

MEMORANDUM REPORT ARBRL-MR-03359

THRUST CHARACTERIZATION OF VERY HIGH
BURNING RATE PROPELLANTS

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July 1984



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BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A series of closed bomb combustion tests were conducted on several very high burning rate (VHBR) propellants in which, in addition to the standard pressure measurements, the thrust produced by a burning propellant column was measured using a dynamic force gage located at the end of the propellant column. The results indicate that in several instances the total force imparted to the force gage substantially exceeded that due to the gas pressure alone. The difference is ascribed to the thrust or impulse resulting from very high		

1. INTRODUCTION

Our research on the combustion characterization of very high burning rate (VHBR) propellants is motivated by the need for such propellants for the successful exploitation of the traveling charge gun propulsion concept proposed initially by Langweiler.¹ The traveling charge concept remains perhaps the only propellant approach to overcome the severe intrinsic ballistic inefficiency of conventional chemical gun propulsion if muzzle velocities greater than 2 km/s are to be attained. In a traveling charge configuration, a projectile is accelerated by a combination of gas pressure and impulse produced by a fast burning propellant attached to and moving with the projectile. A discussion of previous work and the basic concept has been given by May et al.² Combustion diagnostics in a standard closed bomb configuration for a family of VHBR propellants have been described by Juhasz et al.³ These observations can be summarized as follows: apparent very high burning rates appear to be density-, confinement-, and formulations-dependent. The extracted apparent burning rates are, therefore, not true intrinsic linear burning rates explainable by conventional combustion models. A mechanism such as convection burning⁴ or progressive stress-induced surface breakup⁵ is thought to be the process responsible for very high apparent burning rates. Because such burning rates result in the production of substantial amounts of thrust, we have developed a modified closed bomb described below in which the total force produced by the combined gas pressure and thrust transmitted through a column of VHBR propellant is measured. Experimental observation of thrust can then be used to extract apparent burning rates in a direct manner. Such burning rates should be more reliable for interior ballistic modeling than those obtained by standard closed bomb techniques as previously described.³

¹H. Langweiler, "A Proposal for Increasing the Performance of Weapons by the Correct Burning of Propellant," British Intelligence Objective Subcommittee, Group 2, Fort Halstead Exploiting Center, No. 1247.

²I. W. May, A. F. Baran, P. G. Baer, and P. S. Gough, "The Traveling Charge Effect," Ballistic Research Laboratory Memorandum Report ARBRL-MR-03034, July 1980 (AD B052135L).

³A. A. Juhasz, I. W. May, F. R. Lynn, R. E. Bowman, W. P. Aungst, "Combustion Diagnostics of Very High Burning Rate Propellants," 17th JANNAF Combustion Meeting, CPIA Publication 329, pp 209-240, November 1980.

⁴R. A. Fifer and J. E. Cole, "Transitions from Laminar Burning for Porous Crystalline Explosives," Seventh Symposium (International) on Detonation, Naval Surface Weapons Center, MP 82-334, June 1981.

⁵D. E. Kooker and R. D. Anderson, "A Mechanism for the Burning Rate of High-Density, Porous, Energetic Materials," Seventh Symposium (International) on Detonation, Naval Surface Weapons Center, MP 82-334, June 1981.

2. EXPERIMENTAL DETAILS

2.1 PROPELLANTS

In this study, a series of propellant formulations based on salts of the decahydrodecate anion as the important fuel ingredient were used.⁶ Results for only three VHBR propellants listed in Table 1 are presented in this paper. Their computed thermochemical performance parameters are given in Table 2.

TABLE 1. VHBR PROPELLANT FORMULATIONS

<u>Sample Code</u>	<u>Fuel</u>	<u>%</u>	<u>Oxidizer</u>	<u>%</u>	<u>Binder</u>	<u>%</u>	<u>Density (% TMD)</u>
1086-3	466	25.7	AN	59.1	NC/DNT	15.2	91
1086-5A	498	8.8	TAGN	76.0	NC/DNT	15.2	98
1086-6B	466	27.0	AN	67.1	C4000	5.0	88

TABLE 2. VHBR THERMOCHEMICAL PROPERTIES

<u>Sample Code</u>	<u>Impetus (J/g)</u>	<u>Flame Temperature</u>	<u>Covolume (cm³/g)</u>	<u>Specific Heat Ratio</u>
1086-3	985	2538	1.095	1.1974
1086-5A	1055	2647	1.220	1.2500
1086-6B	983	2488	1.089	1.1916

The fuel ingredients used are proprietary to Teledyne-McCormick/Selph.* Triaminoguanidinium nitrate (TAGN) and ammonium nitrate (AN) are the oxidizers. Nitrocellulose (NC), dinitrotoluene (DNT), and carbowax (C4000), a polyethylene glycol with an approximate molecular weight of 4000, are the binders. All samples were pressed to right circular cylinders 51-mm long with a diameter of 12.7 mm.

2.2. THRUST TEST FIXTURE

The thrust bomb experiments were conducted at Calspan Corporation, Buffalo, NY.** The device is depicted in Figure 1. It is a 419-mm-long closed bomb with an internal diameter of 12.7mm. The propellant sample is mounted against one end of the chamber, which consists of a 934-mm-long steel rod. Strain gages are located on this stress bar 40.2 mm from the chamber propellant/bomb interface. Pressure transducers (PCB 118A) P1, P2, P3, and P4, are located 4.8, 27.0, 55.6, and 219.4 mm respectively in the chamber from the same interface. Gage P3 is located near the initial propellant/chamber interface. Data from this gage were used in the subsequent analysis. Gages

* Contract DAAK11-77-C-0035

** Contract DAAK11-80-C-0062

⁶C. S. Leveritt, "Ultra High Burning Rate Propellants for Traveling Charge Gun," Ballistic Research Laboratory Contractor Report, ARBRL-CR-00447, Feb, 1981.

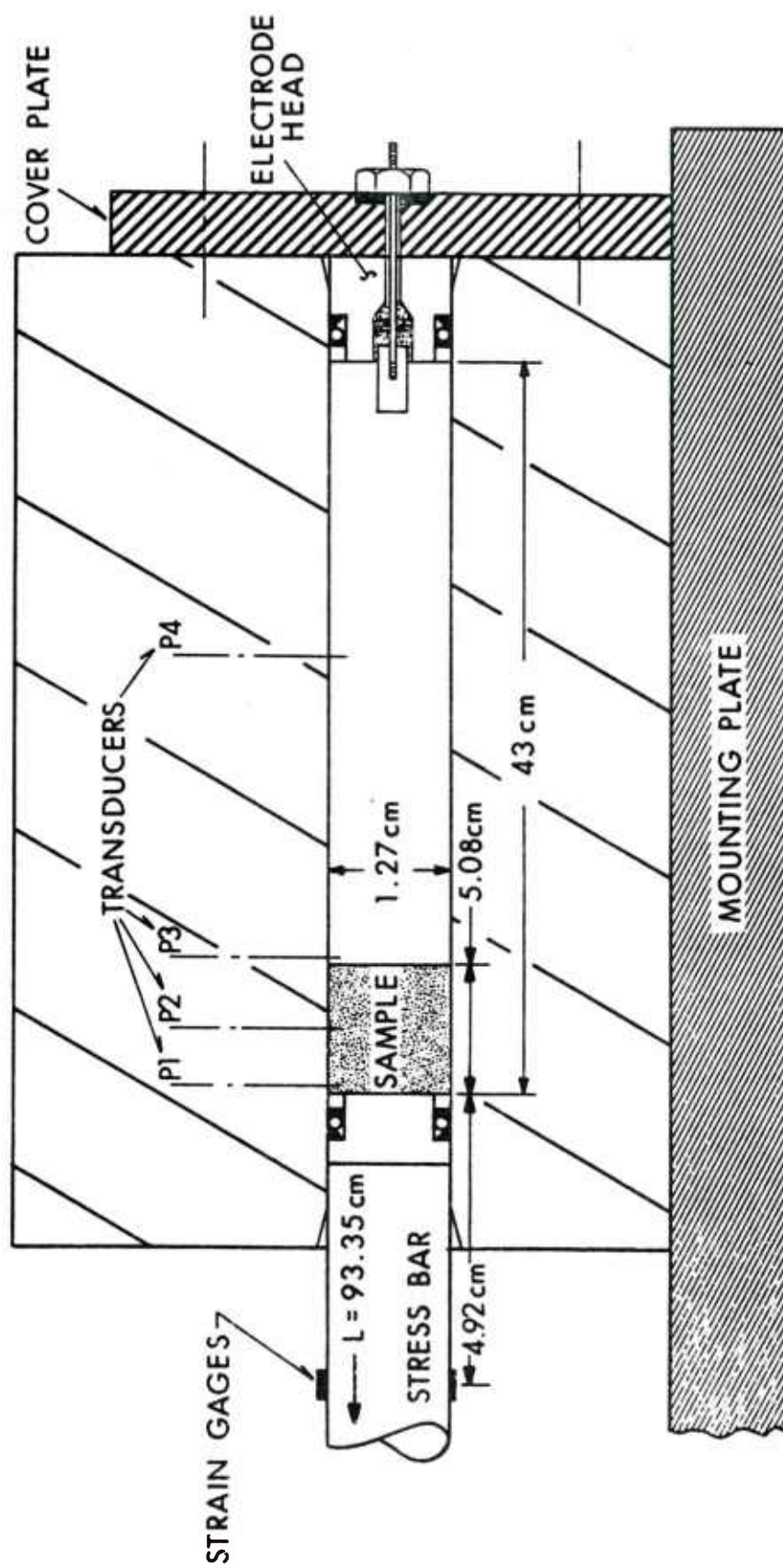


Figure 1. Thrust Bomb Fixture

P2 and P1 are difficult to use for the analysis because they respond to solid stress. They are flush-mounted and are in virtual contact with the propellant. The long rod allows dynamic stress measurements to be made unperturbed by rod-end reflections for a period of about 350 microseconds. The propellant is ignited cigarette-fashion with an electric match boosted with 1 g of FFFG black powder. The stress in the rod is due to the combined gas pressure and impulse transmitted through the propellant column as the VHBR material burns.

2.3 DATA ACQUISITION

The data for the experiments were acquired on three NICOLET Explorer III digital memory oscilloscopes. Where necessary, the digital data were filtered using Fast Fourier Analysis techniques. Small, but important, uncertainties in timing among the oscilloscopes required some time-biasing to achieve an internally consistent sequence of events. The method of biasing employed was overlaying and matching the P3 and the rod stress (RS) in the initial slow pressurization region where steady state conditions should prevail. Adjustments of this sort up to 24 microseconds were made in the same runs.

2.4 ANALYSIS

The effectiveness of the traveling charge concept depends directly on the production of substantial amounts of impulse as thrust. The direct observation of thrust, although critical from a practical standpoint, allows the extraction of effective burning rates. From a combustion characterization standpoint, this is of great significance. To determine the rate of surface regression of the propellant grain, we assume the flame to be sufficiently thin as to be quasi-steady. Then the equations⁷ describing the conservation of mass, momentum, and energy for the propellant transported across the surface discontinuity are in consistent units,

$$\rho_g \cdot (u_g - \dot{X}_p) = -\rho_p \cdot r \quad (1)$$

$$P + \frac{\rho_g}{g_o} (u_g - \dot{X}_p)^2 = \sigma + \frac{\rho_p}{g_o} \cdot r^2 \quad (2)$$

$$e + \frac{P}{\rho_g} + \frac{1}{2g_o} (u_g - \dot{X}_p)^2 = e_p + \frac{\sigma}{\rho_p} + \frac{r^2}{2g_o} \quad (3)$$

where

$$\dot{X}_p = u_p + r \quad \text{is the velocity of the gas/propellant interface} \quad (4)$$

$$e = \frac{P(1-b\rho_g)}{(\gamma - 1) \rho_g} \quad \text{is the internal energy of the gas} \quad (5)$$

⁷P. S. Gough, "A Model of the Traveling Charge," Ballistic Research Laboratory Contractor Report, ARBRL-CP-00432, July 1980.

ρ_g, ρ_p are the gas and propellant densities

u_g, u_p are the gas and propellant velocities

r is regression rate of grain surface

P is gas pressure at interface

g_o is gravitational constant

σ is propellant stress at interface (positive in compression)

e_p is energy of propellant

b is covolume of propellant

γ is ratio of specific heats of propellant

Combination and simplification of these three equations yields:

$$r^2 = \frac{g_o}{2\rho_p^2} \cdot \frac{(\sigma - P) \cdot (\sigma + \frac{\gamma + 1}{\gamma - 1} \cdot P)}{e_p + \frac{P}{\gamma - 1} \cdot (b - \frac{1}{\rho_p})} \quad (6)$$

In order to determine σ and P at the reaction front, the experiment is idealized as in Figure 2. Density is denoted by ρ , and c is the sound speed in each medium. The mechanical response of both the propellant grain and the steel bar - taken to be semi-infinite - was assumed to be linear-elastic and one-dimensional. Then, employing the characteristic form of the equations of motion and applying the appropriate boundary conditions, we have the stress at the reaction front, $\sigma^o(-l, t)$, and velocity, $u_p^o(-l, t)$, in terms of the measured stresses, $\sigma(l_1, t_i)$,

$$\sigma^o(-l, t) = \frac{\rho_p c_p}{2\rho_s c_s} \cdot \{\sigma(l_1, t_1) - \sigma(l_1, t_2)\} \quad (7)$$

$$u_p^o(-l, t) = \frac{g_o}{2\rho_s c_s} \cdot \{\sigma(l_1, t_1) + \sigma(l_1, t_2)\} + \frac{g_o}{2\rho_p c_p} \cdot \{\sigma(l_1, t_1) - \sigma(l_1, t_2)\} \quad (8)$$

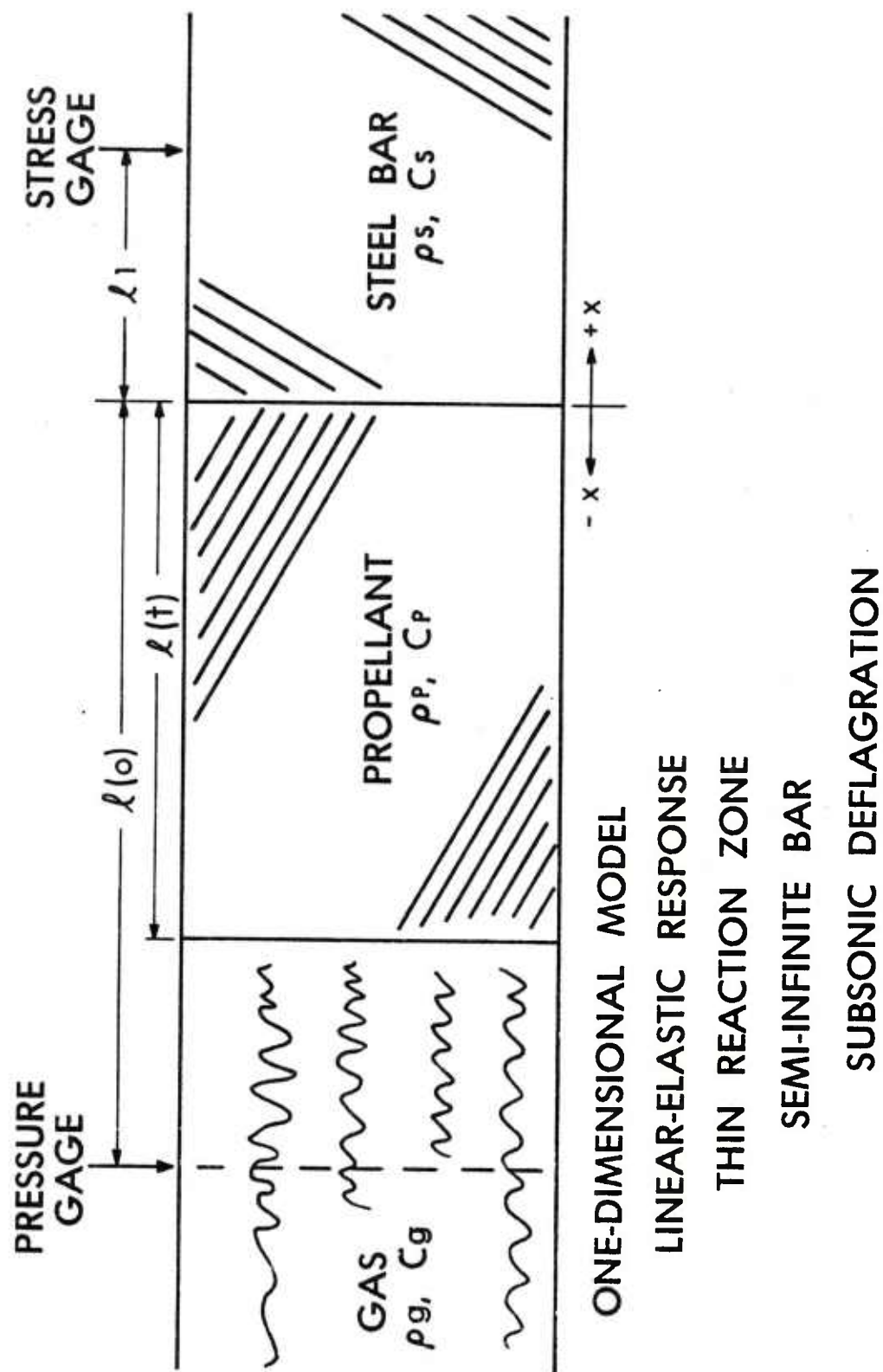


Figure 2. Model Used in Analysis

where

$$t_1 = t + \frac{\ell(t)}{c_p} + \frac{\ell_1}{c_s} \quad (9)$$

$$t_2 = t - \frac{\ell(t)}{c_p} + \frac{\ell_1}{c_s} \quad (10)$$

Incorporation of a simplified representation for wall friction, f_w , taken to be acting on the grain as a whole gives the friction-corrected stress and velocity

$$\sigma(-\ell, t) = \sigma^0(-\ell, t) + \frac{c_p}{2g_0} \cdot \left\{ f_{w1} \cdot \Delta t_1 + f_{w2} \cdot \Delta t_2 \right\} \quad (11)$$

$$u_p(-\ell, t) = u_p^0(-\ell, t) + \frac{1}{2\rho_p} \cdot \left\{ f_{w1} \cdot \Delta t_1 - f_{w2} \cdot \Delta t_2 \right\} \quad (12)$$

where

$$f_{w1} = \frac{\mu}{R} \cdot \left\{ \sigma(-\ell, t) + \sigma(\ell_1, t_1) \right\} \quad (13)$$

$$f_{w2} = \frac{\mu}{R} \cdot \left\{ \sigma(-\ell, t) + \sigma(\ell_1, t_2) \right\} \quad (14)$$

$$\Delta t_1 = t_1 - t \quad (15)$$

$$\Delta t_2 = t - t_2 \quad (16)$$

μ = coefficient of friction

R = radius of sample

The method of characteristics is also invoked to extract the pressure at the reaction front, $P(-\ell, t)$, from gage pressures measured at a position coincident with the initial grain surface, $P_m(-\ell(0), t)$, assuming no discontinuities in the gas column, i.e., subsonic flow throughout, and a lack of pressure waves reflected from the empty end of the chamber. This analysis yields

$$P(-\ell, t) = 2 \cdot P_m(-\ell(0), t_3) - P(-\ell, t_4) + \frac{\rho_g(t_3) \cdot c_g(t_3)}{g_0} \cdot \left\{ u_g(t_4) - u_g(t) \right\} \quad (17)$$

where

$$t_3 = t - \frac{\ell(0) - \ell(t)}{u_g(t_3) + c_g(t_3)} \quad (18)$$

$$t_4 = t_3 - \frac{\ell(t_4) - \ell(0)}{u_g(t_3) - c_g(t_3)} \cdot \quad (19)$$

The original conservation equations imply that, at any time $T > 0$, the gas velocity is

$$u_g(T) = u_p(T) - \frac{g_o}{\rho_p(T)} \cdot \frac{\sigma(-\ell, T) - P(-\ell, T)}{r(T)} \quad (20)$$

and the gas density is

$$\rho_g(T) = \frac{-\rho_p(T) \cdot r(T)}{u_g(T) - u_p(T) - r(T)} \cdot \quad (21)$$

The propellant density is taken to be

$$\rho_p(T) = \rho_p(0) + \frac{g_o \cdot \sigma(-\ell, T)}{c_p^2} \quad (22)$$

and the covolume equation of state gives the gas sound speed

$$c_g^2(T) = \frac{\gamma \cdot P(-\ell, T) \cdot g_o}{\rho_g(T)} \cdot \frac{1}{1 - b \cdot \rho_g(T)} \cdot \quad (23)$$

By suitable iteration until convergence, the stress, $\sigma(-\ell(t), t)$, and pressure, $P(-\ell(t), t)$, at the reaction front are thus calculated, producing the desired regression rate, $r(t)$, and the net thrust on the propellant grain, $\sigma - P$. A computer program written in BASIC to reduce the experimental data according to the above method is listed in APPENDIX A.

3. RESULTS AND DISCUSSION

Three separate tests are reported. In the first test, results for a very fast burning propellant are presented. The second case shows results for an intermediate burning rate propellant. The last case is an anomalous case, for which no thrust production was observed.

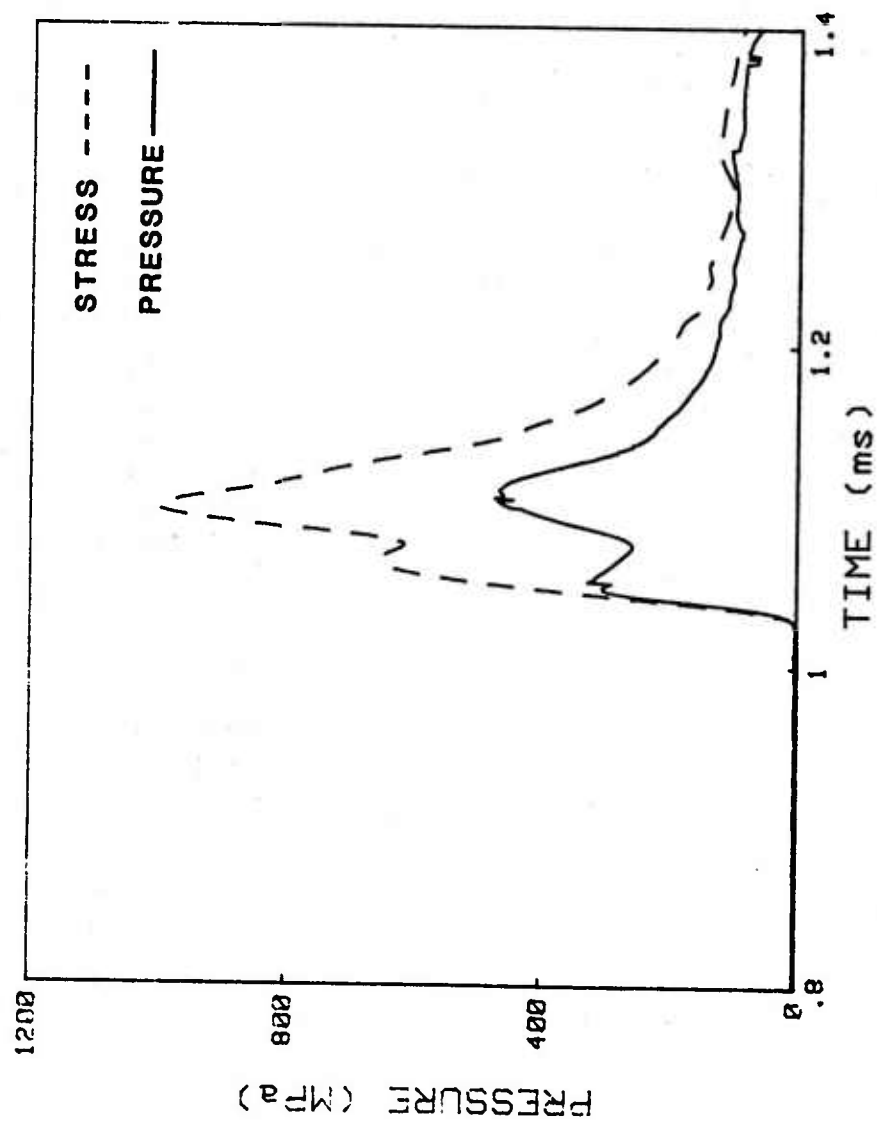
3.1. FAST BURNING CASE

A propellant sample of composition 1086-5A at a TMD of 98% resulted in the most dramatic demonstration of a substantial thrust contribution due to very high burning rates. The printed output from a computer reduction of the data from this experiment is listed in APPENDIX B, and plotted in Figures 3 through 5. Figure 3 shows derived pressure and stress at the gas-propellant interface as a function of time. The data look quite similar to the measured values of P_3 and rod strain but offset in time. The maximum value of stress to pressure (σ/P) max is greater than two. The force produced by thrust alone, therefore, exceeded the force produced by the gas pressure!

Regression rates up to 300 m/s were computed for this case. Considering the different assumptions in the two analysis methods, our value matches the high burning rate value from the standard closed bomb analysis³ remarkably well. The computed regression rate, as a function of pressure, is plotted in Figure 4. Contrary to the previous³ analysis results, however, Figure 4 shows a clear regression-rate dependence on pressure, the burning rate rising and falling as the pressure rises and falls. The rise and decay times of this event are on the order of 100 microseconds. In this highly transient environment it is, perhaps, not surprising that the regression rates are not the same in both the pressurization and the depressurization region. A more thought-provoking result is shown in Figure 5, which correlates regression rate and stress. With such a strong correlation, it is natural to conjecture that a solid-phase stress-induced mechanism such as surface breakup is a strong factor in the burning mechanism.

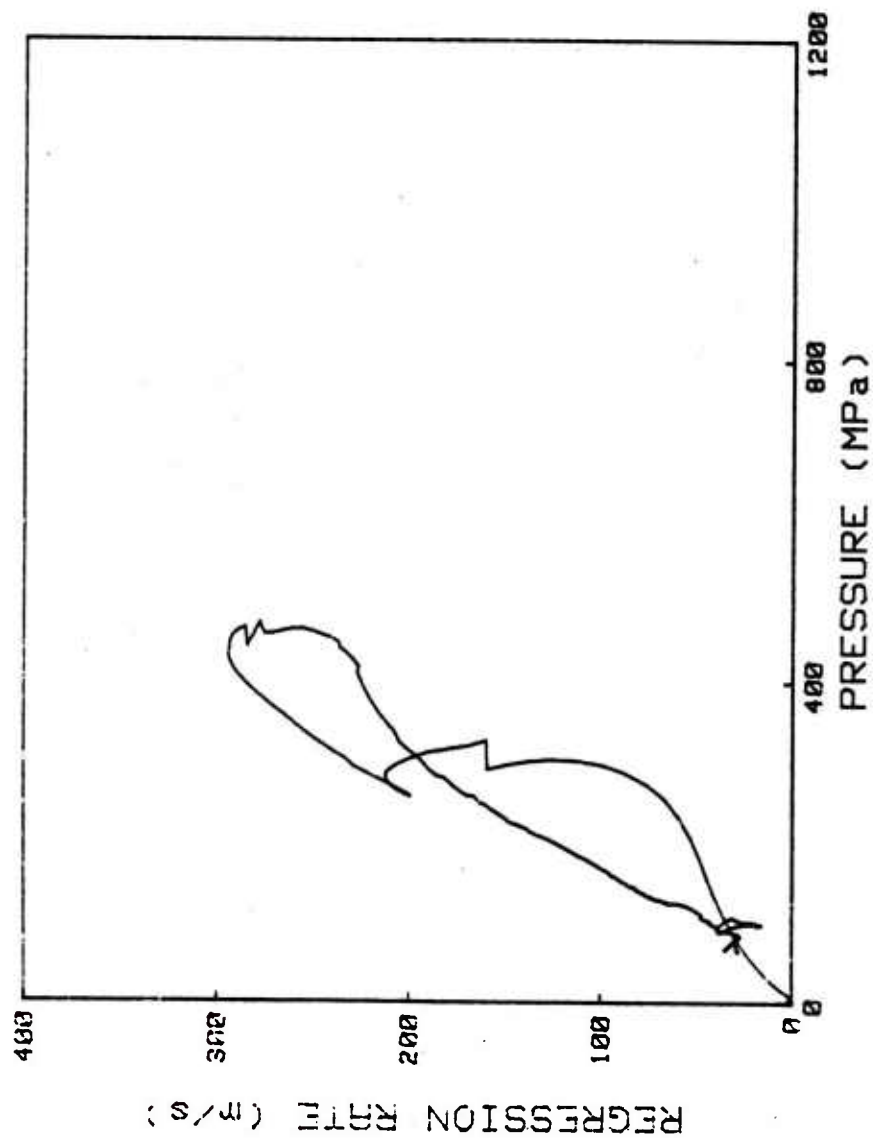
In the analysis of the data, a constant value of longitudinal sound speed equal to 2 km/s was assumed for the propellant. This value is similar to an experimentally determined value for a comparable propellant formulation reported by Finger.⁸ A small parametric study of the effect of propellant sound speed shows interesting results. Reducing the sound speed to 1.8 km/s improves the correlation of apparent burning rate versus stress in the initial portion of the curve as shown in Figure 6. Increasing the sound speed to 2.5 km/s significantly improves the correlation at the upper end of the curves of both stress and pressure. The stress vs apparent burning rate for this case is shown in Figure 7. It is tempting to suppose that the sound speed should increase with compaction as the density increases, but it is essential that independent measurements of sound speed as a function of imposed stress be made.

⁸M. Finger, "Hivelite Propellant Characterization," Lawrence Livermore Laboratory Report, UCID-16478, March 1975.



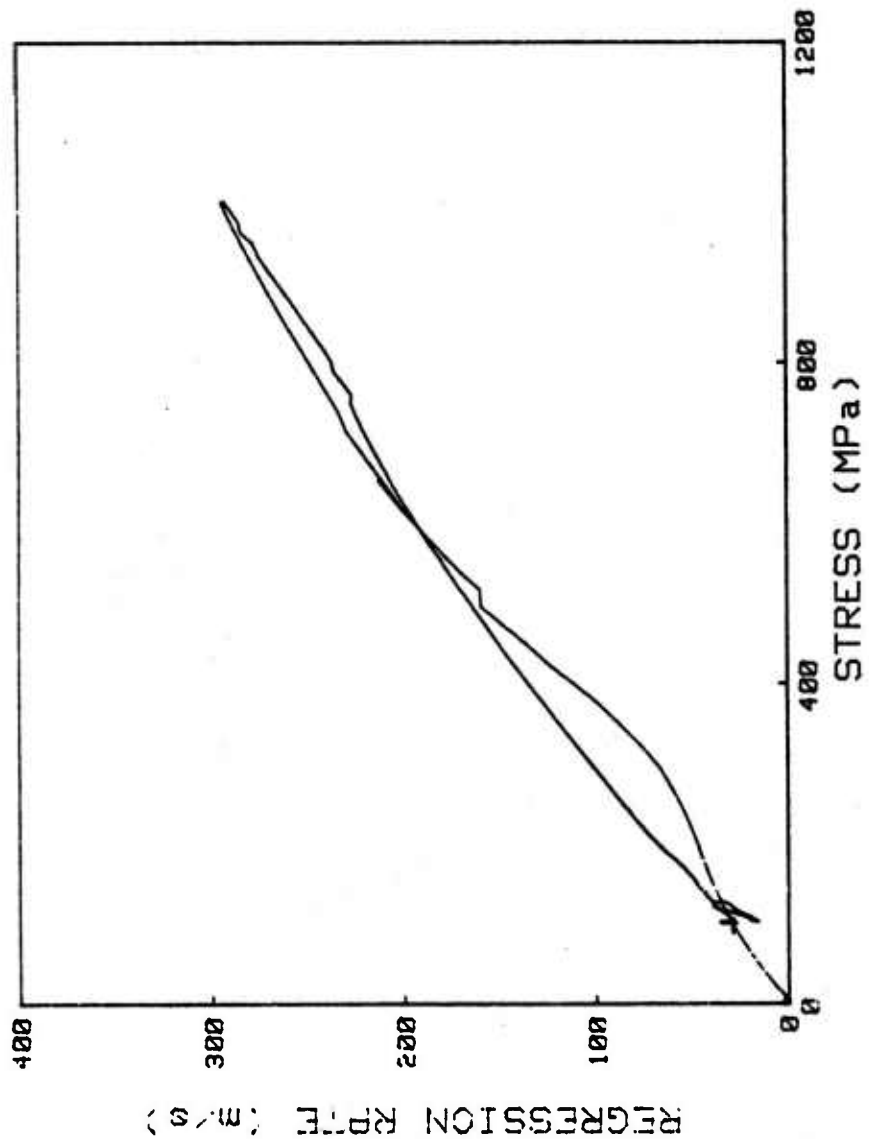
1086-5A
 98% TMD
 $C_p = 2.0 \text{ km/s}$
 $\mu = 1$

Figure 3. 1086-5A: Interface Pressure (-) and Stress (---)



1086-5A
 98% TMD
 $C_p = 2.0 \text{ km/s}$
 $\mu = 1$

Figure 4. 1086-5A: Regression Rate vs Pressure



1086-5A
 98% TMD
 $C_p=2.0 \text{ km/s}$
 $\mu=1$

Figure 5. 1086-5A: Regression Rate vs Stress

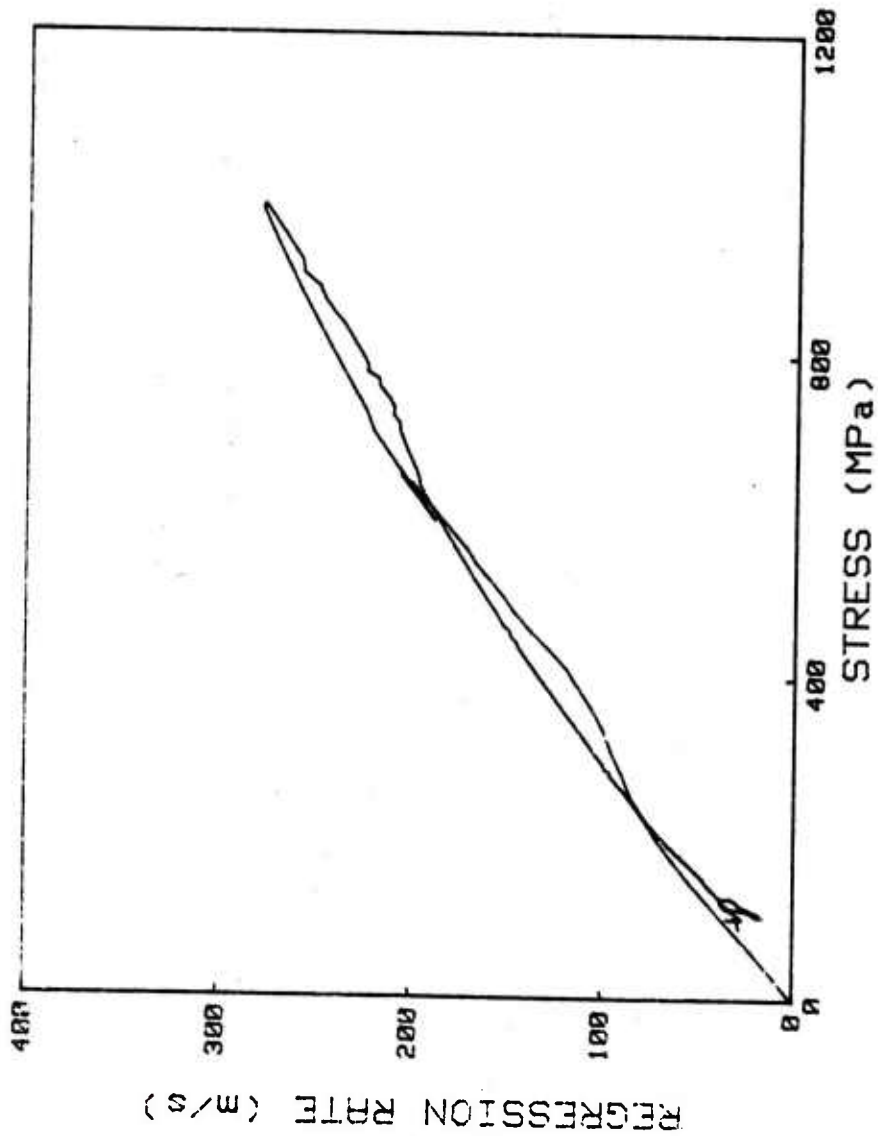
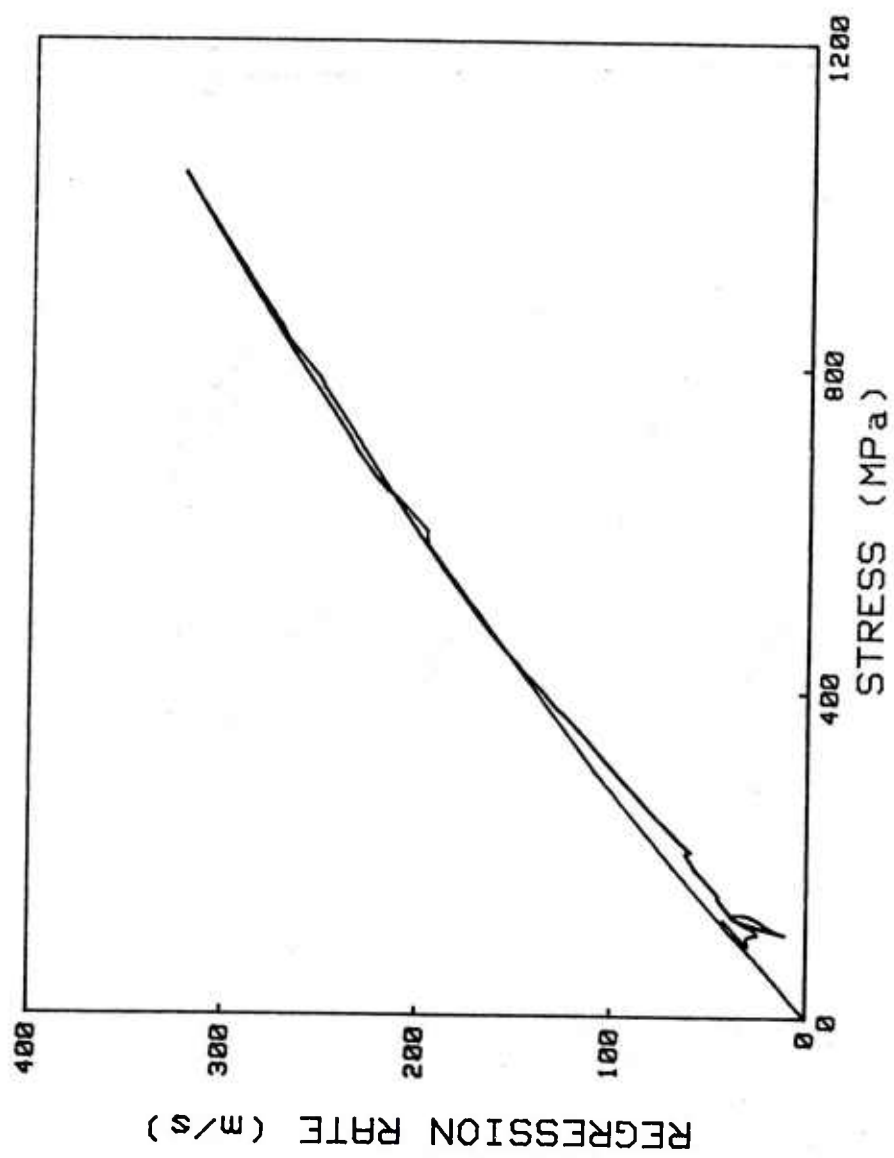


Figure 6. 1086-5A: Regression Rate @ $C_p = 1.8 \text{ km/sec}$



1086-5A
 98% TMD
 $C_p = 2.5 \text{ km/s}$
 $\mu = 1$

Figure 7. 1086-5A: Regression Rate @ $C_p = 2.5 \text{ km/sec}$

A similar parametric study on the effect of wall friction resulted in only minor effects on the apparent burning rate correlations. Further, a simple error analysis of Equation (6) indicates that regression rates lower than about 20 m/s in the pressure region of interest will not yield believable results even given small uncertainties in the measured stress and pressure.

A major concern in our analysis is the experimental observation of the drop of pressure and stress at a point where the analysis predicts that only about one-half of the propellant is consumed (maxima in Figure 3). Theoretical arguments for such a reversal are not yet fully developed. A plausible physical mechanism such as massive propellant column breakup can be postulated. Such refinements are not included in the current model. It is intriguing, however, that at least for the stress vs apparent burning rate, the burning rates march fairly well back down the same path after the peak stress is observed.

3.2 MODERATE BURNING CASE

A sample of 1086-03, (91.5% TMD), although a significantly slower-burning material, also exhibited substantial thrust. The reduced pressure and stress at the combustion gas-propellant interface is depicted in Figure 8. The analysis is terminated at about 350 microseconds after rapid pressurization occurs to eliminate complexities due to wave reflections in the stress rod. Regression rates are shown in Figures 9 and 10. Again, a better correlation is obtained for stress than for pressure. The agreement with the standard closed bomb results³ of the unconfined samples of the same density is satisfactory in the peak values obtained.

3.3 ANOMALOUS CASE

In two tests of 1086-6B at both 86.6% and 84% TMD, unusual results were obtained. Detailed examination of the pressure and stress gages indicated that both the stress and the pressure (P1) near the stress rod begin to rise almost simultaneously (Figure 11), but the pressures at gages P2, P3, and P4 begin to rise sequentially later in time, as shown in Figure 11. It is our conjecture that in these cases, the fast burning process started at the end-wall and then propagated toward the front end of the sample where ignition due to the igniter first occurred. Flashing down the sidewall or compaction-induced accelerated burning at the endwall are possible mechanisms for such an event. Friction-induced heating and ignition, however, cannot be ruled out. No thrust production was observed for these cases. At this point, it has not been possible to obtain replicate data, due in large part to sample limitations as well as severe instrumentation difficulties. Specifically, for the several fast burning samples that were tested, it has been difficult to maintain strain gage integrity. With only two exceptions, the very high stresses encountered have destroyed the strain patches during the experiment. Further experiments are required.

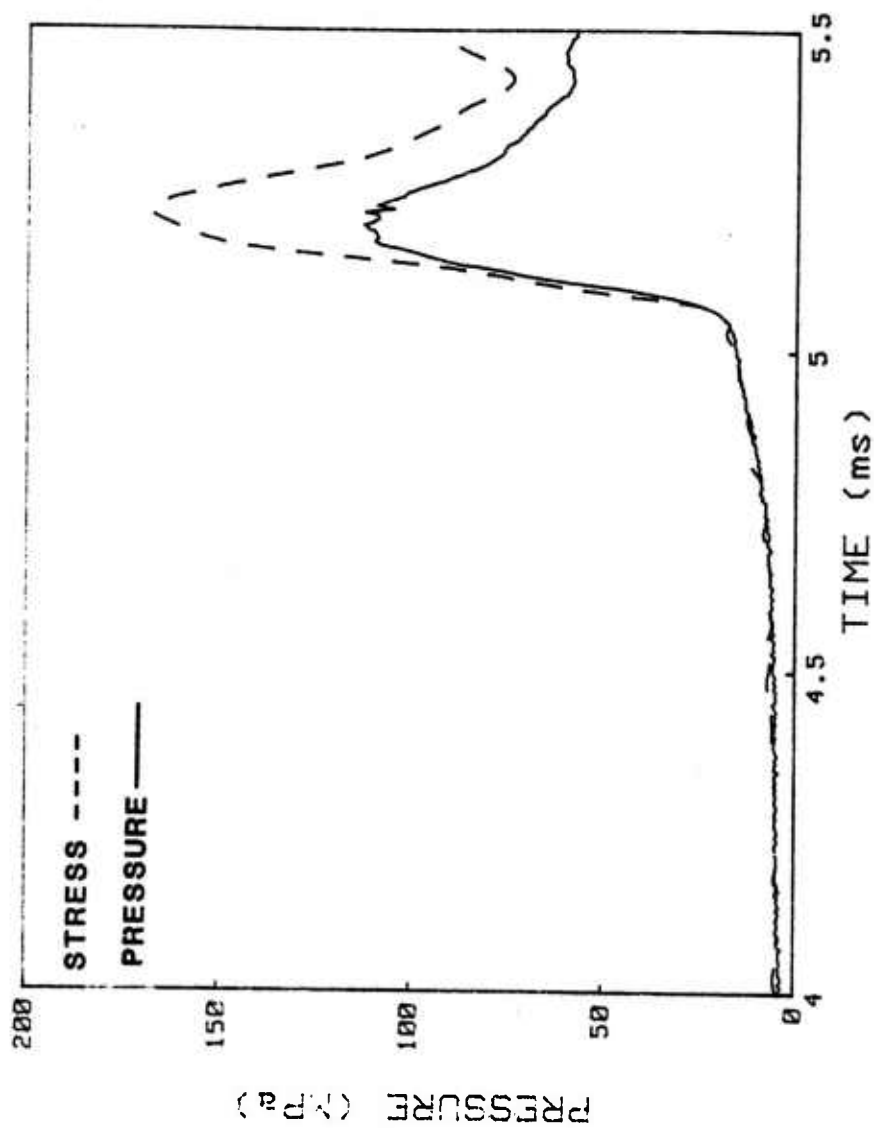


Figure 8. 1086-3: Interface Pressure (-) and Stress (---)

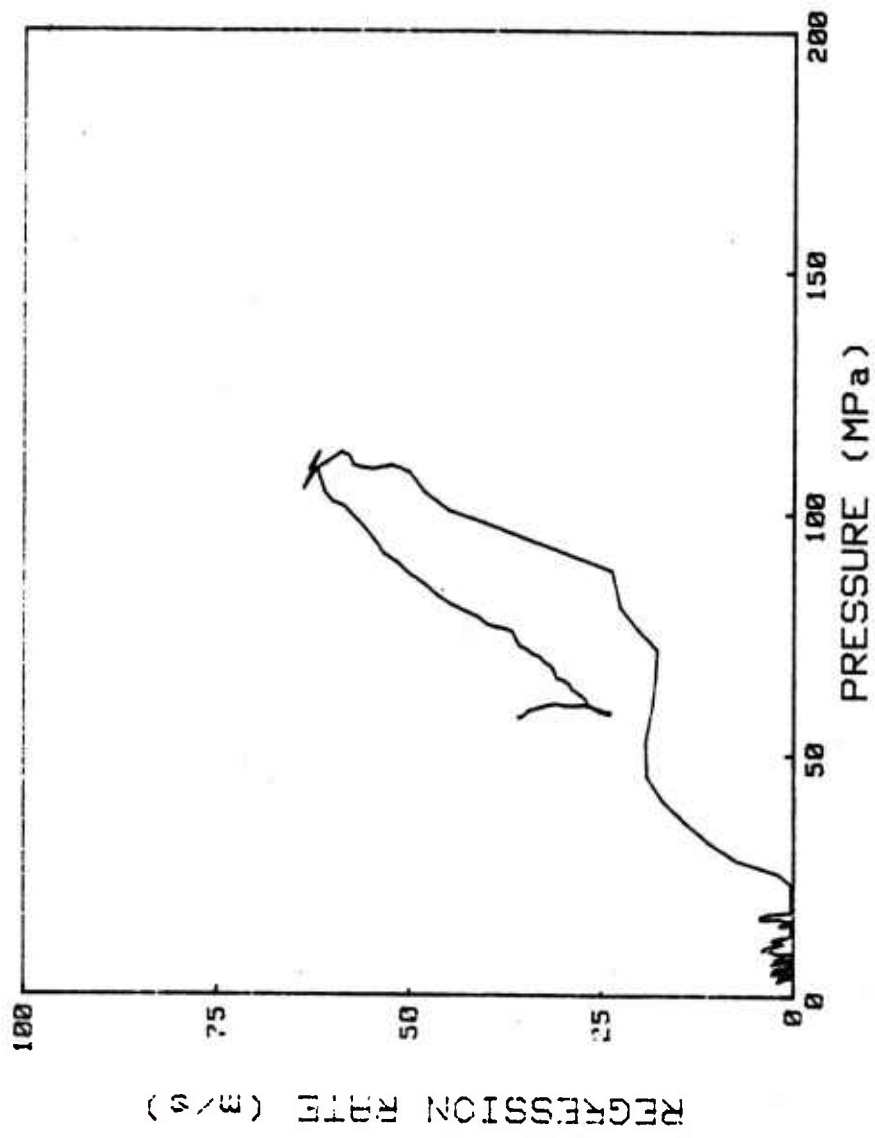


Figure 9. 1086-3: Regression Rate vs Pressure

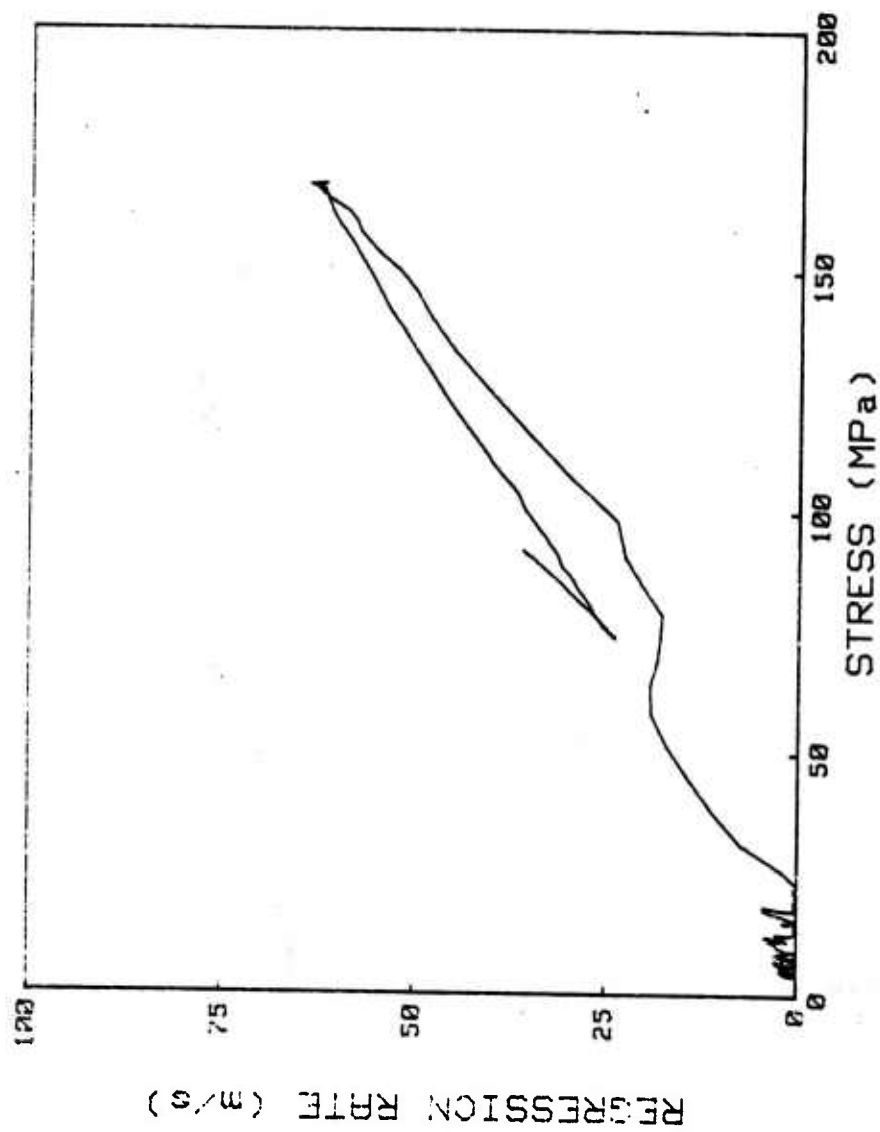


Figure 10. 1086-3: Regression Rate vs Stress

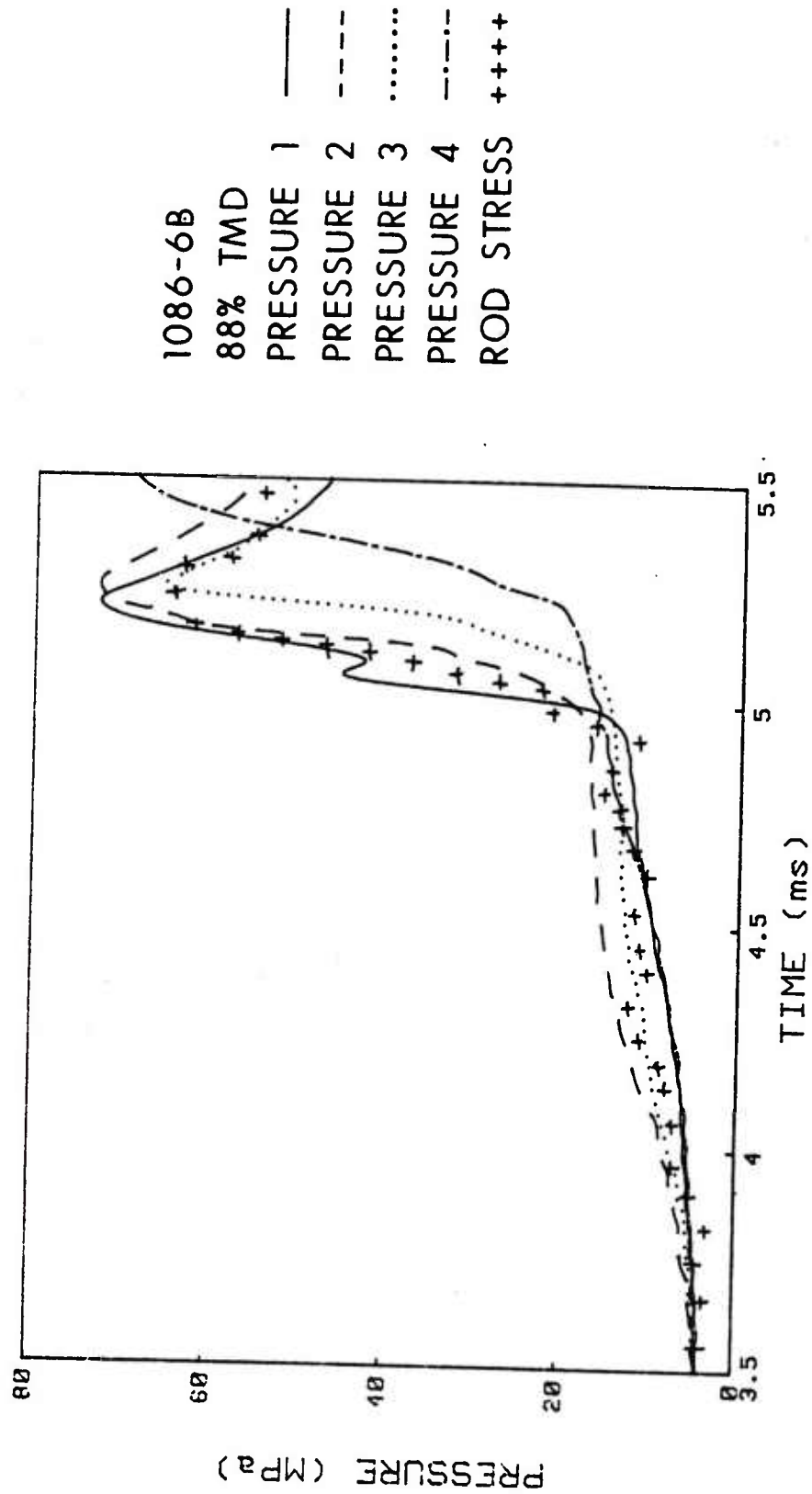


Figure 11. 1086-6B: P1(-), P2(---), P3(...), P4(-.-), RS(++++)

4. CONCLUSIONS AND ISSUES

The analysis employed has certain limitations. It is directly valid only for a reacting flame zone sufficiently thin to be considered quasi-steady. The assumption of elastic behavior of the propellant is also weak at the high dynamic stresses encountered. An explanation for the reversal in pressure and stress at a point where only about one-half of the propellant column is burned requires either a theoretical or an experimental answer, which we are not yet able to provide.

These shortcomings, notwithstanding the experiments described above, have clearly shown significant thrust contributions from VHBR propellant burning. Further, the levels of the thrust generated have been shown to be burning-rate dependent. This, together with the regression rate data obtained earlier, represents a substantial step forward in the development of a traveling charge propellant. Though the precise mechanism of sample burning is not clear, it is possible that a stress-induced breakup is involved in VHBR propellant burning. In that event, a breakup zone not significantly shorter than the sample length would invalidate our model.

The results of the thrust experiments in which the sample ignited on the "wrong" side are strong indications that there are many processes involved with these materials which we do not adequately understand. Effects such as compressive or friction-induced ignition or flamespread along the outer edges of the charge could markedly affect combustion and thrust behavior. Further projected studies, including flash x-ray diagnostics as well as thrust and closed bomb experiments will, hopefully, improve our understanding in these areas.

5. ACKNOWLEDGMENTS

We wish to acknowledge the help and insights provided to us by Mr. Paul Baer, Dr. Douglas Kooker, and Dr. R. Bernecker. In addition, we would like to thank Dr. James Walbert, who supplied us with a powerful Fourier analysis package.

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8. M. Finger, "Hivelite Propellant Characterization," Lawrence Livermore Laboratory Report, UCID-16478, March 1975.

APPENDIX A: DATA REDUCTION PROGRAM

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10  ! *****
20  ! +      "THBM17" -- Burn-Pate Reduction # 17 -- 06-OCT-81      *
30  ! *****
40  OPTION BASE 1
50  COM SHORT Press_3(2048),Press_2(2048),S(2048),Pfront(2048),Tfront(2048)
60  COM SHORT Timplt(2048),Prsplt(2048),Strplt(2048),Thrplt(2048),Ratplt(2048)
70  COM SHORT G0,Cp,Cs,Rs,Gamma,Ep,B,Gage_off,Sync,Epsilon,Mach_no
80  COM SHORT Tdel,T0,T_end,T_plus,T,T_minus,Thi,Tlo,T_prime,T_stop,T_off
90  COM SHORT L_plus,L,L_minus,L0,L_prime
100 COM SHORT Sig_hi,Sig_lo,Sigma_plus,Sigma,Sigma_minus
110 COM SHORT Num,Den,R_plus,R,R_minus,R_prime,R_last
120 COM SHORT Up_plus,Up,Up_minus,Up_prime,Up_last
130 COM SHORT P_plus,P,P_minus,Pm
140 COM SHORT Ug_plus,Ug,Ug_minus
150 COM SHORT Rg_plus,Rg,Rg_minus
160 COM SHORT Cg_plus,Cg,Cg_minus
170 COM SHORT Rp0,Rp_plus,Rp,Rp_minus,Rp_prime,Rp_last
180 COM SHORT Mu,Radius,Df_hi,Df_lo
190 COM SHORT K1,K2,K3,K4,K5,K6,K7,X
200 COM INTEGER K,M,N,Vsn,Output
210 COM Title$(30),Mode$(11),Ax_lab$(4)(30),Tag$(2)(30)
220 ! *****
230 Vsn=17
240 N=2048
250 Ax_lab$(1)="TIME (ms)"
260 Ax_lab$(2)="PRESSURE (MPa)"
270 Ax_lab$(3)="REGRESSION RATE (m/s)"
280 Ax_lab$(4)="STRESS (MPa)"
290 !
300 Top: PRINTER IS 16
310 PRINT PAGE
320 PRINT "                                THRUST REDUCTION -- VSN";Vsn
330 PRINT
340 PRINT "Run options: [1] Std run with initialization"
350 PRINT "                  [2] Std run w/o initialization"
360 PRINT "                  [3] Plot input data file(s)"
370 PRINT "                  [4] Plot results of last std run"
380 PRINT "                  [5] Store results of last std run"
390 PRINT "                  [6] Retrieve results of a std run"
400 PRINT "                  [7] End program ..."
410 K=1
420 INPUT K
430 IF (K<1) OR (K>6) THEN GOTO Finis
440 ON K GOTO Reset,Ask,Graf,Done,Perm,Perm
450 !
460 Perm: ! Store / get generated arrays ...
470 !
480 CALL Results(K,M,Timplt(*),Prsplt(*),Strplt(*),Thrplt(*),Ratplt(*))
490 GOTO Top
500 !
510 Graf: ! Plot input data ...
520 !
530 T_off=0
540 CALL Raw_plot(N,Timplt(*),Prsplt(*),Ax_lab$(1),Ax_lab$(2),Tag$(*),Tdel,T_o
ff)
550 GOTO Top
560 !
570 Reset: ! Initialization ...
580 !
590 Title$="TEST #11 1086-5A TMD=98%"
600 PRINT "Enter name of PRESSURE 3 file ..."
610 CALL Readf(Press_3(*),N,Tdel,K)
620 ! PRINT "Enter name of PRESSURE 2 file ..."
630 ! CALL Readf(Press_2(*),N,Tdel,K)
640 PRINT "Enter name of ROD STRESS file ..."
650 CALL Readf(S(*),N,Tdel,K)

```



```

660 !
670 G0=386.4      ! in/sec**2
680 Cp=73740      ! in/sec
690 Cs=195600     ! in/sec
700 Rp0=.0537     ! lb/in**3
710 Rs=.2818      ! lb/in**3
720 L0=2          ! in
730 Gamma=1.250   ! ----
740 Ep=1.696E7    ! in-lb/lb
750 B=33.80       ! in**3/lb
760 Gage_off=2    ! in
770 Sync=3.2E-5   ! sec
780 Mu=1          ! ???
790 Radius=.25    ! in
800 Output=0
810 T0=0
820 T_stop=(N-1)*Tdel
830 !
840 Ask: ! Solicit inputs ...
850 !
860 PRINT "Propellant sound speed [in/sec] ...";Cp;" ..."
870 INPUT Cp
880 PRINT "Propellant density [lb/in**3] ...";Rp0;" ..."
890 INPUT Rp0
900 PRINT "Gamma ...";Gamma;" ..."
910 INPUT Gamma
920 PRINT "Energy [in-lb/lb] ...";Ep;" ..."
930 INPUT Ep
940 PRINT "Covolume [in**3/lb] ...";B;" ..."
950 INPUT B
960 PRINT "Wall-friction coefficient ...";Mu;" ..."
970 INPUT Mu
980 PRINT "Sync offset [sec] ...";Sync;" ..."
990 INPUT Sync
1000 PRINT "Title ...";Title$;" ..."
1010 LINPUT Title$
1020 Tag$(1)=Title$
1030 Tag$(2)=" "
1040 PRINT "Output device ...";Output;" ..."
1050 INPUT Output
1060 PRINT "Enter start & end times [sec] ...";T0;" ";T_stop;" ..."
1070 INPUT T0,T_stop
1080 !
1090 T_end=T_stop-T0
1100 T_plus=0
1110 L_plus=L0
1120 Cg_plus=1
1130 Ug_plus=0
1140 Rp_plus=Rp0
1150 M=0
1160 Epsilon=.005
1170 !
1180 PRINTER IS Output
1190 PRINT "                THRUST REDUCTION -- VSN";Vsn
1200 PRINT "                ";Title$
1210 PRINT
1220 PRINT
1230 PRINT "Input Parameters:"
1240 PRINT USING Fmt0;Rp0,Cp,Gamma
1250 Fmt0:IMAGE "Propellant Density".20X,D.DDDD," lb/in**3"/11X,"Sound Speed",16
X,DDDDDD," in/sec"/11X,"Specific Heat Ratio",8X,D.DDDD
1260 PRINT USING Fmt1;Ep,B,Mu
1270 Fmt1:IMAGE 11X,"Energy",19X,D.DDE," in-lb/lb"/11X,"Covolume".20X,DD.DD," in
**3/lb"/11X,"Wall-Friction Coeff",8X,D.DDDD
1280 PRINT USING Fmt2;Rs,Cs,Sync

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1290 Fmt2: IMAGE "Stress Bar Density",20X,D,DDDD," 1b/in**3"/11X,"Sound Speed",16
X,DDDDDD," in/sec"/"Sync Offset",25X,D,DDE," sec"
1300 PRINT
1310 PRINT
1320 PRINT " TIME PPESSURE STRESS THRUST LENGTH U BURNING
RATE MACH NO"
1330 PRINT " (ms) (MPa) (MPa) (MPa) (mm) (m/sec) (m/sec)"
1340 PRINT
1350 !
1360 L0: ! Unconnected ...
1370 !
1380 Mode$=" "
1390 T_prime=T_plus+(L0-L_plus)/(Cg_plus-Ug_plus)
1400 CALL Interp(T_prime,T0,Tdel,Press_3(*),P_plus,N)
1410 Tlo=T_plus-L_plus/Cp+Gage_off/Cs-Sync
1420 CALL Interp(Tlo,T0,Tdel,S(*),Sig_lo,N)
1430 Thi=T_plus+L_plus/Cp+Gage_off/Cs-Sync
1440 CALL Interp(Thi,T0,Tdel,S(*),Sig_hi,N)
1450 !
1460 L05: Sigma_plus=Rp_plus*Cp*(Sig_hi-Sig_lo)/(2*Rs*Cs)+(Sig_hi+Sig_lo)/2
1470 Up_plus=G0*(Sig_hi+Sig_lo)/(2*Rs*Cs)+G0*(Sig_hi-Sig_lo)/(2*Rp_plus*Cp)
1480 !
1490 ! Wall-friction correction ...
1500 !
1510 Df_lo=L_plus/Cp+Gage_off/Cs
1520 Df_hi=L_plus/Cp+Gage_off/Cs
1530 Sigma_plus=(2*G0*Radius*Sigma_plus+Cp*Mu*(Sig_hi+Df_hi+Sig_lo*Df_lo))/(2*G
0*Radius-Cp*Mu*(Df_hi+Df_lo))
1540 IF Sigma_plus<P_plus THEN Sigma_plus=P_plus+1
1550 Up_plus=Up_plus+Mu*((Sigma_plus+Sig_hi)*Df_hi-(Sigma_plus+Sig_lo)*Df_lo)/(
2*Rp_plus*Radius)
1560 !
1570 Num=G0*(Sigma_plus-P_plus)*(Sigma_plus+(Gamma+1)/(Gamma-1)*P_plus)
1580 Den=2*Rp_plus*Rp_plus*(Ep+P_plus*(B-1/Rp_plus)/(Gamma-1))
1590 R_plus=SQR(Num/Den)
1600 Ug_plus=Up_plus-G0*(Sigma_plus-P_plus)/(Rp_plus*R_plus)
1610 Rg_plus=-Rp_plus*R_plus/(Ug_plus-Up_plus-R_plus)
1620 Cg_plus=SQR(Gamma+G0*(P_plus+14.7)/(Rg_plus*(1-B*Rg_plus)))
1630 Rp_prime=Rp_plus
1640 Rp_plus=Rp0+G0*Sigma_plus/Cp^2
1650 IF ABS((Rp_plus-Rp_prime)/Rp_prime)>Epsilon THEN GOTO L05
1660 !
1670 L1: ! Store & setup next step ...
1680 !
1690 M=M+1
1700 Timplt(M)=(T_plus+T0)*1000 ! ms
1710 Prsplt(M)=P_plus/1000*6.89475 ! MPa
1720 Strplt(M)=Sigma_plus/1000*6.89475 ! MPa
1730 Thrplt(M)=(Sigma_plus-P_plus)/1000*6.89475 ! MPa
1740 Ratplt(M)=R_plus*.0254 ! m/s
1750 Tfront(M)=T_plus ! sec
1760 Pfront(M)=P_plus ! psi
1770 R_prime=R_plus*.0254 ! m/s
1780 L_prime=L_plus*25.400000 ! mm
1790 Up_prime=Up_plus*.0254 ! m/s
1800 Mach_no=ABS(Ug_plus/Cg_plus) ! ---
1810 R_last=R_plus
1820 Up_last=Up_plus
1830 Rp_last=Rp_plus
1840 !
1850 PRINT USING Fmt3;Timplt(M),Prsplt(M),Strplt(M),Thrplt(M),L_prime,Up_prime,
R_prime,Mach_no,Mode$
1860 Fmt3: IMAGE DD,DDD,4X,DDDD,D,4X,DDDD,D,4X,DDDD,D,5X,DD,DD,4X,DDD,DDD,5X,DDD
,DDD,5X,D,DD,X,A
1870 !

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```

1880 ! New time T_plus ...
1890 !
1900 L15: T_plus=T_plus+Tdel
1910 IF T_plus>T_end THEN Done
1920 L_plus=L_plus-(R_last+Up_last)*Tdel
1930 IF L_plus<=0 THEN Done
1940 IF M<2 THEN GOTO L8
1950 T=Tfront(M)
1960 K=0
1970 R=R_last
1980 Up=Up_last
1990 Rp=Rp_last
2000 !
2010 L2: ! Determine T & values at time T ...
2020 !
2030 CALL Interp2(T,Tfront(*),Pfront(*),P,M)
2040 L=L_plus+(R+Up)*(T_plus-T)
2050 Tlo=T-L/Cp+Gage_off/Cs-Sync
2060 CALL Interp(Tlo,T0,Tdel,S(*),Sig_lo,N)
2070 Thi=T-L/Cp+Gage_off/Cs-Sync
2080 CALL Interp(Thi,T0,Tdel,S(*),Sig_hi,N)
2090 Sigma=Rp*Cp*(Sig_hi-Sig_lo)/(2*Rs*Cs)+(Sig_hi+Sig_lo)/2
2100 Up=G0*(Sig_hi+Sig_lo)/(2*Rs*Cs)+G0*(Sig_hi-Sig_lo)/(2*Rp*Cp)
2110 !
2120 ! Wall-friction correction ...
2130 !
2140 Df_lo=L/Cp-Gage_off/Cs
2150 Df_hi=L/Cp+Gage_off/Cs
2160 Sigma=(2+G0*Radius+Sigma+Cp*Mux*(Sig_hi*Df_hi+Sig_lo*Df_lo))/(2*G0*Radius-C
p*Mux*(Df_hi+Df_lo))
2170 IF Sigma<=P THEN Sigma=P+1
2180 Up=Up+Mux*((Sigma+Sig_hi)*Df_hi-(Sigma+Sig_lo)*Df_lo)/(2*Rp*Radius)
2190 !
2200 Num=G0*(Sigma-P)*(Sigma+(Gamma+1)/(Gamma-1)+P)
2210 Den=2*Rp*Rp*(Ep+P*(B-1/Rp)/(Gamma-1))
2220 R=SQR(Num/Den)
2230 Ug=Up-G0*(Sigma-P)/(Rp+R)
2240 Rg=-Rp*R/(Ug-Up-R)
2250 Cg=SQR(Gamma+G0*(P+14.7)/(Rg*(1-B*Rg)))
2260 Rp=Rp0+G0*Sigma/Cp^2
2270 !
2280 T_prime=T_plus-(L0-L)/(Ug+Cg)
2290 IF ABS((T_prime-T)/T)<Epsilon THEN GOTO L3
2300 T=(T_prime+T)/2
2310 K=K+1
2320 IF K<25 THEN GOTO L2
2330 GOTO L15
2340 !
2350 L3: T_minus=T-Tdel
2360 R_minus=R
2370 Up_minus=Up
2380 Rp_minus=Rp
2390 K=0
2400 !
2410 L4: ! Determine T_minus & values at T_minus ...
2420 !
2430 CALL Interp2(T_minus,Tfront(*),Pfront(*),P_minus,M)
2440 L_minus=L_plus+(R+Up)*(T_plus-T)+(R_minus+Up_minus)*(T-T_minus)
2450 Tlo=T_minus-L_minus/Cp+Gage_off/Cs-Sync
2460 CALL Interp(Tlo,T0,Tdel,S(*),Sig_lo,N)
2470 Thi=T_minus-L_minus/Cp+Gage_off/Cs-Sync
2480 CALL Interp(Thi,T0,Tdel,S(*),Sig_hi,N)
2490 Sigma_minus=Rp_minus*Cp*(Sig_hi-Sig_lo)/(2*Rs*Cs)+(Sig_hi+Sig_lo)/2
2500 Up_minus=G0*(Sig_hi+Sig_lo)/(2*Rs*Cs)+G0*(Sig_hi-Sig_lo)/(2*Rp_minus*Cp)
2510 !
2520 ! Wall-friction correction ...

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```

2530 !
2540 Df_lo=L_minus/Cp+Gage_off/Cs
2550 Df_hi=L_minus/Cp+Gage_off/Cs
2560 Sigma_minus=(2*G0*Radius*Sigma_minus+Cp*Mu*(Sig_hi+Df_hi+Sig_lo*Df_lo))/(2
+G0*Radius-Cp*Mu*(Df_hi+Df_lo))
2570 IF Sigma_minus<P_minus THEN Sigma_minus=P_minus+1
2580 Up_minus=Up_minus+Mu*((Sigma_minus+Sig_hi)*Df_hi-(Sigma_minus+Sig_lo)*Df_l
o)/(2*Rp_minus*Radius)
2590 !
2600 Num=G0*(Sigma_minus-P_minus)*(Sigma_minus+(Gamma+1)/(Gamma-1)*P_minus)
2610 Den=2*Rp_minus*Rp_minus*(Ep+P_minus*(B-1/Rp_minus)/(Gamma-1))
2620 R_minus=SQR(Num/Den)
2630 Ug_minus=Up_minus-G0*(Sigma_minus-P_minus)/(Rp_minus*R_minus)
2640 Rg_minus=-Rp_minus*R_minus/(Ug_minus-Up_minus-R_minus)
2650 Cg_minus=SQR(Gamma+G0*(P_minus+1+.7)/(Rg_minus*(1-B*Rg_minus)))
2660 Rp_minus=Rp0+G0*Sigma_minus/Cp^2
2670 !
2680 T_prime=T-(L_minus-L0)/(Ug-Cg)
2690 IF ABS((T_minus-T_prime)/T_minus)<Epsilon THEN GOTO L5
2700 T_minus=T_prime
2710 K=K+1
2720 IF K<25 THEN GOTO L4
2730 GOTO L15
2740 !
2750 L5: ! Determine stress at reaction front ...
2760 !
2770 Rp_plus=Rp
2780 Cg_plus=Cg
2790 Ug_plus=Ug
2800 CALL Interp(T,T0,Tdel,Press_3(*),Pm,N)
2810 Tlo=T_plus-L_plus/Cp+Gage_off/Cs-Sync
2820 CALL Interp(Tlo,T0,Tdel,S(*),Sig_lo,N)
2830 Thi=T_plus+L_plus/Cp+Gage_off/Cs-Sync
2840 CALL Interp(Thi,T0,Tdel,S(*),Sig_hi,N)
2850 !
2860 L55: Sigma_plus=Rp_plus*Cp*(Sig_hi-Sig_lo)/(2*Rs+Cs)+(Sig_hi+Sig_lo)/2
2870 Up_plus=G0*(Sig_hi+Sig_lo)/(2*Rs+Cs)+G0*(Sig_hi-Sig_lo)/(2*Rp_plus*Cp)
2880 !
2890 ! Wall-friction correction ...
2900 !
2910 Df_lo=L_plus/Cp+Gage_off/Cs
2920 Df_hi=L_plus/Cp+Gage_off/Cs
2930 Sigma_plus=(2*G0*Radius*Sigma_plus+Cp*Mu*(Sig_hi+Df_hi+Sig_lo*Df_lo))/(2*G
0*Radius-Cp*Mu*(Df_hi+Df_lo))
2940 Up_plus=Up_plus+Mu*((Sigma_plus+Sig_hi)*Df_hi-(Sigma_plus+Sig_lo)*Df_lo)/(
2*Rp_plus*Radius)
2950 !
2960 L6: ! Solve cubic for P_plus ...
2970 !
2980 K1=2*Pm-P_minus+Rg*Cg*(Ug_minus-Up_plus)/G0
2990 K2=2*Rg^2*Cg^2/G0
3000 K3=(B-1/Rp_plus)/(Gamma-1)
3010 K4=(Gamma+1)/(Gamma-1)
3020 K5=Sigma_plus-2*K1*K4+K2*K3
3030 K6=-2*K1*Sigma_plus+K1^2*K4-K2*Sigma_plus+K3+K2*Ep
3040 K7=K1^2*Sigma_plus-K2*Ep*Sigma_plus
3050 X=P
3060 !
3070 L7: Fx=K4*X^3+K5*X^2+K6*X+K7
3080 Fx_prime=3*K4*X^2+2*K5*X+K6
3090 P_plus=X-Fx/Fx_prime
3100 IF ABS((X-P_plus)/P_plus)<.0001 THEN GOTO L8
3110 X=P_plus
3120 GOTO L7
3130 !
3140 L8: ! Determine values at time T_plus when P_plus found ...

```

```

3150 !
3160 Mode$="*"
3170 IF P_plus>0 THEN GOTO L9
3180 Mode$="?"
3190 T_prime=T_plus*(L0-L_plus)/(Cg_plus-Ug_plus)
3200 CALL Interp(T_prime,T0,Tdel,Press_3(*),P_plus,N)
3210 L9: IF Sigma_plus<=P_plus THEN Sigma_plus=P_plus+1
3220 !
3230 Num=G0*(Sigma_plus-P_plus)*(Sigma_plus+(Gamma+1)/(Gamma-1)*P_plus)
3240 Den=2*Rp_plus*Rp_plus*(Ep+P_plus*(B-1/Rp_plus)/(Gamma-1))
3250 R_plus=SQR(Num/Den)
3260 Ug_plus=Up_plus-G0*(Sigma_plus-P_plus)/(Rp_plus+R_plus)
3270 Rg_plus=-Rp_plus*R_plus/(Ug_plus-Up_plus-R_plus)
3280 Cg_plus=SQR(Gamma*G0*(P_plus+14.7)/(Rg_plus*(1-B*Rg_plus)))
3290 Rp_prime=Rp_plus
3300 Rp_plus=Rp0+G0*Sigma_plus/Cp^2
3310 IF ABS((Rp_plus-Rp_prime)/Rp_prime)<Epsilon THEN GOTO L1
3320 GOTO L55
3330 !
3340 Done: ! Run complete; time to plot ...
3350 !
3360 PRINT
3370 PRINT
3380 PRINTER IS 16
3390 !
3400 PRINT PAGE
3410 K=1
3420 PRINT "Burning Rate vs. Stress ..."
3430 CALL Plotit(K,M,Strplt(*),Ratplt(*),Ax_lab$(4),Ax_lab$(3),Tag$(*))
3440 PRINT "Pressure vs. Time ..."
3450 CALL Plotit(K,M,Timplt(*),Prsplt(*),Ax_lab$(1),Ax_lab$(2),Tag$(*))
3460 PRINT "Burning Rate vs. Thrust ..."
3470 CALL Plotit(K,M,Thrplt(*),Ratplt(*),Ax_lab$(2),Ax_lab$(3),Tag$(*))
3480 PRINT "Stress vs. Time ..."
3490 CALL Plotit(K,M,Timplt(*),Strplt(*),Ax_lab$(1),Ax_lab$(4),Tag$(*))
3500 PRINT "Thrust vs. Time ..."
3510 CALL Plotit(K,M,Timplt(*),Thrplt(*),Ax_lab$(1),Ax_lab$(2),Tag$(*))
3520 PRINT "Burning Rate vs. Time ..."
3530 CALL Plotit(K,M,Timplt(*),Ratplt(*),Ax_lab$(1),Ax_lab$(3),Tag$(*))
3540 PRINT "Burning Rate vs. Pressure ..."
3550 CALL Plotit(K,M,Prsplt(*),Ratplt(*),Ax_lab$(2),Ax_lab$(3),Tag$(*))
3560 !
3570 PEN -1
3580 Finis: STOP
3590 END
3600 ! *****
3610 SUB Interp(SHORT Time,SHORT T0,SHORT Tdel,SHORT Q(*),SHORT Ans,INTEGER Max)
3620 OPTION BASE 1
3630 SHORT T1
3640 INTEGER N1,Nr
3650 !
3660 N1=INT((Time+T0)/Tdel)+1
3670 IF N1<1 THEN N1=1
3680 IF N1>Max-1 THEN N1=Max-1
3690 Nr=N1+1
3700 T1=(N1-1)*Tdel-T0
3710 Ans=Q(N1)+(Q(Nr)-Q(N1))*(Time-T1)/Tdel
3720 !
3730 SUBEND
3740 ! *****
3750 SUB Readf(SHORT Out(*),INTEGER N,SHORT Delta,INTEGER Iflag)
3760 OPTION BASE 1
3770 SHORT Get(2085)
3780 INTEGER I
3790 DIM Fname$(6)

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```

3800 !
3810 INPUT Fname$
3820 Iflag=1
3830 IF Fname$="NONE" THEN GOTO Bypass
3840 Iflag=0
3850 !
3860 FREAD Fname$":C12",Get(*)
3870 Delta=Get(37)/1000
3880 !
3890 FOR I=1 TO N
3900 Out(I)=Get(I+37)*1000
3910 NEXT I
3920 !
3930 Bypass: ! Done ...
3940 !
3950 SUBEND
3960 ! *****
3970 SUB Plotit(INTEGER Nlo,INTEGER Nhi,SHORT X(*),SHORT Y(*),X_lab$,Y_lab$,Tag
s(*))
3980 OPTION BASE 1
3990 SHORT Xaxlen,Yaxlen,Offset,Xmin,Xmax,Xdel,Ymin,Ymax,Ydel,Tuid,Thgt,Tspec
4000 SHORT Amin,Amax,Bmin,Bmax,Xlim,Ylim,Xpos,Ypos,Cuid,Chgt,Cspec,Fact
4010 INTEGER J,L_code,Over,Loop
4020 DIM Vst(30)
4030 !
4040 Over=0
4050 PRINT "Overlay on current plot [-1=Escape, 0=No, 1=Yes] ..."
4060 INPUT Over
4070 IF Over=1 THEN GOTO Overlay
4080 IF Over<0 THEN GOTO Return
4090 !
4100 Offset=25.4
4110 Xaxlen=5
4120 Yaxlen=4
4130 PRINT "Enter x- & y-axis lengths [";Xaxlen;Yaxlen;" in] ..."
4140 INPUT Xaxlen,Yaxlen
4150 !
4160 Amin=Amax=X(Nlo)
4170 Bmin=Bmax=Y(Nlo)
4180 FOR J=Nlo TO Nhi
4190 IF X(J)<Amin THEN Amin=X(J)
4200 IF X(J)>Amax THEN Amax=X(J)
4210 IF Y(J)<Bmin THEN Bmin=Y(J)
4220 IF Y(J)>Bmax THEN Bmax=Y(J)
4230 NEXT J
4240 !
4250 PRINT "Enter Xmin, Xmax, & Xdel [range: ";Amin;Amax;X_lab$;" ] ..."
4260 INPUT Xmin,Xmax,Xdel
4270 PRINT "Enter Ymin, Ymax, & Ydel [range: ";Bmin;Bmax;Y_lab$;" ] ..."
4280 INPUT Ymin,Ymax,Ydel
4290 PRINT "Title 1 ... ";Tag$(1)
4300 LINPUT Tag$(1)
4310 PRINT "Title 2 ... ";Tag$(2)
4320 LINPUT Tag$(2)
4330 !
4340 PLOTTER IS "9872A"
4350 DEG
4360 Xlim=25.4*Xaxlen+Offset
4370 Ylim=25.4*Yaxlen+Offset
4380 LIMIT 0,Xlim+Offset,0,Ylim+Offset
4390 SCALE 0,Xlim+Offset,0,Ylim+Offset
4400 !
4410 Chgt=.15*25.4
4420 Cuid=9/15*Chgt
4430 Fact=1.5
4440 Cspec=Chgt*100*MAX(1,RATIO)/(Xlim+Offset)

```

```

4450 Thgt=Chgt*Fact
4460 Twid=Cwid*Fact
4470 Tspec=Thgt*100*MAX(1,RATIO)/(Xlim+Offset)
4480 !
4490 CSIZE Tspec
4500 Xpos=.5*(Xlim+Offset-LEN(X_lab$))*Twid)
4510 Ypos=Offset-2.5*Chgt
4520 MOVE Xpos,Ypos
4530 LABEL X_lab$
4540 !
4550 CSIZE Cspec
4560 Loop=INT(1.01*(Xmax-Xmin)/Xdel)+1
4570 !
4580 FOR J=1 TO Loop
4590 V$=VAL$(Xmin+(J-1)*Xdel)
4600 Xpos=Offset+(J-1)*(Xlim-Offset)/(Loop-1)-.5*LEN(V$)*Cwid
4610 Ypos=Offset-Chgt
4620 MOVE Xpos,Ypos
4630 LABEL V$
4640 NEXT J
4650 !
4660 LDIR 90
4670 CSIZE Tspec
4680 Xpos=Offset-5*Cwid
4690 Ypos=.5*(Ylim+Offset-LEN(Y_lab$))*Twid)
4700 MOVE Xpos,Ypos
4710 LABEL Y_lab$
4720 !
4730 LDIR 0
4740 CSIZE Cspec
4750 Loop=INT(1.01*(Ymax-Ymin)/Ydel)+1
4760 !
4770 FOR J=1 TO Loop
4780 V$=VAL$(Ymin+(J-1)*Ydel)
4790 Xpos=Offset-(.5+LEN(V$))*Cwid
4800 Ypos=Offset+(J-1)*(Ylim-Offset)/(Loop-1)-.275*Chgt
4810 MOVE Xpos,Ypos
4820 LABEL V$
4830 NEXT J
4840 !
4850 MOVE 2*Offset,Ylim+.75*Offset
4860 LABEL Tag$(1)
4870 MOVE 2*Offset,Ylim+.25*Offset
4880 LABEL Tag$(2)
4890 !
4900 LIMIT Offset,Xlim,Offset,Ylim
4910 SCALE Xmin,Xmax,Ymin,Ymax
4920 FRAME
4930 AXES Xdel,Ydel,Xmin,Ymin
4940 !
4950 Overlay: ! Lay down next curve ...
4960 !
4970 L_code=1
4980 PRINT "Enter line-type code [1 thru 10] ..."
4990 INPUT L_code
5000 LINE TYPE L_code
5010 PENUP
5020 !
5030 FOR J=Nlo TO Nhi
5040 PLOT X(J),Y(J)
5050 NEXT J
5060 PENUP
5070 LINE TYPE 1
5080 !
5090 Return: ! Done ...
5100 !

```



```

5110 PRINT
5120 SUBEND
5130 ! *****
5140 SUB Raw_plot(INTEGER N, SHORT Eks(*), SHORT Wye(*), X1$, Y1$, Title$(*), SHORT D
    elta, SHORT Offset)
5150 OPTION BASE 1
5160 SHORT Tmin, Tmax
5170 INTEGER I, Nlo, Nhi
5180 !
5190 Title$(1)=Title$(2)=" "
5200 Top: PRINT PAGE
5210 PRINT "Enter name of data file ..."
5220 CALL Readf(Wye(*), N, Delta, I)
5230 IF I=1 THEN GOTO Ask
5240 Delta=Delta+1000
5250 PRINT "Enter desired offset ["; Offset; X1$; "]" ...
5260 INPUT Offset
5270 !
5280 FOR I=1 TO N
5290 Eks(I)=(I-1)*Delta+Offset
5300 Wye(I)=Wye(I)/1000*6.39475
5310 NEXT I
5320 !
5330 Ask: PRINT "Select plot window [range: "; Eks(1); Eks(N); X1$; "]" ...
5340 Tmin=Eks(1)
5350 Tmax=Eks(N)
5360 INPUT Tmin, Tmax
5370 IF Tmin>Tmax THEN GOTO Ask
5380 Nlo=(Tmin-Offset)/Delta+1
5390 IF Nlo<1 THEN Nlo=1
5400 Nhi=(Tmax-Offset)/Delta+1
5410 IF Nhi>N THEN Nhi=N
5420 !
5430 CALL Plotit(Nlo, Nhi, Eks(*), Wye(*), X1$, Y1$, Title$(*))
5440 PRINT "Plotting complete [0=No, 1=Yes] ..."
5450 I=0
5460 INPUT I
5470 IF I=0 THEN GOTO Top
5480 !
5490 PEN -1
5500 SUBEND
5510 ! *****
5520 SUB Interp2(SHORT Time, SHORT T(*), SHORT Q(*), SHORT Ans, INTEGER Max)
5530 OPTION BASE 1
5540 INTEGER N1, Nr
5550 !
5560 FOR N1=Max-1 TO 1 STEP -1
5570 IF Time>T(N1) THEN GOTO Hit
5580 NEXT N1
5590 !
5600 N1=1
5610 Hit: Nr=N1+1
5620 Ans=Q(N1)+(Q(Nr)-Q(N1))*(Time-T(N1))/(T(Nr)-T(N1))
5630 IF Ans<=0 THEN Ans=Q(Nr)
5640 !
5650 SUBEND
5660 ! *****
5670 SUB Results(INTEGER Opt, INTEGER M, SHORT Time(*), SHORT P(*), SHORT S(*), SHOR
    T T(*), SHORT R(*))
5680 OPTION BASE 1
5690 DIM Fname$(6), Fullname$(10)
5700 !
5710 PRINT
5720 PRINT "Enter name of data file ..."
5730 INPUT Fname$
5740 Fullname$=Fname$&":C12"

```



```

5750 |
5760 | IF Opt=6 THEN GOTO Retrieve
5770 |
5780 | Store arrays ...
5790 |
5800 | CREATE Fullnames$,161
5810 | ASSIGN #1 TO Fullnames$
5820 | BUFFER #1
5830 | PRINT #1;M,Time(*),P(*),S(*),T(*),R(*)
5840 | ASSIGN #1 TO *
5850 | GOTO Done
5860 |
5870 | Retrieve: ! Get arrays ...
5880 |
5890 | ASSIGN #1 TO Fullnames$
5900 | BUFFER #1
5910 | READ #1;M,Time(*),P(*),S(*),T(*),R(*)
5920 | ASSIGN #1 TO *
5930 |
5940 | Done: ! Return ...
5950 |
5960 | SUBEND
5970 | *****
5980 | *END* *END* *END*
5990 | *****

```

APPENDIX B: SAMPLE RUN OF 1086-5A

THRUST REDUCTION -- VSN 17

Input Parameters:

Propellant Density .0537 lb/in**3
 Sound Speed 118110 in/sec
 Specific Heat Ratio 1.2500
 Energy 1.70E+07 in-lb/lb
 Volume 33.80 in**3/lb
 Wall-Friction Coeff 1.0000
 Stress Bar Density .2818 lb/in**3
 Sound Speed 195600 in/sec
 Burn Offset 2.40E-05 sec

TIME (ms)	PRESSURE (MPa)	STRESS (MPa)	THRUST (MPa)	LENGTH (mm)	Up (m/sec)	BURNING RATE (m/sec)	Ug/Cg
.800	2.9	3.8	.9	50.80	.090	1.216	.49
.801	2.9	3.8	.9	50.80	.061	1.182	.48
.802	2.9	3.7	.8	50.80	.029	1.133	.46 *
.803	2.9	3.6	.7	50.80	-.004	1.067	.43 *
.804	2.9	3.5	.6	50.80	-.036	.984	.40 *
.805	2.9	3.4	.5	50.79	-.066	.893	.36 *
.806	2.9	3.3	.4	50.79	-.092	.760	.31 *
.807	2.9	3.2	.2	50.79	-.115	.615	.25 *
.808	2.9	3.0	.1	50.79	-.132	.432	.18 *
.809	2.9	2.9	.0	50.79	-.142	.128	.05 *
.810	2.8	2.8	.0	50.79	-.149	.029	.01 *
.811	2.8	2.8	.0	50.79	-.150	.117	.05 *
.812	2.7	2.7	.0	50.79	-.146	.090	.04 *
.813	2.7	2.7	.0	50.79	-.138	.182	.08 *
.814	2.7	2.7	.0	50.79	-.127	.098	.04 *
.815	2.7	2.7	.0	50.79	-.113	.211	.09 *
.816	2.8	2.8	.0	50.79	-.097	.006	.00 *
.817	2.8	2.8	.0	50.79	-.080	.087	.04 *
.818	2.9	2.9	.0	50.79	-.061	.080	.03 *
.819	3.0	3.0	.0	50.79	-.042	.157	.06 *
.820	3.0	3.1	.1	50.79	-.022	.325	.13 *
.821	3.0	3.2	.2	50.79	-.003	.537	.21 *
.822	3.0	3.3	.3	50.79	.017	.725	.29 *
.823	3.0	3.4	.5	50.79	.036	.864	.34 *
.824	3.0	3.6	.6	50.79	.054	.971	.39 *
.825	3.0	3.7	.7	50.79	.072	1.061	.42 *
.826	3.0	3.8	.8	50.79	.088	1.143	.45 *
.827	3.0	3.9	.9	50.79	.102	1.214	.48 *
.828	3.0	4.0	1.0	50.78	.114	1.271	.50 *
.829	3.0	4.0	1.0	50.78	.124	1.313	.52 *
.830	3.0	4.1	1.1	50.78	.133	1.338	.53 *
.831	3.0	4.1	1.1	50.78	.139	1.342	.53 *
.832	3.0	4.0	1.1	50.78	.144	1.325	.53 *
.833	3.0	4.0	1.0	50.78	.147	1.283	.51 *
.834	3.0	3.9	.9	50.78	.149	1.217	.49 *
.835	3.0	3.7	.8	50.77	.150	1.124	.45 *
.836	3.0	3.6	.6	50.77	.151	1.003	.40 *
.837	3.0	3.4	.5	50.77	.154	.853	.34 *
.838	3.0	3.2	.3	50.77	.157	.669	.27 *
.839	3.0	3.1	.1	50.77	.163	.431	.17 *
.840	2.9	2.9	.0	50.77	.171	.035	.01 *

TIME (ms)	PRESSURE (MPa)	STRESS (MPa)	THRUST (MPa)	LENGTH (mm)	Up (m/sec)	BURNING RATE (m/sec)	Ug/Cg
.841	2.8	2.8	.0	50.77	.182	.076	.03 *
.842	2.7	2.7	.0	50.77	.196	.162	.07 *
.843	2.6	2.7	.0	50.77	.212	.162	.07 *
.844	2.6	2.7	.0	50.77	.231	.194	.08 *
.845	2.7	2.7	.0	50.77	.251	.101	.04 *
.846	2.8	2.8	.0	50.77	.271	.093	.04 *
.847	2.9	2.9	.0	50.77	.290	.076	.03 *
.848	3.0	3.0	.0	50.77	.308	.202	.08 *
.849	3.0	3.1	.1	50.77	.324	.408	.16 *
.850	3.0	3.3	.3	50.77	.336	.644	.25 *
.851	3.0	3.4	.4	50.77	.345	.836	.33 *
.852	3.0	3.6	.6	50.76	.349	.973	.39 *
.853	3.0	3.7	.7	50.76	.349	1.076	.42 *
.854	3.0	3.8	.8	50.76	.345	1.160	.45 *
.855	3.1	4.0	.9	50.76	.336	1.231	.47 *
.856	3.1	4.1	1.0	50.76	.324	1.290	.49 *
.857	3.1	4.1	1.0	50.76	.308	1.339	.51 *
.858	3.1	4.2	1.1	50.76	.290	1.380	.52 *
.859	3.1	4.3	1.2	50.75	.271	1.416	.53 *
.860	3.1	4.3	1.2	50.75	.251	1.446	.55 *
.861	3.1	4.4	1.3	50.75	.233	1.473	.56 *
.862	3.1	4.4	1.3	50.75	.216	1.496	.57 *
.863	3.1	4.4	1.3	50.75	.203	1.515	.58 *
.864	3.0	4.4	1.4	50.74	.194	1.530	.59 *
.865	3.0	4.4	1.4	50.74	.189	1.541	.60 *
.866	3.0	4.4	1.4	50.74	.189	1.545	.61 *
.867	2.9	4.4	1.4	50.74	.193	1.541	.61 *
.868	2.9	4.3	1.4	50.74	.201	1.528	.61 *
.869	2.9	4.3	1.4	50.74	.211	1.506	.61 *
.870	2.9	4.2	1.4	50.73	.221	1.473	.60 *
.871	2.9	4.1	1.3	50.73	.230	1.431	.59 *
.872	2.8	4.0	1.2	50.73	.236	1.379	.57 *
.873	2.9	3.9	1.1	50.73	.238	1.319	.54 *
.874	2.9	3.9	1.0	50.73	.234	1.252	.51 *
.875	2.9	3.8	.9	50.73	.223	1.179	.48 *
.876	2.9	3.7	.8	50.72	.206	1.103	.45 *
.877	2.9	3.6	.7	50.72	.182	1.025	.41 *
.878	3.0	3.5	.6	50.72	.152	.947	.38 *
.879	3.0	3.5	.5	50.72	.117	.869	.34 *
.880	3.0	3.4	.4	50.72	.079	.793	.31 *
.881	3.1	3.4	.3	50.72	.037	.719	.28 *
.882	3.1	3.3	.3	50.72	-.006	.648	.25 *
.883	3.1	3.3	.2	50.72	-.049	.581	.22 *
.884	3.1	3.3	.2	50.72	-.089	.519	.20 *
.885	3.1	3.3	.1	50.72	-.126	.465	.18 *
.886	3.1	3.2	.1	50.72	-.158	.424	.16 *
.887	3.1	3.2	.1	50.72	-.194	.401	.15 *
.888	3.1	3.2	.1	50.72	-.202	.404	.15 *
.889	3.1	3.2	.1	50.72	-.212	.435	.17 *
.890	3.1	3.2	.1	50.71	-.215	.492	.19 *
.891	3.1	3.3	.2	50.71	-.209	.554	.21 *
.892	3.1	3.3	.2	50.71	-.197	.633	.25 *
.893	3.1	3.4	.3	50.71	-.179	.721	.28 *
.894	3.0	3.4	.4	50.71	-.158	.809	.32 *
.895	3.0	3.5	.5	50.71	-.134	.893	.35 *
.896	3.0	3.6	.6	50.71	-.109	.969	.38 *
.897	3.0	3.7	.7	50.71	-.086	1.037	.41 *
.898	3.0	3.7	.7	50.71	-.066	1.096	.43 *
.899	3.0	3.8	.8	50.71	-.049	1.145	.45 *
.900	3.0	3.8	.9	50.71	-.035	1.186	.47 *
.901	3.0	3.9	.9	50.71	-.025	1.217	.48 *
.902	3.0	3.9	.9	50.71	-.017	1.239	.49 *
.903	3.0	3.9	1.0	50.70	-.011	1.252	.50 *
.904	3.0	3.9	1.0	50.70	-.006	1.258	.50 *
.905	3.0	3.9	1.0	50.70	-.000	1.255	.50 *

TIME (ms)	PRESSURE (MPa)	STRESS (MPa)	THRUST (MPa)	LENGTH (mm)	Up (m/sec)	BURNING RATE (m/sec)	Ug/Cg
.906	3.0	3.9	.9	50.70	.006	1.244	.50 *
.907	2.9	3.9	.9	50.70	.014	1.226	.49 *
.908	2.9	3.8	.9	50.70	.025	1.202	.48 *
.909	2.9	3.8	.9	50.70	.038	1.171	.47 *
.910	2.9	3.7	.8	50.70	.053	1.134	.46 *
.911	2.9	3.6	.8	50.69	.070	1.092	.45 *
.912	2.9	3.6	.7	50.69	.088	1.044	.43 *
.913	2.9	3.5	.6	50.69	.108	.990	.41 *
.914	2.9	3.4	.6	50.69	.129	.930	.39 *
.915	2.8	3.3	.5	50.69	.150	.862	.36 *
.916	2.8	3.2	.4	50.69	.171	.787	.33 *
.917	2.8	3.2	.3	50.69	.191	.703	.29 *
.918	2.8	3.1	.2	50.69	.210	.609	.25 *
.919	2.9	3.0	.2	50.69	.227	.506	.21 *
.920	2.9	3.0	.1	50.69	.242	.393	.16 *
.921	2.9	2.9	.0	50.68	.255	.270	.11 *
.922	2.9	2.9	.0	50.68	.264	.135	.06 *
.923	2.9	2.9	.0	50.68	.270	.017	.01 *
.924	2.9	2.9	.0	50.68	.272	.068	.03 *
.925	3.0	3.0	.0	50.68	.270	.024	.01 *
.926	3.0	3.0	.0	50.68	.265	.037	.01 *
.927	3.1	3.1	.0	50.68	.257	.110	.04 *
.928	3.2	3.2	.0	50.68	.247	.236	.09 *
.929	3.2	3.3	.1	50.68	.235	.406	.15 *
.930	3.2	3.4	.2	50.68	.223	.575	.22 *
.931	3.1	3.4	.3	50.68	.210	.712	.27 *
.932	3.1	3.5	.4	50.68	.199	.811	.31 *
.933	3.1	3.6	.5	50.68	.190	.884	.34 *
.934	3.1	3.6	.5	50.68	.183	.940	.36 *
.935	3.1	3.7	.6	50.68	.179	.986	.38 *
.936	3.1	3.7	.6	50.68	.179	1.024	.39 *
.937	3.1	3.8	.7	50.67	.182	1.053	.40 *
.938	3.1	3.8	.7	50.67	.188	1.090	.42 *
.939	3.1	3.9	.7	50.67	.196	1.123	.43 *
.940	3.1	3.9	.8	50.67	.206	1.157	.44 *
.941	3.1	4.0	.8	50.67	.216	1.191	.45 *
.942	3.1	4.0	.9	50.67	.226	1.226	.46 *
.943	3.1	4.1	.9	50.67	.235	1.259	.47 *
.944	3.1	4.1	1.0	50.66	.243	1.290	.49 *
.945	3.1	4.1	1.0	50.66	.248	1.316	.50 *
.946	3.1	4.1	1.0	50.66	.250	1.338	.51 *
.947	3.1	4.1	1.1	50.66	.250	1.351	.52 *
.948	3.1	4.2	1.1	50.66	.248	1.362	.53 *
.949	3.0	4.1	1.1	50.66	.245	1.371	.53 *
.950	3.0	4.1	1.1	50.66	.241	1.376	.54 *
.951	3.0	4.1	1.2	50.65	.236	1.380	.55 *
.952	3.0	4.1	1.2	50.65	.232	1.384	.55 *
.953	2.9	4.1	1.2	50.65	.228	1.388	.56 *
.954	2.9	4.1	1.2	50.65	.225	1.393	.56 *
.955	2.9	4.1	1.2	50.65	.223	1.401	.56 *
.956	2.9	4.1	1.2	50.65	.222	1.409	.57 *
.957	2.9	4.2	1.2	50.64	.221	1.419	.57 *
.958	2.9	4.2	1.3	50.64	.220	1.429	.57 *
.959	2.9	4.2	1.3	50.64	.220	1.440	.58 *
.960	3.0	4.2	1.3	50.64	.219	1.449	.58 *
.961	3.0	4.3	1.3	50.64	.219	1.456	.57 *
.962	3.0	4.3	1.3	50.64	.219	1.462	.57 *
.963	3.0	4.3	1.3	50.63	.219	1.466	.57 *
.964	3.1	4.3	1.3	50.63	.220	1.467	.56 *
.965	3.1	4.3	1.3	50.63	.220	1.467	.56 *
.966	3.1	4.4	1.2	50.63	.221	1.466	.55 *
.967	3.1	4.4	1.2	50.63	.221	1.464	.55 *
.968	3.2	4.4	1.2	50.63	.220	1.462	.54 *
.969	3.2	4.4	1.2	50.62	.217	1.461	.54 *
.970	3.2	4.4	1.2	50.62	.213	1.461	.54 *

TIME (ms)	PRESSURE (MPa)	STRESS (MPa)	THRUST (MPa)	LENGTH (mm)	Up (m/sec)	BURNING RATE (m/sec)	Ug/Cg
.971	3.2	4.4	1.2	50.62	.206	1.463	.53 *
.972	3.2	4.4	1.2	50.62	.196	1.466	.53 *
.973	3.3	4.5	1.2	50.62	.184	1.470	.53 *
.974	3.3	4.5	1.2	50.61	.170	1.474	.53 *
.975	3.3	4.5	1.2	50.61	.155	1.476	.53 *
.976	3.3	4.5	1.2	50.61	.139	1.476	.53 *
.977	3.3	4.5	1.2	50.61	.124	1.474	.53 *
.978	3.3	4.5	1.2	50.61	.110	1.468	.53 *
.979	3.2	4.4	1.2	50.61	.097	1.461	.53 *
.980	3.2	4.4	1.2	50.61	.087	1.450	.53 *
.981	3.2	4.4	1.2	50.60	.080	1.436	.53 *
.982	3.2	4.3	1.1	50.60	.074	1.422	.52 *
.983	3.2	4.3	1.1	50.60	.071	1.407	.52 *
.984	3.2	4.3	1.1	50.60	.070	1.392	.52 *
.985	3.2	4.3	1.1	50.60	.069	1.379	.51 *
.986	3.2	4.2	1.1	50.60	.068	1.366	.51 *
.987	3.2	4.2	1.0	50.59	.067	1.355	.50 *
.988	3.2	4.2	1.0	50.59	.065	1.344	.50 *
.989	3.2	4.2	1.0	50.59	.061	1.332	.50 *
.990	3.2	4.2	1.0	50.59	.056	1.319	.49 *
.991	3.2	4.1	1.0	50.59	.049	1.304	.49 *
.992	3.2	4.1	.9	50.59	.041	1.287	.48 *
.993	3.2	4.1	.9	50.59	.033	1.269	.47 *
.994	3.2	4.1	.9	50.59	.026	1.251	.46 *
.995	3.2	4.1	.9	50.58	.019	1.235	.45 *
.996	3.2	4.1	.8	50.58	.015	1.223	.45 *
.997	3.3	4.1	.8	50.58	.014	1.219	.44 *
.998	3.3	4.1	.3	50.58	.017	1.226	.44 *
.999	3.3	4.2	.9	50.58	.024	1.247	.45 *
1.000	3.3	4.2	.9	50.58	.037	1.282	.45 *
1.001	3.4	4.3	1.0	50.58	.055	1.333	.47 *
1.002	3.4	4.4	1.0	50.58	.078	1.398	.49 *
1.003	3.4	4.6	1.1	50.57	.105	1.473	.51 *
1.004	3.4	4.7	1.3	50.57	.137	1.555	.53 *
1.005	3.4	4.3	1.4	50.57	.171	1.640	.56 *
1.006	3.4	5.0	1.5	50.57	.208	1.723	.59 *
1.007	3.4	5.1	1.7	50.57	.246	1.800	.61 *
1.008	3.4	5.2	1.8	50.56	.284	1.870	.64 *
1.009	3.4	5.4	1.9	50.56	.320	1.931	.66 *
1.010	3.4	5.5	2.0	50.56	.355	1.982	.67 *
1.011	3.4	5.5	2.1	50.56	.387	2.024	.68 *
1.012	3.5	5.6	2.2	50.56	.417	2.057	.69 *
1.013	3.5	5.7	2.2	50.55	.443	2.082	.70 *
1.014	3.5	5.7	2.2	50.55	.464	2.098	.70 *
1.015	3.5	5.7	2.2	50.55	.480	2.104	.69 *
1.016	3.5	5.7	2.2	50.55	.485	2.095	.69 *
1.017	3.5	5.7	2.1	50.54	.477	2.061	.68 *
1.018	3.5	5.5	2.0	50.54	.447	1.991	.67 *
1.019	3.4	5.2	1.8	50.54	.389	1.870	.65 *
1.020	3.2	4.3	1.6	50.54	.295	1.680	.62 *
1.021	2.9	4.1	1.2	50.53	.159	1.407	.57 *
1.022	2.5	3.3	.8	50.53	-.019	1.040	.48 *
1.023	2.0	2.3	.3	50.53	-.232	.571	.33 *
1.024	1.3	1.3	.0	50.53	-.457	.010	.01 *
1.025	.1	.3	.2	50.53	-.659	.130	.09 *
1.026	.0	.0	.0	50.53	-.783	.010	.21 *
1.027	.0	.0	.0	50.53	-.757	.009	.21 *
1.028	3.9	4.0	.0	50.53	-.490	.121	.04 ?
1.029	3.2	3.7	.5	50.53	.119	.911	.34 *
1.030	3.7	3.4	4.7	50.53	1.172	3.242	.99 *
1.032	22.7	25.7	3.0	50.52	4.992	6.037	.31 ?
1.033	31.4	38.9	7.5	50.51	7.905	11.239	.41 *
1.034	44.2	55.2	11.0	50.49	11.509	16.112	.41 *
1.035	57.9	74.3	16.9	50.47	15.798	22.775	.44 *
1.036	75.3	97.2	21.9	50.43	20.711	29.451	.43 *

TIME (ms)	PRESSURE (MPa)	STRESS (MPa)	THRUST (MPa)	LENGTH (mm)	Up (m/sec)	BURNING RATE (m/sec)	Ug/Cg
1.037	94.7	122.3	27.6	50.38	26.170	36.789	.41 +
1.038	116.9	149.4	32.5	50.31	32.057	44.322	.39 +
1.039	140.8	178.1	37.3	50.24	38.260	51.317	.37 +
1.040	166.1	207.3	41.8	50.15	44.659	58.421	.34 +
1.041	191.8	238.1	46.3	50.05	51.147	65.506	.32 +
1.042	217.3	268.5	51.2	49.93	57.632	72.687	.31 +
1.043	241.7	298.7	57.0	49.80	64.055	80.157	.30 +
1.044	264.1	328.5	64.4	49.65	70.358	88.505	.29 +
1.045	283.7	357.7	74.0	49.50	76.537	97.740	.29 +
1.046	300.0	386.3	86.3	49.32	82.552	108.046	.30 +
1.047	312.3	414.3	102.0	49.13	88.416	119.432	.32 +
1.048	328.4	441.6	121.1	48.92	94.114	131.531	.34 +
1.049	324.3	468.0	143.7	48.70	99.629	144.244	.37 +
1.050	329.7	493.4	163.8	48.45	105.074	155.346	.39 +
1.051	329.8	517.9	188.1	48.19	110.235	166.805	.42 +
1.052	328.3	541.1	212.7	47.92	115.131	177.434	.45 +
1.053	325.3	562.8	237.5	47.62	119.873	187.178	.48 +
1.054	321.6	582.8	261.3	47.32	124.291	195.859	.50 +
1.055	317.4	600.3	293.4	47.00	128.332	203.356	.53 +
1.056	312.9	616.7	303.8	46.66	131.996	209.806	.55 +
1.057	308.7	630.6	321.9	46.32	135.228	215.222	.57 +
1.058	304.6	642.6	338.0	45.97	137.962	219.766	.59 +
1.059	301.0	653.1	352.0	45.61	140.124	223.579	.61 +
1.060	297.8	662.4	364.7	45.25	141.602	226.905	.63 +
1.061	295.3	671.2	375.9	44.88	142.311	229.916	.64 +
1.062	293.4	680.0	386.6	44.51	142.168	232.849	.66 +
1.063	292.5	689.5	397.0	44.14	140.424	234.673	.67 +
1.064	292.2	699.6	407.4	43.76	138.285	237.824	.68 +
1.065	297.8	711.2	423.4	43.38	135.155	241.465	.70 +
1.066	288.4	724.4	436.1	43.01	131.072	245.460	.72 +
1.067	289.9	739.5	449.6	42.63	126.102	249.941	.73 +
1.068	292.4	756.3	463.9	42.25	120.333	254.892	.74 +
1.069	295.5	774.3	478.8	41.88	113.972	260.160	.75 +
1.070	299.2	793.2	494.0	41.51	107.187	265.641	.76 +
1.071	306.4	812.6	506.2	41.13	100.144	271.257	.76 +
1.072	310.7	832.3	521.6	40.76	93.000	276.890	.77 +
1.073	315.4	852.0	536.6	40.39	85.887	282.499	.78 +
1.074	320.1	871.7	551.5	40.02	78.894	288.064	.78 +
1.075	325.1	891.3	566.2	39.66	72.086	293.563	.79 +
1.076	330.2	910.8	580.5	39.29	65.506	299.001	.79 +
1.077	335.3	930.2	594.9	38.93	59.168	304.381	.80 +
1.078	340.1	949.4	609.3	38.56	53.090	309.682	.80 +
1.079	345.7	968.4	622.7	38.20	47.295	314.891	.80 +
1.080	350.6	986.9	636.2	37.84	41.807	319.905	.81 +
1.081	354.7	1004.3	649.6	37.48	36.636	324.622	.81 +
1.082	358.9	1020.4	661.5	37.11	31.820	328.938	.81 +
1.083	362.6	1034.6	672.0	36.75	27.386	332.732	.82 +
1.084	366.4	1046.2	679.3	36.39	23.404	335.949	.82 +
1.085	371.4	1055.0	683.6	36.03	19.870	338.252	.81 +
1.086	374.0	1060.9	686.9	35.68	16.771	339.814	.81 +
1.087	376.1	1063.5	687.4	35.32	14.097	340.528	.81 +
1.088	377.7	1062.8	685.0	34.97	11.798	340.370	.81 +
1.089	379.5	1058.9	680.4	34.61	9.861	339.372	.80 +
1.090	379.8	1052.1	673.3	34.26	8.246	337.589	.80 +
1.091	378.5	1042.6	664.1	33.92	6.907	335.082	.80 +
1.092	375.4	1030.7	655.4	33.58	5.806	331.915	.80 +
1.093	376.8	1016.9	640.1	33.24	4.894	328.224	.79 +
1.094	375.0	1001.6	626.6	32.91	4.097	324.096	.78 +
1.095	374.2	985.3	611.1	32.58	3.364	319.654	.78 +
1.096	373.7	968.4	594.7	32.25	2.643	315.003	.77 +
1.097	369.6	951.3	581.7	31.94	1.889	310.302	.77 +
1.098	367.5	934.4	566.9	31.62	1.070	305.590	.76 +
1.099	365.4	918.0	552.6	31.32	.151	300.967	.76 +
1.100	363.3	902.2	538.8	31.02	-.386	296.479	.75 +
1.101	361.2	887.1	525.9	30.72	-2.145	293.535	.75 +
1.102	359.4	872.7	513.3	30.43	-3.381	288.882	.74 +

TIME (ms)	PRESSURE (MPa)	STRESS (MPa)	THRUST (MPa)	LENGTH (mm)	Up (m/sec)	BURNING RATE (m/sec)	Ug/Cg
1.103	359.3	358.3	499.6	30.14	-4.664	283.382	.74 *
1.104	357.4	345.3	487.9	29.86	-6.305	279.545	.73 *
1.105	355.4	332.0	476.5	29.59	-7.331	275.151	.73 *
1.106	353.3	318.7	465.4	29.32	-8.582	270.744	.73 *
1.107	350.7	305.3	454.7	29.06	-9.897	268.133	.72 *
1.108	347.3	291.6	443.9	28.80	-10.301	264.853	.72 *
1.109	344.4	277.6	433.3	28.55	-11.587	259.683	.72 *
1.110	341.0	263.4	422.4	28.30	-12.222	255.593	.71 *
1.111	337.3	248.9	411.6	28.06	-12.489	251.235	.71 *
1.112	333.0	234.3	401.4	27.82	-12.480	246.854	.71 *
1.113	328.3	219.8	391.5	27.58	-12.202	242.474	.71 *
1.114	323.3	205.4	382.1	27.35	-11.674	238.151	.71 *
1.115	318.1	191.0	373.2	27.13	-10.938	233.906	.71 *
1.116	312.8	177.5	364.7	26.91	-10.027	229.754	.71 *
1.117	307.9	164.1	356.8	26.69	-8.991	225.721	.71 *
1.118	301.4	151.0	349.6	26.47	-7.876	221.794	.71 *
1.119	293.0	138.2	343.2	26.25	-6.726	218.109	.72 *
1.120	289.3	125.4	336.1	26.04	-5.584	214.104	.72 *
1.121	282.6	112.6	330.1	25.83	-4.493	210.285	.72 *
1.122	275.8	99.7	323.9	25.63	-3.474	206.406	.73 *
1.123	268.8	86.7	317.8	25.43	-2.552	202.467	.74 *
1.124	261.6	73.5	311.8	25.23	-1.744	198.465	.74 *
1.125	254.8	60.1	305.3	25.03	-1.055	194.380	.75 *
1.126	251.0	54.8	295.8	24.84	-.498	190.098	.75 *
1.127	244.9	533.7	288.8	24.65	-.076	186.003	.75 *
1.128	239.6	521.0	281.4	24.46	.202	181.976	.75 *
1.129	234.5	508.9	274.4	24.28	.346	178.109	.75 *
1.130	229.7	497.5	267.8	24.10	.363	174.465	.76 *
1.131	225.8	486.9	261.1	23.93	.267	171.034	.75 *
1.132	222.2	477.2	255.0	23.75	.084	167.884	.76 *
1.133	219.6	468.4	248.8	23.59	-.156	164.959	.75 *
1.134	222.8	460.3	237.6	23.42	-.419	161.837	.73 *
1.135	218.7	452.9	234.2	23.26	-.667	159.489	.73 *
1.136	219.9	445.9	226.0	23.10	-.863	156.842	.72 *
1.137	217.7	439.2	221.4	22.94	-.982	154.565	.72 *
1.138	218.3	432.5	214.2	22.79	-1.001	152.033	.70 *
1.139	217.3	425.8	208.5	22.64	-.910	149.612	.70 *
1.140	207.0	419.0	212.0	22.49	-.707	148.105	.73 *
1.141	221.6	411.9	190.3	22.34	-.406	143.682	.66 *
1.142	220.1	404.7	184.6	22.20	-.026	141.032	.65 *
1.143	219.9	397.3	177.4	22.06	.405	138.087	.64 *
1.144	220.0	389.9	170.0	21.92	.361	135.031	.62 *
1.145	220.2	382.6	162.4	21.79	1.312	131.903	.61 *
1.146	220.1	375.3	155.2	21.65	1.735	128.909	.60 *
1.147	221.0	368.3	147.3	21.52	2.108	125.544	.58 *
1.148	221.3	361.5	140.2	21.39	2.419	122.443	.57 *
1.149	221.2	355.0	133.9	21.27	2.662	119.507	.55 *
1.150	216.9	348.9	132.0	21.15	2.840	117.711	.56 *
1.151	196.2	343.1	146.9	21.03	2.955	119.523	.63 *
1.152	206.6	337.6	130.9	20.90	3.019	114.949	.57 *
1.153	196.2	332.3	136.1	20.79	3.038	114.871	.60 *
1.154	213.4	327.3	114.0	20.67	3.028	108.382	.52 *
1.155	191.2	322.6	131.3	20.56	2.997	111.562	.60 *
1.156	211.0	317.9	107.0	20.44	2.958	104.400	.51 *
1.157	192.5	313.4	120.9	20.33	2.921	107.163	.58 *
1.158	208.0	309.1	101.0	20.22	2.894	100.794	.50 *
1.159	200.6	304.8	104.1	20.12	2.883	100.858	.52 *
1.160	199.6	300.5	100.9	20.02	2.892	99.047	.52 *
1.161	202.3	296.4	93.6	19.92	2.921	95.878	.49 *
1.162	201.0	292.3	91.3	19.82	2.967	94.317	.49 *
1.163	199.4	288.3	88.9	19.72	3.030	92.722	.48 *
1.164	197.9	284.4	86.5	19.62	3.101	91.135	.48 *
1.165	196.3	280.5	84.2	19.53	3.177	89.601	.48 *
1.166	194.7	276.7	82.0	19.44	3.251	88.075	.47 *
1.167	192.9	272.9	80.0	19.35	3.319	86.622	.47 *

TIME (ms)	PRESSURE (MPa)	STRESS (MPa)	THRUST (MPa)	LENGTH (mm)	Up (m/sec)	BURNING RATE (m/sec)	Ug/Cg
1.168	191.2	269.2	78.0	19.26	3.377	85.173	.47 *
1.169	189.8	265.5	75.7	19.17	3.422	83.626	.46 *
1.170	188.3	261.9	73.6	19.08	3.456	82.173	.46 *
1.171	186.9	258.4	71.5	18.99	3.481	80.713	.45 *
1.172	185.8	255.0	69.2	18.91	3.497	79.164	.45 *
1.173	183.2	251.7	68.5	18.83	3.509	78.267	.45 *
1.174	182.8	248.6	65.8	18.75	3.519	76.604	.44 *
1.175	181.0	245.6	64.6	18.67	3.530	75.549	.44 *
1.176	180.3	242.7	62.4	18.59	3.543	74.128	.43 *
1.177	179.5	239.9	60.4	18.51	3.559	72.763	.43 *
1.178	173.1	237.2	59.1	18.43	3.578	71.709	.43 *
1.179	177.1	234.6	57.4	18.36	3.599	70.309	.42 *
1.180	176.1	231.9	55.9	18.28	3.622	69.335	.42 *
1.181	174.3	229.3	55.0	18.21	3.645	68.476	.42 *
1.182	173.4	226.7	53.3	18.14	3.671	67.225	.41 *
1.183	172.5	224.1	51.6	18.07	3.701	66.000	.41 *
1.184	171.8	221.6	49.8	18.00	3.737	64.719	.40 *
1.185	170.3	219.3	48.9	17.93	3.786	63.894	.40 *
1.186	169.4	217.1	47.7	17.86	3.849	62.885	.40 *
1.187	168.6	215.1	46.5	17.79	3.932	61.965	.39 *
1.188	168.3	213.3	45.0	17.73	4.034	60.908	.39 *
1.189	167.4	211.7	44.3	17.66	4.153	60.284	.38 *
1.190	166.6	210.3	43.7	17.60	4.285	59.722	.38 *
1.191	165.8	208.9	43.0	17.54	4.418	59.144	.38 *
1.192	165.5	207.4	41.9	17.47	4.541	58.291	.38 *
1.193	164.8	205.9	41.1	17.41	4.639	57.607	.37 *
1.194	164.3	204.2	39.9	17.35	4.697	56.690	.37 *
1.195	163.3	202.3	39.0	17.29	4.702	55.889	.37 *
1.196	150.9	200.3	49.4	17.22	4.647	60.398	.43 *
1.197	148.7	198.1	49.4	17.16	4.530	60.544	.44 *
1.198	147.9	195.9	48.0	17.09	4.358	59.509	.43 *
1.199	145.9	193.8	47.9	17.03	4.142	59.091	.44 *
1.201	144.8	189.9	45.1	16.90	3.656	57.131	.43 *
1.202	143.1	188.3	45.2	16.84	3.431	56.849	.43 *
1.203	137.8	186.8	49.0	16.79	3.244	58.312	.46 *
1.204	136.5	185.4	48.9	16.72	3.109	57.995	.46 *
1.205	135.2	184.0	48.9	16.66	3.032	57.726	.46 *
1.206	134.1	182.6	48.4	16.60	3.008	57.268	.46 *
1.207	133.1	180.9	47.8	16.54	3.022	56.700	.46 *
1.208	132.0	179.0	47.0	16.48	3.051	56.026	.46 *
1.209	130.7	176.8	46.1	16.42	3.069	55.228	.46 *
1.210	129.2	174.3	45.1	16.36	3.048	54.307	.46 *
1.211	127.5	171.5	44.0	16.30	2.965	53.314	.46 *
1.212	125.7	168.4	42.8	16.25	2.804	52.196	.45 *
1.213	123.7	165.2	41.5	16.19	2.564	51.063	.45 *
1.214	121.7	162.0	40.3	16.14	2.257	49.907	.45 *
1.215	119.7	158.9	39.2	16.09	1.907	48.331	.45 *
1.216	118.0	155.9	37.9	16.04	1.551	47.736	.45 *
1.217	116.1	153.3	37.2	15.99	1.233	46.913	.45 *
1.218	114.7	151.0	36.3	15.94	1.000	46.102	.44 *
1.219	113.3	149.2	35.9	15.89	.893	45.555	.45 *
1.220	112.2	147.7	35.5	15.85	.941	45.100	.45 *
1.221	111.2	146.5	35.2	15.80	1.163	44.773	.45 *
1.222	110.5	145.6	35.2	15.75	1.556	44.571	.45 *
1.223	109.8	144.9	35.1	15.71	2.098	44.422	.45 *
1.224	109.1	144.4	35.3	15.66	2.753	44.419	.45 *
1.225	108.5	143.9	35.4	15.61	3.469	44.369	.45 *
1.226	108.0	143.4	35.5	15.57	4.188	44.317	.45 *
1.227	107.5	143.0	35.5	15.52	4.850	44.229	.45 *
1.228	107.1	142.5	35.5	15.47	5.404	44.149	.45 *
1.229	106.6	142.1	35.5	15.42	5.807	44.065	.45 *
1.230	106.3	141.7	35.5	15.37	5.033	44.010	.46 *
1.231	106.1	141.5	35.4	15.32	5.073	43.918	.46 *
1.232	106.0	141.4	35.3	15.27	5.950	43.874	.46 *
1.233	105.8	141.4	35.5	15.22	5.668	43.733	.46 *

TIME (ms)	PRESSURE (MPa)	STRESS (MPa)	THRUST (MPa)	LENGTH (mm)	Up (m/sec)	BURNING RATE (m/sec)	Ug/Cg
1.234	105.9	141.5	35.6	15.17	5.293	43.795	.46 *
1.235	105.9	141.6	35.6	15.12	4.858	43.924	.46 *
1.236	105.9	141.9	35.9	15.07	4.408	44.039	.46 *
1.237	106.2	142.0	35.9	15.02	3.986	44.030	.46 *
1.238	106.1	142.1	36.0	14.98	3.625	44.105	.46 *
1.239	106.4	142.0	35.7	14.93	3.348	43.953	.46 *
1.243	105.5	140.0	34.5	14.74	3.105	43.047	.45 *
1.244	104.9	139.1	34.3	14.69	3.192	42.782	.45 *
1.245	104.2	138.2	33.9	14.65	3.296	42.468	.45 *
1.246	103.6	137.2	33.6	14.60	3.394	42.117	.45 *
1.247	102.8	136.2	33.3	14.55	3.471	41.812	.45 *
1.248	102.1	135.2	33.0	14.51	3.514	41.498	.45 *
1.249	101.4	134.2	32.7	14.46	3.516	41.173	.45 *
1.250	101.0	133.2	32.1	14.42	3.473	40.718	.45 *
1.251	100.5	132.2	31.7	14.38	3.402	40.334	.45 *
1.252	100.0	131.3	31.3	14.33	3.297	39.974	.45 *
1.253	99.4	130.3	30.9	14.29	3.174	39.593	.44 *
1.254	98.7	129.4	30.6	14.25	3.043	39.310	.45 *
1.255	99.0	128.4	30.4	14.20	2.918	39.027	.45 *
1.256	97.3	127.5	30.2	14.16	2.809	38.761	.45 *
1.257	96.8	126.5	29.7	14.12	2.724	38.342	.44 *
1.258	96.1	125.6	29.5	14.08	2.670	38.083	.44 *
1.259	95.3	124.6	29.3	14.04	2.649	37.831	.44 *
1.260	94.6	123.7	29.1	14.00	2.661	37.574	.45 *
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1.264	93.4	120.3	27.0	13.84	2.931	35.945	.43 *
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1.287	100.5	104.3	3.8	13.18	2.868	13.838	.15 *
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1.296	101.2	104.2	2.9	13.05	3.525	12.187	.13 *
1.297	101.8	105.1	3.3	13.03	3.802	13.008	.14 *
1.298	102.4	106.2	3.8	13.02	4.123	13.973	.15 *
1.299	103.2	107.6	4.4	13.00	4.474	15.103	.16 *
1.300	104.0	109.1	5.1	12.98	4.838	16.304	.17 *
1.301	104.9	110.8	5.9	12.96	5.190	17.559	.18 *

TIME (ms)	PRESSURE (MPa)	STRESS (MPa)	THRUST (MPa)	LENGTH (mm)	Up (m/sec)	BURNING RATE (m/sec)	Ug/Cg
1.302	105.9	112.6	6.7	12.94	5.511	18.918	.20 *
1.303	106.8	114.5	7.7	12.91	5.776	20.317	.21 *
1.304	107.7	116.4	8.3	12.89	5.966	21.779	.22 *
1.305	108.4	118.3	9.9	12.86	6.067	23.222	.24 *
1.306	109.1	120.1	11.1	12.83	6.071	24.622	.25 *
1.307	110.1	121.3	11.8	12.80	5.977	25.494	.26 *
1.308	110.5	123.4	12.9	12.77	5.793	26.779	.27 *
1.309	110.5	124.7	14.2	12.73	5.532	28.384	.28 *
1.310	111.0	125.9	14.3	12.70	5.213	29.799	.29 *
1.311	110.8	126.8	15.9	12.67	4.861	29.846	.30 *
1.312	110.3	127.5	17.2	12.63	4.501	30.923	.31 *
1.313	110.3	127.9	17.6	12.60	4.157	31.339	.31 *
1.314	109.9	128.1	18.3	12.56	3.851	31.855	.32 *
1.315	109.3	128.2	18.9	12.52	3.599	32.329	.33 *
1.316	108.3	128.1	19.7	12.49	3.411	32.932	.34 *
1.317	107.6	127.3	20.2	12.45	3.291	33.221	.34 *
1.318	101.6	127.4	25.9	12.42	3.235	36.734	.40 *
1.319	100.3	127.0	26.7	12.38	3.234	37.115	.41 *
1.320	99.2	126.5	27.3	12.34	3.276	37.349	.42 *
1.321	98.6	125.9	27.4	12.29	3.345	37.301	.42 *
1.322	97.8	125.4	27.6	12.25	3.425	37.342	.42 *
1.323	97.2	124.9	27.6	12.21	3.502	37.248	.43 *
1.324	96.7	124.3	27.6	12.17	3.563	37.165	.43 *
1.325	95.9	123.9	28.0	12.13	3.602	37.247	.43 *
1.326	95.5	123.4	27.9	12.09	3.615	37.148	.43 *
1.327	95.1	123.0	27.9	12.05	3.603	37.056	.43 *
1.328	94.7	122.6	27.9	12.01	3.571	36.963	.43 *
1.329	94.4	122.2	27.8	11.97	3.526	36.861	.43 *
1.330	94.1	121.8	27.7	11.93	3.475	36.742	.43 *
1.331	93.8	121.5	27.6	11.89	3.426	36.657	.44 *
1.332	93.7	121.1	27.5	11.85	3.387	36.499	.43 *
1.333	93.9	120.8	26.9	11.81	3.362	36.128	.43 *
1.334	93.7	120.4	26.7	11.77	3.352	36.003	.43 *
1.335	93.7	120.1	26.4	11.73	3.357	35.754	.43 *
1.336	93.8	119.7	26.0	11.69	3.375	35.463	.42 *
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1.360	93.4	108.4	15.0	10.85	2.921	26.736	.32 *
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1.362	92.3	107.3	14.5	10.80	2.900	26.157	.32 *
1.363	92.5	106.7	14.2	10.77	2.890	25.982	.32 *
1.364	92.2	106.2	14.0	10.74	2.880	25.640	.31 *
1.365	91.8	105.7	13.3	10.71	2.871	25.432	.31 *
1.366	91.3	105.1	13.3	10.68	2.864	25.367	.31 *

TIME (ms)	PRESSURE (MPa)	STRESS (MPa)	THRUST (MPa)	LENGTH (mm)	Up (m/sec)	BURNING RATE (m/sec)	Ug/Cg
1.367	90.8	104.6	13.8	10.65	2.860	25.270	.31 *
1.369	89.7	104.1	14.4	10.62	2.858	25.698	.32 *
1.372	88.2	102.4	14.2	10.51	2.882	25.295	.32 *
1.373	87.1	102.0	15.0	10.48	2.896	25.835	.34 *
1.374	85.9	101.7	15.8	10.45	2.913	26.355	.35 *
1.375	85.0	101.4	16.4	10.42	2.931	26.757	.36 *
1.376	85.3	101.1	15.8	10.39	2.951	26.306	.35 *
1.377	84.3	100.9	16.6	10.37	2.970	26.810	.36 *
1.378	83.2	100.7	17.5	10.34	2.987	27.359	.37 *
1.379	82.1	100.5	18.4	10.31	3.000	27.880	.38 *
1.380	81.1	100.3	19.2	10.27	3.002	28.351	.40 *
1.381	79.8	100.0	20.2	10.24	2.990	28.909	.41 *
1.382	78.4	99.7	21.3	10.21	2.957	29.464	.43 *
1.383	76.8	99.3	22.4	10.18	2.896	29.965	.44 *
1.384	75.4	98.7	23.4	10.15	2.799	30.332	.46 *
1.385	73.8	98.0	24.2	10.11	2.661	30.599	.47 *
1.386	72.1	97.1	25.0	10.08	2.481	30.748	.48 *
1.387	70.4	95.9	25.6	10.05	2.262	30.773	.50 *
1.388	68.5	94.6	26.1	10.01	2.015	30.692	.51 *
1.389	66.8	93.1	26.3	9.98	1.762	30.468	.52 *
1.390	65.1	91.5	26.4	9.95	1.534	30.170	.53 *
1.391	63.4	89.9	26.5	9.92	1.371	29.856	.54 *
1.392	62.0	88.6	26.5	9.89	1.323	29.578	.54 *
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