Determination of detonation velocity and plate dent properties of DPX-5

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Approved by

Jan Ivar Botnan Director

English summary

Detonation velocity for DPX-5 Ch 01/07 has been determined both experimentally and theoretically by use of the Cheetah 2.0 code. The measured detonation velocity was found to be 8276 m/s or approximately 350 m/s higher than what the Cheetah 2.0 code gives by use of the BKWC product database.

Detonation pressure determined by Plate Dent test gave an average pressure of 253 kbar for DPX-5 Ch 01/07. This result is equal to the theoretically calculated pressure obtained by use of the Cheetah 2.0 code of 25.3 MPa.

Sammendrag

Detonasjonshastigheten for DPX-5 Ch 01/07 har blitt bestemt både eksperimentelt og teoretisk ved bruk av Cheetah 2.0 koden. Den eksperimentelle detonasjonshastigheten ble målt til 8276 m/s som er omlag 350 m/s høyere enn hva man oppnår ved bruk av Cheetah 2.0 koden og BKWC produktdatabase.

Detonasjonstrykket bestemt ved bruk av ”Plate Dent test” ga et gjennomsnittlig detonasjonstrykk på 253 kbar for DPX-5 Ch 01/07, et resultat i overensstemmelse med det teoretisk beregnede trykket på 25.3 GPa ved bruk av Cheetah 2.0 koden.

Contents

1 Introduction

M72 LAW (Light Antiarmour Weapon) has been redesigned with a new warhead for urban warfare. M72 ASM-RC (Anti-Structure Munition Reduced Caliber) has as the name indicates a new warhead for combat of light buildings. This requires a main charge explosive different from those used in shaped charge warheads. Studied explosive composition DPX-5 is an aluminized PBX which is press filled into the warhead. This composition is not qualified, and before DPX-5 can be used in weapons it has to be type qualified according to STANAG 4170 (1) and accompanying AOP-7 (2). Detonation velocity is an important property of explosives since it has influence on the performance. To experimentally determine the detonation velocity we have used a cylindrical charge with two sensors of twisted Copper wires. The first sensor was placed 8 cm from the booster to register the start and the second sensor 4 cm from the opposite end of the charge to register the stop. After measuring the distance between the start and stop and the time the reaction front used between these two points we easily can calculate the detonation velocity.

To determine the detonation pressure we used the same charges as for detonation velocity measurement to perform the Plate Dent test. In addition we have performed theoretical calculations of detonation properties by use of the Cheetah 2.0 code (3).

2 Experimentally

2.1 Detonation Velocity

The tested DPX-5 charges consist of single pellets glued together to a length that reduces the uncertainty in the measurement to an acceptable level. The used pellets were pressed by Chemring Nobel AS. Dimensions, weight and density of single pellets are given in Appendix B. The used material DPX-5 was from Lot DDP07J0001E Ch. 01/07, and the control report for this material is given in Appendix A. 30 pellets were received and used to produce three test items. All three test items contained 10 pellets, pellet 1-10 in item No 1, pellet 11-20 in item No 2 and pellets 21-30 in item No 3. As sensors or measuring probes we used twisted copper wires (4).The Copper wire had a diameter of 0.15 mm with a 0.005 mm thick layer of lacquer. Two wires were twisted together and at the ends the lacquer was removed to obtain contact. We used two measuring probes, one placed between the second and third pellet and one between pellet 9 and 10. The position of the start measuring probe was selected to get a stable detonation front/velocity before starting the measurements and the position of the stop probe was selected not to influence the Dent.

To initiate the charges we use a 16 g RDX/wax booster and a detonator No 8. Picture of the test items is given in Figure 3.3.

To measure the velocity we used the set up shown in Figure 2.1 in addition to two power supplies and a scope of type: HEWLETT PACKARD 54510A. Digitizing Oscilloscope, 250 MHz 1G Sa/s. When the detonation front passes the start sensor there will go a current through the circuit and a signal is observed on the oscilloscope. The same will happen when the detonation front reaches the stop probe. The time between these two signals is used to calculate the detonation velocity since we know the distance between the two sensors.

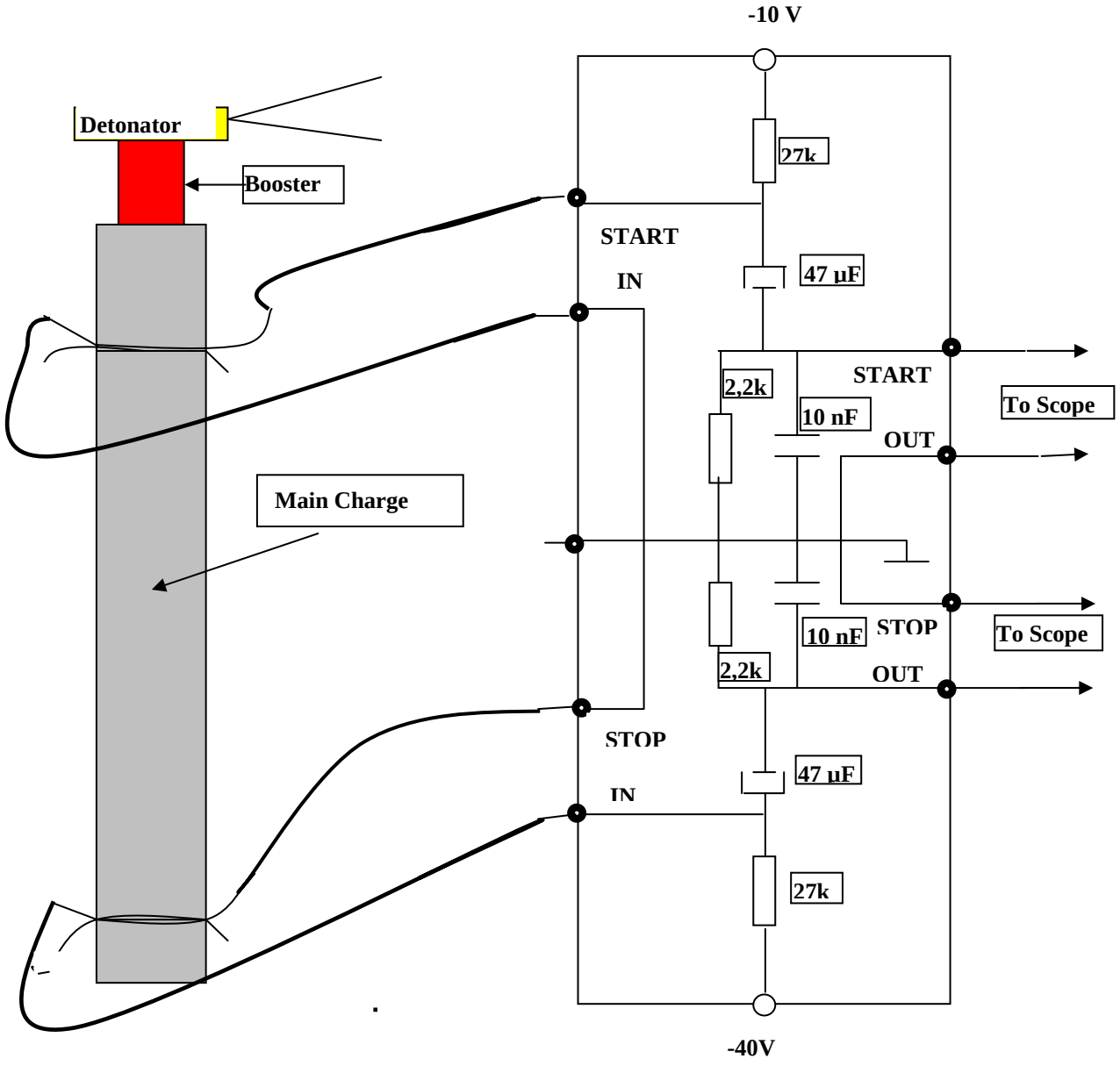

Figure 2.1 Sketch of the instrumentation for measuring the detonation velocity.

2.2 Plate Dent test

The Plate Dent test as described in (5) was performed for all three shots for determination of detonation velocity. As witness plates we used round steel plates with diameter 155 mm and thickness of 50 mm of ST-37 steel.

3 Results

3.1 Theoretical Calculations

The performance of DPX-5 has been calculated by use of Cheetah 2.0 code (3) and the BKWC product database. Calculations have been performed at different densities from TMD (theoretical maximum density) in interval of 0.5% down to 95% TMD. DPX-5 is a composition that is filled into a warhead by pressing and normally the density of the filling will be significantly lower than TMD. The pellets used to determine the detonation velocity and Plate Dent have a measured density of 1.958±0.002 g/cm^3 or 97.6 %TMD, Appendix B.

In Appendix C.1 is the complete printout for a standard Cheetah run for DPX-5 Ch 01/07 at TMD given. As the results show the products at room temperature and pressure contain no aluminium. All the aluminium is consumed and is transformed to Al_2O_3. Appendix C.2 gives the summary report for different densities. Table 3.1 summaries the most important properties at the C-J conditions for different densities.

The C-J	**Density (g/cm^3)**										
Conditions	2.0064	1.996	1.986	1.976	1.966	1.9562	1.956	1.936	1.926	1.916	1.906
%TMD	100	99.5	99.0	98.5	98.0	97.5	97.0	96.5	96.0	95.5	95.0
The pressure (GPa)	27.17	26.78	26.40	26.02	25.65	25.29	24.93	24.58	24.24	23.90	23.57
The volume (cc/g)	0.397	0.399	0.400	0.402	0.404	0.406	0.407	0.409	0.411	0.413	0.414
The density (g/cc)	2.519	2.508	2.498	2.487	2.476	2.466	2.455	2.445	2.434	2.424	2.413
The energy (kJ/cc)	2.76	2.73	2.70	2.67	2.64	2.61	2.58	2.56	2.53	2.50	2.48
Temperature (K)	5717	5708	5699	5690	5681	5673	5664	5654	5645	5636	5627
Shock velocity (m/s)	8157	8107	8057	8008	7958	7910	7861	7813	7765	7718	7671
Particle velocity (m/s)	1660	1655	1649	1644	1639	1635	1630	1625	1621	1616	1612
Speed of sound (m/s)	6497	6452	6408	6363	6319	6275	6231	6188	6144	6102	6059
Gamma	3.914	3.900	3.885	3.870	3.854	3.839	3.823	3.807	3.791	3.775	3.759

Table 3.1 Calculated property at C-J conditions for different densities of DPX-5 Ch 01/07.

3.2 Detonation Velocity

To test that time registration equipment functioned as expected it was tested with a detonating cord with length 80.0 cm. The time between start and stop signal was 109.6 μs, which gives a detonation velocity of 7299 m/s. This velocity is similar to earlier measurement of 7282 m/s (6, 7), and in addition it confirmed that the cabling and time registration equipment did function as expected.

Three charges containing 10 pellets each were tested with regard to determine the detonation velocity experimantally. The start sensor was placed between the second and the third pellet and the stop sensor between pellets nine and ten.

3.2.1 Shot 1

The first shot with DPX-5 Ch 01/07 had a distance between the start and stop sensors of 24.576 cm. In figure 3.1 is given a picture of the time registration on the used oscilloscope. As can be seen from the picture both the start sensor and the stop sensor gave good registration and the difference in time between start and stop is 29.8 µs.

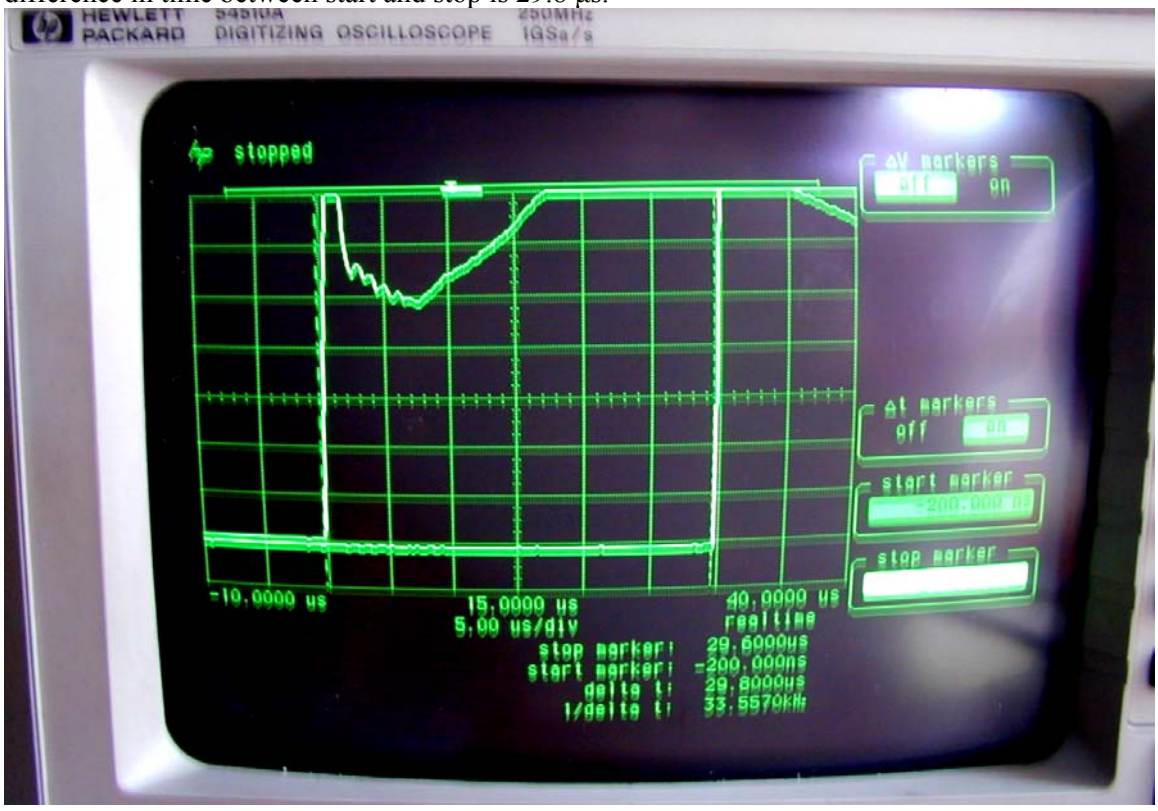

Figure 3.1 Picture of the oscilloscope registrations for the first shot with DPX-5 Ch 01/07.

This gives a detonation velocity of 8247 m/s.

3.2.2 Shot 2

The second shot with DPX-5 Ch 01/07 had a distance between the start and stop sensors of 24.645 cm. In figure 3.3 is given a picture of the time registration on the used oscilloscope. As can be seen from the picture both the start sensor and the stop sensor gave good registration and the difference in time between start and stop is 29.3 µs.

This gives a detonation velocity of 8411 m/s slightly higher than for shot No 1.

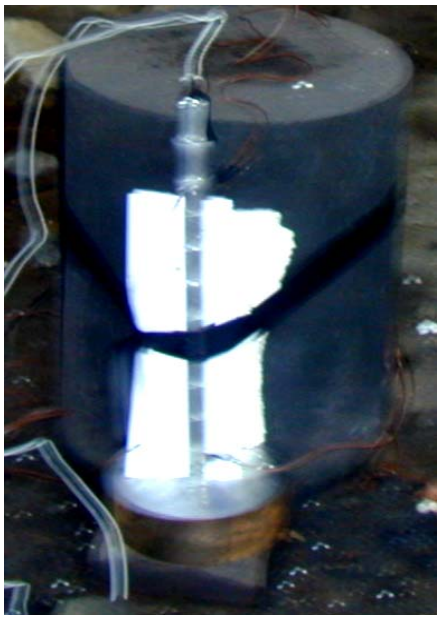

Figure 3.2 Picture of the test upset for shot 2 showing the Plate Dent witness plate at the bottom of the charge.

Figure 3.3 Picture of the oscilloscope registrations for the second shot containing DPX-5 Ch 01/07.

3.2.3 Shot 3

The third shot with DPX-5 Ch 01/07 had a distance between the start and stop sensor of 24.674 cm. In figure 3.5 a picture is given of the time registration on the used oscilloscope. As can be seen from the picture both the start sensor and the stop sensor gave good registration and the difference in time between start and stop is 30.2 µs.

This gives a detonation velocity of 8170 m/s slightly lower than for shot No 1 and 2.

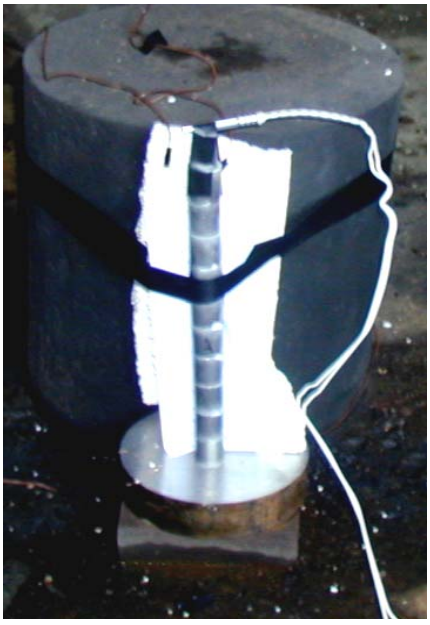

Figure 3.4 Picture of the test upset for shot 3 showing the Plate Dent witness plate at the bottom of the charge.

Figure 3.5 Picture of the oscilloscope registrations for the third shot with DPX-5 Ch 01/07.

3.2.4 Summary of detonation velocities experimental measured.

Table 3.2 summarizes the experimentally obtained detonation velocities for the three tested charges containing pellets of DPX-5 Ch 01/07. The obtained average result of 8276±123 m/s is higher than calculated by use of Cheetah. Cheetah gives for DPX-5 with the experimentally measured density of 97.8% TMD a velocity of approximately 7920 m/s which is approximately 350 m/s lower than the experimental measured detonation velocity. Compared with DPX-6 which contains only 50 wt.% of HMX the average experimental measured detonation velocity for DPX-5 Ch 01/07 is 420 m/s higher.

Shot No	Material	Measuring Distance (mm)	Time (µs)	Velocity (m/s)
0	*Detonating cord*	*800.00*	*109.6*	*7299*
1	DPX-5 Ch 01/07	245.76	29.8	8247
2	DPX-5 Ch 01/07	246.45	29.3	8411
3	DPX-5 Ch 01/07	246.74	30.2	8170
	Average DPX-5 Ch 01/07			8276±123

Table 3.2 Summary of detonation velocities for DPX-5 experimental measured.

Compared with the results for PBXW-11 with 30 wt% Aluminium the obtained detonation velocity for DPX-5 Ch 01/07 is identical, since we for PBXW-11 did obtain 8273 m/s (7).

3.3 Plate Dent test

The Plate Dent tests give results with respect to pressure performance. The depth of the dent in the witness plate is proportional to the detonation pressure for a given charge diameter. A picture of the three witness plates is given in figure 3.6. And the obtained results are summarized in table 3.3.

Figure 3.6 Picture of the plate dent witness plates for DPX-5 Ch 01/07.

Shot No.	Charge diameter (mm)	Dent Depth (mm)	Calculated Detonation Pressure* (kbar)
1	25.67	4.51	253
2	25.67	4.49	252
3	25.67	4.53	254
Average		**4.51**	**253**

**Calculated from calibration curves with TNT charges (4).*

Table 3.3 Results of DPX-5 Ch 01/07 in Plate Dent Test.

Comparing the results for DPX-5 Ch. 01/07 with earlier performed test in reference 4 for TNT and other compositions give that obtained average dent depth is equal to a pressure of approximately 253 kbar. Comparing this result with the theoretical calculated pressure in Appendix C.2 or in Table 3.1 gives good agreement between experimental determined and theoretically calculated J-C pressure.

For the comparable composition PBXW-11 with 30% Aluminium Ch. 07/05 having a slightly higher HMX content (68.4 wt.%), we obtained a dent depth of 4.56 mm (7). This result is slightly higher than for DPX-5 Ch 01/07 (HMX content 66.3 wt%), as expected.

Appendix A Control Report for used Explosive

CHEMRING NOBEL AS
High Energy Materials

Kontrollrapport
etter EN 10204 – 2.2

Kjøper / Mottaker Nammo Raufoss AS Postboks 162 2831 Raufoss	Bestillingsnummer 59919-1/SOL/3	Rapportnummer RD-16/07
	Bestillingsdato 12.09.07	Kontroll dato 04.10.07
Produsent Chemring Nobel AS High Energy Materials N-3475 Sætre NORGE	Produksjonsdato Sept 2007	Offentlig oppdragsnummer
Lot nummer DDP07J0001E	Mengde 100 kg	
Sprengstofftype DPX-5	Leveringsbetingelser/Teknisk underlag Spesifikasjon 016/00-K-005	

Analyseresultater

	Sammensetning				Fuktighet	Volumvekt
	HMX	Aluminium	HyTemp	DOA		
KRAV	64,4±2,0 %	30,0±2,0 %	1,4±0,5 %	4,2±1,0 %	≤ 0,10 %	Min 0,80 g/cm³
RESULTAT Ch 01/07	66,3	30,0	0,9	2,8*	0,02	1,04

	Granulatfordeling, % gjennom USSS Nr.					
	6 (3350 µ)	8 (2360 µ)	12 (1700 µ)	18 (1000 µ)	25 (710 µ)	40 (425 µ)
KRAV	Informativ	Informativ	Informativ	Informativ	Informativ	Informativ
RESULTAT Ch 01/07	100	100	97	51	14	1

*: Avvik godkjent av J.C.Olsen pr tlf 5/10-07
Fremmede partikler: Ingen

Øyvind H. Johansen
FoU Sjef

Alf Berg
Senior Produkt Ingeniør

Figure App. 1 Copy of the control report of the used DPX-5 charge.

Appendix B Properties of use pellets

All tested pellets were before use measured with regard to dimensions and weight. These results, in addition to calculated density are given in Table App. 1.

Pellet No	Weight (g)	Height (mm)	Diameter (mm)	Volume (cm^3)	Density (g/cm^3)
1	35.4476	35.14	25.67	18.186	1.949
2	35.5407	35.09	25.67	18.160	1.957
3	35.4651	35.01	25.66	18.105	1.959
4	35.4776	35.02	25.67	18.124	1.957
5	35.5168	35.03	25.67	18.129	1.959
6	35.4958	35.02	25.67	18.124	1.958
7	35.5351	35.08	25.67	18.155	1.957
8	35.5087	35.02	25.67	18.124	1.959
9	35.5300	35.06	25.67	18.145	1.958
10	35.4974	35.01	25.67	18.119	1.959
11	35.5431	35.09	25.67	18.160	1.957
12	35.5383	35.08	25.67	18.155	1.957
13	35.6026	35.13	25.67	18.181	1.958
14	35.5069	35.06	25.67	18.145	1.957
15	35.5129	35.06	25.67	18.145	1.957
16	35.5176	35.03	25.67	18.129	1.959
17	35.5014	35.04	25.67	18.135	1.958
18	35.5295	35.04	25.67	18.135	1.959
19	35.5024	35.03	25.67	18.129	1.958
20	35.5068	35.04	25.67	18.135	1.958
21	35.5320	35.06	25.67	18.145	1.958
22	35.5268	35.03	25.67	18.129	1.960
23	35.4923	35.02	25.67	18.124	1.958
24	35.5189	35.04	25.67	18.135	1.959
25	35.6285	35.14	25.67	18.186	1.959
26	35.5149	35.02	25.67	18.124	1.960
27	35.5254	35.07	25.67	18.150	1.957
28	35.5552	35.09	25.67	18.160	1.958
29	35.5236	35.03	25.67	18.129	1.959
30	35.5113	35.02	25.67	18.124	1.959
Average density					**1.958±0.002**

Table-App. 1 Properties of pressed pellets of DPX-5 used for detonation velocity and Plate Dent measurements.

Appendix C Cheetah Calculation for Ch 01/07

C.1 Complete printout for TMD

```
The composition:
Name   % wt.  % mol  % vol  Heat of     Mol.   TMD
                           formation     wt.  (g/cc)
                           (cal/mol)
HMX    66.30  16.61  69.83    17866   296.16   1.90 C4H8N8O8
Al     30.00  82.48  22.29        0    26.98   2.70 Al1
DOA     2.80   0.56   6.07  -290392   370.57   0.93 C22H42O4
Hytemp  0.90   0.35   1.81  -205067   188.60   1.00 C10H15.46O3.307

Heat of formation =      8.268 cal/gm
Standard volume   =      0.498 cc/gm
Standard entropy  =      0.000 cal/k/gm
Standard energy   =      8.256 cal/gm

The elements and percent by mole
     c             13.814
     h             27.170
     n             22.300
     o             22.873
     al            13.844
The average mol. wt. =  74.181 g/mol
Input>composition, hmx,66.3, al,30, doa, 2.8, hytemp, 0.9, weight
Input>gas eos, bkw
Input>standard run, rho, 2.006369
The initial equation error was huge: 14570.878374
The hugoniot reference state:
P0 = 1.000000 ATM, V0 = 0.498413 cc/gm, E0 = 8.256308 cal/gm
Using  123915 ATM as a lower bound for the C-J pressure
Using  309787 ATM as an upper bound for the C-J pressure
The C-J point was bracketed in cjbrent
The CJ state was found in 6 iterations
                              The C-J condition
The shock velocity    =   8.15736e+003 m/s
The particle velocity =   1.65995e+003 m/s
The speed of sound    =   6.49741e+003 m/s
P0 = 1 atm, V0 =  0.49841 cc/gm, E0 = 8.25631 cal/gm


                  Reference state = reactants
               H(R) = H- 8.27, E(R) = E- 8.26, S(R) = S- 0.00

  P      V          T        H(R)       E(R)       S(R)      VGS
 (ATM)  (CC/GM)     (K)     (CAL/GM)   (CAL/GM) (CAL/K/GM)(CC/GM)
                     CV        CP         ALPHA      BETA    KAPPA
                 (CAL/K/GM)(CAL/K/GM)
268127  0.396990  5716.8    2907.14    329.295    1.5686  0.23774
                    1.2837    1.83869   5.07614  1.5523  3.9142
```

Product concentrations

Name		(mol/kg)	(mol gas/mol explosive)
n2	Gas	8.911e+000	6.610e-001
h2o	Gas	2.968e+000	2.202e-001
c2h4	Gas	2.518e+000	1.868e-001
ch4	Gas	1.321e+000	9.802e-002
co	Gas	2.287e-001	1.697e-002
h3n	Gas	8.489e-002	6.297e-003
h2	Gas	7.663e-002	5.684e-003
ch3oh	Gas	2.747e-002	2.037e-003
co2	Gas	1.116e-002	8.276e-004
no	Gas	3.000e-003	2.225e-004
ch2o2	Gas	1.998e-003	1.482e-004
c2h6	Gas	3.978e-004	2.951e-005
ch2o	Gas	3.493e-004	2.591e-005
ch3	Gas	3.027e-004	2.246e-005
o2	Gas	2.041e-005	1.514e-006
alo	Gas	8.158e-007	6.051e-008
no2	Gas	1.011e-011	7.503e-013
al2o3	solid	5.039e+000	3.738e-001
*c	solid	4.465e+000	3.312e-001
*al	solid	1.041e+000	7.725e-002
al2o3	liquid	0.000e+000	0.000e+000
*al	liquid	0.000e+000	0.000e+000
Total	Gas	1.615e+001	1.198e+000
Total	Cond.	1.055e+001	7.823e-001

The C-J Adiabat
Reference state = reactants
H(R) = H- 8.27, E(R) = E- 8.26, S(R) = S- 0.00

P (ATM)	V (CC/GM)	T (K)	H(R) (CAL/GM)	E(R) (CAL/GM)	S(R) (CAL/K/GM)	VGS (CC/GM)
		CV (CAL/K/GM)	CP (CAL/K/GM)	ALPHA	BETA	KAPPA
1.)119018	0.498413	4991.84	1327.72	-108.882	1.56868	33.4468
		1.38893	2.46326	4.96766e	1.85424	3.21839

Product concentrations

Name		(mol/kg)	(mol gas/mol explosive)
n2	Gas	8.859e+000	6.572e-001
h2o	Gas	2.191e+000	1.625e-001
c2h4	Gas	2.081e+000	1.544e-001
ch4	Gas	1.834e+000	1.361e-001
co	Gas	1.339e+000	9.936e-002
h2	Gas	5.191e-001	3.851e-002
h3n	Gas	1.892e-001	1.403e-002
co2	Gas	3.843e-002	2.851e-003
ch3oh	Gas	2.742e-002	2.034e-003
ch3	Gas	6.349e-003	4.710e-004
ch2o2	Gas	4.567e-003	3.388e-004
c2h6	Gas	4.427e-003	3.284e-004
ch2o	Gas	3.955e-003	2.934e-004

```
       no  Gas   2.596e-003  1.926e-004
       o2  Gas   1.149e-005  8.522e-007
      alo  Gas   8.808e-006  6.534e-007
      no2  Gas   3.157e-010  2.342e-011
    al2o3  solid 4.906e+000  3.640e-001
       *c  solid 3.669e+000  2.722e-001
      *al  solid 1.306e+000  9.686e-002
    al2o3 liquid 0.000e+000  0.000e+000
      *al liquid 0.000e+000  0.000e+000

     Total Gas   1.710e+001  1.269e+000
     Total Cond. 9.881e+000  7.330e-001
Too many iterations in the etanewt solver
Failed to find equilibrium.  Will try again.

                         Reference state = reactants
                H(R) = H- 8.27, E(R) = E- 8.26, S(R) = S- 0.00

  P      V          T        H(R)       E(R)       S(R)      VGS
 (ATM)  (CC/GM)     (K)     (CAL/GM)   (CAL/GM) (CAL/K/GM)(CC/GM)
                     CV        CP        ALPHA      BETA    KAPPA
                  (CAL/K/GM)(CAL/K/GM)
1.)15855.2 1.09651 3714.71 -378.133  -799.1612   1.56868 0.841325
,                    1.14271 1.62160   7.83557  3.86379 2.28677

Product concentrations
         Name   (mol/kg) (mol gas/mol explosive)
       n2  Gas   8.843e+000  6.560e-001
       h2  Gas   5.214e+000  3.868e-001
      ch4  Gas   1.806e+000  1.339e-001
       co  Gas   1.761e+000  1.306e-001
     c2h4  Gas   7.030e-001  5.215e-002
      h3n  Gas   2.242e-001  1.663e-002
      h2o  Gas   1.444e-001  1.071e-002
      ch3  Gas   8.822e-002  6.544e-003
     c2h6  Gas   2.018e-002  1.497e-003
     ch2o  Gas   4.050e-003  3.004e-004
      co2  Gas   2.567e-003  1.905e-004
    ch3oh  Gas   8.309e-004  6.164e-005
       no  Gas   6.586e-005  4.885e-006
    ch2o2  Gas   5.914e-005  4.387e-006
      alo  Gas   5.195e-005  3.854e-006
       o2  Gas   1.228e-008  9.112e-010
      no2  Gas   1.807e-011  1.340e-012
       *c  solid 5.986e+000  4.440e-001
    al2o3 liquid 5.485e+000  4.069e-001
      *al  solid 1.492e-001  1.107e-002
      *al liquid 0.000e+000  0.000e+000
    al2o3  solid 0.000e+000  0.000e+000

     Total Gas   1.881e+001  1.395e+000
     Total Cond. 1.162e+001  8.619e-001

                         Reference state = reactants
                H(R) = H- 8.27, E(R) = E- 8.26, S(R) = S- 0.00
```

```
  P       V           T         H(R)        E(R)        S(R)       VGS
 (ATM)  (CC/GM)      (K)      (CAL/GM)    (CAL/GM) (CAL/K/GM)(CC/GM)
                     CV         CP          ALPHA       BETA     KAPPA
                 (CAL/K/GM)(CAL/K/GM)
1.) 4742.28 2.04349 3291.61 -756.854    -991.534  1.56868  1.78833
                       1.29802 1.70562    10.2984 6.74257  1.67567

Product concentrations
         Name   (mol/kg) (mol gas/mol explosive)
       n2  Gas   8.899e+000  6.602e-001
       h2  Gas   8.148e+000  6.045e-001
       co  Gas   1.872e+000  1.389e-001
      ch4  Gas   9.635e-001  7.147e-002
     c2h4  Gas   2.404e-001  1.783e-002
      h3n  Gas   1.109e-001  8.229e-003
      ch3  Gas   8.143e-002  6.041e-003
      h2o  Gas   4.067e-002  3.017e-003
     c2h6  Gas   7.668e-003  5.688e-004
     ch2o  Gas   1.831e-003  1.358e-004
      co2  Gas   8.397e-004  6.229e-005
    ch3oh  Gas   8.620e-005  6.394e-006
      alo  Gas   7.666e-005  5.687e-006
       no  Gas   1.104e-005  8.190e-007
    ch2o2  Gas   5.529e-006  4.101e-007
       o2  Gas   5.748e-010  4.264e-011
      no2  Gas   1.430e-012  1.061e-013
       *c  solid 7.678e+000  5.696e-001
    al2o3 liquid 5.484e+000  4.068e-001
      *al  solid 1.498e-001  1.111e-002
      *al liquid 0.000e+000  0.000e+000
    al2o3  solid 0.000e+000  0.000e+000

     Total Gas   2.037e+001  1.511e+000
     Total Cond. 1.331e+001  9.875e-001

                          Reference state = reactants
                 H(R) = H- 8.27, E(R) = E- 8.26, S(R) = S- 0.00

  P       V           T         H(R)        E(R)        S(R)       VGS
 (ATM)  (CC/GM)      (K)      (CAL/GM)    (CAL/GM) (CAL/K/GM)(CC/GM)
                     CV         CP          ALPHA       BETA     KAPPA
                 (CAL/K/GM)(CAL/K/GM)
2321.41 3.23968    3101.81   -904.098  -1086.223  1.56868 2.98497
                      1.35916   1.71063   11.7565 8.83121 1.44448

Product concentrations
         Name   (mol/kg) (mol gas/mol explosive)
       h2  Gas   9.216e+000  6.837e-001
       n2  Gas   8.921e+000  6.618e-001
       co  Gas   1.817e+000  1.348e-001
      ch4  Gas   6.161e-001  4.570e-002
     c2h4  Gas   1.204e-001  8.931e-003
      h3n  Gas   6.669e-002  4.947e-003
      ch3  Gas   5.969e-002  4.428e-003
```

```
      h2o  Gas   2.074e-002  1.538e-003
     c2h6  Gas   3.261e-003  2.419e-004
     ch2o  Gas   9.862e-004  7.316e-005
      co2  Gas   4.447e-004  3.299e-005
      alo  Gas   7.680e-005  5.697e-006
    ch3oh  Gas   2.259e-005  1.676e-006
       no  Gas   4.151e-006  3.079e-007
    ch2o2  Gas   1.392e-006  1.033e-007
       o2  Gas   1.125e-010  8.344e-012
      no2  Gas   2.773e-013  2.057e-014
       *c  solid 8.353e+000  6.196e-001
    al2o3 liquid 5.510e+000  4.087e-001
      *al  solid 9.849e-002  7.306e-003
      *al liquid 0.000e+000  0.000e+000
    al2o3  solid 0.000e+000  0.000e+000

     Total Gas   2.084e+001  1.546e+000
     Total Cond. 1.396e+001  1.036e+000

                          Reference state = reactants
                 H(R) = H- 8.27, E(R) = E- 8.26, S(R) = S- 0.00

  P      V          T        H(R)       E(R)       S(R)      VGS
 (ATM)  (CC/GM)     (K)     (CAL/GM)   (CAL/GM) (CAL/K/GM)(CC/GM)
                     CV        CP        ALPHA      BETA    KAPPA
                 (CAL/K/GM)(CAL/K/GM)
1284.79 4.98413  2966.65  -1003.29  -1158.35     1.56868  4.72990
                   1.37547   1.68136   1.27765 10.49811  1.31228
Product concentrations
         Name   (mol/kg) (mol gas/mol explosive)
       h2  Gas   9.799e+000  7.269e-001
       n2  Gas   8.933e+000  6.627e-001
       co  Gas   1.722e+000  1.277e-001
      ch4  Gas   4.169e-001  3.092e-002
     c2h4  Gas   6.665e-002  4.944e-003
      h3n  Gas   4.261e-002  3.161e-003
      ch3  Gas   4.221e-002  3.132e-003
      h2o  Gas   1.223e-002  9.072e-004
     c2h6  Gas   1.454e-003  1.079e-004
     ch2o  Gas   5.581e-004  4.140e-005
      co2  Gas   2.617e-004  1.941e-005
      alo  Gas   6.973e-005  5.172e-006
    ch3oh  Gas   7.449e-006  5.526e-007
       no  Gas   1.894e-006  1.405e-007
    ch2o2  Gas   4.434e-007  3.289e-008
       o2  Gas   3.091e-011  2.293e-012
      no2  Gas   6.701e-014  4.971e-015
       *c  solid 8.776e+000  6.510e-001
    al2o3 liquid 5.545e+000  4.113e-001
      *al  solid 2.886e-002  2.141e-003
      *al liquid 0.000e+000  0.000e+000
    al2o3  solid 0.000e+000  0.000e+000

     Total Gas   2.104e+001  1.561e+000
     Total Cond. 1.435e+001  1.064e+000
```

Reference state = reactants
H(R) = H- 8.27, E(R) = E- 8.26, S(R) = S- 0.00

P (ATM)	V (CC/GM)	T (K)	H(R) (CAL/GM)	E(R) (CAL/GM)	S(R) (CAL/K/GM)	VGS (CC/GM)
		CV (CAL/K/GM)	CP (CAL/K/GM)	ALPHA	BETA	KAPPA
539.694	9.96826	2762.14	-1126.12	-1256.39	1.56868	9.71698
		46.8502	51.3457	10.6790	9.71349	1.20235

Product concentrations

Name		(mol/kg)	(mol gas/mol explosive)
h2	Gas	1.031e+001	7.645e-001
n2	Gas	8.944e+000	6.635e-001
co	Gas	1.684e+000	1.250e-001
ch4	Gas	2.388e-001	1.771e-002
c2h4	Gas	2.665e-002	1.977e-003
h3n	Gas	2.186e-002	1.622e-003
ch3	Gas	2.151e-002	1.596e-003
h2o	Gas	6.738e-003	4.998e-004
c2h6	Gas	4.116e-004	3.053e-005
ch2o	Gas	2.470e-004	1.832e-005
co2	Gas	1.523e-004	1.130e-005
alo	Gas	3.597e-005	2.668e-006
ch3oh	Gas	1.637e-006	1.215e-007
no	Gas	6.012e-007	4.459e-008
ch2o2	Gas	1.028e-007	7.625e-009
o2	Gas	5.173e-012	3.838e-013
no2	Gas	7.956e-015	5.902e-016
*c	solid	9.095e+000	6.747e-001
al2o3	liquid	5.559e+000	4.124e-001
*al	solid	0.000e+000	0.000e+000
*al	liquid	0.000e+000	0.000e+000
al2o3	solid	0.000e+000	0.000e+000
Total	Gas	2.125e+001	1.576e+000
Total	Cond.	1.465e+001	1.087e+000

Reference state = reactants
H(R) = H- 8.27, E(R) = E- 8.26, S(R) = S- 0.00

P (ATM)	V (CC/GM)	T (K)	H(R) (CAL/GM)	E(R) (CAL/GM)	S(R) (CAL/K/GM)	VGS (CC/GM)
		CV (CAL/K/GM)	CP (CAL/K/GM)	ALPHA	BETA	KAPPA
1.)239.588	19.9365	2576.42	-1225.60	-1341.27	1.56868	19.6889
		0.463655	50.8002	10.6502	10.1538	1.14738

Product concentrations

Name		(mol/kg)	(mol gas/mol explosive)
h2	Gas	1.056e+001	7.835e-001
n2	Gas	8.949e+000	6.638e-001

```
       co  Gas   1.687e+000  1.252e-001
      ch4  Gas   1.442e-001  1.069e-002
      h3n  Gas   1.170e-002  8.679e-004
     c2h4  Gas   1.092e-002  8.099e-004
      ch3  Gas   1.022e-002  7.581e-004
      h2o  Gas   4.304e-003  3.193e-004
     c2h6  Gas   1.213e-004  9.000e-006
     ch2o  Gas   1.152e-004  8.548e-006
      co2  Gas   1.050e-004  7.789e-006
      alo  Gas   1.314e-005  9.747e-007
    ch3oh  Gas   4.237e-007  3.143e-008
       no  Gas   2.004e-007  1.487e-008
    ch2o2  Gas   2.955e-008  2.192e-009
       o2  Gas   9.971e-013  7.397e-014
      no2  Gas   1.006e-015  7.463e-017
       *c  solid 9.230e+000  6.847e-001
    al2o3 liquid 5.559e+000  4.124e-001
      *al  solid 0.000e+000  0.000e+000
      *al liquid 0.000e+000  0.000e+000
    al2o3  solid 0.000e+000  0.000e+000

     Total Gas   2.138e+001  1.586e+000
     Total Cond. 1.479e+001  1.097e+000

                          Reference state = reactants
                 H(R) = H- 8.27, E(R) = E- 8.26, S(R) = S- 0.00

      P       V       T         H(R)        E(R)        S(R)       VGS
    ATM)  (CC/GM)    (K)      (CAL/GM)    (CAL/GM) (CAL/K/GM)(CC/GM)
                     CV         CP          ALPHA       BETA     KAPPA
                  (CAL/K/GM)(CAL/K/GM)
 1.)109.291 39.8730 2408.27 -1312.24  -1417.77   1.56868 39.6290
                       0.459835 0.503795 10.6084 10.3594  1.12057

Product concentrations
         Name   (mol/kg) (mol gas/mol explosive)
       h2  Gas   1.070e+001  7.939e-001
       n2  Gas   8.952e+000  6.640e-001
       co  Gas   1.689e+000  1.253e-001
      ch4  Gas   8.984e-002  6.664e-003
      h3n  Gas   6.425e-003  4.766e-004
      ch3  Gas   4.668e-003  3.463e-004
     c2h4  Gas   4.521e-003  3.354e-004
      h2o  Gas   2.942e-003  2.182e-004
      co2  Gas   7.756e-005  5.753e-006
     ch2o  Gas   5.467e-005  4.056e-006
     c2h6  Gas   3.689e-005  2.736e-006
      alo  Gas   3.880e-006  2.879e-007
    ch3oh  Gas   1.184e-007  8.785e-009
       no  Gas   6.695e-008  4.966e-009
    ch2o2  Gas   9.328e-009  6.919e-010
       o2  Gas   1.989e-013  1.476e-014
      no2  Gas   1.270e-016  9.424e-018
       *c  solid 9.302e+000  6.900e-001
    al2o3 liquid 5.559e+000  4.124e-001
```

```
      *al  solid 0.000e+000  0.000e+000
      *al liquid 0.000e+000  0.000e+000
    al2o3  solid 0.000e+000  0.000e+000

     Total Gas   2.145e+001  1.591e+000
     Total Cond. 1.486e+001  1.102e+000

                          Reference state = reactants
                H(R) = H- 8.27, E(R) = E- 8.26, S(R) = S- 0.00

  P      V          T        H(R)       E(R)       S(R)      VGS
 (ATM)  (CC/GM)     (K)     (CAL/GM)   (CAL/GM) (CAL/K/GM)(CC/GM)
                     CV        CP        ALPHA      BETA    KAPPA
                  (CAL/K/GM)(CAL/K/GM)
1.)52.2866 79.7460 2331.60 -1387.72 -1488.69    1.56868  79.5160
                    135.717  135.957 1338.88 1323.77      1.01217

Product concentrations
         Name   (mol/kg) (mol gas/mol explosive)
       h2  Gas   1.079e+001  8.007e-001
       n2  Gas   8.953e+000  6.641e-001
       co  Gas   1.690e+000  1.254e-001
      ch4  Gas   5.050e-002  3.746e-003
      h3n  Gas   3.387e-003  2.512e-004
      ch3  Gas   2.657e-003  1.971e-004
     c2h4  Gas   2.067e-003  1.534e-004
      h2o  Gas   1.731e-003  1.284e-004
      co2  Gas   4.744e-005  3.519e-006
     ch2o  Gas   2.676e-005  1.985e-006
     c2h6  Gas   1.029e-005  7.632e-007
      alo  Gas   3.476e-006  2.578e-007
       no  Gas   3.253e-008  2.413e-009
    ch3oh  Gas   3.166e-008  2.348e-009
    ch2o2  Gas   2.649e-009  1.965e-010
       o2  Gas   6.296e-014  4.671e-015
      no2  Gas   2.690e-017  1.996e-018
       *c  solid 9.347e+000  6.934e-001
    al2o3 liquid 4.188e+000  3.106e-001
    al2o3  solid 1.372e+000  1.018e-001
      *al liquid 0.000e+000  0.000e+000
      *al  solid 0.000e+000  0.000e+000

     Total Gas   2.150e+001  1.595e+000
     Total Cond. 1.491e+001  1.106e+000
The initial equation error was huge: 12262.923133

                          The End of the Adiabat
                          Reference state = reactants
                H(R) = H- 8.27, E(R) = E- 8.26, S(R) = S- 0.00
  P      V          T        H(R)       E(R)       S(R)      VGS
 (ATM)  (CC/GM)     (K)     (CAL/GM)   (CAL/GM) (CAL/K/GM)(CC/GM)
                     CV        CP        ALPHA      BETA    KAPPA
                  (CAL/K/GM)(CAL/K/GM)
1.)1.000 3083.29 1742.90  -1746.52  -1821.18    1.56868 3083.10
                    0.3683611 0.411315  8.58859 8.58640    1.11672
```

```
Product concentrations
         Name   (mol/kg) (mol gas/mol explosive)
       h2  Gas   1.090e+001  8.086e-001
       n2  Gas   8.955e+000  6.643e-001
       co  Gas   1.691e+000  1.255e-001
      ch4  Gas   4.912e-003  3.644e-004
      h2o  Gas   3.317e-004  2.460e-005
      h3n  Gas   1.701e-004  1.262e-005
      ch3  Gas   3.711e-005  2.753e-006
     c2h4  Gas   2.183e-005  1.619e-006
      co2  Gas   1.434e-005  1.064e-006
     ch2o  Gas   6.135e-007  4.551e-008
     c2h6  Gas   2.446e-008  1.814e-009
      alo  Gas   8.321e-010  6.173e-011
       no  Gas   1.165e-010  8.642e-012
    ch3oh  Gas   6.323e-011  4.690e-012
    ch2o2  Gas   1.120e-011  8.310e-013
       o2  Gas   1.883e-017  1.397e-018
      no2  Gas   6.381e-022  4.733e-023
       *c  solid 9.398e+000  6.971e-001
    al2o3  solid 5.559e+000  4.124e-001
      *al  solid 0.000e+000  0.000e+000
    al2o3 liquid 0.000e+000  0.000e+000
      *al liquid 0.000e+000  0.000e+000

     Total Gas   2.155e+001  1.599e+000
     Total Cond. 1.496e+001  1.110e+000

                 The Products at room temperature and pressure

The initial equation error was huge: 78888.977878
The initial equation error was huge: 30870.914500

                          Reference state = reactants
                H(R) = H- 8.27, E(R) = E- 8.26, S(R) = S- 0.00

   P      V          T        H(R)       E(R)       S(R)      VGS
 (ATM)  (CC/GM)     (K)     (CAL/GM)   (CAL/GM) (CAL/K/GM)(CC/GM)
                     CV        CP         ALPHA      BETA    KAPPA
                  (CAL/K/GM)(CAL/K/GM)
1.0000 374.029   298.00  -2414.99  -2424.04    7.95638  1373.856
                   0. 203356 0.233676  6.70736 6.68979     1.1521

Product concentrations
         Name   (mol/kg) (mol gas/mol explosive)
       n2  Gas   8.954e+000  6.642e-001
      ch4  Gas   4.613e+000  3.422e-001
      h2o  Gas   1.682e+000  1.248e-001
      co2  Gas   4.848e-003  3.596e-004
      h3n  Gas   7.504e-004  5.567e-005
       h2  Gas   2.954e-004  2.191e-005
     c2h6  Gas   6.448e-008  4.783e-009
       co  Gas   8.079e-012  5.993e-013
    ch2o2  Gas   2.333e-015  1.730e-016
    ch3oh  Gas   8.241e-017  6.113e-018
```

```
     c2h4  Gas   5.915e-021  4.388e-022
     ch2o  Gas   2.618e-021  1.942e-022
      ch3  Gas   1.527e-032  1.133e-033
      alo  Gas   0.000e+000  0.000e+000
       o2  Gas   0.000e+000  0.000e+000
      no2  Gas   0.000e+000  0.000e+000
       no  Gas   0.000e+000  0.000e+000
       *c  solid 6.476e+000  4.804e-001
    al2o3  solid 5.559e+000  4.124e-001
      *al  solid 0.000e+000  0.000e+000
    al2o3 liquid 0.000e+000  0.000e+000
      *al liquid 0.000e+000  0.000e+000

     Total Gas   1.526e+001  1.132e+000
     Total Cond. 1.204e+001  8.928e-001
The mechanical energy of detonation =    -15.288 kJ/cc
The thermal energy of detonation    =     -5.061 kJ/cc
The total energy of detonation      =    -20.349 kJ/cc

JWL Tail Fit results:
Initial  E0 = -20.659, Final E0 =    -17.571
E0(V=infty) = -17.571
C = 1.763,  omega =  0.157
Final fitting error = 0.001048

     V/V0     Actual E     Fit E    Actual P      Fit P
              (kJ/cc)     (kJ/cc)    (GPa)        (GPa)

    10.000     -9.724     -9.729      0.130      0.123
    20.000    -10.547    -10.536      0.055      0.055
    40.000    -11.259    -11.261      0.024      0.025
    80.000    -11.902    -11.910      0.011      0.011
   160.000    -12.497    -12.493      0.005      0.005

JWL Fit results:
E0(V=infty) =    -17.571
R[1] =      7.397, R[2] =      1.369, omega =      0.157
A    =   5771.857, B    =     26.557, C     =      1.763
Final fitting error = 0.013268

     V/V0     Actual E     Fit E    Actual P      Fit P
              (kJ/cc)     (kJ/cc)    (GPa)        (GPa)

     0.797      2.764      2.764     27.168     27.168
     1.000     -0.914     -0.907     12.059     12.060
     2.200     -6.709     -6.674      1.607      2.016
     4.100     -8.324     -8.482      0.481      0.442
     6.500     -9.118     -9.179      0.235      0.206
    10.000     -9.724     -9.729      0.130      0.123
    20.000    -10.547    -10.536      0.055      0.055
    40.000    -11.259    -11.261      0.024      0.025
    80.000    -11.902    -11.910      0.011      0.011
   160.000    -12.497    -12.493      0.005      0.005
```

C.2 Summary printout for different densities

Product library title: bkwc
Reactant library title: # Version 2.0 by P. Clark Souers

The composition:

Name	% wt.	% mol	% vol	Heat of formation (cal/mol)	Mol. wt.	TMD (g/cc)	
HMX	66.30	16.61	69.83	17866	296.16	1.90	$C_4H_8N_8O_8$
Al	30.00	82.48	22.29	0	26.98	2.70	Al_1
DOA	2.80	0.56	6.07	-290392	370.57	0.93	$C_{22}H_{42}O_4$
Hytemp	0.90	0.35	1.81	-205067	188.60	1.00	$C_{10}H_{15.46}O_{3.307}$

Density = 2.0064 g/cc Mixture TMD = 2.0064 g/cc %TMD = 100.0000

The C-J condition:

The pressure	=	27.17 GPa
The volume	=	0.397 cc/g
The density	=	2.519 g/cc
The energy	=	2.76 kJ/cc explosive
The temperature	=	5717 K
The shock velocity	=	8.157 mm/us
The particle velocity	=	1.660 mm/us
The speed of sound	=	6.497 mm/us
Gamma	=	3.914

Cylinder runs: % of standards

V/V0 (rel.)	Energy (kJ/cc)	TATB 1.83g/cc	PETN 1.76g/cc	HMX 1.89g/cc	CL-20 2.04g/cc	TRITON 1.70g/cc
1.00	-0.91					
2.20	-6.71	138	106	90	74	154
4.10	-8.32	143	108	94	79	151
6.50	-9.12	146	110	97	82	149
10.00	-9.72	149	112	99	85	148
20.00	-10.55	154	115	104	89	147
40.00	-11.26	157	119	107	93	146
80.00	-11.90	161	122	111	96	144
160.00	-12.50					

The mechanical energy of detonation = -15.288 kJ/cc
The thermal energy of detonation = -5.061 kJ/cc
The total energy of detonation = -20.349 kJ/cc

JWL Fit results:
E0 = -17.571 kJ/cc
A = 5771.86 GPa, B = 26.56 GPa , C = 1.76 GPa
R[1] = 7.40, R[2] 1.37, omega = 0.16
RMS fitting error = 1.33 %

Density = 2.0064 g/cc Mixture TMD = 2.0064 g/cc %TMD = 100.0000

The C-J condition:

The pressure	=	27.17 GPa

```
The volume            =          0.397 cc/g
The density           =          2.519 g/cc
The energy            =           2.76 kJ/cc explosive
The temperature       =           5717 K
The shock velocity    =          8.157 mm/us
The particle velocity =          1.660 mm/us
The speed of sound    =          6.497 mm/us
Gamma                 =          3.914

Cylinder runs:              % of standards
  V/V0     Energy    TATB     PETN      HMX    CL-20   TRITON
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.91
   2.20    -6.71     138      106       90       74      154
   4.10    -8.32     143      108       94       79      151
   6.50    -9.12     146      110       97       82      149
  10.00    -9.72     149      112       99       85      148
  20.00   -10.55     154      115      104       89      147
  40.00   -11.26     157      119      107       93      146
  80.00   -11.90     161      122      111       96      144
 160.00   -12.50

The mechanical energy of detonation =    -15.288 kJ/cc
The thermal energy of detonation    =     -5.061 kJ/cc
The total energy of detonation      =    -20.349 kJ/cc

JWL Fit results:
E0   =  -17.571 kJ/cc
A    = 5771.86 GPa, B  =  26.56 GPa , C  =  1.76 GPa
R[1] =    7.40,   R[2] =   1.37,   omega =  0.16
RMS fitting error =   1.33 %
```

Density = 1.9963 g/cc Mixture TMD = 2.0064 g/cc %TMD = 99.5000

The C-J condition:

```
The pressure          =          26.78 GPa
The volume            =          0.399 cc/g
The density           =          2.508 g/cc
The energy            =           2.73 kJ/cc explosive
The temperature       =           5708 K
The shock velocity    =          8.107 mm/us
The particle velocity =          1.655 mm/us
The speed of sound    =          6.452 mm/us
Gamma                 =          3.900

Cylinder runs: % of standards
  V/V0     Energy    TATB     PETN      HMX    CL-20   TRITON
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.91
   2.20    -6.64     137      105       89       73      152
   4.10    -8.25     142      107       93       78      149
   6.50    -9.04     145      109       96       81      148
  10.00    -9.64     148      111       99       84      147
  20.00   -10.46     152      114      103       88      146
  40.00   -11.17     156      118      107       92      145
```

```
  80.00   -11.82     160      121      110       96      143
 160.00   -12.41
The mechanical energy of detonation =    -15.192 kJ/cc
The thermal energy of detonation    =     -5.056 kJ/cc
The total energy of detonation      =    -20.247 kJ/cc

JWL Fit results:
E0   =  -17.458 kJ/cc
A    = 5643.23 GPa, B  = 26.27 GPa , C   =  1.76 GPa
R[1] =    7.40,   R[2] =  1.37,    omega =  0.16
RMS fitting error =   1.32 %
```

Density = 1.9863 g/cc Mixture TMD = 2.0064 g/cc %TMD = 99.0000

The C-J condition:

```
The pressure          =         26.40 GPa
The volume            =         0.400 cc/g
The density           =         2.498 g/cc
The energy            =          2.70 kJ/cc explosive
The temperature       =          5699 K
The shock velocity    =         8.057 mm/us
The particle velocity =         1.649 mm/us
The speed of sound    =         6.408 mm/us
Gamma                 =         3.885

Cylinder runs: % of standards
  V/V0     Energy    TATB     PETN      HMX    CL-20   TRITON
 (rel.)   (kJ/cc)  1.83g/cc 1.76g/cc 1.89g/cc 2.04g/cc 1.70g/cc
   1.00    -0.90
   2.20    -6.58     136      104       88       73      151
   4.10    -8.18     141      106       92       77      148
   6.50    -8.96     144      108       95       81      147
  10.00    -9.56     147      110       98       83      146
  20.00   -10.38     151      113      102       87      145
  40.00   -11.09     155      117      106       91      143
  80.00   -11.73     159      120      110       95      142
 160.00   -12.32

The mechanical energy of detonation =    -15.095 kJ/cc
The thermal energy of detonation    =     -5.050 kJ/cc
The total energy of detonation      =    -20.145 kJ/cc

JWL Fit results:
E0   =  -17.356 kJ/cc
A    = 5516.52 GPa, B  =  25.98 GPa , C  = 1.76 GPa
R[1] =    7.40,   R[2] =   1.37,   omega = 0.16
RMS fitting error =   1.31 %
```

Density = 1.9763 g/cc Mixture TMD = 2.0064 g/cc % TMD = 98.5000

The C-J condition:

```
The pressure          =         26.02 GPa
The volume            =         0.402 cc/g
The density           =         2.487 g/cc
The energy            =          2.67 kJ/cc explosive
The temperature       =          5690 K
The shock velocity    =         8.008 mm/us
The particle velocity =         1.644 mm/us
```

The speed of sound = 6.363 mm/us
Gamma = 3.870
Cylinder runs: % of standards

V/V0 (rel.)	Energy (kJ/cc)	TATB 1.83g/cc	PETN 1.76g/cc	HMX 1.89g/cc	CL-20 2.04g/cc	TRITON 1.70g/cc
1.00	-0.89					
2.20	-6.52	134	103	87	72	150
4.10	-8.10	139	105	91	77	147
6.50	-8.89	143	107	94	80	145
10.00	-9.48	145	109	97	83	145
20.00	-10.30	150	112	101	87	144
40.00	-11.01	154	116	105	91	142
80.00	-11.64	158	119	109	94	141
160.00	-12.23					

The mechanical energy of detonation = -14.999 kJ/cc
The thermal energy of detonation = -5.045 kJ/cc
The total energy of detonation = -20.044 kJ/cc

JWL Fit results:
E0 = -18.341 kJ/cc
A = 3362.64 GPa, B = 17.54 GPa , C = 1.58 GPa
R[1] = 6.62, R[2] = 1.16, omega = 0.13
RMS fitting error = 1.55 %

Density = 1.9662 g/cc Mixture TMD = 2.0064 g/cc % TMD = 98.0000

The C-J condition:
The pressure = 25.65 GPa
The volume = 0.404 cc/g
The density = 2.476 g/cc
The energy = 2.64 kJ/cc explosive
The temperature = 5681 K
The shock velocity = 7.958 mm/us
The particle velocity = 1.639 mm/us
The speed of sound = 6.319 mm/us
Gamma = 3.854

Cylinder runs: % of standards

V/V0 (rel.)	Energy (kJ/cc)	TATB 1.83g/cc	PETN 1.76g/cc	HMX 1.89g/cc	CL-20 2.04g/cc	TRITON 1.70g/cc
1.00	-0.88					
2.20	-6.46	133	102	86	71	148
4.10	-8.03	138	104	91	76	145
6.50	-8.81	141	106	94	79	144
10.00	-9.41	144	108	96	82	143
20.00	-10.22	149	112	100	86	143
40.00	-10.92	153	115	104	90	141
80.00	-11.56	157	118	108	94	140
160.00	-12.15					

The mechanical energy of detonation = -14.903 kJ/cc
The thermal energy of detonation = -5.039 kJ/cc
The total energy of detonation = -19.942 kJ/cc

JWL Fit results:
E0 = -20.026 kJ/cc
A = 3150.39 GPa, B = 16.86 GPa , C = 1.46 GPa

R[1] = 6.54, R[2] = 1.13, omega = 0.11
RMS fitting error = 1.55 %
Density = 1.9562 g/cc Mixture TMD = 2.0064 g/cc % TMD = 97.5000

The C-J condition:

The pressure	=	25.29 GPa
The volume	=	0.406 cc/g
The density	=	2.466 g/cc
The energy	=	2.61 kJ/cc explosive
The temperature	=	5673 K
The shock velocity	=	7.910 mm/us
The particle velocity	=	1.635 mm/us
The speed of sound	=	6.275 mm/us
Gamma	=	3.839

Cylinder runs: % of standards

V/V0 (rel.)	Energy (kJ/cc)	TATB 1.83g/cc	PETN 1.76g/cc	HMX 1.89g/cc	CL-20 2.04g/cc	TRITON 1.70g/cc
1.00	-0.87					
2.20	-6.39	132	101	86	71	147
4.10	-7.96	137	103	90	75	144
6.50	-8.73	140	105	93	78	143
10.00	-9.33	143	107	95	81	142
20.00	-10.14	148	111	99	85	141
40.00	-10.84	152	114	103	89	140
80.00	-11.47	156	117	107	93	139
160.00	-12.06					

The mechanical energy of detonation	=	-14.807 kJ/cc
The thermal energy of detonation	=	-5.033 kJ/cc
The total energy of detonation	=	-19.840 kJ/cc

JWL Fit results:
E0 = -19.560 kJ/cc
A = 3076.44 GPa, B = 16.75 GPa , C = 1.48 GPa
R[1] = 6.54, R[2] = 1.13, omega = 0.11
RMS fitting error = 1.53 %

Density = 1.9462 g/cc Mixture TMD = 2.0064 g/cc % TMD = 97.0000

The C-J condition:

The pressure	=	24.93 GPa
The volume	=	0.407 cc/g
The density	=	2.455 g/cc
The energy	=	2.58 kJ/cc explosive
The temperature	=	5664 K
The shock velocity	=	7.861 mm/us
The particle velocity	=	1.630 mm/us
The speed of sound	=	6.231 mm/us
Gamma	=	3.823

Cylinder runs: % of standards

V/V0 (rel.)	Energy (kJ/cc)	TATB 1.83g/cc	PETN 1.76g/cc	HMX 1.89g/cc	CL-20 2.04g/cc	TRITON 1.70g/cc
1.00	-0.86					

2.20	-6.33	131	100	85	70	145
4.10	-7.89	136	102	89	75	143
6.50	-8.66	139	104	92	78	142
10.00	-9.25	142	106	95	81	141
20.00	-10.05	146	110	99	85	140
40.00	-10.76	150	113	103	89	139
80.00	-11.39	155	117	106	92	138
160.00	-11.97					

The mechanical energy of detonation = -14.711 kJ/cc
The thermal energy of detonation = -5.027 kJ/cc
The total energy of detonation = -19.738 kJ/cc

JWL Fit results:
E0 = -19.753 kJ/cc
A = 3105.00 GPa, B = 16.83 GPa , C = 1.41 GPa
R[1] = 6.59, R[2] = 1.12, omega = 0.11
RMS fitting error = 1.70 %

Density = 1.9361 g/cc Mixture TMD = 2.0064 g/cc % TMD = 96.5000

The C-J condition:
The pressure = 24.58 GPa
The volume = 0.409 cc/g
The density = 2.445 g/cc
The energy = 2.56 kJ/cc explosive
The temperature = 5654 K
The shock velocity = 7.813 mm/us
The particle velocity = 1.625 mm/us
The speed of sound = 6.188 mm/us
Gamma = 3.807

Cylinder runs: % of standards

V/V0 (rel.)	Energy (kJ/cc)	TATB 1.83g/cc	PETN 1.76g/cc	HMX 1.89g/cc	CL-20 2.04g/cc	TRITON 1.70g/cc
1.00	-0.85					
2.20	-6.27	129	99	84	69	144
4.10	-7.81	134	101	88	74	142
6.50	-8.58	138	103	91	77	140
10.00	-9.17	141	106	94	80	140
20.00	-9.97	145	109	98	84	139
40.00	-10.67	149	112	102	88	138
80.00	-11.30	153	116	106	92	137
160.00	-11.89					

The mechanical energy of detonation = -14.616 kJ/cc
The thermal energy of detonation = -5.021 kJ/cc
The total energy of detonation = -19.637 kJ/cc

JWL Fit results:
E0 = -17.854 kJ/cc
A = 3025.80 GPa, B = 16.87 GPa , C = 1.57 GPa
R[1] = 6.60, R[2] = 1.16, omega = 0.13
RMS fitting error = 1.51 %

Density = 1.9261 g/cc Mixture TMD = 2.0064 g/cc % TMD = 96.0000

The C-J condition:

The pressure	=	24.24 GPa
The volume	=	0.411 cc/g
The density	=	2.434 g/cc
The energy	=	2.53 kJ/cc explosive
The temperature	=	5645 K
The shock velocity	=	7.765 mm/us
The particle velocity	=	1.621 mm/us
The speed of sound	=	6.144 mm/us
Gamma	=	3.791

Cylinder runs: % of standards

V/V0 (rel.)	Energy (kJ/cc)	TATB 1.83g/cc	PETN 1.76g/cc	HMX 1.89g/cc	CL-20 2.04g/cc	TRITON 1.70g/cc
1.00	-0.85					
2.20	-6.21	128	98	83	69	142
4.10	-7.74	133	100	87	73	140
6.50	-8.51	137	103	90	76	139
10.00	-9.09	139	105	93	79	139
20.00	-9.89	144	108	97	83	138
40.00	-10.59	148	111	101	87	137
80.00	-11.22	152	115	105	91	136
160.00	-11.80					

The mechanical energy of detonation	=	-14.521 kJ/cc
The thermal energy of detonation	=	-5.014 kJ/cc
The total energy of detonation	=	-19.535 kJ/cc

JWL Fit results:
E0 = -16.811 kJ/cc
A = 4733.84 GPa, B = 24.13 GPa , C = 1.71 GPa
R[1] = 7.38, R[2] = 1.36, omega = 0.16
RMS fitting error = 1.27 %

Density = 1.9161 g/cc Mixture TMD = 2.0064 g/cc % TMD = 95.5000

The C-J condition:

The pressure	=	23.90 GPa
The volume	=	0.413 cc/g
The density	=	2.424 g/cc
The energy	=	2.50 kJ/cc explosive
The temperature	=	5636 K
The shock velocity	=	7.718 mm/us
The particle velocity	=	1.616 mm/us
The speed of sound	=	6.102 mm/us
Gamma	=	3.775

Cylinder runs: % of standards

V/V0 (rel.)	Energy (kJ/cc)	TATB 1.83g/cc	PETN 1.76g/cc	HMX 1.89g/cc	CL-20 2.04g/cc	TRITON 1.70g/cc
1.00	-0.84					
2.20	-6.15	127	97	82	68	141

4.10	-7.67	132	99	87	73	139
6.50	-8.43	135	102	90	76	138
10.00	-9.02	138	104	92	79	137
20.00	-9.81	143	107	96	83	137
40.00	-10.51	147	111	100	86	136
80.00	-11.14	151	114	104	90	135
160.00	-11.72					

The mechanical energy of detonation = -14.425 kJ/cc
The thermal energy of detonation = -5.008 kJ/cc
The total energy of detonation = -19.433 kJ/cc

JWL Fit results:
E0 = -16.728 kJ/cc
A = 4603.69 GPa, B = 23.81 GPa , C = 1.71 GPa
R[1] = 7.37, R[2] = 1.36, omega = 0.15
RMS fitting error = 1.27 %

Density = 1.9061 g/cc Mixture TMD = 2.0064 g/cc % TMD = 95.0000

The C-J condition:

The pressure	=	23.57 GPa
The volume	=	0.414 cc/g
The density	=	2.413 g/cc
The energy	=	2.48 kJ/cc explosive
The temperature	=	5627 K
The shock velocity	=	7.671 mm/us
The particle velocity	=	1.612 mm/us
The speed of sound	=	6.059 mm/us
Gamma	=	3.759

Cylinder runs:% of standards

V/V0 (rel.)	Energy (kJ/cc)	TATB 1.83g/cc	PETN 1.76g/cc	HMX 1.89g/cc	CL-20 2.04g/cc	TRITON 1.70g/cc
1.00	-0.83					
2.20	-6.09	126	96	82	67	140
4.10	-7.60	131	98	86	72	138
6.50	-8.36	134	101	89	75	137
10.00	-8.94	137	103	91	78	136
20.00	-9.73	142	106	96	82	136
40.00	-10.43	146	110	99	86	135
80.00	-11.05	150	113	103	90	134
160.00	-11.63					

The mechanical energy of detonation = -14.330 kJ/cc
The thermal energy of detonation = -5.001 kJ/cc
The total energy of detonation = -19.332 kJ/cc

JWL Fit results:
E0 = -17.572 kJ/cc
A = 2787.59 GPa, B = 16.36 GPa , C = 1.55 GPa
R[1] = 6.58, R[2] = 1.16, omega = 0.13
RMS fitting error = 1.49 %

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