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SAFETY INFORMATION FROM PROPELLANT SENSITIVITY STUDIES (U)

20 MARCH 1962

NOL
UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

SAFETY INFORMATION FROM PROPELLANT SENSITIVITY STUDIES (U)

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ABSTRACT: This report summarizes recent results of work on the Propellant Sensitivity Project with particular emphasis on the use of gap test and other small scale test results to help answer practical safety questions. It is shown that measured initiating pressures are highest near the critical diameter of the test material and decrease to their lowest value at an effectively infinite acceptor diameter. The standard confinement of the gap test is shown to increase the effective acceptor diameter by a factor of 2.5 for Comp B. Gap test results show good correlation with large-scale field tests, blunt-nosed bullet tests, and the approximately one-dimensional wedge test results; it is therefore believed that the gap test measures a 50% initiating pressure close to that for an infinite diameter acceptor.

A supplement to the NOL Shock Sensitivity Test for propellants has been devised whereby the judicious choice of explosive witness systems makes it possible: (1) to assess the strength of reactions of too low impulse to produce a positive result under the conditions of the standard test and (2) to measure the sensitivity to shock initiation of substances exhibiting such reactions. (U)

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White Oak, Silver Spring, Maryland

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The work reported here was carried out under continuing NOL Task 323, Polaris Sensitivity. It was reported, in less detail, at the Deflagration Detonation Seminar sponsored by the Special Projects Office at Downey, California on 5 and 6 December 1961. The present results will be subject to revision as the work progresses.

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By direction

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SAFETY INFORMATION FROM PROPELLANT SENSITIVITY STUDIES

In common with all sensitivity investigations, the objective of the work on propellants is to understand the process of initiation (by any external stimulus) and any subsequent self-propagating reaction. With sufficiently detailed information, it should be possible to answer practical questions arising from safety considerations. Some of the important questions are:

1. How easily will ignition and propagation of burning occur?
2. Can detonation occur?
3. If so, what is the probability of transition from burning to detonation?
4. What damage will a run-away reaction cause?

It has been found (1) that propellants generally exhibit high to very high impact sensitivity. Hence, propellants are easy to ignite and burn, a characteristic to be expected of materials used as propellants. Work is underway at many laboratories to assess the degree of fire hazard and much still remains to be done in this field, but the present work has been concentrated on more damaging reactions than simple combustion. Any easily combustible material capable of energetic exothermal reaction immediately suggests the possibility of detonation. By use of a standardized gap test (2, 3), it has been possible to obtain much information on whether a propellant is detonable and, if so, how easily (3). Since the gap or shock sensitivity test measures the minimum initiating pressure required to induce detonation, it also provides some information about the probability of an occurance of transition from burning to detonation in the propellant: the lower the pressure required for initiating detonation, the more probable that such a shock pressure could be built up by confined burning of the propellant (4) and hence that a transition could occur.

VARIATION OF SHOCK TEST VALUES WITH TEST DIAMETER

The critical diameter of a detonable material has a limiting effect on any test for shock sensitivity. If the test diameter used is less than the critical diameter for propagation of detonation, the result from the standardized gap test at zero gap is a no-go. Even if the effective test diameter is above but near the critical diameter, the intuitive expectation is that a higher pressure would be required for initiating detonation than in the case of a charge of larger diameter. That this is in fact the case is shown for cast TNT. The computed detonation pressure just above the critical diameter is about 150 kbar (5); under near-failure conditions, where the possibility of reaction build-up is negligible, this should also be the required initiating pressure. In contrast, the measured initiating pressure* on the standard gap test is 37.3 kbar.

While quantitative work on shock sensitivity is still confined to measurement and interpretation of peak pressures, there is general agreement that initiation is the result of the entire pressure loading i.e., of the pressure-time history of the initiating shock. In the region that the shock attenuation by rarefaction is due only to lateral rarefaction waves, the shock duration should be proportional to the charge diameter. Thus increased shock duration can explain the decrease in required peak pressure for initiation as charge diameter is increased.

The trend, decreased initiating pressure with increased diameter, has been found experimentally. It is demonstrated by results from an uncalibrated gap test (6) as well as with those from a calibrated half-inch diameter gap test (7) for which two test materials can be compared quantitatively with approximately the same materials tested on the standardized 1.5 inch confined diameter test. Since the trend is both expected and demonstrated, an estimate of the effective diameter of the standardized test would be desirable. The term "effective" diameter is used to designate the diameter of the unconfined charge for which the gap test value is equal to that found under the standardized confinement. Obviously the

---

* It was pointed out previously (3) that the pressure transmitted into the test charge, the initiating pressure, is 15 to 30% higher than the pressure incident at the Lucite/acceptor boundary. The standardized gap test measures the latter, the incident pressure. To compute the initiating pressure it is also necessary to know the Hugoniot data of the unreacted propellant. In general, these are not known, but the Hugoniots for non-porous propellants and explosives can be approximated by that for unreacted cast TNT (3). The initiating pressures of this report have been obtained by using this approximation.

closer the effective diameter to an infinite diameter, for the standardized test load , the better the approximation of considering the measured initiating pressure an intrinsic sensitivity property of the test material.

EFFECT OF CONFINEMENT ON TEST RESULTS IN THE STANDARDIZED GAP TEST

Six different materials, including the explosive itself, were used as confinement in the standard test geometry (2, 3). The results for two cast explosives, pentolite and Comp B, are given in Table 1. The more shock sensitive material, pentolite, exhibited no confinement effect; for this charge the effective diameter in the standard test is approximately infinite. On the other hand, Comp B showed a definite confinement effect; these results indicate that the effective diameter in the standard geometry will differ for each charge and that the confinement will have increasing effect as the shock sensitivity of the test charge decreases.

In the case of Comp B, confining materials of impedance approximating that of the explosive (glass, Lucite, and Comp B itself) all have approximately the same effect on the gap test value. The metals (lead, steel, and aluminum) have an appreciably greater effect. If it is assumed that the required incident pressure varies linearly with the reciprocal diameter of the equivalent bare charge, the data indicate that the standard steel confinement has increased the effective diameter of Comp B by a factor of 2.5*. On the same assumption it is possible to obtain a fair approximation to all the results of Table 1 by a simple inertial effect of the confining tube i.e., by considering the mass of the tube replaced by an equal mass of explosive. This may be merely a fortuitous result of the selection of confining materials because the shock impedance of the confinement, which was not measured, would be expected to control the confining effect.

The most useful results of this exploratory work are the indications that confinement is most effective on materials

*This is the diameter effect for a given donor; it is not the factor to be expected when both donor and acceptor are scaled.

showing lower shock sensitivities and that the standard gap test confinement results in an effective diameter of about 9.2 cm. for Comp B. In terms of reciprocal diameter, this is 0.11 cm^{-1} as compared to zero for infinite diameter.

TABLE 1
Effect of Confinement on Gap Test Values

Confinement	Outer Diameter cm. Test Charge	Outer Diameter cm. Container	50% Point Gap No. Cards	50% Point Incident Pressure kbars
	Cast Pentolite 50/50			
None	3.81	-	266	5.3
Steel	3.66	4.76	264*	5.5
	Cast Composition B			
Lead	3.66	4.76	204	17.1
Steel	3.66	4.76	201	17.7
Aluminum	3.66	4.76	179	21.5
None	4.76	-	159	25.9
Glass	3.66	4.44	158	26.3
Lucite	3.66	4.76	156	26.8
None	3.31	-	143	30.0

* Tested at ambient temperature; all other tests at 25°C.

PREDICTION OF LARGE-SCALE FIELD TEST RESULTS FROM GAP TEST VALUES

For propellants, which generally exhibit shock sensitivities less than that of Comp B, the confinement of the standardized gap test should be quite effective, and the initiating pressures so measured should approximate those required under large-scale field test conditions. This has so far proved to be the case.

Drop Tests

Data are now available for large scale (20 lbs. or more), 40-foot drop tests of three propellants (8, 9, 10); the sample is dropped onto a flat, three inch thick, steel plate backed up by a concrete slab. Drops are also made on plates containing 0.75 in. diameter by one inch high steel lugs. The propellants tested were ANP-2639AF, DGV, and a nitrasol; their gap test values ranged from no-go to 70 cards and impact height values, 9 to 22 cm. Field experience has shown no unsafe incidents from handling non-porous propellants with such characteristics, and the gap test value gives a required initiating pressure of 65 kbar or more to induce detonation in the two materials detonable in the standard configuration. After a 40-foot free drop, the impact velocity is 51 ft/sec or 0.016 mm/μsec; the resulting pressure in the propellant is about one kbar. Consequently no detonation would be expected from this height drop, nor was any obtained. In some cases - particularly from drops on lugs - burning did occur.

These results may be compared with those for cast TNT, HBX-1, HBX-3, Comp B and H-6 (8, 11). This group of explosives shows a gap test value range of 138 - 201 cards (minimum initiating pressure of 21.2 kbar) and of 45 - 215 cm in impact height values. Again no detonation would be expected and none was observed. There was only one case of burning induced by the drop; this shows, as does the impact height test values, that the propellants are easier to ignite and burn than the high explosives.

High Velocity Impact

BULLPUP warheads, loaded with about 104 lbs. of M-3515 nitrasol were placed on rocket sleds which were accelerated to 940 - 960 ft/sec. The sleds were stripped off and the warhead struck the target at a velocity of about 1000 ft/sec (680 miles per hour). The target was either $1\frac{1}{4}$ inch steel plate or 12 in. reinforced concrete walls. In both cases, the warhead completely penetrated the target without detonating although rapid deflagrations did occur after penetration. This testing was carried out at the Naval Weapons Laboratory, Dahlgren, Va. (12).

M-3515 nitrasol has not been tested at this Laboratory although a very similar composition, H-3515 has been. The gap test value was 74 cards; the impact test height, 14 cm. The required initiating pressure is 63.5 kbar whereas that induced by 1000 ft/sec impact on steel is only 14 kbar. Consequently no detonation would be expected from this test. The burning after impact and penetration is in accord with the low impact test height.

Shock Sensitivity Test

A full scale test of a motor loaded with 7500 lbs of DDP-70 was made to determine the sensitivity of this load to shock from a one lb., so-far bomb (13). The bomb, containing an aluminized explosive, was separated from the propellant by four feet of mixed media (instrumentation and air). By approximating the mixed media with water and using experimental data for underwater pressure-distance curves obtained from aluminized explosives, a very rough estimate of several tenths of a kilobar transmitted to the propellant was obtained. DDP-70 had a gap test value of 60 cards i.e., a required initiating pressure of 69.7 kbar. Hence the failure to obtain detonation in the field test is explained. Moreover, the low estimate of transmitted pressure was confirmed by the fact that the propellant was not even broken up by the pressure transmitted to it.

Wedge Test Results

Both the effect due to the confinement on the gap test values and the correlation found between the gap test values and the large-scale field tests indicate that the initiating pressures measured in the standardized test are close to the infinite diameter values, i.e., are a measure of the intrinsic shock sensitivity of the material tested. Very recent work (14) offers much stronger evidence. Shock initiation studies by means of the wedge test, an approximately one-dimensional experiment, showed that "the value of pressure, which will just produce detonation in wedges and cylinders in an indefinitely long run distance (asymptotic value), appears to be approaching that of the 50% card-gap pressure value". If subsequent work confirms the present results, they mean that the initiating pressure measured by the wedge test and the initiating pressure measured in the standardized gap test are the same.

EQUIVALENCE OF GAP AND BLUNT-NOSED BULLET TESTS

Further safety information is available from the blunt-nosed bullet test. Indeed, because of its equivalence to the gap test, the bullet test results also assist in the interpretation of the standardized test results.

Brown and Whitbread (15) first established the equivalence between the gap and the blunt-nosed bullet tests. They measured the velocity required for the 50% probability of detonation of explosives struck by high velocity cylinders and balls; they showed for nine explosives that the 50% brass gap thickness varied linearly with the 50% velocity measured for steel balls. Both the donor and ball diameter were 0.5 in. Moreover, using 0.5 in. diameter cylinders* of four different materials, they were able to determine the required initiating pressure of the test explosive. They did this by using projectile materials for which the Hugoniot data (pressure-particle velocity) were known; the measured 50% velocity value for a given projectile material gave the initial point from which its curve could be drawn in the pressure-particle velocity plane. The curves for the four materials intersect at the pressure required to initiate the test material. By this procedure, the initiating pressure was measured for two explosives: tetrytol 91/9 and RDX/Wax, 83/17.

Later Wenograd (16) working with Whitbread began a study of the effect of cylinder diameter i.e., of impacted area, on the initiating pressure required for RDX/Wax, 83/17. Using only two materials, steel and aluminum, he varied the diameter of his cylinders from 0.188 to 0.685 in. and measured the 50% velocity required to initiate the 1.5 inch diameter RDX/Wax acceptor. Wenograd's unsmoothed data are given in metric units in the first four columns of Table 2.

These velocity data can be treated in two ways to obtain the initiating pressures: (a) determine the pressure at the intersection of the metal Hugoniot with that of the explosive in the pressure-particle velocity plane, and (b) determine the pressure at the intersection of the two metal Hugoniots. The initial particle velocity from which the metal Hugoniots are drawn is, of course, the measured 50% velocity value. Method (a) requires the Hugoniot data for iron and 2S aluminum (17) as well as that for TNT to approximate the RDX/Wax. Its use gives two values of the initiating pressure for each diameter tested; the values are the same within 5% or less. They are

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* Effectively infinite in length.

TABLE 2

Preliminary Data on Diameter Effect in RDX/Wax, 83/17

Cylinder Diameter d, cm.	d^{-1}	50% Velocities mm/µsec Steel	Al	Initiating Pressure kbar ** Steel	Al	Avg	Initiating Pressure kbar ***
1.74	0.575	0.829	0.988	45.0	44.7	44.8	41
1.27	0.787	0.908*	1.097*	50.5	50.7	50.6	50
0.953	1.05	0.994	1.253	57.0	59.5	58.2	68
0.635	1.57	1.122	1.295	65.5	62.0	63.8	47
0.478	2.09	1.247	1.497	75.0	74.3	74.6	72

*Reported in Ref. (13a)

**By intersection of metal Hugoniot with that for cast TNT

***By intersection of two metal Hugoniots tabulated and averaged in Table 2; the averaged values are plotted in Fig. 1. Method (b) gives one value for each diameter and the pressures derived by this method show no reasonable trend with changing diameter as do the set from method (a). The intersections used in method (b) are very small angled; this increases the error of reading and magnifies the effect of small errors in the measured velocities. Method (a), in contrast, utilizes Hugoniots intersecting at larger angles, and thus results in better values.

Fig. 1 shows an apparently linear variation of the required initiating pressure with the reciprocal diameter of the area of impact for diameters equal to or greater than 0.95 cm. It also shows the expected trend of decreasing initiating pressure with increasing diameter. Further experimental data are necessary to define all portions of this curve, particularly that at the smaller diameters.

The explosive RDX/Wax, 83/17, has a sensitivity near that of Comp B (RDX/TNT/Wax, 60/40/1). Comparative data from Ref. (15) on results for 0.5 in. diam. cylindrical steel projectiles are:

	50% Velocity ft/sec.
RDX/TNT, 60/40	2760
RDX/Wax, 83/17	2980

From the Hugoniots of the explosive and iron, this 50% velocity gives an initiating pressure of 46 kbar for cyclotol 60/40; this should also be very nearly the initiating pressure for Comp B and has been so labelled in Fig. 1. If through this one value for Comp B a curve is constructed parallel to that for RDX/Wax, it extrapolates to an initiating pressure of 29.9 kbar for a projectile of two in. diameter (corresponding to the donor diameter) impacting on an unconfined Comp B acceptor of $1\frac{1}{2}$ in. diameter. The analogous gap test result for unconfined Comp B is an incident pressure of 30 kbar (Table 1) and an initiating pressure of 36 kbar, 17% higher than the value measured by the blunt nosed bullet test. This difference is in the direction to be expected from the fact that the projectiles were effectively infinite in length whereas the gap test donor is not; its length to diameter ratio is only one. Some of the difference may also arise from the different pressure loading in the two cases. From the impact of 0.5 in. diameter

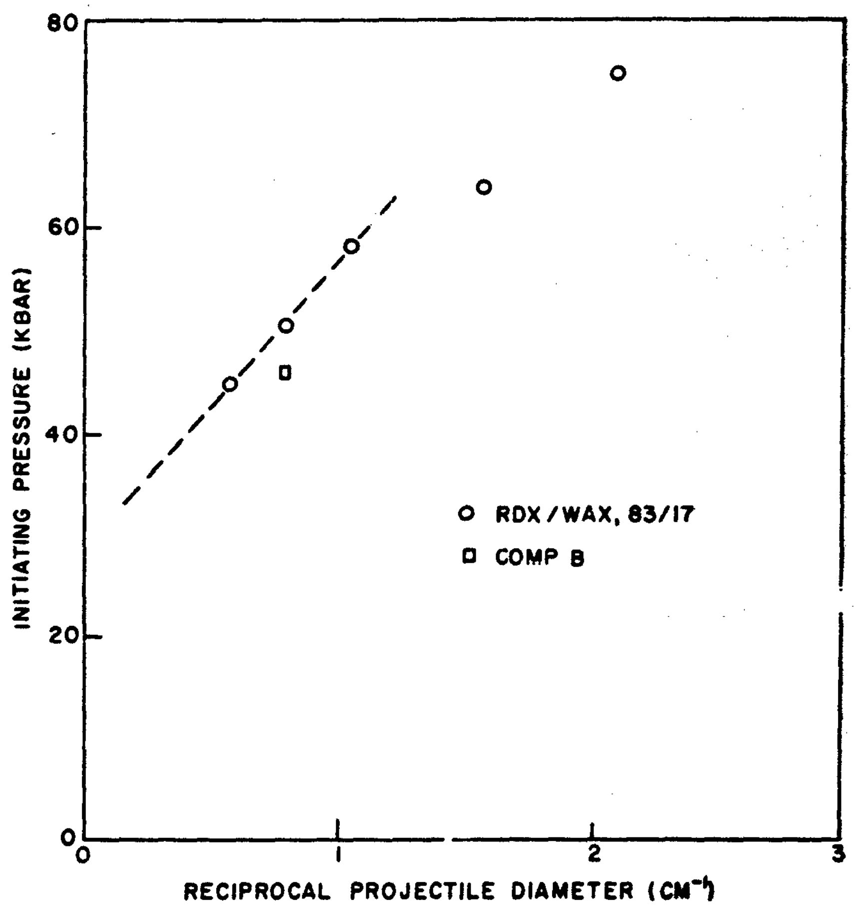


FIG.1 PROJECTILE DIAMETER EFFECT ON INITIATING PRESSURE OF RDX/WAX, 83/17

cylinders, Brown and Whitbread believe a square pressure pulse is formed; in the case of RDX/Wax, 83/17, they report a required initiating pressure of 50 kbars with a duration of 0.6 µsec or greater. The shock loading of the standardized gap test gives a peak pressure followed by an exponential pressure decay; it is estimated that the pressure will fall to 50% of its peak value in 2 to 5 µsec (5).

Comparison of the projectile results with those from the standardized gap test introduces another factor, the confinement of the acceptor; this is absent in the bullet test, present in the gap test. Thus the initiating pressure of 21.2 kbar for confined Comp B in the gap test is lower than the 29.9 kbar for unconfined Comp B in the bullet test. Again the difference and shift is in the direction to be expected as a result of the confinement.

It is quite evident from the present results that the blunt nosed bullet and gap tests, under comparable impact conditions, measure initiating pressures of approximately the same value. In view of the present analysis as well as the Brown and Whitbread (15) results for gap and bullet tests carried out on identical preparations of explosives, it seems probable that the initiating pressures measured under comparable conditions in the two ways are quantitatively the same. Additional data and analysis of the type given in Fig. 1 will be necessary to establish quantitative or semi-quantitative equivalence.

By use of the Hugoniots, and on the assumption that the blunt nosed bullet and standard gap tests measure the same initiating pressure, 50% velocities for steel cylinders of diameter equivalent to that of the gap test can be found from gap test values. Moreover, by comparison with Ref. (15) data, the variation in 50% velocity with bullet diameter and from cylinders to spheres can be seen. The comparisons are shown in Table 3 and Figure 2.

H-3515 has been included in Table 3 as a typical nitrasol; its initiating pressure is also representative of the double-base and older hybrid double-base propellants. Pressed TNT has been included as an example of material more shock sensitive than cast Comp B; the values for TNT(p) are enclosed in parentheses because the approximation of its Hugoniot by that for cast TNT introduces greater error than a similar approximation for the three non-porous materials. Bracketed values are estimates obtained by approximations described in the

TABLE 3

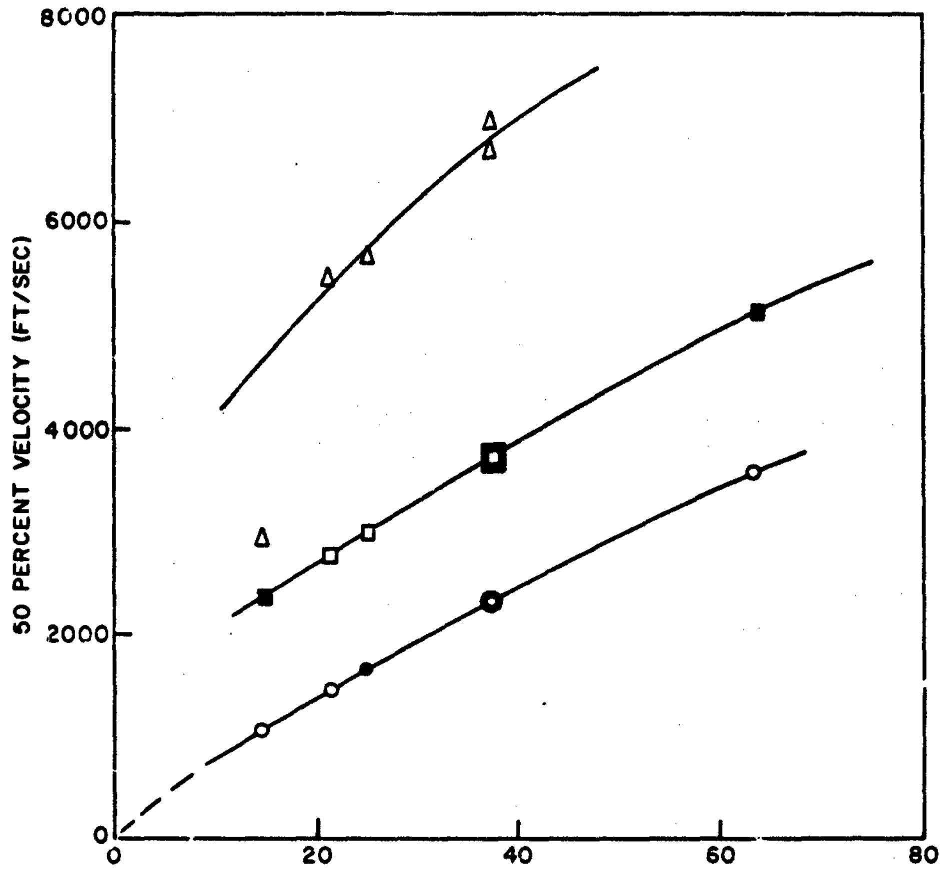
Comparison of Gap and Steel Bullet Test Values

MATERIAL*	From Gap Test: Init. Pressure kbar	From Gap Test: Cyl. Vel. ft/sec	Velocity for 0.5 in. diam. projectiles: Cylinders ft/sec	Velocity for 0.5 in. diam. projectiles: Spheres ft/sec
H-3515	63.5	3592	[5086][a]	-
TNT(c)	37.3	2296	[3720][a]	6924
Tetryltol 91/9(c)	[37.3][a]	2296	3720	6650
RDX/Wax(c) 93/17	[24.9][a]	1640	2980	5655
Comp B(c)	21.2	1411	2760	5471[b]
TNT(p) ρ_o=1.32	(14.7)	(1050)	[2346][a]	2913

* (c) cast, (p) pressed

a Estimated from Fig. 1 and results for Comp B

b Ref.(15b) gives 3980 but Ref.(15a) gives 5471 for cyclotol 60/40 made with Bridgewater RDX. According to Ref.(14) the RDX/Wax is also Bridgewater RDX. Value in table is that of Ref.(15a) which is in better accord with curve of Fig. 2.



o STEEL CYLINDERS OF 2.0 IN. DIAMETER; ACCEPTOR IN CONFINEMENT OF GAP TEST.

□ STEEL CYLINDERS OF 0.5 IN. DIAMETER; UNCONFINED ACCEPTOR.

Δ STEEL SPHERES OF 0.5 IN. DIAMETER; UNCONFINED ACCEPTOR.

SHADED POINTS ARE ESTIMATED, NOT MEASURED.

FIG. 2 COMPARISON OF 50 % VELOCITY VALUES FOR DIFFERENT STEEL PROJECTILES WITH INITIATING PRESSURE FROM GAP TEST VALUE footnotes of the table. The 50% velocity of 3592 ft/sec for the nitrasol explains again the failure to obtain detonation in the field test at 1000 ft/sec.

Fig. 2 illustrates the variation found: an increase in the 50% velocity required for initiation with decrease in impact area; the decrease in area follows that in diameter: the effective diameter of the gap test, the 0.5 in. diameter cylinder, the 0.5 in. diameter sphere. The least satisfactory curve is that for the spherical projectiles. It has been drawn through the data for non-porous materials because the impact area caused by the spherical projectile should be about the same within this group. The impact area created in a porous charge should be considerably larger. It is to this difference between the porous and non-porous materials that the large departure from the curve of the point for TNT(p) is ascribed.

It is interesting to note that the initiation of cast TNT (critical diameter about 2.7 cm.) by the impact of a 1.27 cm. diameter sphere is an instance of shock initiation with the impact area well below the material's critical diameter. The point is of interest because it has been claimed that "the initiation source must have a diameter at least equal to the critical diameter of the acceptor" (if detonation is induced in the acceptor)(14).

As the data of Table 3 show, the accumulative effect of the approximations used has wiped out any sensitivity difference between TNT and tetrytol 91/9. Addition of 9% tetryl to TNT would be expected to increase its shock sensitivity by a small amount; that this is, in fact, the case is indicated by the difference in the 50% velocities measured with spherical projectiles. The difference is about 4% of the measured velocity values and in the direction to show tetrytol more sensitive than TNT.

The chief assumptions used have been:

(a) that the other explosives of Table 3 will have curves parallel to that of Fig. 1 for RDX/Wax.

(b) that the other explosives of Table 3 will show about the confinement effect exhibited by Comp B.

(c) that the values of initiating pressure vs. reciprocal diameter of impact extrapolated to a two in. diameter donor will exceed the initiating pressure measured by the standardized gap test by a factor of 1.41 as is the case for Comp B in the standard confinement. Extrapolation of this curve assumes that the trend continues evenly at least to the two in. diameter. Of course, a point beyond which there is no measurable diameter effect should be reached at some finite diameter.

(d) that the British cyclotol 60/40 prepared from Bridgewater RDX approximates closely the NOL Comp B.

(e) that the Hugoniot of the unreacted explosive can be approximated by that for cast TNT.

It is obvious that so many approximations will introduce some error; such error is illustrated by the results for TNT and tetrytol 91/9 described above. The error introduced is believed to be small as the illustration suggests. Consequently, although the two lower curves of Fig. 2 may not be exact, the qualitative trends they indicate are valid as well as expected.

SHOCK SENSITIVITY OF RECENT PROPELLANTS

Earlier work (2, 3) showed that the most sensitive nonporous propellant received and tested required an initiating pressure of 57 kbar as compared to 37 kbar for cast TNT, the least sensitive of the conventional field explosives. During the past six months, six samples of hybrid double-base (NG, NC, Al, AP, and HMX) propellants have been tested. Their test values are given in Table 4 and plotted in Fig. 3. In the range of 11 to 44% HMX, the reciprocal initiating pressure shows an apparent linear variation with the HMX content of the propellant. The linear curve extrapolates to 47.8 kbar at 0% HMX, as compared to 69.7 (DDP-70), and to 21 kbar at 100% HMX, as compared to 5.6 kbar for RDX. Thus the curve of Fig.3 is probably not the correct relationship. Although the present results are inadequate to establish a relationship, they do show very clearly that the hybrid propellants containing HMX destroy the former division between propellants and field explosives. The two materials containing 25.9% and 44% HMX, a high explosive, exhibit lower initiating pressures than does cast TNT.

TABLE 4

Effect of HMX Content on Shock Sensitivity

Material*	HMX %	50% Gap Cards	Incid. Pressure kbar	Init. Pressure kbar	Reciprocal Init. Pressure $kbar^{-1} \times 10^2$
DGV (DDP-70)	0	60	57.5	69.7	1.44
DMM	10.9	123	35.3	42.8	2.34
DNS	10.8	127	34.2	41.8	2.39
EFG	19.3	137	31.5	38.0	2.63
DRR	20.9	137	31.5	38.0	2.63
EJC	25.9	144	29.6	35.7	2.80
PFG	44.0	ca.161	25.5	30.7	3.26

* Compositions will be found in NOLTR 61-4 and Progress Reports on NOL 323 for Nov-Dec, Sep-Oct, and May-Jun, 1961 except for PFG which is NC/NG/HMX/Al/2-nitrodiphenylamine, 5/30/44/20/1.

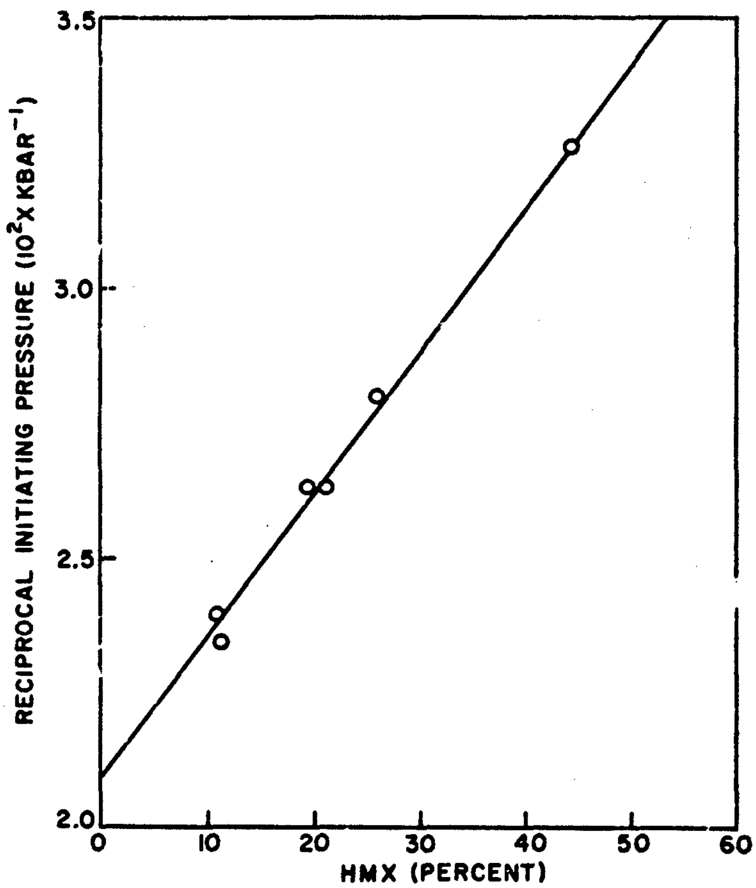


FIG. 3 VARIATION OF INITIATING PRESSURE WITH HMX CONTENT

INFORMATION ABOUT LOW IMPULSE REACTIONS

The standardized gap test is designed to measure the shock sensitivity of materials reacting to give a high impulse; the minimum impulse for the reactions it tests is that necessary to punch a hole in the cold-rolled steel witness plate (3). All non-porous propellants which have been tested have either produced much more than this minimum impulse or so little that the witness plate was undamaged. However, some porous materials have exhibited no-go at zero gap i.e., failed to punch the plate, but have also shown a shock initiated reaction of sufficient impulse to bulge and bend the witness plate. Any reaction capable of damaging a 3/8 in. thick steel plate is of importance for safety considerations even if the damage it can cause is less than that of the higher impulse reactions. It is therefore desirable to have a means of assessing such lower impulse reactions.

In principle, it is possible to design separate tests to measure:

(a) Sensitivity of initiation to any self-propagating reaction, and

(b) The strength i.e., maximum pressure of the self-propagating reaction initiated by shock.

In practice, such an absolute division in testing non-porous propellants seems unnecessary because no sample tested has been in the lower impulse region; the division seems undesirable because of the long time required to develop new reliable tests. Consequently, it is proposed that the standardized gap test be used, as in the past, to cover simultaneously parts of (a) and (b) and that if a material is found to damage, but not punch, the witness plate, information be obtained to supplement the gap test result.

The simplest way to obtain such supplementary information is to use the standardized test geometry with the replacement of the 3/8 in. witness plate by another sensor capable of responding unambiguously to lower impulse loadings. The first substitute investigated was thinner witness plates. It was found that they gave too small a range in response to be satisfactory. (See Appendix A).

The method which was then developed, and which is satisfactory, utilizes an explosive witness system. Fig. 4 shows the standardized gap test with a steel witness plate. To study lower impulse reactions i.e., those that result in pressures of about 55 kbar or less in the reacting material, the steel plate adjacent to the test material is replaced by another 5.5 in. length tube of any detonable material for which the initiating pressure is already known; the modified geometry is shown in Fig. 5. As the figure shows, the steel plate is still used to witness the high impulse reaction of the explosive witness after the high impulse reaction has been initiated by the low impulse reaction of the test material.

The choice of explosive sensors can be made from materials already studied. A typical selection is:

Explosive witness	Initiating Pressure-kbar
Propellants	ca 50
TNT (cast)	37.3
Comp B (cast)	21.2
DINA (cast)	6.3

Intermediate levels can be obtained by combining or diluting these materials. Since all of them are non-porous and have approximately the same impedance as the non-porous propellants, the incident pressure, or pressure generated by the reaction of the test material and the quantity of interest in assessing damage, will be nearly equal to the initiating pressure required by the explosive witness. Porous sensors e.g., PETN at ρ_o = 1 g/cc with 2.5 kbar initiating pressure (18), should be avoided because the incident pressure from a non-porous test material must be much higher than the low initiating pressure of such a sensor to induce its detonation. Similar difficulties from impedance mismatch arise in testing a porous material with a non-porous explosive witness. The study of low impulse materials by the method indicated in Fig. 5 is best applied only to non-porous materials.

The present method not only provides an estimate of reaction pressure of the test material but also, if the strength of the reaction warrants it, a way of measuring the shock sensitivity of the reaction. This can be done by using the standard gap testing procedure with the appropriate explosive witness system in place of the steel witness plate. Thus a measure of both the ease of initiation and of the strength of a low impulse reaction can be obtained.

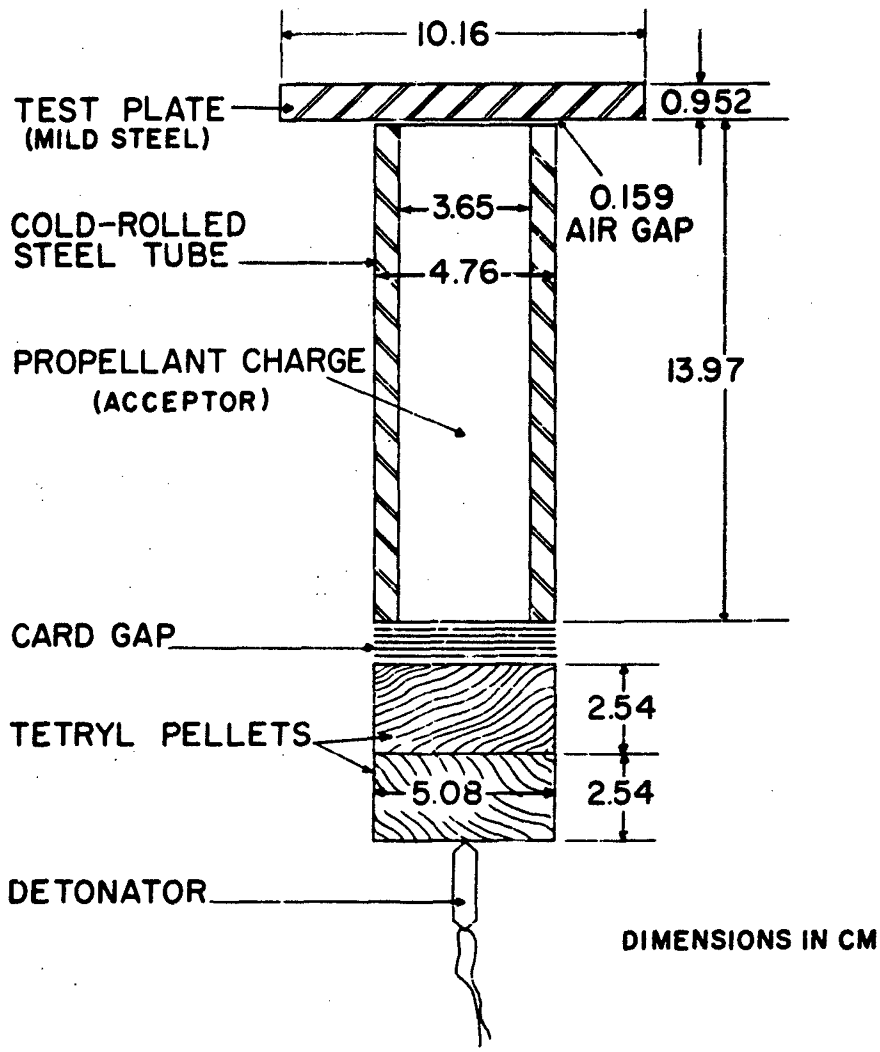


FIG. 4 CHARGE ASSEMBLY AND DIMENSIONS FOR NOL STANDARDIZED GAP TEST

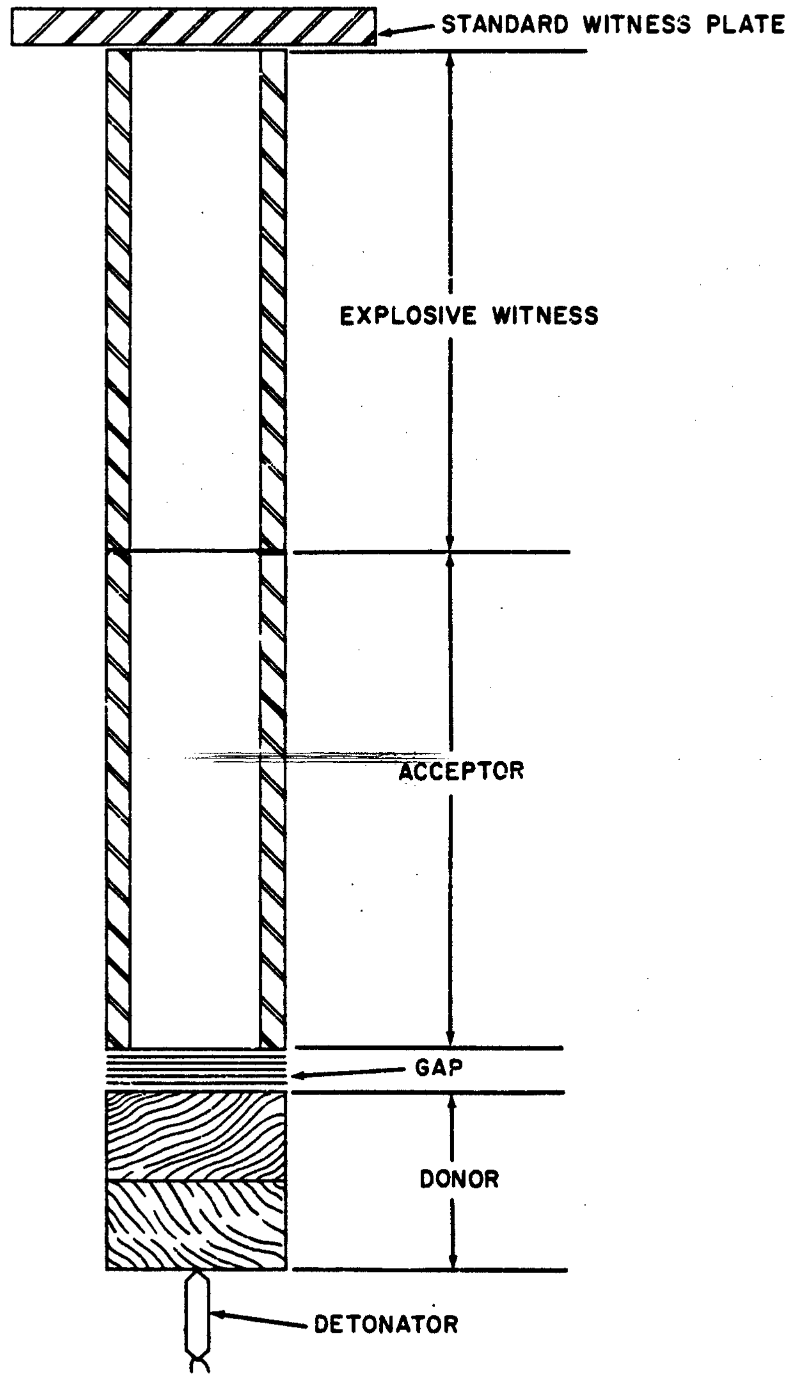


FIG. 5 TEST ASSEMBLY USING THE EXPLOSIVE WITNESS SYSTEM

Although the method is designed to study non-porous materials, it is necessary to illustrate its application with a porous substance; this is because no non-porous propellant exhibiting the lower impulse behavior is available. Porous ammonium perchlorate (AP) of average particle size of 25μ and loading density of 0.85 g/cc was chosen; the test results are given in Table 5.

First, the initiating pressures of cast TNT and cast Comp B, the materials to be used in explosive witness systems were determined to be about 37 and 23 kbar respectively. It was also shown that doubling the length of the Comp B acceptor had no effect on the measured initiating pressure i.e., that the length/diameter ratio of the standard gap test is sufficient for complete build-up. Earlier results on porous AP were repeated: a no-go at zero gap in the standardized test but obvious damage to the witness plate. With both of the explosive witness systems, a go was obtained and in both cases the required incident pressure was about 15 kbar. To determine the pressure required to initiate the AP it is necessary to use a Hugoniot for this material. Of the available Hugoniot data, that set which might best approximate porous AP is the Hugoniot for porous PETN (ρ_o = 1 g/cc) (18). Use of this Hugoniot and an incident pressure of 15 kbar at the Lucite/AP boundary gives an initiating pressure of about 5 kbar for the AP. This material is therefore very shock sensitive and its low impulse reaction easy to initiate.

The maximum pressure generated by the low impulse reaction is harder to estimate since it requires Hugoniot data for the reaction products. Qualitatively, it is more than sufficient to initiate TNT, the less sensitive explosive, but not much more than sufficient since an attenuation of about 0.22 inches of Lucite prevents the initiation. The computed detonation pressure for AP (ρ_o = 0.85) is about 30 kbar (19); this is a reasonable loading at the AP/TNT boundary to transmit about 37 kbar to the TNT and thus initiate detonation of the TNT.

Finally, the test data in Table 5 for the length of gap between the acceptor and explosive witness, necessary to attenuate the loading from the AP reaction until it is too weak to initiate the explosive witness, serves also to show that the initiation of the explosive witness is by shock not by a flame front from the decomposing AP. The plastic material of the gap will transmit compression pulses, but prevent propagation of any normal burning front.

TABLE 5

Study of Low Impulse Reactions

Material	Density	Temperature* °C	Witness System	50% Gap No. Cards	Initiating Pressure, kbar	Comments
TNT(c)	1.[illegible]	[illegible] to [illegible]	Steel Plate	141 ± 1	36.7	
Comp B(c)	1.[illegible]	[illegible]	" "	195 ± 1	23.2	Same value within difference to be expected for temperature difference.
Comp B(c)	[illegible]	[illegible]	Comp B(c)	[illegible]<N<1[illegible]	24.5	
AP**	ca. [illegible]	[illegible]	Steel Plate	N < 0	?	Plate deformed by large hump.
AP	"	[illegible]	Comp B(c)	212<N<225	ca. 5	See text. Gap value same within difference to be expected for temperature difference.
AP	"	13.[illegible] to 14.[illegible]	TNT(c)	207	ca. 5	

Gap Placed between Acceptor and Witness System
(Zero gap between donor and acceptor)

Material	Density	Temperature* °C	Witness System	50% Gap No. Cards	Initiating Pressure, kbar	Comments
AP	ca. 0.85	24 to 25	Comp B(c)	100<N<150		Reaction of AP gives impulse more than sufficient to initiate cast TNT, and therefore much more than sufficient to initiate Comp B. Excess of impulse over that to initiate TNT is small.
AP	"	12.8 to 14.4	TNT(c)	18<N<25		

* Temperature conditioning facilities were not available at time of this work.

** The ammonium perchlorate used was micromilled to an average particle size of 25μ.

IMPORTANT RESULTS OF STUDY

The more important results of the present study can be briefly summarized as follows:

1. The pressure required to initiate detonation in a given detonable material decreases from its highest value near the material's critical diameter to its lowest value at a charge diameter which is effectively infinite; this latter value is an intrinsic sensitivity property of the material in the physical state (temperature, density, particle size) tested.

2. The confinement used in the standardized gap test varies in effectiveness with the material tested; for cast Comp B, it increases the effective diameter by about 2.5 times for the standard loading provided by the standard tetryl donor.

3. The initiation pressure measured by the standardized gap test is near that for the infinite diameter charge; this is indicated by the correlations found between (a) large scale field tests and 50% gap values, (b) blunt-nosed bullet tests and 50% gap values, and (c) the wedge test results and 50% gap values.

4. Recent propellant samples show greater shock sensitivity than that of cast TNT.

5. Shock initiated reactions of such low impulse that they damage but do not punch the standard witness plate can be studied by use of a high explosive system as a witness.

6. Judicious choices of explosive witnesses permit not only the measurement of the shock sensitivity but also of the maximum pressure generated by the low impulse reaction. The latter quantity gives an estimate of the damage to be expected from the reaction.

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APPENDIX A

SOME PROPERTIES OF VARIOUS STEEL WITNESS PLATES

A short investigation was made of the feasibility of using steel witness plates thinner than the standard 3/8 in. plate of the standardized test. The purpose was to obtain a witness sensitive to lower impulse loadings than is the standard plate. A series of plates, varying in thickness from 1/16 up to 3/8 inch, was tested. The loading required to punch a hole was determined as in Ref. (3). The data obtained are given in Table A1. They show:

1. The standard 3/8 in. cold-rolled plate varied from batch to batch so that the minimum transmitted pressure for punching a hole varied from 64 to 96 kbar. (This variation has no effect on the results for high impulse reactions.)
2. The 1/4 inch plates required almost as high a pressure as the 3/8 inch.* They were superior to the 3/8 inch in having less tendency to spall.
3. The 1/8 inch plates showed little difference from the 1/4 inch in required loading and were less practical in that they were badly bent from impact on the bombproof ceiling.
4. The 1/16 inch plates were completely impractical.
5. Annealing either increased the pressure required to punch the plate or had no effect on it. There was no correlation found between the Rockwell B hardness and the required pressures.

Since the steel plates provided too narrow a range in required pressures and too wide a variation from batch to batch, it was decided that they would be unsatisfactory witnesses for low impulse reactions.

Metallurgical examination of the various 3/8 inch witness plates showed no differences in their chemical composition, but did show different microstructure. The plates which spalled easily had fairly large pearlitic areas tending to be aligned parallel to the rolling direction of the plate whereas such areas in the Batch 1 plates were smaller and uniformly distributed.

---

* Batch No. 2 unannealed excepted.

TABLE A1

Tests on Various Cold-Rolled Steel (1010-1020) Plates

Batch	Rockwell B Hardness	Thickness in.	Annealed	50% Point No. cards	Incident Pressure kbar	Transmitted Pressure, kbar	Comments
1	Unknown	3/8	No	100	42.7	93.0	No spalling
2	ca. 88-91	3/8	No	140	30.7	64.0	Bad spalling
2	59-63	3/8	Yes	98	43.5	95.5	" "
3	85-89	7/8	Yes	98	43.5	95.5	" "
4	95-97	1/4	No	ca. 113	38.3	83.0	No "
5	92-97	1/4	Yes	112-114	38.3	83.0	" "
6	90-92	1/8	Yes	112	38.3	34.3	Plates badly bent
7	81-88	1/16	Yes	?	?	?	" " broken

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CONFIDENTIAL

Gap test results show good correlation with large-scale field tests, blunt-nosed bullet tests, and approximately one-dimensional wedge test results; it is therefore believed gap test measures 50% initiating pressure close to that for infinite diameter acceptor. Supplement to NOL shock sensitivity test for propellants has been devised whereby judicious choice of explosive witness systems makes it possible: (1) to assess strength of reactions of low impulse and (2) to measure sensitivity to shock initiation of such substances.
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