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TECHNICAL REPORT

ESTABLISHMENT OF IMPROVED STANDARDS FOR CLASSIFICATION OF EXPLOSIVES AND PROPELLANTS REPORT #1

A METHOD FOR DETERMINATION OF SUSCEPTIBILITY OF PROPELLANTS AND EXPLOSIVES TO UNDERGO TRANSITION FROM DEFLAGRATION TO DETONATION

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S. WACHTELL C. E. McKNIGHT L SHULMAN

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SUBMITTED BY: S Wortteel REVIEWED BY: 5 Florden

S. WACHTELL Specialist Section 5. FLEISCHNICK Chief, Applications Pranch

APPROVED BY:

AARON RODKIN C' of Ammunition Production & Maint E. G.n. Sering Division

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SECTION 1

INTRODUCTION

In assessing the hazard of an explosive under operational conditions, consideration of types of initiation which are foreign to the operation could lead to classification and costs far exceeding actual need. The intent of this project is to establish ealistic methods of classification which will define precautions required under realistic operating conditions.

One condition of grave concern in this area is the possibility of transition from burning to detonation occurring in large high energy solid propellant motors. Many propellants are known to be detonable under extreme conditions of shock. If all propellants exhibiting this shock sensitivity were handled as high explosives the costs of large missile manufacturing and storage sites could be greatly increased.

In an earlier report (Reference 1a) recommendations of a series of screening tests were made for establishment of the hazard classification of the propellants in end items. The tests of this series could necessitate testing the end item itself. The method discussed here is an effort to develop a laboratory test which will supply the same type of information that is obtained from large-scale tests but as a much lower cost.

With this in mind, the work in this report is the first step in an attempt to determine under what conditions of thermal ignation, she hazard of high order detonation actually exists.

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SECTION II

SUMMARY

A new approach to the classification of high energy propellants and explosives according to their susceptibility to undergo transition to detonation shows promising results. Thus far, most of the materials tested show a critical pressure above which this transition can occur. The method involves the burning of large solid cylinders of the material under consideration in a closed bomb at high pressure. At a pressure which is characteristic for each composition and condition, the burning rate vs. pressure curve obtained shows a marked deviation from the results predicted from strand burning tests. This deviation is indicative of a pre-detonation reaction which takes place in the explosive and which could proceed into detonation if sufficient material were available.

At the present time, this method can determine the gross detonation characteristics of propellant materials -- those which will undergo DDT and those which will not -- under most severe conditions. Future developments will be aimed toward determining how such factors as size, physical condition and geometry will affect the detonability of these propellant materials so that a quantitative haza: I evaluation can be made. This will eliminate the need for expensive testing programs on full-scale motors.

This interim report covers data obtained by this proposed method for two secondary explosives and a number of rocket propellants.

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SECTION III CONCLUSIONS

It appears from results of these tests that for each of the materials studied, there is a critical pressure above which the transition from deflagration to detonation (DDT) can occur. This is helieved to be the result of a surface cracking or crazing which increases the hurning surface and the rate of pressure rise to a point where a shock front can form. The existence of this condition is considered necessary for DDT to occur. If enough explosive material were available, the shock front could reach sufficient intensity to establish a detonation in the explosive.

The application of this test to explosives and propellants should cventually give a basis for a quantitative evaluation of these materials in terms of critical transition pressure, slope of the transition curve and minimum charge diameter. This would make possible classification of these materials as to severity of the conditions to which they can be subjected before the danger of DDT will exist. It would also make possible a study of the effects of temperature, porosity, particle size, crystal size and other physical variables on the detonability of existing propellants and new materials as they are developed. This test will be a valuable tool in the development of new for mulations to study the effect of composition and processing modifications on the detonability of high energy materials.

SECTION IV

RECOMMENDATIONS

This method of testing should be used to classify propellants and explosives as to the possibility of transition to detonation taking place after ignition. In its present state of development, this testing method can be used to establish the gross detonation hazard characteristics of a proportion when subjected to the most severe conditions of temperature and geometry. For large missile motors, it can replace costly tests, such as fire hazard tests on full-scale motors, which are generally run to determine their transition to detonation (or explosive) characteristics.

SECTION V

Background:

Generally, the classification of an explosive material has been based on its ability either to burn or its ability to burn and detonate. This is the basis for ICC Classifications A and B -- tested for by building a fire under the item to be checkliched and be string the input. The formed Forces use a similar basis for classification. Class 2 represents fire hazards (violent burning without detonation or explosion or projection of missiles of appreciable size or range). Class 2A represents fire hazards which, under certain conditions, are capable of low order detonations. (These may mass detonate under very heavy confinement.) Class 9 materials are capable of mass detonation and include many of the higher energy compositions. The ability of a material to under go transition from deflagration to detonation is not considered in this classification, since only the final condition of detonation is of concern.

As long as propellant compositions remained essentially nitrocellulose and nitroglycerin mixtures and were made in fairly small sized units, this method of classification was adequate. With the development of composite propellants and new high energy formulations, the 20% nitroglycerin concept (which had been established as the dividing line between Class 2 and Class 9 for N. G. types) no longer covers the field. For very large propellant motors, booster sensitivity tests up not tell the entire story either ... since there are numerous factors which will

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affect the ability of such a unit to detonate. Conditions of temperature, mass, particle size, geometry, porosity, aging, etc. will markedly affect the ability of a propellant to detonate. It may also markedly affect its ability to undergo transition from deflagration to detonation.

From an economic standpoint, the detonability or non-detonability of a propellant will have a tremendous effect not only on the cost of propellant manufacturing facilities, but also on the cost of handling large solid propellant motors and in the storage of large motors. Therefore it becomes important to find a method of evaluating the possibility of transition taking place under normal conditions of firing or under abnormal conditions, such as accidental or defective ignition or the development of defects in a propellant grain.

Existing test methods for evaluation of sensitivity fall into two basic categories: 1) those involving thermal ignition (ignition temperatures, friction pendulum, thermal decomposition tests) and 2) those involving shock initiation (booster sensitivity, gap tests). Some methods (drop test, bullet impact test) are a combination of both. None of these gives direct information about the basic property of the material which defines its susceptibility to undergo transition from deflagration to detonation. In this report, a method is presented by which a general conduction of this property can be made.

Theoretical Basis

Kistiakowsky (Reference 1) described this mechanism for the development of detonation in a large mass of granular or crystalline explosive ignited thermally at a localized region within the bulk: As the explosive burns, the gases formed cannot readily escape between the explosive crystals and a pressure gradient develops. This crease in gas pressure causes an increase in burning rate which, in turn, causes an increase in pressure with constantly increasing velocity. This condition results in the formation of shock waves which are reinforced by the energy released by the burning explosive, these eventually reach an intensity where the entire energy of the reaction is used for propagation of the shock wave, and a stable detonation wave is produced. A critical size exists for each material above which this deflagration can pass over into detonation under proper conditions. Below this size, the burning will first increase, then fall off as the material is consumed. The transition to detonation is considered largely a physical process in which the linear burning rate of the bed of material increases to the rate of several thousand meters per second, although the individual particles are consumed at the rate of only several hundred inches per second.

The validity of this mechanism for propellants in granular form has been demonstrated by a number of investigators (Reference 2 and 4). While this mechanism is applied to granular material, why should it not apply all well to composite or homogeneous propellants, if the growth of a shock front can be shown (Reference 4) which is accomposited by an increasing break-up of the surface of the propellant? Analysis of the

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data from the following experiments indicates that this is a possible explanation of this phenomenon in solid propellants and explosives.

The apparent non-detonability (through transition) of nitrocellulose propellants may be attributed to the dense surface preventing deflagration from taking place in the interstices of the materials. In spite of this, under conditions (such as low temperature) where the propellant becomes very brittle or possibly crystalline. these propellants have blow, up gun tubes. For composite propellants, the continuous and highly elastic nature of the binder probably prevents this type of reaction. However, it has been shown that many highly elastic materials will undergo brittle failure when stress at very high strain rates is applied (Reference 5 and 6). Experimental Approach

If it is assumed that the surface burning theory holds for the release of energy to support detonation behind \pm shock front, and that the tremendous increase in burning rate in detonation is due to a large increase in burning surface due to a breaking up or surface cracking of the explosive material at the shock front, then by developing a technique for studying the burning rate of a propellant composition as it progresses into the very high pressure ranges, a basis for evaluating its relative susceptibility to detonation might be found.

Based on experience with some cannon propellants in closed bomb tests -- in vluch unexpectedly high rates of change of pressure were observed -- it was considered possible that the closed bomb technique might be used to demonstrate the property of detonability for rocket propellants. It had been found that when the tested lot of cannon propellant

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deviated from normal behavior, the occurrence of high rate of change of pressure started at a reproducible specific pressure. Since the burning rate law holds for these propellants up to high pressures, a reasonable explanation is that surface cracking or creating occurred under the pressure and thermal stress of the reaction. This increase in burning surface is believed the initial step in the transition from deflagration to detonetion and the critical pressure and the rate at which the increase in surface area occurs can be calculated from measurements made in the closed bomb.

The calculation of linear burning rate from closed bomb measurements has been standard procedure for many years (Reference 7 and 8). From a consideration of the original geometry of a grain of material and a knowledge of the rate of change of pressure in the bomb when the grain is burned, the linear burning rate at any particular pressure can be calculated. This calculation assumes that the grain is ignited uniformly over its entire surface and always burns normal to that surface. However, it surface cracking or crazing should occur, the calculated linear burning rate will be far in excess of the value expected, and the increase in surface area can be calculated from this apparent increase in linear burning rate. Details of these calculations is in Appendix A.

RESULTS

1. TNT

To determine whether the closed bomb method would throw any light on the burning of high explosives, cylinders of TNT were prepared with diameters of 1" to 1-1/4" and lengths of 1" to 3". There are index a were machined from solid blocks of TNT which had been carefully cast to make

certain that they contained no voids or porosity. All the cylinders were machined from the same block and were considered to have approximately the same crystalline structure. These cylinders were blaced in a standard 200cc closed bomb with a reinforced cylinder will and fired with a small amount of Grade A5 black powder and in MIAI Squibb. Tracings of typical oscillograms resulting from the traings are in Figure 1. These represena series of firings made with cylinders of TNT of various loading densities. In the first of these, while as inserted contrementing the trace which should have been obtained if the cylinder of TNT of various loading densities. In each case a marked deviation from a contract or curred at 6, 600-8,000 psi. In examining these tracings in must be remembered that the standard closed bomb instrumentation produces an oscillogram of dp/dt vs. P and that the horizontal axis represents P and the vertical case represents rate of change of P. The scale as varied to have the trace fill the oscillogram. The calculated scales of P and dp/dt case added to the tracings.

When linear burning rites were calculated from these traces, the results in Table 1 and Figure 2 were obtained. As overlage line is drawn for burning rates calculated from the closed bomb test.

To establish the true burning r to for TNT stouds 1/8"X1/8"X7" long were prepared by cutting them from block of TNT similar to the second previously. These strands were burned in a strand burner using the standard technique at pressures from 1 000 psi to 20,000 psi. The test results are included in Figure 2

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The results in Figure 2 show that the calculated closed bomb burning rates approximately coincide with strand burner result up to about 6,000-8,000 psi and then shably curve upward. This "apparent" increase in burning rate is consistent with the acsumption of an increase in burning surface which occurs on the cylinder due to burface crazing or cracking. Figure 3 shows a graph of the expected surface area vs. pressure (incorcurve) assuming normal geometry during burning of the grain and the supported which such a some second for a claubied by combining the dp/dt of the bomb test with the actual linear burning rate from the strand burner (upper curve) This shows an increase in surface area of close to 20 times for TNT.

It was desired to determine whether the change of slope in Figure 2 was strictly a pressure and thermal effect and independent of the amount of TNT burned. Therefore, a technique was devised whereby a quantity of thin sheets of a very fast burning propellant was loaded into the bomb with the TNT. On ignition, this material burned quickly, giving an initial high pressure and temperature to the bomb before any appreciable burning of the TNT took place. This technique permits a larger mass of TNT to be present at higher pressure. Measurement made in this way showed virtually no change in the pressures at which the change in slope show place in the lower part of the curve or in the slope of the middle plate of the curve. However, an increase in the slope of the upper part of the burning rate curve did result. This tends to confirm the idea that there is possibly some minimum mass of explosive necessary to methering in the formation of increasing burning surface. This area will be further investigated.

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2. Composition B

Cylinders of Composition B prepared in a manner similar to the TNT samples were then burned in the bomb at varying loading densities. To obtain adequate ignition of Composition B it was necessary to use a small amount of sheet propellant as igniter. This masked that part of the curve below about 5,000 pai. However, strands cut from the same block of Composition B as the cylinders were burned in the strand burner to obtain the normal burning rate vs. pressure curve (Table II and Figure 4 and 5). The conclusion is that the break in the Composition B curve occurs about 4,000-5,000 psi. The slope of the closed bomb curve past the transition may be even greater than that obtained for TNT. The surface area vs. pressure curves for calculated normal burning vs. actual closed bomb burning of a sample of Composition B is in Figure 6.

3. ARP Propellant

A sample of ARP propellant was subjected to the closed bomb test. To establish the applicability of the closed bomb technique to determine detonability of high energy propellants. Figure 7 shows a series of tests resulting from increasing loading densities up to about 0.40. When increased to 0.43 by preloading with sheet propellant, a change in slope occurred at about 35,000-40,000 psi similar to those obtained for TNT and Composition B. This was accompanied by a disintegration of cur or the scale in the bomb. Unfortunately, each time conditions were used in which the traruition was expected to appear, the rate of energy release was so great that some part of the bomb seal was destroyed and a part of the trace was lost. A bomb is being designed to hold the pressures produced and measure transition pressures similar to those obtained for TNT and Composition B.

Table III and Figure 8 how a plot of linear burning rate vs. pressure calculated from the available data for the ARP propellant burned with and without preloading. The linear burning rates obtained with the strand burner are almost coincident with those calculated from the closed bomb at pressures of 10,000 psi and above.

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A sample of highly sensitive experimental propellant was then subjected to this detonability test. This material had been found to be detonable with No. 6 blasting cap. Cylinders of different diameters were tested and pressures up to 85,000 psi were obtained. A sharp transition was nutained at about 15,000 psi (Figure 9). Also, the fall-off from the maximum dp/dt begins at a much lower percentage of the maximum pressure than for the high explosive samples. Figure 10 and Table IV show the data and a plot of the linear burning rates calculated from the closed bomb traces. The strand burner curve was extrapolated from low pressure data since strands of this material were not available for high pressure testing. Figure 11 shows the surface area relationship between expected area and supposed actual area obtained.

5. Rohin & Haas QZ Propellant

z sample of QZ propellant composition was obtained from Rohm and Haas at Redstone Arsenal, Huntsville, Alabama This material is the same propellant composition that detonated in $\approx 7,000$ -pound mator in the

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summer of 1959. While the failure of this motor was attributed to some porosity of the propellant or poor case bonding in some areas (Reference 9), there is little doubt that the explosion was high order.

The samples were machined to cylinders of $1.25^{"}$ and $1.50^{"}$ diameter and tested, first at 70°F and then at -60°F. Figure 12 shows traces of typical oscillograms from these tests. The 70°F tests showed normal burning rates when calculated up to 90,000 psi. The low temperature test showed an abrupt change from normal burning at about 55,000 psi. The increase in burning surface calculated from this apparent increase in burning rate is of the order of four times and is in Table V ... as are the apparent burning rates. While this increase in burning rate is small compared to some of the other materials tested, the abrupt change at only low temperature indicates the development of an undesirable property which might lead to a hazard.

Discussion of Results

A preliminary study of the data obtained for the ratio of cylinder area to supposed actual area -- the area that would exist if normal burning took place with no break-up -- indicates the existance of a diameter below which the continued cracking or increase in surface area stops and the explosive tends to return to normal burning. This occurs because there is not sufficient material available to develop a shock wave of sufficient intensity to go to detonation.

Figure 13 shows the ratio of surface area from closed bomb to expected surface area for the same cylinder of TNT presented in Figure 3 (assuming no break-up takes place). This shows that the ratio increased until about 50% of the mass of the grain was left (determined from percent of P max).

An equivalent study for a Composition E cylinder in Figure 14 shows that the increase in surface did not start to level off until about 70% of the grain was consumed.

The "Experimental Fropellant" was tested in cylinders of different diameters and the changes in burning rate as a function of geometry were calculated. It was found that for cylinders of two different diameters, increases in surface area were obtained as long as burning proceeded to a diameter of about .78 inch -- the same for both sizes tested. This indicates the possibility that there is a minimum diameter characteristic of each material. It may explain why in earlier work on burning of explosives in a closed bomb by Buck, Epstein and Jacobs under the NDRC (Reference 11), the high burning rates described in this report were not observed, since the explosives were burned in small grains.

An analysis of the relationship of unburned fraction and remaining diameter to the changing burning surface for Rohm and Haas QZ Propellant shows that the burning surface stops increasing when the diameter of the grain reaches 0.8 inches at -60°F and then decreases back to normal burning. If sufficient mass were available, it is believed this increasing burning area would be maintained and might be sufficient to set up the conditions necessary for transition to detonation.

In addition to the data reported above, a number of other less sensitive materials were tested in the bomb, with and without preloading. OIO propellant taken from "Honest John" grains were tested in 1" diameter cylinders and Polysulfide Perchlorate propellant samples from XM30 motors were tested and found to give normal traces up to pressures of 80,000 psi. This indicates that, at the temperature of testing and in the p..ysical condition of the tested samples, transition to detonation from normal burning could not occur unless conditions were more severe than those used in the tests.

The correlation of severity of conditions in the bomb, with the severity of conditions which might be encountered in actual burning still needs to be investigated. Since the Rohm & Haas QZ propeilant is considered to have detonated in a 7,000-lb. motor on a test stand after high pressure conditions were obtained because of porosity and poor bonding (Reference 9), the possibility exists that the shock conditions resulting from the high pressure development in this test motor might have induced this material to undergo transition.

The question has been raised: Is it possible for cracking or crazing of the surface of this material to occur due to hydrostatic pressure applied in the bomb? Considering the rapidity of the rate of pressure rise under the conditions of the bomb test, it is conceivable that hydrostatic conditions are not attained within the time that the event occurs; rather an unbalanced time as develops in the grain giving rise to a tensile stress in the material. For crystalline nuterials like TNT the cracks could develop in the crystal boundaries. Confirmation of this might be obtained if casting: of TNT of different crystal size were subjected to the Closed Bomb Test. Different

rates of change of surface area should be obtained for the different crystal sizes. For Composition B, the brittle matrix of TNT plus the interfaces of the RDX particles probably lowers the pressure and dp/dt at which this phenomenon occurs. For propellants which are more elastic in nature, this mechanism does not occur until very high pressures and rates of change of pressure are reached. The fact that builtle fracture occurs for highly elastic materials at very high rates of strain has been demonstrated by J. W. Jones (Reference 5 and 6).

In any case, the pre-detontation reaction is probably a function of the three conditions of prossure, rate of change of pressure and temperature.

It is believed that any explosive or propellant material which can be detonated should exhibit the phenomenon of the pre-transition reaction and critical pressure described in this work. In the case of very sensitive primary explosives, the level of the controlling parameters required to start high order detonation is so low that they cannot be measured by present techniques. For "non-detonable" composites or single base propellants, it is possible that the pressures and rates of change of pressure required are extremely high. Efforts are being made to develop the technique into a practical test of propellants at much higher pressures so that any materials which can be detonated with high explosive boosters can give a positive test in the closed bomb. After this technique has been worked out, entire series of propellants in use in existing missiles, and those compositions under development, will be subjected to this test for the purpose of classification.

Future Work

A program has been undertaken to design a high pressure vessel capable of making the required measurements up to 400, 000 psi. The principle being explored is that of a disposable unit which will hold the pressure long enough to make the necessary measurements of pressure and rate of change of pressure. The design of a transducer with a frequency response sufficiently high (200-500 KC) to obtain accurate measurements is also being investigated.

To relate the results of this test to actual conditions in a large motor, in effort is being made to establish the relationship between the rate of pressure rise which might occur in a large mass of propellant and the time to tensile failure of this mass of propellant, if a small defective area should exist (one containing a porous section in which the surface area available for burning is much larger than normal). If it can be shown that the local pressures obtainable under reasonable conditions of defects are in the range of the critical pressure required for the pre-transition reaction to occur, then it is considered reasonable to assume that transition from burning to detonation is possible in the given full scale grain.

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APPENDICES

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APPENCIX A

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METHODS OF DATA REDUCTION AND CALCULATIONS

APPENDIX A

METHODS OF DATA REDUCTION AND CALCULATIONS

I. Linear Burning Rate

A. Theory

The linear burning rate is the rate at which the burning surface of a propellant recedes in a direction normal to the flame front.

If dx is the distance burning more eds during any time interval dt, then dx/dt is the linear burning rate.

By assuming that all surfaces of the burning propellant burn at the same rate, and by using a known geometry, the linear burning rate can be deduced from the mass rate of burning. By the assumption of a suitable equation of state the mass rate of burning can be deduced from the rate of change in pressure surrounding the hurning propellant in a closed vessel.

For particles of known shape, such as perforated or solid cylinders, the closed bomb fitted with a rapid response pressure gage is a suitable experimental apparatus for determining the linear rate of burning of propellants or explosives at any pressure.

The apparatus produces an oscillographic trace of piezo-criginized volvages as measures of the rate of change of pressure, dp/dt, and pressure, P. Sample traces are shown in Figure 1. The rate of change of pressure is calculated from the ordinate voltage T_{x} , and the pressure

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from the abscissa voltage. V_y , after appropriate calibration and determination of gage constants.

$$P = K_g C_x V_x + K_1$$
(1)
$$dp/dt = \frac{K_g V_y}{R}$$
(2)

The maximum pressure (at the end of burning) can be used to measure the combined temperature and gas molecular weight function, thus completing an expression for the equation of state in terms of Z, the weight fraction burned, and P_i , the pressure due to prepressurizing and igniter, if any, where K_g , C_x and K_i are equipment constants:

$$P_{\max} = K_g C_x V_{\max} + K_1$$
 (3)

$$P = P_{i} + \frac{Z}{1 - \left[\frac{(1 - \frac{m_{i}a_{i}}{m_{o}} + a) D_{o}}{[b + \frac{m_{i}a_{i}}{m_{o}} + (a - b) Z] D_{o}} \right] (P_{max} - P_{i})$$
(4)

To simplify calculations the term (m_i/m_0) a_i is considered negligible because of the relatively small quantity involved in m_i , the mass of igniter and prepressurising materials.

The geometry for solid cylinders of propellant or explosives burning on all surfaces is stated in terms of fraction burned, Z, and dimension remaining, (d-2x) and (h-2x), at any time:

$$Z = \frac{(d-2x)^2}{d^2}$$
 (h-2x) (5)

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The derivative, dp/dZ, may be found from equation 4 and the derivative dZ/dx from Equation 5:

 $dp/dZ = f_1$ (Z) (6) $dZ/dx = f_2$ (x) (7)

The linear burning rate can be calculated from Equations 2, 6, and 7:

$$dx/dt = \frac{dp/dt}{(dp/dZ) (dZ/dx)}$$
(6)

B. Calculation Method.

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The Equations 4-3 have. in principle, been re-arranged by W.F. Wallace (Reference 8) to a form suitable for direct solution. The solution was made in terms of the surface area (S_x) at any value of x. With slight modifications, Wallace's equations were used to convert the closed bomb data to linear burning rates.

The equations used for this solution for a solid cylinder are listed helow. These equations were programmed for solution in an IBM 650 computer.

$$K_6 = (d-h)^2 / 1.5 hd^2$$
 (9)

$$K_5 = 27 hd^2/2 (d-h)^{.5}$$
 (10)

$$B = (P_{max} - P_i) (1 - aD) / (a - b) D$$
(11)

$$C = (1-bD) / (a-b) D$$
 (12)

$$Z = (P - P_i) (1-bD)$$

$$(P_{max} - P_i) (1-aD) + (P - P_i) (a-b) D$$
(13)

A- 3

$$E = 1 + K_{5} (1-Z)$$
 (14)

$$\boldsymbol{\phi} = \cos^{-1} \mathbf{E} \tag{15}$$

$$S_{x}/V_{o} = [1-2\cos(60^{\circ}+2/3\phi)] K6$$
 (16)

If
$$E \ge 1$$

 $S_x / V_o = \left[\left(\left[E_1 + \left(E^2 - 1 \right)^{\frac{1}{2}} \right]^{\frac{1}{3}} + \left[E_2 \left(E^2 - 1 \right)^{\frac{1}{2}} \right]^{\frac{1}{3}} \right]^{\frac{1}{3}} \right]^{\frac{1}{3}} - 1 \right] K_6$ (17)

$$dx/dt = \frac{dp/dt}{\frac{B}{C} (1 + \frac{P}{B})^2 \frac{S_x}{V_0}}$$
(18)

In these equations certain special cases had to be recognized to allow for discontinuities introduced by algebraic and trigonometric solutions. When diameter exactly equals length, a discontinuity arises in (Equation 9) for K_{6^+} . An increment of 0, 01 inch is therefore added to one dimension for this special case. If the quantity E is less than unity a cosine procedure is used (Equation 15); if equal to or greater than unity a cube-root procedure is used (Equation 15); if equal to or greater than unity a cube-root procedure is used (Equation 17). Either procedure leads to S_{χ}/V_{0} which is then used in the final equation (Equation 18) with the experimentally observed dp/dt to calculate the linear burning rate dx/dt.

II. Equivalent Surface Areas

A. Theory

When linear burning rates of single cylinders of propellant or explosive are found from closed bomb data using the solid cylinder geometry as described above, the results compare well with strand burner results below a certain characteristic pressure. At other pressures the burning rate so calculated must be regarded as an "apparent" burning rate because it deviates a great deal from strand burner results.

This suggests that the general configuration may be cylindrical, but the surface may be full of cracks or may be breaking into small pieces, with the strand burning rate governing the reaction for each burning particle. Combining experimentally determined rate of pressure rise, dp/dt, and pressure, p. with strand burning rates, dx/dt, permits solving for a surface area, Sx, which will reflect the abnormally high mass rate of burning.

Thus P, dp/dt, and P_{max} are found as before Equations 1, 2, 3. The equation of state showing total pressure as function of fraction burned is also applicable(Equation 4). Likewise the fraction burned is related to the burning cylinder dimensions by Equation 5 for a smooth cylinder. In Equations 8 and 18, however, the predicted linear burning rate from strand burner data,

$dx/dt = ap^n$

would be used. Then from Equation 18 the equivalent area S_{χ} is function representing surface area of cracks and convolutions on the surface of a rough cylinder. The equivalent areas are found to proceed through a maximum (Figure 3) before reaching zero during burning.

A-5

APPENDIX B TABLES

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CLOSED BOMB

Test #24

BC

24

350

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g I sec

Loading Density, g/cc-, 350 Max Pressure psi-63, 650 Diameter. m-1,25 Length, m-2.00

PX10	dp dt X 10 ⁻⁵	burning Rata in/sec
12. 5	23.7	13.6
16.5	64.6	37.5
20.9	:03.3	61.3
24, 9	:31.3	80.1
28.9	55.0	97.9
33.0	170.0	112.3
37.0	185.1	129,4
41.0	158, 3	141.5
45.1	177.5	146.4

Test #51

Test #12

2,72

4.88

8,23

14.3

Loading Density, g/cc-. 221 Max Pressure, psi-35,885 Diameter, in-1.00 Length, in-1.95

Fraction

Burned (Z)

. 100

. 264

.266

. 467

.565

. 662

.757

.850

Loading Density, g cc-, 273 Max Pressure, psi-41, 286 Diameter, in-1.25 Length, in-1.55

Test #14

Test #10

Burning Rate

in sec

. 439

1.13

3.08

8.81

18.6

52.6

51.0

77.6

Fraction

Burned (Z)

.162

. 286

.407

. 522

.634

.742

.847

.949

Loading Density, g. co., 165

dp dt

x10⁻⁵

.448

1.07

2.69

6,90

12.6

18.3

21.1

16.6

Max Pressure, psi -23, 600

Diameter, in-1.00

Length, in-1.65

PX10-3

3.39

6.08

8.77

11.46

14.15

16.84

19.53

22.22

Loading Density. g/cc-, 197 Pre-Loading, psi-5,000 Max Pressure, psi-36, 170 Diameter, in-1.08 Length, in-1.45

PX 10-3	dp/dt X10 ⁻⁵	Burning Rate	Fraction Burned (Z)	PX10-3	dp, dt X 10 ⁻⁵	Burning Rate in sec	Fraction Burned (Z)	PX10 ⁻³	dp dt <u>X 10</u> -5	Burning Rate in/sec
4,74	.978	.71	. 159	13.1	25.8	20,9	. 361		ን ሰዓ	1. 44
6.75	1.71	1.27	. 223	19.3	54.8	49.3	, 537	9, 86	27.0	22.0
8.77	3.18	2.41	. 286	25.4	78.5	82.9	. 681	12,00		30.5
10.8	6.60	5, 15	. 347	31.6	83.9	116,4	.813	16-01	35. 0	49.0
12.8	13.9	10.6	. 407	37.8	50.6	130, 2	.936	19.12	62, 4	62.7
16.8	32.0	28.5	. 522					22.21	72,8	81.4
20,9	47.0	47.0	. 632					25, 30	74.9	96. 3
24.9	56.7	66.8	. 738					28, 39	62.4	97 5
26,9	56.7	74.6	.788						•	

B-1

Loading Density, g. cc-.11 Max Pressure, psi-14, 310 Diameter, in-1.00 Length, in-1.01

PX 10 ⁻³	dp dt X10 ⁻⁵	Burning Rate in sec
2.11	ودز .	, <i>231</i>
3.52	.315	. 473
4.94	. 460	,749
5.35	.751	1.35

1.36

2.08

2.86

3.68

Test #7

7.76

9.17

10.5

11.9

TABLE I

CLOSED BOMB AND STRAND BURNING DATA FOR TNT

[est #24

Loading Density, g. cc., 350 Max Pressure, psi-63, 650 Drameter, in-1, 25 Length, in-2, 00

OMB

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Rate

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Rate

1,

2

PX10 ⁻³	$\frac{d_{\rm P}}{X 10} \frac{dt}{-5}$	Buttolica Bate	Fraction Burned (Z)
12, 8	23.7	13.0	.275
16. 5	64,6	•	.351
20.9	103.3	1. 1. 5	. 424
24.9	131.3	Ster	. 492
28.9	155.0	4 * , 4	. 357
33.0	170.0	1.7.3	.618
37.0	185.1	12:4 -4	.677
41.0	185.3	141.5	1.52
15.1	177.5	: .	.785

Test 31

Loading Density, g. 604, 176 Pre-Loading, psi-5, 000 Max Pressure, psi-36, 170 Diameter, in-1,08 Length, in-1,45 Test #25

Loading Density, g. cc-, 387 Max Pressure, pci-72, 040 Diameter, in-1, 25 Length, in-2, 20

PX10 ⁻³	$\frac{dp}{x} \frac{dt}{10} = \frac{5}{x}$	Buming Rate	Fraction Burned (7)
12. 8	21.5	11.6	.260
16.5	54, 2	29,7	.331
.0.9	194.4	57.U	, 400
24, 9	146.3	81.0	. 462
28.9	175.4	98.9	. 521
33.0	195. 8	113.0	. 578
37.0	213.0	127.3	,632
41.0	222.7	138,9	. 682
45,0	222.7	146.4	.231
49, 1	213.0	149,9	.776

Test #52

Loading Density, g. cc-, 197 Pre-Loading, psi-10, 000 Max Pressure, psi-45, 060 Diameter, in-1, 08 Length, in-1, 45

×10 ⁻³	dp∉dt X10 ⁻⁵	Buming Rate in sec	Fraction Burned (2)	PX10 ⁻³	dp dt X10 ⁻⁵	Burning Rate in sec	Fraction Burned (2)
6.78	2.08	1.62	.065	12, 95	26.0	18.2	. 099
9,86	27.0	22.0	,182	16,04	49.9	36.5	. 200
.95	42.6	36, 5	, 292	19, 13	68.6	52.8	297
04	53.0	49.0	, 398	22. 21	85.3	69.7	391
12	62.4	62,7	. 499	25, 30	98.8	86.9	
21	72.8	81,4	. 597	28, 39	107.1	103.0	570
. 30	74.9	96.3	. 692	31.48	110.2	118.0	. 570
39	62.4	97.5	,783	34, 56	107.1	133.8	737
				37, 56	88.4	135.7	.818

Test #20

Loading Density, queee, 273 Max Pressure: 181-45, 150 D. meter: 181-45, 150 Length, in 1, 55

	dp. dt	Barnava Rata	Frantion
PX 10 ⁻³	X10 ¹⁰	11 Sec.	Burned (Z)
12.5	15.6	:0,5	, 325
15.8	35.1	-HU, 0	. 394
18.9	76.9	• • • • •	. 461
21.9	52.5	65.5	, 526
24,9	101.6	\$2.1	.588
27.9	105.1	1.5	. 645
31.0	110.3	10.47	.705

Pressure, psi 2,000 3,000 6,000 10,000 20,000

Str 4

3,000 3,000 3,000 3,000 3,000

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i (Z)

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NG DATA FOR TNT

:#25

Test #20

Burning Rate

in sec

10.3

40.6

55,9

05.5

82.1

93,5

103.7

Fraction

Burned (Z)

, 325

. 394

.461

. 526

. 588

, 648

,705

Loading Density, 4 cc-, 273

dp dt

X10⁻⁵

......

55.1

S. 5

101.6

10×.1

110.3

Max Pressure, psi-48, 150

Diameter, in-1,25

Length, in-1, 55

PX 10⁻³

•

15.8

15.9

21.9

24.9

27,9

31.0

Test #23

Burning Rate

in/sec

16.9

36.2

59.7

75.8

94.3

104.6

117.3

118.8

Fraction

Burned (Z)

. 362

. 386

.465

.539

.610

. 677

.740

. 800

Loading Density, g/cc-. 330

dp/dt

X10⁻⁵

26.9

56.0

89.3

108.7

128.0

132.3

135.6

121.6

Max Pressure, psi-55, 900

Diameter, in-1,25

Length, in-1.85

PX10⁻³

12.8

16.8

20.9

24.9

28.9

33.0

37.0

41.1

ding Density, g. cc., 387 1 Pressure: psi-72, 040 meter: in-1, 25 1th. in-2, 20

) ⁻³	$\frac{dp}{X10} \frac{dt}{5}$	Burning Rate in sec	Fraction Burned (Z)
i	21.5	11.6	260
	54.9	29.7	. 331
)	104.4	57.0	, 400
	146.3	\$1.0	. 462
	175.4	98.9	, 521
	195, 5	113.0	. 578
	213.0	127.3	.632
	222.7	138.9	. 682
	222.7	146, 4	.731
	213.0	149.9	.776

Test #52

ing Density, y -cc-, 197 oading, psi-10,000 Pressure, psi-45,060 leter, in-1,45 h, in-1,45

	dt.			Strand Burning Rate of INT		
Stra -3	x:0 ⁻⁵	Burning Rate	Fraction Burned (Z)	Pressure, pai	Burning Rate	
i 🔤	26.0	18.2	.099	2,000	0.386	
	49,9	36.5	. 200	3,000	U. 457	
	65.6	52.8	. 297	6,000	99.2 u	
	85.3	69.7	. 491	10,000	2. 60	
	95.8	56.9	. 482	23,000	3.46	
	107, 1	103.0	, 570			
	110,2	118.0	. 655			
	107,1	133.8	.737			
	88, 4	135.7	.818			

Rate, in/sec

on

(Z)

2

6

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9

0

7

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e, psi

100

100

)

CLOSED BOMB AND

Loading Deasity, g/cc-. 165

Pre-Loading, pt.-10,000

Max Pressure . DSI+50, 675

dp dt

∵e⁻⁵

6.2.

24.96

67.60

119.6

164.3

182.0

176.8

104.0

Diameter, in-1.05

Length, in-1.20

12.5

12, 30

15,23

21.08

26.93

32.78

38, 63

41.55

47.40

Test #68

Burning Rate

· · · · ·

3.24

13,66

40.61

81.08

131, 53

185.6

214.6

243,9

16

1

5

in

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13

4**(** 81

31 81

1.

41

71

2

in

Test #61

Loading Density, g/cc-.110 Pre-Loading, psi-none Max Pressure, psi-20, 620 Length, in-1.00 Diameter, in-0.800

n

(Z)

PX 10-3	dp dt X 10 ⁻⁵	Burning Rate	Fraction Burned (Z)
2.23	. 52	. 46	. 115
3.85	1.04	. 97	. 197
5.48	2, 34	2, 32	. 279
7.10	2,60	2,75	. 360
8.72	4.16	4.76	. 440
10.35	5.46	6.83	. 519
11.98	8, 32	11.55	. 597
13.60	9,88	15,61	. 675

Tett #64

Loading Density, g. cc-, 110 Pre-Loading, rei-2, 500 Max Pressure, psi-24, 260 Diameter, in-1.06 Length, in-0.800

ap at X10 ⁻⁵	Burning Rate in sec	Fraction Burned (Z)
2.03	1.69	.066
4.16	3, 55	. 145
8.32	7.49	. 223
13.52	12,90	, 300
18.72	19.0	. 377
24,96	27.40	. 452
28.08	33, 60	. 527
33.28	44.07	. 602
36.40	54. 49	. 675
38.48	67.21	.747
	2.03 4.16 8.32 13.52 18.72 24.96 28.06 33.28 36.40 38.48	dp dt Burning Rate -5 in sec 2.03 1.69 4.16 3.55 8.32 7.49 13.52 12.90 18.72 19.01 24.96 27.40 28.06 33.60 33.28 44.07 36.40 54.49 38.48 67.21

Test #62

Loading Density, g cc-, 110 Pre-Loading, psi-S,000 Max Pressure, psi-27, 900 Length. in -1.06 Diameter, in-0.800

_3 	dp. dt 	Burning Rate	Fraction
7.10	6, 84	5.41	. 098
8.75	11.33	9.36	. 172
10, 35	15.60	13, 57	. 246
11.98	21.84	20.11	. 319

Test #65

Burning Rate

in sec

5.80

11.30

19,24

26.23

34, 22

42.43

\$3.52

64.53

77.38

91.78

Fraction

Burned (2)

. 099

.174

.244

. 323

. 396

. 465

. 541

613

. 682

. 752

Loading Density, g cc-, 110 Pre-Loading. psi-5,000 Max Pressure, psi-27, 630 Diameter, in-1.06 Length, in-0.800

dp dt

x10⁻⁵

7.28

13, 52

21,84

28.05

34.32

39, 52

45.76

49,92

53.04

54.08

PX10-3

7. :0

8,73

10.35

11.98

13.60

15,23

16.85

18.48

20.10

21.73

Test #70 Loading Density, g cc-, 220

Pre-Loading, psi-10,000 Max Pressure, psi-66, 432 Diameter, in-1.06 Length, in-1.60

dp dt X 10 ⁻⁵	Burning Rate	
50, 27	21, 83	
1.11	40.64	£ .
1 A A	64, 41	
	133.7	Γ.
303.5	171.3	
346.7	207.2	
397,0	283.	
377.9	313. 4	
	dp dt <u>X10</u> ⁻⁵ 50, 27 1, 13 303, 5 346, 7 395, 0 377, 9	dp dt X10 ⁻⁵ Burning Rate 50, 27 21, 83 51, 13 40, 64 133, 7 64, 41 133, 7 305, 5 346, 7 207, 2 390, 0 283, 1 377, 9 313, 8

8-2

TABLE II

CLOSED BOMB AND STRAND BURNING DATA FOR COMPOSITION B

Test #65

Loading Density, q cc-, 105 Pre-Loading, psi-10,000 Max Pressure, psi-50.075 Diameter, in-1.06 Length, in-1.20

AND

tóâ

165

S

ing Rate

n/se c

3, 24

13, 66

40. o1

81.08

31. 53

85.6

14.6

43, 9

70

2:50

2

ing Rate

160

21.83 40.64 64, 41 33.7 71.3 b7.2 B3. O

13. 4

PX10 ⁻³	$\frac{dp}{X10} - 5$	Barrin (E 🖓 m 🤞	Fraction Burned (7)
12, 30	6,24	3. <u>.</u> .	. Uni
15.23	24.96	2 × 18	: 41
21.05	67.60	n 1, 2	, 295
26,93	119.6	N	. 443
32.78	164.3	1.5	. 557
35. 05	152.0		. 726
41.55	176.5	2 •	.794
47.40	104.0	24	. 42,

Tett

Loading Density of Pre-Loading, pti-1 (k-Max Pressure, par-ter 1.2 Diameter, 10-1.96 Length, m-1.80

PX10 3	dy-dt X 10 ⁻⁵	Barri ete Di en	Fraction Numical (a
16, 20	50, 27	21.44	. 12+
20, 10	20, 13	44 F. H. B	70 -
24.00	136, 9	+ 1, 41	. 275
31.30	256.5	133.2	. 424
35.70	105.5	171.4	
39.60	346.7	307.2	. 561
47.40	390, 0	2=1.0	. 497
51.30	377.9	313.4	. 761

l'est #69

Loading Density, g. cc-, 220 P---Loading, pti-5,000 Max Pressure, psi 58,090 Diameter, in-1.06 Leigth, in-1,60

PX10 ⁻³	dp di N 10 ⁻⁵	Bummy Rate	Fraction
7.75	6.24	2.72	.060
11.44	17,000	8,20	. : 17
14, -61	40.5	2., 54	. 211
22.05	123.5	65, 11	. 356
25, 63	153.9	55, 45	. 426
\$2,78	216.3	137.2	, 562
30. 35	237.1	163.7	. 627
47.05	234.0	240, 3	. 817

Test #71

Lasting Dangery, 1 . . . 164 Pre-Loading, pti-15,000 Max Pressure: per-55,090 Diameter, m-1.06 Length, in-1.30

p dt 10 ⁻⁵	Bart ste di se	Fraction Sumical (2)	PX 10 ⁻⁺	и чь ⁶ чі Х	Runcing Rate	Fraction Numed (Z)
50, 27	21.64	. 12+	15, 18	5. 6	4, 84	, 089
io, 13	\$63, 85 \$	20 -	22.05	14.3	7.55	. 179
16, 9	+ 1, 41	. 275	25, 63	178.5	78, 5	. 268
56.5	133.2	. 424	24, 20	.0s.J	122.9	. 15 1
)5.5	171.4		32.78	225. 5	145,9	. 439
16.7	307.2	. 563	14.41	253. 1	196. 2	. 605
io, n	2=1.0	. 677	41, 50	253.1	224, 4	. 686
7.9	313.4	. 761	47,05	234.0	247, 1	.765

rest #66

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3) 14) 179, 25, 28, 28, 28, 53,

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Loading Densit 1 q cc-, 110 Pre-Loading, par 10,000 Max Pressure: 34, 140 Diameter, in-1.06 Length, in C. Vill

ny .n = 3	dp dr Min ¹³	Burning Rate	Fraction
12.30	14.56	10, 90	. 101
14.25	27.04	41. 37	. 136
16.20	35. 36	29.69	. 270
15.15	42.64	38, 33	. 353
20, 10	49,92	48.51	. 435
22.05	56.16	59, 76	. 516
24.00	59.28	70.26	. 596
25.95	59.28	80.18	. 676

Test #72

Loading Density, groces 220 Pre-Loading, jei 15.000 Max Pressure. jui-76, 310 Diameter, in-1.06 Length, in-1.40

PX10 ⁻³	dr .8 X10 ⁵	Burning Rate	Fraction Insmed (Z)
21.72	240.0	49,7	. 125
25, 95		.	1 · · · #
30. 18	444	141, L	278
44. 40	31.	* L L	5 5 1
18. 65	\$73.0	1.4.5	. 423
42.9	563.4	210,6	. 493
SS. S	SES. O	159. 5	. 695
60.4	211.0	405, 2	.760

R COMPOSITION B

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ction

4ed (Z)

101

156 270

353 435

516 596

* 676

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<u>Test #.</u> nsity. ; cc-, 220 p. ;wi-5, (00) re. js: 55, 090 in-1, 06 s1, 60					Test #66		Test #67			
			Loading I Pre-Load Max Pres Dianietes Length,	Loading Denaity, q. ees, 110 Pre-Loading, pro 10,000 Max Pressure, 181-34, 140 Dianteter, m. 1.06 Length, 16-4, 800			Loading Denvity, g. cc., 164 Pre-Loading, psi-5, 000 Max Provinsi, psi-42, 620 Diameter in-1,06 Longth, in-1,20			
dr .it 10 ⁻⁵	Burning Bate	Fraction Burned (4)	PXIO	њ. њ Хао	Burnins, Kate	Fraction		dp_dc ر5	Burning Rate	Fraction
0.21	2.72	.0=0	12.30	14. 10	10, 40	. 101	5.80	1.42	1.73	. 224
17.05	· 20	.:**	14		- i - i -	. 190	8,40	6.24	3. 61	. 100
40. 5	22.53	. 211	16.20	3 y	24.04	. 270	11.00	14.56	N. 77	. 175
23.5	61.11	. 330	18, 15	42.64		. 153	13.60	27.04	16.92	. 245
53.9	54 60	. 420	20, 10	44. 42	45.51	. 435	18.80	63.44	44, 37	. 393
2e, 1	137.2	. 502	22.03	Se. 10.	54. 6	. 516	24,00	95.68	77.25	. 532
• · · · ·	103.7	. 627	21,00	54.28	10. 20	546	29, 20	115.4	113. 5	. 668
1-4 <u>1</u> 0	240,3	. 517	23, 45	54,28	ND, 15	. 6.*8	31, 80 37, 00	119.6 100.9	134, 4 171, 7	.734 .864
<u>.</u>	Test #71			Test #72						
			ورادا د ه اما	Arcusty	9					
i parat), paratis, una Producerta antina, par			3.n.g. 20.	15 000					
- jac. 54, 040		Max Pro	sints jan	76, ilU						
n 1,0h	n Lub Dameter n Lub									
1.30			Longth, second car			Strand	Burning R	ate Test		
dr at	-			te di						

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iction		sumine Rate	Frantising		трл. -	Barring Rate	Fraction		Burning Rate
(Z) L'HE	112	a sec	Ramed (2)	PX:0	<u>X:0</u>	146 14 c	Humed (2)	Pressure	in sec
1.125	3.6	4. 14	.05%	21.72	344. B	22,7	. 125	2, 000	0. 51
1.203	14. 5	*, 55		21.55	Leses, S.	132.1	, 203	3,000	¥
1.275	74.5	23. 5	. 204	N. 11	442.0	191.1	. 27%	5.000	
1.151	65. O	122.9	. 154	34, **	07.0	210.2	. 15:	:0. 00C	1. 35
1. 423	24, 4	145.9	. 119	10.	\$72.0	274.2	. 421	30,000	6.5
1.493	53. :	196.2	. 005	4 9	16.9. 4	290, 6	. 493	30,000	10, 42
1,695	53, 1	224.4	. 656		545.0	iny, S	. 695		
1,700	14.0	247.1	.765	· · · . •	531.0	403.2	.702		

TABLE III

CLOSED BOMB AND STRAND BURNING DATA FOR

Test #32

Test #33

Loading Density, g. cc-, 249Loading Density, g. cc-, 273Max Premure, ps.-45, 160Max Premure, psi-50, 440Diameter, in-1 25Diameter, in-1, 25Length, in-1, 40Length, in-1, 55

PX10 ⁻³	ىلەر، مەر 10 ⁻⁵	Burning Rate	Fraction	· nije	dp/dt X10 ⁻⁵	Burning Rate	Fraction Rumod (Z)	PX 10-3
6.34	2. 44	1, 43	. 157	6, 34	2.70	1.47	. 143	10, 39
:2.08	4.09	2.61	. 294	12.08	4. 26	2, 69	. 265	30, 18
17.43	S.us	3, 58	20	17, 83	5.74	3, 65	, 388	29, 96
23, 57	5, 92	4, 40	. 554	23, 57	6.79	4, 79	, 504	19.75
29. 31	6.35	6, 30	. 673	25.31	7.31	5.11	. 617	49.54
				15.05	7.22	7.05	.725	\$9.32
								69.11

Test #34

Londing Density, g. cc-, 209 Max Pressure, pii-56, 410 Diameter, in-1, 25 Length, in-1, 70

Tes: #37

Lunding Density, g/cc-, 327 Max Premire, pti-62, 065 Diameter, in-1, 25 Length, in-1, 85 Loading De Pre-Lo II.a Max Pressa Dlameter Leopth, in

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Loading De

Max Pressu

Diameter,

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PX10-3	49.41 X 10 ⁻³	Burning Kate	Fraction Jurned (2)	PX10-3	dq.'dt X10 ⁻⁵	Burbing Rate	Proctice S and (7)	PX:0 ⁻³
6. 34	1,05	t . 5 3	. 130	10, 39	4.79	2, 34		e\$.07
17. M	4.79	2, 55	. 244	30, 15	7.83	4. 21	٠4 .	25.96
17.85	6. 35), 62	. 151	29, 96	10,01	6. 16	. \$30	34.86
21.57	7.83	4. 65	. 460	39.75	¥9.88	8, 15	. 663	30.75
29.31	6.70	5, 98	. 561	4.54	9. \$7	10.02	. 827	
35.05	2.14	7.18	, 660	39 , 13	4, 17	s 44	963	



TABLE III

CLOSED BOMB AND STRAND BURNING DATA FOR ARP PROPELLANT

est #33			Test #39				Test #41				
ading Density, g/cc 273 IX P:essure, psi-50, 440 ameter, in-1.25 ngth, in-1.55				Loading Density, g/cc 393 Max Pressure, psi-83, 600 Diameter, in-1. 25 Length, in-2. 20				Loading Density, g/cc 297 Pre-Loading, psi-15,000 Max Pressure-82,425 Diameter, in-1.25 Length, in-1.70			
10-3	$\frac{dp}{x_{10}} \frac{dt}{5}$	Burning Rate in/sec	Fraction Burned (Z)	PX10 ⁻³	dp/dt 10 ⁻⁵	Burning Rate	Fraction Run,ed (7)	PX10-3	dp/dt v 10 ⁻⁵	Burning Rate in/sec	Fraction Burned (Z)
34	2,70	1.47	. 143	10, 39	5. 00	2.33	. 154	25,07	11. 57	4.96	. 172
.08	4, 26	2, 49	. 268	20, 18	10, 27	4.18	. 283	29,96	12.99	5.77	, 252
. 83	5.74	3, 65	. 385	29,96	14.01	6. 10	. 417	34, 86	14.62	6.87	. 330
. S7	6.79	4.79	, 504	59.75	16,70	7.95	. 537	39,75	15.75	7.81	406
. 31	7.31	5, 11	. 617	49.54	18, 27	9.83	. 650	44, 64	16,53	8.74	. 553
. 05	7.22	7,05	.725	59, 32	17,84	11.45	.758	49.54	17.66	10.07	. 624
				69.11	15.23	13.01	. 859	54, 43	17.40	11.51	, 694

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Test #37

ading Density, g/cc-. 327 ax Pressure, psi-62,065 ameter, in-1.25 ngth, in-1.85

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10 ⁻³	dp/dt X10 ⁻⁵	Burning Rate in/sec	Fraction Burned (2)	PX10-3
. 39	4. 79	2, 34	. 195	25,07
. 18	7,83	4, 21	. 368	29,96
. 96	10.01	6.10	. 530	34.86
. 75	10.88	8, 15	. 683	39, 75
. 54	9.57	10.02	. 827	
. 33	4, 35	11, 42	.963	

Test #42

17.78

.956

59, 33

64. 21

Loading Density, g/cc. 331 Pre-Loading, pri 15,000 Max Pressure, psi-98, 500 (approx) Diameter, in-1.25 Length, in-1.85

dp/itt

X10-5

13.05

14, 79 17, 52

23.92

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Friction		Burning Rate	
Burned (Z)	Pressure rel	1%/MPC	
مغصوب ويستعدانها		 • • • • • • • • 	
. 143	10,000		
. 209	15,000	4. <u>1</u> .	
. 274	20,000	< 00	
. 338	30, 000	5, 5ú	
	Prection Burned (Z) . 143 . 209 . 274 . 338	Praction Pressure nti . 143 10,000 . . 209 15,000 . . 274 20,000 . . 338 30,000 .	

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TABLE IV

CLOSED BOMB DATA FOR EXPERIMENTAL PROPELLANT

		Test #R3		Test #84					
Loading	Density,	y, cc -, 204		Loading Density, g/cc-, 204					
Max. Pr	essure, poi	- 12, 720		Max Pres	sure, psi-42	2, 200			
Diamete	r, in1.	25		Diamete	, in-1.25				
Le uyth,	in-1.00			Length,	in-1.00				
PX10 ⁻³	dp, dt X 10 ⁻⁵	Bunning Rate	Fraction Burned (Z)	P (10 ⁻³)	dp/dt (10 ⁻⁵)	dx/dt	Fraction Burned (Z)		
1.9	1,62	. 845	.049	3, 2	1.6	. 858	.085		
3,2	1.62	. 858	.084	4.5	2,4	1.31	. 219		
4.5	2,92	1,57	. 117	5.8	3, 2	1.78	. 153		
5.8	3, 58	1.95	. 151	8.4	4.8	2.77	. 219		
7.1	3, 9	2, 17	. 184	11.0	6. 4	3.85	. 285		
8.4	4.94	2.80	. 216	13.6	8.0	5.05	. 349		
9.7	5, 85	3, 39	. 249	17.5	10, 4	7.12	. 447		
11.0	6.5	3, 85	. 281	20, 1	142, 5	103, 8	. 507		
12.3	7.15	4, 33	. 313	21.4	173.7	131.0	. 538		
13.6	29, 2	18.1	. 345	24.0	197.6	161.3	. 598		

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Tex #87

Loading Density, g. cc-, YOR Max Premure, pai-70, 570 Diameter, in-1.25 Length, in 1.50

	dp dt		
P(10-3)	(10)	de. et	1
2.71	2.06	.811	
4. 82	4, 10	1.64	
~.05	8, 12	3, 37	
15, 4	14.0	5.95	
	98.0	42, 6	
19.6	195.0	85. é	
21.7	273.0	122,2	
23,8	348.4	(59.)	
26.0	391.0	183.5	
34. 4	501.8	240.8	
45.0	4-4 0	293.6	

Loading Density, g/cc-, 235 Pre-Loading, jui-5,000 Max Pressure, psi-65, 500 Diameter, in-1.25 Length in. -1,25

Fraction Burned (Z)	P(10 ⁻³)	dp/dt (:0 ^{-\$})	da i di	Fraction Bursed (2)
. 047	4.8	2.6	1. 5 .	00 115
.083	9.1	5, ž	2.17	
. 153	13.2	7.3	3. 18	. 15
. 255	17.5	163,8	73,9	. 23
. 213	21.7	240. 6	117.9	. 31
. 321	26.0	117.7	157.9	. 34
. 353	30. 2	390, C	206, 1	. 45
. 385	34.4	414.0	214 0	. 52
. 417				
810				

Test #88

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TABLE IV

CLOSED BOMB DATA FOR EXPERIMENTAL PROPELLANT

Test #84

Test #85

Loading Density, g/cc-. 204 Max Pressure, psi-42, 200 Diameter, in-1. 25 Length, in-1. 20

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3 7 10, 16, 20, 23, 36,

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6. 11. 17. 22. 28. 33. 39.

Loading Density, g/cc-, 255 Max Pressure, 1si-57, 800 Diameter, in-1, 25 Length, in-1, 25

Fraction Burned (Z)	P (10 ⁻³)	dp/dt (10 ^{-S})	dx. dt	Fraction Burned (Z)	P(10
.049	3.2	1.6	. 356	.085	3. 8
.084	4. ×	2.1		.:::Э	5.4
. 117	5,8	3, 2	1.78	. 153	10, 4
. 151	8.4	4.8	2.77	. 219	16.8
. 184	11.0	6.4	3. 8.7	.285	æ.,
.216	13.6	8.0	5.05	. 349	23. 4
, 2 (.)	17.5	10.4	7.12	. 447	36. 3
. 281	20.1	142, 5	103.8	, 507	
. 313	21.4	173.7	131.0	. 538	
. 345	24.0	197.6	161.3	, 598	

د- مب	dp/dt		Fractio
P(10)	(10)	dx/dt	Burned (2)
3. 8	2. 6	1.14	. 073
5.1	3. ž	2. 54	. 141
10.4	7.8	3.62	. 204
16.8	13.0	6.48	, 326
Ξυ, s	169.0	88.0	. 385
23. 4	253.5	138.4	. 443
36. 3	292.5	208.0	. 666

Test #94

Tc# #88

Loading Deutity, g. cc-, d55 Pre-Loading, psi-5,000 Max Pressure, psi-65,500 Diameter, in-1,25 Length in, -1,25 Loading Density, g/cc-, 377 Max Pressure, psi-69,000 Diameter, in, -1, 50

Leugth, in. -1. 27

Fraction Burned (2)	P(10 ⁻³)	dp/dt (10 ⁻⁵)	dx/dt	Fraction Nurned (2)	(P 10 ⁻³)	dp/dt (10 ^{-\$})	dx/dt	Fraction Burned (Z)
.047	4.8	2.6	1.05	0085	6. 1	5.2	1.9	. 0 8 9
.083	9. t	5.2	2, 17	.073	11.6	10.4	3. 8	. 165
. 153	13.2	7.8	2. 38	. 15	17.2	15.6	5.8	. 239
. 255	17.5	163.4	71.9	. 23	22.7	113.8	44.0	. 211
. 258	21.7	213.5	117.9	. 31	28, 2	364.0	146.0	. 379
. 321	16.0	\$17.2	.57.9	. 38	33. 8	585,0	243. 3	. 446
. 353	.10. 2	390,0		. 45	39, 3	780.0	340.0	. 510
. 385	34.4	416.0	236,0	. 52				
. 417								
. 539								

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. 683

Table V

Linear Burning Rates of Rohm & Haas QZ Propellant Octained From

-	Linear Bu	rning Rate	Calculated	Surface Area
Pressure PX103	in/sec	-60°F	70°F	60°F
5.8	2,04	1.55	-	-
11.0	3.91	2,82	-	-
16 2	5,72	1 70		-
21.4	7.34	6.31	۴	-
31.8	8,92	7.60	-	-
37.0	10,30	9.54	-	-
42.2	11.25	10,20	4,95	4,95
47.4	12,14	10.77	4,40	4,40
52.6	12,88	11,72	3.79	3.79
57.8	13,20	45, 51	3,27	12,40
63.0	11.39	42.17	2,67	9.00

Closed Bomb Test

B-5

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APPENDIX C FIGURES



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Figure 2. Linear Burning Rates of TNT Obtained with Closed Bomb and Strand Burner



Figure 3. Expected Surface Area vs Actual Area Obtained for TNT Cylinder Burned in Closed Bomb

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Figure 5. Linear Burning Rates of Composition B Obtained with Closed Bomb and Strand Burner









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C -8

Figure 7. Closed Bomb Test ARP Propellant

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PRESSURE, PSI (THOUSANDS)

Figure 9. Closed Bomb Test Experimental Propellant

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Figure 10. Linear Burning Rate of Experimental Propellant Obtained with Closed Bomb

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PRESSURE, PSI (THOUSANDS)







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Figure 13. Ratio of Expected Area to Actual Area Found for TNT Cylinder



Figure 14. Ratio Expected Area to Actual Area Fusiki for Composition B Cylinder





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ABSTRACT DATA

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AD	UNCLASSIFIED UNCLASSIFIED 1. Propellants- Defonation 2. Explosues- Defonation UNITERMS Propellant Explosues Defonation Classfochen Classfochen Classfochen Classfochen UNCLASSIFIED	 AD AD Peatrage sesting, Ammunition Group Dover, New Jerse ESTABLE-HALLE & OF LINPROVED STANDARDS FOR CLASTE-REPAILS OF LAPLOSIVES AND PROPEL- LANF - Repertion of A MERIOD FOR DEFERMI- MAHON OF SUSS FPERPILTY OF FROPELLANTS AND ENTLOSIVES TO UNDERIGO TRANSITION FROM DE- ILAGRATION TE DEFEONATION S. Wachoul, C. E. d. Knight, L. Shuhuan Technical hepott OB-TR. 5 ol., June 1961, 24 pp. figures, Gubles. Chalsadied Repert CovER) 	UNCLASSIFIED UNCLASSIFIED 1. Propellants- Defonation 2 Explosives- Defonation 1. Proj No. 7503(e)(w) UNITERMS Propellant Explosives Defonds to Hazards Classification Hazards Classification Classification Classification UNCLASSIFIED
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	Large solid extinder of the material is burners in a closed formb at high pressure. The burning rate vs. pressure curve deviates markedly from reads predicted from strand horn- ing tast, indicaring a predictantion reaction which could recover to detection a nonce material were no sort. The	UNCLASSIFIED UNLTERMS Compristing R	Large solid cylinder of the material is burned in a closed bonds at high pressure. The burning rate vs. pressure curve divides the markedy from really predicted from strand burn- ng tests, mult after a predeficition on which could recovered to deviation it more notical size massert. The	UNCLASSIFIED UNITERMS (turnpositiona B
****	method can determine the gross detonation characteristics of prop-funits in cer the nost severe conditions. It can replace such costs tests as the fine-nazard tests on full-cale motors. This interm report covers data for two secondary	QZ Washell, S Iroj No. 77030400	Included can de cumue the gross de tea done characteristics of propellants, aider the most sectre conditions. It con replaces up to dy tests as the fire-based tests on full-scale most ss. This raternu report covers datt for two scondary	QZ Wachtell, S. Proj No. 7503.0100
	esphoise and a number of rocket propellants.	Menuels, C. C. Schultrau, L.	espirators and a number of rocket propellants.	Burnur, Felen Mittau (a. s. S. S. attaut, L.
		ühCLASSIFIED		UNCLASSIFIED
•••••	Large wild cylinder of the material is harned in a closed touch at high pressure. The humang rate we pressure crive features made the fram results meals one stored here.	UNCLASSIFIED L NI TERMS	Large solid equation of the material is burned in a closed bould at high passure. The forming rate vs. passure curve devices marked from strand hum-	UNCLASSIFIED
••••	ag test, industrig a pre-defourtion reaction win h could proceed to det carton if note material wert private. The particular an determine the grow demation characteristics	Composition B ARP OZ	ing tests menual og a presidentation reaction which could proceed to deter drom it more mikeral were present. The medica, can determine the grass defonation characteristics	Composition B ARP OZ
	of propellarity and/or the most wavere conditions. It can replace such to the tests as the fire-hazard tests on full-val- motors. This oterion report covers data for two wrondary	Wachtell, S. Proj No. 7503.0100	of propullars — der the not sever conditions — it can reply exacts or j tests as the fireburard tests of full-scale meters. This is error epoet covers data for two secondary	W.ac'stell, S. Proj No. 7505.0100 B
	explosion and a number of reduct propulsion.	Burning Rate Mckungth, C. E. Schulman, L.	explores and a number of nodet propellants.	Purnung Hate Mickinglu, C. P. Schulteur, L.
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AD L. diamy Arsenal, Ammunitian Group Diver, New Jewer ESTABLISHMENT OF INDROVED STANFARDS FOR CLASSIFICATION OF EXPLOSIVES AND PROFEL- LAVE, Award No. L. A GELICO FOR DELEMI- LAVE, Award No. L. A GELICO FOR DELEMI- LAVE, Award No. L. A GELICO FOR DELEMI- MATEN OF SUSCEPTIBULITY OF PROFELLANTS AND VPLONTES TO UNDROV TRANSITION FROM DE- LAVE, C. E. M. Mught, L. Shuman Technical Report Db-TR: 361, June 1961, 24 pp. fusiees the- Undrovided Report Cover)	unclassified L. Propellants- Det mateer Det mateer Det mateer I. Wadnell S. UNITERMS Fropellant Explores Det mateer B. tanden H. actor Classified TNT UNCLASSIFIED	 AB Peatany Arenel, An munition Group Door, No. Jerev ESTABLISHMENT OF IMPROVED STANDARDS FOR CLANE Report OF EAPLOSIVES AND PROPEL- LANE Reports OF A VETHOD FOR DETERMENT RATIONAL REPORTS OF STANDARDS FOR DETERMENT NALREE OF SUP EPTHRILITY OF PROPELLAYTS AND FARTON 20 FETOVATION S.W.GORM, C.J. MCKIRGH, L. Shuhman Techeiral heport DB-TR (-64, June 1964, 24 pp, figures, table) t. d. Safed Bep rt (CVER) 	UKCLASSIFIED UKCLASSIFIED 1. Propellants
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I use sold sylinds of the material is berned in a closed leady at high seconds. The burning rate vs. pressure curve obvious the process is a present of thom strand burn- ougle sts, not a trug a present atom reaction which could presend to detourth of those solution is present. The ratio do not detourth of the grow solution is harderistics of properties and the nost sector condition. It can explore out to the site strecker conditions. It can explore out to the site the kazard tests on full-scale nucles. This intern report covers data for two secondary explosites and a nu about of resket propellants.		Large sele sylinds, of the indexial schured in a closed breads at it is pressue. The horizing rate vs. pressue curve deviates to, dadly from strong rate vs. pressue curve and the strong is pre-different strong strong hum- ang tests, rads attegraphend to attom relation which could prove edite a trender of more electronic discreteristics of propelli de nucle die nucle severe conditions. It can reglie even at a nucle die nucle severe conditions. It can reglie even at a nucle electron to site of the severe explosives and a nucle of recast propellarity.		
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Large what evidence of the extend of harved in a closed embradiactic growin. The harmony actors present struc- bertains reachedly from nearby production are all hitto- active reachedly from nearby production are the structure of the distantion of provident reaction of the coll environ to distantion of provident reaction of the extend case distantion of provident reactions of progradient number the most action to the reaction of progradient and an endort of the two evidences. It can be not structure the structure of the two evidences. It is a progradient and the the structure of the two evidences. It is appeared in a number of it for the pollarity		Large while a harder of the material is harder in a chied to the large while a harder of the material is harder of the material provides the second of the material is the stand harder the rank material to the material were provide the provides to the material were provide the material were the grow of transfer share to the propertients much the material were provide the attends. This mate material were no fully a here we have the material were no fully a here we have the material were no fully a here we have the material were no fully a here we have to as the furthward to the no fully a here we have and a no material no fully a fully a here we have the material were to be the the second here we have the second to be the propertient.		

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