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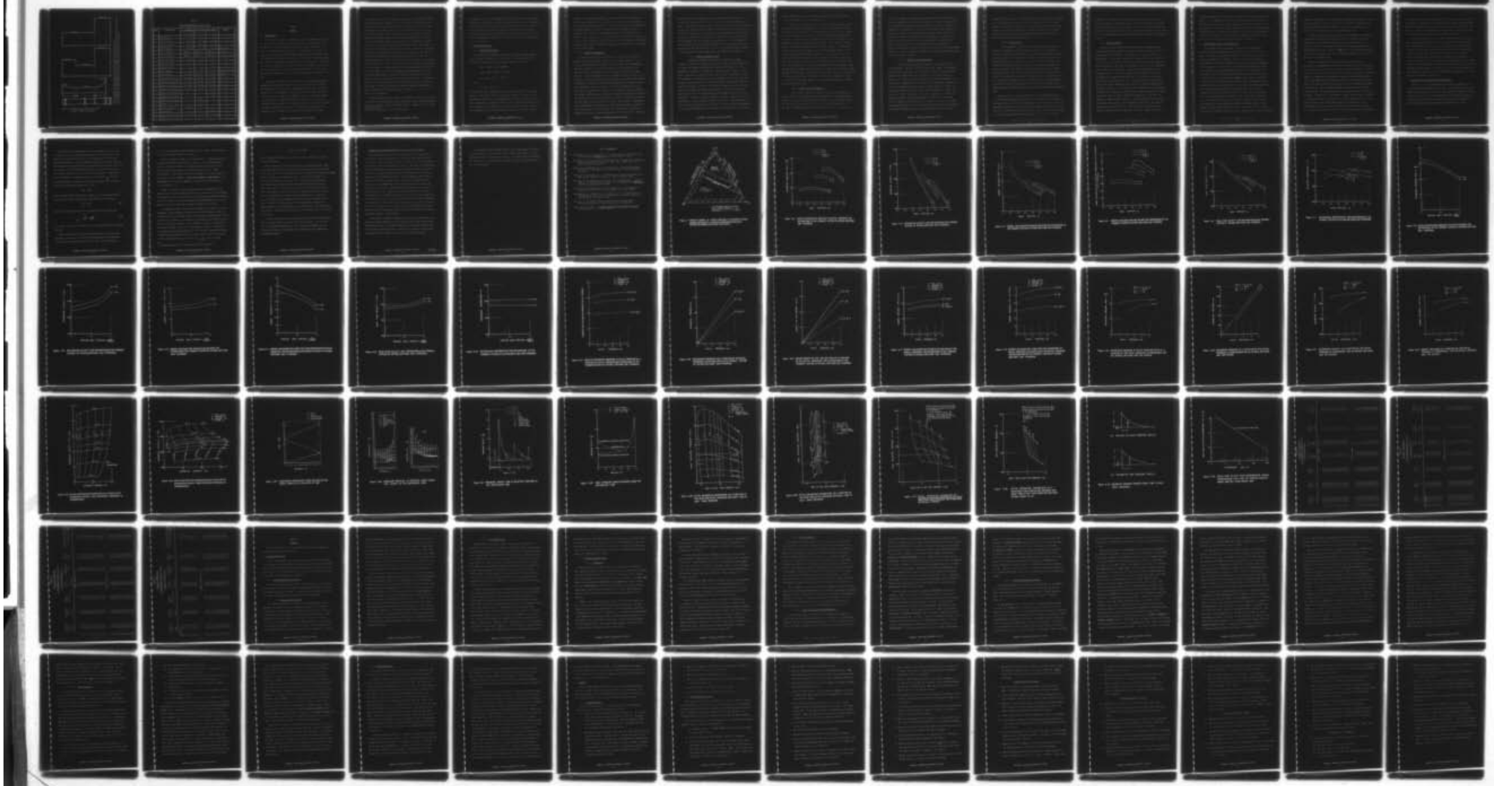

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AND

OPERATION MANUAL

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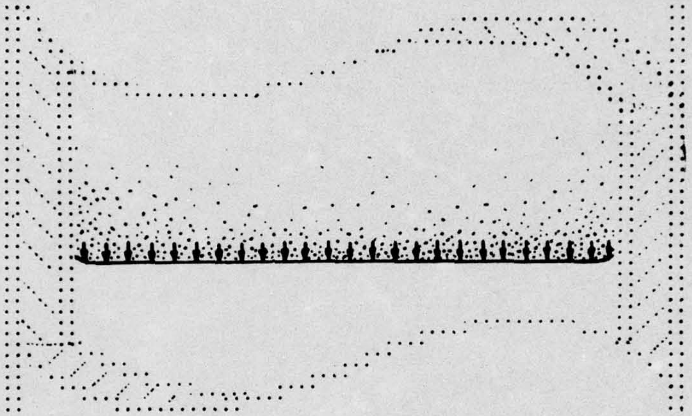

prepared for

WATERWAYS EXPERIMENTAL STATION

VICKSBURG, MISSISSIPPI 39180

CONTRACT NO. DACA 39-68-C-0047

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THEORY AND OPERATION MANUAL

1500 PSI DYNAMIC LOAD SIMULATOR

by

R. J. Klima
L. E. Fugelso

GENERAL AMERICAN RESEARCH DIVISION
General American Transportation Corporation

Prepared for

U.S. Army Corps of Engineers
Waterways Experimental Station
Vicksburg, Mississippi

Under

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FOREWORD

This manual was prepared by the General American Research Division of the General American Transportation Corporation for the U.S. Army Corps of Engineers, Waterways Experimental Station, Vicksburg, Mississippi, under Contract No. DACA 39-68-C-0047. The manual culminates a 12 month program to design, fabricate, install, and make operational a 1500 psi Dynamic Load Simulator. The program was performed during the period 1 May 1968 to 10 October 1969.

The manual contains the theory behind, and operation of, the 1500 psi Dynamic Load Simulator and is divided into four sections. The first section is a general description of the system and lists its specifications. The second section covers the theory of thermochemical and detonation wave analysis. The third section describes the operating procedure. The last section provides guidance for maintaining and trouble-shooting the system.

The overall management of the program was the responsibility of Dr. M.J. Balcerzak, Associate Manager of Engineering. The Project Engineer was R.J. Klima.

Appreciation is extended to the following personnel who contributed to this program: L.E. Fugelso, R.S. Koike, S.A. Stohl, and F.E. Wolosewick. Appreciation is also extended to Messrs. W. Flathau, J. Ballard and J. Hossley of the Waterways Experimental Station for the cooperation and assistance given to General American Research Division during the performance of this program.

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SECTION 1

INTRODUCTION

1.1 Purpose

The purpose of the 1500 psi Dynamic Load Simulator is to provide the Waterways Experimental Station with the capability of producing peak reflected overpressures of up to 1500 psi which decays to 1/2 the peak pressure in 2 milliseconds. This dynamic model test facility will augment static test information in determining structural response characteristics.

1.2 General Description

The generation of high overpressure shock waves may be accomplished by the detonation shock tube. This device basically consists of a cylindrical tube containing an explosive gas mixture. If the initial mixture and pressure are correct, the explosive gas will produce, upon ignition at one end of the tube, a detonation wave that travels at a high velocity toward the other end of the tube. Proper choice of explosive constituents controls the detonation wave overpressures and velocities independently.

The 1500 psi Dynamic Load Simulator is basically a detonation shock tube. It is 41 ft. 3 in. long, has a 46-3/4 in. I.D. and is flanged into five sections. The bottom section, 21 in. long, contains the model. The intermediate sections are 4 ft., 15 ft. 9 in., 17 ft. 3-9/16 in., and 2 ft. 5-7/16 in. consecutively. The latter refers to the 2:1 semielliptical head that closes off the top end of the tube. In order to efficiently operate the detonation shock tube certain subsystems are required. They are the gas loading and firing system, the handling system, and the instrumentation system.

The gas loading and firing system consists of a valve and manifold control box, a methane-oxygen-hydrogen gas supply, a vacuum pump, a monitoring and electronic control panel, assorted valves, regulators, and associated pneumatic and electrical lines. Figure 1.1 shows a schematic of the 1500 psi Dynamic Load Simulator with the gas loading and firing system.

The handling system consists of structural steel members arranged to allow shock tube disassembly for model removal. In its operating position, the tube and handling system would appear as shown in Figure 1.2. Figure 1.3 shows the disassembled position.

The instrumentation system referred to here is required to verify that the anticipated detonation parameters have been met. The instrumentation associated with the structural response of the model is not presented in this manual. The instrumentation system consists of four pressure transducers. Two will indicate the peak reflected pressure at the model. The other two will provide data of the actual detonation pressure and velocity.

1.3 Facility Specifications

The 1500 psi Dynamic Load Simulator was designed according to ASME-API Design Codes for Unfired Pressure Vessels. The simulator was designed to provide the capability of being utilized either as a closed end, 1500 psi (maximum) indoor facility or an open end, 3000 psi (maximum) remote outdoor site facility. The open end configuration will require a frangible diaphragm instead of an elliptical head to reduce the upward stress in the tube and preclude strength problems in the foundation. The indoor facility has the capability of a decay to 1/2 peak pressure in 2 milliseconds. The 3000 psi remote outdoor site facility will require an additional 20 foot section on top of the present 40 foot tube, if the same pressure decay characteristics at the model end are desired.

The tube was designed with a factor-of-safety of 4 (according to ASME codes) for the 1500 psi indoor facility. When used as a 3000 psi remote outdoor facility the factor-of-safety will drop to 2 which is sufficient for the remote outdoor case.

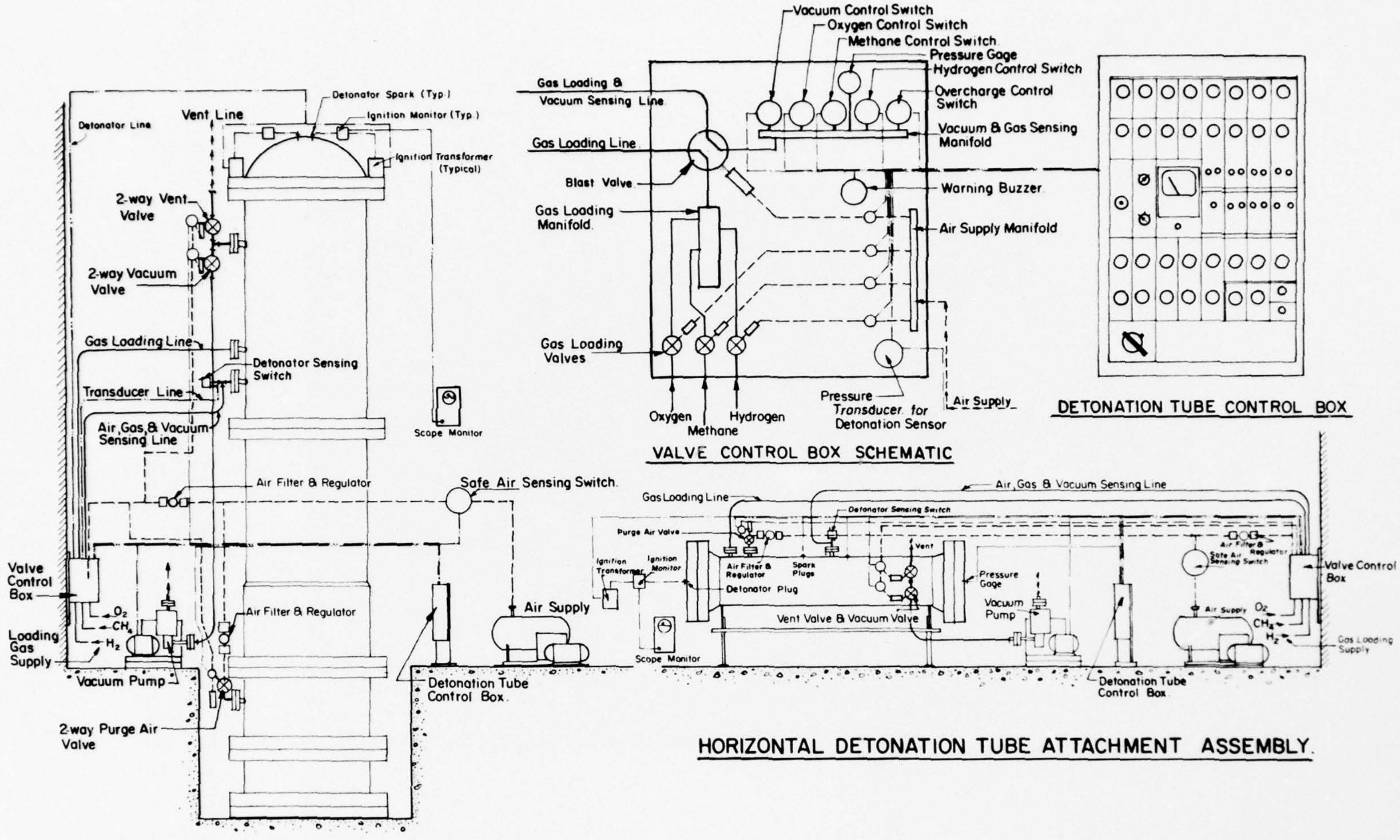
The peak pressures as a function of length in the 1500 psi Dynamic Load Simulator will appear as shown in Figure 1.4 Curve A. These are internal pressures acting along the tube. The peak pressures could not be used for design purposes because they are transient and the dynamic effects must be considered. These effects can be expressed in terms of a dymanic load factor (maximum dynamic deflection/maximum static deflection). A GARD sponsored test program empirically determined a dynamic load factor of approximately 2.0 with the 12-inch shock tube. A dynamic load factor of 2.0 was used in the design of the Simulator. (See Figure 1.4 Curve B.) Curve C of Figure 1.4 is the pressure loading curve used for the design of the Simulator.

Table 1.1 lists the specifications for the 1500 psi Dynamic Load Simulator.

The connecting flanges, pipe, valves, and pneumatic lines to the tube were sized compatible with the maximum pressures anticipated (3000 psi peak reflected). The detonable gas source pressures have to be regulated to less than 500 psi. Both 220-volt 3 phase A.C. and 110-volt 1 phase A.C. are required for operation of the facility along with an 80 psi minimum air supply.

The initial pressure of the detonable gas mixture inside the tube cannot exceed 5 atmospheres and still have a programmed gas loading sequence. The initial temperature and relative humidity have little or no effect.

The shot-to-shot recycle time, not including model replacement, is approximately 2 hours or one hour for the purge cycle, 1/2 hour for the evacuatin cycle, and 1/2 hour for the detonable gas loading cycle.



VALVE CONTROL BOX SCHEMATIC

DETONATION TUBE CONTROL BOX

HORIZONTAL DETONATION TUBE ATTACHMENT ASSEMBLY.

VERTICAL DETONATION TUBE ATTACHMENT ASSEMBLY

Figure 1.1

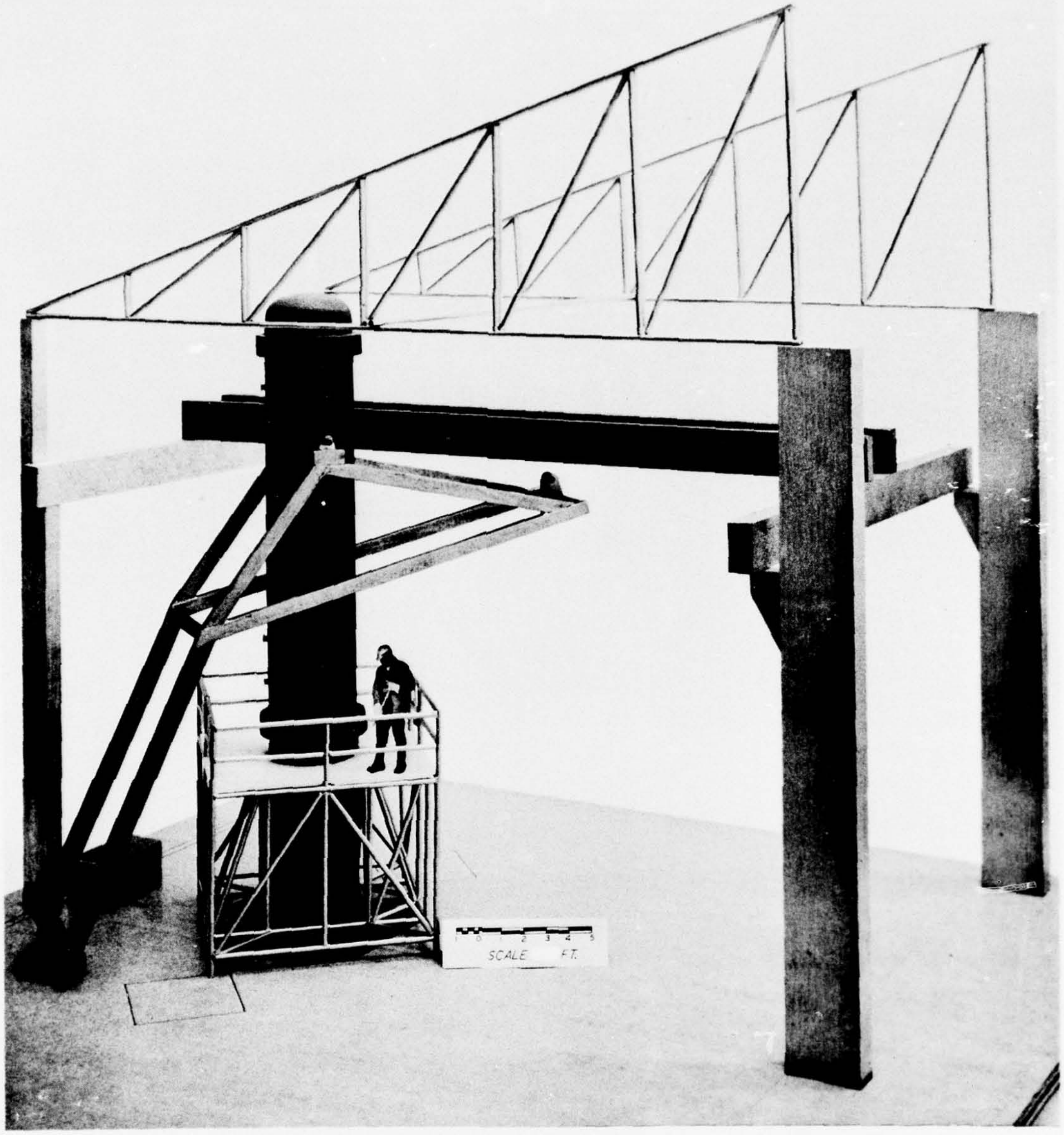


Figure I. 2 SHOCK TUBE IN OPERATING POSITION

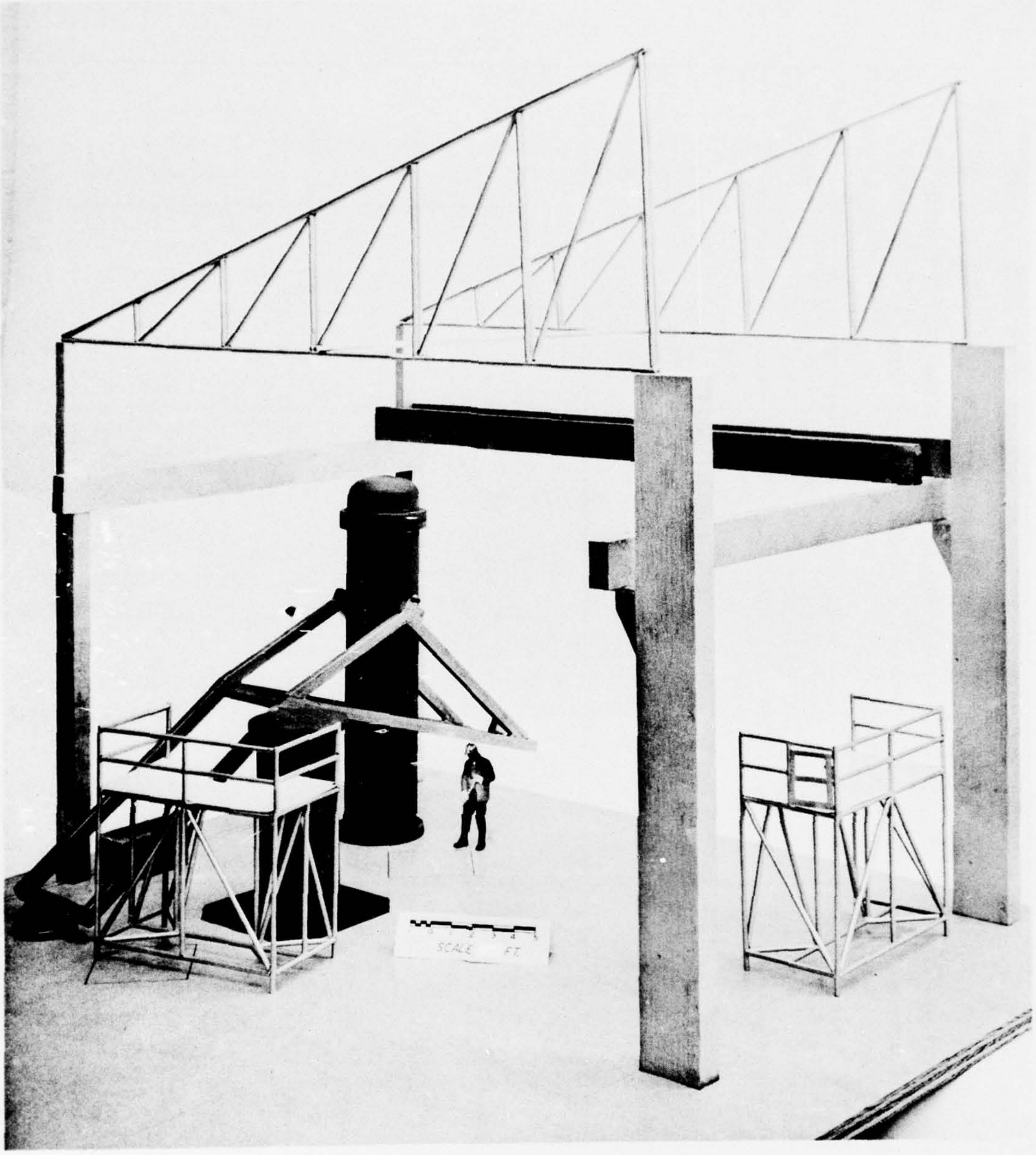
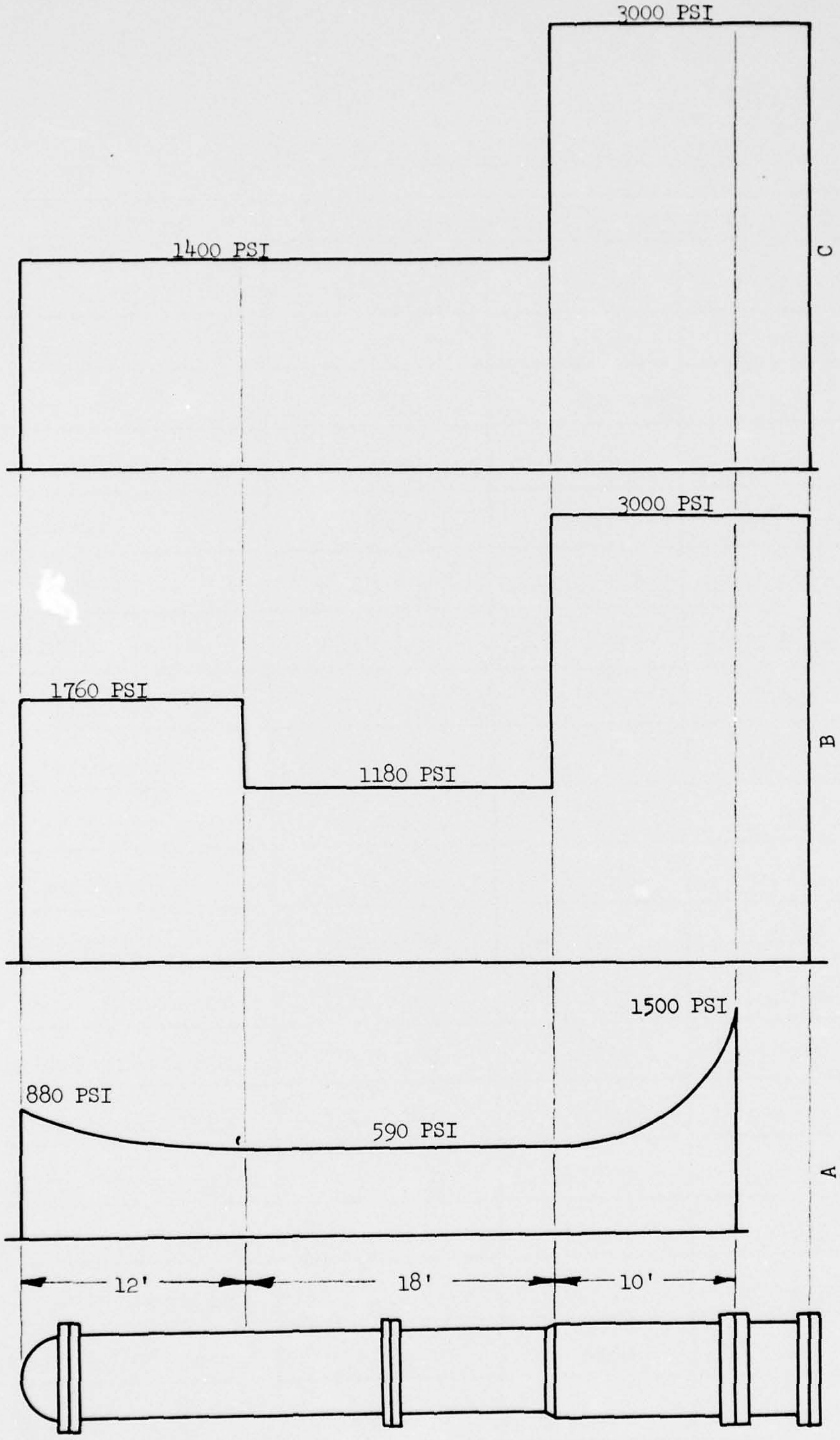


Figure 1.3 SHOCK TUBE IN DISASSEMBLED POSITION



Curve A represents the peak detonation and reflected pressures acting along the tube.

Curve B represents the design pressures including a dynamic load factor of two for three constant wall thicknesses

Curve C represents the design pressures for the more economical two constant wall thicknesses

Figure 1.4 Maximum Pressure Loading Curves for the 1500 PSI Dynamic Load Simulator

TABLE 1.1

FACILITY TABULATION ON SHOCK TUBE

ITEM	DESCRIPTION	FLANGED SECTION HEIGHT FROM GRADE			REMARKS
		-11' 11 $\frac{1}{2}$"	+ 2' 5"	+ 32' 0"	
1	Temperature	300°F	300°F	300°F	---
2	Blast pressure	880 psi	590 psi	1500 psi	---
3	Design pressure	1760 psi	1180 psi	3000 psi	---
4	Test pressure	4000 psi	4000 psi	4000 psi	Water test
5	Shell material	ASTM A517	ASTM A517	ASTM A514	T1 steel
6	Flange material	ASTM A515	ASTM A515	ASTM A515	70,000 psi Gr. C.
7	Shell thickness	1.375"	1.375"	3.00"	---
8	Flange thickness	5.75"	5.75"	5.50"	---
9	Number of bolts	40	40	40	---
10	Bolt diameter	1.75"	1.75"	1.75"	Root A=1.98 in.^{2}
11	Bolt strength	340,000#	340,000#	340,000#	Minimum
12	Bolt prestress, test	186,000#	186,000#	186,000#	F.S. = 1.6
13	Torque for prestress	2700'#	2700'#	2700'#	f = 0.075
14	Bolt prestress opera.	100,000#	100,000#	100,000#	F.S. = 3.4
15	Torque for prestress	1500'#	1500'#	1500'#	f = 0.075
16	Weight of test specim.	---	---	5,600#	---
17	Weight of 4' section	---	---	7,770#	---
18	Weight of 15'9" sect.	---	21,870#	---	---
19	Weight of 17' 3 $\frac{9}{16}$"	---	17,000#	---	---
20	Weight top head	4,520#	---	---	---
21	Total weight	---	---	56,740#	---
22	Hoop stress operating	29,600 psi	20,000 psi	23,000 psi	---
23	Longitud. stress opera.	14,800 "	10,000 "	11,500	---

SECTION 2

THEORY

2.1 Introduction

The loading on a model in a detonation tube is accomplished by filling in the tube with a detonable gas mixture under some initial pressure and detonating the mixture at some point along the length of the tube. The model is contained in one end of the tube. The model end of the tube is designed to withstand the peak detonation pressures and is considered rigid. The detonator is situated at the other end of the tube. The detonator end of the tube is designed not to rupture and is considered rigid. The detonation wave, reflected shock waves and subsequent flow pattern that occur in the tube following the ignition of the gas are dependent upon the initial pressure, the composition of the initial gas mixture and the length of the tube.

Initially the detonation tube is filled with a uniform detonable gas mixture of some specified composition which is maintained at a uniform initial pressure. This mixture is detonated at one end which initiates a detonation wave that propagates along the length of the tube. The detonation wave is a shock wave which propagates through the explosive mixture, and the pressure and temperature immediately behind the front drive an exothermic chemical reaction. The energy released by this reaction sustains the shape and magnitude of the front. The propagation velocity of the detonation wave is determined by the physical properties of the media on both sides of the front. Equations representing the conversation of mass, momentum, and energy, supplemented by a thermochemical analysis describing the reaction that occurs immediately behind the detonation front, allow the determination of the properties of the burnt gas mixture behind the front. Balcerzak and Johnson (1965)* and Balcerzak, Johnson and Kurz (1966) have computed the detonation parameters for selected compositions and initial conditions for propane, oxygen and air systems. The computational system assumes that the initial and final gas mixtures are perfect gases, that the rates of the reaction are so fast that the reaction occurs at the detonation front, that the detonation velocity is sonic with respect to the flow just behind the detonation front. Klima, Balcerzak and Johnson (1968) give a detailed analysis of the reactions considered in establishing the equilibrium conditions behind the front. They also compute the thermochemical parameters for the detonation of methane-oxygen-air and hydrogen-oxygen-air mixtures at initial pressures of less than one atmosphere and temperatures below 0°C., the specific application for these calculations being predictions of gas detonation behavior at high altitudes (less than 100,000 feet). Ostrem and Fugelso (1967), Feddersen, Fugelso, Ostrem, and Watts (1968), and Fugelso, Guttenberger, and Byrne (1968) present tables and graphs of thermochemical data on detonation of methane and propane mixtures for initial pressures from 1 to 40 atmospheres.

The pressure and velocity fields in a detonation tube have been evaluated for the basic configuration previously (Feddersen, Fugelso, Ostrem, and Watts (1968) and Balcerzak, Johnson and Fugelso (1968)). Evaluations for the basic

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*See List of References at the end of Section 2.

configuration, in which the detonator and the model end are completely rigid at pressures intermediate to the initial pressure and peak reflected pressure, were made. The pressure-time history at the model end, i.e., the end away from the detonator, was obtained, together with predictions for the peak pressures that will occur at any position along the length of the tube. The theory and computational procedure is reviewed and the results are presented here for convenience.

2.2 Thermochemical Data

2.2.1 Reactions Considered

The thermochemical detonation properties of various methane-hydrogen-oxygen mixtures are presented in this section. The general form of the reaction that takes place at the detonation front has the form

$$n_1O_2 + n_2CH_4 + n_3H_2 + n_4N_2 \longrightarrow$$

$$\alpha\, CO_2 + \beta CO + \delta\, H_2O + \epsilon\, H_2 + \zeta\, N_2$$

$$+ \lambda\, (OH) + \mu\, (H) + \nu\, (NO) + Q$$

with

$$n_1 + n_2 + n_3 + n_4 = 1$$

All the Greek letters represent moles of the products and Q is the energy released. The reaction above is written for one mole of reactants. Both reactants and products are considered perfect gases and the thermochemical data is obtained by a numerical solution of the conservation equations under the assumption that the products are in chemical equilibrium at the detonation temperature and that the detonation satisfies the Chapman - Jouguet condition. A detailed presentation of the conservation equations and the chemical equilibrium equations, together with a discussion of the numerical techniques and methodology used in the solution, is given in Klima, Balcerzak and Johnson (1968). This set of equations is quite lengthy and is not reproduced here. No air is considered for any of the cases presented in Section 2.2.1, so $n_4 = \zeta = \nu = 0$. The effect of air is discussed in Section 2.2.2.4. In the reference cited in the previous section (Fugelso, Guttenberger and Byrne 1968), several cases were evaluated with air present and these terms were considered there.

2.2.2 Detonation Parameters

The detonable gas mixtures considered in this manual are composed of oxygen, methane and hydrogen. Figure 2.1 is a ternary diagram of the O_2 - CH_4 - H_2 system showing the compositions for the thermochemical parameters that were evaluated. The ternary diagram also shows qualitatively the detonation limits for explosions in this system. Limits for the binary system O_2 - H_2 were presented in Lewis and Von Elbe (1961) and those for the system O_2 - CH_4 were presented in Klima, Balcerzak and Johnson (1968). Linear interpolation between these limits defines approximately the region wherein true detonations can occur. Table 2.1 lists the mole fractions, initial pressures, and oxygen-to-fuel ratios (the fuel being the sum of the methane and hydrogen volumes) and several pertinent computed thermochemical quantities. The presented data includes initial density, detonation pressure, detonation velocity, peak flow velocity behind the front, peak detonation temperature, energy released per unit weight of initial mixture, and energy released per unit volume per unit initial pressure. All thermochemical calculations presented assumed an initial gas temperature of 20°C. (293.16°K.) Graphical representations of the thermochemical data were made to illustrate their dependence on several variables. In the first set of graphs presented, the relative composition of the fuel gases, H_2 and CH_4, to each other is maintained constant, and variable ratios of oxygen to total fuel were considered. For the second set of graphs, the ratio between the two constituents of the fuel gas were varied. This specific variation was carried out over a line AB on the ternary diagram. The two end members represent points on their respective binary systems where the detonation pressure to initial pressure ratios are near or at the peak value possible. The third set demonstrates the influence of initial pressure at fixed composition on the detonation parameters.

2.2.2.1 Effect of Oxygen Content

Detonation parameters for mixtures of methane and oxygen; hydrogen and oxygen; and methane, hydrogen and oxygen with equal molar parts of methane and hydrogen are presented in Figures 2.2 through 2.7. The independent variable in all graphs is the mole fraction of oxygen. On each graph, three sets of curves are shown. Each set has a fixed ratio of fuel gas components. Considered are the two end members, the fuel gas being pure hydrogen or pure methane, and an equimolar mixture of methane and hydrogen. Figure 2.2 presents the ratio of the detonation pressure to the initial gas pressure for these three types of gas mixtures. Two curves are shown for each type, one curve at one atmosphere initial pressure, the other at five atmospheres. Figure 2.3 shows the detonation velocity. Figures 2.4 and 2.5 demonstrate the energy released, Figure 2.4 shows the energy released per pound of original gas mixture, while Figure 2.5 plots the energy released per unit volume per atmosphere of initial pressure. The peak flow velocity and the peak temperature, both of which are attained at the detonation front, are shown in Figures 2.6 and 2.7, respectively.

In Figure 2.2, the detonation-pressure-to-initial-pressure ratio shows a definite, sharply defined maximum for all three fuel compositions as the mole fraction of oxygen varies. The largest pressures occur for the methane-oxygen mixtures while the smallest occur for the hydrogen-oxygen mixtures. The peaks occur near the initial compositions which are stoichiometric to the appropriate mixture of carbon monoxide and water. With increasing initial pressure the detonation pressure ratio increases slightly. In Figure 2.3, the detonation velocity increases with increasing hydrogen content in the rather broad compositional range considered. In Figures 2.4 and 2.5, the energy released by the reaction is demonstrated in two different ways, the first being energy released per pound of original gas mixture and the second being energy release per cubic foot per atmosphere initial gas pressure. The hydrogen mixture releases more energy per unit weight while the methane mixture detonations release more energy per unit volume. As a function of mole fraction of oxygen, these curves are very broad. The detonation temperature, Figure 2.7, shows a similar shape compared to the pressure-ratio data, but the peak values are nearly the same.

2.2.2.2 Effect of Fuel Composition

This section contains the variation of the fuel gas composition and its effect on thermochemical detonation properties. The peak detonation pressure in the O_2 - H_2 binary system occurs near the stoichiometric mixture ratio of $O_2/F = 1/2$ (O_2/F equals the ratio of moles of oxygen to moles of fuel gas). The peak detonation pressure for the equimolar mixture of fuels occurs at the composition intermediate and on a straight line between the two binary compositions indicated. The independent variable then considered is the reduced mole fraction of hydrogen $n_3/(n_2 + n_3)$, while the mixture composition is constrained to be on the line indicated as AB on Figure 2.1. Figures 2.8 through 2.13 show the same six parameters while varying the percentage of methane and hydrogen. The methane-oxygen end member has an oxygen to fuel ratio of 3/2 while the hydrogen-oxygen end member has an oxygen to fuel ratio of 1/2. The intermediate points shown are on a straight line between the ends as indicated by line AB on the ternary diagram (Figure 2.1). All the detonation parameters vary smoothly and monotonically as the fuel mixture is varied.

2.2.2.3 Effect of Initial Pressure

The next major independent variable to be considered is the initial pressure. For three selected compositions, namely, the end-points and the "middle point" ($n_2 = n_3$) on line AB of Figure 2.1, the detonation properties are examined for their dependence on initial gas pressure. Figures 2.14 through 2.18 show the variation of detonation properties of three specific compositions as a function of initial pressure. Figure 2.14 shows the detonation-pressure-to-initial-pressure ratio as a function of initial gas pressure for the following initial compositions: $O_2/F = 3/2$, $H_2/CH_4 = 0$; $O_2/F = 1/2$, $H_2/CH_4 = \infty$; $O_2/F = 1$, $H_2/CH_4 = 1$. Figure 2.15 shows the detonation pressure and Figure 2.16 shows the initial weight density. Figures 2.17 and 2.18 show the energy released in its two forms of presentation, Figure 2.17 showing energy released per pound of detonable gas mixture and Figure 2.18 showing energy released per cubic foot per atmosphere initial pressure. The two properties that increase almost linearly with initial pressure are the density of the reactants and the detonation pressure. The detonation pressure to initial pressure ratio and the energy release (in both forms of presentation) increase slightly with increasing initial pressure, thus indicating that these detonations become slightly more efficient at higher initial pressures.

2.2.2.4 Effect of Air

If the operation of the detonation tube facility is such as to preclude the evacuation of the tube prior to gas fill, the tube will be initially filled with one atmosphere air. The detonation parameters for one gas mixture added to a volume of air originally occupying the tube at one atmosphere pressure is included in this section. The air is assumed to be composed of 79% N_2 and 21% O_2, and the minor constituents such argon and CO_2 are neglected. As a typical case, a detonable gas mixture of methane and oxygen is selected. The ratio of the mixture is such that the final oxygen to fuel gas ratio, including the oxygen in the air, is maintained at 3/2. The detonation parameters for those mixtures at an initial temperature of 300°K (26.84°C) and initial pressures ranging up to 5 atmospheres were computed previously (Fugelso, Guttenberger and Byrne (1969)) and are reproduced here.

Figure 2.19 shows the detonation-pressure-to-initial pressure ratio for the methane-oxygen-air mixture from 2 to 5 atmospheres initial pressure. Also shown is the curve for the methane-oxygen mixture without air from 1 to 5 atmospheres initial pressure. The detonation pressure ratio for the mixture with air lies below the methane-oxygen mixture curve. The difference between the two curves is greater at lower pressures. This is due to a greater proprotion of nitrogen in the mixture which tends to retard the reaction. Figure 2.20 shows the detonation pressure for the methane-oxygen and methane-oxygen-air mixtures, while the detonation velocities and energy released per pound of initial gas mixture are shown in Figures 2.21 and 2.22. In the latter two curves, a difference between the two curves exists because of the presence of air.

2.2.3 Engineering Data

Feddersen, Fugelso, Ostrem and Watts (1968) have demonstrated that the pressure-histories obtained at the model end of a detonation tube are dependent upon four parameters. The magnitude of the profile which is proprotional to the detonation pressure; the shape of the decay curve which is a function of γ, the ratio of specific heats of the burnt gas mixture; and the duration or time scale of the pressure history which is proportional to the length of the detonation tube and inversely proportional to the detonation velocity. Two basic properties of the detonation which are descriptive of the magnitude and duration of the flow are the detonation pressure and the detonation velocity. Figures 2.23 and 2.24 show initial pressure and initial composition as a function of detonation pressure and detonation velocity. On each figure a network composed of arcs representing constant initial pressure and those denoting constant composition are shown. Figure 2.23 shows mixtures of hydrogen and oxygen over a portion of the composition range considered earlier. The more hydrogen-rich mixtures are not plotted on this graph. They overlap the region shown. Two types of mixtures are shown in Figure 2.24. The solid arcs are methane-oxygen mixtures, tending toward the oxygen-rich end of the composition mixture.

The highest detonation velocities are represented by the mixture $O_2/F = 3/2$, $H_2/CH_4 = 0$. The methane-richer mixtures not plotted have lower detonation velocities and that portion of the graph would overlap that shown here. The upper portion of this curve (shown in dashed lines) represents oxygen-methane-hydrogen mixtures of the same series described for the detonation parameters in Figures 2.8 through 2.13. The mixtures considered in Figures 2.23 and 2.24 lie on the three lines CA, AB, BD as shown in Figure 2.1.

2.3 Pressure-Time History at the Model End

The detonation wave initiated by the ignition of an appropriate detonable gas mixture propagates along the length of the tube. At its point of initiation, the detonation front is not plane; however, after the wave has propagated a few diameters down the tube, the front has become almost plane and conditions immediately behind the front become independent of radial position. The detonation wave and other flow properties exhibit small dependence on any radial property and the flow is essentially one dimensional. When the detonation wave reaches the model end of the tube, a compressive shock is reflected and propagates back toward the detonator. The flow between the detonation front and the first reflected shock can be determined from the similarity solution to the basic conservation equations. The burnt gas mixture is assumed to be a perfect gas with a constant composition given at the detonation front. Further, the flow is assumed to be one dimensional from its inception. The flow behind the reflected shock front has been evaluated by a numerical integration of the conservation equations for mass, momentum and energy (Feddersen, Fugelso, Ostrem and Watts, 1968; Ostrem and Fugelso, 1967). The equations for the nonisentropic flow of a perfect gas were written in characteristic form and difference equations corresponding to the differential equations were formulated. These difference equations were used unaided only in regions of continuous flow. Utilizing the Rankine-Hugoniot equations for shock front behavior, the progress of the reflected shocks was evaluated explicitly.

The flow variables behind the detonation can be expressed in terms of nondimensional variables, the pressures behind the detonation front are proportional to the detonation pressure and the flow velocity can be measured in units of the detonation velocity. The pressure profiles at any position along the length of the tube, $\mathbf{X} = X/L$, is a function of the reduced time variable, $T = Dt/L$, where D is the detonation velocity, and L is the length of the detonation tube.

After the detonation wave strikes the model end of the tube, a reflected shock propagates back toward the detonator end. With the assumption that the model end is rigid, the peak reflected pressure may be established. The peak occurs at the end and is 2.56 times the detonation pressure. Figure 2.25, reproduced from Feddersen, Fugelso, Ostrem and Watts (1968), shows the propagation of the detonation front and the reflected shock front. Figure 2.26 shows the pressure as a function of the nondimensional distance (X/L) along the tube for several sequential times during the first two reflected waves. The pressure-time history at three positions in the tube are shown in Figure 2.27. The pressure is shown from the time of initiation of the detonation until the arrival of the second reflected shock. At the model end of the tube the following sequence of events occur: (1) a pressure spike as the detonation wave strikes the model end of the tube, (2) a rapid decay of pressure until the pressure reaches $\sim PD/3$, followed by

(3) a period of almost constant pressure until the next shock front arrives. This pattern is repeated with the peak pressures becoming gradually smaller. Qualitatively similar descriptions hold for other positions along the tube. Figure 2.28 shows the peak pressure obtained at each length along the tube as calculated by this one-dimensional detonation wave model.

It must be emphasized that this graph of peak pressures was calculated from a one-dimensional theory. At the side nearest the detonator, higher peak reflected pressures of 2.56 P_D can occur during the earliest stages of ignition. This highly localized effect can arise if two conditions are met: (1) the induction distance for the detonation, i.e. length the initial disturbance must travel before it steepens into a detonation, is less than the radius, (2) the side wall must be perpendicular to the radial direction at the nearest point. If either of the two conditions do not occur, the peak reflected pressure at that point will be significantly lower. The semielleptical head design of the 1500 PSI Dynamic Load Simulator is such to preclude this pressure concentration.

2.4 Selection of the Initial Mixture and Pressure

Sections 2.1 - 2.3 have demonstrated the detonation parameters for various oxygen-methane-hydrogen-air systems. The selection of the initial composition and pressure, and thereby the gas quantities required is demonstrated in this section. The main parameters of the detonation profile at the model end which describes the resulting pressure-time history are the peak reflected pressure and some measure of the duration or decay.

The initial mixture compositions and initial pressures as a function of detonation velocity and detonation pressure have been recast in a form deemed more convenient for direct use by the operators of the 1500 PSI Dynamic Load Simulator. The two independent variables are the two descriptive parameters of the pressure-time curve generated at the model end of the tube, namely, the peak reflected pressure and the time that it takes for the pressure history to decay to half of the peak pressure. Symbolically, the first parameter is designated by p_R and the second by $t_{\frac{1}{2}}$. The peak reflected pressure is related to the detonation pressure (for a burnt gas mixture with an adiabatic exponent of 1.2) by:

$$p_R = 2.56 p_D \tag{1}$$

From the pressure-time history shown in Figure 2.27, the pressure profile decays to half its peak value during a nondimensional time interval,

$$T_{\frac{1}{2}} = 0.28 \tag{2}$$

Using the relationahips between the nondimensional time and real time

$$t_{\frac{1}{2}} = \frac{L\,T_{\frac{1}{2}}}{D} = \frac{0.28L}{D} \tag{3}$$

with, again, L being the length of the tube and D representing the detonation velocity.

Figure 2.29 shows the initial mixture compositions and initial gas pressures as a function of the peak reflected pressure and half-pressure decay time for a detonation tube with L = 40 feet. The gas mixture is

$H_2 - O_2$. An intersecting network showing lines of constant initial pressure and lines of constant composition are shown.

Use of this graph is shown by the typical point a. Suppose the following pressure profile at the model end is desired: (1) the peak pressure should be 1500 psi and (2) the half-pressure decay time should be 2 msec. The two values of the abscissa and ordinate meet at point a. Linear interpolation is sufficiently accurate to determine the initial composition and pressure. In this example, the initial pressure is approximately 2.9 atmospheres and the initial composition is specified by the mole ratio of O_2 to H_2 equal to 3.4.

Figure 2.30 shows the peak reflected pressure and decay time to half peak pressure for selected O_2-CH_4-H_2 mixture as a function of initial pressure and composition. The solid lines indicate methane-oxygen mixtures corresponding to the line AC on the ternary composition diagram (Figure 2.1) and the dashed lines refer to the three component mixtures on the line AB.

All graphs have been calculated for a detonation tube length of 40 feet. Adaptation of these graphs to detonation tubes of other lengths is made by changing the scale of the decay time to half pressure. Multiplication of this scale by L'/40, where L' is the length of the detonation tube under consideration, is all that is required. As an example, the point a in Figure 2.29, for a tube of length 27 feet has a decay time of 1.35 msec. To determine the composition and initial pressure in the 27 foot tube necessary to obtain a peak reflected pressure of 2 psi and a decay time of 1 msec., one should look for the intercept of P_R = 1200 psi and $t_{\frac{1}{2}} = \frac{40}{27}\ (1) = 1.48$ msec

(illustrated by point b). The general form of the equation is

$$t_{\frac{1}{2}}(L') = t_{\frac{1}{2}}(40)\,\frac{40}{L'}$$

Linear interpolation to obtain the required initial conditions is similar to the prior example.

Similar engineering curves for determining initial pressure and composition requirements for the case where the detonation tube initially filled with air and the air is not evacuated from the tube prior to gas fill are included. Figure 2.31 shows the initial data for O_2 - H_2 gas fill and Figure 2.32 shows the same data for O_2 - CH_4 gas fill. The abscissa and ordinate of these graphs are again the peak reflected pressure and the decay time to half peak pressure. A net of curves defining initial pressure and composition requirements to attain the specific conditions is plotted. One set of arcs are labelled for constant total gas pressure (this includes all gas in the tube, both the oxygen-fuel mixture and the air already in the tube. To obtain the partial pressure of the oxygen-fuel mixture to be added, subtract one atmosphere from the indicated amount). The intersecting set of arcs is labelled by the O_2/F ratio of the gas mixture which is injected into the tube.

It must be pointed out that the detonability limits for the gas mixtures with the initial volume of air have not been established. This criteria must be established experimentally. It is strongly recommended that the detonability limits for these mixtures be established by the appropriate experimental methods.

2.5 Comparison with Air Blast Pressure from a 1 MT Nuclear Blast

One possible application of this detonation tube is the simulation of the pressure histories anticipated in a surface or high altitude nuclear burst. Brode (1964) summarizes extensive calculations of air blast pressure that might be expected from large yield devices. The shape of the pressure-histories attainable at the model end of the detonation tube indicate that an excellent fit may be obtained during the early portion of the blast, namely during that detonation where the blast overpressure decays from its peak value to one-half its peak value. This time is denoted by N^t 1/2. Figure 2.33 shows schematically the pressure profile and this decay time. Also shown is the decay to half peak pressure as obtained at the model end of the detonation tube. Figure 2.34 shows the decay time to half peak overpressure for a one MT nuclear surface burst versus the peak overpressure. The decay time scales as the cube root of the yield. For the gas detonation the differences in decay times defined from $P_D/2$ and $(P_D - P)/2$ is less than 3%. Similar statements can be made for the decay times defined from peak pressures and peak overpressures from a surface nuclear burst in the higher overpressure regions ($\Delta P > 100$psi).

Consideration of pressure decays after the decay to half-pressure shows that the nuclear overpressure air blast profile decays faster than the gas detonation profiles. The nuclear overpressure curve becomes negative after a finite time, indicating absolute pressures below ambient condition while the gas pressures are always in excess of the initial gas pressure.

In conclusion the gas detonation may be used to approximate the pressure profile induced by a nuclear surface burst from the peak pressure to half-peak pressure with a high degree of accuracy. For decays after half-pressure the gas profile is higher than that expected from the nuclear burst and the fit is less adequate.

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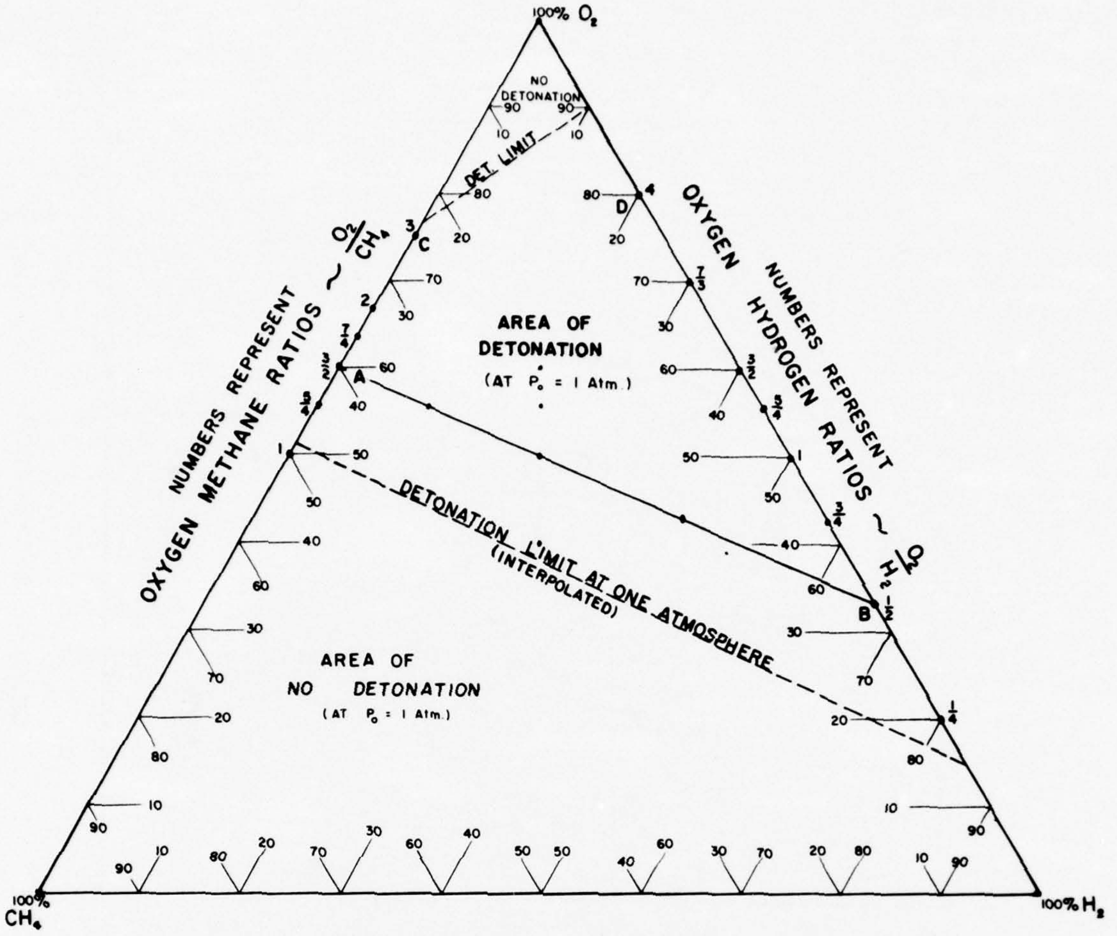


LIGHT FACE NUMBERS SHOW MOLE FRACTION

INITIAL LOADING PRESSURE, P_0 ---- 1 Atm.

TEMPERATURE, T_0 ------------- 293 ° K

Figure 2.1 TERNARY DIAGRAM OF OXYGEN, METHANE, & HYDROGEN SYSTEM SHOWING DETONABILITY LIMITS AND COMPOSITIONS FOR WHICH DETONATION PARAMETERS WERE CALCULATED.

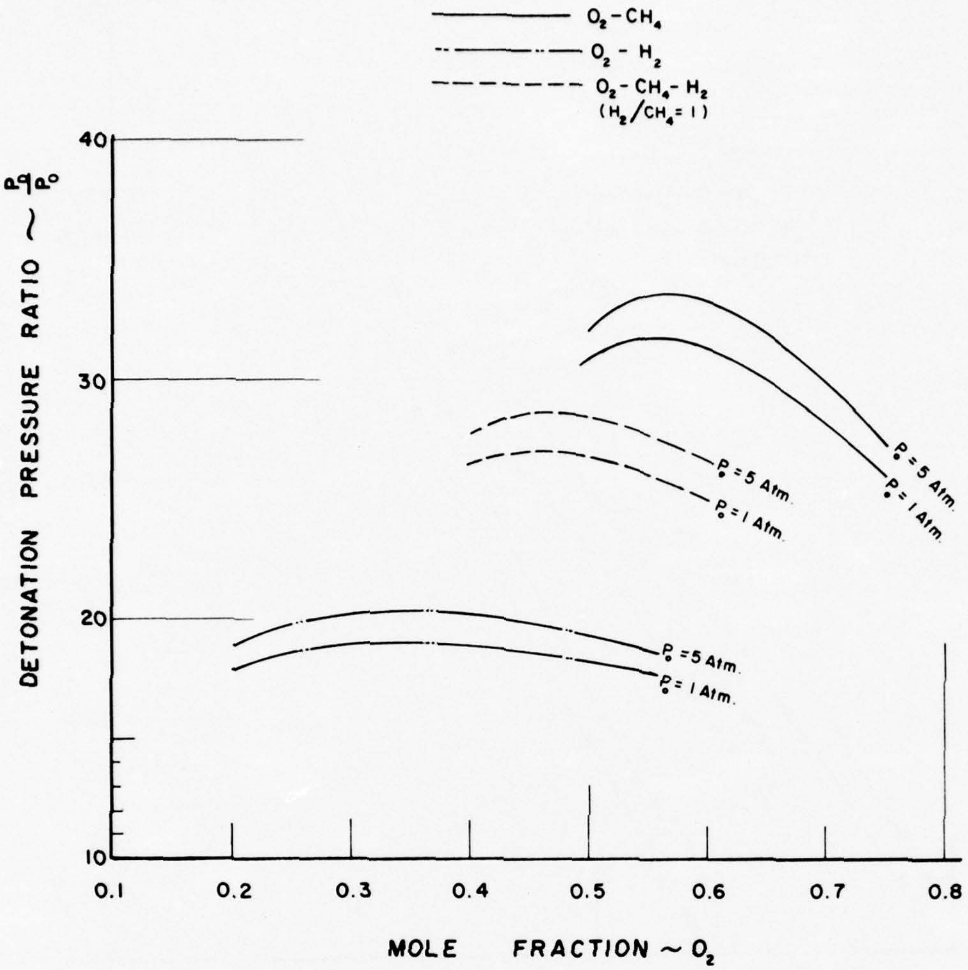


Figure 2.2 RATIO OF DETONATION PRESSURE TO INITIAL PRESSURE FOR DETONATIONS IN THE TERNARY SYSTEM OF OXYGEN METHANE AND HYDROGEN.

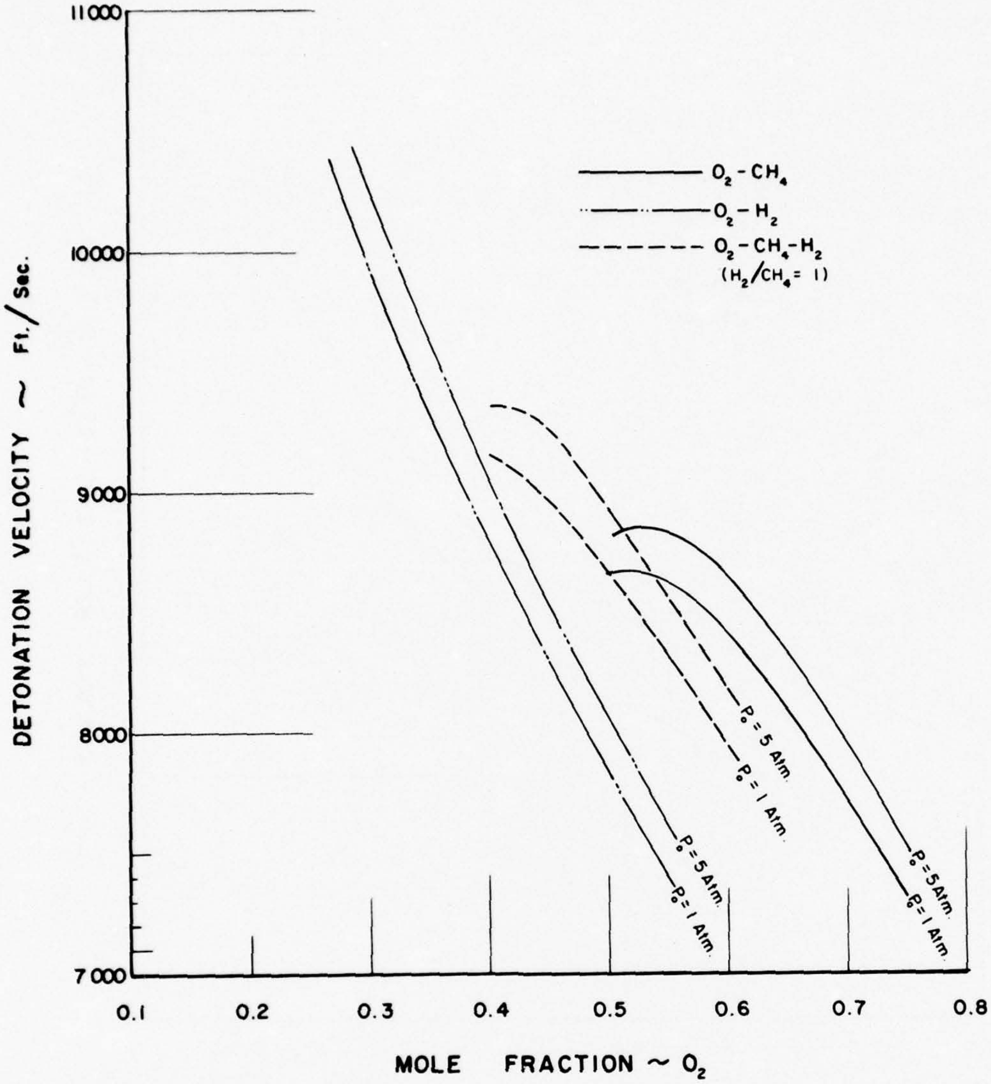


Figure 2.3 DETONATION VELOCITY FOR DETONATIONS IN THE TERNARY SYSTEM OF OXYGEN, METHANE AND HYDROGEN.

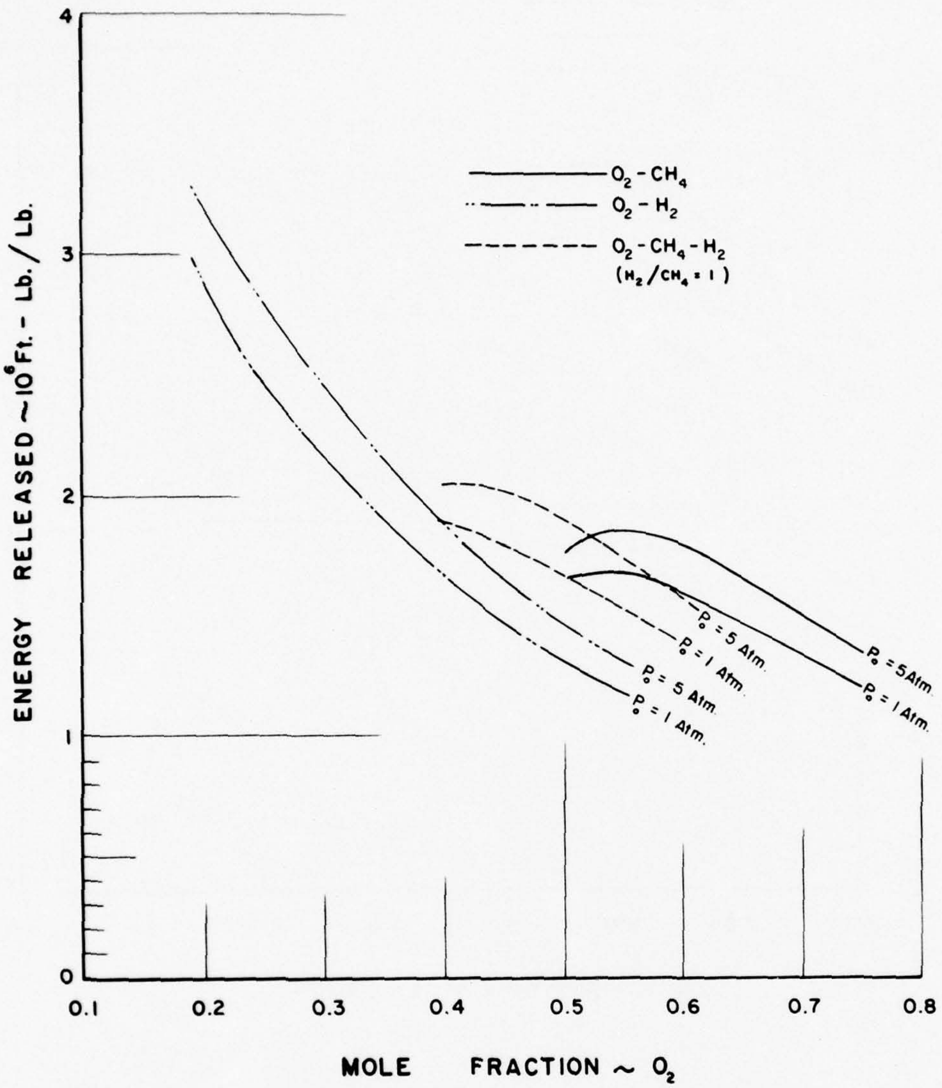


Figure 2.4 ENERGY RELEASED PER POUND OF MIXTURE FOR DETONATIONS IN THE TERNARY SYSTEM OF OXYGEN, METHANE AND HYDROGEN.

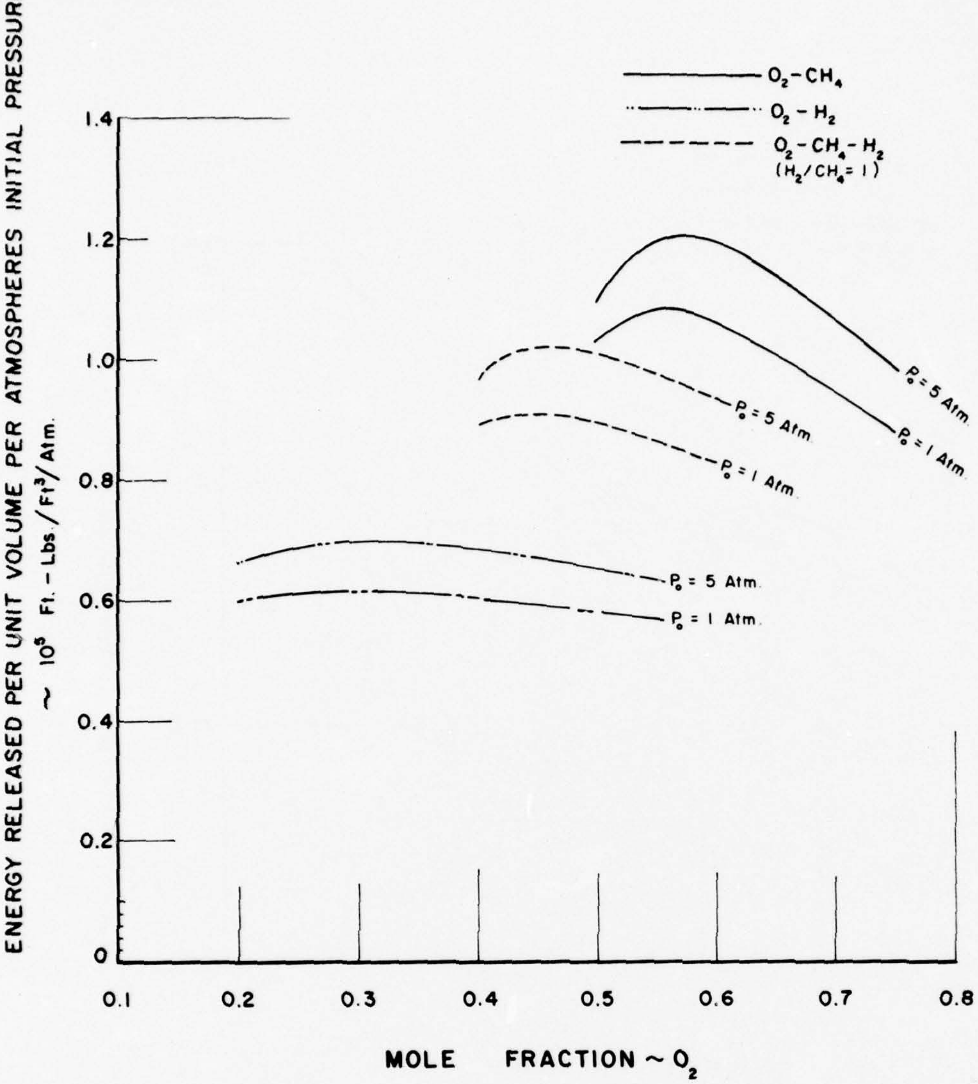


Figure 2.5 ENERGY RELEASED PER UNIT VOLUME FOR DETONATIONS IN THE TERNARY SYSTEM OF OXYGEN, METHANE AND HYDROGEN.

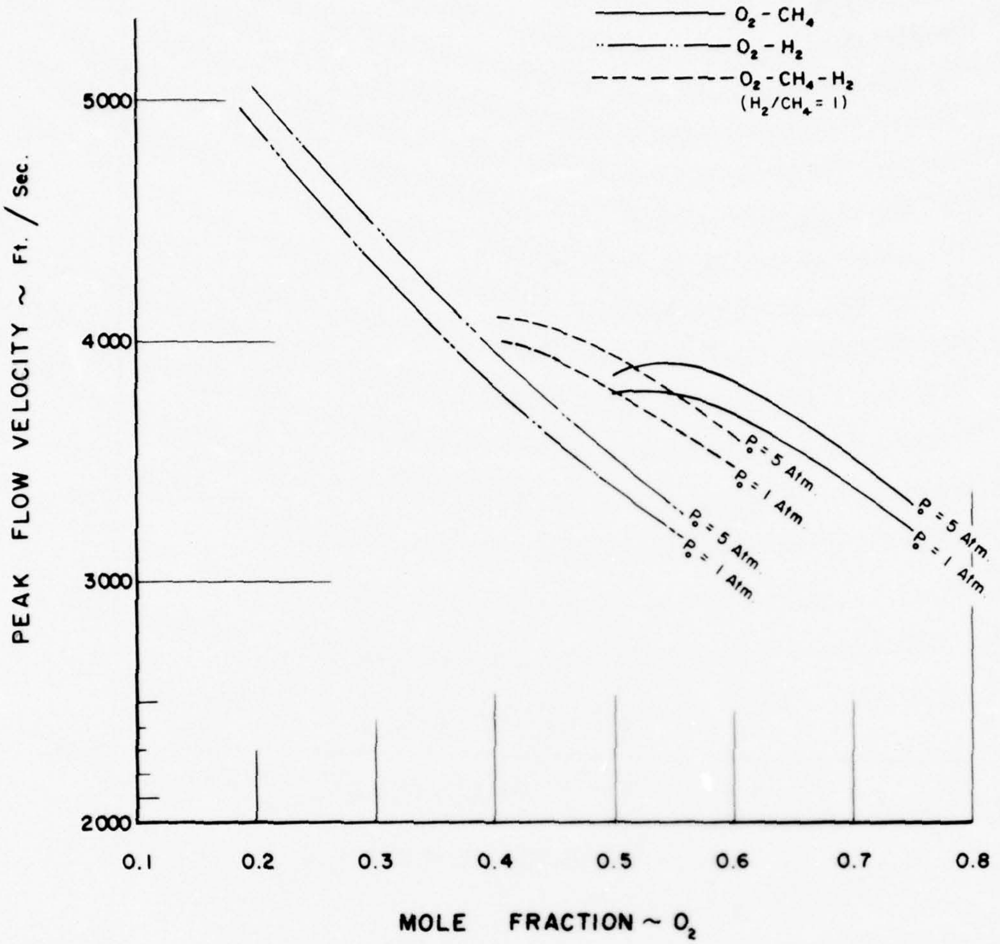


Figure 2.6 PEAK FLOW VELOCITY FOR DETONATIONS IN THE TERNARY SYSTEM OF OXYGEN, METHANE AND HYDROGEN.

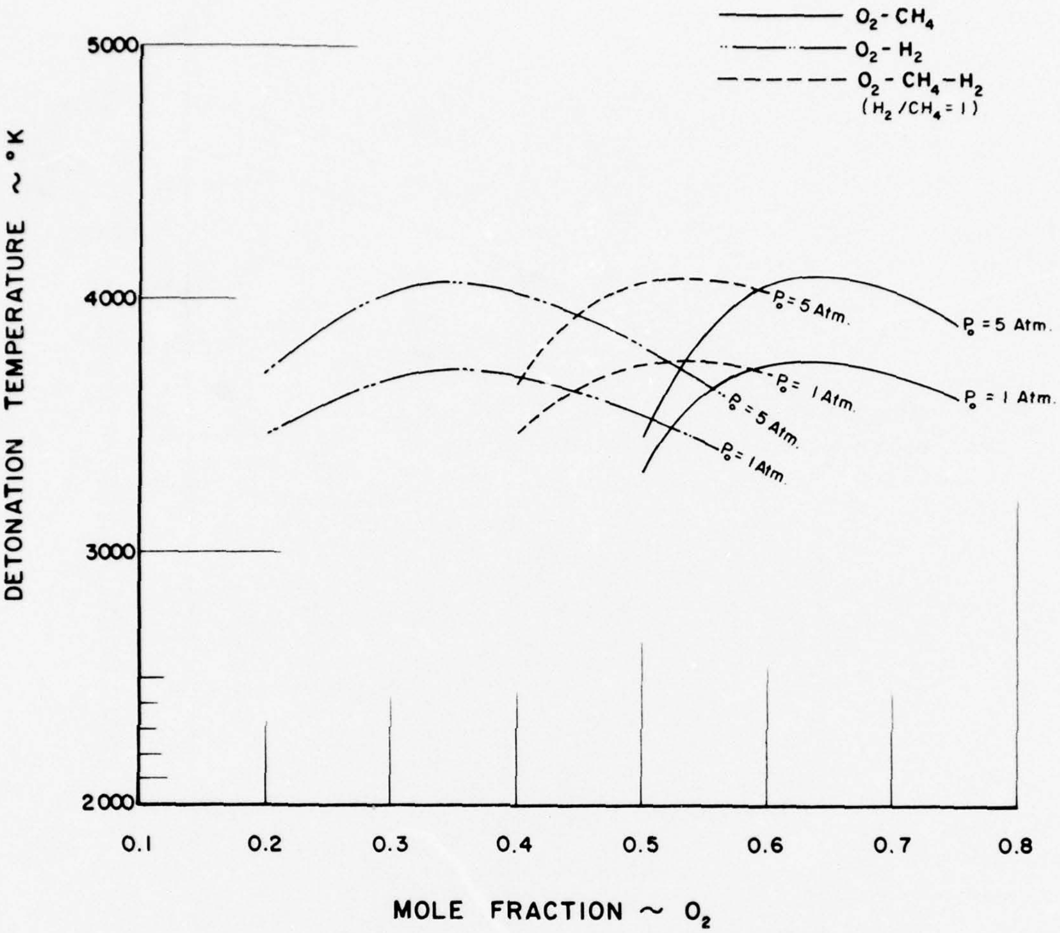


Figure 2.7 DETONATION TEMPERATURE FOR DETONATIONS IN THE TENARY SYSTEM OF OXYGEN, METHANE AND HYDROGEN

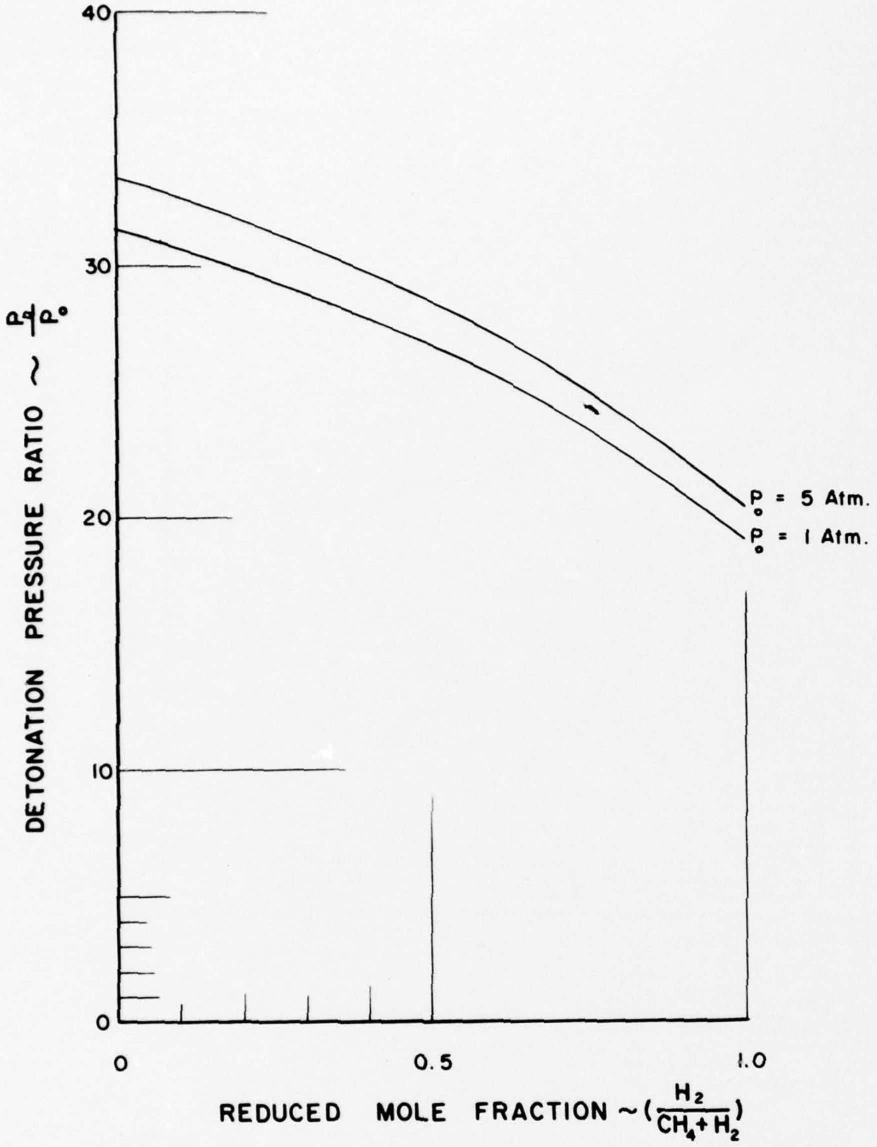


Figure 2.8 RATIO OF DETONATION PRESSURE TO INITIAL PRESSURE FOR DETONATIONS IN THE TERNARY SYSTEM OF OXYGEN, METHANE AND HYDROGEN.

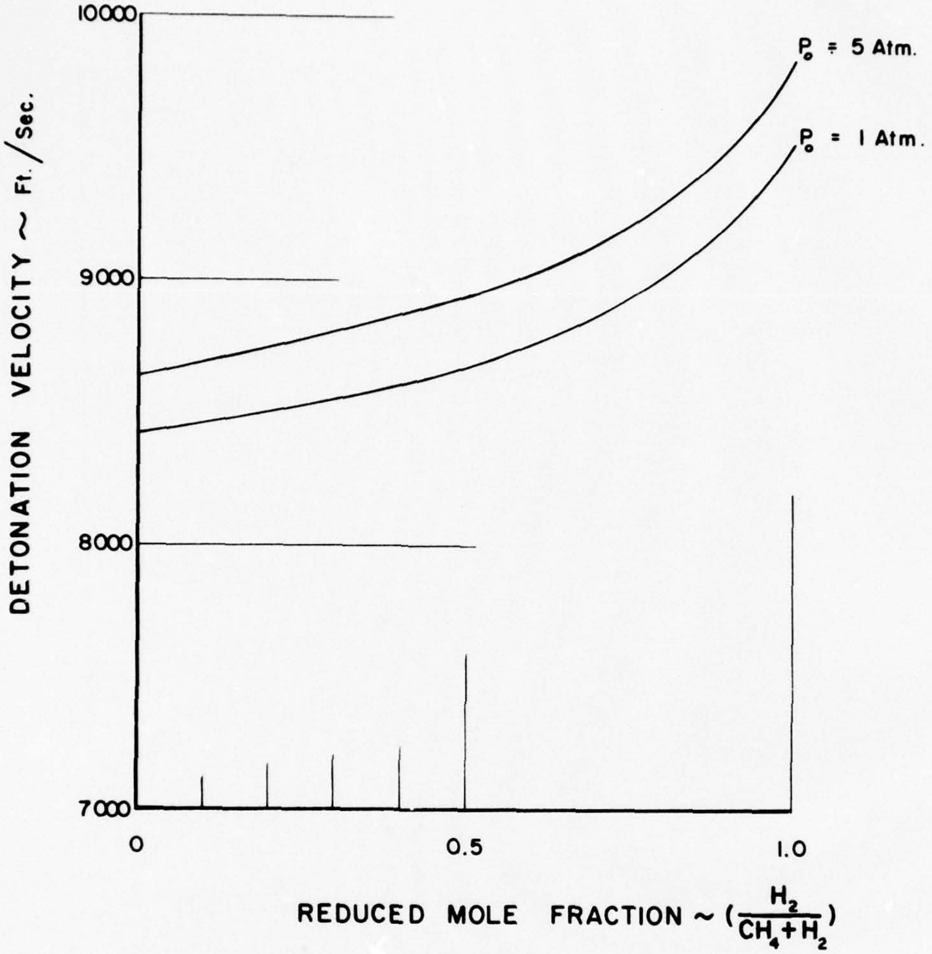


Figure 2.9 DETONATION VELOCITY FOR DETONATIONS IN THE TERNARY SYSTEM OF OXYGEN, METHANE AND HYDROGEN.

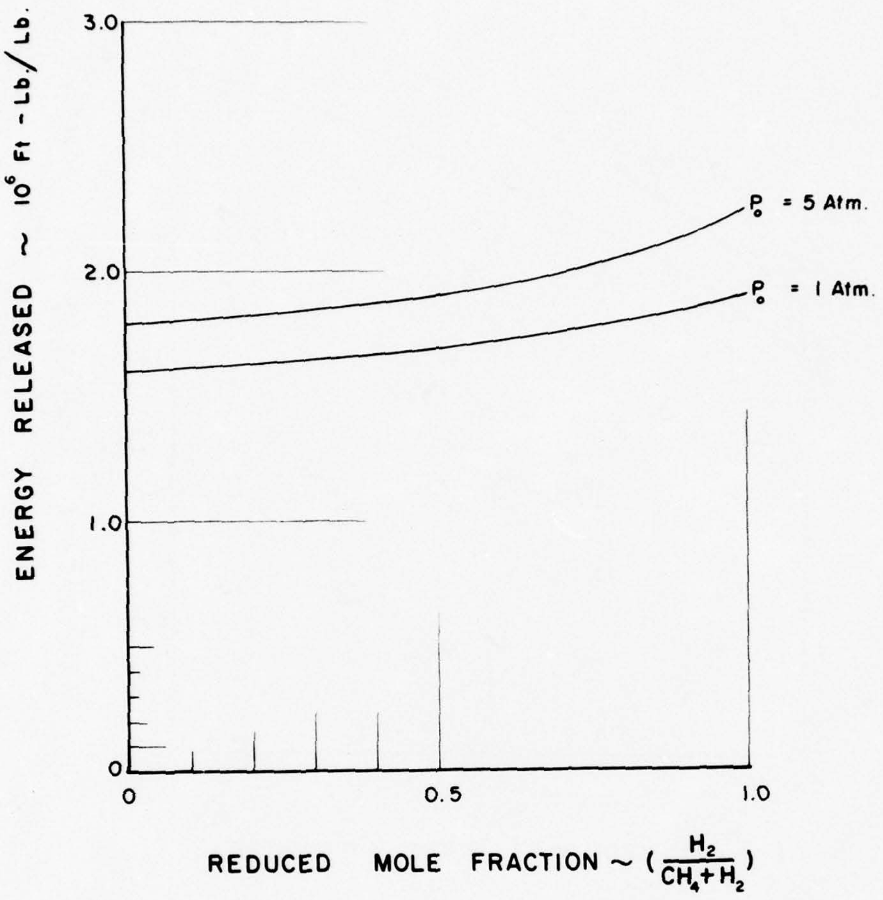


Figure 2.10 ENERGY RELEASED PER POUND OF GAS MIXTURE FOR DETONATIONS IN THE TERNARY SYSTEM OF OXYGEN, METHANE AND HYDROGEN.

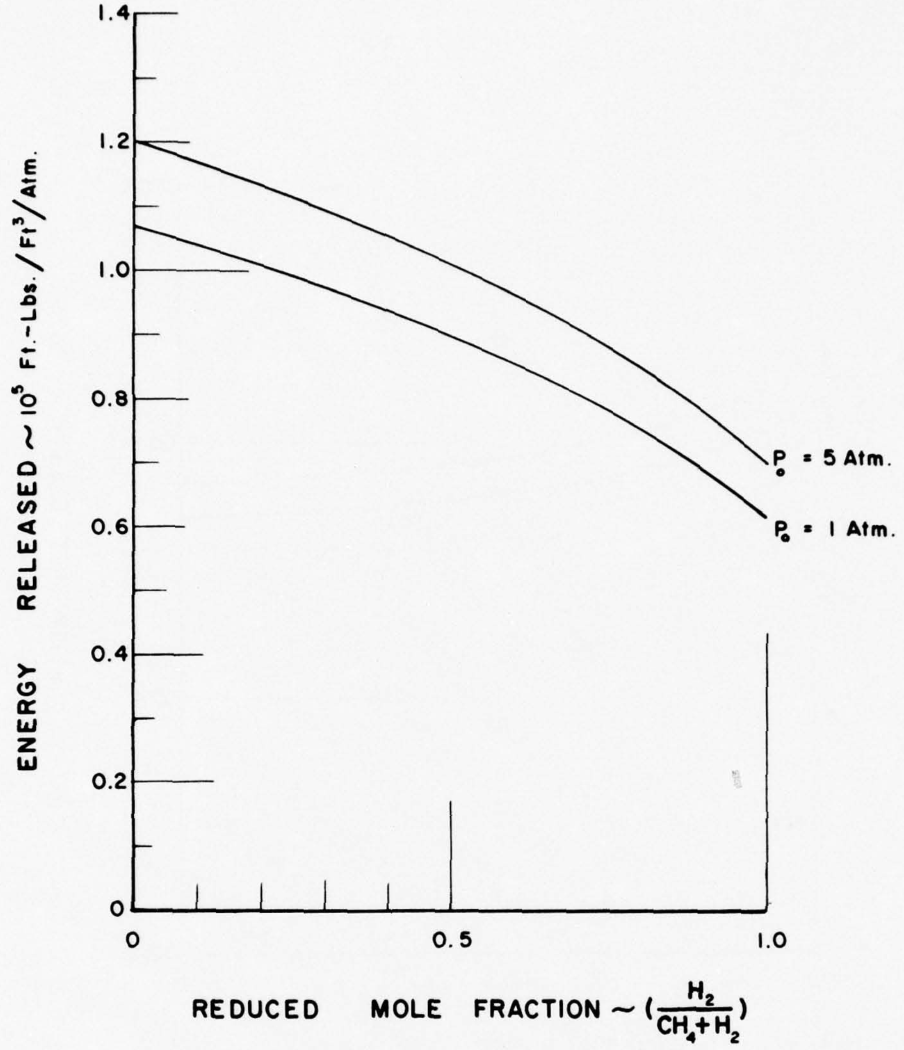


Figure 2.11 ENERGY RELEASED PER CUBIC FOOT PER ATMOSPHERE OF INITIAL PRESSURE FOR DETONATIONS IN THE TERNARY SYSTEM OF OXYGEN, METHANE AND HYDROGEN.

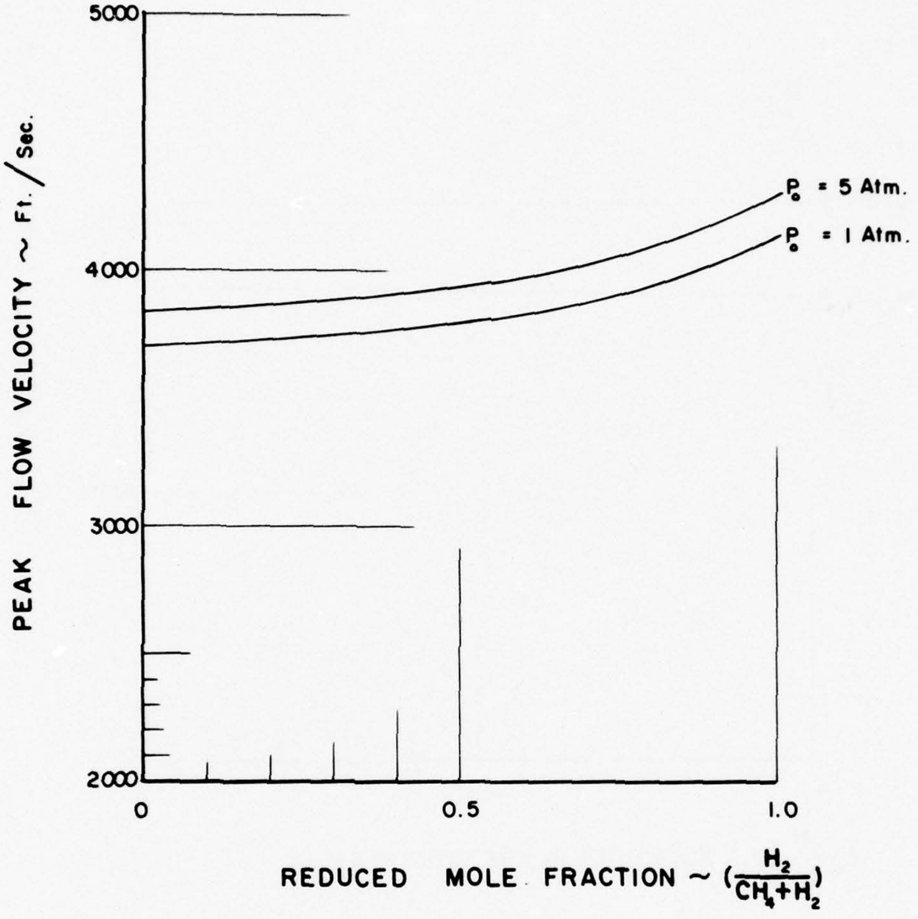


Figure 2.12 PEAK FLOW VELOCITY FOR DETONATIONS IN THE TERNARY SYSTEM OF OXYGEN, METHANE AND HYDROGEN.

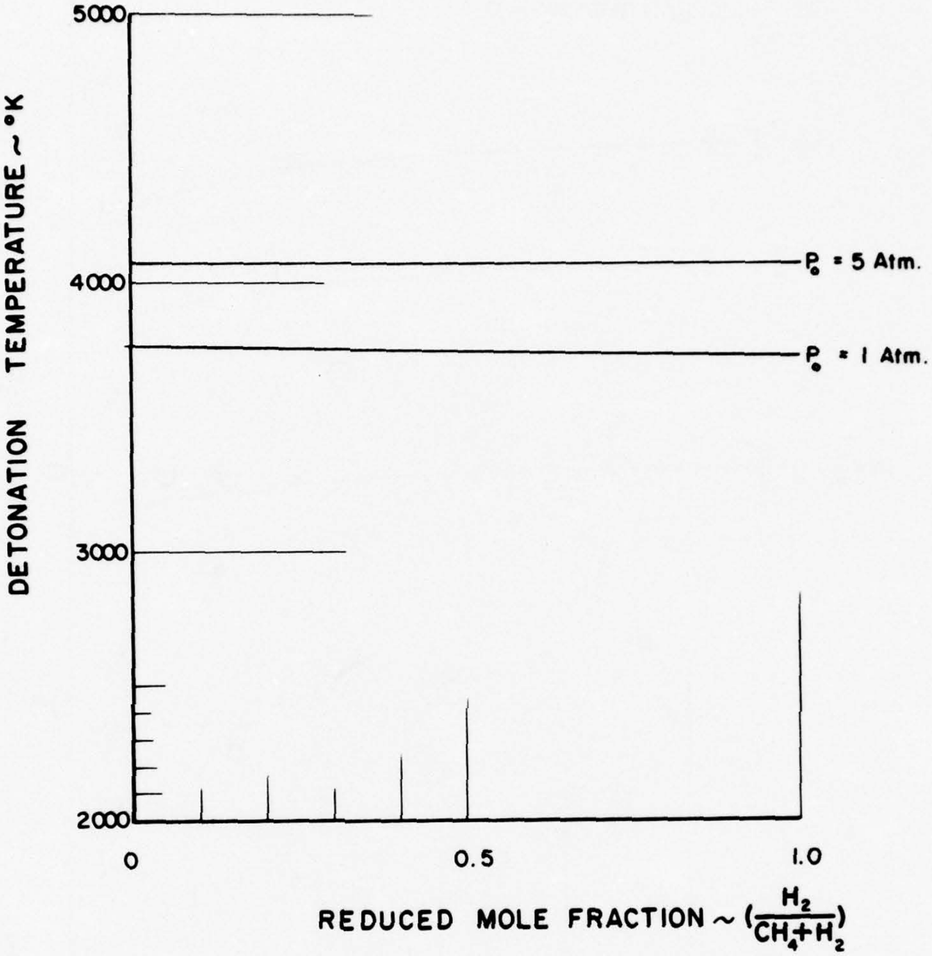


Figure 2.13 DETONATION TEMPERATURE FOR DETONATIONS IN THE TERNARY SYSTEM OF OXYGEN, METHANE AND HYDROGEN.

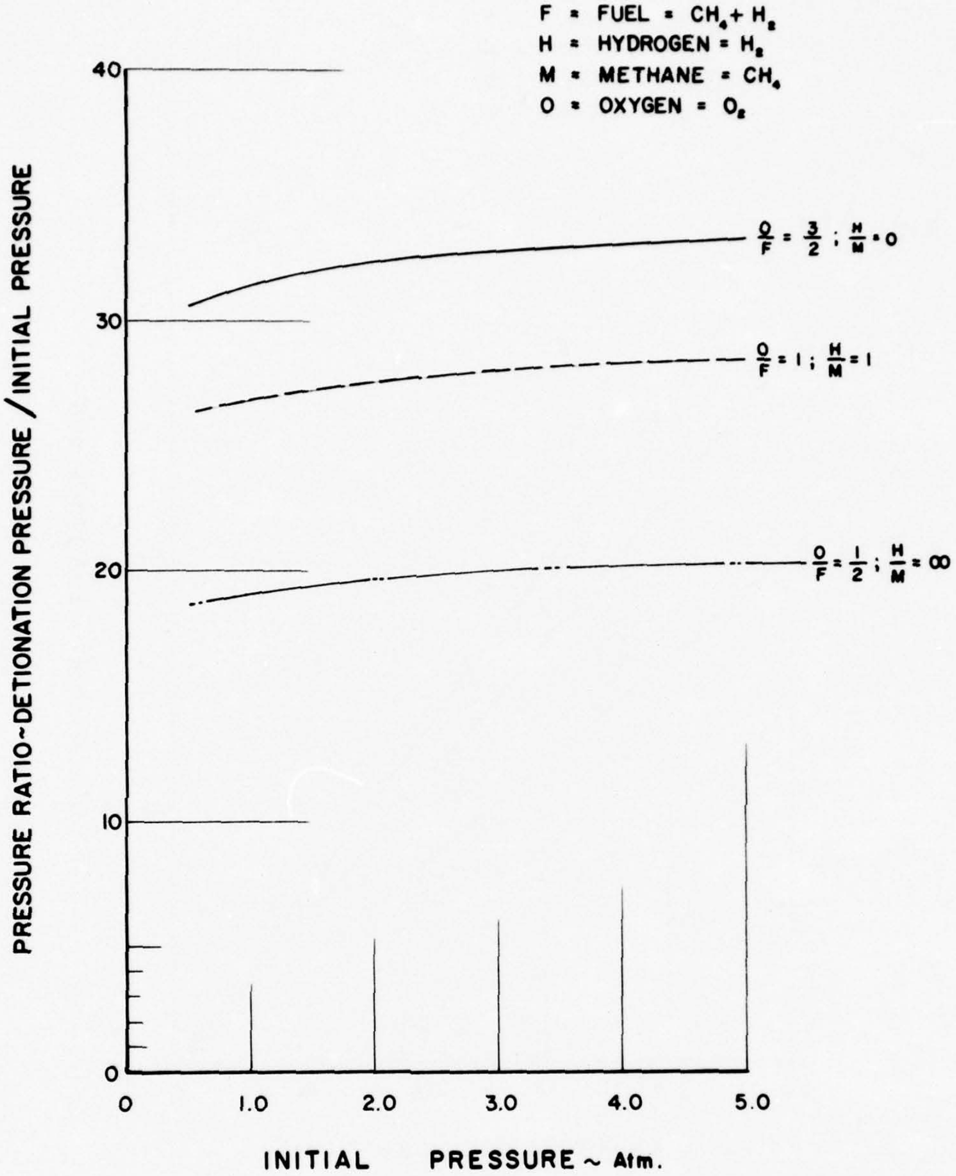


Figure 2.14 RATIO OF DETONATION PRESSURE TO INITIAL PRESSURE AS A FUNCTION OF INITIAL PRESSURE FOR DETONATIONS IN THE TERNARY SYSTEM OF OXYGEN, METHANE AND HYDROGEN.

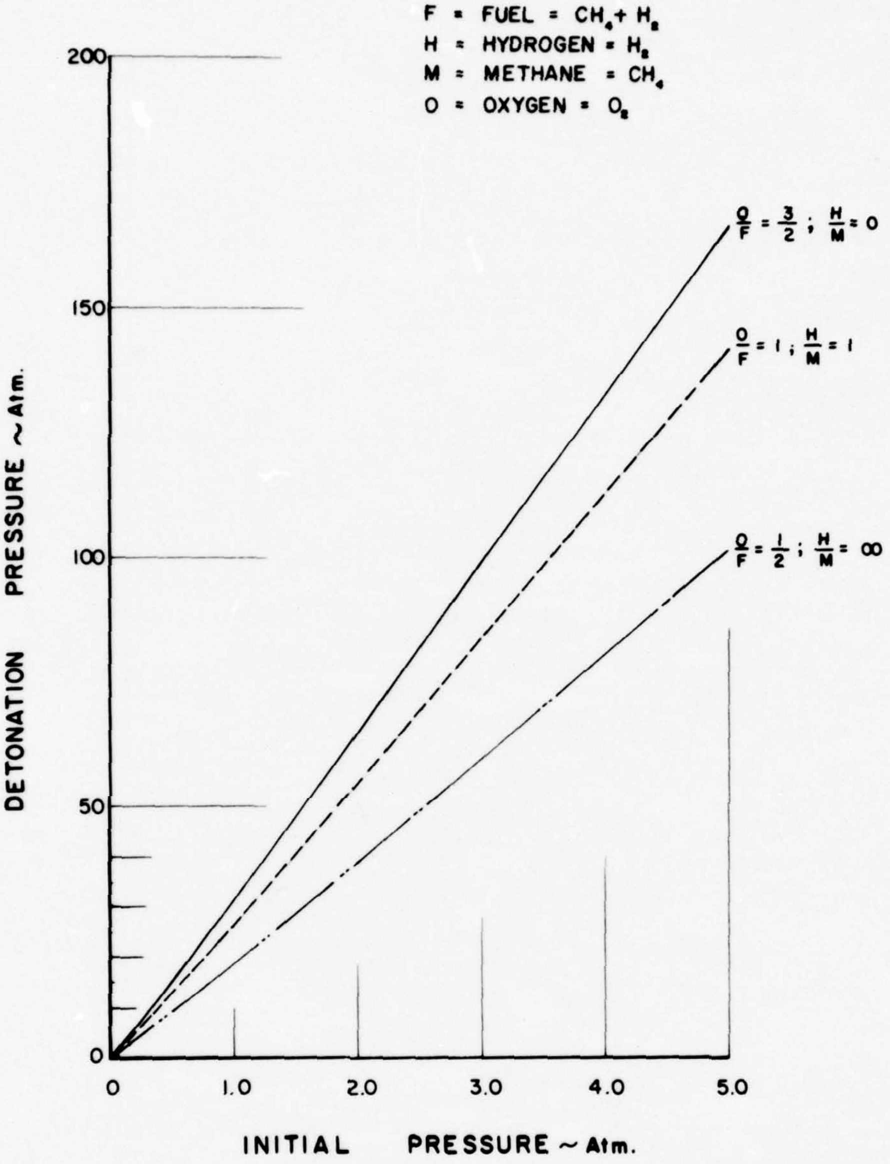


Figure 2.15 DETONATION PRESSURE AS A FUNCTION OF THE INITIAL PRESSURE FOR DETONATIONS IN THE TERNARY SYSTEM OF OXYGEN, METHANE AND HYDROGEN.

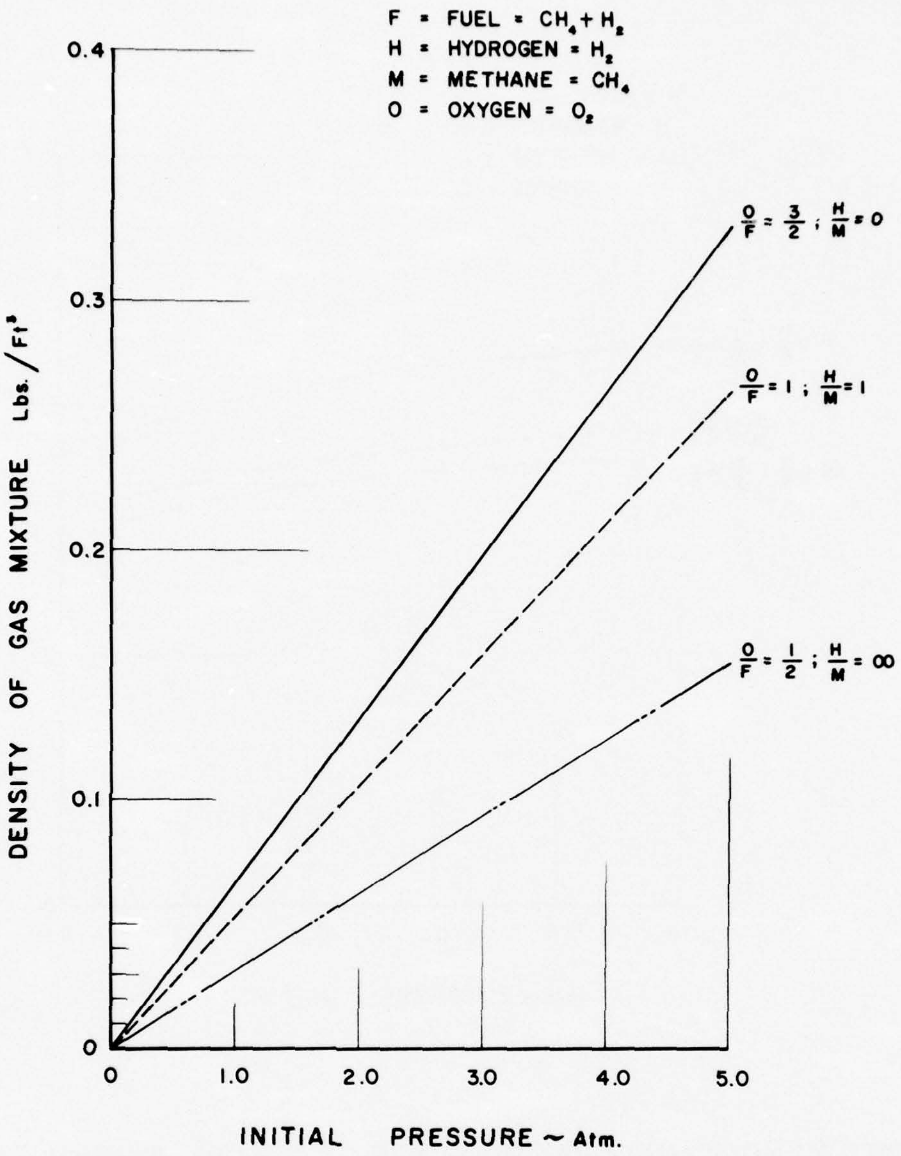


Figure 2.16 WEIGHT DENSITY OF THE GAS MIXTURE AS A FUNCTION OF THE INITIAL PRESSURE FOR DETONATIONS IN THE TERNARY SYSTEM OF OXYGEN, METHANE AND HYDROGEN.

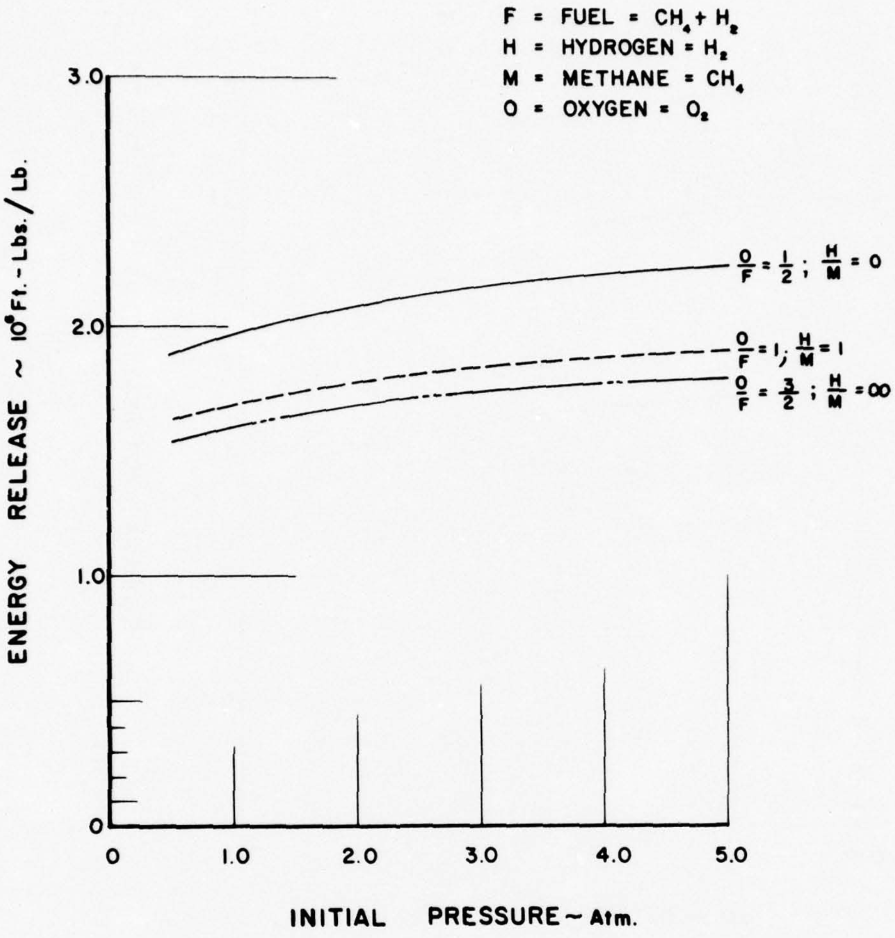


Figure 2.17 ENERGY RELEASED PER POUND AS A FUNCTION OF THE INITIAL PRESSURE FOR DETONATIONS IN THE TERNARY SYSTEM OF OXYGEN, METHANE AND HYDROGEN.

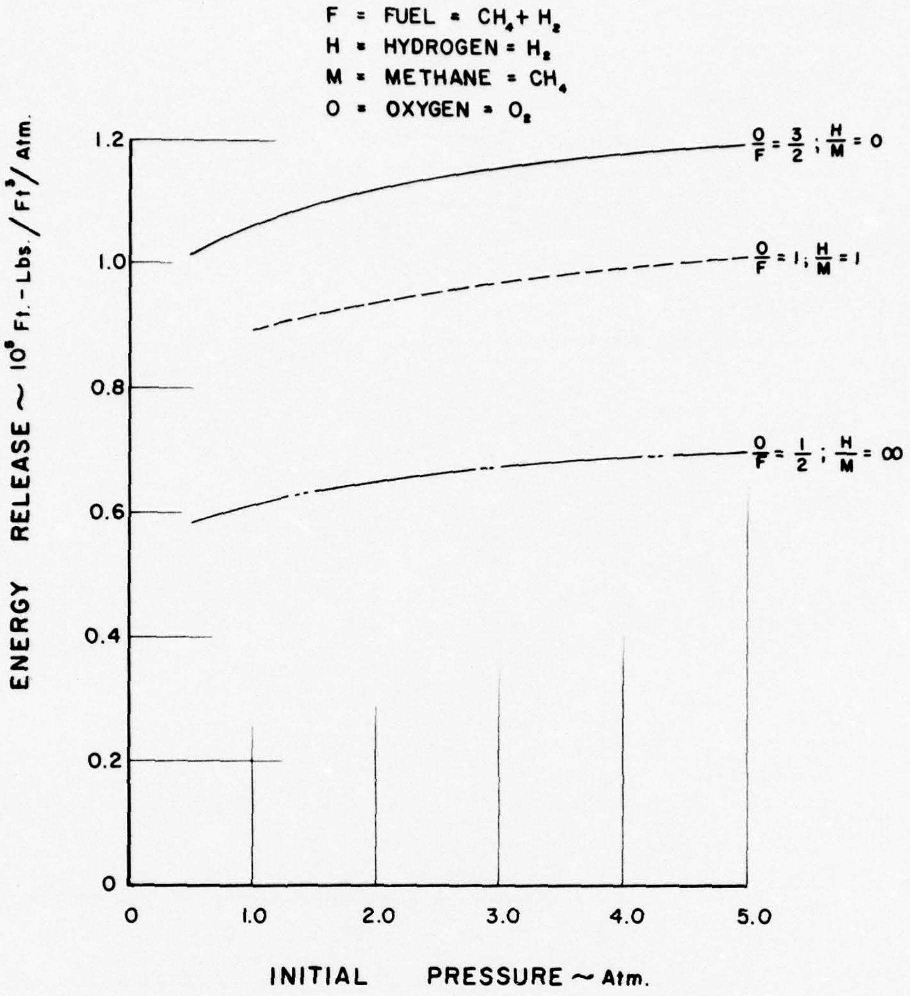


Figure 2.18 ENERGY RELEASED PER CUBIC FOOT PER ATMOSPHERE OF INITIAL PRESSURE AS A FUNCTION OF THE INITIAL PRESSURE FOR DETONATIONS IN THE TERNARY SYSTEM OF OXYGEN, METHANE AND HYDROGEN.

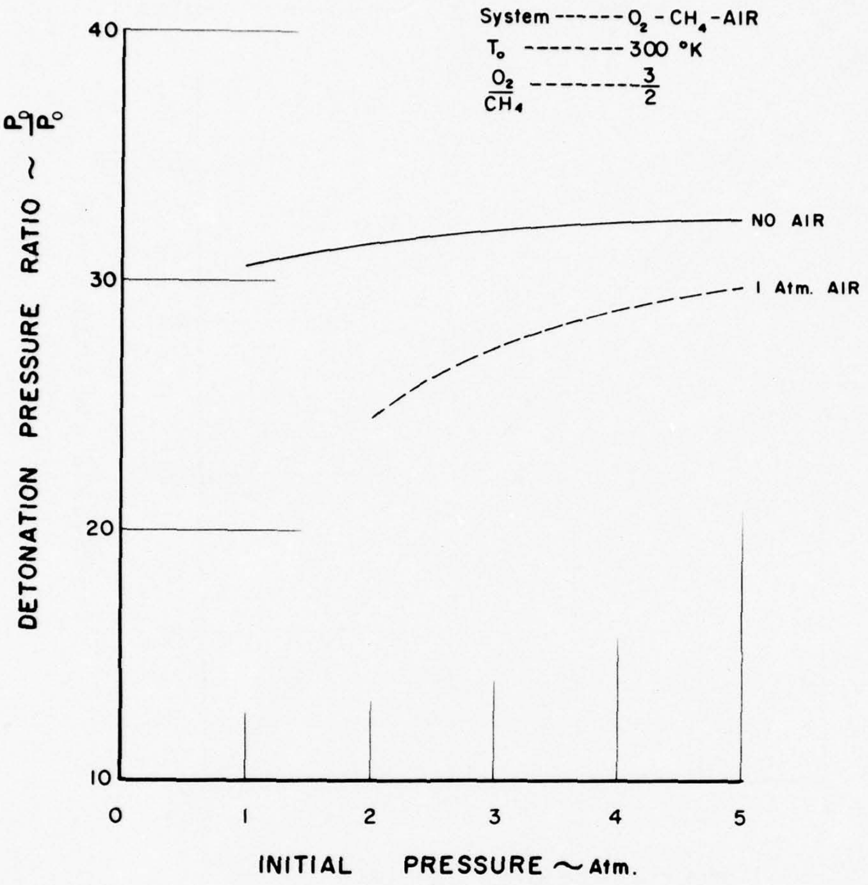


Figure 2.19 DETONATION PRESSURE TO INITIAL PRESSURE RATIO AS A FUNCTION OF THE INITIAL PRESSURE IN ATMOSPHERES FOR AN OXYGEN, METHANE AND AIR SYSTEM.

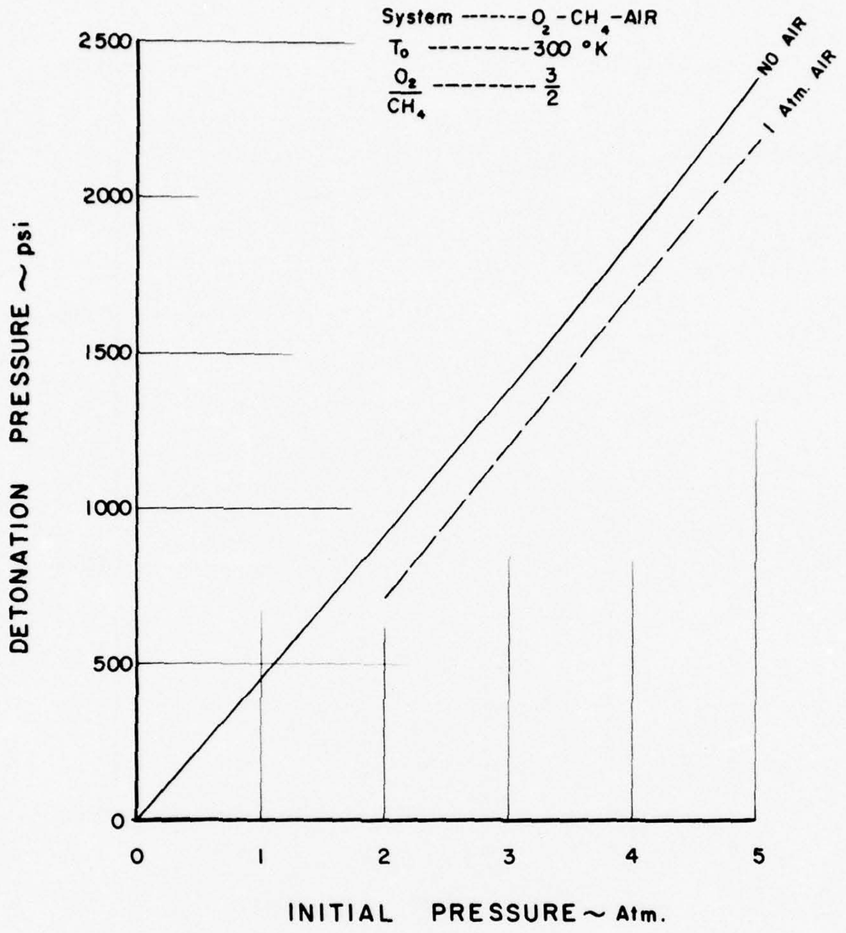


Figure 2.20 DETONATION PRESSURE AS A FUNCTION OF THE INITIAL PRESSURE IN ATMOSPHERES FOR AN OXYGEN, METHANE AND AIR SYSTEM.

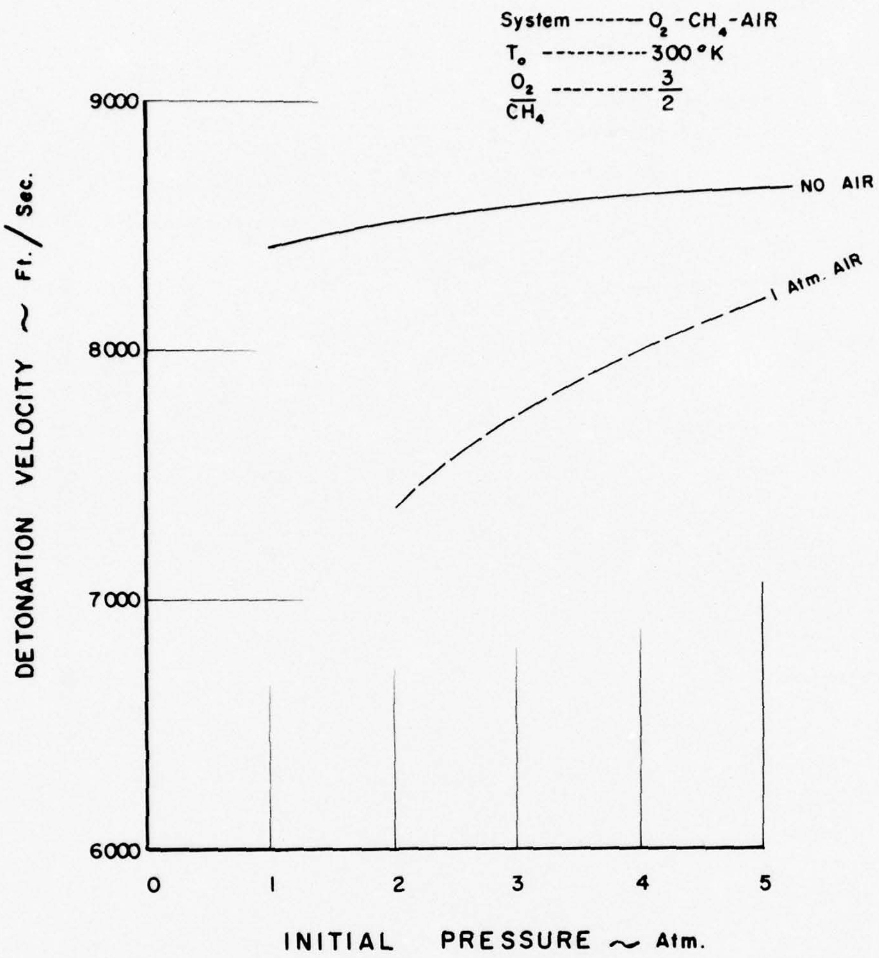


Figure 2.21 DETONATION VELOCITY AS A FUNCTION OF THE INITIAL PRESSURE IN ATMOSPHERES FOR AN OXYGEN, METHANE AND AIR SYSTEM.

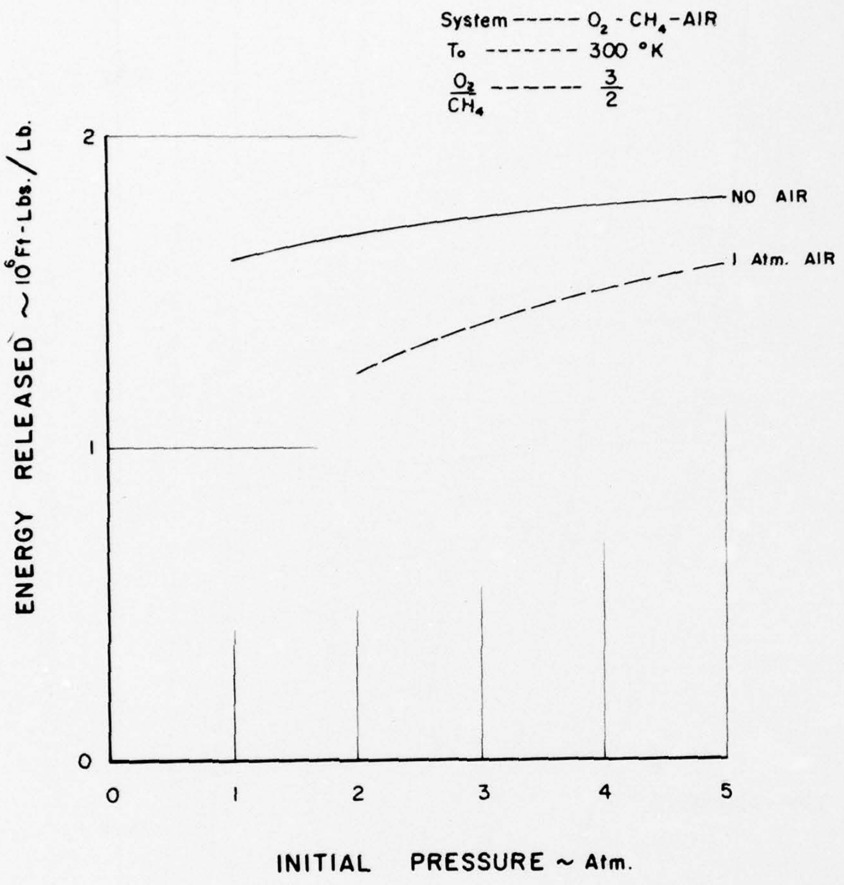


Figure 2.22 ENERGY RELEASED AS A FUNCTION OF THE INITIAL PRESSURE IN ATMOSPHERES FOR AN OXYGEN, METHANE AND AIR SYSTEM.

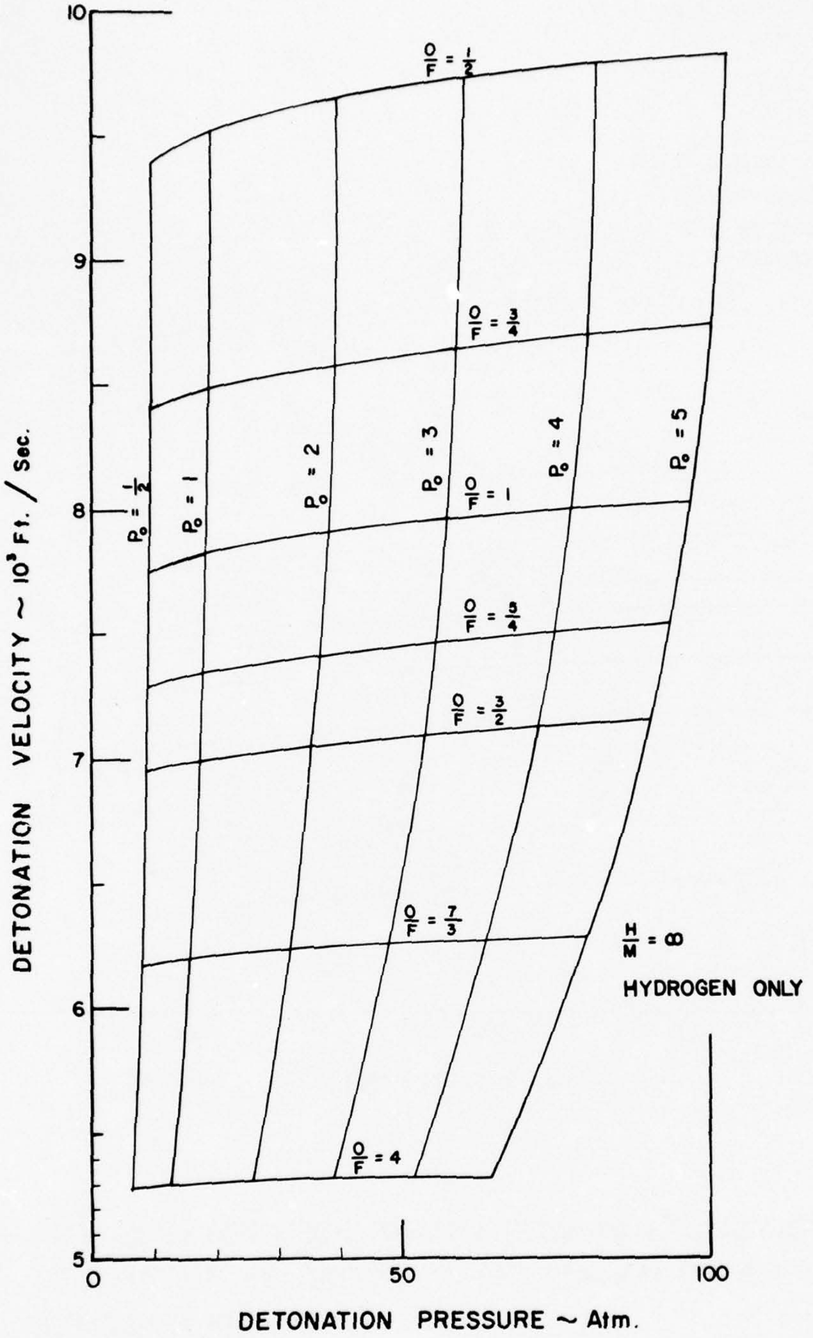


Figure 2.23 INITIAL DETONATION PARAMETERS AS A FUNCTION OF DETONATION VELOCITY AND DETONATION PRESSURE IN ATMOSPHERES.

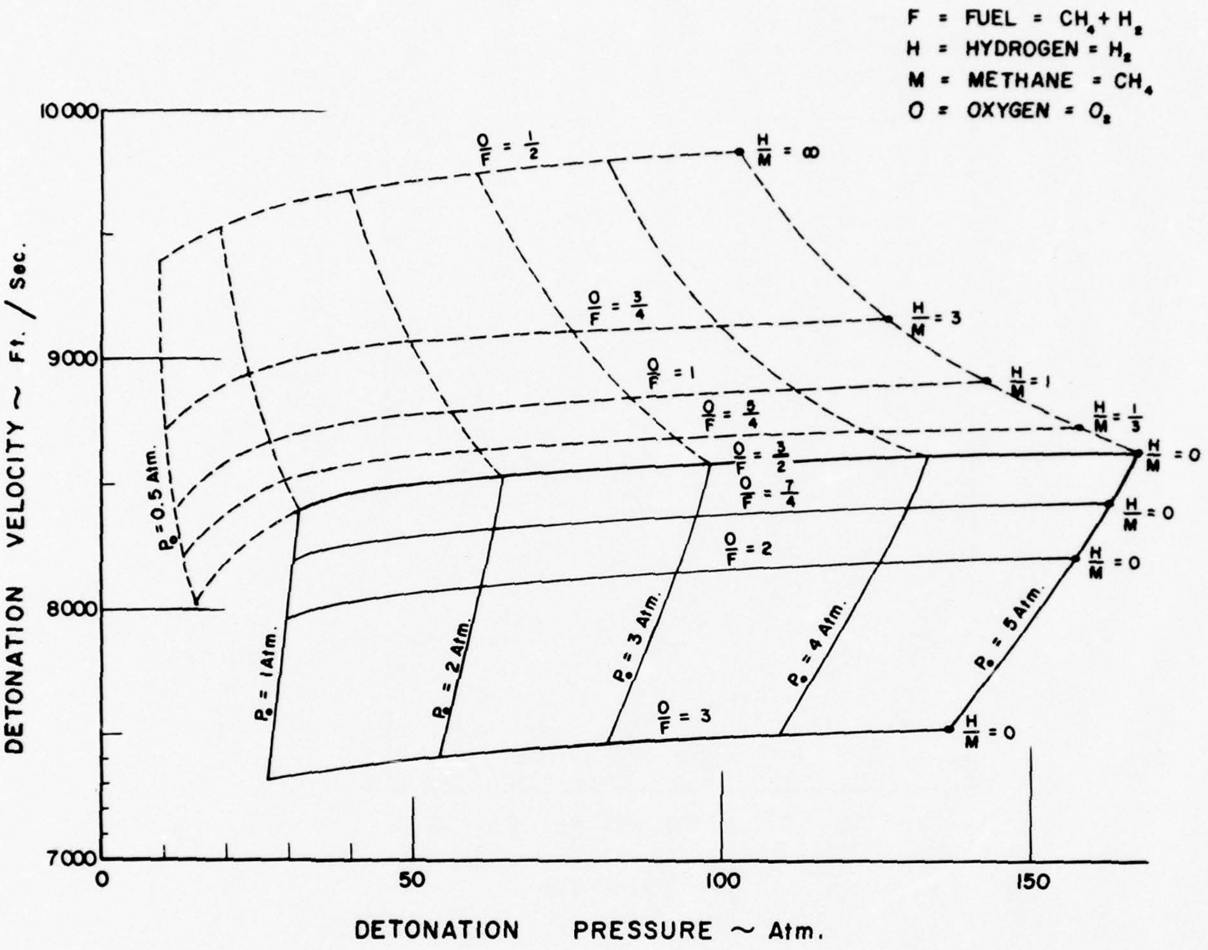


Figure 2.24 INITIAL DETONATION PARAMETERS AS A FUNCTION OF DETONATION VELOCITY AND DETONATION PRESSURE IN ATMOSPHERES.

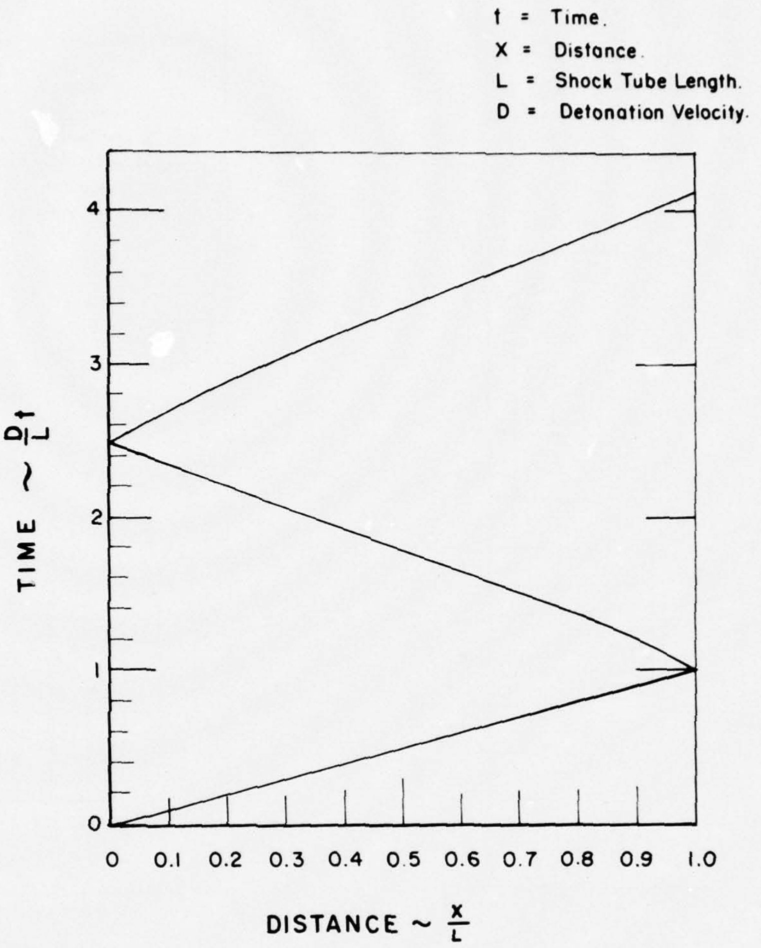


Figure 2.25 POSITIONS OF DETONATION FRONT AND REFLECTED SHOCK FRONTS AS A FUNCTION OF TIME.

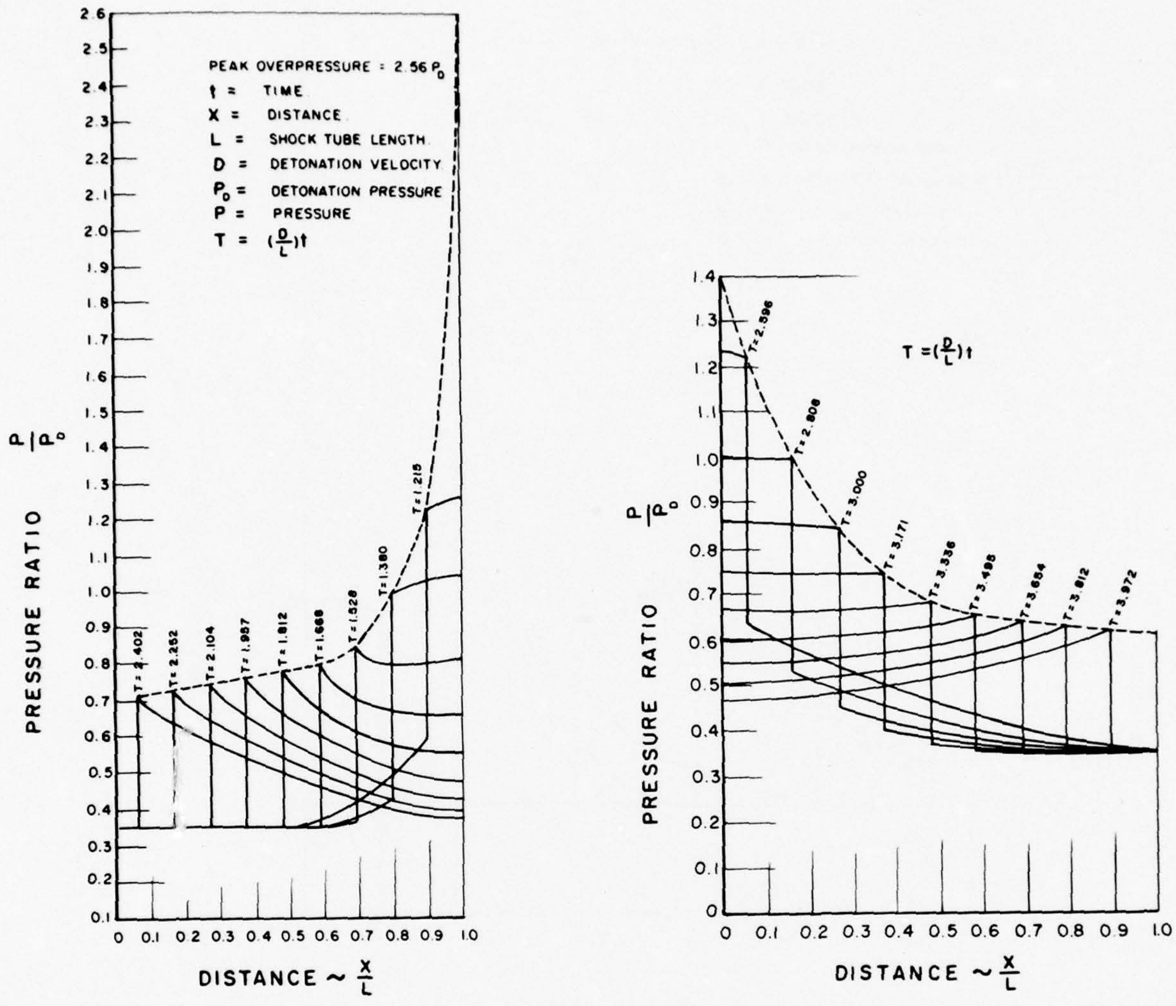


Figure 2.26 PRESSURE PROFILES AT SELECTED TIMES ALONG THE LENGTH OF THE DETONATION TUBE.

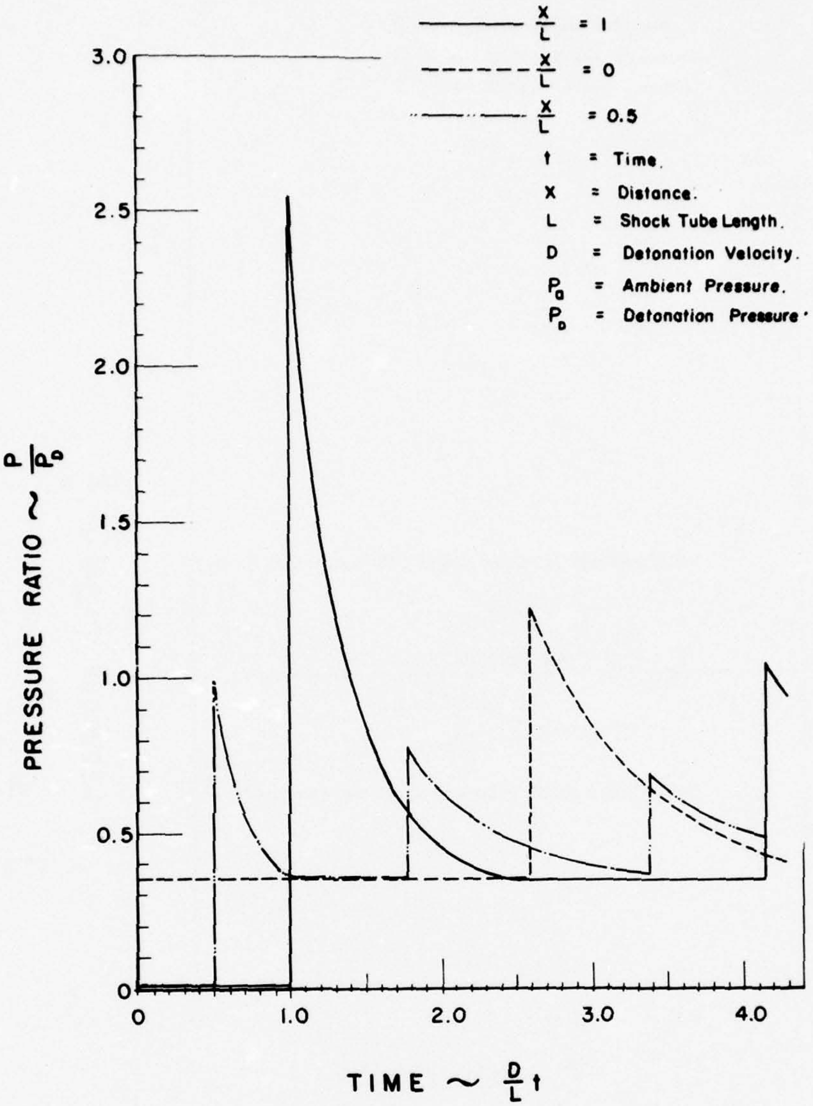


Figure 2.27 PRESSURE VERSUS TIME AT SELECTED POSITIONS IN THE DETONATION TUBE.

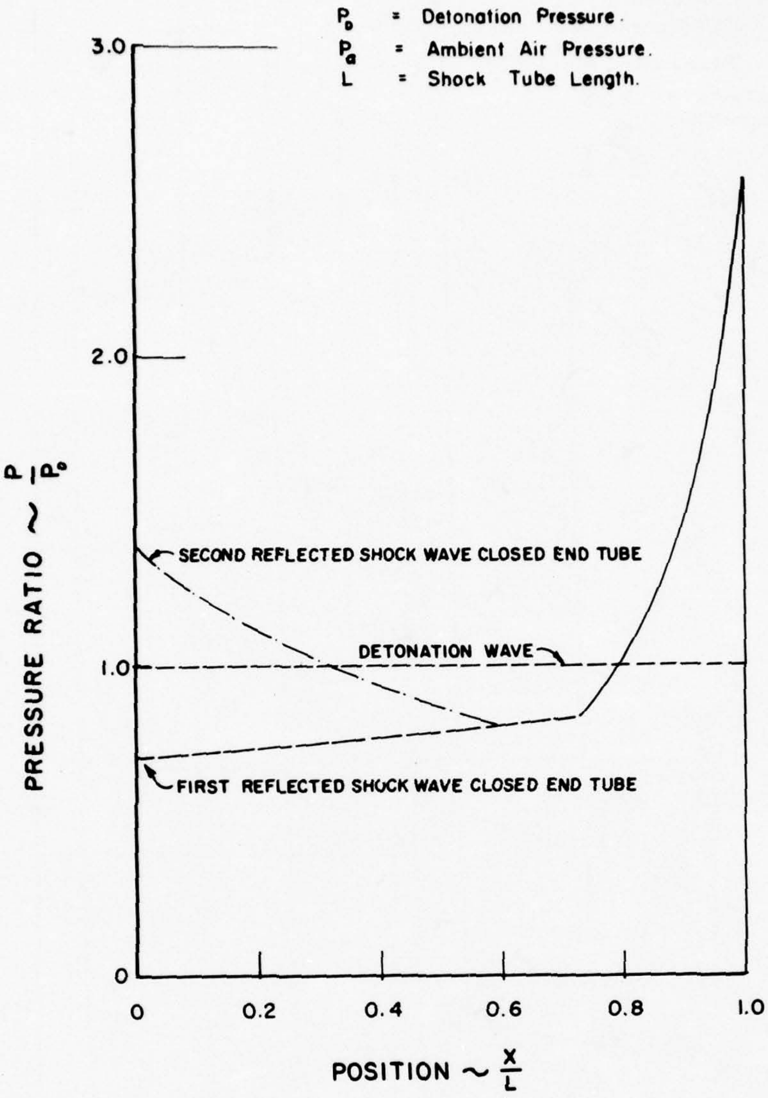


Figure 2.28 PEAK PRESSURE VERSUS DISTANCE ALONG THE DETONATION TUBE.

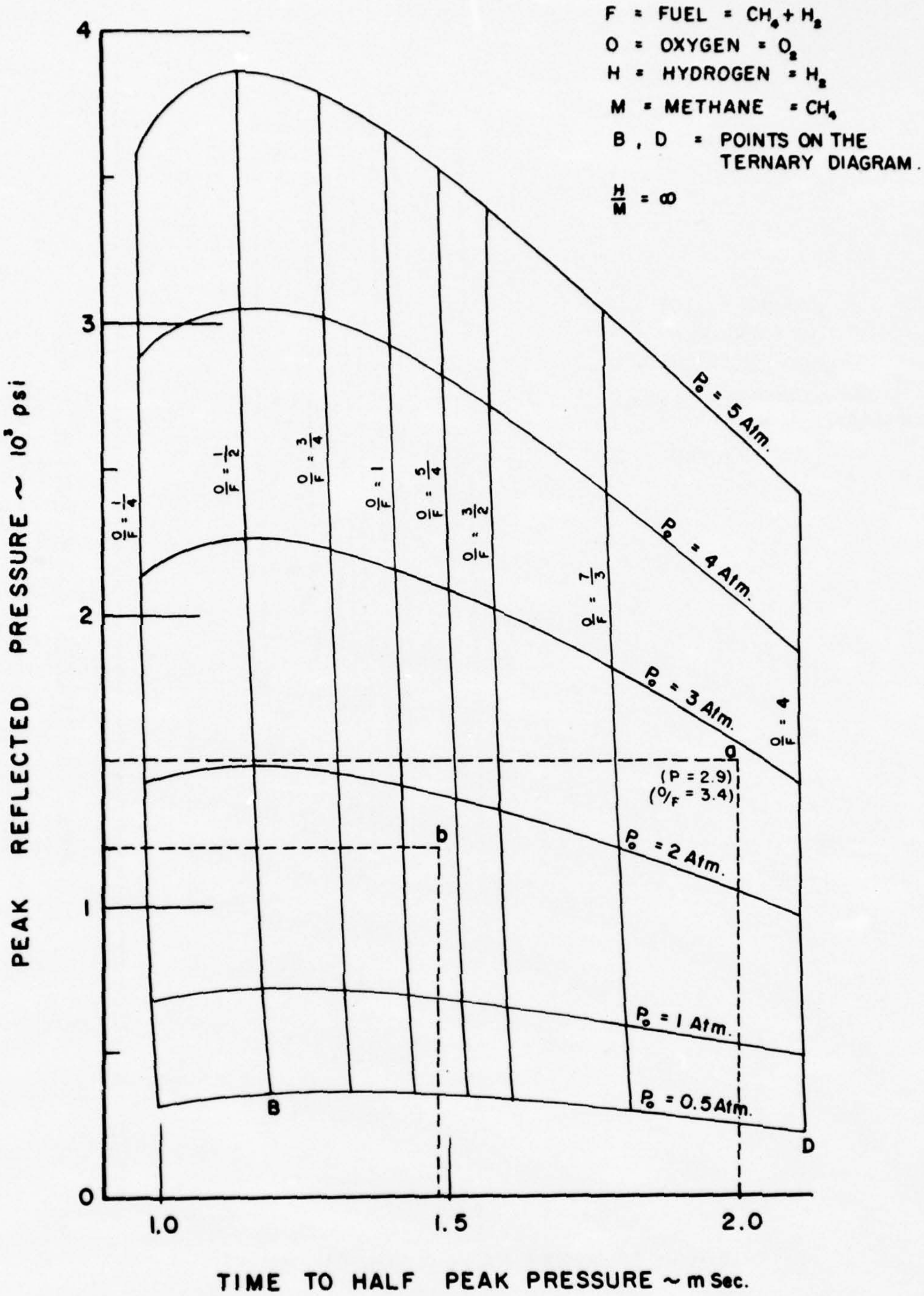


Figure 2.29 INITIAL DETONATION PARAMETERS AS A FUNCTION OF THE PEAK REFLECTED PRESSURE AND DECAY TIME TO HALF PEAK PRESSURE.

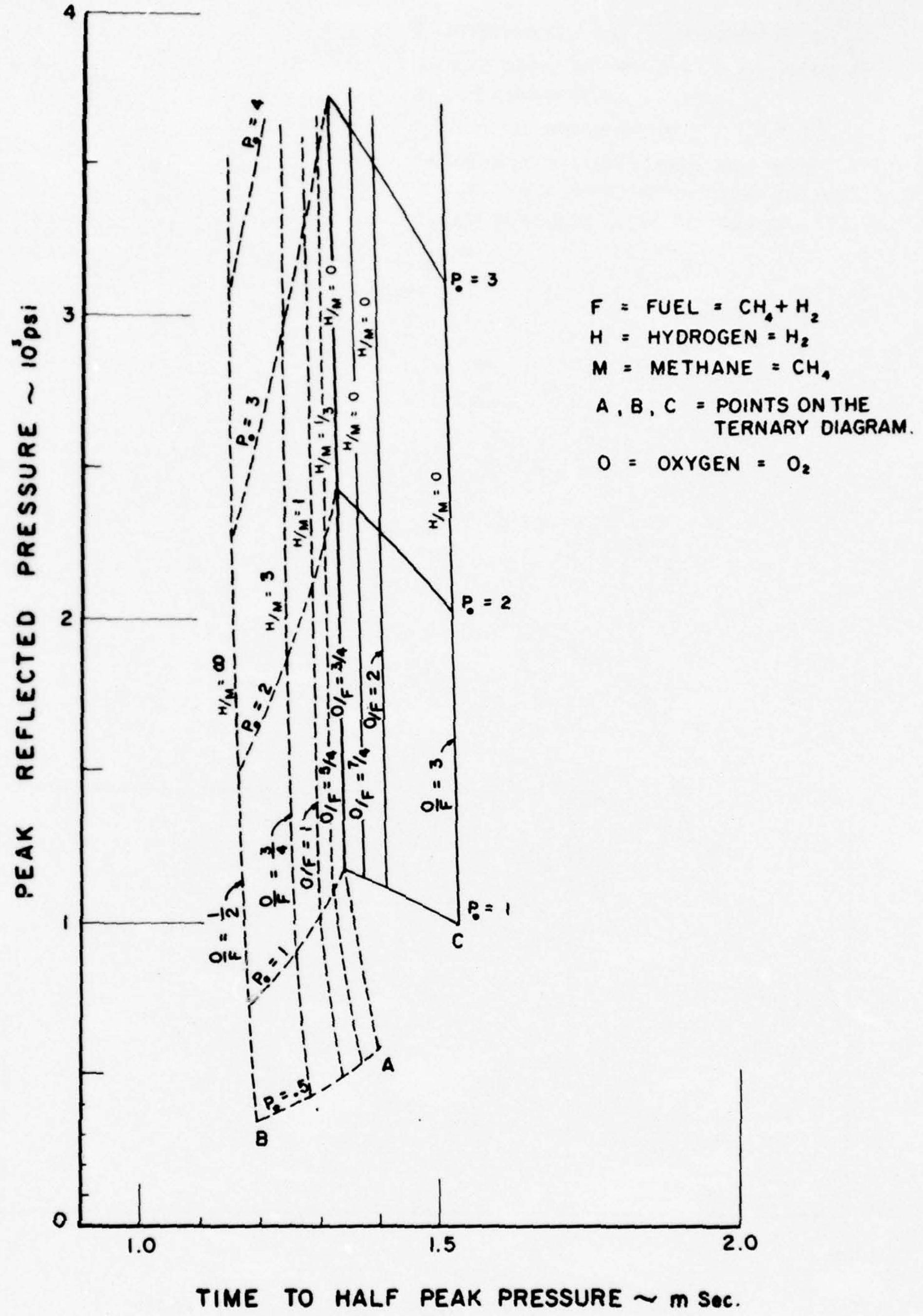
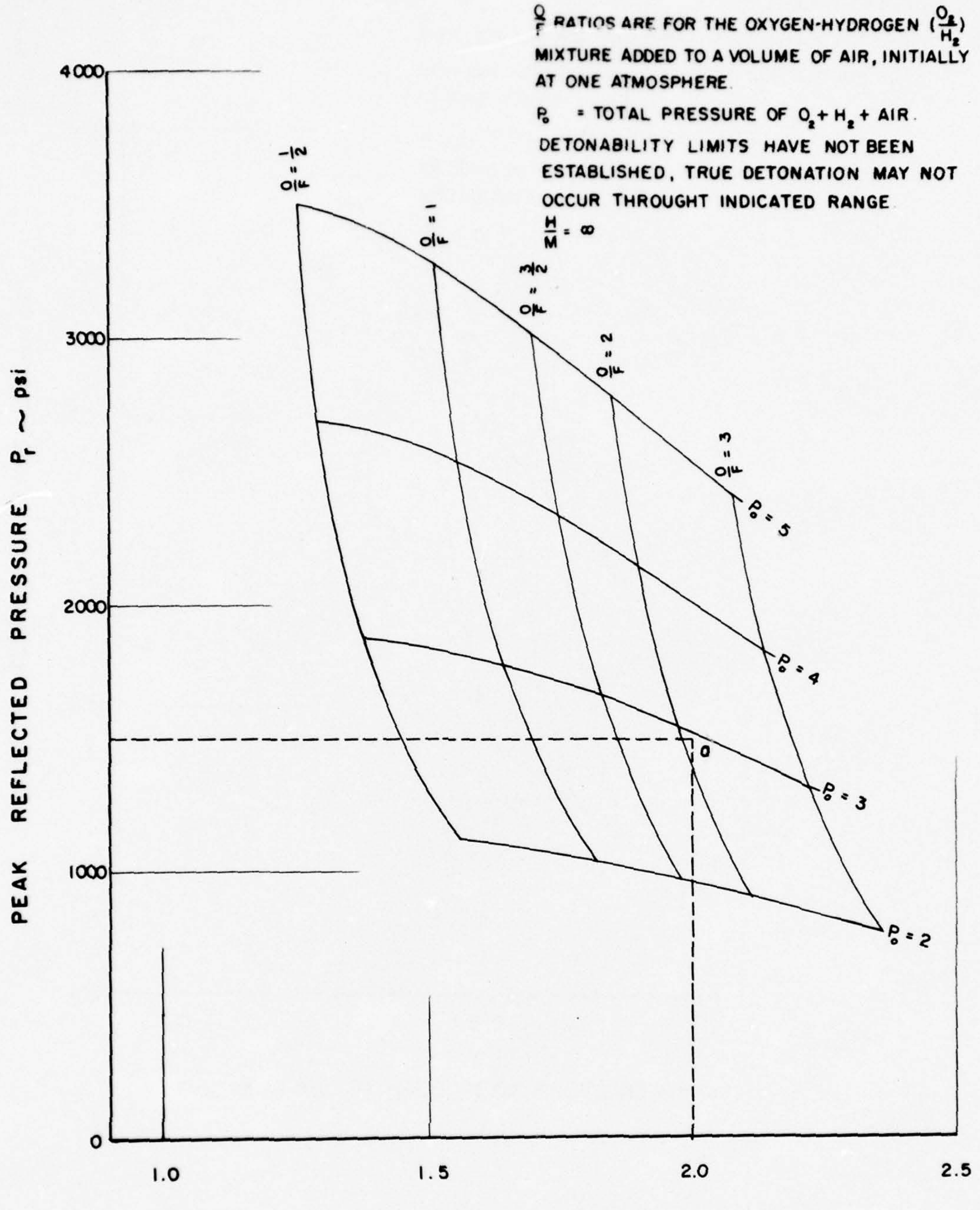


Figure 2.30 INITIAL DETONATION PARAMETERS AS A FUNCTION OF THE PEAK REFLECTED PRESSURE AND DECAY TIME TO HALF PEAK PRESSURE.



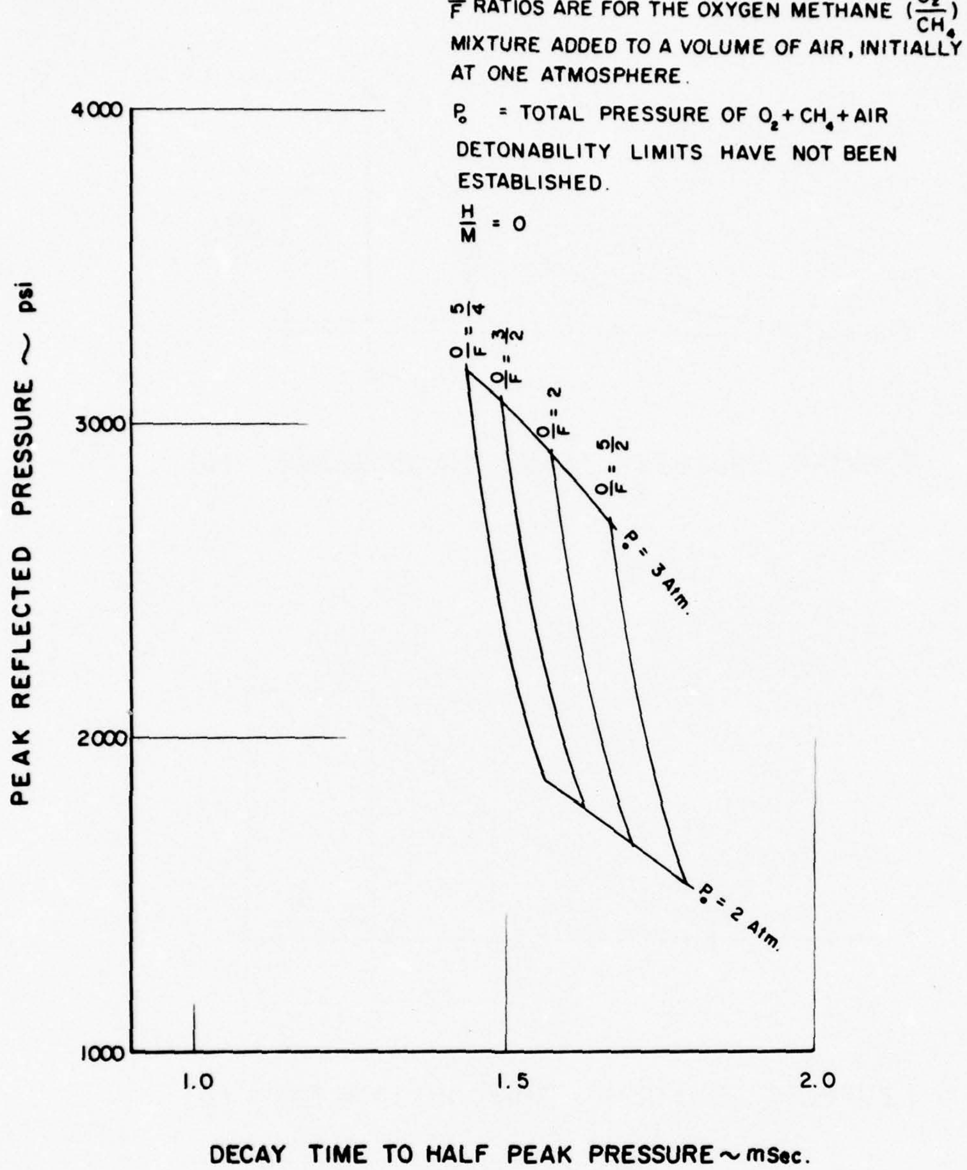
$\frac{O}{F}$ RATIOS ARE FOR THE OXYGEN-HYDROGEN ($\frac{O_2}{H_2}$) MIXTURE ADDED TO A VOLUME OF AIR, INITIALLY AT ONE ATMOSPHERE.

P_o = TOTAL PRESSURE OF $O_2 + H_2$ + AIR.

DETONABILITY LIMITS HAVE NOT BEEN ESTABLISHED, TRUE DETONATION MAY NOT OCCUR THROUGHT INDICATED RANGE.

$\frac{H}{M} = \infty$

Figure 2.31 INITIAL DETONATION PARAMETERS AS A FUNCTION OF PEAK REFLECTED PRESSURE AND DECAY TIME TO HALF PEAK PRESSURE - ONE ATMOSPHERE AIR INITIALLY PRESENT.



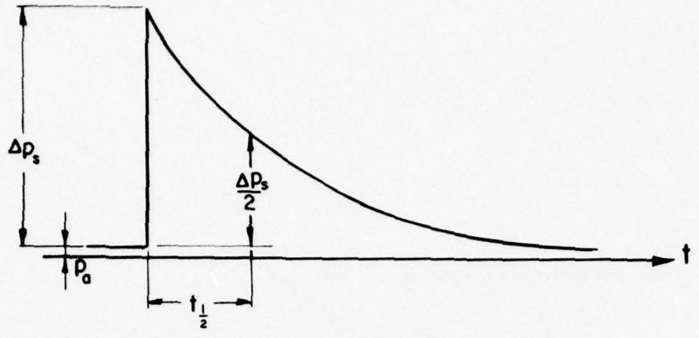
$\frac{O}{F}$ RATIOS ARE FOR THE OXYGEN METHANE $(\frac{O_2}{CH_4})$ MIXTURE ADDED TO A VOLUME OF AIR, INITIALLY AT ONE ATMOSPHERE.

P_o = TOTAL PRESSURE OF $O_2 + CH_4 +$ AIR

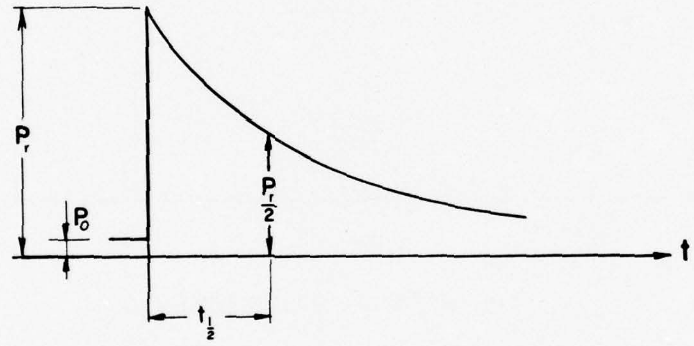
DETONABILITY LIMITS HAVE NOT BEEN ESTABLISHED.

$\frac{H}{M} = 0$

Figure 2.32 INITIAL DETONATION PARAMETERS AS A FUNCTION OF PEAK REFLECTED PRESSURE AND DECAY TIME TO HALF PEAK PRESSURE-METHANE OXYGEN ADDED TO AIR.



(a) NUCLEAR AIR BLAST PRESSURE PROFILE



(b) DETONATION TUBE PRESSURE PROFILE

Figure 2.33 SCHEMATIC DRAWING SHOWING DECAY TIME TO HALF PEAK PRESSURE.

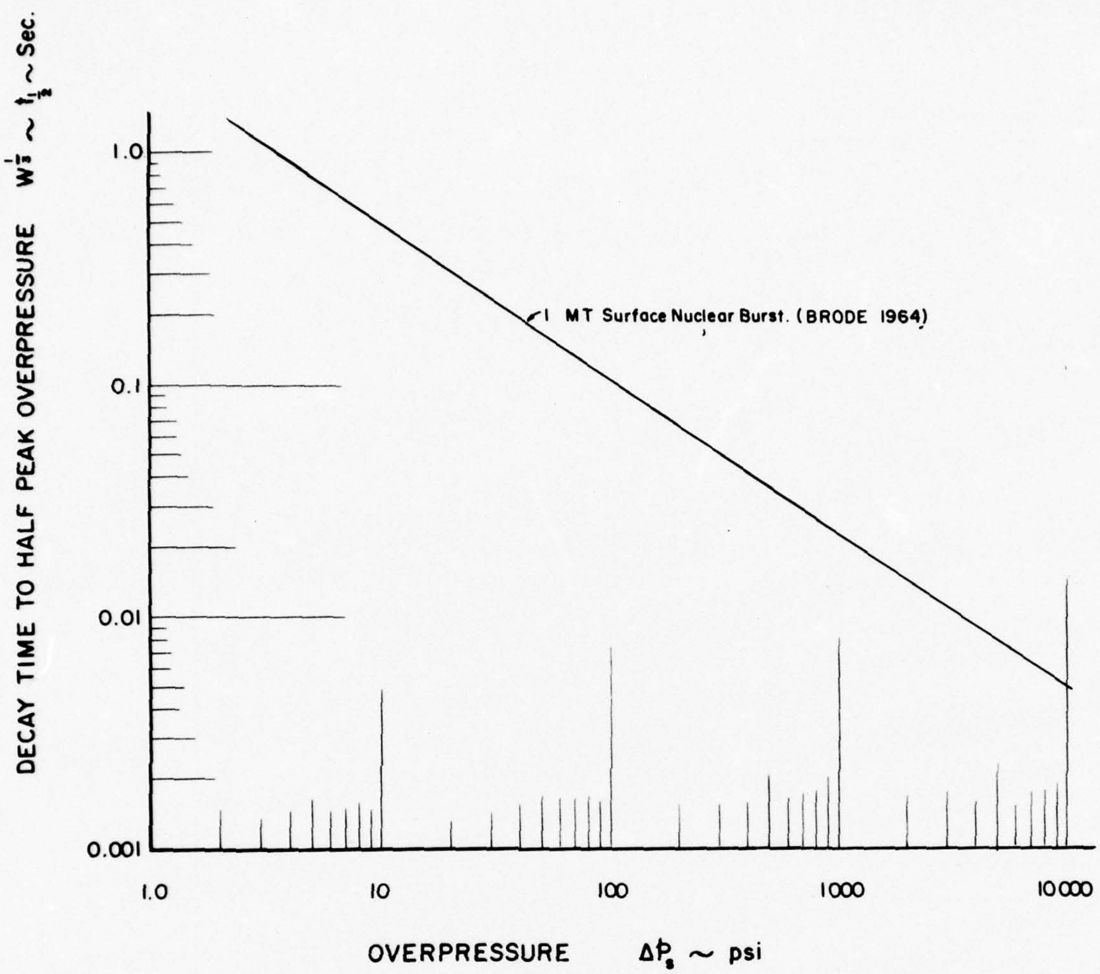


Figure 2.34 DECAY TIME TO HALF PEAK OVERPRESSURE VERSUS OVERPRESSURE FOR A ONE M.T. SURFACE NUCLEAR BURST ADAPTED FROM BRODE 1964.

TABLE 2.1

DETONATION PARAMETERS

IN THE TERNARY SYSTEM O_2-CH_4-H_2

Initial Conditions

	Mole Fraction O_2 n_1	Mole Fraction CH_4 n_2	Mole Fraction H_2 n_3	Mole Ratio $\frac{O_2}{CH_4}$	Mole Ratio $\frac{O_2}{H_2}$	Initial Pressure P_o (ATM)	Initial Density ρ_o (lbs/ft^3)
				BINARY SYSTEM - CH_4-O_2			
1.	0.6000	0.4000	.0000	1.5	0.000	0.5	.0332
2.	0.6000	0.4000	.0000	1.5	0.000	1.0	.0664
3.	0.6000	0.4000	.0000	1.5	0.000	2.0	.1329
4.	0.6000	0.4000	.0000	1.5	0.000	3.0	.1993
5.	0.6000	0.4000	.0000	1.5	0.000	5.0	.3322
6.	0.5000	0.5000	.0000	1.0	0.000	1.0	.0623
7.	0.5000	0.5000	.0000	1.0	0.000	5.0	.3115
8.	0.6667	0.3333	.0000	2.0	0.000	1.0	.0692
9.	0.6667	0.3333	.0000	2.0	0.000	5.0	.3461
10.	0.5556	0.4444	.0000	1.25	0.000	1.0	.0646
11.	0.5556	0.4444	.0000	1.25	0.000	5.0	.3230
12.	0.6364	0.3636	.0000	1.75	0.000	1.0	.0680
13.	0.6364	0.3636	.0000	1.75	0.000	5.0	.3398
14.	0.7500	0.2500	.0000	3.0	0.000	1.0	.0727
15.	0.7500	0.2500	.0000	3.0	0.000	5.0	.3634
				BINARY SYSTEM - O_2-H_2			
16.	0.3333	0.0000	.6667	0.000	0.5	0.5	.0156
17.	0.3333	0.0000	.6667	0.000	0.5	1.0	.0311
18.	0.3333	0.0000	.6667	0.000	0.5	2.0	.0623
19.	0.3333	0.0000	.6667	0.000	0.5	3.0	.0934
20.	0.3333	0.0000	.6667	0.000	0.5	5.0	.1557
21.	0.5000	0.0000	.5000	0.000	1.0	1.0	.0441
22.	0.5000	0.0000	.5000	0.000	1.0	5.0	.2206
23.	0.4286	0.0000	.5714	0.000	0.75	1.0	.0386
24.	0.4286	0.0000	.5714	0.000	0.75	5.0	.1928
25.	0.2000	0.0000	.8000	0.000	0.25	1.0	.0208
26.	0.2000	0.0000	.8000	0.000	0.25	5.0	.1038
27.	0.5556	0.0000	.4444	0.000	1.25	1.0	.0484
28.	0.5556	0.0000	.4444	0.000	1.25	5.0	.2422

Cont'd

TABLE 2.1

DETONATION PARAMETERS

IN THE TERNARY SYSTEM O_2-CH_4-H_2

Initial Conditions

	Mole Fraction O_2 n_1	Mole Fraction CH_4 n_2	Mole Fraction H_2 n_3	Mole Ratio $\frac{O_2}{CH_4}$	Mole Ratio $\frac{O_2}{H_2}$	Initial Pressure P_o (ATM)	Initial Density ρ_o (lbs/ft^3)
O_2-H_2	Cont'd.						
29.	0.6000	0.0000	.4000	0.000	1.5	1.0	.0519
30.	0.6000	0.0000	.4000	0.000	1.5	5.0	.2595
31.	0.7000	0.0000	.3000	0.000	2.34	0.5	.0298
32.	0.7000	0.0000	.3000	0.000	2.34	1.0	.0598
33.	0.7000	0.0000	.3000	0.000	2.34	2.0	.1196
34.	0.7000	0.0000	.3000	0.000	2.34	3.0	.1794
35.	0.7000	0.0000	.3000	0.000	2.34	5.0	.2990
36.	0.8000	0.0000	.2000	0.000	4.0	1.0	.0675
37.	0.8000	0.0000	.2000	0.000	4.0	5.0	.3373
				TERNARY SYSTEM O_2-H_2-CH_4			
38.	0.4286	0.1428	.4286	3.0	1.0	1.0	.0438
39.	0.4286	0.1428	.4286	3.0	1.0	5.0	.2188
40.	0.5000	0.2500	.2500	2.0	2.0	1.0	.0532
41.	0.5000	0.2500	.2500	2.0	2.0	5.0	.2660
42.	0.5556	0.3333	.1111	1.66	5.0	1.0	.0606
43.	0.5556	0.3333	.1111	1.66	5.0	5.0	.3028
44.	0.4000	0.3000	.3000	1.33	1.33	1.0	.0472
45.	0.4000	0.3000	.3000	1.33	1.33	5.0	.2362
46.	0.6000	0.2000	.2000	3.0	3.0	1.0	.0592
47.	0.6000	0.2000	.2000	3.0	3.0	5.0	.2959
48.	0.4500	0.2750	.2750	1.64	1.64	1.0	.0502
49.	0.4500	0.2750	.2750	1.64	1.64	5.0	.2511
50.	0.5556	0.2222	.2222	2.5	2.5	1.0	.0565
51.	0.5556	0.2222	.2222	2.5	2.5	5.0	.2826

TABLE 2.2

DETONATION PARAMETERS

IN THE TERNARY SYSTEM O_2-CH_4-H_2

Detonation Parameters

	Detonation Pressure P_D (ATM)	Detonation Velocity D (ft/sec)	Energy Release (10^6ft-lb/lb)	Flow Velocity U (ft/sec)	Detonation Temperature (°K)	Pressure Ratio P_D/P_o	Energy/per Unit Volume/ per Unit Initial Pressu (105^5ft-lbs/ft^3/ATM)
				BINARY SYSTEM - CH_4-O_2			
1.	15.30	8035.	1.529	3648.	3622.	30.59	1.015
2.	31.45	8416.	1.607	3704.	3752.	31.45	1.067
3.	64.62	8525.	1.690	3760.	3886.	32.31	1.122
4.	98.43	8589.	1.740	3793.	3966.	32.81	1.155
5.	167.2	8667.	1.806	3833.	4069.	33.44	1.199
6.	31.06	8664.	1.660	3791.	3319.	31.06	1.034
7.	160.8	8809.	1.764	3864.	3465.	32.15	1.099
8.	29.49	7975.	1.434	3512.	3762.	29.49	0.992
9.	157.2	8224.	1.620	3639.	4093.	31.44	1.121
10.	32.00	8619.	1.689	3789.	3646.	32.00	1.091
11.	168.8	8842.	1.868	3903.	3909.	33.76	1.207
12.	30.49	8190.	1.515	3606.	3774.	30.49	1.030
13.	162.5	8443.	1.711	3736.	4105.	32.50	1.163
14.	26.11	7315.	1.215	3216.	3631.	26.11	0.883
15.	136.7	7529.	1.362	3326.	3924.	27.75	0.990
				BINARY SYSTEM - O_2-H_2			
16.	9.27	9397.	1.876	4078.	3594.	18.54	0.583
17.	19.10	9534.	1.980	4148.	3731.	19.10	0.616
18.	39.35	9670.	2.092	4218.	3874.	19.68	0.651
19.	60.03	9750.	2.161	4260.	3961.	20.01	0.672
20.	102.2	9850.	2.252	4311.	4074.	20.44	0.700
21.	18.27	7826.	1.319	3401.	3549.	18.27	0.582
22.	96.83	8051.	1.476	3518.	3822.	19.37	0.651
23.	18.79	8494.	1.547	3695.	3663.	18.79	0.597
24.	100.2	8762.	1.748	3833.	3978.	20.04	0.675
25.	17.94	11322.	2.889	4901.	3471.	17.94	0.601
26.	94.51	11613.	3.183	5051.	3710.	18.90	0.662
27.	17.73	7356.	1.177	3193	3432.	17.73	0.570
28.	93.43	7546.	1.303	3292.	3666.	18.69	0.631

TABLE 2.2

DETONATION PARAMETERS

IN THE TERNARY SYSTEM O_2-CH_4-H_2

Detonation Parameters

	Detonation Pressure P_D (ATM)	Detonation Velocity D (ft/sec)	Energy Release (10^6 ft-lb/lb)	Flow Velocity U (ft/sec)	Detonation Temperature (°K)	Pressure Ratio P_D/P_o	Energy/per Unit Volume/ per Unit Initial Pressu (105^5 ft-lbs/ft^3/ATM)
O_2-H_2 Cont'd.							
29.	17.21	7000.	1.077	3035.	3319.	17.21	0.559
30.	90.20	7162.	1.180	3119.	3519.	18.04	0.612
31.	7.69	6170.	0.839	2526.	2923.	15.38	0.502
32.	15.58	6205.	0.860	2675.	2969.	15.58	0.514
33.	31.60	6246.	0.883	2696.	3018.	15.80	0.528
34.	47.76	6269.	0.897	2708.	3045.	15.92	0.536
35.	80.25	6295.	0.912	2721.	3076.	16.05	0.545
36.	12.82	5300.	0.607	2250.	2394.	12.82	0.410
37.	64.55	5318.	0.616	2259.	2413.	12.91	0.416
TERNARY SYSTEM O_2-H_2-CH_4							
38.	23.52	8947.	1.780	3915.	3744.	23.52	0.780
39.	125.5	9232.	2.016	4062.	4079.	25.11	0.883
40.	26.83	8676.	1.691	3808.	3749.	26.83	0.899
41.	143.0	8945.	1.909	3946.	4076.	28.60	1.016
42.	29.40	8519.	1.640	3745.	3751.	29.40	0.994
43.	156.6	8777.	1.847	3878.	4073.	31.29	1.119
44.	26.51	9170.	1.891	4008.	3467.	26.51	0.893
45.	138.7	9373.	2.054	4111.	3673.	27.75	0.969
46.	25.11	7948.	1.405	3488.	3714.	25.11	0.832
47.	138.8	8192.	1.587	3615.	4036.	26.76	0.940
48.	27.08	8979.	1.825	3936.	3669.	27.08	0.916
49.	143.5	9291.	2.036	4065.	3957.	28.70	1.022
50.	26.01	8282.	1.526	3635.	3752.	26.01	0.862
51.	138.7	8546.	1.729	3770.	4086.	27.75	0.977

SECTION 3

OPERATION

Included in this section is a description of the control systems and information necessary to perform tests.

3.1 Subsystem Description

The ancillary equipment required to efficiently control and operate the 1500 psi Dynamic Load Simulator may be catagorized into three basic subsystems. They are the Valve & Manifold Control Box, the Monitoring Control Panel, and other miscellaneous, auxiliary equipment. The following describes, in detail, the equipment these subsystems are comprised of.

3.1.1 Valve and Manifold Control Box

The Valve and Manifold Control Box is shown in Figure 3.1. This unit's prime function is to provide a remote, semi-automatic capability of loading the detonable gases into the tube. To accomplish this function, the control box contains a pressure sensing system and a gas loading system.

3.1.1.1 Pressure Sensing System

The essential hardware in the Pressure Sensing System are the five pressure sensing switches, shown typically in Figure 3.2. The desired volumes of air, oxygen, methane or hydrogen are obtained in the shock tube by monitoring the tube pressure with the pressure sensing switches. Each pressure swtich has the capability of being set to within ± 1 psig or 2 in. Hg. of the anticipated pressure. Reference Figure 3.1, the pressure switch shown on the extreme left senses the amount of air remaining in the tube before gas loading. Although this swich has the capability of sensing pressures throughout the indicated range (0-28 in. Hg.), normally it would be set to one of two positions; 28 in. Hg. (no air) or 0 in. Hg. (1 atm air). The second pressure switch from the left senses the amount of oxygen while the third and fourth sense the amount of methane and hydrogen respectively. The fifth pressure switch senses the accumulated total volumes of gas loaded in the tube. This switch precludes the possibility of an accumulated error from the oxygen, methane, and hydrogen pressure switches. Appendix A shows that an error of ±1 psia (2 in. Hg.) in the gas loading would result in a ± 9.0 percent error in the detonation and peak reflected overpressures.

All five pressure switches are connected to a common pressure sensing manifold along with a compound pressure gage for set up testing (See Section 3.2.2) and a pressure transducer for remote reading at the Control Panel. The manifold, in turn, is connected by 13/32" 2000 psi flexible hose to the four-way blast valve. (See Figure 3.3.) The four-way blast valve is rated for 2000 psi (air), has 1 1/2 inch ports, and is air cylinder operated. Thru the blast valve, the pressure sensing manifold is connected to the shock tube by means of a pressure sensing line which has a 5/16" I.D., is 25 ft. long and rated from 2000 psi to 28 in. Hg. vacuum. At the shock tube the sensing line is attached as shown in Figure 3.4. The connecting flange shown in Figure 3.4 is bolted to a mating flange on the shock tube. Also in Figure 3.4 is a Detonation Sensing Switch. This sensing switch is an adjustable (0-1000 psi) pressure switch that was incorporated into the system to provide immediate preliminary information at the Control Panel of detonation occurance.

3.1.1.2 Gas Loading System

The detonable gases (oxygen, methane, and hydrogen) are stored in standard 1 A cylinders which are separately manifolded together and connected to three separate gas loading valves in the control box by independent tubing thru gas regulators. (See Figure 3.5) The gas loading ball valves are rated 500 lb. W.O.G., have 1-1/2 in. ports, carbon steel body construction, teflon seats and are air cylinder actuated. The gas loading valves are connected to a common gas loading manifold (Figure 3.6) by 7/8" 2000 psi flexible hose. The gas loading manifold is connected to the shock tube thru the blast valve by means of a gas loading line. This line has a 1" I.D. with a Buna N liner, is 35 ft. long, and rated for 2000 psi. The gas loading line is attached to the shock tube by means of a connecting flange bolted to a mating flange on the shock tube.

The air cylinders mounted on the three gas loading valves and the blast valve require air (80 psi) to both, extend and retract the control rod that closes and opens the valves. Air is supplied to either side of an air cylinder piston by tubing connected to four-way miniature solenoid valves. (Ref. Figure 3.3). Each cylinder operated valve has its own separate solenoid valve. The solenoid valve is actuated remotely from the Control Panel (Ref. Section 3.1.2). The solenoid valves receive air from the pilot valve manifold (Ref. Figure 3.6) which is welded to the framework of the control box. The pilot valve manifold is supplied with air from a compresser thru two air control units. (See Figure 3.7) The purge air control unit regulates and cleans the air from the compresser. It has 1" NPT ports, regulates from 0-125 psi, is capable of 150 CFM maximum flow, and removes particulate down to

40 microns in size. The purge air control unit delivers air to both the shock tube and pilot valve air control unit which in turn supplies air to the pilot valve manifold. The pilot valve air control unit is similar to the purge air control unit with the exception that the former has 1/4" NPT ports and is only capable of 20 CFM maximum flow rates.

3.1.2 Monitoring Control Panel

3.1.2.1 Description

Figure 3.8 depicts the face-on view of the Monitoring Control Panel. Each control and indicator lamp is clearly labeled as to the function initiated (controls) and the resulting circuit condition (indicators). All controls are of the momentary push button type with but four exceptions. The MAIN POWER SWITCH (door interlocked), MODE SWITCH and GAS SELECTOR are rotary switches while the POWER SWITCH is of the "push-pull" variety. The large indicator lamps require 115V for circuit operation while the small lamps operate in conjunction with individual valve position switches and require 6.3V for operation.

Figure 3.9 is the face-on view of the unit with the control panel door open. All circuit control and time delay relays are mounted on the upper chassis sub-unit and are clearly labeled. The wiring terminals number from 1 through 84 on this sub-unit. Terminal No. 1 is located at the extreme lower left; terminals running consecutively and vertically upward through No. 27, horizontally left to right (No. 28 through No. 57) and vertically downward (No. 58 through No. 84). The unlabeled relay positions are not used in the circuit and provide storage for spare control relays.

Figure No. 3.10 is a close-up view of the unit interior. The Monitoring Control Schematic, (See Appendix B) presents reference designations for component parts. All designations contained in Section 3.1.2 and 4.2 are referenced to this drawing.

The large Three-Pole Disconnect Switch (S3) located in the lower left hand corner provides Main Power control and also includes the main line Fuses F1, F2 and F3. Immediately to its right is the Vacuum Pump Contactor (MR), the function of which is to provide 3 phase power control to the vacuum pump. In the lower right hand corner the large Transformer (T1) provides step-down and isolation from one main power phase to the control voltage, i.e., nominally 115V. A.C.

The four-pole Relay (1PR) located to the upper left of this transformer provides control for the 115 V. A.C. The small Transformer (T4) to the immediate right of this relay steps down the control voltage to 6.3 V. A.C. for use in valve position indication. The Fuse (F6) and fuse block to the right of this transformer provides fusing in the 6.3V. circuit.

Figure 3.11 depicts the inner right hand surface of the Monitoring Control Panel. The twin procelain fuse block mounts the control voltage Fuses (F4 and F5). Immediately above, the Power Supply and Signal Converter Unit (SC-1) is mounted to the Control Panel side wall. This unit in conjunction with the Panel Meter (M1) and the pressure transducer located in the Valve and Manifold Control Box provides remote monitoring of shock tube pressure (absolute). Figure No. 3.12 is a close-up view of the rear of the Control Panel door. Control switch and light identification is made by reference to the individual titles on the reverse side.

3.1.2.2 Circuit Operation

The signal flow diagram (Figure No. 3.13) provides an overall picture of the individual control and indicator lamp circuit functions and also the circuit relationships between the control relays. Each solid block with the particular relay reference designation shown therein depicts the position of the individual relay coils in the circuit. In some cases a number of relays must be paralleled to provide the necessary number of contacts (See Attachment B), however, in all instances a single solid block is shown. A number of identical relay reference designations are enclosed in dotted lines on the diagram. These blocks indicate the circuit position of one or more sets of contacts of the particular relay(s) referenced therein. Control switches are shown in a simplified form and a distinction is made between the main power flow (dashed lines) and the controlled power flow (solid lines.)

Circuit operation will be discussed in three separate sections as follows: Power Control and Program Preparation, Air or Detonable Gas Loading, and Ignition Sequence. Circuit flow begins at the lower left hand corner of the diagram and proceeds to the right. The uppermost portion of the diagram is alloted to those adjustable switches and valve solenoids remotely located from the Monitoring Control Unit, i.e., in the Valve and Manifold Control Box.

3.1.2.2.1 Power Control and Program Preparation

Three phase main power is controlled by the main power disconnect switch which when actuated provides power at the contacts of the Vacuum Pump Contactor (MR) and also provides primary power to the Control Transformer (T1). The control power (secondary of T1) is controlled by the power switch, which, when closed, actuates the power Relay (1PR) provided that the Safe Air Switch (1PS) is closed (sufficient air supply for valve operation) which in turn operates Control Relay (1PCR). With the previous conditions attained, the Vacuum Pump Switch may now be turned on, energizing the Pump Contactor (MR) and permitting control voltage to appear at the Evacuation Switch (2PS) and at both the EVACUATION and PRESSURE DECREASE controls. Evacuation must be preceeded by a CLOSED VENT condition (1CR energized and self latched). This may be accomplished by actuating the VENT switch provided that Time Delay(1TD)has timed out (Vent Timer light not illuminated). A minimum vent open time of approximately 10 minutes is imposed when the power is first turned on (2PCR) or the previous program involved one or more of the three detonable gases (5CR). Conversely, a VENT CLOSED condition is forced during the Ignition Sequence period (15CR). A VENT open condition always involves an Air Purge (4CR); disabled when the Program Relay (3CR) is latched closed.

Tube evacuation is started by actuating the EVACUATION control which latches up relay (2CR) providing the Vent Relay (1CR) is closed and the Program Relay (3CR) is not latched up. Evacuation proceeds until the vacuum setting of the Evacuation Pressure Switch is reached. At that time the Vacuum Pressure Switch latches up the Program Relay (3CR) through the vent closed contacts of 1CR. At the same time the switch drops out relay 19CR permitting the EVACUATION COMPLETE light to illuminate. Subsequent raising of the tube pressure and, therefore, return of the Evacuation Switch to its original position does not drop out the Program Relay (3CR), as it is self-latching. The program may be stopped only by opening the tube vent, i.e., STOP PROGRAM or by turning the power off either at the POWER or MAIN POWER controls. The evacuation switch action however, does reactivate relay 19CR permitting the PRESSURE DECREASE momentary control to be used, provided that, no detonable gas (5CR) has entered the tube for that particular program. The EVACUATION COMPLETE light will no longer illuminate with the increase of tube pressure, however a Program Relay (3CR) latch up may be confirmed by observing the condition of the TEST or SET UP indicator lights. One of these lights will illuminate, depending upon the position of the MODE switch, thereby confirming the program condition. The MODE switch may be changed at any time. However, once one or more the the detonable gases have entered the tube, the Mode Relay (HCR) latches 5CR in the TEST position for that particular program.

3.1.2.2.2 Air and Detonable Gas Loading

Gas loading proceeds with the advent of a program latch up. The SET UP mode of operation will be described first, as this procedure preceeds the actual detonable gas loading and subsequent detonation in normal equipment usage. All testing and associated procedures are described in detail in Section 3.2.

The GAS SELECTOR switch is positioned for the number and type of gases to be used and the MODE switch is placed in the SET UP position. For the purposes of this discussion it will be assummed that all three gases (simulated) are to be used. The Time Load Jumper is to be considered in the position shown. A Time Modulated Gas Loading circuitry was incorporated into the control circuitry to provide for intermittent gas loading. The purpose of this system is to alternately load slugs of oxygen, methane and/or hydrogen to enhance the gas mixing process should it become necessary. The required volumes of detonable gas would have to be premeasured prior to gas loading into the shock tube. A discussion on Time Modulated Gas Loading circuitry will follow later in this section.

Momentarily depressing the AIR CHARGE control latches up the Compressed Air Solenoid through Relay 4CR, provided that, the Blast Valve is open (18CR), the Mode Relay (HCR)is in the SET UP position, the first gas (oxygen) relay is inactivated (8CR) and the Program Relay (3CR) is latched in. The latter relay locks out the VENT control of the Compressed Air solenoid as it enables AIR CHARGE loading in the SET UP Mode. The air charging continues, raising the pressure in the tube until the pressure setting of the Oxygen Pressure Sensing Switch is reached. At this time the Oxygen Relay (8CR) is activated (as selected by the SET UP Mode switch, i.e., HCR), dropping out the Compressed Air Solenoid Relay (4CR) and illuminating the O_2 light. Relay 4CR is now controlled through the 11CR - 8CR relay path, the latter relay contacts being enabled by the transfer action of the oxygen loading circuit. Depressing the CHARGE control once again raises the tube pressure toward the setting of the Methane Pressure Sensing Switch. Actuation of this switch energizes relay 11CR thereby transfering control to the 14CR - 11CR (hydrogen) loading path, dropping out 4CR and illuminating the CH_4 light. A similar action occurs for the loading of the simulated hydrogen gas charge. During the entire loading process all related pressure sensing switch settings may be trimmed and adjusted through use of the PRESSURE DECREASE and PRESSURE INCREASE controls. The operation of the former control has previously been described while the latter is a momentary push button control which operates to bypass the simulated gas loading paths. This control is subject to the same circuit constrictions however, as those previously described for simulated gas loading (i.e, the Blast Valve open (18CR), the MODE control in SET UP (HCR), and the program relay latched in (3CR)).

Upon completion of the simulated hydrogen loading the Blast Valve is closed by the transfer action of relay 14CR as selected by the Mode relay and subsequent closing of relay 18CR. The action of the latter disables any additional AIR CHARGE loading while the Blast Valve is in the closed position. All three simulated Gas Relays (8CR, 11 CR, and 14CR) are not self-latching and therefore may be dropped out during the SET UP procedure. This feature permits the resetting of one or more of the gas pressure sensing switches and subsequent pressure rechecking during the Air Charge Loading. During the Ignition Sequence however, the Hydrogen Relay (14CR) is held energized by the Ignition Program Relay (15CR) through HCR. This action forces the Blast Valve to remain closed during the Ignition Sequence.

The loading of the detonable gases proceeds in a similar manner to that described for the AIR CHARGE program above, however, a number of notable circuit constrictions are imposed. The GAS SELECTOR switch will electrically remain in any one of the three positions when the MODE switch is placed in the TEST position. Tube evacuation and the achievement of a program latch-up is identical to that described for the SET UP mode of operation. With the advent of the program latch-up, the TEST indicator lamp will become illuminated, indicating the sense of the mode relay HCR. The imposed circuit constrictions are as follows: (1) the Compressed Air loading circuit and PRESSURE INCREASE control is disabled; (2) necessary gas loading circuits are enabled, depending upon the position of the GAS SELECTOR switch;

(3) the Oxygen, Methane and Hydrogen Pressure Sensing Switches will now operate relays 7CR, 10CR, and 13 CR respectively, and (4) the action of relay 13CR will now control the closing of the Blast Valve (18CR).

Gas loading may now proceed by momentarily depressing the OXYGEN control. The subsequent action of Oxygen Relay (6CR) operates the oxygen solenoid through the Blast Valve Relay (18CR) and activates the self-latching Detonable Gas Sensing Relay (5CR) imposing additional operational restrictions. Actuation of the Methane relay (9CR)or Hydrogen Relay (12 CR) would also operate 5CR. These restrictions are (1) the PRESSURE DECREASE control is disabled, (2) a minimum tube vent open time is imposed by the action of 5CR on 1TD when the program is eventually stopped and (3) the Mode Relay (HCR) is locked in the test position. The Oxygen Relay (6CR) is self-latching and not breakable except by the action of the Oxygen Pressure Sensing Switch operating Relay 7CR or stopping the program, the methods of which have been previously described. The actuation of Relay 7CR disables the Oxygen gas loading circuit and enables the methane loading circuit. This circuit transfer is noted by the illumination of the O_2 light, signaling the completion of the oxygen loading. Depressing the METHANE gas charging control loads this gas until the setting of the Methane Pressure Sensing Switch is reached in the tube circuit operation is similar to that for the oxygen loading, i.e., Relay 10CR operating to disable the methane loading line while simultaneously enabling the hydrogen loading circuit to operate. Upon completion of the hydrogen loading as evidenced by the illumination of the H_2 light (O_2 and CH_4 light also illuminated for three gas loading), the transfer action of Relay 13CR disables the hydrogen loading circuit while closing the Blast Valve and deactivating the Blast Valve Relay (18CR). This relay action disables any possible additional oxygen or methane loading with the Blast Valve closed. The Hydrogen loading circuit is inherently protected.

The Gas Selector Switch serves the following circuit functions in both the SET UP and TEST modes of operation. It (1) enables only those gas loading circuits and associated Pressure Sensing Switches to operate that are selected, (2) enables only the proper gas indicating lights to illuminate and (3) provides drive voltage in the second (O_2 - CH_4 - H_2) or third (O_2 - H_2) positions for time modulated gas loading operation. The latter method of operation is achieved by removing the Time Load Jumper from its present indicated position and connecting it in the dotted line circuit position shown in Figure 3.13. It will be noted that in this position the gas sensing Relay 5CR is held closed as soon as a Program Relay (3CR) latch-up is achieved. All the circuit restrictions previously listed for an energized 5CR relay are now applicable. Removing the jumper from its present indicated position completely disables the gas loading and pressure sensing switch circuits for both the oxygen and methane gases and thereby indirectly disables the hydrogen loading control thru the blocking action of Relay 10CR. The ydrogen pressure sensing switch circuit is operable, however, and serves to control the final total gas load pressure by disabling the drive voltage (13CR) at the particular pressure switch setting. This method of operation includes the same evacuation and program latch-up procedure that has been previously described, however, the Mode switch is placed directly in the TEST position and the jumper is repositioned. (See Appendix B.) It is suggested that the drive voltage be used to operate a small 110V. A.C. motor which in turn drives three programed, cam operated, gas switches. The same drive voltage is then controlled by the individual switches on a time sharing basis, each switch operating the particular gas loading solenoid. The three switches referred to above <u>MUST</u> be series interlocked so that only one gas solenoid, i.e., gas valve may be open at any given time.

3.1.2.2.3 Ignition Sequence

The Ignition Sequence circuit operates in an identical manner for both the Set Up and Test modes of operation with but two exceptions. These exceptions involve (1) a RETEST control (optional), which is operational in the Set Up (air) mode only, and (2) an extended restart disable period which functions in the Test (detonable gas) mode only.

The Time Bar Graph, Figure 3.14, depicts the time relationships between the various relays and time delay relays in this circuit. The dashed horizontal lines and associated titles in parenthesis indicate circuit operations associated with a Retest operation. The remaining dashed horizontal lines indicate circuit conditions peculiar to detonable gas operation (TEST) and are appropriately labeled. The vertical dashed lines depict time coincidence between various circuit component operations and/or control intiations. Reference to this graph and the Signal Flow Diagram, Figure 3.13, will aid in understanding the following text.

Upon completion of the air or detonable gas loading operation, the actuation of relays 14CR (air) or 13CR (detonable gas) closes the Blast Valve and enables the ignition sequence to be started constrained by the following conditions:

(a) The Program Relay (3CR) is latched closed.

(b) The Overcharge Pressure Sensing Switch is not actuated, i.e. the GAS OVERCHARGE light is not illuminated.

(c) The Vacuum, Vent, Air and Blast Valve interlock switches are all closed, thereby confirming all four valves are closed.

(d) Relay 16CR is not actuated, i.e., a previous Ignition Sequence has timed out.

(e) The Remote Ignition Jack is not being used and therefore is in the shorted (closed) position.

(f) The Time Delay Relay (5TD) is timed out, i.e.,contacts closed.

Depressing the Ignition START momentary control self-latches the Ignition Relay (15CR) in the actuated condition and illuminates the IGNITION SEQUENCE STARTED light. Simultaneously a set of contacts of this relay imposes a holding voltage on the Vent Relay (1CR) to insure a Vent Closed condition, while a separate set of contacts places a holding voltage on either 13CR or 14CR to insure a Blast Valve closed condition. Along with actuation of relay 15CR, Time Delay Relays 2TD and 3TD begin their timing cycles. Relay 2TD provides for a 10 second period of audio warning while 3TD times out a 15 second period prior to the application of ignition voltage. At the end of this 15 second period a separate set of contacts of 15CR provides self-latching holding voltage that is not interruptable except by a power shut down. (Note shaded area under 15CR in Figure 3.14.) Prior to this time the Ignition Sequence may be interrupted by depressing the STOP button should this action be desired. A new Ignition Sequence may then be started or the shock tube vented of the detonable gas or air load as conditions require.

Upon completion of the timing period of 3TD (15 seconds) the ignition voltage is applied for a period of 10 seconds as determined by the timing cycle of 4TD. The subsequent transfer action of this time delay relay interrupts the ignition and simultaneously initiates the timing cycle of relay 5TD. A separate set of contacts of relay 4TD operates to self-latch relay 16CR(now energized). The dropping-out of relay 15CR disables all time delay relays including 5TD while relay 16CR remains self-latched. In the case of a SET UP mode of operation, this relay will remain latched until the RETEST button is depressed, breaking the holding voltage and permitting an additional ignition sequence. In the TEST mode of operation, the delayed drop out of 5CR at the instant of tube venting transfers control to the auxillary contacts of 1TD for a holding period of approximately 30 seconds on relay 16CR. During this period the IGNITION SEQUENCE COMPLETE and the DETONATION SENSOR lights will remain illuminated. The DETONATION SENSOR light circuit operates upon closure of the Detonation Sensor switch, which self-latches relay 17CR and illuminates the Detonation Sensor lamp.

Remote Ignition Sequence control may be used through use of a two wire cable, a mating plug for the front panel jack and a suitable single-pole-single-throw switch. Plug cable and switch are interwired so as to provide a simple switch control across the tip and ring connections of the plug; the sleeve section of the 3-way plug is not used. The Test Conductor plus a remote operator are required to start the Ignition Sequence in this type of operation. Both must close their individual switch controls to start the sequence. Once started, the sequence may be interrupted only at the Control Panel.

3.1.3 Auxiliary Equipment

The auxiliary equipment may be classified into three subsystems. They are the purge air system, the vacuum system and the gas ignition system.

The purge air system's prime function is to purge the products of combustion from the shock tube before and after each test. The system also serves as a simulated detonable gas for set up testing. The system consists of a purge air inlet valve assembly (see Figure 3.15) and a purge air vent valve which is part of a vent-vacuum valve assembly (see Figure 3.16). The purge air inlet valve is connected to the lowest mating flange on the shock tube and to the air compressor through the purge air control unit (reference Section 3.1.1.2). The purge air valve is rated for 4000 psi (air), has 1-1/2" NPT ports, and is air cylinder actuated. The operation of the purge system valves is through miniature solenoid valves and the control panel. The vent and vacuum valves are identical. Both are rated for 2000 psi (air), have 1" NPT ports and are air cylinder actuated. The operation of the vacuum and vent valves is through a miniature solenoid valve and the control panel. The assembly is attached to the uppermost mating flange on the shock tube.

The vacuum system's function is to remove the ambient air in the shock tube prior to detonable gas loading. The air is removed because of its high nitrogen content which retards the detonable gas reaction. The effects of air upon the reaction parameters is discussed in Section 2.2.2.4. The vacuum system consists of a vacuum pump, vacuum valve, and connecting vacuum line. The single stage vacuum pump is V-belt driven by a 5 HP, 3 phase, 60 Hertz, 220/440 volt, 1800 RPM electric motor. The vacuum pump has a pumping speed of 75 CFM in the intended range (0-28 in. Hg vacuum) and an ultimate evacuation capability of 10 microns. The shock tube evacuation time and vacuum line size calculations are presented in Appendix C. The vacuum line has a 1" ID with a Buna N liner, is 40 ft. long and rated for 28 inches Hg.

The function of the gas ignition system is to provide a sufficient amount of energy to initiate a detonation reaction in the gas mixture. The energy is provided by means of an automotive spark plug. The spark plug is energized by a high voltage step-up transformer. The primary winding of the transformer is supplied with 110 V.A.C. and the secondary winding delivers a nominal 30,000 V.A.C. to the spark plug thru automotive ignition leads. There are two complete ignition systems mounted at the very top of the shock tube along the longitudinal axis. Also included in each ignition system is an ignition monitor unit. This device includes a capacity probe mounted coaxially around the spark plug lead, an isolation high voltage capacitor and an 110 volt A.C. contact protector. The latter two components provide for personnel and circuit protection against the unlikely possibility that the capacity probe and/or the high voltage cable it surrounds would experience a voltage breakdown. A connector mounted on the unit allows coaxial cable attachment for remote oscilloscope monitoring. The oscilloscope's picture presents a characteristic waveform when a normal arc condition is present at the plug points. This wave form is characterized by voltage drop-outs and reinforcements at both the positive and negative peaks of the indicated sine wave. An unshorted plug that is not arcing at all presents an oscilloscope picture of an undistorted and uniform sine wave. A considerable amount of leakage at the plug points reduces this wave form in amplitude (secondary voltage low due to loading) to the point where a completely shorted plug would indicate a straight line on the oscilloscope face.

3.2 Testing

The necessary sequence of events leading to the successful operation of the 1500 psi Dynamic Load Simulator is contained in this subsection. The sequential operations are: Test Preparation, Set Up Testing Procedure, and Live Testing Procedure. Each of these operations is detailed below.

3.2.1 Test Preparation

Prior to testing of any sort, certain steps need to be accomplished. These steps may be conveniently segregated as follows:

1. Assure the system is assembled as shown in Figure 1.1. It is recommended that initial testing be confined to the 10 ft. horizontal tube built for use as a training aid. After the sequence of operations and detonability of a gas mixture is established, then the 1500 psi Dynamic Load Simulator may be used.

2. Determine the gas constituents, mole ratio and initial pressure of the intended live test. (See Section 2.4). Record these values in the appropriate space on the Checklist. See Appendix D for Sample Checklist. Also record the vacuum, oxygen, methane, hydrogen, overcharge and detonation sensing switch values in the appropriate space on the checklist. Appendix D also contains an example calculation to determine sensing switch values.

3. Turn on air supply and adjust the purge air regulator to 150 psi for the large tube or 80 psi for the small tube.

4. Adjust the control air regulator to 75 psi.

5. Set the air supply pressure switch at 100 psi for the large tube or 70 psi for the small tube.

6. Assure 220 V AC is available at the control panel.

7. Assure cooling water is available for the vacuum pump.

3.2.2 Set Up Testing Procedure

The purpose of a set up testing procedure is two fold. First, it allows the Test Engineer to operate the entire control sequence with air simulating detonable gases so that a visual inspection of the operating functions may be noted to establish the working integrity of the system. Second, it is a convenient method to assure the calibration of the pressure sensing switches.

The following steps are to be performed prior to any Live Testing and subsequent to steps outlined in Test Preparation.

1. At the Control panel, turn "ON" the"Main Power" switch and "Pull-On" the panel "Power" switch.

2. Verify the"Power On" and "Air Supply" lights are illuminated.

3. Verify the "Air Valve Open" light, "Vent Valve Open" light, "Blast Valve Open" light, and "Vent Timer On" light are illuminated and all other valve position lights are "Closed". NOTE: the vent timer will be automatically activated for approximately 10 minutes. During this time steps 4 through 5 may be accomplished.

4. Turn the "Mode" switch to the "Set Up" position.

5. Turn the "Gas Selector Switch" to the appropriate position. NOTE: The appropriate position of the gas selector switch should have been entered in the Checklist as part of the Test Preparation procedure.

6. After the "Vent Timer" light goes off, depress and release the "Tube Vent Close" push-button switch.

7. Verify the "Vent Closed" light is illuminated. NOTE: At this time the "Blast Valve Open" light should be illuminated; all other valve lights indicate "Closed".

8. At the Valve and Manifold Control Box, set the vacuum, oxygen, methane, hydrogen, and overcharge pressure switches to their appropriate value. Record these settings on the Checklist in the space provided. NOTE: The appropriate values should have been entered in the Checklist as part of the Test Preparation Procedure.

9. At the Control Panel depress and release the "Vacuum Pump On" push-button switch.

10. Verify the "Vacuum Pump On" light is illuminated.

11. Depress and release the "Evacuation Start" push-button switch.

12. Verify the "Evacuation Started" light, the "Vacuum Valve Open" light and the "Blast Valve Open" light are illuminated. All other valve indicator lights should show "Closed".

13. Observe the absolute tube pressure on the meter at the Control Panel and the gauge in the Valve and Manifold Control Box. Verify both meter and gauge are indicating a drop in pressure.

14. After a maximum of 30 minutes for the large tube or 10 minutes for the small tube, verify the "Evacuation Complete" and the "Vacuum Valve Closed" lights are illuminated.

15. Verify the "Set Up (Air)" indicator light becomes illuminated at the same time as the "Evacuation Complete" light; thereby confirming the setting of the Mode switch. NOTE: Do not proceed unless the "Mode" switch is in the "Set Up" position.

16. If the vacuum indicated on the meter and gauge are within ± 2 in. Hg (1 psi) of the vacuum pressure switch setting proceed to Step 24; if not, continue.

17. If the vacuum pressure swtich was set so that there is an insufficient vacuum in the tube proceed to Step 18. If there is too much of a vacuum in the tube proceed to Step 22.

18. Move the vacuum pressure switch indicator to a higher setting on the dial until the "Evacuation Complete" light is no longer illuminated.

19. Depress and hold the "Pressure Decrease" push-button switch until the desired vacuum is indicated on both meter and gauge.

20. If the desired vacuum level is not reached before the "Evacuation Complete" light becomes illuminated, repeat Step 18.

21. When the desired vacuum level is reached, slowly move the vacuum pressure switch indicator back to the point, and no further, where the light is once again illuminated. Go to Step 24.

22. Depress and hold the "Pressure Increase" push-button switch until the desired vacuum is indicated on both meter and gauge.

23. Move the vacuum pressure switch indicator to a lesser vacuum so that the "Evacuation Complete" light is no longer illuminated. Slowly return this control to the point at which this light is once again illuminated.

SIMULATED OXYGEN GAS LOADING

24. Depress and release the "Air Charge Start" push-button switch.
NOTE: The "Evacuation Complete" light will no longer illuminate.

25. Verify the "Air Valve Open" light and the "Blast Valve Open" light are illuminated. All other valve indicator lights should show closed.

26. Observe the absolute tube pressure on the meter at the Control Panel and the gauge in the Valve and Manifold Control Box. Verify both meter and gauge are indicating an increase in pressure.

27. After a period of time, verify the "Oxygen (O_2)" light is illuminated.

28. If the pressure indicated on the meter and gauge are within ± 1 psi or (2 in. Hg) of the oxygen pressure switch setting proceed to Step 34; if not, continue.

29. If the oxygen pressure switch was set so that there is an insufficient pressure in the tube proceed to Step 30. If there is too much pressure in the tube proceed to Step 32.

30. Depress and hold the "Pressure Increase" push-button switch until the desired pressure is indicated on both meter and gauge.

31. Move the oxygen pressure switch indicator to a higher pressure so that the "Oxygen (O_2)" light is no longer illuminated. Slowly return

the oxygen pressure switch indicator until the "Oxygen (O_2)" light illuminates. Go to step 34.

32. Depress and hold the "Pressure Decrease" push-button switch until the desired pressure is indicated on both meter and gauge.

33. Move the oxygen pressure swtich indicator to a higher pressure so that the "Oxygen (O_2)" light is no longer illuminated. Slowly return the oxygen pressure switch indicator until the "Oxygen (O_2)" light illuminates.

SIMULATED METHANE GAS LOADING

34. Depress and release the "Air Charge Start" push-button switch.

35. Verify the "Air Valve Open" light and the "Blast Valve Open" light are illuminated. All other valve indicator lights should show closed.

36. Observe the absolute tube pressure on the meter at the Control Panel and the gauge in the Valve and Manifold Control Box. Verify both meter and gauge are indicating an increase in pressure.

37. After a period of time, verify the "Methane (CH_4)" light is illuminated.

38. If the pressure indicated on the meter and gauge are within ± 1 psi or 2 in. Hg of the oxygen pressure switch setting proceed to Step 44; if not, continue.

39. If the methane pressure swtich was set so that there is an insufficient pressure in the tube proceed to Step 40. If there is too much pressure in the tube proceed to Step 42.

40. Depress and hold the "Pressure Increase" push-button switch until the desired pressure is indicated in both meter and gauge.

41. Move the methane pressure switch indicator to a higher pressure so that the "Methane (CH_4)" light is no longer illuminated. Slowly return the methane pressure switch indicator until the "Methane (CH_4)" light illuminates. Go to step 44.

42. Depress and hold the "Pressure Decrease" push-button switch until the desired pressure is indicated on both meter and gauge.

43. Move the methane pressure switch indicator to a higher pressure so that the "Methane (CH_4)" light is no longer illuminated. Slowly return the methane pressure switch indicator until the "Methane (CH_4)" light illuminates.

SIMULATED HYDROGEN GAS LOADING

44. Depress and release the "Air Charge Start" push-button switch.

45. Verify the "Air Valve Open" light and the "blast Valve Open" light are illuminated. All other indicator lights should show closed.

46. Observe the absolute tube pressure on the meter at the Control Panel and the gauge in the Valve and Manifold Control Box. Verify both meter and gauge are indicating an increase in pressure.

47. After a period of time, verify the "Hydrogen (H_2)" light is illuminated.

48. If the pressure indicated on the meter and gauge are within ± 1 psi or 2 in. Hg of the oxygen pressure switch setting, proceed to Step 54; if not, continue.

49. If the hydrogen pressure switch was set so that there is an insufficinet pressure in the tube proceed to Step 50. If there is too much pressure in the tube proceed to Step 52.

50. Depress and hold the "Pressure Increase" push-button switch until the desired pressure is indicated on both meter and gauge.

51. Move the hydrogen pressure switch indicator to a higher pressure so that the "Hydrogen (H_2)" light is no longer illuminated. Slowly return the hydrogen pressure switch indicator until the "Hydrogen (H_2)" light illuminates. Go to step 54.

52. Depress and hold the "Pressure Decrease" push-button switch until the desired pressure is indicated on both meter and gauge.

53. Move the hydrogen pressure switch indicator to a higher pressure so that the "Hydrogen (H_2)" light is no longer illuminated. Slowly return the hydrogen pressure switch indicator until the "Hydrogen (H_2)" light illuminates.

54. Verify the "Gas Overcharge" light is not illuminated. Depress and release the "Vacuum Pump Off" push-button switch.

SIMULATED IGNITION SEQUENCE

55. Confirm the following Control Panel status prior to initiating Ignition Sequence Start.
    (a) All valve "Closed" lights are illuminated.
    (b) The "Air" light is not illuminated.
    (c) The oxygen light in conjunction with the Methane and/or Hydrogen lights are illuminated.

NOTE: The "Gas Selector" switch determines which of the latter two indicators may not be applicable.

(d) The "Vent Closed", "Set Up (Air)", "Air Supply" and "Power On" lamps are illuminated.

56. Station an observer with an oscilloscope at the ignition monitor station, the scope being cabled to the ignition monitor jack (s) and operating to observe a 60 cycle basic frequency pattern at a level of approximately 1/2 volt.

57. Depress and release the "Ignition Sequence Start" push-button switch (T-15 sec.).

58. Verify the "Ignition Sequence Started" light is illuminated.

59. Verify the buzzer is sounding at the Valve Manifold Control Box (T-15 to T5 sec.). NOTE: The Ignition Sequence may be interrupted for any reason up to time T-0 by depressing and releasing the "Ignition Sequence Stop" push-button switch. A new complete sequence will then have to be initiated as in Step 57 above. Beyond T-0 the sequence is not interruptable except by turning "Off" the "Main Power" switch or pushing "Off" the "Power" push-button.

60. Scope monitor the ignition voltage at both of the ignition monitor jacks. Observe a characteristic pattern for normal spark plug operation. (T-0 to T + 10 sec.)

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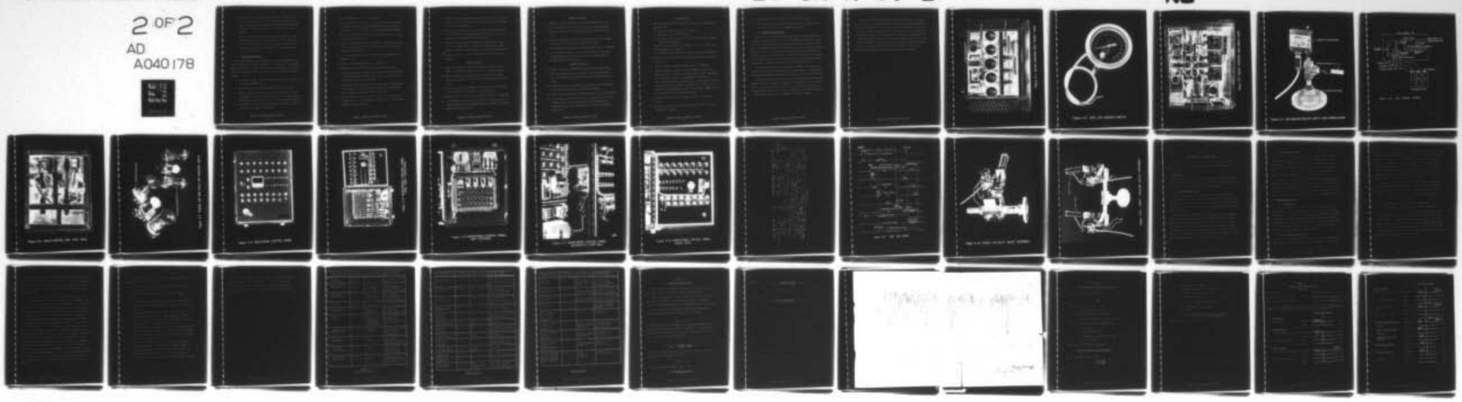

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61. Verify the "Ignition Sequence Complete" lamp is illuminated (T + 60 sec.). NOTE: A new ignition sequence may now be initiated if required by depressing and releasing the "Ignition Sequence Retest" push-button. Proceed to Step No. 57 above to initiate a new sequence.

62. Clear the tube of the air charge by depressing and releasing the "Stop Program" (Tube Vent Open) push-button. NOTE: This may be done for any reason during the gas loading procedure (Set Up or Test) or during the Ignition Sequence with the exception of the period T-0 to T + 60 sec.

3.2.3 Live Testing Procedure

The following steps are to be performed only after Test Preparation and the Set Up Procedure have been accomplished. This procedure only covers the sequential operation of the shock tube and ancillary equipment. No mention is made of intermediate steps associated with the test specimen and instrumentation.

1. At the control panel, turn "On" the "Main Power" switch and "Pull-On" the panel "Power" switch.

2. Verify the "Power On" and "Air Supply" lights are illuminated.

3. Verify the "Air Valve Open" light, "Vent Valve Open" light, "Blast Valve Open" light, and "Vent Timer On" light are illuminated and all other valve position lights are "Closed". NOTE: The vent timer will be automatically activated for approximately 10 minutes. During this time Steps 4 and 5 may be accomplished.

4. Turn the "Mode" switch to the "Test" position.

5. Turn the "Gas Selector Switch" to the appropriate position. NOTE: The appropriate position of the gas selector switch should have been entered in the Checklist as part of the Test Preparation procedure.

6. After the "Vent Timer" light goes off, depress and release the "Tube Vent Close" push-button switch.

7. Verify the "Vent Closed" light as illuminated. NOTE: At this time the Blast Valve Open" light should be illuminated; all other valve lights indicate "Closed".

8. At the Control Panel depress and release the "Vacuum Pump On" push-button switch.

9. Verify the "Vacuum Pump On" light is illuminated.

10. Depress and release the "Evacuation Start" push-button switch.

11. Verify the "Evacuation Started" light, the "Vacuum Valve Open" light, and the "Blast Valve Open" light are illuminated. All other valve indicator lights should show "Closed".

12. Observe the absolute tube pressure on the meter at the Control Panel and the gauge in the Valve and Manifold Control Box. Verify both meter and gauge are indicating a drop in pressure.

13. After a maximum of 30 minutes for the large tube or 10 minutes for the small tube verify the "Evacuation Complete" and the "Vacuum Valve Closed" lights are illuminated.

14. Verify the "Test (Detonable Gas)" indicator light becomes illuminated at the same time the "Evacuation Complete" lights, thereby confirming the setting of the Mode switch.

15. If the vacuum indicated on the meter and gauge are not within ± 2 in Hg (1 psi) of the vacuum pressure switch setting,abort the test by depressing the "Stop Program" push-button switch.

16. Adjust the oxygen, methane and hydrogen gas regulators to 400 psi each for the large tube or 50 psi each for the small tube. NOTE: Regulator adjustment is only required on those gases intended for use.

17. Assure the immediate area surrounding the tube is evacuated of all personnel.

OXYGEN GAS LOADING

18. Depress and release the "Oxygen Gas Charging" push-button switch. NOTE: The "Evacuation Complete" light will no longer illuminate.

19. Verify the "Oxygen Valve Open" light and the "Blast Valve Open" light are illuminated. All other valve indicator lights must show closed.

20. Observe the absolute tube pressure on the meter at the Control Panel. Verify the meter is indicating an increase in pressure.

21. After a period of time, verify the "Oxygen (O_2)" light is illuminated.

22. If the pressure indicated on the meter is not within ± 1 psia of the oxygen pressure switch setting,abort the test by depressing the "Stop Program" push-button switch.

METHANE GAS LOADING

23. Depress and release the "Methane Gas Charging" push-button switch.

24. Verify the "Methane Valve Open" light and the "Blast Valve Open" light are illuminated. All other valve indicator lights must show closed.

25. Observe the absolute tube pressure on the meter at the Control Panel. Verify the meter is indicating an increase in pressure.

26. After a period of time, verify the "Methane (CH_4)" light is illuminated.

27. If the pressure indicated on the meter is not within ± 1 psi of the methane pressure switch setting abort the test by depressing the "Stop Program" push-button switch.

HYDROGEN GAS LOADING

28. Depress and release the "Hydrogen Gas Charging" push-button switch.

29. Verify the "Hydrogen Valve Open" light and the "Blast Valve Open" light are illuminated. All other valve indicator lights should show closed.

30. Observe the absolute tube pressure on the meter at the Control Panel. Verify the meter is indicating an increase in pressure.

31. After a period of time, verify the "Hydrogen (H_2)" light is illuminated.

32. If the pressure indicated on the meter is not within ± 1 psi of the hydrogen pressure switch setting or the "Gas Overcharge" light is illuminated, abort the test by depressing the "Stop Program" push-button switch.

IGNITION SEQUENCE

33. Confirm the following Control Panel status prior to initiating Ignition Sequence Start.

(a) All valve "Closed" lights are illuminated.

(b) The "Air" light is not illuminated.

(c) The oxygen light in conjunction with the Methane and/or Hydrogen lights are illuminated.

NOTE: The "Gas Selector" switch determines which of the latter two indicators may not be applicable.

(d) The "Vent Closed", "Test", and "Power On" lamps are illuminated.

34. Depress and release the "Ignition Sequence Start" push-button switch (T-15 sec.).

35. Verify the "Ignition Sequence Started" light is illuminated.

36. Verify the buzzer is sounding at the Valve Manifold Control Box (T-15 to T-5 sec.). NOTE: The Ignition Sequence may be interrupted for any reason up to time T-0 by depressing and releasing the "Ignition Sequence Stop" push-button switch. A new complete sequence will then have to be initiated as in Step 34 above. Beyond T-0 the sequence is not interruptable except by turning "Off" the"Main Power" switch or pushing "Off the Power" push-button.

37. Verify the "Ignition Sequence Complete" lamp is illuminated (T + 60 sec.).

38. Determine the status of the "Detonation Sensor" light. Record the status in the Checklist.

39. Depress and release the "Stop Program" push-button switch.

40. The "Ignition Sequence Complete" lamp will become extinguished after a period of approximately 30 seconds after Step 39.

3.2.4 Detonation Data Evaluation

There are three detonation parameters that may be conveniently measured to define a pressure signature in the 1500 PSI Dyanamic Load Simulator. They are the detonation velocity, detonation pressure and the peak reflected pressure. The detonation velocity and detonation pressure are independant variables that depend upon the gas consituents, mole ratio and initial pressure of the detonable gas mixture. The peak reflected pressure will always be 2.56 times the detonation pressure. By knowing any one of the three detonation parameters a pressure-time signature may be defined by theory. (See Section 2.)

The detonation velocity can be empirically determined by measuring the detonation wave times-of-arrival over fixed, known distances. These times can then be used to determine average detonation velocities over the known distance.

The detonation and peak reflected pressures are measured with both strain gage and piezoelectric pressure transducers. The purpose of the dual measurements are to provide the data evaluator with a cross-check and a means to eliminate characteristic difficulties in interpretation of data from each gage. The measured pressure should be a compromise of the two readings.

During the course of data evaluation it may be noted that in some cases there is not an exact agreement between the predicted and measured parameters. The data evaluator must then decide which data most represents the real conditions that occurred. In general, the evaluator's decision must be tempered by engineering judgement and a certain amount of experience in interpreting data of this type. However, certain confidence levels may be assigned to the three measured parameters. The first, second and third most accurate data measured will be the detonation wave times-of-arrival (detonation velocity), the detonation pressure, and the peak reflected pressure, respectively.

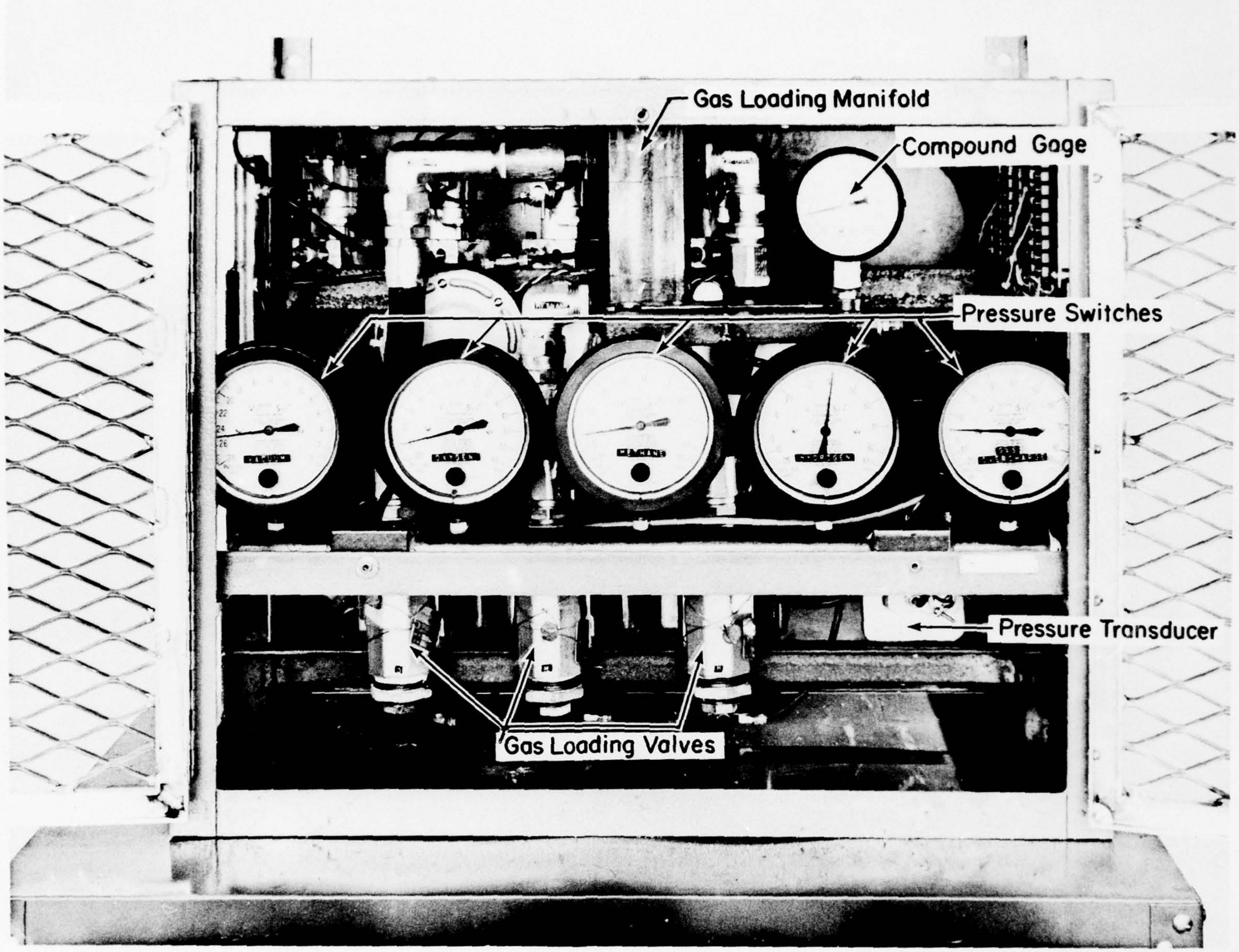


Figure 3.1 VALVE CONTROL BOX FRONT VIEW

Figure 3.2 SAFE AIR SENSING SWITCH

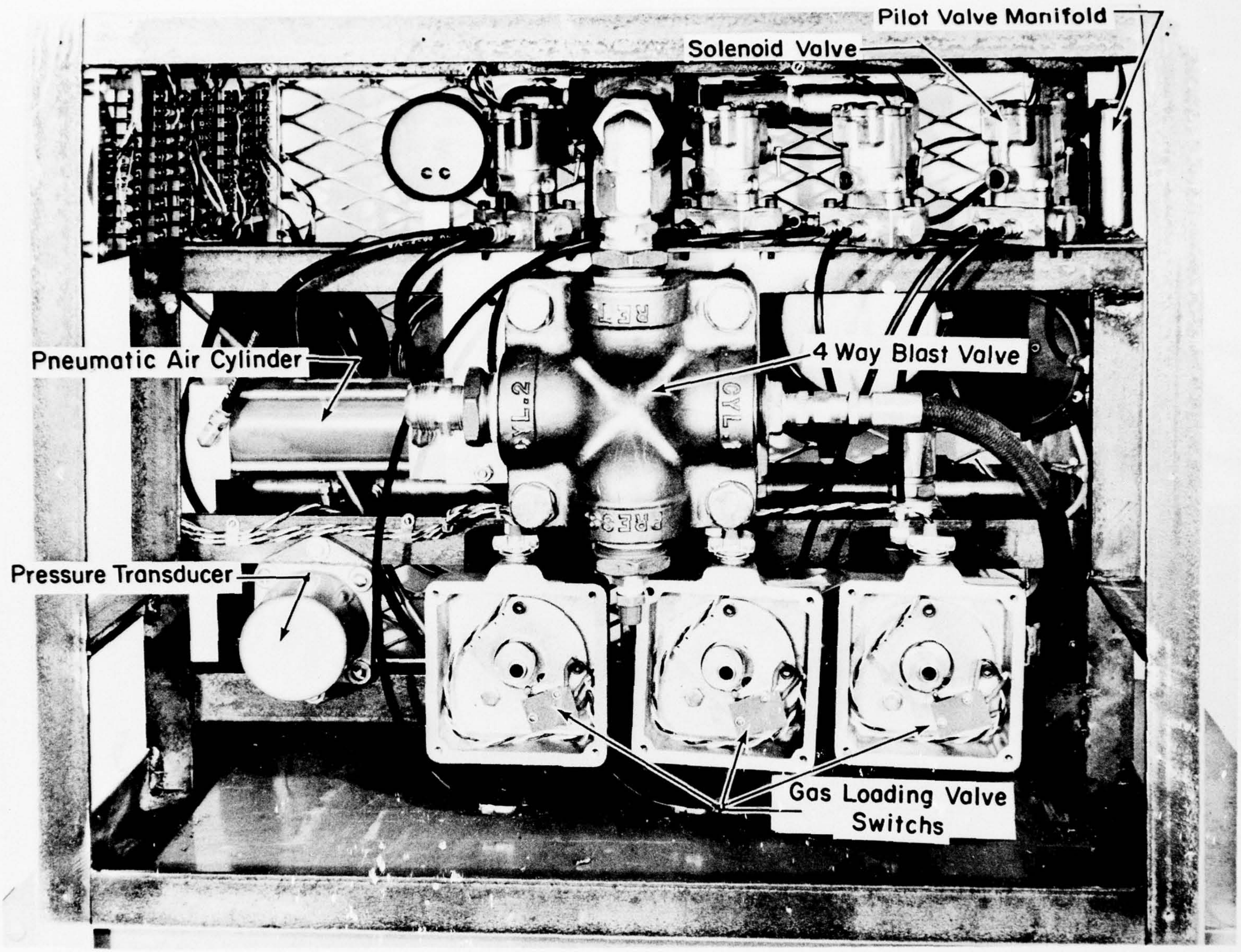
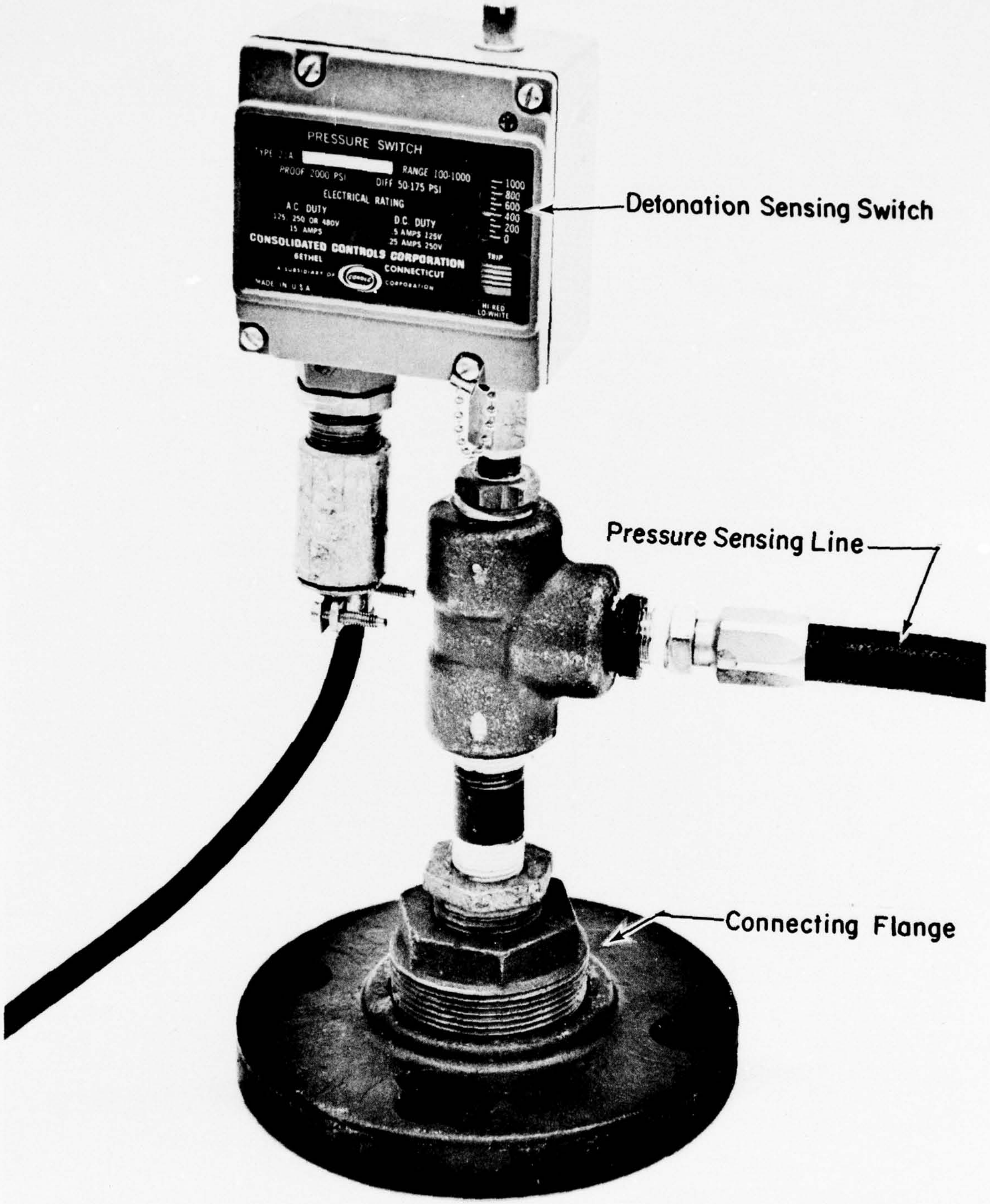


Figure 3.3 VALVE CONTROL BOX BACK VIEW



Detonation Sensing Switch

Pressure Sensing Line

Connecting Flange

Figure 3.4 DETONATION SENSOR SWITCH AND CONNECTIONS

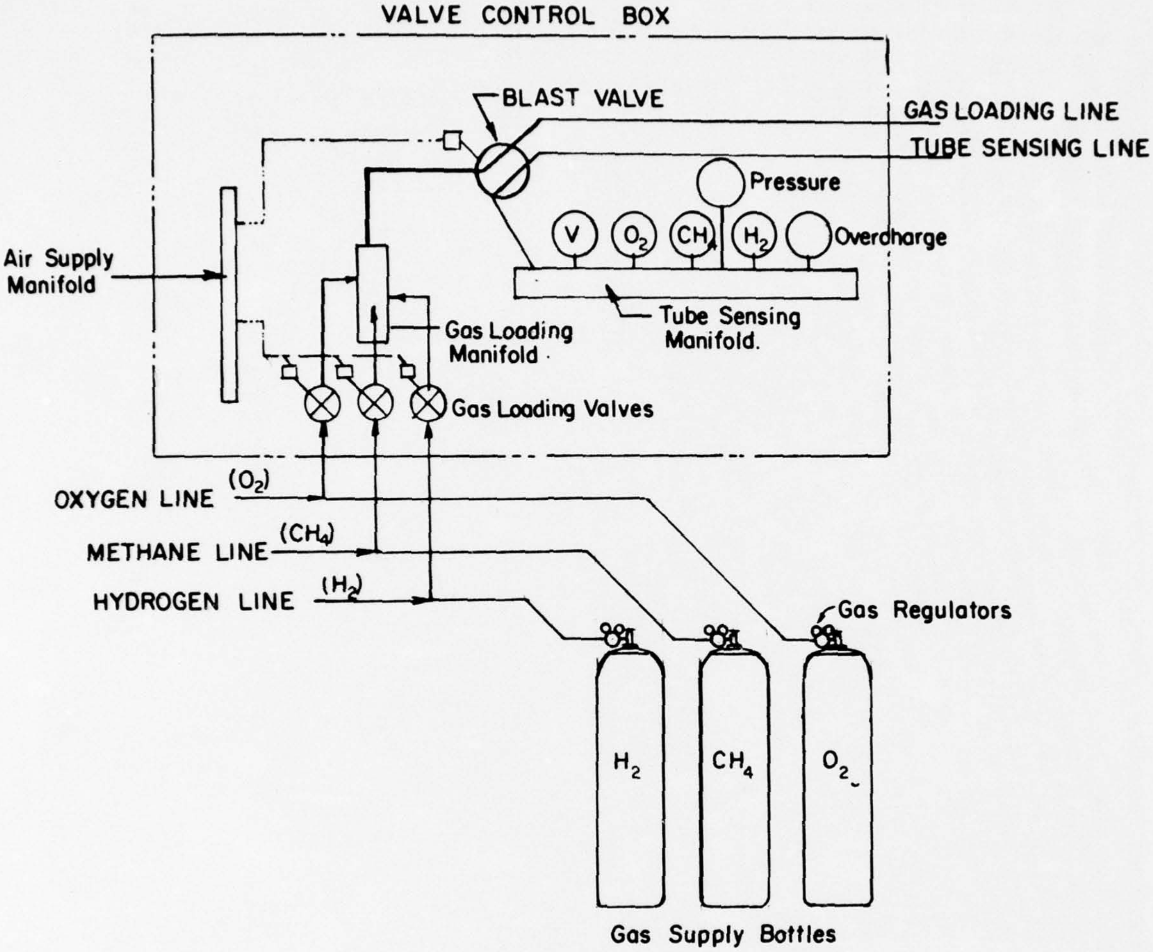


Figure 3.5 GAS LOADING SYSTEM

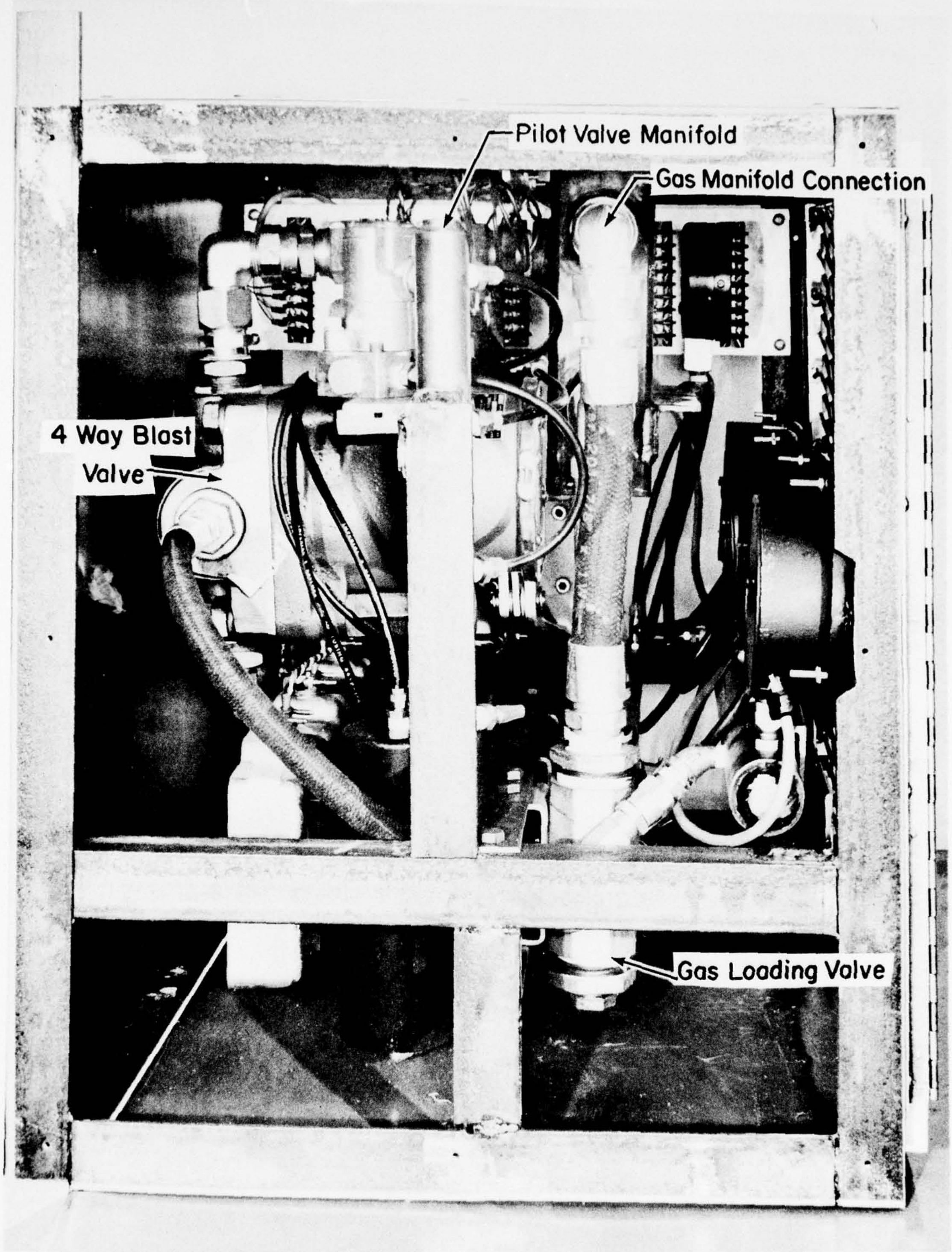


Figure 3.6 VALVE CONTROL BOX SIDE VIEW

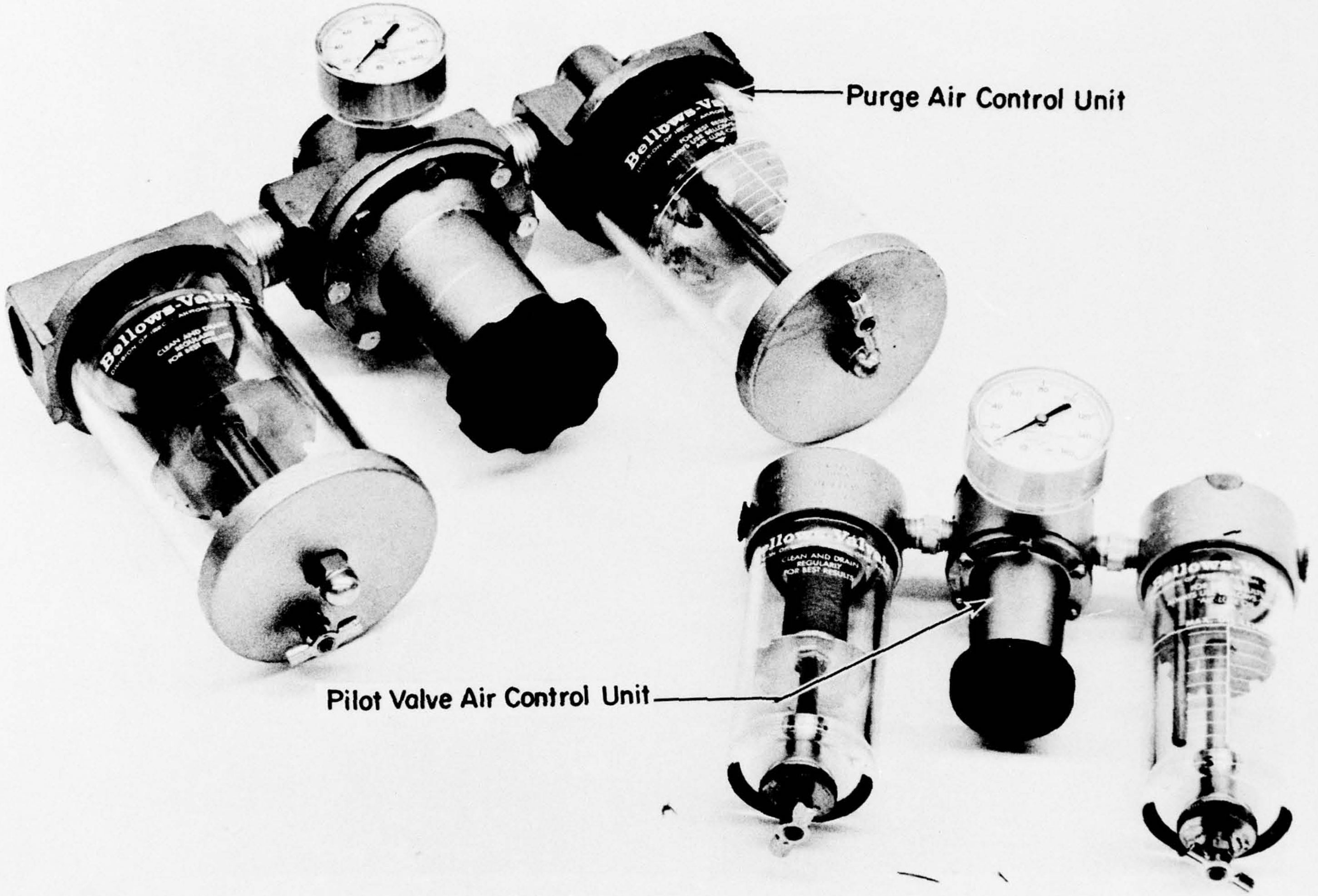


Figure 3.7 PURGE AIR AND PILOT AIR CONTROL UNITS

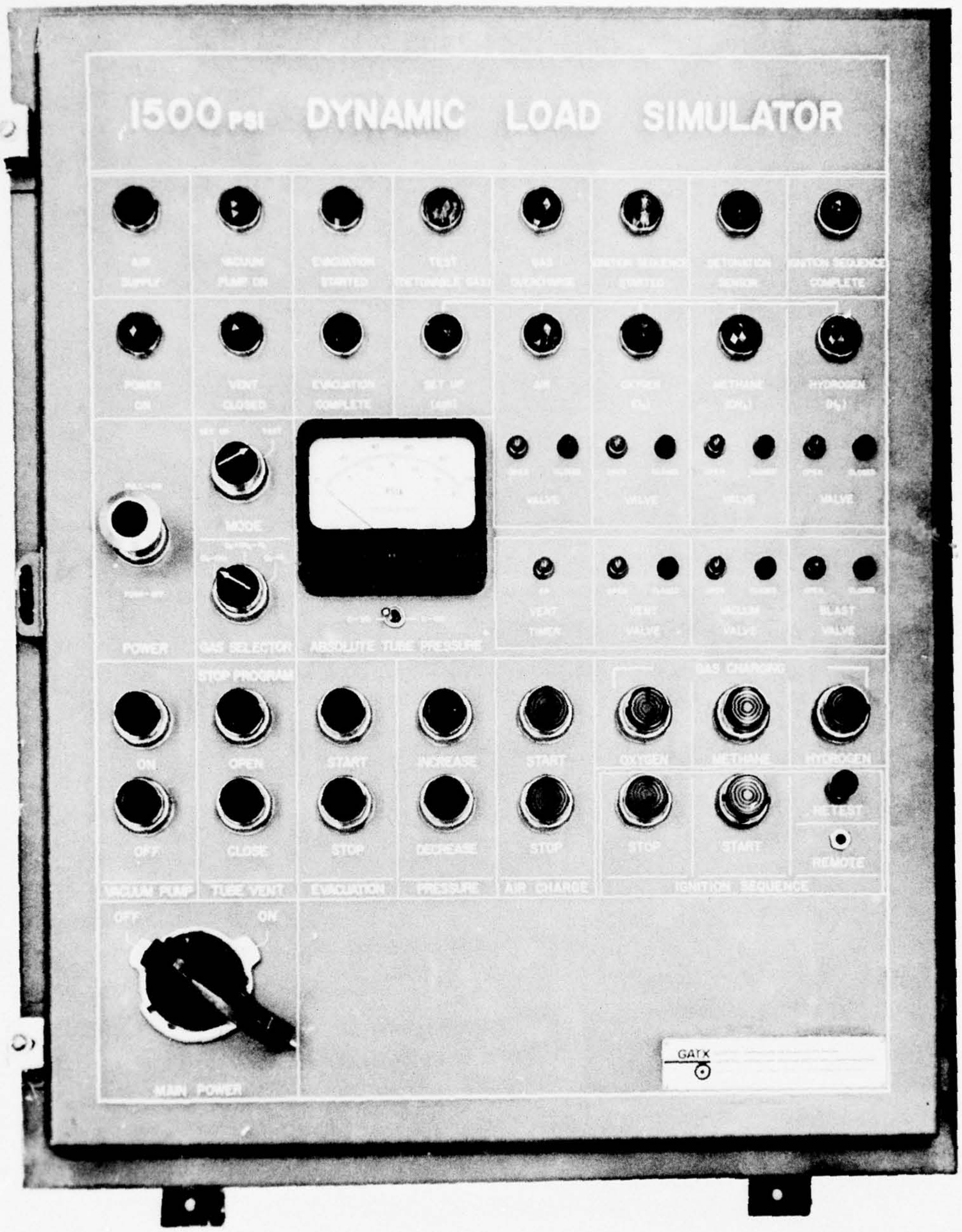


Figure 3.8 MONITORING CONTROL PANEL

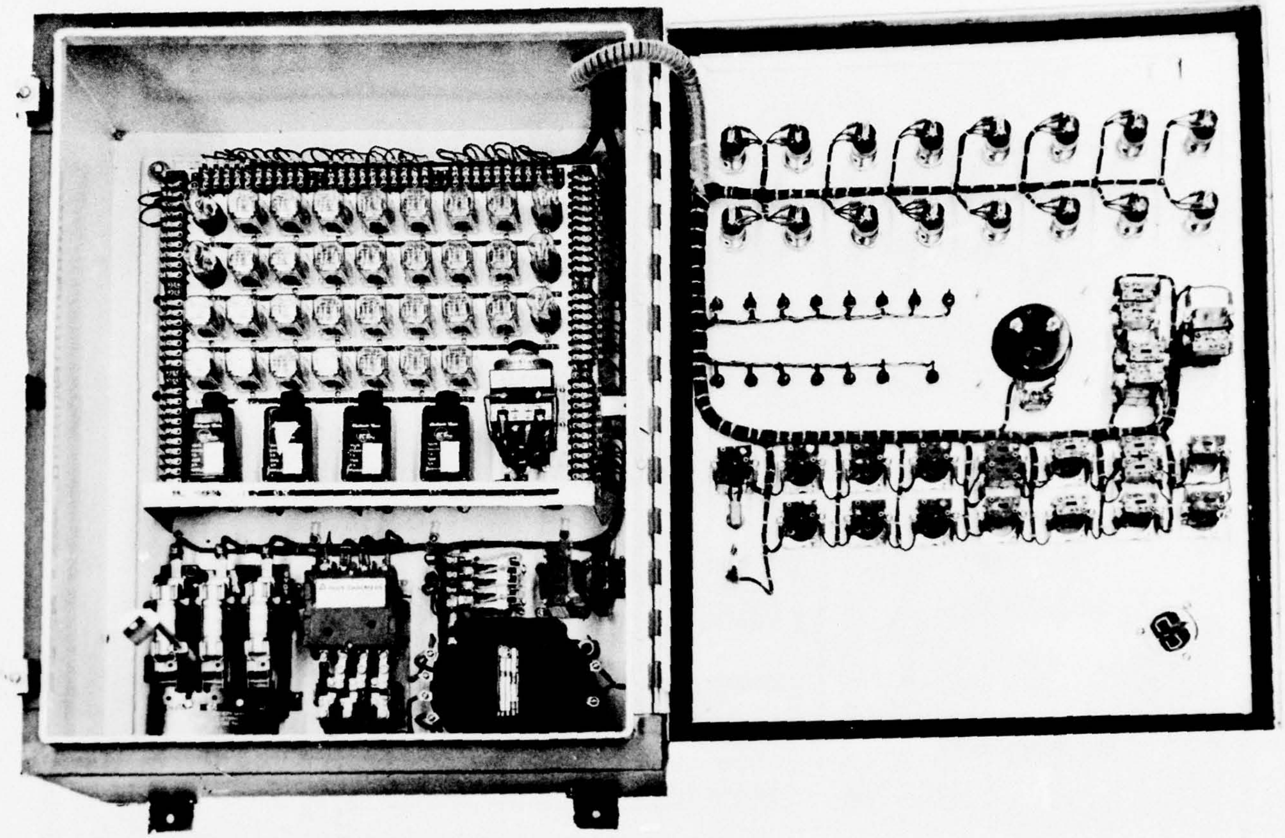


Figure 3.9 MONITORING CONTROL PANEL
FACE VIEW – DOOR OPEN

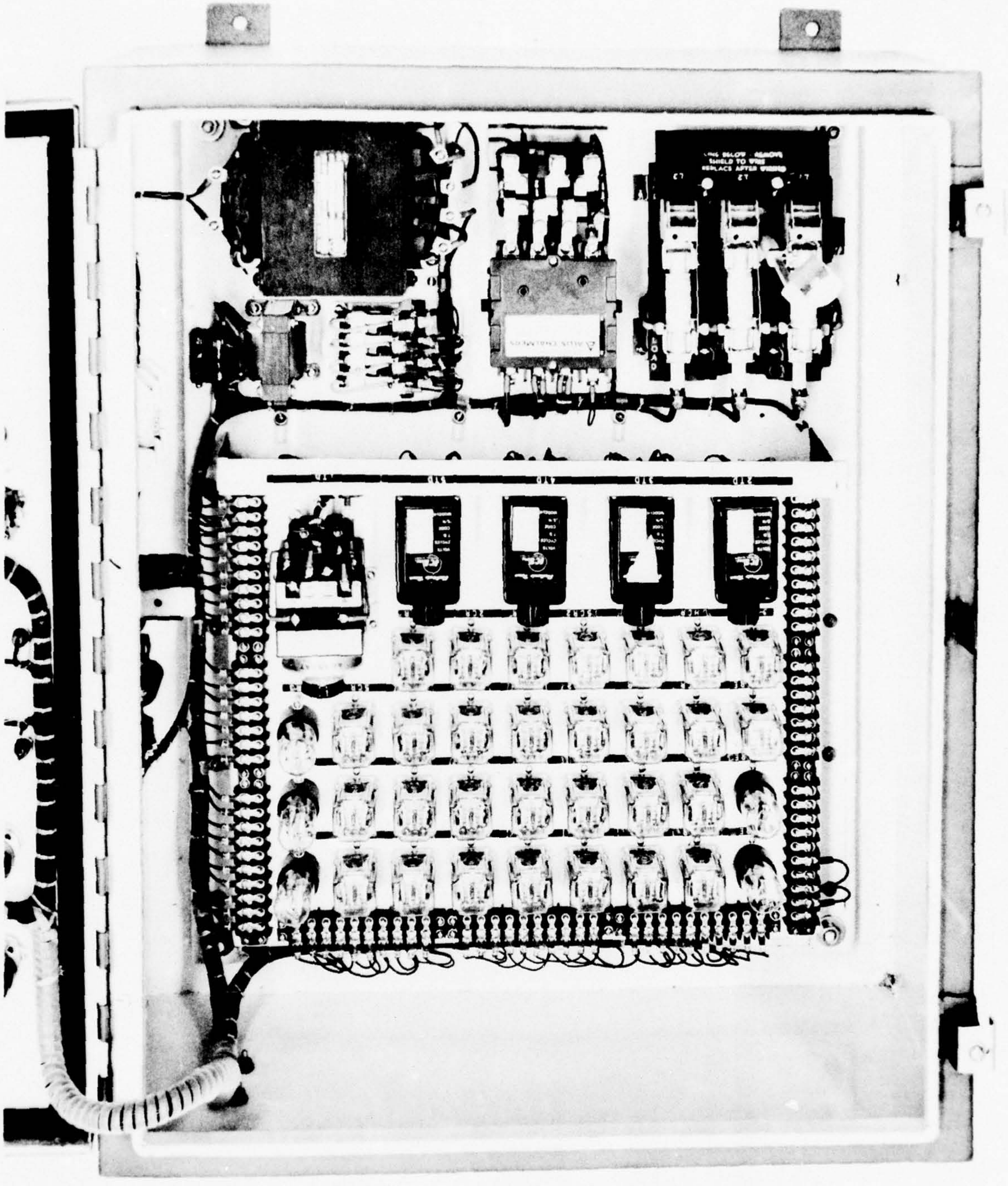


Figure 3.10 MONITORING CONTROL PANEL UNIT INTERIOR

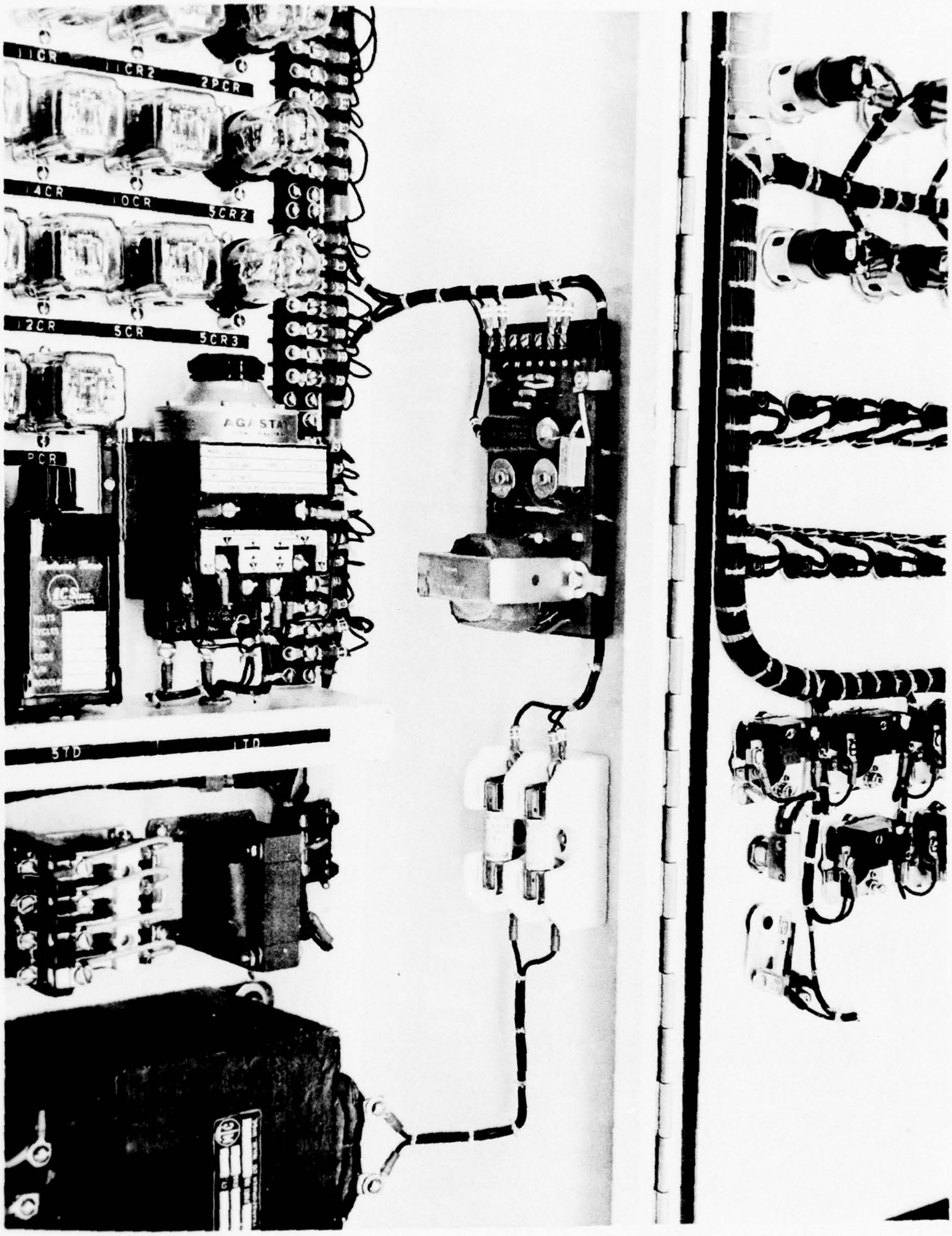


Figure 3.11 MONITORING CONTROL PANEL
INTERIOR R. H. SIDE WALL

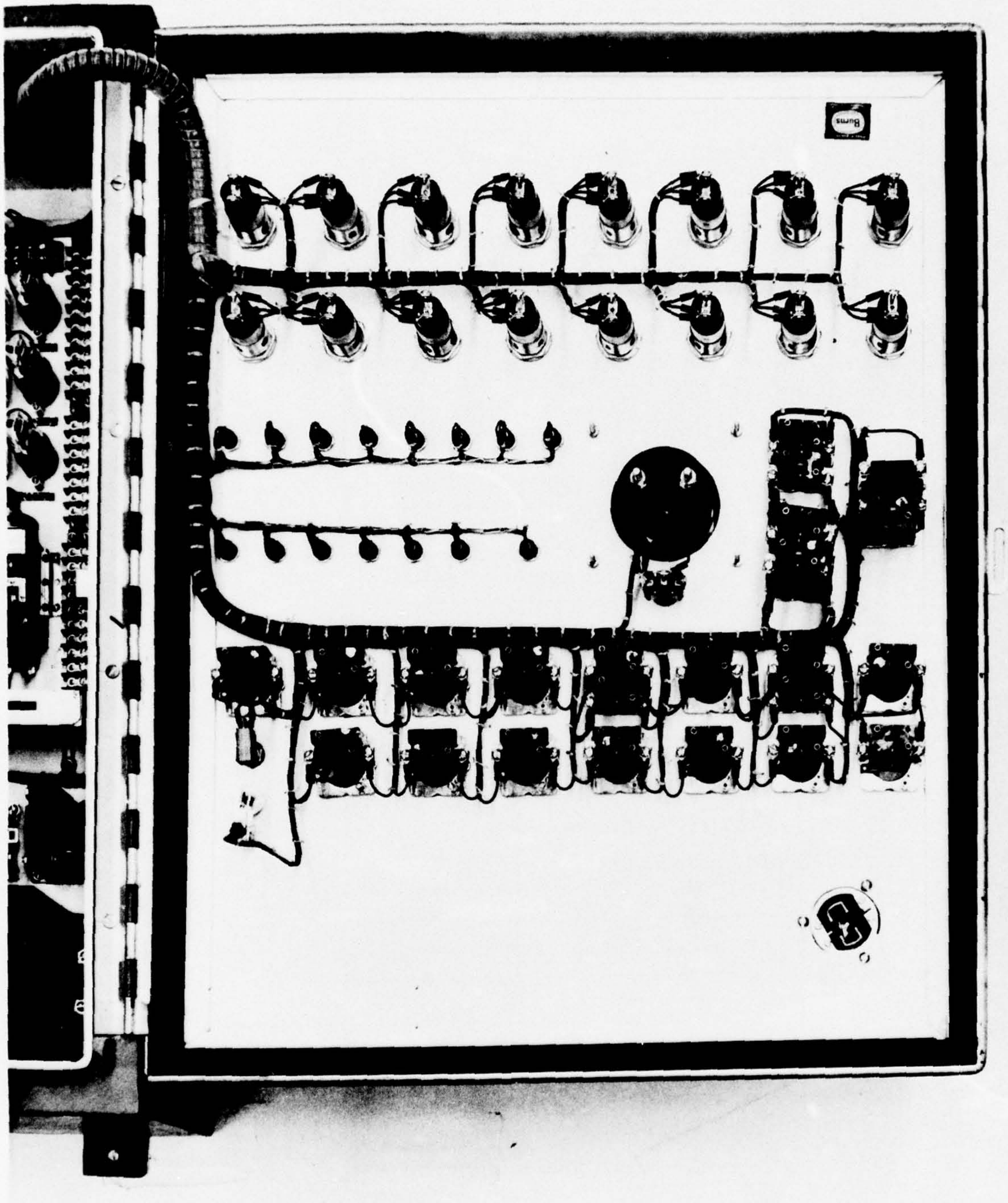
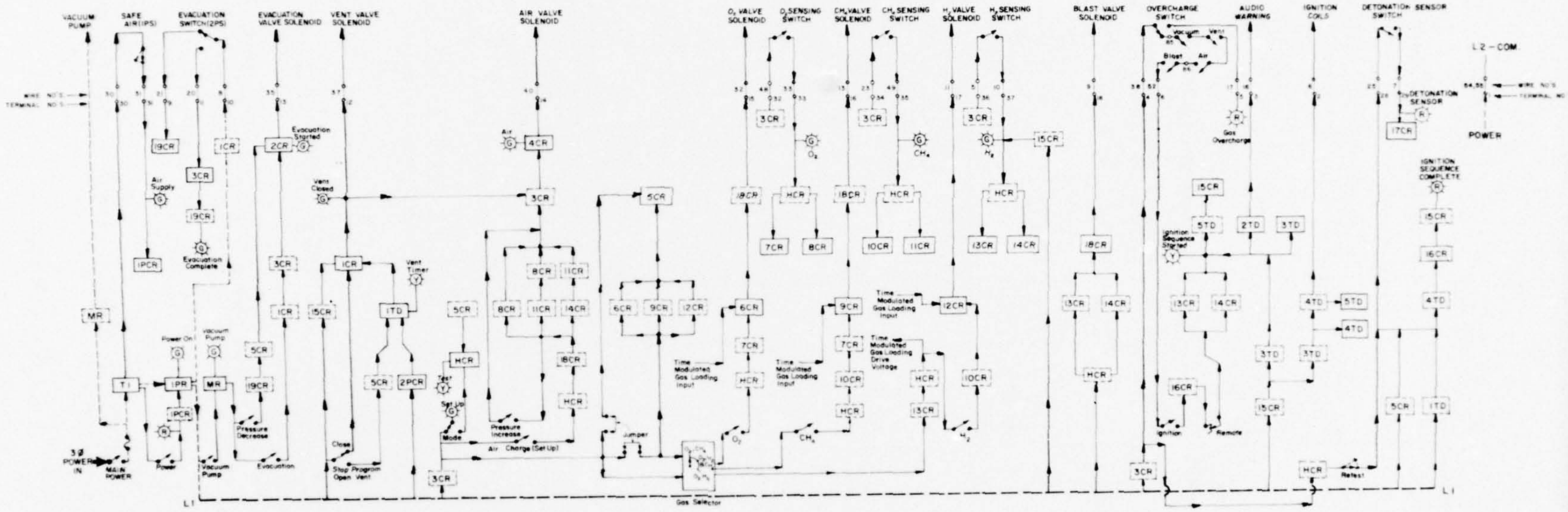


Figure 3.12 MONITORING CONTROL PANEL REAR VIEW



SIGNAL FLOW DIAGRAM

Figure 3.13

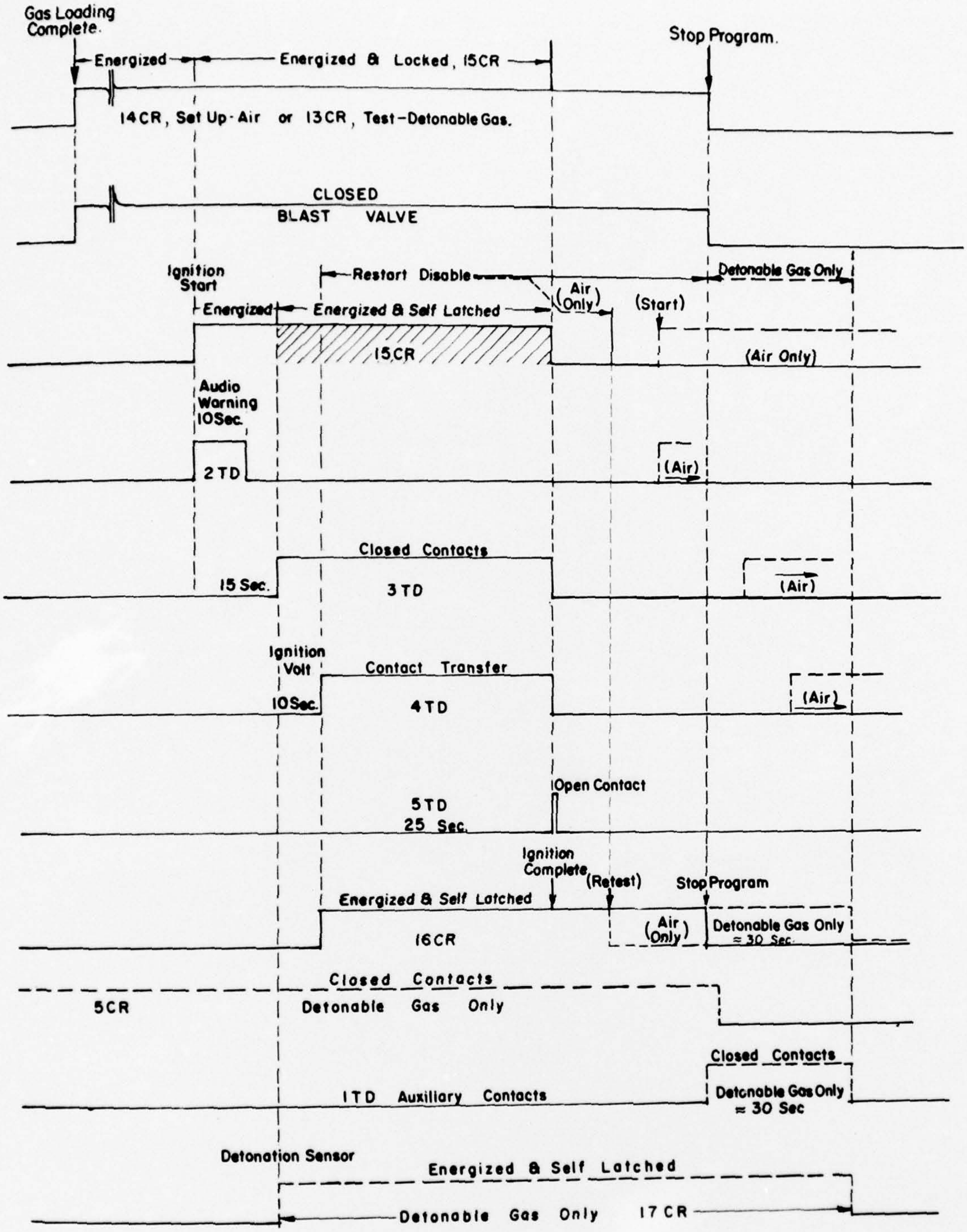


Figure 3.14 TIME BAR GRAPH

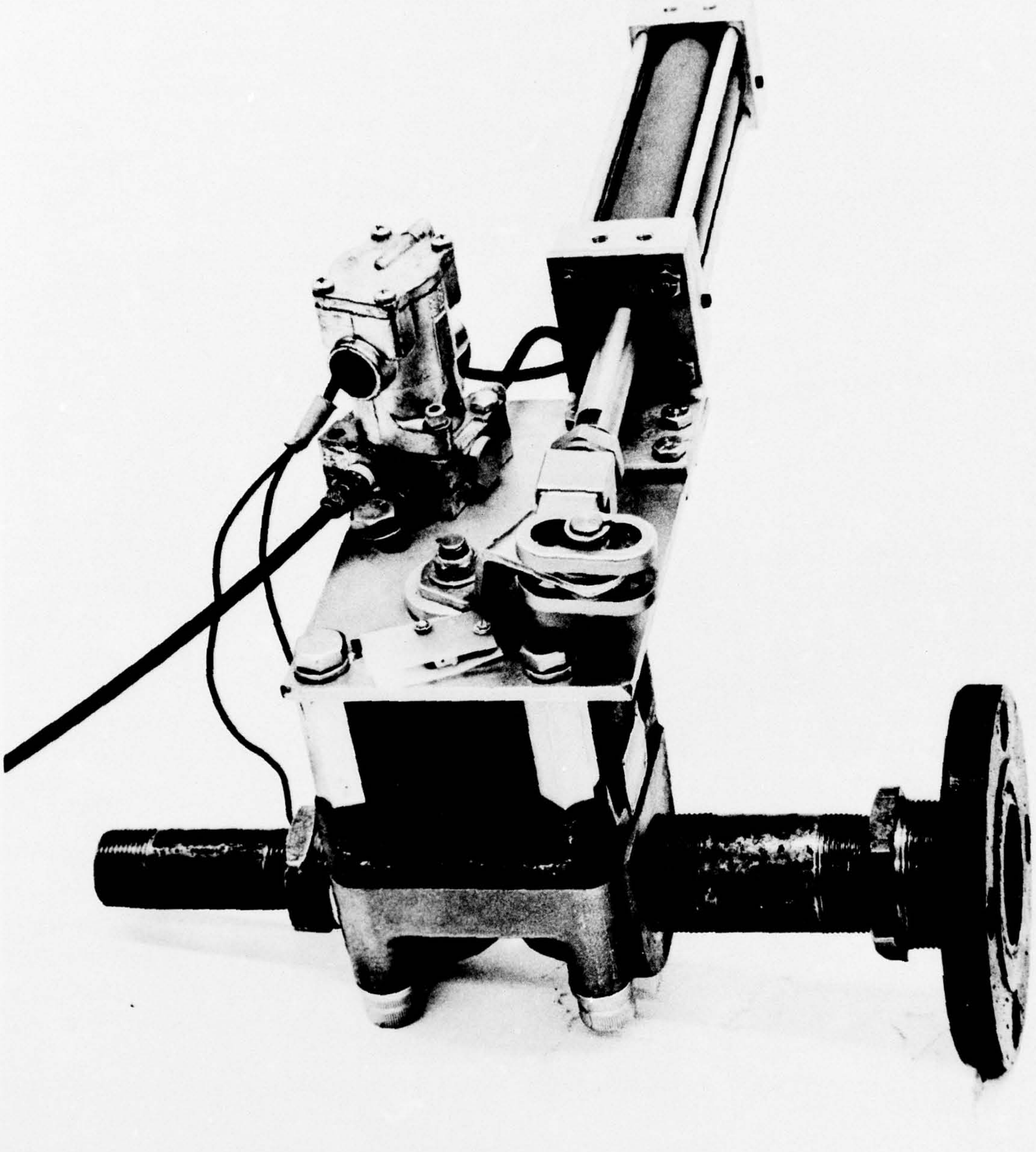


Figure 3.15 PURGE AIR INLET VALVE ASSEMBLY

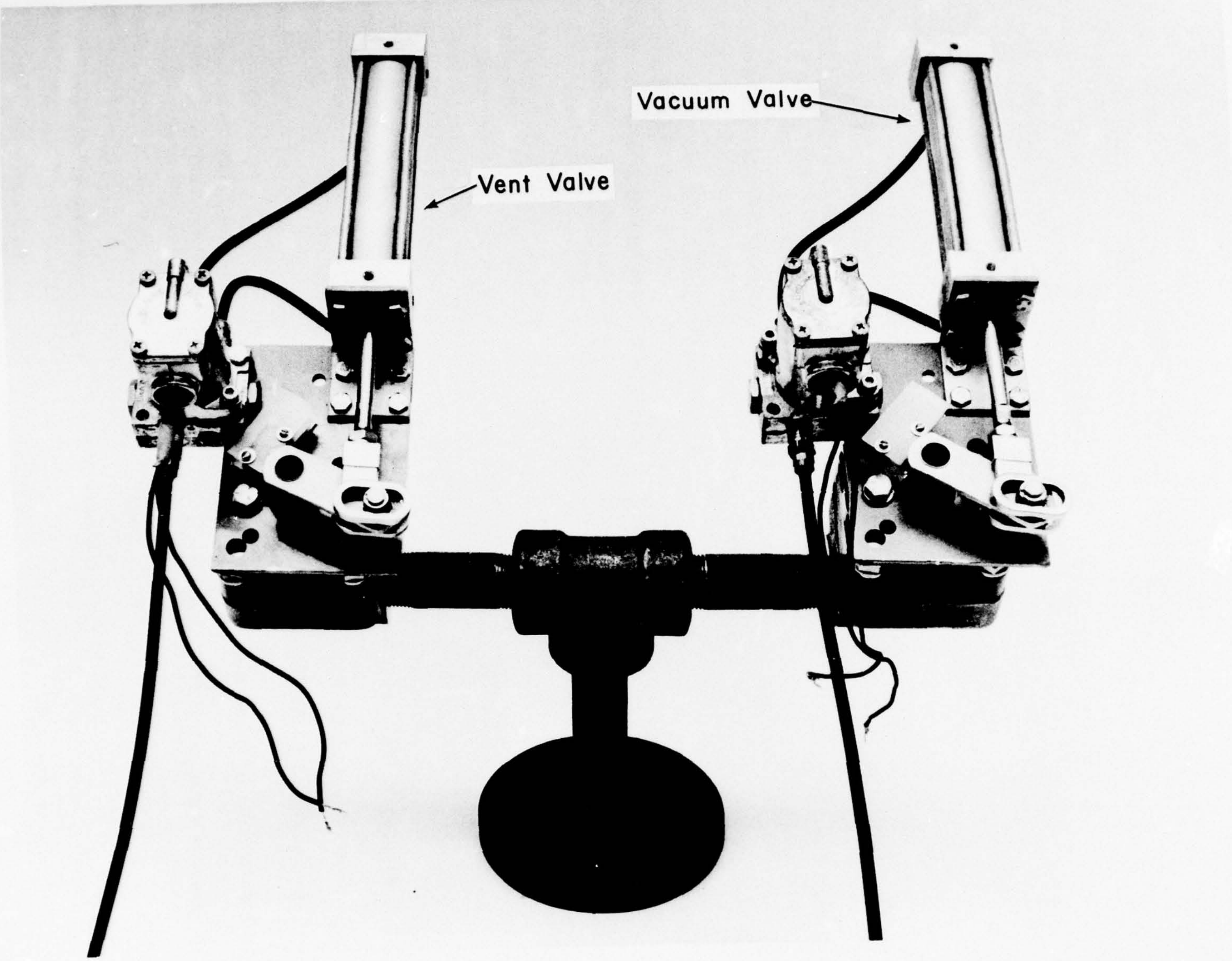


Figure 3.16 VENT – VACUUM VALVE ASSEMBLY

SECTION 4

MAINTENANCE AND TROUBLESHOOTING

This section contains the information required to ensure a continued operational facility, and contains a guide to identify malfunction in control electronics.

4.1 Maintenance

Maintenance of the 1500 psi Dynamic Load Simulator requires very little effort. The minor maintenance that is necessary may be categorized into two types, i.e., preventive maintenance and periodic maintenance.

4.1.1 Preventive Maintenance

When used indoors, the 1500 psi Dynamic Load Simulator requires no preventive maintenance. The entire assembly was designed and fabricated with durability built into each system. This does not imply, however, that certain systems (e.g., pnenumatic and electrical lines) can suffer an unlimited amount of physical abuse.

If the simulator is moved to a remote outdoor site, it is recommended that the Monitoring Control Panel, Valve and Manifold Control Box, and Vacuum Pump be housed in a protective structure. These systems were not designed for outdoor use without shelter. A protective cover would be necessary for the simulator firing transformers and spark plugs. For extended storage outdoors, it is recommended that all valves be removed from the shock tube and that the connecting flanges be replaced with blind flanges.

4.1.2 Periodic Maintenance

Other than normal cleaning and lubrication of the valves and vacuum pump, only the spark plugs require periodic maintenance, i.e., cleaning and regapping. This primarily refers to ignition spark plugs located at the top of the 1500 psi Dynamic Load Simulator, however, the same periodic maintenance would be required of spark plugs used to obtain detonation wave time-of-arrival information in the small shock tube.

The procedure for determining whether the ignition spark plug requires periodic maintenance is discussed in Section 3.1.3. The interval at which periodic maintenance must be performed on the spark plug is a function of the amount of free carbon in the products of combustion. The greater the amount of free carbon available, the greater the frequency of periodic maintenance.

4.2 System Troubleshooting

4.2.1 Introduction

It is anticipated that the majority of circuit malfunctions will be traceable to the failure of one or more control relays in the Monitoring Control Panel. Although false control panel light indication may accompany a relay failure, normal circuit operation without proper light indication would most likely be caused by a burned-out bulb. As such, the panel bulbs would be the first item checked. All panel bulbs are replaceable from the front of the unit without opening the panel door.

4.2.2 Troubleshooting Procedure

The Signal Flow Diagram (Figure 3.13) may be used in conjunction with an A.C. voltmeter of 5000 ohm/volt sensitivity or higher to troubleshoot the majority of circuit malfunctions. This diagram indicates terminal numbers and the associated interconnecting wire numbers used in wiring the Monitoring Control Panel to the Valve and Manifold Control Box. Identical numbered terminals were interwired between the two units. Therefore the terminals in the Valve and Manifold Control Box correspond in number to those shown in the Signal Flow Diagram for the Monitoring Control Panel. Identical voltage measurements may be made at either unit with certain exceptions. These exceptions involve the Power On control circuits.

Voltage troubleshooting at the Monitoring Control Panel requires that the panel door be opened and the power disconnect switch (S3) be bypassed. This is accomplished by rotating the switch extension handle 90° clocksiwe.

NOTE: This handle must be returned to its original position prior to closing the panel door.

CAUTION: DANGEROUS VOLTAGE LEVELS EXIST WITHIN THIS UNIT; EXERCISE SUITABLE CARE WHEN CIRCUIT TROUBLESHOOTING.

Control voltage (nominally 115 volts A.C.) may now be measured between terminals 30 and 83. If sufficient air for valve operation is available as determined by the Air Supply Pressure Sensing Switch, the control voltage can also be measured between terminals 31 and 83, and the Air Supply lamp will be illuminated. Pulling the Power Swithc to the ON position will bring control voltage between terminals 82 and 84. The control handle lamp and panel Power ON lamp will now become illuninated.

The above sequence describes normal operation and normal voltage measurements at the terminals listed. Should a circuit fault develop in this portion of the unit, the number of components and interwiring between them is easily followed on the Control Schematic drawing (Appendix B) and servicing should present no problem.

In Table 4.1, the voltage level at the terminal number listed is given for various control operations. In some instances, a circuit change or transfer will normally occur automatically during a specific part of the program sequence. For these occurrences, the transfer action is listed in parenthesis inthe Control Operation column. In all cases, except the vent timer light, the voltage measured at each terminal is with reference to terminals No. 1 or No. 84 (common wired) and is schematically shown in Appendix B as L2-COM. The terminal number and voltage required at that location is shown in the second column of Table 4.1. The third column gives the latching or holding relay (where applicable) for the operation listed. This column also lists, in parenthesis, the applicable indicator lamp, when illuminated, and associated terminal number for the particular operation or transfer action. The low voltage valve position lamps are not listed in Table 4.1. Their illumination is controlled entirely by cam-actuated microswitches mounted at the valve-operating shafts. The fourth column in Table 4.1 lists the relay(s) involved with the particular control operation or transfer action. Where an associated terminal voltage measurement may be made for a particular relay listed, the the terminal number and correct voltage level follows the relay listed in parenthesis.

Troubleshooting with the aid of the charted information in Table 4.1 may be performed in the following manner:

1. Determine that control operation and/or transfer action that does not perform in a correct manner.
2. Find the particular function involved in the first column of Table 4.1.
3. At the Monitoring Control Panel, determine if the correct voltage is present at the interwiring terminal listed in the second column of Table 4.1.
4. Find the holding relay and light information from the third column listings. If the correct voltage appears, as determined in Step 3, only by holding the push-button switch depressed during the measurement, check the holding relay listed.
5. Use the information in the fourth column to aid in determining which interacting relay may be defective. If one or more control operations and/or circuit transfers are malfunctioning simultaneously, a common relay to each may be suspected.
6. If the correct terminal voltage (Step 3) has been measured at the interwiring terminal of the Monitoring Control Panel, repeat the same voltage measurement at the identical terminal number in the Valve and Manifold Control Box. A correct voltage at this point would lead to an investigation of the associated components involved.

Specific point-to-point circuit wiring may be followed by referencing the Control Schematic Drawing (Appendix B). Circuit troubleshooting involving the valve position circuits, the absolute pressure measuring circuit and the ignition monitor circuits may be performed with the aid of this schematic.

CONTROL OPERATION OR (TRANSFER ACTION)	TERMINAL NO. - VOLTAGE	HOLDING RELAY AND/OR (IND. LAMP)	APPLICABLE RELAYS (TERMINAL VOLTAGE)
VENT OPEN-STOP PROGRAM	12-115 V. 14-115 V.		15CR, 1CR (69-115 V.) 3CR2
(MINIMUM VENT OPEN TIME-POWER ON)	12-115 V. 14-115 V.	1TD (VENT TIMER-6.3 V.-48-49)	15CR, 1CR, 3CR2 2 PCR (2 SEC. ONLY) 1TD (M ON RELAY-115 V.-2 SEC.)
(MINIMUM VENT OPEN TIME-DETONABLE GAS)	12-115 V. 14-115 V.	1TD (VENT TIMER-6.3 V.-48-49)	15CR, 1CR, 3CR2 5CR2 (.5 SEC ONLY) 1TD (M ON RELAY-115 V.-.5 SEC.)
VENT CLOSE	12-0 V. 14-0 V.	1CR (VENT CLOSE-72)	1CR, 1CR2 (72-115 V.)
EVACUATION START-VACUUM PUMP ON	12-115 V.	2CR (EVACUATION STARTED-74)	1CR, 1CR2, 3CR 2CR (77-115 V.) MR(78-115 V.)(10-115 V.)
(EVACUATION COMPLETE)	13-0 V.	3CR (EVACUATION COMPLETE-73) (SET UP-AIR-68) OR (TEST-DETONABLE GAS-67)	1CR, 1CR2 (10-115 V.) 19CR (9-0 V.) 3CR (11-115 V.) 1HCR, 3CR2 (79-115 V.)
PRESSURE DECREASE-MOMENTARY PUSH BUTTON	13-115 V.	(EVACUATION STARTED-74)	1CR, 1CR2 (10-115 V.) 19CR (9-115 V.) 5CR (75-115 V.) MR(78-115 V.)
AIR CHARGE-SET-UP-SIMULATED O_2	14-115 V.	4CR (AIR-65)	4CR (62-115 V.) 8CR (64-115 V.) 18CR (61-115 V.) 1HCR 3CR2 (79-115 V.)
(SIMULATED O_2 LOADING COMPLETE)	14-0 V.	(O_2-33)	8CR (64-0 V.) 3CR2 (32-115 V.) 4HCR, 2HCR, 18CR (61-115 V.) 1HCR
AIR CHARGE-SET UP SIMULATED CH_4	14-115 V.	4CR (AIR-65)	4CR (62-115 V.) 11CR, 8CR2 (64-115 V.) 18CR (61-115 V.) 1HCR 3CR2 (79-115 V.)

TABLE 4.1

TROUBLESHOOTING CHECK LIST

CONTROL OPERATION OR (TRANSFER ACTION)	TERMINAL NO. - VOLTAGE	HOLDING RELAY AND/OR (IND. LAMP)	APPLICABLE RELAYS (TERMINAL VOLTAGE)
(SIMULATED CH_4 LOADING COMPLETE)	14-0 V.	(CH_4-35)	11CR, 8CR2 (64-0 V.) 3CR (34-115 V.) 4HCR, 2HCR, 18CR (61-115 V.) 1HCR
AIR CHARGE-SET UP SIMULATED H_2	14-115 V.	4CR (AIR-65)	4CR (62-115 V.) 11CR2, 14CR (64-115 V.) 18CR (61-115 V.), 1HCR 3CR2 (79-115 V.)
(SIMULATED H_2 LOADING COMPLETE)	14-0 V.	(H_2-37)	11CR2, 14CR (64-0 V.) 3CR2 (36-115 V.) 4HCR, 2HCR, 18CR (61-115 V.) 1HCR
PRESSURE INCREASE -MOMENTARY PUSH BUTTON	14-115 V.		3CR2 (79-115 V.) 18CR (61-115 V.) 1HCR
OXYGEN GAS CHARGING- TEST MODE	15-115 V.	6CR	18CR, 6CR (51-115 V.) 7CR 2HCR, 3HCR (50-115 V.) 3CR2 (25-115 V.)
(OXYGEN GAS CHARGING COMPLETE)	15-0 V.	7CR (O_2-33)	4HCR, 2HCR 3CR2 (32-115 V.)
METHANE GAS CHARGING TEST MODE	16-115 V.	9CR	18CR, 9CR (53-115 V.)7CR, 10CR, 2HCR, 3HCR (52-115 V.) 3CR2 (34-115 V.)
(METHANE GAS CHARGING COMPLETE)	16-0 V.	10CR (CH_4-35)	4HCR, 2HCR 3CR2 (34-115 V.)
HYDROGEN GAS CHARGING- TEST MODE	17-115 V.	12CR	12CR (55-115 V.), 10CR 2HCR, 3HCR (54-115 V.) 13CR, 3CR2 (36-115 V.)
(HYDROGEN GAS CHARGING COMPLETE)	17-0 V.	13CR (H_2-37)	4HCR, 2HCR 3CR2 (36-115 V.)
(BLAST VALVE OPEN-SET UP)	18-115 V.		1HCR, 2HCR, 14CR
(BLAST VALVE OPEN-TEST)	18-115 V.		1HCR, 2HCR, 13CR (37-0 V.)
(BLAST VALVE CLOSED-SET UP)	18-0 V.	15CR2 ON 14CR DURING IGNITION SEQUENCE	1HCR, 2HCR, 14CR, 4HCR ALSO 15CR, 15CR2 DURING IGNITION SEQUENCE

TABLE 4.1 CONT'D.

CONTROL OPERATION OR (TRANSFER ACTION)	TERMINAL NO. - VOLTAGE	HOLDING RELAY AND/OR (IND. LAMP)	APPLICABLE RELAYS (TERMINAL VOLTAGE)
(BLAST VALVE CLOSED-TEST)	18-0 V.	15CR2 ON 13CR DURING IGNITION SEQUENCE	1HCR, 2HCR, 13CR (37-115 V.), 4HCR ALSO 15CR, 15CR2 DURING IGNITION SEQUENCE
IGNITION SEQUENCE START-SET UP	56-115 V.	15CR (IGNITION SEQUENCE START-56)	5TD, 14CR, 15CR (59-115 V.) 16CR (58-115 V.), 3CR, 3CR2 (4-115 V.)(6-115 V.)
IGNITION SEQUENCE START-TEST	56-115 V.	15CR (IGNITION SEQUENCE START-56)	5TD, 13CR, 15CR (59-115 V.) 16CR (58-115 V.), 3CR, 3CR2 (4-115 V.)(6-115 V.)
(AUDIO WARNING -10 SEC.)	3-115 V.		AS EITHER OF PREVIOUS TWO CONTROL FUNCTIONS PLUS 2TD
(IGNITION VOLTAGE -10 SEC. AFTER 15 SEC. DELAY) SET UP OR TEST AFTER START	2-115 V.	15CR2	15CR, 15CR2, 13TD, 4TD
(IGNITION SEQUENCE COMPLETE) 40 SEC. AFTER START-SET UP	58-0 V.	16CR (IGNITION SEQUENCE COMPLETE-57)	1HCR, 2HCR (39-115 V.) 4TD, 15CR, 15CR2, 16CR (57-115 V.) 3CR2 (4-115 V.)
(IGNITION SEQUENCE COMPLETE) 40 SEC. AFTER START-TEST	58-0 V.	16CR (IGNITION SEQUENCE COMPLETE-57)	5CR3 (28-115 V.) 4TD, 15CR2, 16CR (57-115 V.)
(IGNITION SEQUENCE COMPLETE) DURING 30 SEC. PERIOD AFTER STOP PROGRAM TUBE VENT-TEST	58-0 V.	16CR (IGNITION SEQUENCE COMPLETE-57)	1TD-3 (28-115 V.) 15CR2, 16CR (57-115 V.)
(DETONATION SENSOR) 15 SEC. AFTER START AND UNTIL IGNITION SEQUENCE COMPLETE LIGHT EXTINGUISHES TEST	29-115 V.	17CR (DETONATION SENSOR-29)	5CR3 (28-115 V.) OR 1TD-3 (28-115 V.)

TABLE 4.1 CONT'D.

APPENDIX A

ERROR IN SHOCK TUBE LOADING

This section includes a sample calculation to determine the effect of gas loading error on the detonation and peak reflected pressures.

Assume a binary mixture of oxygen and methane in a mole ratio of 2:1, and also assume initial fill pressure is to 1 atmosphere. The partial pressures of oxygen and methane are then 9.8 psia and 4.9 psia, respectively.

If no error ocurred in gas loading, the precise detonation pressure ratio expected would be as shown in Figure 2.2 or in Table 2.2,

$$P_D/P_0 = 29.49$$

The detonation pressure is, therefore, 433.5 psia and the peak reflected pressure expected is 433.5 psia x 2.6 or 1127 psia. If the gas loading is accomplished within an accuracy of ± 1 psia, the maximum errors that could be incurred would be calculated as follows

$$P_{O_2}/P_{CH_4} = \frac{9.8 \text{ psia} + 1 \text{ psia}}{4.9 \text{ psia} - 1 \text{ psia}} = 2.77$$

The detonation pressure ratio for this mole ratio may be found either in Figure 2.2 or by interpolation in Table 2.2

$$P_D/P_0 = 26.89$$

The resulting detonation pressure error is then

$$E_D = \frac{433.5 \text{ psia} - 395.3 \text{ psia}}{433.5 \text{ psia}} = 8.8 \% \text{ low}$$

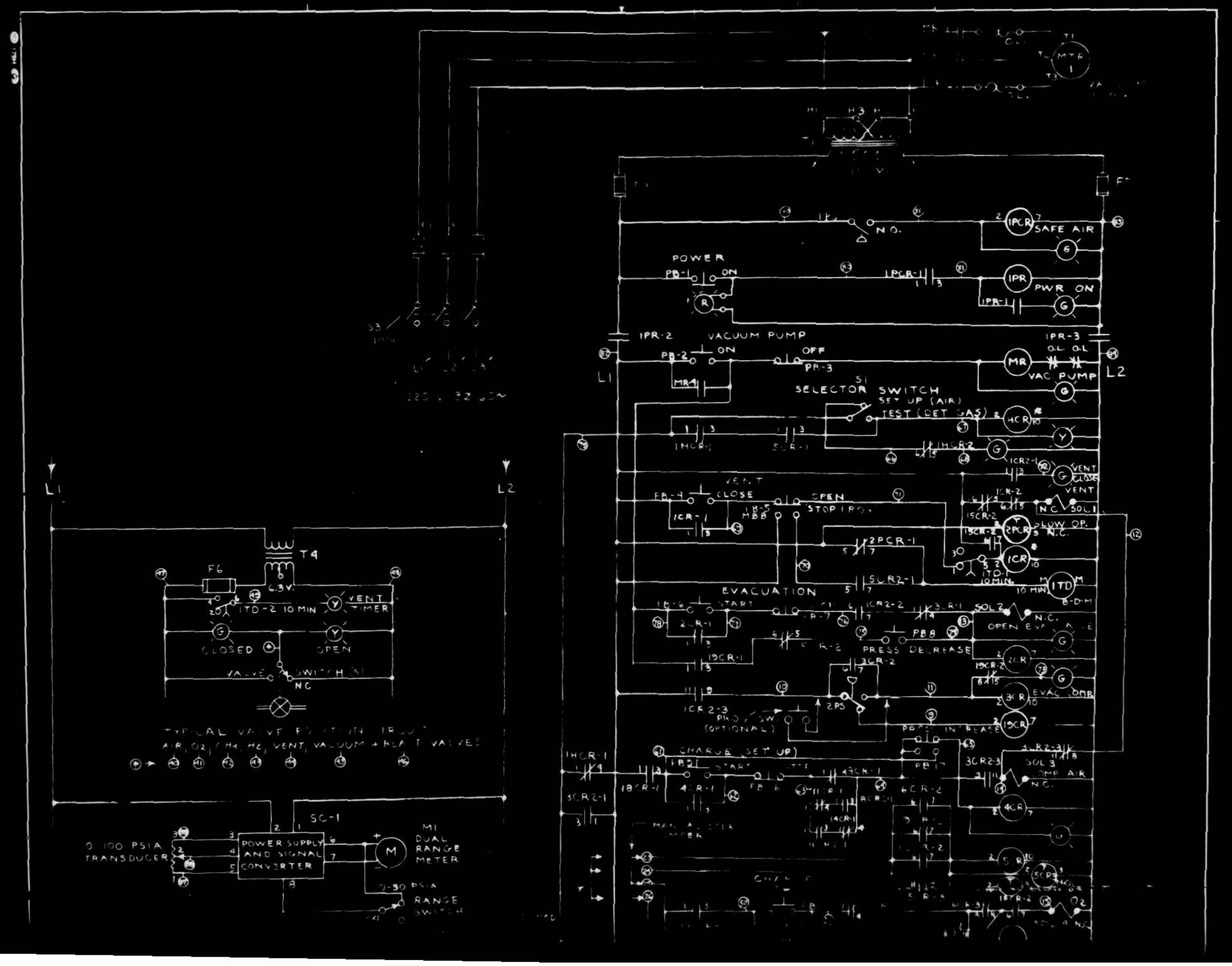
Similarly

$$P_{O_2}/P_{CH_4} = \frac{9.8 \text{ psia} - 1 \text{ psia}}{4.9 \text{ psia} + 1 \text{ psia}} = 1.49$$

$$P_D/P_O = 31.45$$

and the error is

$$E_D = \frac{433.5 \text{ psia} - 462.3 \text{ psia}}{433.5 \text{ psia}} = 6.6 \text{ \% high}$$


SAFE AIR
POWER
PB-1 ON
PWR ON
IPR-2
VACUUM PUMP
ON
OFF
PB-2
PB-3
IPR-3
O.L. O.L.
VAC PUMP
L1
L2
MR
S1
SELECTOR SWITCH
SET UP (AIR)
TEST (GET GAS)
VENT
CLOSE
OPEN
STOP PROG
VENT
SOL 1
SLOW OP.
N.C.
ITD
10 MIN
EVACUATION
START
SOL 2
OPEN EVAC
PRESS DECREASE
EVAC DNR
PRESS INCREASE
CHARGE (SET UP)
SOL 3
N.C.
2PS
(OPTIONAL)
S3
220 V 3Ø 60~
T4
F6
6.3V
ITD-2 10 MIN
VENT TIMER
CLOSED
OPEN
VALVE SWITCH (S)
NC
TYPICAL VALVE POSITION CIRCUIT
AIR, O2, CH4, H2, VENT, VACUUM + HEAT VALVES
SC-1
POWER SUPPLY AND SIGNAL CONVERTER
0-100 PSIA TRANSDUCER
M1
DUAL RANGE METER
0-30 PSIA
RANGE SWITCH

APPENDIX C

EVACUATION TIME FOR A KDH-80 VACUUM PUMP

Using a standard pneumatic pump formula

$$t = \frac{V F_A}{D}$$

Where t = evacuation time, in minutes

V = system volume, in cubic feet

F_A = pump-down factor, non-dimensional

D = pump displacement, in cubic feet per minute

In the case of the 1500 psi Dynamic Load Simulator,

V = 500 cubic feet

F_A = 4 @ 29 inches of mercury

D = 75 standard cubic feet per minute @ 29 inches of mercury

Upon substitution, t becomes 26.6 minutes.

PIPING DIAMETER FOR VACUUM MANIFOLDING

Using a standard pneumatic formula

$$d = \left[\frac{1.9\ DL}{1000\ P}\right]^{1/4}$$

where d = pipe diameter, in inches

D = pump displacement, in cubic feet per minute

L = length of connecting pipe, in feet

P = pressure drop, in Torr.

In the case of the 1500 psi Dynamic Load Simulator,

D = 75 standard cubic feet per minute

L = 35 feet

P = 5 Torr. (Operating pressure = 25 Torr., Allowable P = 20 percent of operating pressure)

Upon substitution, d becomes 1 inch.

APPENDIX D

1500 PSI DYNAMIC LOAD SIMULATOR

- CHECK LIST -

Test Director (TD)	Test Conductor (TC)
Name________________	Name________________
Date________________	Date________________

Each following blank in this check list must be filled in (enter N/A where not applicable) by the Test Director who determines the theoretical test parameters. The test conductor is responsible for entering the actual test parameters.

			SET UP	TEST		
1.	GAS SELECTOR					
	Switch Setting	theoretical	O_2-CH_4-H_2			(TD)
		actual				(TC)
2.	TUBE EVACUATION					
	Vacuum pressure switch setting	theoretical	28.0		in. Hg	(TD)
		actual			in. Hg	(TC)
	Final vacuum readings	meter			psia	(TC)
		gage			in. Hg	(TC)
3.	OXYGEN LOADING					
	Oxygen pressure switch setting	theoretical	14.0		[✓ in. Hg] psig	(TD)
		actual			in. Hg psig	(TC)
	Final oxygen readings	meter			psia	(TC)
		gage			in. Hg psia	(TC)

			SET UP	TEST		
4.	METHANE LOADING					
	Methane pressure switch setting	theoretical	7.5		[✓ in. Hg] psig	(TD)
		actual			in. Hg psig	(TC)
	Final methane readings	meter			psia	(TC)
		gage		XXXX	in. Hg psig	(TC)
5.	Hydrogen pressure switch setting	theoretical	0.0		[✓ in. Hg] psig	(TC)
		actual			in. Hg psig	(TC)
	Final hydrogen readings	meter			psia	(TC)
		gage		XXXX	in. Hg psig	(TC)
6.	OVERCHARGE PRESSURE SWITCH SETTING	theoretical	3.0		[✓ in. Hg] psig	(TD)
		actual			in. Hg psig	(TC)
7.	DETONATION SENSOR SWITCH SETTING	theoretical	300		psia	(TD)
		actual			psia	(TC)
8.	INITIAL PRESSURE OF GAS MIXTURE	theoretical	14.7		psia	(TD)
		actual			psia	(TC)
9.	MOLE RATIO (O_2/FUEL	theoretical	1.0			(TD)
		actual				(TC)
10.	FUEL RATIO (CH_4/H_2)	theoretical	1.0			(TD)
		actual				(TC)
11.	DETONATION	yes				(TC)
		no				(TC)