecting the results, provided that the total potential energy remains the same. With that assumption, one would use critical energy distribution and not critical height distribution. The assumption is made here that a constant hammer mass is used and that drop height is the only variable.

Some of the more important methods will be given below. They are standard methods and are discussed in detail elsewhere. References 2 and 3 are good sources for information and further references. Thus only outlines of the methods and some of their advantages and disadvantages will be given.

TESTS AT A SINGLE DROP HEIGHT

If comparisons between materials are to be made from tests conducted at a single drop height, the simplest procedure is the following:

1. A height must be selected which falls at some place of interest in the critical height distribution. The test height is usually selected from previous measurement.

2. A sample of N trials is run which result in $[n]$ fires and $[N - n]$ no-fires.

3. The percentage fire, $p = 100 \ x n/N$, is calculated. The number p gives an estimate of the percentage of area under the critical height distribution (see Fig 1) which is to the left of the vertical line at the drop height h .

4. A standard deviation for the number of fires may be calculated:

$$S = \sqrt{\frac{n(N - n)}{N}}$$

A value for the number of fires obtained for some other material may be compared with this value of n by noting that percentage areas under a normal curve for numbers of fires which differ by s , $2s$, and $3s$ from the value for n are respectively 34%, 14%, and 2%.

A more elaborate procedure may be adopted where it is assumed that the procedure for getting the control sample or some other variable such as time of preparation may affect results. An example would be a case where materials are prepared, tests are run with a fixed sample size, and it is wished to make the control sample a composite of a large number N of batches. In this case the number of fires would be calculated for each of the batches and an estimate of the standard deviation of n calculated from

$$S = \sqrt{\frac{\sum n^2 - N\bar{n}^2}{(N - 1)}}$$

where $\bar{n}$ is the mean of the values of n .

Here $\bar{n}$ and s may be used to determine a confidence interval for the value of the mean. The interval is obtained from

$$\bar{n} \pm t \ s/\sqrt{N}$$

where t is found from tables of the percentiles of the student t distribution for the desired level of confidence and $N - 1$ degrees of freedom.

Statements that may be made when comparing results from two separate tests, A and B (conducted, of course, at the same drop heights), are, for example, "The mean percentage fire for sample A does (or does not) lie within one (or more) estimated standard deviations for sample B," or: "The mean of sample A lies (or does not lie) within some specified confidence limits for the mean of sample B."

Tests at a single drop height may be made if it is assumed that a height is selected at which changes in the critical height distribution will result in a change in the percentage fire. In order to examine more of the critical height distribution it is necessary to make measurements at more than one height.

MEASUREMENTS AT MORE THAN ONE HEIGHT

Kärber Method

This method assumes that, for one material, measurements of percentage fire have been made at a number of different heights, and yield results in the form of an estimated mean critical height and an estimated standard deviation. On the assumption that the critical height distribution is normal (contrary to experiment), values for the mean critical height and standard deviation completely specify the performance of the sample in drop testing. The mean may be used as some measure of the sensitivity and the standard deviation as some measure of the predictability of impact behavior of the sample. In cases where materials are assumed to be different, the Kärber method is useful in ordering materials as regards sensitivity. It is not useful in detecting small differences between materials.

Briefly, the calculation assumes that the differences in percentage fire at two heights (for example, h and h^1 in Figure 2) gives the percentage of the critical distribution lying between the class limits h and h^1 , and that sufficiently large numbers of tests are conducted at each height so that the variance of percent fire at that height may be neglected. This calculation is given in detail in Reference 2.

Probit Analysis

This method is discussed in detail in Reference 2. Measurements made at a number of different heights are tested against an assumed functional form for the critical height distribution. While the method may be useful for testing the validity of particular functional forms for the distribution of critical heights, it is not considered to be of much use for comparing materials or for detecting differences between them. Attempts at establishing theoretical shapes for impact test curves (see, for example, Ref 1) have shown it is not possible to give them simple functional forms.

"Chi-squared" or Goodness of Fit Test

This test is discussed in References 2 and 3. Here, comparison is made between two materials which have been tested at a number N_h of drop heights. At each drop height the samples are tested for differences in the proportion of "fires" and "no-fires" and at each height a value of χ^2 is calculated from

$$\chi^2 = N_1 N_2 \left(\frac{n_1}{N_1} - \frac{n_2}{N_2} \right)^2 \left(\frac{1}{n_1 + n_2} + \frac{1}{N_1 + N_2 - n_1 - n_2} \right)$$

where n_1 and n_2 are the numbers of fires for the two samples, and N_1 and N_2 are the numbers of trials. (In some cases it is necessary to group the results from heights which lie near the extremes of the critical height distribution. This is discussed in Reference 3.) The resulting values of χ^2 are summed for all heights $\Sigma \chi^2$. For a chosen level of confidence and the number of degrees of freedom corresponding to the number of heights N_h a value of $\chi^2_{1-\alpha}$ is obtained. A value of $\Sigma \chi^2$ larger than $\chi^2_{1-\alpha}$ indicates that the samples cannot be said to be the same in regard to their proportions of "fires" and "no-fires."

This test has the advantage that specimens may be compared without making any assumptions about the distribution of critical heights. If the drop heights cover a sufficiently wide range, the test should be sensitive to changes in that distribution. One does not obtain, however, any information about the distribution, or any means of placing samples in order of sensitivity.

Bruceton or "Up and Down" Methods

These methods are also described in Reference 1 (Sec. 10.6). They enable one to make estimates of the mean and standard deviation of the critical level distribution. Samples are tested and the drop height is adjusted for each succeeding test, depending on the result of the last. These tests have the advantage that they require no knowledge, or at least only a very rough estimate, of the mean of the critical height distribution. However, like the Kärber method, they assume a normal distribution, and provide no simple way of testing two samples for differences.

SUMMARY

If one sets out to detect minor differences in impact sensitivity between materials or changes in a material the χ^2 or "goodness of fit" test recommends itself. It does not involve an assumption about the functional form of the critical height distribution. In addition, unlike the Bruceton methods or tests involving single drop heights, it is sensitive to differences in any part of the distribution. However, where a large amount of testing or limited amounts of material are involved, such methods may have to be used.

The main disadvantage of the χ^2 method, that it fails to provide any means of categorizing materials as regards relative sensitivity, may be overcome by combining it with one of the simpler tests such as the Kärber method. The χ^2 and Kärber tests have been coded in FORTRAN IV for the C.D.C. 6600 computer. A listing of the program is available from the Explosives Laboratory on request.

The general statistical techniques discussed here can be applied to other sensitivity tests. For example, the so-called "arbor test" can be treated by the same statistical methods. In the "arbor test" an uniaxial load is slowly applied to the explosive mixture in a suitable container geometry until explosion occurs, with the force applied noted at time of explosion. Instead of a distribution of critical impact drop heights for a given explosive composition one obtains a distribution of critical applied forces for the explosive composition. Once again the mean critical force and standard deviation about this mean indicate relative sensitivity and predictability of the explosive composition. How closely the distribution of critical forces approaches a normal distribution again will help evaluate the relative merit of the various statistical techniques discussed above.

REFERENCES

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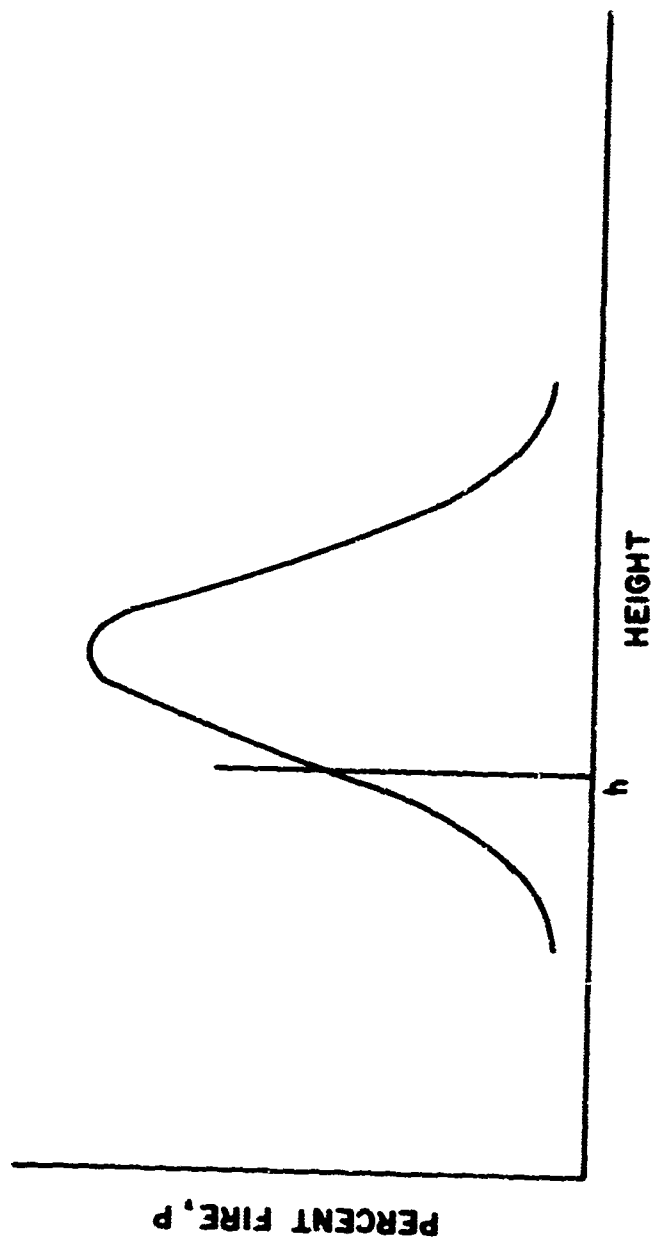


Fig 1 Distribution of critical heights for a typical explosive material. The vertical axis represents the fraction of the samples having this critical height.

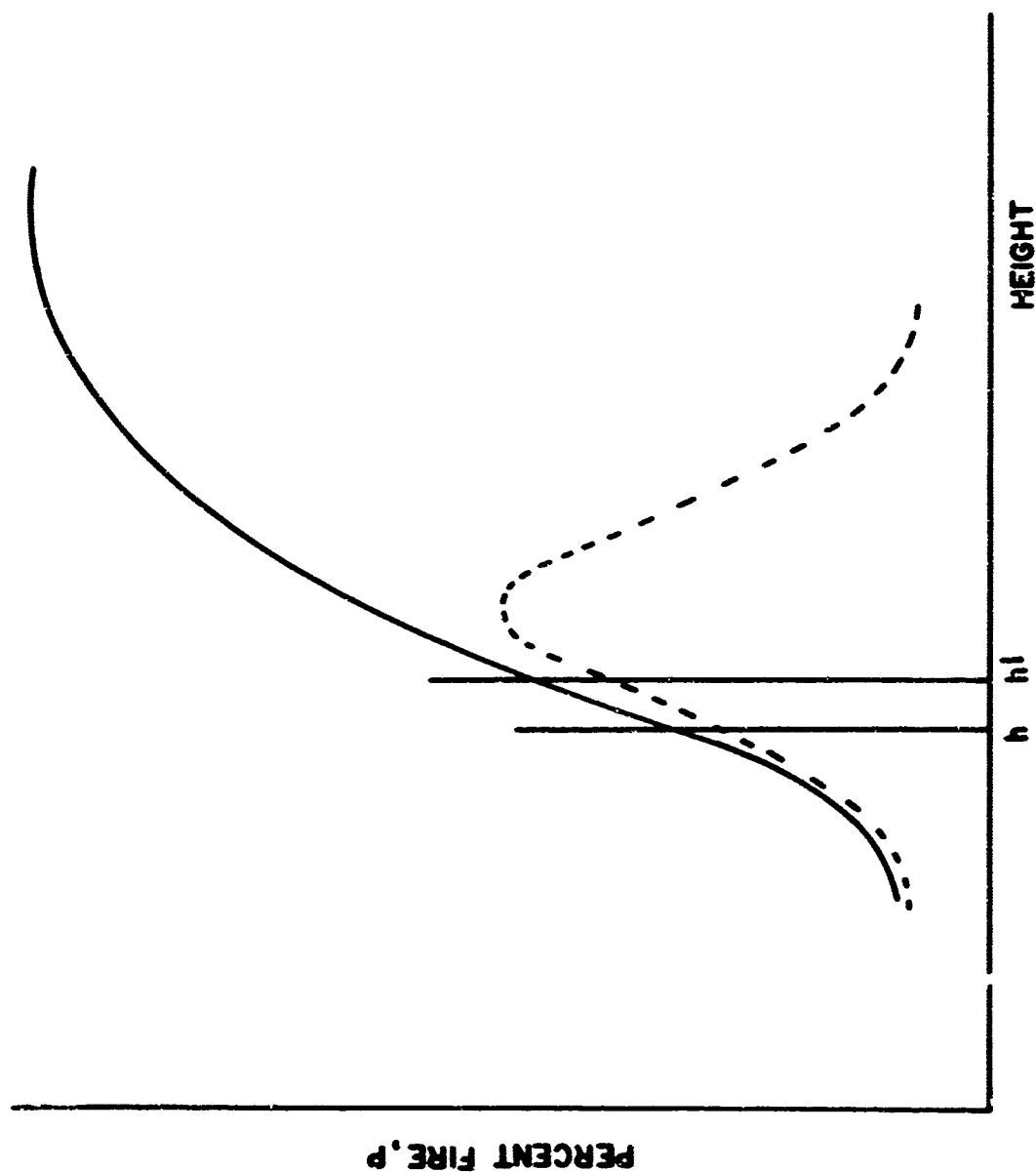


Fig 2 Cumulative "percent fire" curve (solid line) obtained from measurements on large number of samples at various heights. The dashed line represents the corresponding distribution of critical heights.

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Various statistical methods are presented for the analysis of explosive sensitivity test data. The Karber, Probit, "chi-squared," and Bruceton methods are presented. Criteria are developed for choice of the most suitable methods for reaching decisions about relative changes in, absolute values of, and predictability of the sensitivity of explosive materials.			

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