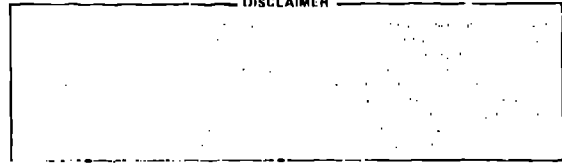TITLE: NONIDEAL DETONATION AND INITIATION BEHAVIOR OF A COMPOSITE-SOLID ROCKET PROPELLANT

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NONIDEAL DETONATION AND INITIATION BEHAVIOR OF A
COMPOSITE SOLID ROCKET PROPELLANT

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Shock initiation and detonation behavior of an HMX/AP/Al rocket propel-
lant was studied for nonideal character. Low detonation velocities and
unusual shock initiation behavior were observed. Failure to propagate
steady detonation in cylinders of the propellant was also noted.

A nonideal explosive has been defined by
C. Mader as one having a detonation velocity,
C-J pressure, or an expansion isentrope
significantly different from those predicted by
an equilibrium thermodynamic calculation such as
BKW. In this paper we are concerned with
deviations from predicted values of detonation
velocities, atypical shock initiation behavior,
and detonation failure in cylinders of explosive.

Two types of experiments were done on
SPIS-44, an Air Force propellant. Plane shock
initiation wedge experiments were performed to
study the nature of the buildup to detonation.
One also obtains a measure of detonation
velocity and particle velocity associated with
the front. Bare cylinders of the propellant
were fired as rate sticks to determine failure
diameter and detonation velocity.

The wedge experiments show unusual
initiation behavior, a low detonation velocity,
and a free-surface particle velocity indicative
of some degree of reaction. The rate sticks
showed that the failure diameter is greater than
50 mm. In fact, a 74-mm-diameter rate stick may
have been heading for failure after propagating
six diameters with decelerating velocity. The
nature of the shorting pin signals also
indicates unusual behavior.

The formulation for SPIS-44 is given in
Table I. It is 20/49/21 wt% HMX/AP/Al, and has
an inert binder. Its density, 1.83 g/cm^3, is
full density.

Figure 1 shows the nature of the unusual
character of the buildup to detonation in
SPIS-44. For comparison, typical buildup curves
for two other formulations are shown. Formula-
tion A with 44/16/19 wt% HMX/AP/Al plus binder,
has trajectories typical of heterogeneous
explosives and its detonation velocity of 7.8 ±
0.3 mm/μs and product velocity against ambient
air of 8.2 ± 0.7 mm/μs agree with a BKW

calculation (cf. Ref. 1 for more details). The
trajectory for Formulation B (29/36/18 wt%
HMX/AP/Al plus binder) looks like that of
formulation A, but both detonation velocity 6.6 ±
0.1 mm/μs and product velocity of 6.0 ± 0.2 mm/μs
are well below BKW values of 8.0 and 8.6 mm/μs,
respectively. So Formulation B is in some sense
nonideal. The measured detonation velocity is
evidence of incomplete reaction before the sonic
surface driving the detonation front. A BKW
calculation treating the AP as inert gives a
detonation velocity of 6.5 mm/μs in agreement
with the measured value. Calculated product
velocity is 5.8 mm/μs, also in agreement with
measured values.

Table 1

SPIS-44 Propellant Formulation

Ingredient	Average Particle Size (μm)	Weight Percent
Ammonium Perchlorate	200	28
" "	6	21
Cyclotetramethylene Tetranitramine	9	20
Aluminum	6	21
Hydroxy-terminated Polybutadiene	-	7.27
Polybutene Oil	-	2.00
Isophorene Diisocyanate	-	0.51
Bonding Agent from Glycidol, Tetraethylene Pentamine and Acrylonitrile	-	0.15
Methylene Bis(Tertiarybutyl Phenol)	-	0.07

The SPIS-44 trajectories show behavior
different from that of the other formulations.
There is some acceleration for 7.0 GPa input
stress, and there is some evidence of a
transition for the 11.7 GPa shot. But the
accelerations involved are much lower than for

other, more sensitive formulations. Most explosive formulations have trajectories which can be modeled by an acceleration which diverges as the transition is approached. For formulation C the acceleration through the transition region for the 11.7 GPa shot was nearly constant at 0.8 mm/μs², whereas the peak acceleration for formulation B was 4.8 mm/μs² and 6.8 mm/μs² for formulation A (Fig. 2). For even higher input stresses the SPIS trajectories show no transitions, but the detonation velocities are increased. The detonation velocities (Fig. 1) correspond to incomplete reaction. BKW calculations predict 8.0 mm/μs. For the 25.7 GPa shot, the flow velocity at the wedge heel was 6.9 mm/μs against ambient air. This compares with 8.6 mm/μs expected for complete reaction and 4.2 mm/μs for twice the particle velocity of the Hugoniot state at the input face of the wedge. So the 6.9 mm/μs flow velocity is consistent with incomplete reaction near the detonation front.

The detonation velocity increases with increased input stress, an indication of overdriven detonation. The problem is to explain the nature of the transition for the 11.7 GPa

shot. It could be interpreted as the buildup phase of an overdriven detonation. BKW results for 0% AP reacted give a detonation velocity of 5.8 mm/μs and a CJ pressure of 12.2 GPa; for 15% AP reacted the detonation velocity is 6.2 mm/μs with CJ pressure of 15.0 GPa.

The question then remains whether unsupported detonation is possible in this material. In an attempt to answer this question, several rate stick/plate-dent shots were fired. Cylinder diameters were 25, 51, and 74 mm. The mild-steel witness plates were 51 mm thick.

The first shot was a simple plate-dent experiment with a 25.2-mm-diam charge, 101.2 mm long. The stick was initiated by a 40-mm-diam planewave lens and 6.4 mm of PBX-9404 (strongly overboosted). There was no deformation of the steel plate (Fig. 1). A good deal of black smoke emanated from the shot, and a few 1-cm chunks of unconsumed propellant were found lying beside the steel plate.

The next shot was a 73.5-mm-diam rate stick 407.7 mm long. The shot was placed in a
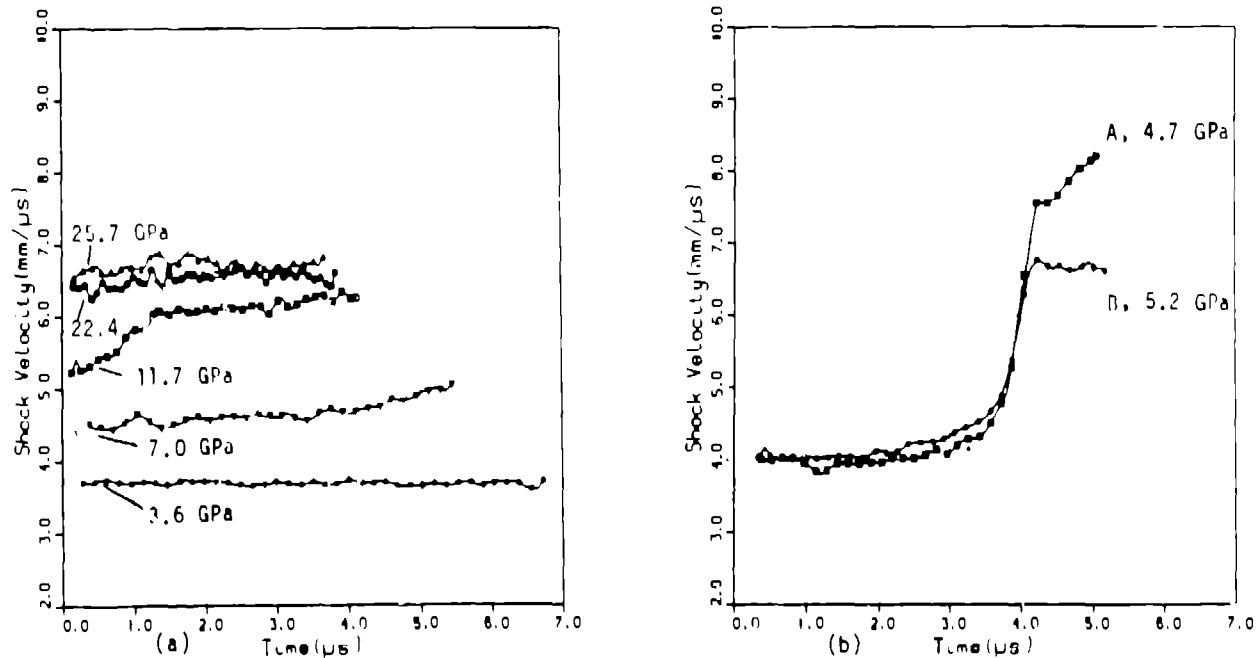

Fig. 1.   Shock velocity-time trajectories obtained by differentiating the shock position-time trajectories measured in wedge experiments. The shock velocity was obtained as the slope calculated by a running linear least-squares fit to the data. Only every other point is shown. (a) shows the trajectories for SPIS-44 for a number of input pressures. (b) shows results for two other propellants, one ideal and one nonideal. The pressures given are the input pressures.

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Styrofoam box for temperature control at 19 ±
1°C. The stick was initiated by a 100-mm-diam
planewave lens and 10.4 mm of PBX-9404. There
were nine SPIS-44 segments with 51-μm-diam,
insulated, magnet-wire pins between segments.
Two wires were laid parallel along a diameter a
few millimeters apart. A sizeable dent was made
in the steel plate (Fig. 1), but the pin signals
were erratic (65 V on the pins). Only four of
10 pin signals looked normal. The segmental
velocities from the normal signals are displayed
in Fig. 3.

The final shot was a 50.8-mm-diam stick
235.6 mm long. The shot was placed in a
Styrofoam box for temperature control. Shot
temperature was 20.5°C. The stick was
initiated by a 56-mm-diam planewave lens and
12.7 mm of PBX-9404. In order to try to solve
the pin problems, two new pin designs were
tried. The first set used one insulated wire
and one bare ground wire making an "x" across
the center of the segment face, with about a
15° angle between the wires. This set did not
require ionization of the explosive for
shorting, but was shorted by mechanical action
of the shock wave. The second set used a pair
of bare wires lying parallel a few millimeters
apart and extending about a centimenter in from
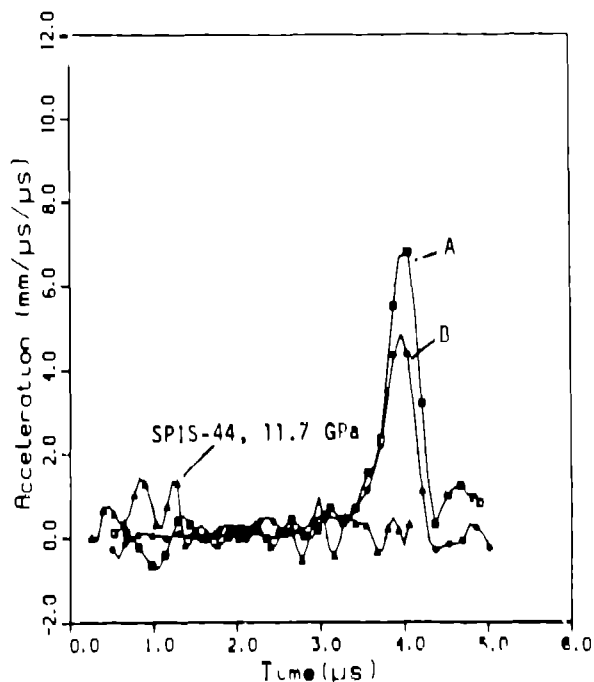the edge of the face (50 V on the pins).

The first set gave good, normal signals.
Those from the second set were not sharp, normal
signals except for the first two. This
indicates that the incompletely reacting SPIS-44
propellant does not provide a good electrical
path for shorting pins. The segmental
velocities obtained from the first set of pins
are shown in Fig. 3. Note that shorting signals
were not received from the ends of the last two
segments. This is consistent with the fact that
the steel witness plate was not deformed. There
was some black residue on it.

In conclusion, SPIS-44 propellant failed at
25 and 51 mm diam. For the 51-mm-diam shot
strongly initiated by PBX-9404, it propagated
about four diameters before failing. From a
study of Fig. 3, noting that the shock in the
last segment of the 74-mm-diam stick was
propagating at 5.35 mm/μs, it appears that the
reactive wave in the stick may have been headed
for failure after propagating something more
than six diameters. This is consistent with the
suggestion of D. Price (2) that Group 2
explosives fail slowly. These results do not
entirely lay to rest the question of whether
unsupported detonation is possible in SPIS-44
propellant. The data do indicate that failure
occurs in sticks less than 50 mm diam and
perhaps up to 74 mm diam. They add weight to
the earlier suggestion that the trajectories
observed in shock-initiation wedge tests on
SPIS-44 are evidence for overdriven, nonideal
flows.

There are several reasons why the reactive
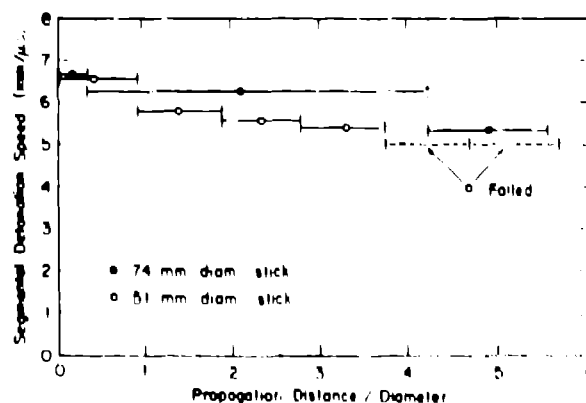flow might be nonideal in these materials.

Fig. 2. Acceleration-time trajectories obtained
for three propellant formulations by
numerical differentiation of trajec-
tories in Fig. 1. Peak acceleration
decreases with increasing departure
from ideality.

Fig. 3. Detonation velocity measured by transit
time through cylindrical segments vs the
ratio of propagation distance to cylin-
der diameter. Detonation in the 51-mm-
diameter stick failed after propagating
almost 4 diameters. Detonation in the
74-mm-diameter stick may be on its way
tu failure after propagating 5 1/2
diameters.

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These propellants are composite materials with fuel and oxidizer on separate particles, except for the HMX. This means that the reaction rate (progress towards complete decomposition) can be diffusion-limited. Furthermore, the pressure in the reaction zone may remain low because of a low number of moles of gas per cubic centimeter in the reaction products. The propellant is also oxygen-deficient.

ACKNOWLEDGMENTS

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REFERENCES

1. J. J. Dick, "Detonation Initiation Behavior of Some HMX/AP/Al Propellants," Combust. Flame, Vol. 37, pp. 95-99, 1980.

2. D. Price, "Contrasting Patterns in the Behavior of High Explosives," Eleventh Symposium (International) on Combustion, pp. 693-702, The Combustion Institute, Pittsburgh, 1967.