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EXPLOSIVE HAZARDS TESTS FOR ESTABLISHING HAZARDS CLASSIFICATIONS FOR M1 PROPELLANT FOR AUTOMATED SINGLE-BASE FINISHING OPERATIONS - PART II

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LARGE CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

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18. SUPPLEMENTARY NOTES

This project was accomplished as part of the US Army's Manufacturing Methods and Technology Program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques, and equipment for use in production of Army materiel.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Vented vessel
Vent ratio
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Subscale vented vessels of two sizes were tested at various levels of vent ratio to determine the effects of vent area and scale (vessel size) on pressurization rates for cannon propellants. Two cannon propellants, M26 and M30, were used in the experimental work.

Test results were used to predict the performance of a full-scale vessel - Continuous Automated Multi-Base Line (CAMBL) dryer. Analyses of the results

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20. ABSTRACT (cont)

show that the CAMBL dryer containing 680 kg of M26 or M30 propellant would produce a burning-only reaction if these propellants were ignited. The CAMBL dryer should, therefore, be classed a 1.3 burning only hazard.

The results of the test were subjected to math modeling efforts. The modeling efforts demonstrated that the variables--vent ratio, scale, and pressure exponent--can be used to predict vented vessel performance.

General recommendations for performing similar studies, at some future date, were made.

TABLE OF CONTENTS

TABLES

FIGURES

INTRODUCTION

In Phase I of this project, the adequacy of vessel pressure relief venting to preclude an in-process explosion hazard Class 1.1, for 204 kg of M1 propellant in the air dry module discharge hoppers in the Continuous Automated Single-Base Line (CASBL) (ref 1), was demonstrated. Based on the success of studies, a proposal was submitted to determine the hazards classification of M26 and M30 cannon propellants in the automated multi-base dryer (Figure 1) in the Continuous Automated Multi-Base Line (CAMBL) through the use of subscale vented vessel tests. Presently this operation would be assessed as a Class 1.1 mass detonating hazard because the nitroglycerin content of M26 and M30 is greater than 20 percent (ref 2). It is estimated that approximately one million dollars in facility construction costs would be saved if the dryer system could be demonstrated to present a Class 1.3, burning-only, hazard. Since full-scale tests were prohibitive from an exposure and cost standpoint, it was discussed and jointly proposed by ARRADCOM and Radford Army Ammunition Plant personnel that subscale tests be conducted to determine the hazards classification of M26 and M30 in the CAMBL dryer. Under Phase I studies, initial investigations demonstrated that subscale vessels could be used to determine the effects of vessel size and vent area on rate of pressurization from burning M26 or M30 cannon propellants; and such data could be used as a method of predicting full-scale dryer performance (ref 3). Since these tests were conducted in thin-wall vessels (1/8 inch and 1/4 inch), low values of maximum pressure and rate of pressurization were obtained. To obtain higher values for these parameters and to verify Phase I results, Phase II[2] was conducted to obtain pressurization data in heavy-wall (1/2 inch) subscale vessels having the same basic design characteristics as the vessels used for Phase I studies.

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[1]Private communication from SARRA-MT-S, 28 October 1975.
[2]Private communication from SARRA-EN, 10 February 1978.

EXPERIMENTAL

The experimental program for Phase II, discussed in the subsequent pages of this report, was based on results obtained in Phase I (ref 3) of the project. Phase I results indicated that one-fourth scale model vessels were highly variable in strength and did not give reproducible results. The one-third and one-half scale vessels tended to fail at low pressures, but results indicated that rate of pressure rise had achieved a constant slope before vessel rupture. As a consequence, the one-fourth scale vessels were excluded from additional testing, and one-third and one-half scale vessels were redesigned to provide higher rupture pressures. The redesigned vessels incorporated 1/2-inch carbon steel plates with angle iron reinforcement along the welded seams. The vessels were also designed to permit variation of the vent ratio by bolting predrilled steel plates to the underside of the top of the vessel. Typical dimensions and construction details are shown in Figure 2.

As in Phase I, propellants tested were restricted to M26 double-base and M30 triple-base cannon propellants. The propellant charge for the one-third scale vessel was 25.2 kg, and for the one-half scale vessel 85 kg, corresponding to full-scale dryer propellant weight of 680 kg. Propellant properties are listed in Appendix A. Ignition was accomplished by a 2-gram bag igniter submerged in the center of the propellant bed.

Pressure-time records were taken from pressure transducers centrally located in one side and one end of each vessel. The records were reduced to maximum pressure and maximum rate of pressure rise. The instrumentation setup is shown in Figure 3.

The pressure-time records were reduced according to procedures in Appendix B. Pressure-time traces representative of typical test results are also shown in Appendix B, Figures c, d, and e.

The actual tests were conducted to obtain a maximum number of tests from a limited number of test vessels. This was done by adjusting vent ratio for a given test based on results obtained in preceding tests.

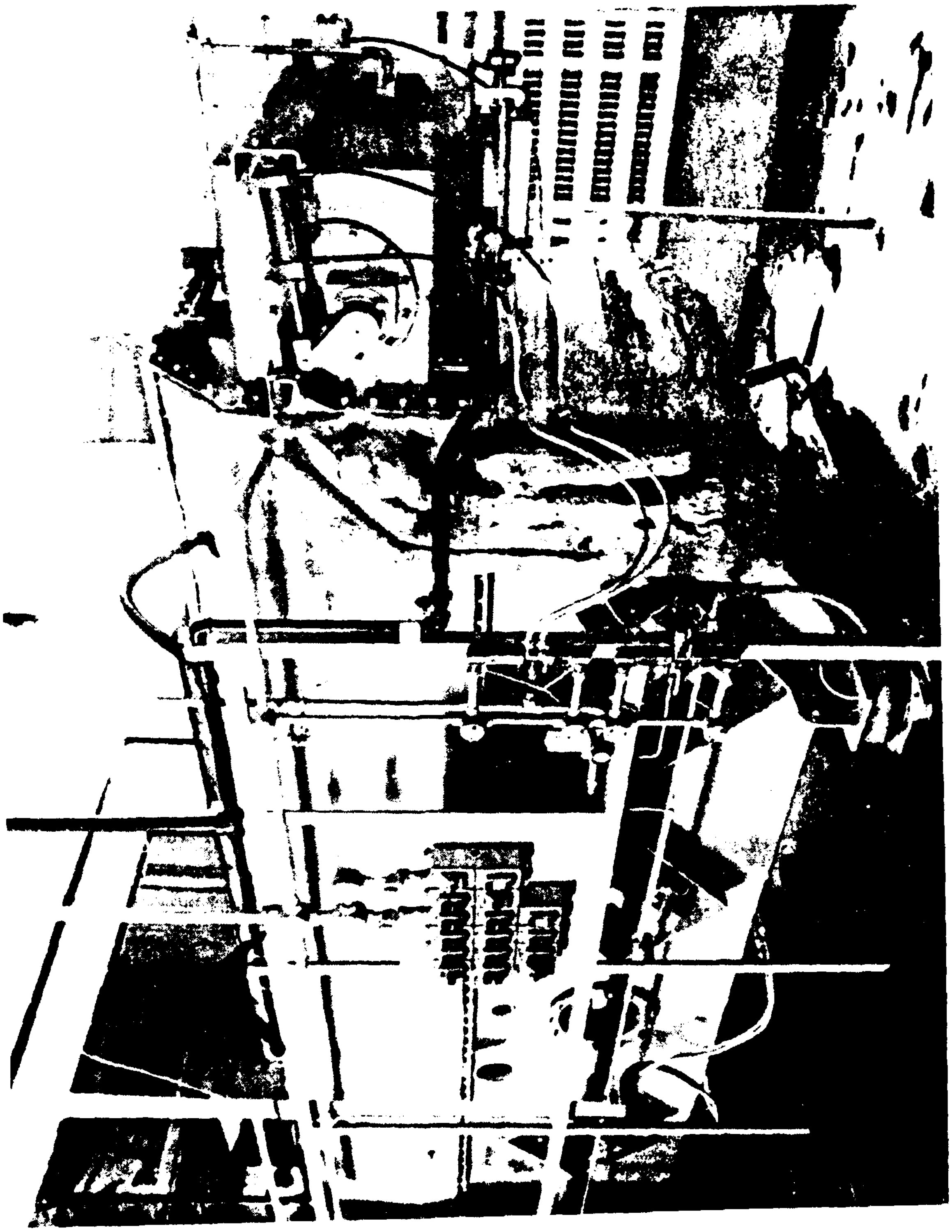
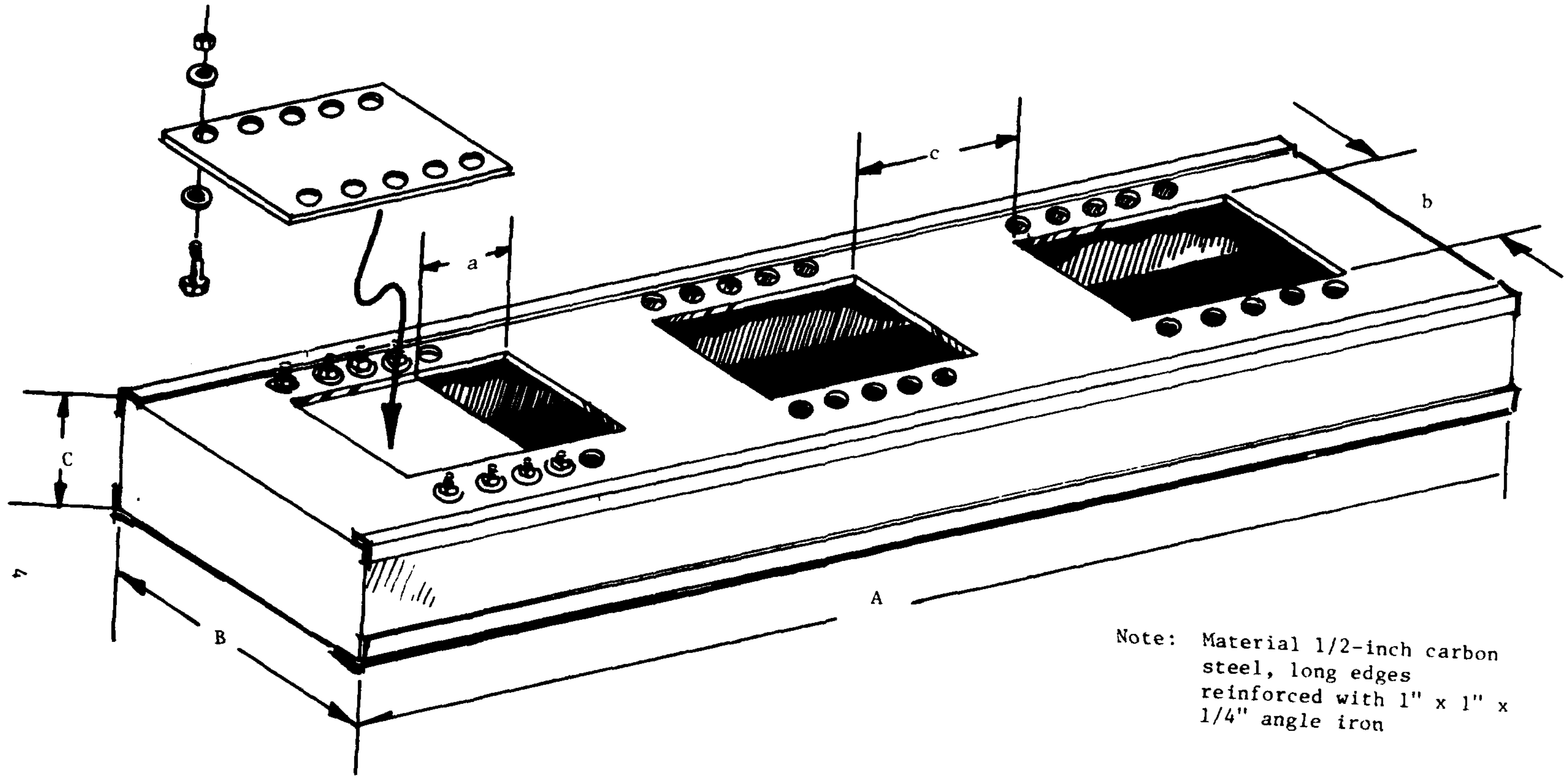


Figure 1. Full-Scale Propellant Dryer



Note: Material 1/2-inch carbon steel, long edges reinforced with 1" x 1" x 1/4" angle iron

Scale	Dimensions, inches A	B	C	Vent Ratio	Vent Dimensions, inches a	b	c
1/3	80	13	8	500	4.8	5	26.8
				650	3.7	5	28.4
				800	3.0	5	29.5
				1100	2.2	5	30.8
				1500	1.6	5	31.5
1/2	120	19.5	12	500	16.4	5	29.5
				650	12.5	5	35.3
				800	10.2	5	38.5
				1100	7.4	5	42.8
				1500	5.5	5	45.8

Figure 2. Heavy-wall test vehicle with typical vent dimensions

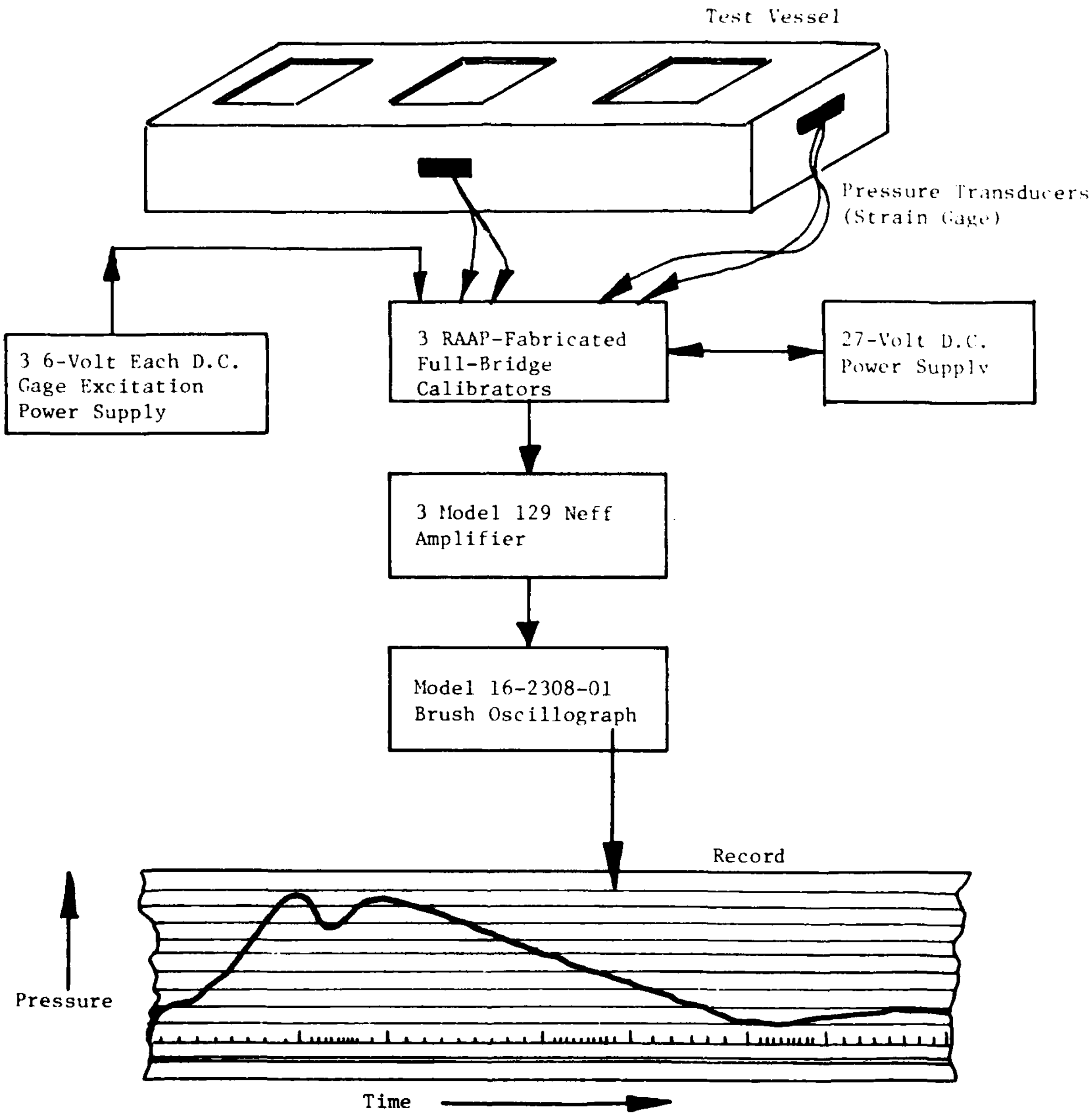


Figure 3. Data acquisition system arrangement

DISCUSSION OF TEST RESULTS

Maximum pressure and maximum rate of pressure rise test results for M26 are shown in Table 1. The scaled parameters for the M26 tests are shown in Table 2. The total reaction times for these tests ranged from 120 to more than 2,000 msec. Of the 17 vessels tested, four failed because of overpressurization.

The pressurization results for M30 are shown in Table 3, and the scale parameters for M30 in Table 4. Fifteen tests were conducted with M30,with only two failing because of overpressurization. The total reaction times for the M30 tests ranged from 48 to more than 1,500 msec.

The reaction times for both M26 and M30 tests are very long compared to the reaction times for vessels **transitioning to detonation** (order of microseconds). This is an indication that all tests produced burning-only reactions.

The failure rate (six out of 32 tests) for the heavy-wall vessels was much lower than the rate (nine out of 12) for thin-wall vessels tested under Phase I. This further indicates that the burning of propellants in properly vented vessels leads to overpressurization rather than detonation for these large granulated cannon propellants.

Analysis of M26 Results

The results of M26 tests are plotted in Figures 4, 5, and 6. Figure 4 shows rate of pressure rise as a function of vent ratio for the one-third and one-half scale vessels. The data demonstrate a rapid increase in pressure rise as vent ratio increases for both scaled vessels. The data also show an increase in pressure rise as vessel size decreases, regardless of vent ratio.

Figure 5 shows the effect of vessel size on pressurization at the levels of vent ratio tested. These curves show that for any vent ratio the rate of pressure rise increases as vessel size (scale) decreases and support the conclusions drawn from the data in Figure 4. The large increase in rate of pressure rise between the R = 650 and R = 725 lines indicate that the reaction is accelerating non-linearly between these values and is approaching a critical value where venting is not practical.

Figure 6 shows scaled rate of pressure rise as a function of scaled area. This type of plot considers both vessel volume and vent area as one variable, scaled area defined as vent area divided by the two-thirds power of vessel volume. The curves show how pressurization would vary if vent area was actually scaled according to vessel size rather than propellant area.

Table 1

Parameters and Results of Scaled Vented Vessel Tests for M26 Cannon Propellant

Test No.	Scale, λ	Vent Ratio, R	Vessel Volume, m^3	Vent Area, m^2	Propellant Surface Area, m^2	Maximum Pressure, kPa	Maximum Rate of Pressure Rise, MPa/sec	Remarks
1	1/3	500	0.1360	0.047	23.40	524	4.1	No deformation of vessel
2	"	500	"	0.047	"	689	4.7	"
3	"	500	"	0.047	"	717	5.2	"
4	"	650	"	0.036	"	1516	5.7	"
5	"	650	"	0.036	"	1516	5.6	"
6	"	650	"	0.036	"	1447	5.8	"
7	"	725	"	0.032	"	6635	25.0	Vessel failed
8	"	800	"	0.029	"	7125	43.3	"
9	"	1100	"	0.021	"	6874	47.3	"
10	1/2	267	0.4602	0.296	79.1	475	0.52	No deformation of vessel
11	"	500	"	0.158	"	806	3.6	"
12	"	500	"	0.158	"	758	3.0	"
13	"	500	"	0.158	"	854	4.0	"
14	"	650	"	0.122	"	1185	4.7	"
15	"	650	"	0.122	"	1329	4.7	"
16	"	650	"	0.122	"	951	5.5	"
17	"	725	"	0.109	"	3861	21.2	Vessel failed

Table 2

Scaled Parameters and Results from Scaled Vented Vessel Tests of M26 Cannon Propellant

Test No.	Scale, λ	Mass Propellant, kg	Energy, MJ	$\bar{E}$	$\bar{A}$	$\bar{S}$	$\bar{P}$	$\bar{\dot{P}}$
1	1/3	25.2	100.8	7.32	0.178	0.01052	5.172	0.0615
2	"	"	"	"	0.178	"	6.802	0.0645
3	"	"	"	"	0.178	"	7.078	0.0780
4	"	"	"	"	0.136	"	14.965	0.0855
5	"	"	"	"	0.136	"	14.965	0.0840
6	"	"	"	"	0.136	"	14.284	0.0870
7	"	"	"	"	0.121	"	65.499	0.375
8	"	"	"	"	0.109	"	70.335	0.650
9	"	"	"	"	0.079	"	67.858	0.708
10	1/2	85	340	7.29	0.497	0.0536	4.689	0.012
11	"	"	"	"	0.265	"	7.957	0.0806
12	"	"	"	"	0.265	"	7.483	0.0672
13	"	"	"	"	0.265	"	8.430	0.0896
14	"	"	"	"	0.205	"	11.698	0.1053
15	"	"	"	"	0.205	"	13.119	0.1053
16	"	"	"	"	0.205	"	9.388	0.1232
17	"	"	"	"	0.183	"	38.115	0.4749

$\bar{A} = A/V^{2/3}$

$\bar{E} = E/PoV$

$\bar{P} = P/Po$

$\bar{S} = SPoV^{1/3}/a_o^2$

$\bar{\dot{P}} = \dot{P}V^{1/3}/a_oPo$

Po = 101.3 kPa

a_o = 340.3 m/s

Po = atmospheric pressure

ao = velocity of sound in air at STP

Table 3

Parameters and Results of Scaled Vented Vessel Tests of M30 Cannon Propellant

Test No.	Scale, λ	Vent Ratio, R	Vessel Volume, m^3	Vent Area, m^2	Propellant Surface Area, m^2	Maximum Pressure, kPa	Maximum Rate of Pressure Rise, MPa/sec	Remarks
1	1/3	312	0.1360	0.0194	14.36	87	0.186	No deformation of vessel
2	"	312	"	0.0194	"	76	0.159	"
3	"	312	"	0.0194	"	110	0.221	"
4	"	400	"	0.0151	"	138	0.869	"
5	"	400	"	0.0151	"	186	1.089	"
6	"	400	"	0.0151	"	138	0.979	"
7	"	500	"	0.0121	"	4137	85.32	Vessel failed
8	1/2	312	0.4602	0.1553	48.45	<35	<0.07	No deformation of vessel
9	"	312	"	0.1553	"	<35	<0.07	"
10	"	312	"	0.1553	"	<35	<0.07	"
11	"	400	"	0.1211	"	90	0.35	"
12	"	400	"	0.1211	"	67	0.29	"
13	"	400	"	0.1211	"	117	0.42	"
14	"	500	"	0.0969	"	2544	21.4	Vessel deformed
15	"	500	"	0.0969	"	3379	42.2	Vessel failed

Table 4

Scaled Parameters and Results from Scaled Vented Vessel Tests of M30 Cannon Propellant

Test No.	Scale, λ	Mass Propellant, kg	Energy, MJ	$\overline{E}$	$\overline{A}$	$\overline{S}$	$\overline{P}$	$\overline{\dot{P}}$
1	1/3	25.2	100.8	7.32	0.073	0.0065	0.859	0.0030
2	"	"	"	"	0.073	"	0.750	0.0024
3	"	"	"	"	0.073	"	1.089	0.0033
4	"	"	"	"	0.057	"	1.362	0.0130
5	"	"	"	"	0.057	"	1.836	0.0162
6	"	"	"	"	0.057	"	1.362	0.0146
7	"	"	"	"	0.046	"	40.839	1.28
8	1/2	85.0	340	7.29	0.261	0.0327	0.346	0.001
9	"	"	"	"	0.261	"	0.346	0.001
10	"	"	"	"	0.261	"	0.346	0.001
11	"	"	"	"	0.203	"	0.888	0.005
12	"	"	"	"	0.203	"	0.681	0.0043
13	"	"	"	"	0.203	"	1.155	0.0062
14	"	"	"	"	0.163	"	25.11	0.320
15	"	"	"	"	0.163	"	33.36	0.631

$\overline{A} = A/V^{2/3}$

$\overline{E} = E/PoV$

$\overline{P} = P/Po$

$\overline{S} = SPoV^{1/3}/a_o^2$

$Po = 101.3$ kPa

$a_o = 340.3$ m/s

Po = atmospheric pressure

a_o = velocity of sound in air at STP

$\overline{\dot{P}} = \dot{P}V^{1/3}/a_oPo$

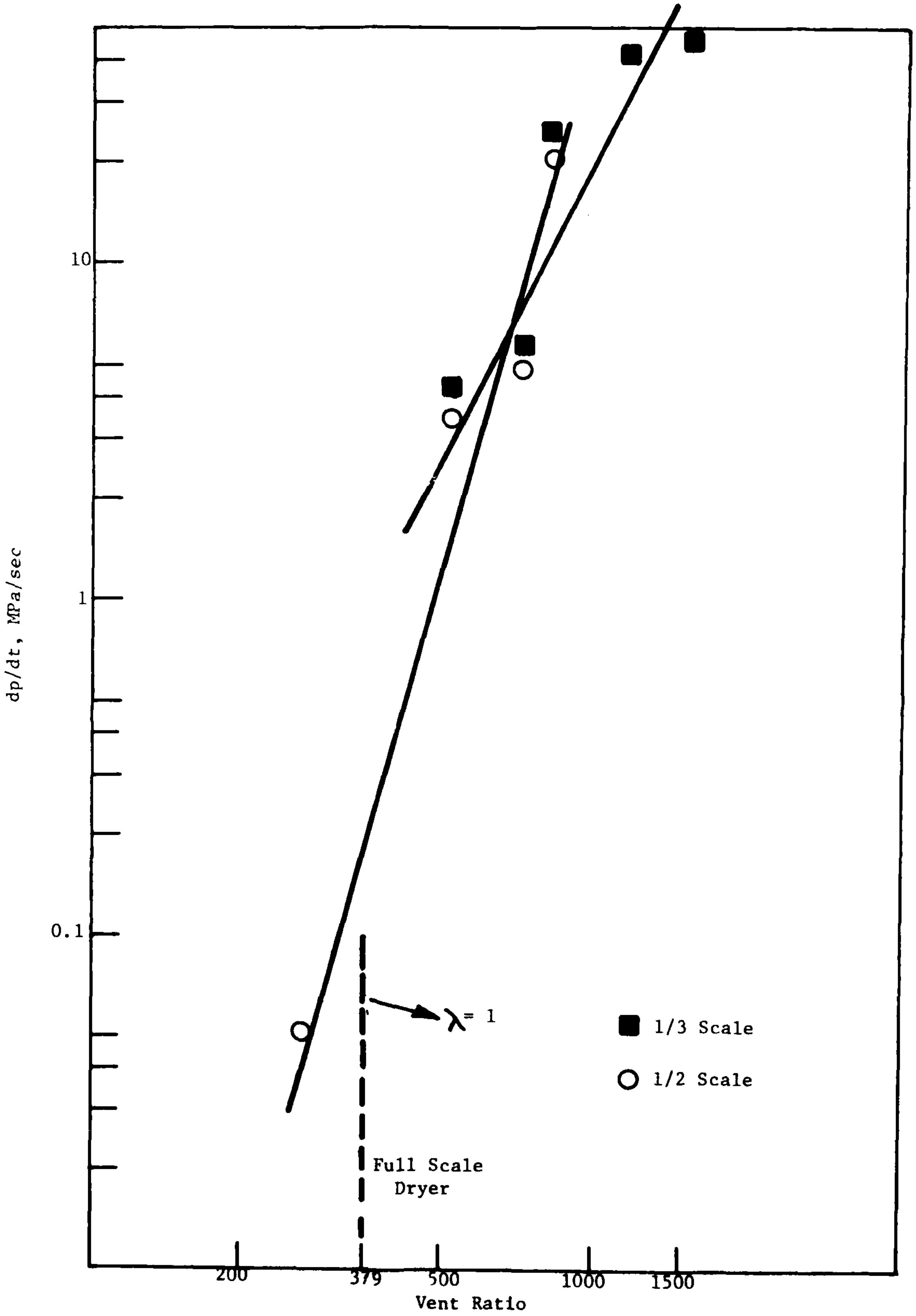


Figure 4. Rate of pressure rise versus vent ratio for M26 cannon propellant

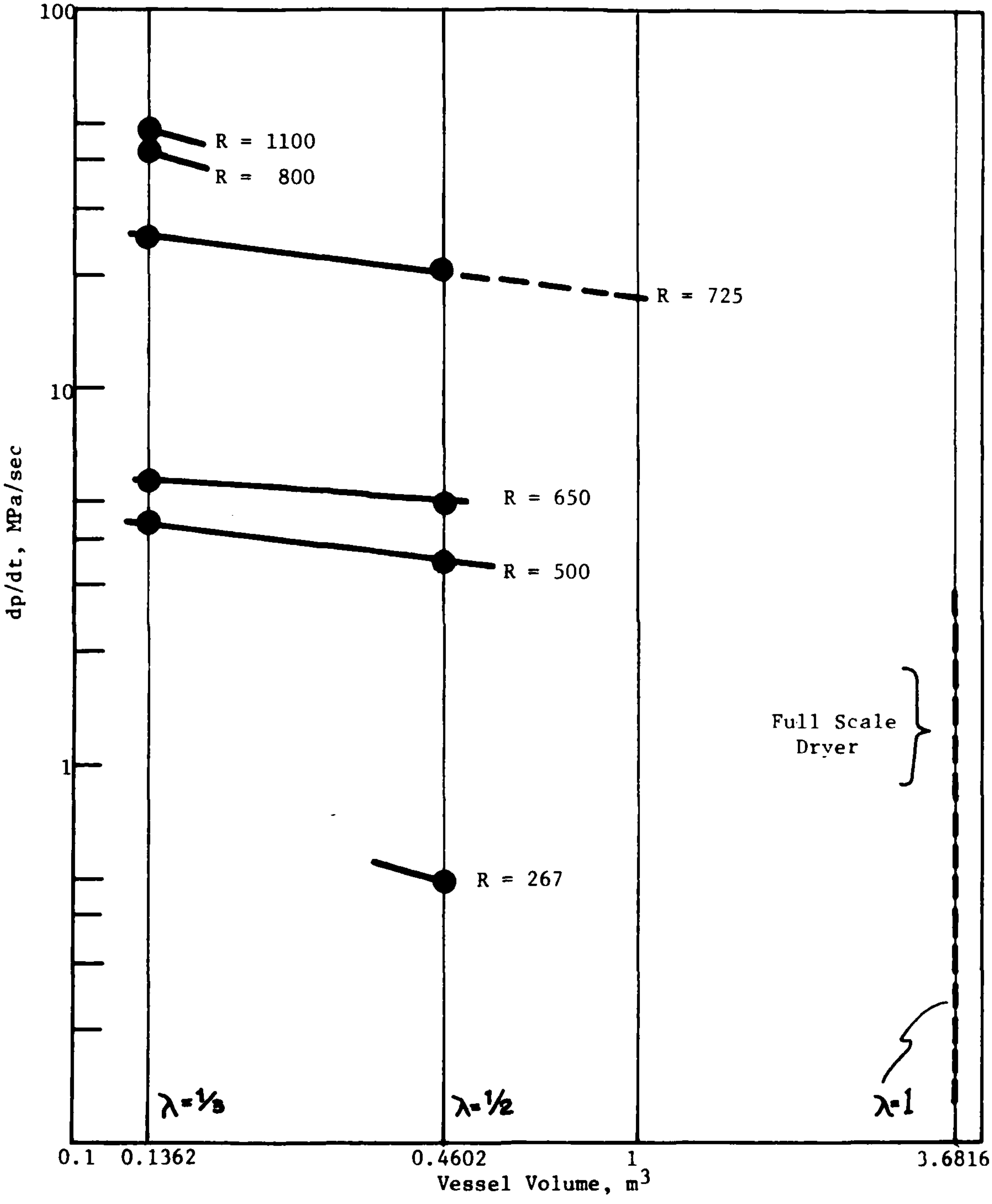


Figure 5. Rate of pressure rise versus vessel scale for M26 cannon propellant

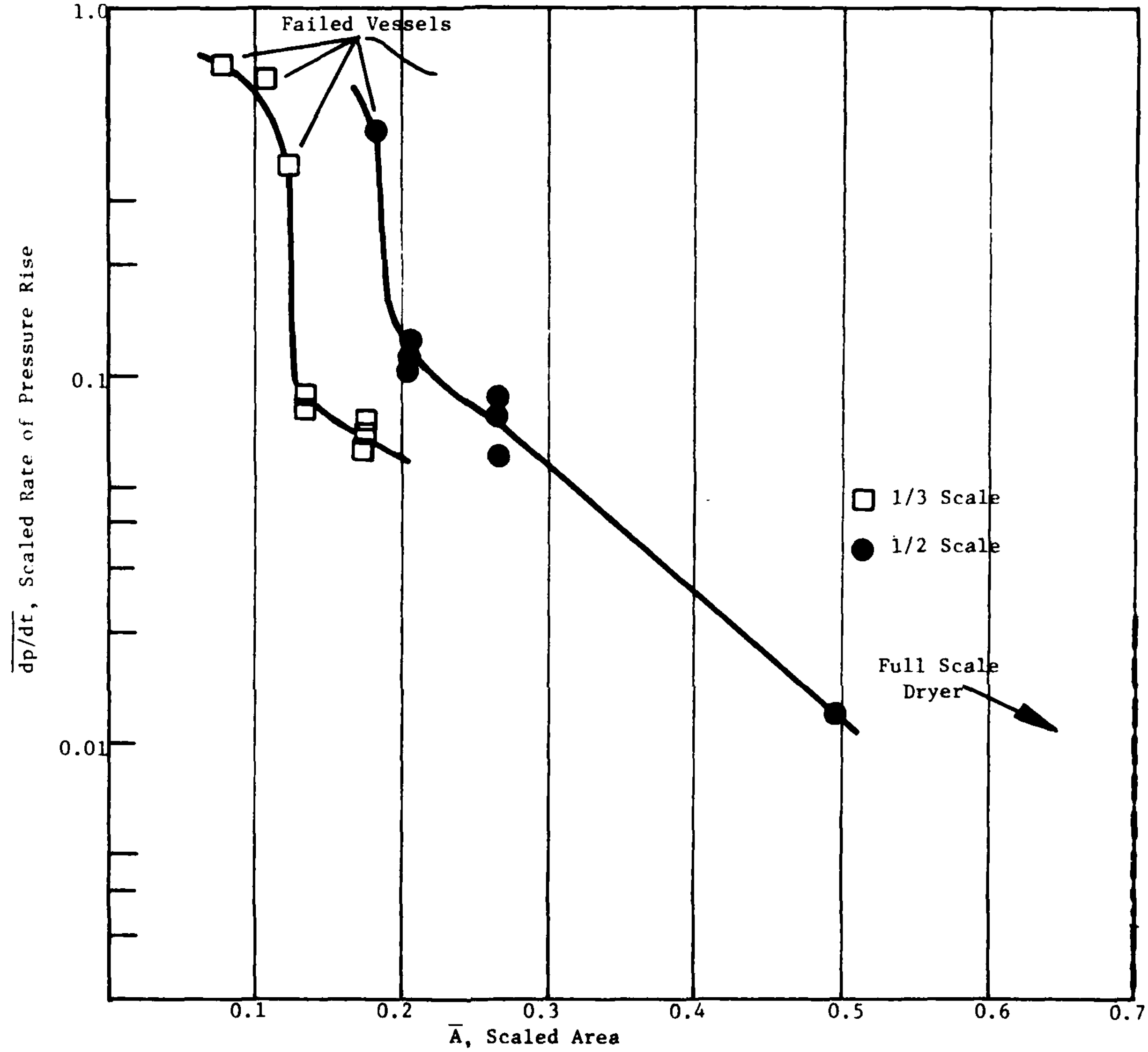


Figure 6. Scaled rate of pressure rise versus scaled vent area for M26 cannon propellant

The appropriate independent variable for the full-scale dryer containing M26 propellant is indicated on each of these curves. The rate of pressure rise, based on vent ratio (Figure 4), indicates a maximum in the full-scale dryer of 0.1 MPa/sec. The rate of pressure rise versus scale data (Figure 5) show a range, by extrapolation of lines of constant vent ratio, of 0.3 to 2.0 MPa/sec for the full-scale dryer. Using the scaled parameter data (Figure 6), a scaled rate of rise of .002 to .003 is predicted for the full-scale dryer. This corresponds to a rate of rise of 1.0-1.5 MPa/sec. All three treatments of the subscale data show that the full-scale dryer, containing 680 kg of M26 propellant, would produce very low rates of pressure rise if the M26 was bottom initiated, the worst case for pressurization. As a consequence, only burning reaction would occur. The dryer containing M26 should then be treated as a Class 1.3 hazard.

Analysis of M30 Results

The results of M30 tests are shown in Figures 7, 8, and 9. The M30 data follow the same trend as M26 data in each of the three graphical methods of analysis. Comparison of M26 and M30 data shows that the spread in rate of pressure rise between the one-third and one-half scale vessels is greater for M30. The rate of pressure rise, for a given scale, between vent ratios is also greater for M30 compared to M26. These differences for low pressures are likely a result of the larger burning rate coefficient (a) for M30 (Appendix A). If this be the case, then at high pressures M26 would exhibit a similar effect as a result of the much larger pressure exponent (n).

Using the same method for predicting the full-scale dryer results for M30 as for M26, a maximum rate of pressure rise based on vent ratio is 0.01 MPa/sec; based on extrapolation of lines of constant vent ratio between scales, the maximum rate of pressure rise would be about 0.01 MPa/sec; and using the scaled parameter curve the maximum rate of pressure rise would be less than 0.05 MPa/sec. These values indicate a very low reaction rate for M30, if bottom initiated, in the full-scale dryer. As a consequence, the dryer/M30 system should be given a Class 1.3 burning only hazard.

Math Modeling

Efforts were made to determine the type of function best describing the rate of pressure rise as a function of individual variables, and as a function of all independent variables through stepwise regression techniques.

The function best describing rate of pressure rise ($\dot{P}$) as a function of vent ratio (R) was found to be

$$\dot{P} = aR^b$$

This function describes the data plotted in Figures 4 and 7, and is the same type of function used to describe reaction in solid propellant rocket motors as throat area varies.

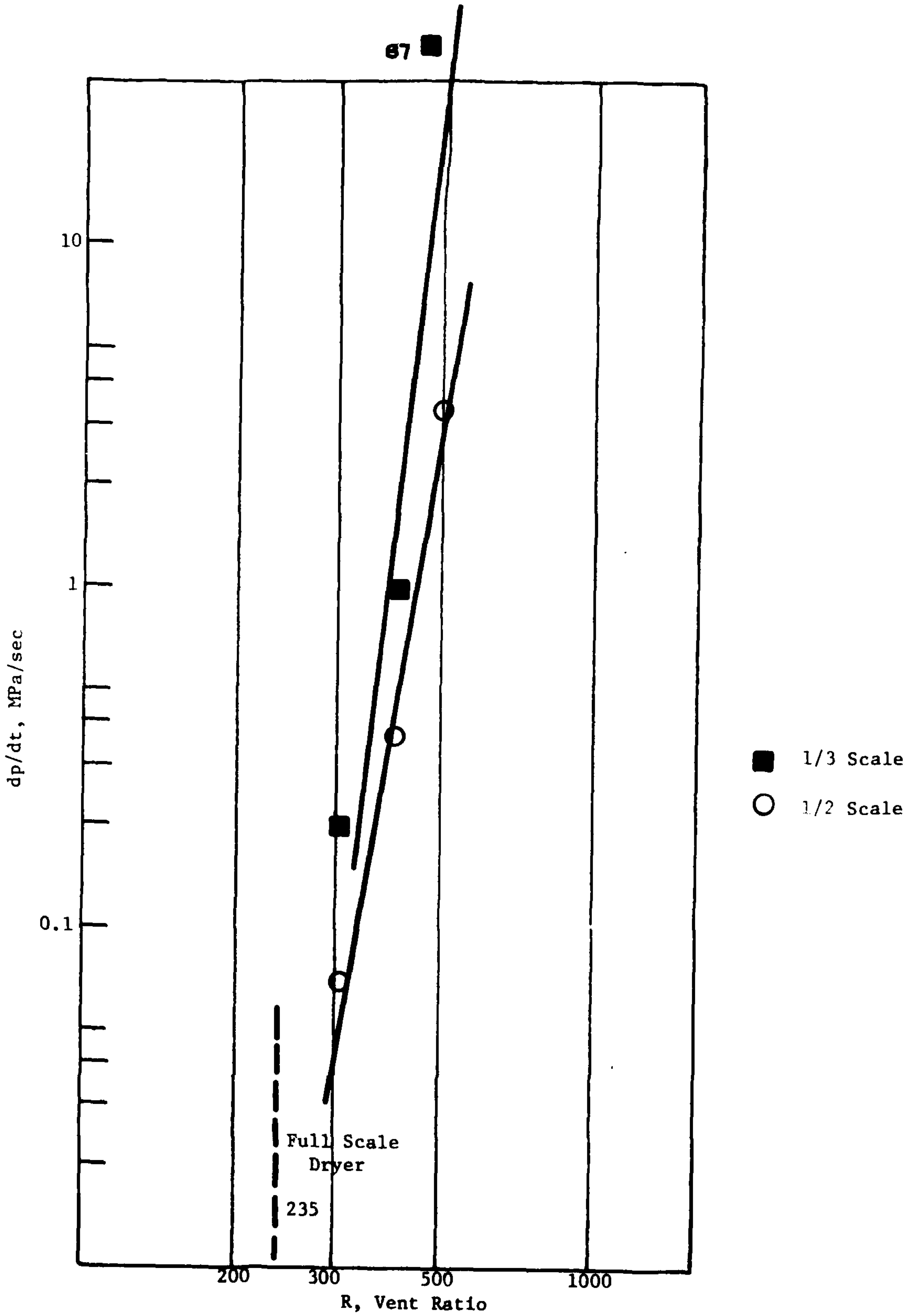


Figure 7. Rate of pressure rise versus vent ratio for M30 cannon propellant

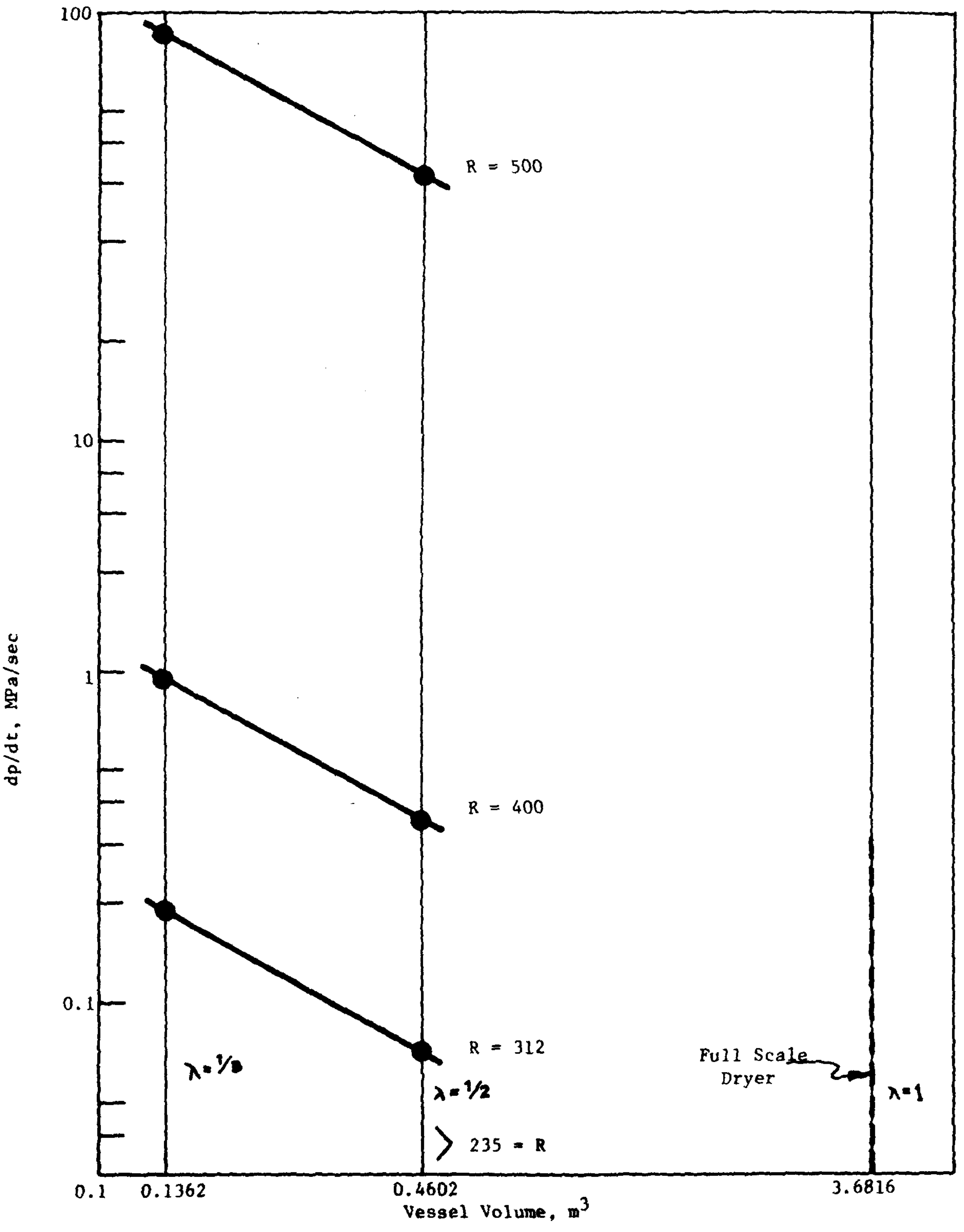


Figure 8. Rate of pressure rise versus vessel scale for M30 cannon propellant

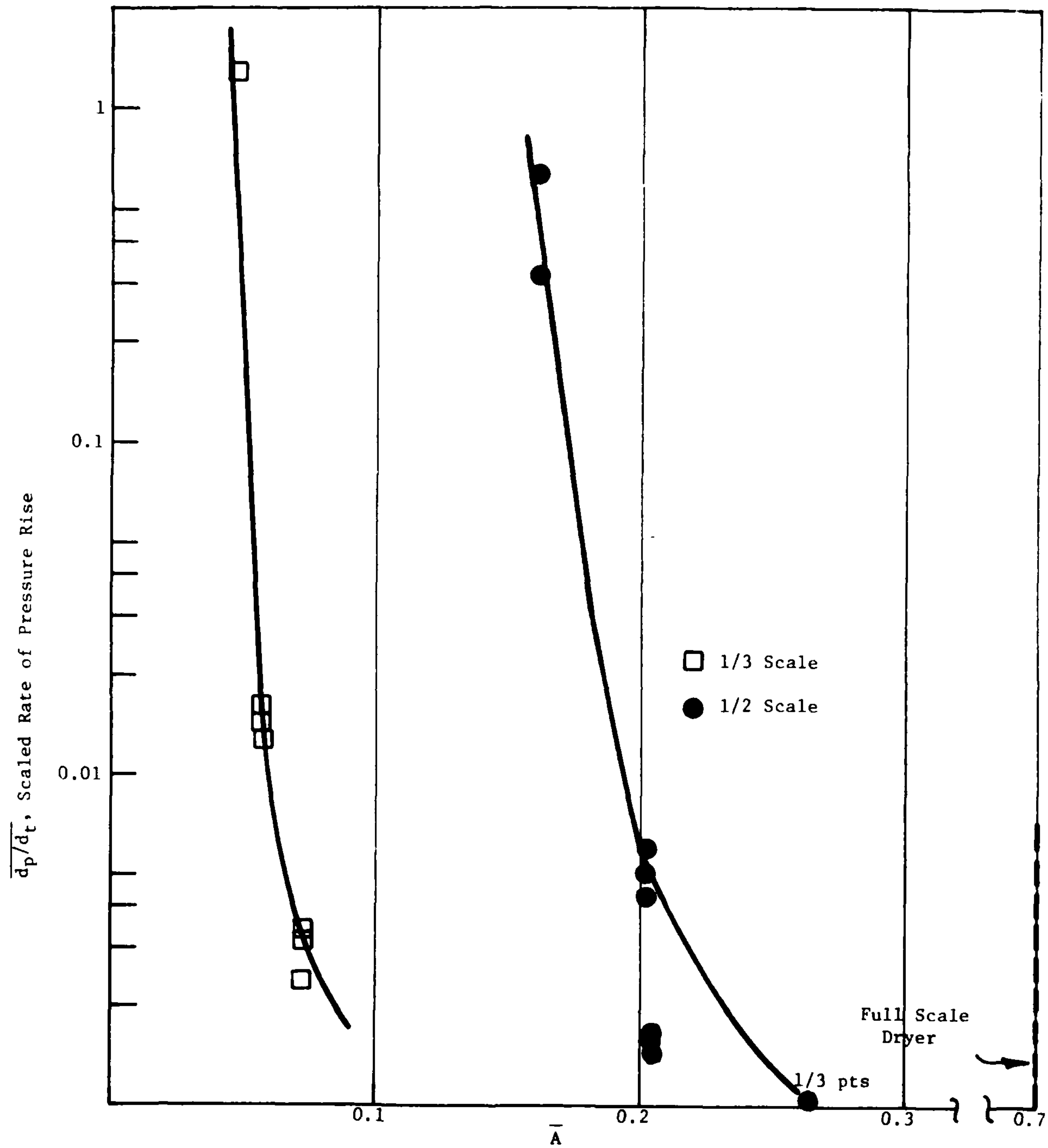


Figure 9. Scaled rate of pressure rise versus scaled vent area for M30 cannon propellants

For rate of pressure rise as a function of scale (λ) at a constant vent ratio, only two points were available. However, the consistency of the results across the various ratios indicates a function of the form

$$\dot{P} = c\lambda^{-d}, \text{ where c and d are constants,}$$

indicating that $\dot{P}$ decreases as λ increases.

For the variables treated together, a stepwise regression technique was used. The stepwise regression model considers the effect of each independent variable and any combination of independent variables on the dependent variable. A brief explanation of this technique is given in Appendix C. Using the stepwise regression technique for both M26 and M30 test results, the pressure exponent tended to explain more than 80 percent of the difference in performance between M26 and M30. This is desirable since any model must show the effects of n when several formulations are tested.

For the case of a single propellant, the important parameters from the regression were R^2 and $R\lambda$, indicating a power dependence on R and on interaction between λ and R. This is further verified by the fact that the lines in Figures 5 and 8 are not parallel (ref 3). The model best describing the data for a given propellant is then of the form

$$\dot{P} = P(R^2, R\lambda)$$

In another form the basic model would be

$$\dot{P} = aR^2 + bR\lambda + cn, \text{ where a, b, c are constants.}$$

This model explained approximately 80 percent of the variability in Phase II studies.

To determine a, b, and c, it will be necessary to refine vented vessel testing, particularly in the areas of pressure measurements. In addition, values of pressure parameters should be obtained over a much wider range of vessel sizes, which will require the construction of vessels able to withstand 20,000-30,000 MPa pressure.

CONCLUSIONS

1. Pressure rise rates increase in magnitude as vent ratio increases regardless of vessel size.

2. Pressure rise rate decreases as vessel size increases if vent ratio remains constant.

3. Vent ratio squared, scale, and pressure exponent are the primary variables for model consideration.

4. The CAMBL dryer would produce low reaction rates if the contents, M26 or M30, were bottom initiated based upon the scaled tests and mathematical analysis that have been conducted.

5. Based on the results of the scaled down tests and mathematical analysis, the 680 kg of either M26 or M30 cannon propellants in the CAMBL dryer are expected to burn if initiated; therefore, the dryer should be assessed a burning-only Class 1.3 hazards classification.

RECOMMENDATIONS

Based on the results of this study, the following recommendations are made:

1. That the CAMBL dryer, containing 680 kg of M26 or M30 cannon propellant, be assigned a Class 1.3 burning-only hazard classification.

2. Since the scaled down tests and analysis resulted in a valid prediction for the full scale dryer, consideration should be given to further efforts toward math modeling on other configurations.

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2. AMCR 385-100.

3. J. L. Evans, R. Rindner, and W. Seals, "Explosives Hazards Tests for Establishing Hazards Classifications for M1 Propellant for Automated Single-Base Finishing Operations (PE-482, Phase I)," ARLCD-CR-78014, U.S. Army Armament Research and Development Command, Dover, NJ, January 1978.

APPENDIX A

PROPERTIES OF CANNON PROPELLANTS USED IN SUBSCALE TESTS

Property	Formulation[1/]	
	M26	M30
Dimensions:		
Perforations	7	7
L - Length, mm	11.36	16.82
OD - Outside Diameter, mm	5.182	7.722
ID - Inside Diameter, mm	0.457	0.711
W - Web, mm	0.940	1.473
S - Surface Area per Unit Weight, m^2/kg	0.92	0.57
ρ - Density, kg/m^3	1619	1661
S/V - Specific Surface, m^{-1}	9.73	6.22
H_{exp} - Heat of Explosion, J/kg[2/]	4.0	4.3
$(\overline{M}p)g$ - Average Molecular Weight of Products, g/g-mole	24.06	23.21
T_V - Isochoric Flame Temperature, °C	2803	2767
$(\overline{C}_p)g$ - Heat Capacity at Constant Pressure, J/kg.K	1.80×10^{-3}	1.80×10^{-3}
a[3/] - Pressure Coefficient	0.00083	0.0057
n[3/] - Pressure Exponent	0.87	0.65

1/ Formulation refers to ingredients and granulation refers to physical size and design of granules.

2/ Experimental

3/ From $r = ap^n$ at °C (21°)

APPENDIX B

REDUCTION OF PRESSURE-TIME RECORDS

The output from the pressure transducers is in ohms, and the resulting oscillograph record is a curve of output in ohms as a function of time. To convert ohms to gage pressure, the output of the gage is measured for four pressure levels during calibration, and a gage factor is established. These four steps are recorded on the record prior to the actual test (see Figure a. below). The height from the base line (zero pressure) to each step is measured and recorded as h_1. The pressure at any desired point is obtained by measuring the height (h_o) of the pressure point above the base line (see Figure b.) and using the formula:

$$\text{Pressure} = \frac{h_o}{h_1} \times \text{gage factor}$$

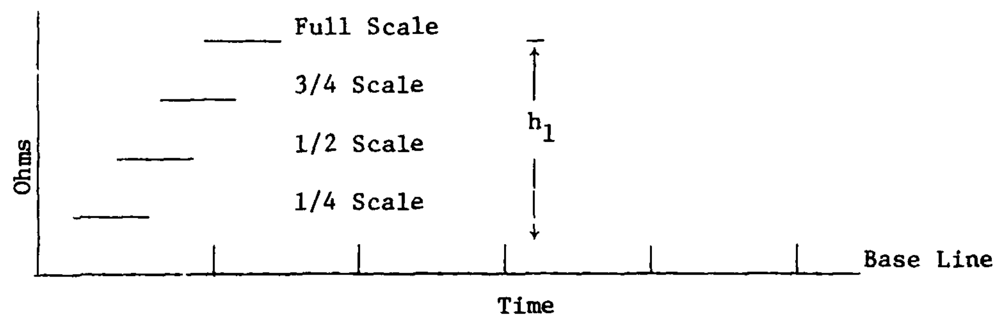

Figure a.

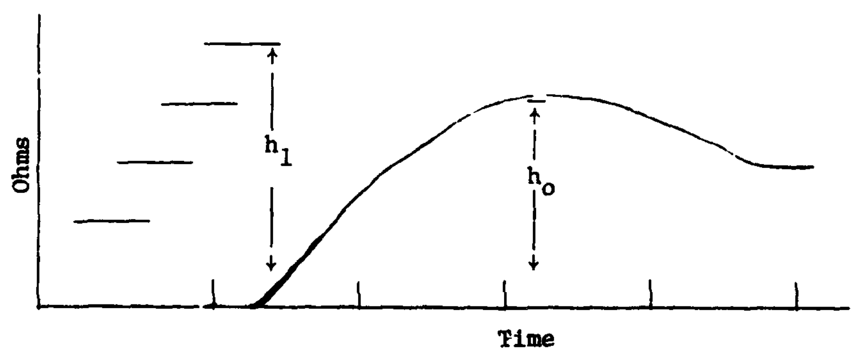

Figure b.

The time between any two points along the base line is determined by counting the timing marks between two points and multiplying by the time factor. This factor is selected prior to testing and the marks are from an internal oscillator.

To calculate rate of pressure rise, two points on the pressure-time curve are selected and the pressure measured at these points. The time between these points is measured and rate of pressure is calculated from:

$$\text{Rate of Pressure Rise} = \frac{P_2 - P_1}{t_2 - t_1}$$

Typical pressure-time records from Phase III tests are shown in Figures c, d, and e.

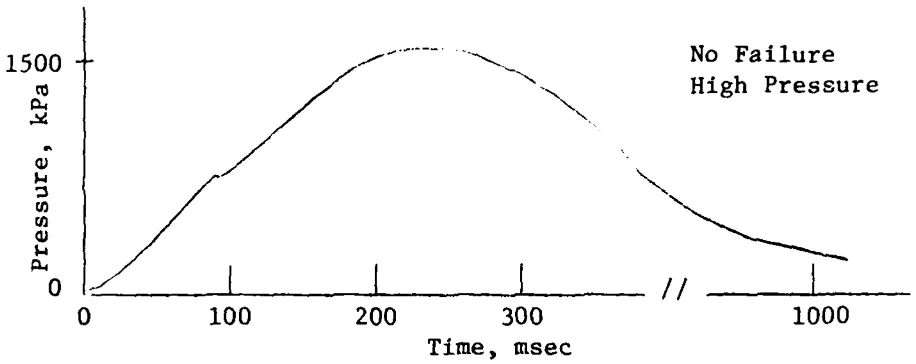

Figure c. M26 Test 6

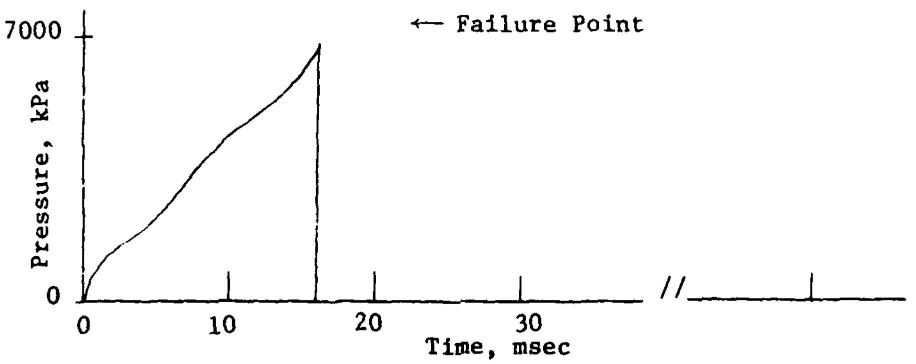

Figure d. M26 Test 8

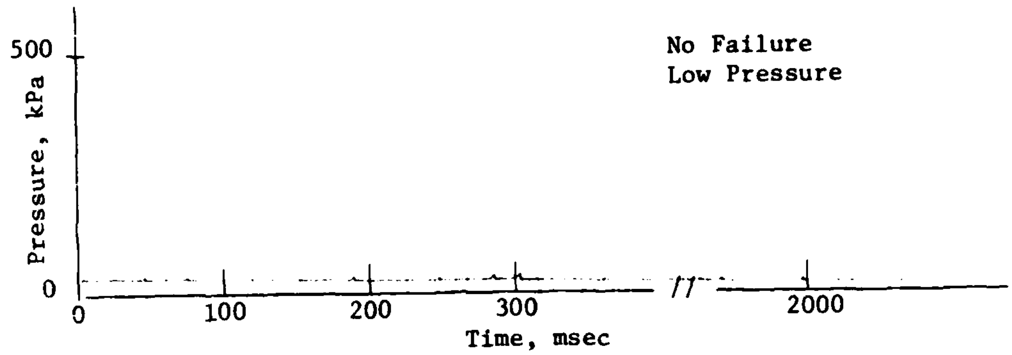

Figure e. M30 Test 8

APPENDIX C

BRIEF EXPLANATION OF STEPWISE REGRESSION TECHNIQUE

The stepwise regression technique used for analyses of pressurization was described by the model written.

$$Y = a_o + (a_1X_1 + b_1X_2 + ... + K_1X_n)$$
$$+ (b_2X_1^2 + b_2X_2^2 + ... + K_2X_n^2)$$
$$+ (b_3X_1^3 + b_3X_2^3 + ... + K_3X_n^3)$$
$$+ .... + (a_4X_1X_2 + b_4X_1X_3 + ...)$$
$$+ (a_5X_1X_2X_3 + ...)$$

+ higher order terms, where a_n, b_n, ... K_n are arbitrary constants (coefficients), and the X's are independent variables.

The data for each dependent variable and the associated independent variables are input to the computer program. The program performs the necessary operation on the independent variables (such as squaring each variable and multiplying two or more variables) to obtain a new set of variables. The new variables are then entered one at a time and the fit to the data computed. This process continues until all new data are entered into the program. The best fit is then determined from the statistical output. The variables and coefficients for this fit are selected and the model written. The model giving the best fit for the Phase III data was of the form

$$\frac{dp}{dt} = a_1R^2 + a_2R\lambda + a_3n.$$

APPENDIX D

Definition of Terms

vent ratio = $\frac{\text{propellant surface area}}{\text{vessel vent area}}$

propellant energy = heat of explosion per unit weight

free volume = volume above propellant within test vehicle

vessel size = volume and cross sectional area

scaled vessel = dimensional relationship to full scale

rate of pressure rise = $\left(\frac{dP}{dt}\right)$

scaled vent ratio = $\frac{(\text{subscale area})^{2/3}}{\text{actual area for given vent ratio}}$ X given vent ratio

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