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USNOL ltr, 29 Aug 1974 ; USNOL ltr, 29 Aug 1974

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DV Lick NNOUNCET UNCLASSIFIED 051 U. S. Naval Ordnance Laboratory mite Oak, Silver Spring 19, Maryland NAVAL ORDMANCE LABORATORY MEMORANDUM 10577 N Πr 266 Jul 1971 27 From: R. H. Stresau, Jr. L. E./Starr, Jr. AD4 Tor N.O.L. Files Via: Chief, Explosives Research Department Sub Some studies of the Propagation of Detonation Between Small Confined Explosive Charges, NOL-Re2c-1-2(a)-51 Abst: VA series of measurements is in protress of the conditions for propagation of detonation between men confined charges in the size range of fuze explosive train components. The point at which propagation **V**d **V**J across a gap or other relative displacement should occur for fifty percent of trials was determined by varying the displacement in accordance with the socalled Bruceton up and down method Critical axial air gaps were determined as functions of column diameter, density, explosive material, and column length and critical transverse displacement was measured as a function of explosive material. Axial gap, as might be expected, varies directly with donor diameter. For any given donor diameter there is, apparently, an optimum acceptor diameter which is slightly smaller than the donor diameter. The gap also increases with donor column length, but a given increase in quantity of explosive is more effective when added by increasing the diameter than by INTERVALS increasing the length. The sensitivity of various explosives as indicated by the gap across which they can YEARS be initiated shows a reasonably good agreement with 12 impact and minimum priming charge sensitivities of the same explosives. The critical gap is related directly 5200-AFTER YEAR to donor density, in general, and inversely to acceptor density, but the effect of acceptor density is much DOD DIR ю greater. The critical transverse displacement for DECLASSIFIED AT. propagation between various explosives shows a similar pattern to the axial gap but the relationship is not DOWNGRADED linear because the more sensitive materials are initiated by shock transmitted through the metal while the less sensitive materials require an overlap of the two columns, so that two different mechanism are involved. 650 UNCLASSIFIED nt

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The above observations apply to the explosive materials. confinements, charge dimensions, and densities used in these experiments. Extreme caution is recommended in their application to other conditions.

Fwrd: The data and conclusions presented here are not the final judgment of the Explosives Research Department or this specific project. Additional reports will be made as the data becomes available.

- Ref:
- (a) Ordnance Board Investigation No. 808 "The Propagation of a Detonation Wave through Explosive Trains in Fuzes", C. Dodd (S-6300)
- (b) OSRD Report #4040 "Statistical Analysis for a New Procedure in Sensitivity Experiments", Applied Mathematics Panel, National Defense Research Committee (S-5892)
- (c)NOLM 8696 "A Method for the Fabrication of Low Energy Electric Initiators"
- NOLM 10336 "The Sensitivity of High Explosives (d) to Pure Shocks".
- (e) NOLM 10765 "Density of a Pressed Explosive as a Function of Loading Pressure" NavOrd Report #87-46 "Table of Military High Explo-
- (f) sives" Hercules Powder Co. (S-10982)
- (g)NavOrd Report #57-46 "The Stability of Detonation" H. Eyring et al.

(1) Plates 1 through 18. Encl:

INTRODUCTION

1. Although successful explosive trains have been designed and built for years, many of the principles which should govern such designs are imperfectly understood.

2. One field in which quantitative information is particularly lacking is that of the propagation of detonation between small confined charges such as detonators and leads. Failure at this point has resulted in more than one serious delay late in the development of an urgently needed ordnance item. The cost of such delays in war time cannot be reckoned. Most experimental work in this field has been tests of specific items. Where failure occurred several changes were frequently made simultaneously so that it became virtually impossible to ascertain the relative importance of the changes to any improvement which may have resulted. Thus, although the designer gradually acquired a "feel" for the art, he was usually unable to state any rules which he followed: Among exceptions to this general rule is the work of C. Dodd, reference (a), who made systematic investigation of an explosive system. His experiments were comprehensive enough to yield information of quite general usefulness.

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3. With the object of broadening the scope of generally applicable data in this field, a series of measurements has been undertaken of the "critical" conditions for the transmission of detonation between small charges. Although some thousands of firings have been made in obtaining the data recorded herein, the effects of many important variables have not been investigated and many of the mean values quoted may have been obtained with samples which were smaller than might have been desired. It is hoped that the data will be useful to the designer. It is believed that the derivation of a few qualitative relationships is justified. The formulation of various mathematical relationships will have to wait for more complete data.

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4. The object of the experiments discussed herein is to determine the "critical" relative positions for the initiation of detonation in one explosive element (The "acceptor") by means of another (The "donor"). (See Plate 1.) The "critical" position is defined as the most remote of a series of related points at which the donor will initiate detonation of the acceptor. Such information, unfortunately, cannot be obtained for any one combination of a donor and an acceptor. All that can be learned from one shot is that the acceptor was or was not initiated. The first experiment which suggests itself is that of "working up" to the critical point from each side with a series of straddling shots using identical donors and acceptors. However, it is impractical if not impossible to wake components which are nearly enough identical for this type of experiments. Thus, each set of donor and acceptor has a unique critical point. The experiment must be directed toward determining the average critical point which, upon a little reflection, can be seen to be the point at which fifty percent of the acceptors fire. During the past war a method (reference (b)) for determining such statistics was devised by the Explosives Research Laboratory at Eruceton, Pa. and was analyzed and refined by the Applied Mathematics Panel at Princeton. This method, which will be referred to herein as the "Bruceton Method", involves a series of trials the conditions for each of which is determined by the result of the previous trial.

The Sruceton Method

5. The Bruceton Method (reference (b)), was originally devised for use in import sensitivity work with drop test machines, but is applicable to a variety of other similar experiments. As applied to the axial gap tests the method is as follows: A series of gaps are chosen such that the differences between the logarithms of each pair of successive gaps

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are equal. A donor and acceptor are located so that their axes coincide and the distance between their closest faces is equal to one of the chosen gaps (Plate 1). The donor is fired. If the acceptr detonates, the next trial is made using the next larger gap, and if it fails, the next trial is made using the next smaller gap. This is repeated for successive trials until the desired number of trials have been made. The results, which are recorded as shown on the sample record (Plate 2), may be analyzed by procedures outlined in reference (b) to obtain an estimate of the mean (fifty percent point) and standard deviation.

6. Although reference (b) suggests 100 shots as a reasonable sample size, the tests discussed herein were generally limited to samples sizes of 15 to 50 shots because of the considerable expense and effort involved in the preparation of specimens. This results in a loss of accuracy in the estimate but it is compensated to some extent by the rather small deviations observed in these experiments compared with most impact sensitivity data.

Criteria of Detonation

The Bruceton Method is applicable only where the result 7. of a single trial can be definitely placed in one of two categories, in the case of propagation tests detonation or failure of the acceptor. In general this can quite easily be accomplished by direct visual observation of the deformation of the acceptor container. In the usual experiment, however, a few acceptors are found in which the deformation is quite appreciable yet noticeably less than average. A standard is necessary to classify these as "fires" or "misfires". The enlargement of the hole into which the acceptor charge was loaded was used as such a criterion. The enlargement association with complete full rate detonation was determined by firing a few shots at zero gap. The hole size was measured using the shanks of number size drills as plug gages. The largest size drill shank which would enter each of three acceptor bodies, which had been fired at zero gap, was used as a criterion of detonation for that particular type of acceptor. The measurements were made at the end opposite to that from which the acceptor had been fired since the other end was distorted by the action of the donor. This standard may be somewhat arbitrary, but experience indicates that the choice of a standard should have relatively little influence on the estimated critical points, since most acceptor bodies show quite unmistakable evidence of either failure or detonation. In some of the larger sizes a conical slug of metal is spalled from the end of the acceptor body when detonation occurs. In such cases, this type of fragmentation was used as a criterion of detonation.

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Nonexplosive Components

8. The donor and acceptor charges are loaded into heavy walled cylinders as shown on Plates 3 and 4. The donor is merely a cylinder with a hole of the desired column diameter and a counterbore to take the initiator (Plate 3). Brass was chosen because of its machining properties. The outer contours of the acceptor (Plate 4) were so designed to facilitate holding and locating. Copper was chosen because its properties should be more uniform than those of alloys as it is a pure metal.

Explosive Materials, Preparation and Loading.

9. Most of the explosives were used as received without preparation or modification except for drying where necessary. Relatively early in the investigation, it was found that the sensitivity of tetryl was strongly affected by particle size distribution and perhaps other factors. For this reason, all of the tetryl used was from the same two lots (whichwere compared and found indistinguishable). A through 35 on 45 U. S. Standard sieve cut of this tetryl was used. All explosives used for flash charges were ground in a small ball mill (reference (c)).

10. Both donor and acceptor charges were loaded with the mating faces down on flat anvils so that the charges came flush with these ends. Thus, in the experiments, it could be assumed that if the containers were in surface contact the charges were in similar contact. Except where the effects of varying density were under consideration, all explosives in acceptors and the main columns of the donors were loaded at 10,000 pounds per square inch. The flash charges of the initiators were loaded at 4,000 pounds per square inch.

11. In some of the early experiments, lead styphnate was used as a flash charge. It was observed that, when lead styphnate flash charges were used, enough time elapsed between the firing of the flash charge and the detonation of the donor charge for the initiator plug to be forced out of place in some cases. The resulting forward movement of the donor reduced the gap by an undetermined movement. It was determined that with lead azide flash charges this time was too short for appreciable movement to occur. For this reason lead azide flash charges were used in all experiments reported herein.

Apparatus

12. Tests of the kind described above required rather precise location of the acceptor with respect to the donor. The large number of firings required puts a premium on convenience. A scrapped lathe was adapted for this purpose. In a typical test the acceptor was mounted in the chuck and the donor in a fixture which was mounted on the tool rest. The donor is brought to a position such that it is concentric and in surface contact

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with the acceptor. Its displacement from this position can be accurately adjusted by means of the compound of the lathe. Plate 5 shows the apparatus with donor and acceptor containers in place. (Note the cushioned chuck jaws and the rotatable donor fixture.) The lathe is shielded with armor plate (Plate 6), and the doors of the shield are fitted with safety interlock switches which disconnect the firing line when the doors are open. The initiators are fired by the discharge of a 50 microfarad paper condenser charged to 135 volts.

RESULTS AND DISCUSSIONS

13. Since it would be quite impractical to exactly duplicate the arrangements used in these experiments in an ordnance explosive system, the results of these experiments are interesting in that they indicate trends rather than as absolute numbers. For this reason the data are given, with a few exceptions, in the form of curves relating the variables. Most of the results are indicated on Plates 7 through 18.

Diameter Effects

14. On Plate 7 are plotted data obtained with various diameters of donors and acceptors. All donors in this test were approximately 1/2 inch long columns of lead azide loaded at 10,000 psi. as might be expected, the most notable trend is the direct relationship between donor diameter and gap. The relationship between acceptor diameter and gap is more complicated. Unfortunately, the range covered is too limited to give very complete curves for any of the donor diameters used, but it is apparent that each curve reaches a maximum at a point where the acceptor diameter is somewhat smaller than that of the This phenomenon can quite readily be explained in terms donor. of radial losses. The radial losses of small column to the surrounding material are larger in proportion to the chemical potential energy available, so a smaller column must be more vigourously initiated than a larger column. On the other hand, if an impinging shock front strikes only a small fraction of the face of an explosive column initiating detonation of the affected area only, the radial losses to the surrounding explosive will be greater than they would be to a denser confining medium such as steel. As can be seen from Plate 12, these relationships are affected by variations of other conditions such as the loading density of both donor and acceptor. An attempt was made to reduce the results of this particular set of experiments to a useful analytical form. Plates 8, 9, and 10 are various non-dimensional and semi-nondimensional plots from which it was hoped to obtain some hint of a systematic relationship. Plate 9 gives indication of such a relationship. A slight modification of the coordinates of Plate 9 gives Plate 10 on which all of the experimental

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points fall reasonably close to a single curve. The curve which best fits these points is, however, a cubic and the substitution of the coordinate in the equation gives an expression so complex that it is difficult to imagine a use for it.

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15. Curve number (1) on Plate 11 shows the relationship between column length and critical sxial sir gap. It will be noted that even when the length dismeter ratio is as large as 6, additional increments of column length are accompanied by increases in critical gap. Curve number (2) indicates that, in the range covered, a given increase in explosive weight is more effective when it is added by increasing the diameter than when it is added by increasing the length. To put it another way, the optimum length-diameter rario from the point of view of initiating efficiency is apparently considerably below the 2 to 4 which is the most common practice in Navy detonators. This type of efficiency, however, is not necessarily the controlling factor in explosive train design. For example, where a shutter mechanism is to used as a safety device, less novement is probably necessary for a given degree of safety with a long, slender detonator than with a shorter, stouter detonator of the same initiating effectiveness. The curves on Flate 11, as noted, are for lead azide donors and tetryl acceptors. It is quite probable that the optimum length-diameter ratio for other primary explosives, such as mercury fulminate, which are not as quickly detonated as lead azide is somewhat larger than that for lead azide.

Density &ffects.

16. The sensitivity of explosives might be expected to increase with percentage voids for two reasons:

- (a) hs the voids in an explosive increase, a shock of a given pressure can do more work per unit mass in compressing the material, thus raising it to a higher average temperature.
- (b) The increasing inhomogeneity of the materials tends to increase the nonuniformity of heat distribution with the result that the hottest areas may be well above the average temperature.

17. This latter effect has two opposing results; the higher temperature in some spots improves the probability of initiation, while the lower temperature at other points increases the time required for complete reaction (lengthening the reaction aoue), allowing more time for radial losses. The first effect, while quite applicable when the initiating shock is transmitted to the explosive through air or some other gas, becomes such more complicated when the shock is transmitted to the explosive from a lass compressible material, in which case the intensity

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of the transmitted shock depends upon the matching of acoustic impedances of the transmitting medium and the explosive. With so many variables involved, the relation between acceptor density and the probability of transmission of detonation is ouite complex. Unfortunately, experimental data are available for only a few of the many possible combinations of the variables involved. On Plates 12 and 13 are plotted critical gaps obtained with various combinations of two denor diameters, two acceptor diameters and four densities of each charge. It will be noted that the gaps tend to increase with increasing denor density and to decrease with increasing acceptor density.

18. The experiment discussed in reference (a) indicates that the maximum sensitivity as measured by the thickness of a steel barrier through which a tetryl lead could be initiated by means of a certain British type of detonator reached a maximum when the density of the tetryl was about 1.35 grams per cubic centimeter. When copper was substituted for the steel or when air gap was introduced between the detonator and the degrading discs, this optimum density apparently increased, in many tests, to the highest density used (1.65).

19. Figure 14, which is taken from reference (d), shows the effect of density on the initiation sensitivity of several explosives as measured by the booster sensitivity tests described in reference (d). It will be noted that although the sensitivity of tetryl and TNT increases with percentage voids, that of Pentolite and Composition A is nearly independent of density. This may be because each of the last two explosives is a mixture of a sensitive high melting point material with a lower melting, less sensitive material. The most probable form that they would take would be particles with sensitive cores and insensitive surfaces. Thus the high temperature areas resulting from the inhomogeneity of the less dense charges are at the less sensitive parts of the explosive grains.

Confining Media

20. Experiments with varying confining media have been limited in scope up to now. One series was run using O"100 diameter denors and acceptors of lead azide and tetryl, respectively, both loaded at 10,000 psi. The donor container, as usual, was of brass but the acceptor charges were loaded into copper, lead, aluminum and steel. The results are given below:

Confining Medium (Acceptor)	Critical (50%) gap (Inches)	Acoustic (Shock) Impedance (Millions of gm/cm ²
Steel	160	41
Copper	84	47.7
Lead	79	31 - 34.1
Aluminum	43	19.3 - 21.2
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The acoustic impedences given were obtained from data (as yet unpublished) from measurements of shock velocities in metals close to detonating explosives. In general, the velocities are higher than sound velocities in the same materials. It will be noted that the gaps fall in the same general order as the impedances except in the case of steel. It might be postulated that the critical shock pressures lies within the strength of the steel yet well beyond that of the other materials so that the confining action of the steel is by a different mechanism than the other materials which confine the detonation only by virtue of their inertials.

21. On Plate 15, critical gaps obtained using various high explosives as acceptors are plotted against the drop sensitivity of the same explosives. It will be noted that the initiation sensitivity of the various explosives is in as good agreement with the impact sensitivity as can be expected with sensitivity tests. It would seem that the dream of discovering an explosive which is sensitive to initiation by means of enother explosive yet mechanically insensitive will probably remain a dream. On Plate 15 the larger gaps obtained with mercury fulminate donors than with lead azide is mainly due to the higher loading density of the fulminate (both materials were pressed at 10,000 psi which gives a density of the order of 3 grams per cubic centimeter for lead azide and a density of the order of 3.6 grams per cubic centimeter for mercury fulminate) (reference (e)).

Transverse Displacement

A series of experiments was made in which the critical 22. transverse displacement was determined for propagation between lead azide and mercury fulminate donors and acceptors of various high explosives. Plate 16 is a diagram of the test arrangement. On Plate 17 these data are plotted against the axial gaps obtained with the same combinations of explosives. The "s" shape of the curves is quite apparently related to the point at which the expanded hole in which the donor charge had been loaded is tangent to the unexploded acceptor, as shown on the sketch at the bottom of Plate 17. Evidently the initiation of some explosives, including tetryl, is quite probable when the holes overlap and quite improbable when they do not. This suggests that the initiation of these and less sensitive explosives is accomplished primarily by the not highly compressed gases. For more sensitive materials such as RDX and PETN the metal borne shock is apparently an important mechanism. Some of the PETN and RDX acceptors were initiated in the interior as evidenced by the way in which the container was deformed, Plate 18. These data all were obtained using explosives loaded at 10,000 psi in "150 diameter holes. Experiments with other sizes and loading pressures are projected.

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23. The specific conclusions which can be drawn from these experiments are discussed above and summarized in the abstract. In general it can be concluded that the field covered by these experiments is quite complex not only because of the number of variables involved, but because the relationship between some of these variables and the probability of transmission is not simple. On the other hand, taken individually the trends indicated are in general quite reasonable. Many questions remain which may well be answered by further experiments of a similar nature.

A. H. Stresau, Fr.

L. E. Sterr, Jr.

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GAP AS A FUNCTION OF COLUMN DIAMETER FOR THE CRITICAL PROPAGATION BETWEEN HIGHLY CONFINED LEAD AZIDE DONORS AND HIGHLY CONFINED TETRYL ACCEPTORS

CONFIDENTIAL

PLATE 8



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PLATE 10



CONFIDENTIAL

CRITICAL AXIAL AIR GAPS ACROSS WHICH DETONATION IS TRANSMITTED BETWEEN LEAD AZIDE AND TETRYL



AND -

CONFIDENTIAL







PLATE 14



50% POINT vs % VOIDS

CONFIDENTIAL



13



DONOR 0" (50 DIAMETER X 0" 500 LONG ACCEPTOR 0" 150 DIAMETER X 1" 00 LONG







DONOR

ARRANGEMENT OF DONOR AND ACCEPTOR IN THE TRANSVERSE DISPLACEMENT TESTS

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TEAL

