AD 421954

MIDWEST RESEARCH INSTITUTE

Contract No. DA 18-108-AMC-118(A)

QUARTERLY PROGRESS REPORT NO. 2

Covering the Period

18 June - 17 September 1963

INVESTIGATION OF THE FLASHING OF AEROSOLS

Prepared by

Alan R. Pittaway

25 October 1963

AD__________ Accession No.__________

Midwest Research Institute, Kansas City, Missouri
INVESTIGATION OF THE FLASHING OF AEROSOLS -
Alan R. Pittaway
Quarterly Report No. 2, 24 Oct 1963, 25 pp - 10 illus, 1 table, refs. Contract DA 18-108-AMC-118(A)

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2. Chemical warfare agents
3. Aerosol generation*
4. Explosive gases
5. Explosions
6. Combustion*
7. Ignition*
8. Shock waves
9. Inhibition
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PREFACE

This is Quarterly Progress Report No. 2 on Contract No. DA 18-108-AMC-118(A), M.R.I. Project 2685-C, titled "Investigation of the Flashing of Aerosols." It covers the period 18 June through 17 September 1963. All information presented in the monthly letter reports is contained in the project quarterly reports.

The purpose of this project is to obtain information on aerosol flammability as a function of (a) fuel concentration, vapor pressure, and particle size, (b) source of ignition, and (c) composition of the environmental gas. Additives which will tend to suppress either the ignition or the combustion of the aerosol are to be evaluated.

This one-year project is sponsored by the U. S. Army Chemical Research and Development Laboratories, Director of Weapons Systems, Physicochemical Research Division, Colloid Branch. Mr. Joseph Pistritto is the Project Officer. Work on this program is being accomplished at M.R.I. under the supervision of Dr. R. W. Shortridge, Assistant Director, Chemistry Division. Mr. Alan R. Pittaway is the principal investigator. Mr. Harry Pollock and Mr. Roger Schroeder have made significant contributions to the design and fabrication of equipment during this report period. Mr. Pollock and Mr. Frank Brink have participated in the experimental work during this period.

Approved for:

MIDWEST RESEARCH INSTITUTE

F. V. Morriss, Director
Chemistry Division

25 October 1963

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SUMMARY

This program is concerned with determining flammability of aerosol systems. Equipment to be used consists of a constant pressure combustion chamber and a shock tube. The combustion chamber as designed and fabricated is reviewed. Design calculations for the shock tube are presented. The technique of generating the desired aerosol particle size in the desired quantity is reviewed. Problems uncovered during the course of the work are discussed.

I. INTRODUCTION

This program is related to the phenomenon known as "flashing" which occurs during the explosive dissemination of combustible liquids. An analysis of the flashing phenomenon was given in Quarterly Report No. 1. The purpose of this project is to provide additional fundamental information on aerosol combustion. The information can then be applied to specific flashing problems.

The method of approach to be used in obtaining this information is given in Quarterly Report No. 1. In brief, we are using an electrically-ignited "combustion chamber" to determine the influence of fuel particle size, fuel concentration, fuel vapor pressure, and environmental gas composition on aerosol flammability. A shock tube will be used to evaluate shock waves as ignition sources on mixtures found to be flammable in the combustion chamber.

This report reviews the current status of the project and covers its development since the last quarterly report.

II. CURRENT PROGRESS

A. Particle Size Determination

An important part of this program is the establishment of a known aerosol particle size. Studies by Burgoyne[1/] and co-workers have shown that when a liquid aerosol particle size is below about 10µ, a combustion wave in such a mixture behaves like one in a premixed vapor-air system. Above about 40µ the particles were observed to burn individually in their own air envelope. Burgoyne and co-workers have also shown that the flammability limit is particle size-dependent. With small particles the lower limit approaches the lower limit of the vapor-air mixture. With large particles (above 40µ) the lower limit is about 18 mg. fuel/liter. This corresponds to distances between particles of about 31 times the droplet diameter which is slightly larger than the radius of the theoretical air sphere required for particle combustion.

A study by Kamo and Werle[2/] has shown the similar results for high-boiling-point fuels. There is some indication that the particle size which produces the lowest flammability limit is on the order of 100µ at a fuel concentration on the order of 18 mg/liter. These data tend to show that with these high-boiling fuels, flame could be transmitted over larger distances between particles. This conclusion is hard to justify in view of the data of Burgoyne.

The scatter in the data is fairly wide (which is understandable in view of the difficulty in working with aerosols) and the true position of the curves may be closer to the results of Burgoyne, or vice versa.

To eliminate ambiguity in determining in which of the two regimes we were operating, we selected two particle sizes as desirable for study, those below an arithmetic mean diameter of 5μ and those above 100μ . To generate these particle sizes in both the combustion chamber and the shock tube, we proposed to use a diesel fuel injector nozzle. Two Bosch nozzles were purchased: a No. ADN 15S2 and a No. ADN 15S3. Material is supplied to these nozzles with a Bacharach Nozzle Tester, Model YFL. This is a hand-operated positive displacement pump which will supply to the nozzle 0.95 ml. of liquid per stroke at a maximum pressure of 5,000 psig.

The particle size of the aerosol can be adjusted by varying the size of the nozzle and the operating pressure. A No. AKB-355-59P Bosch Nozzle Holder is used to adjust the pressure. This holder contains an adjustable check valve which prevents opening of the nozzle until a preselected pressure has been obtained. This insures that all flow through the nozzle occurs at the desired pressure. The pump also has a check valve which permits the entire flow system to be pumped to the set pressure of the nozzle. Once the system is at the desired pressure, the next stroke of the pump delivers fluid through the nozzle.

Particle-size studies are being made in the combustion chamber using a water-glycerin mixture which has the same viscosity of QL. The study was initiated with water-glycerin to avoid a loss in time pending receipt of QL (CRDL material code). The studies were made using the method of K. R. May[3] which consists of measuring the diameter of holes caused by droplets in a magnesium oxide coated slide. Slides were placed coated side toward the injector nozzle at eight different levels in the chamber. In addition, two slides were placed "edge on," one at the top and one at the bottom of the chamber.

As a first step, pressures of 2,000, 3,000 and 4,000 psig were evaluated with the ADN 15S2 nozzle, which is the larger of the two. The arithmetic mean particle diameter decreased regularly as the pressure increased, as shown in Table I. Since the smaller nozzle should produce smaller particles, an attempt was made to leap ahead by evaluating the particle size produced by the 15S3 nozzle (smaller of the two) at 5,000 psig. In addition, to get larger particles, the 15S2 nozzle was operated at 500 psig and the resulting particle size determined. The results of these experiments are shown in Table I.

TABLE I

PARTICLE SIZES AS A FUNCTION OF PUMP PRESSURE

Nozzle Pressure (psig)	Nozzle	Arithmetic Mean Particle Diameter (μ)
500	15S2	~ 356
2,000	15S2	23.0
3,000	15S2	20.7
4,000	15S2	12.8
5,000	15S3	16.8

The particle size for the 15S2 nozzle at 500 psig is shown as approximate because several of the slides were so heavily coated that they could not be read. However, the average of the six slides counted indicates that the size is greater than that desired. The desired 100μ size has been bracketed between 500 and 2,000 psig nozzle pressure.

The data on the 15S3 nozzle at 5,000 psig confound our prediction. The particle size observed is larger than that obtained from the larger nozzle at a lower pressure.

The obvious next step is to obtain additional data at 5,000 psig and 1,000 psig on the 15S2 nozzle. The initial attempt to obtain these data was thwarted by corrosion of the lapped piston in the pump by the glycerin-water solution. The corrosion resulted from improper cleaning and drying of the pump prior to a weekend.

Replacement parts for the pump have been ordered and received. The replacement parts were inexpensive in terms of out-of-pocket dollars but were costly in time.

These studies have now been resumed using QL as the liquid pumped. Additional data will be presented in the next report.

B. Combustion Chamber Development

The basic parameters of the combustion chamber were presented in Quarterly Report No. 1. In summary, it is a 36-in.-long Plexiglass tube, 5-1/2 in. I.D., set vertically in a stand. The chamber (tube) is separated from a plastic bag by a Saran Wrap rupture diaphragm. The diaphragm allows evacuation and filling of the tube (chamber) but breaks readily to allow the combustion gases to expand into the plastic bag.

The entire system is now complete and over-all views are shown in Figs. 1 and 2. It will be noted that quite a number of additions have been made since the last quarterly report. The additions can be broken down into several subsystems such as (a) aerosol injection system; (b) detonation product gas introduction system; (c) gas volume measuring system; and (d) ignition system. These are discussed below:

1. Aerosol injection system: The aerosol injection system must be protected from the atmosphere since QL reacts with both oxygen and water. In addition, it is necessary that means be provided to determine how much liquid is aerosolized in each experimental run. Further, the pump is a positive displacement type and requires a head of at least 15 psia to fill the pump chamber on each stroke. All of these features are incorporated in the assembly shown in Fig. 3.

The QL is received in sealed ampoules containing about 400 ml. of material. Such an ampoule is shown at the top of Fig. 3. This is joined by a Teflon sleeve to the balance of the filling system. The filling system consists of two parts, a storage area and a burette. The storage area is separated from the burette by two stopcocks. Essentially, the entire assembly is just a standard burette filling system with provision for replenishing the atmosphere above the stored liquid with dry nitrogen gas rather than having it open to the atmosphere. The lower Teflon stopcock selectively opens the storage area to fill the burette, or connects the burette to the pump. At the top of the burette are three stopcocks. The one on the right opens the system to a nitrogen cylinder to bleed nitrogen gas into the system. The one directly above the burette (almost hidden in Fig. 3) opens the system to the atmosphere through a tiny hole about 1/2 mm. diameter. This allows a continuous nitrogen flush in the system and breaks the "pump vacuum" so that the aerosol injector pump chamber will fill. The third stopcock (the one on the left in Fig. 3) allows nitrogen gas to pass into the storage bulb so that the burette will fill. A close examination of Fig. 3 will disclose a breather tube which extends from the storage area inlet nitrogen line up into the storage ampoule. This permits the nitrogen gas to pass directly into the open volume above the liquid. More importantly, this breather tube allows excess pressure that can build up in the storage area to be vented to the atmosphere.

The filling system is connected to the pump via a glass-to-stainless-steel ball and socket joint as shown. The stainless-steel socket terminates in a special pump adapter which can be seen in Fig. 2. A Teflon "O" ring between the adapter and pump seals this inlet line.

The quantity of liquid delivered can be controlled by the piston displacement in the pump, i.e., by the length of stroke of the pump handle. By

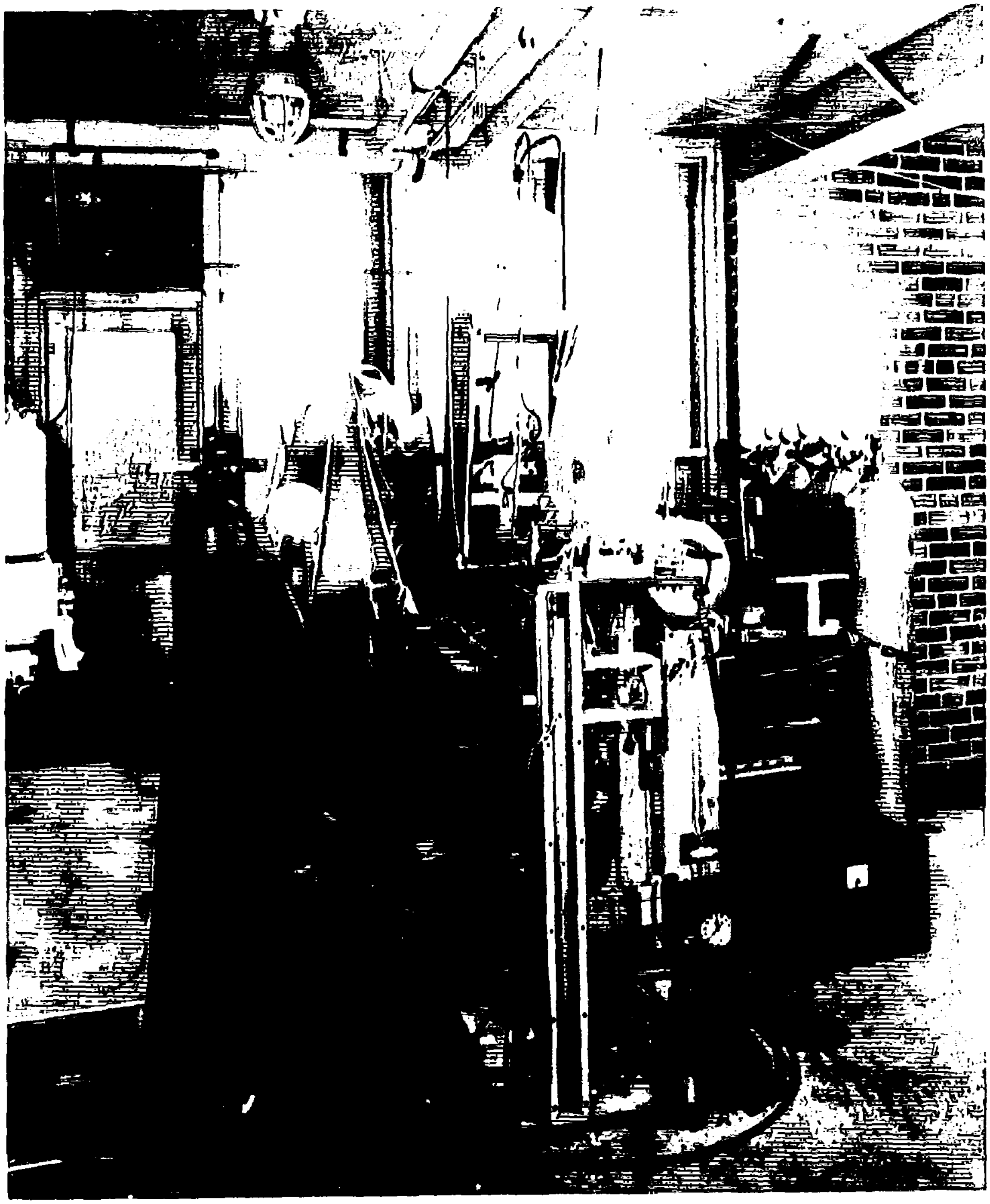

Fig. 1 - Over-All View of Combustion Chamber Showing All Accessory Equipment and Facilities

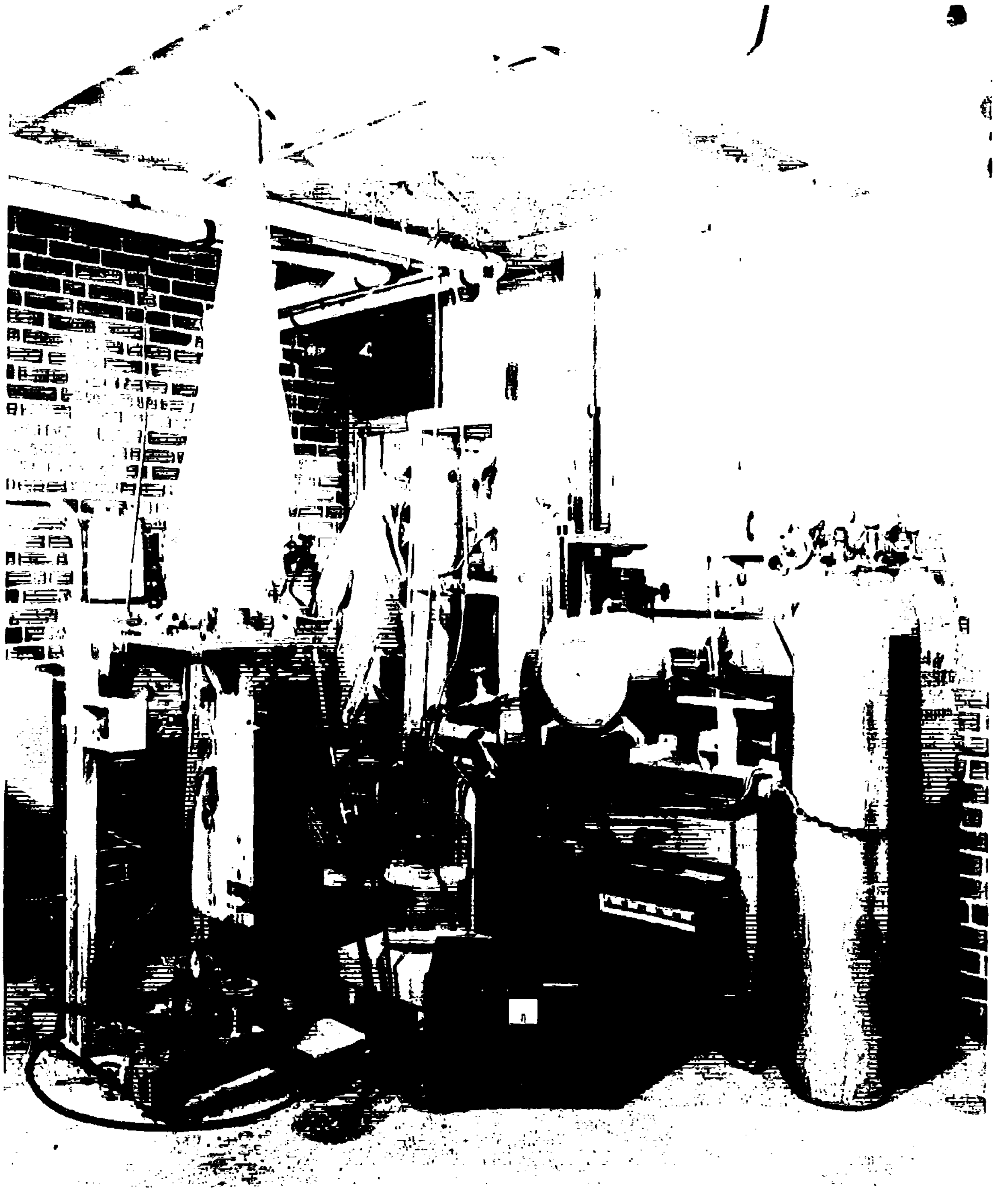

Fig. 2 - Over-All View of Combustion Chamber Showing All Accessory Equipment and Facilities

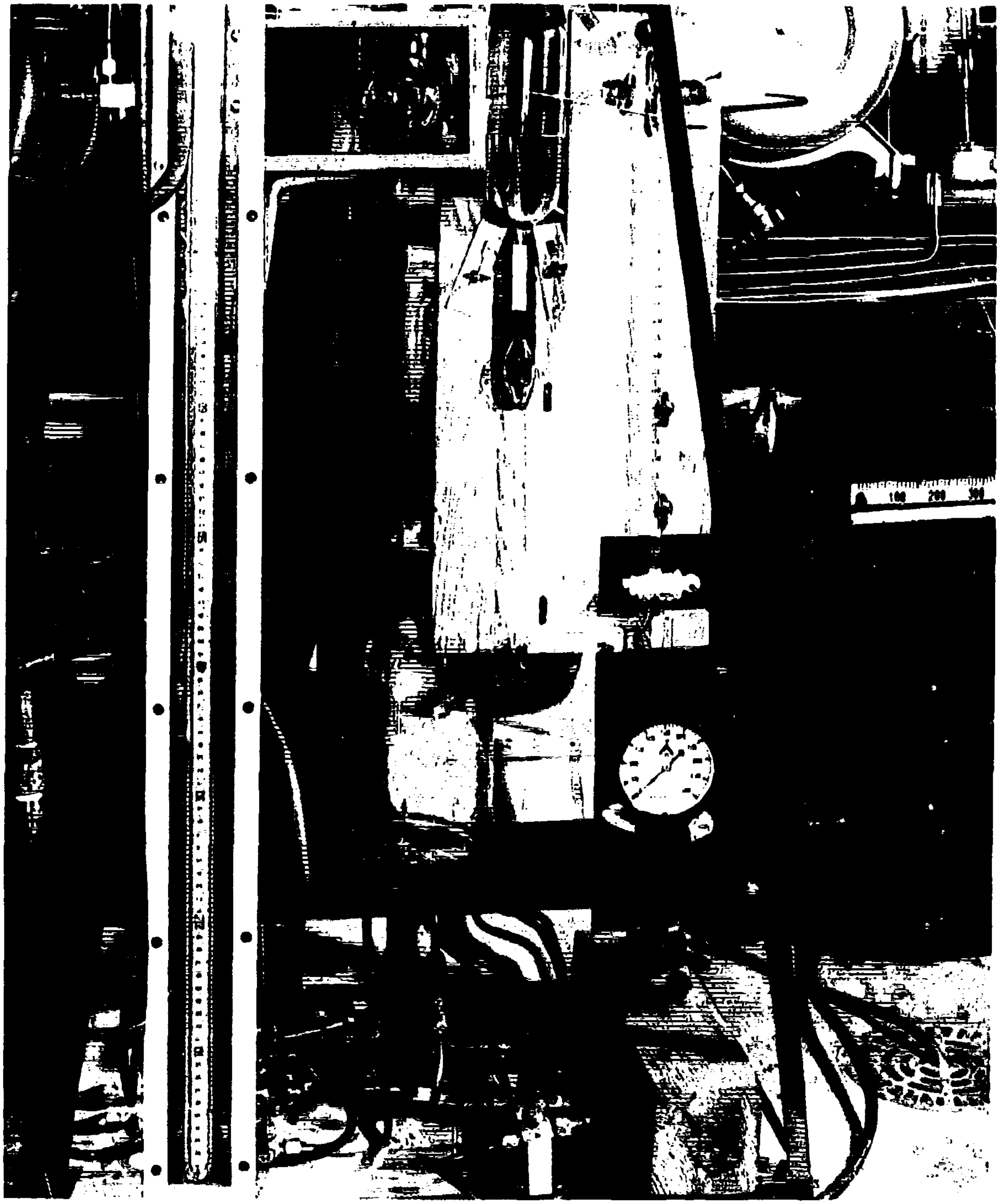

Fig. 3 - Aerosol Injection System Showing Method of Isolating QL From Atmosphere

using various sizes of drill rod stock as blocks between the pump housing and the handle, the quantity of liquid delivered at any pressure can be controlled to within ±0.005 ml. In the volume of the test equipment, the flammability range will probably be between 1 to 4 ml. of material, so this accuracy of delivery will be quite adequate. However, it is necessary to insert a check in the system to insure that the "dead-reckoned" quantity was actually delivered. This is the reason for the burette. With the burette it is quite easy to take before and after readings to determine the quantity actually injected when drill rod is used to limit the pump stroke to set the quantity it is desired to inject.

The system was "activated" by opening the QL ampoule under a nitrogen blanket in a sealed plastic bag and assembling it to the storage part of the system which was also contained in the bag. The glass parts were flushed with nitrogen for a day prior to introducing the QL ampoule. With the ampoule attached, the filling system was attached to the pump. By flowing nitrogen through the burette, the pump and injector nozzle are thoroughly flushed before admitting QL into the burette.

2. Detonation product gas: The composition of the explosive detonation product gas to be used as an environment gas for the aerosol was given in Quarterly Report No. 1. Cylinders of this gas mixture were ordered from Matheson. They were able to supply the CO, CO_2, H_2, N_2 and CH_4 components as a mixture but could not add in the H_2O, CH_3OH or NH_3 components to form the complete mix. To enable us to work with the original gas mixture as planned, we have made up a simple system to form the complete eight-component mix in the chamber.

A stock solution of NH_3 dissolved in a mixture of methyl alcohol and water was prepared in proportions equivalent to those found in the detonation product gas mixture. An arrangement was made whereby a hypodermic syringe is attached to the stock solution bottle which enables us to withdraw known measured quantities. A similar adapter for the hypodermic syringe is attached to a "flasher" chamber. The "flasher" chamber is merely a glass bottle set on a hot plate. The stopper contains the hypodermic syringe adapter and has a gas entrance and exit line. The entrance line is from the cylinder containing the five-component gas mix. The exit line leads to the combustion chamber. The solution of NH_3, H_2O, and CH_3OH is injected into the warmed chamber where the Matheson gas mixture evaporates it, and carries it into the combustion chamber. Mixing is accomplished in the combustion chamber. Of course, the amount of solution injected is in proportion to the quantity of five-component Matheson gas which is being used. All lines in this portion of the system are stainless steel. A flow schematic of this system is included in Fig. 4. A "flasher" chamber can be seen between the Wet Test Meter

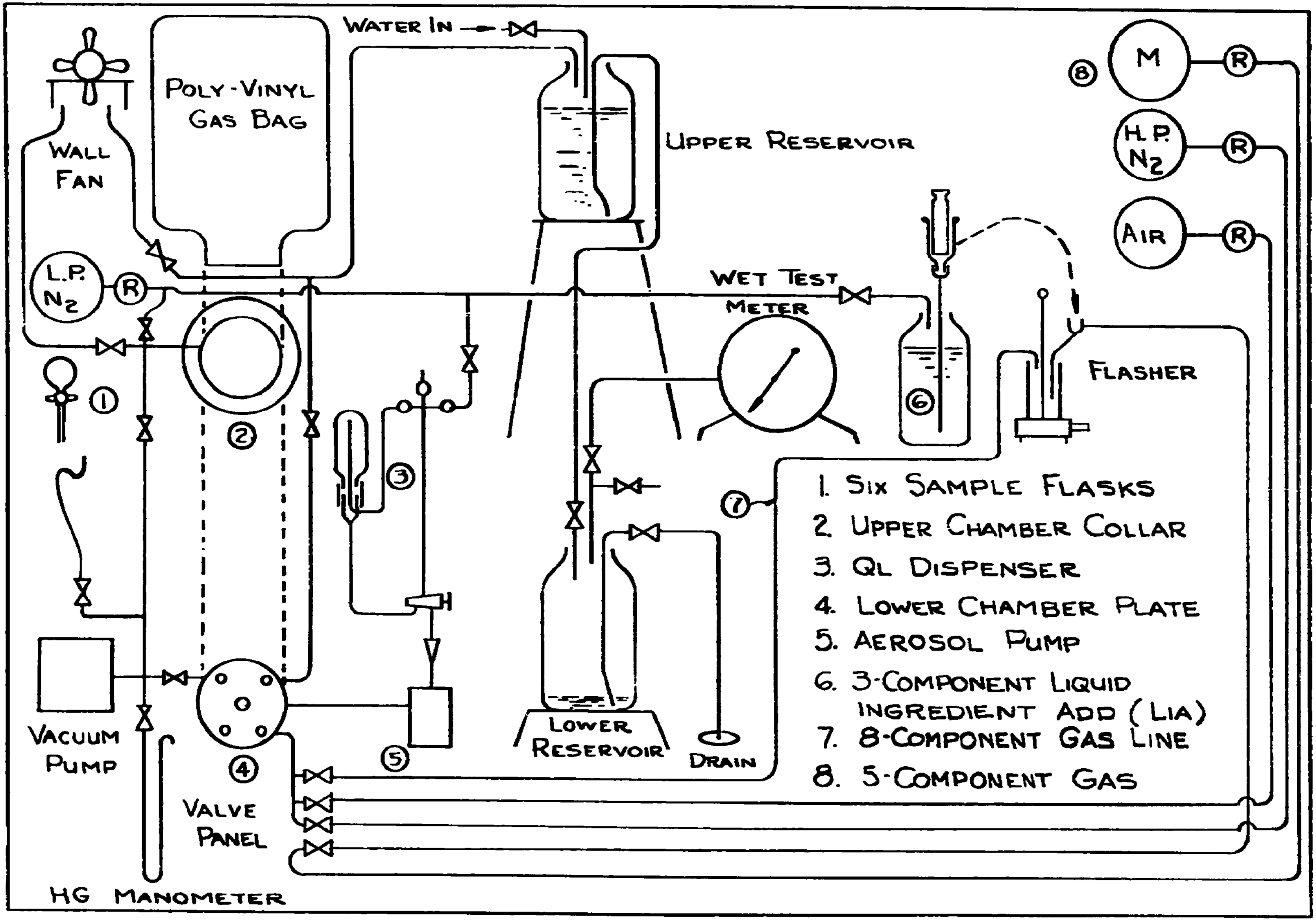

Fig. 4 - Schematic of Combustion Chamber System Showing Gas Lines

and the gas cylinders on the table in Fig. 2. Immediately behind the hypodermic syringe sticking above the flasher in Fig. 3, is the bottle containing the three-component liquid stock solution.

3. Ignition system: The ignitor is basically a capacitor bank fired on command by a 5C22 hydrogen thyratron tube. Pointed, 1/8-in. diameter tungsten rods are used as spark electrodes. A circuit diagram of this unit is presented in Fig. 5. The output is variable up to 160 joules maximum. The system is shown at the lower center of Fig. 2.

It turns out that the output is not really as variable as was originally planned. The system is designed to vary the output by varying the voltage at constant capacitance, since the output in joules is equal to $1/2\ CV^2$ where C is the capacitance and V is the voltage. However, it is desirable to keep the spark gap constant at about 0.1 in. If the ignition system output is varied as a function of voltage, the spark gap has to be continuously readjusted in order to get a current flow in the system because the maximum voltage available (5,000 v.) is the voltage required to breakdown on a 0.1 in. spark gap. Consequently, we will normally use the unit at maximum output. This will eliminate any question of not having sufficient energy available to cause ignition if the mixture is at all flammable.

4. Gas sampling system: It has been planned to sample the gas after combustion to determine the proportion of aerosol consumed. It was originally planned that the system would be washed with a water spray to collect the glycerine aerosol. With the change to QL, we elected to attempt gas sampling rather than trying to wash the system. Consequently, based on the assumed sensitivity of gas chromatography to QL we decided to take a 200-ml. gas sample. If all of the QL in a 200-ml. sample is dissolved into 10 ml. of benzene, the chromatograph should be able to detect 1 per cent of the quantity of QL required to form what we believe might be equivalent to the fuel lean limit mixture.

The sample bulb rack is shown at the left of the combustion chamber stand in Fig. 1. The sample bulbs are 200 ml. flasks with stopcock attached. The long shank on the bulb goes through a bushing in the chamber wall as shown at the left center in Fig. 2. A sample bulb in position is shown in both Figs. 1 and 2. The wood frame around the bulb is to protect it and keep it from being accidentally broken. The bulbs are evacuated before use.

Since we have changed to a gas sampling procedure, it is necessary to know the total volume of gas after the combustion reaction in order to be able to calculate the quantity of unconsumed QL. Any increase in volume is

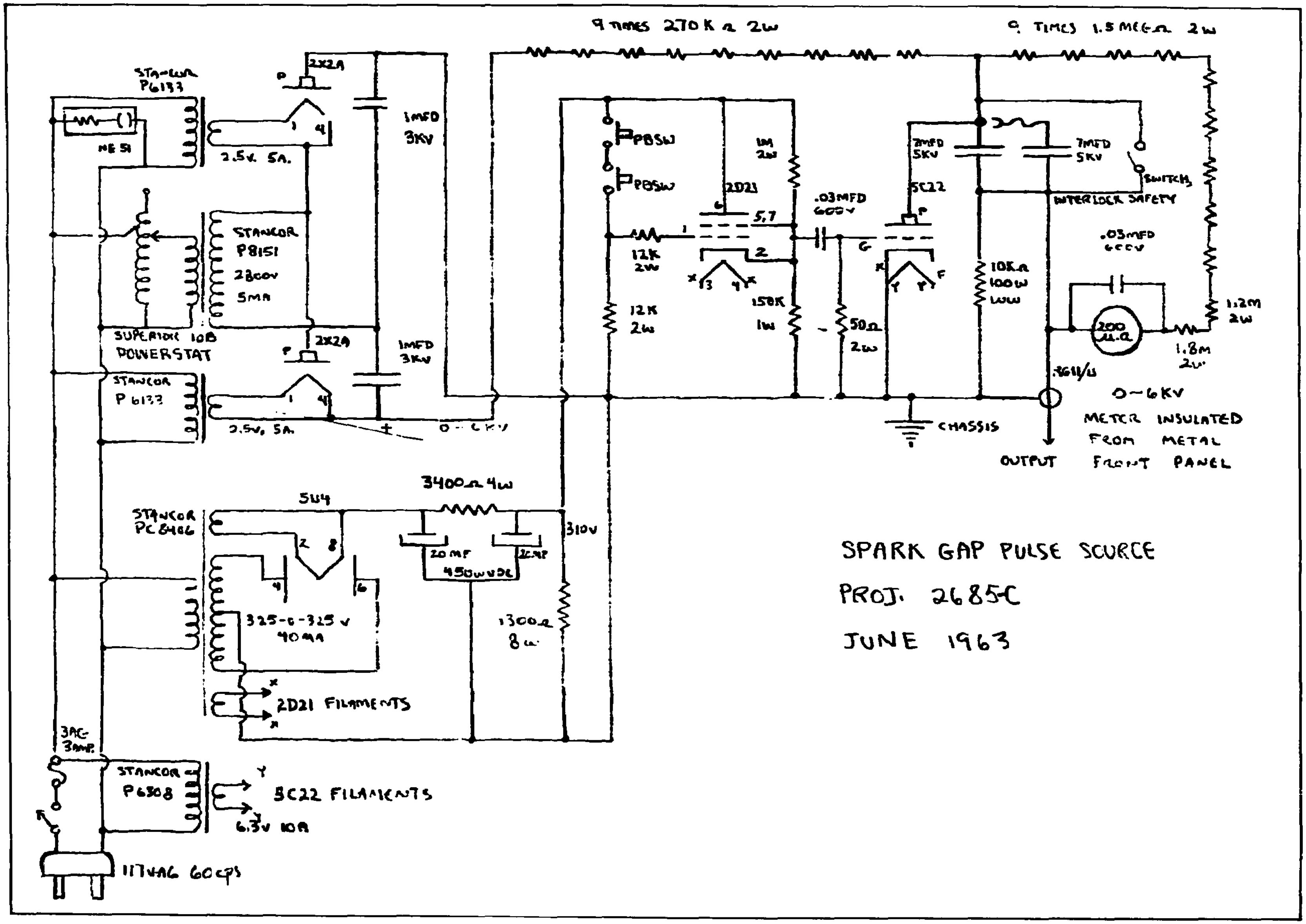

Fig. 5 - Circuit Diagram of Spark Ignitor

captured by the plastic bag. Therefore, if the quantity of gas in the bag were measured after an experiment, the total gas volume could be obtained. Measurement of this gas volume is the purpose of the two water jugs and the Wet Test Meter shown in Figs. 1 and 2. The flow diagram is given in Fig. 4. Basically it works as follows: The introduction of the combustion gas directly into the meter is undesirable because of its corrosive and possible toxic nature. Therefore, it is separated from the meter by the two jugs. The elevated jug is filled with water and the lower jug of Fig. 2 is filled with air. When a syphon is started between the two jugs, gas is pulled (pumped) out of the chamber to replace the lost volume. As the water level rises in the lower jug, clean air is forced through the Wet Test Meter. Since there is a one-to-one correspondence between the chamber combustion gas and the clean air measured by the Wet Test Meter via the water displaced, we have a very simple, clean, self-pumping, gas measuring system.

C. Shock Tube Design and Fabrication

Calculations have been made to determine the operating parameters of a shock tube which will achieve the temperature pulses predicted to ignite the aerosol-product gas mixtures. The physical design of the tube is based on these calculations.

The analysis described herein is applicable to conventional shock tubes which provide high temperature regions behind reflected shock waves at the closed end of the "receiver" section. The reflected expansion wave from the closed end of the "driver" section is returned to the "receiver" end and terminates the high temperature operation after a predictable time interval.

Figure 6 illustrates a travel time diagram of the shock tube operating characteristics.

The incident shock wave A, traveling along the tube at W_A, is generated when the diaphragm is ruptured. The bursting of the diaphragm also generates a centered expansion wave which moves to the left into the high pressure driver gas. The "contact surface" is the interface between the driver gas and the receiver gas and moves at a velocity equal to U_2. The shock wave B reflected from the closed end of the receiver generates a high-pressure, high-temperature region. The interaction of the reflected shock wave B with the contact surface will, in general, produce reflected shock waves which will subject the test section gases to a series of temperature steps. Since this is considered to be undesirable, it was decided to return the reflected expansion wave head at a point in time and space coincident with or below the coincidence point m formed by the intersection of the reflected shock B and the contact surface. This requirement therefore specifies a minimum length L_R (receiver section) for a given L_d length (driver section).

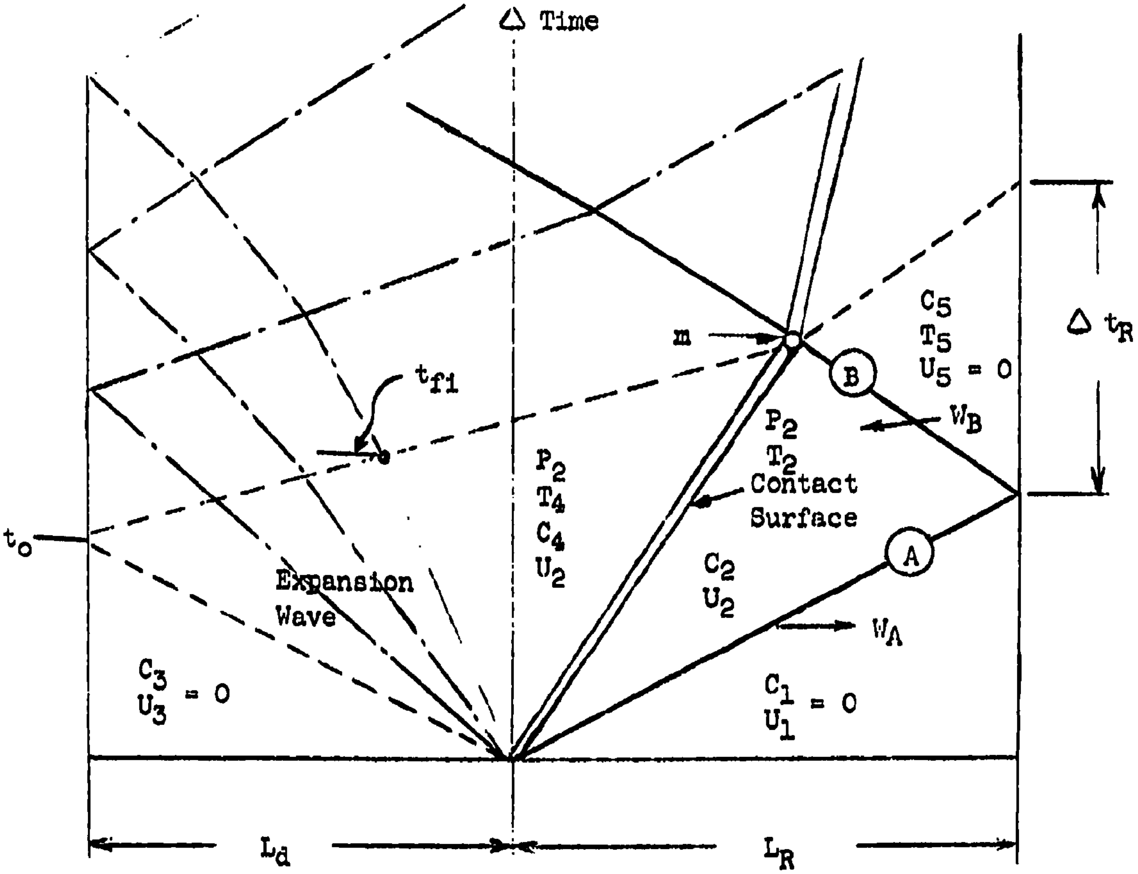

Fig. 6 - A Shock Wave Time-Travel Diagram

The intensities of the properties in the various regions can be quite simply determined from the shock wave and expansion wave relationships and the thermodynamic properties of the gases involved. The following is a listing of significant shock tube relationships derived for a receiver gas with an assumed specific heat ratio (k) of 1.35:

$$\frac{P_2}{P_1} = \frac{2kM^2_{xA}-(k-1)}{k+1} = \frac{7.72M^2_{xA}-1}{6.72} \qquad (1)$$

$$\frac{T_2}{T_1} = \frac{\left(\frac{P_2}{P_1}\right)\left[(k-1)M^2_{xA}+2\right]}{(k+1)M^2_{xA}} = \frac{\left(\frac{P_2}{P_1}\right)\left[M^2_{xA}+5.72\right]}{6.72M^2_{xA}} \tag{2}$$

$$\frac{C_2}{C_1} = \sqrt{\frac{T_2}{T_1}} \tag{3}$$

$$\phi = \frac{M^2_{xA}-1}{M_{xA}\left(\frac{C_2}{C_1}\right)} \qquad (W_A = M_{xA}C_1) \tag{4}$$

$$M_{xB} = \frac{\phi + \sqrt{\phi^2+4}}{2} \qquad (W_B = U_2 - M_{xB}C_2) \tag{5}$$

$$\frac{P_5}{P_2} = \frac{2kM^2_{xB}-(k-1)}{k+1} = \frac{7.72M^2_{xB}-1}{6.72} \tag{6}$$

$$\frac{T_5}{T_2} = \frac{\left(\frac{P_5}{P_2}\right)\left[(k-1)M^2_{xB}+2\right]}{(k+1)M^2_{xB}} = \frac{\left(\frac{P_5}{P_2}\right)\left[M^2_{xB}+5.72\right]}{6.72M^2_{xB}} \tag{7}$$

$$\frac{C_5}{C_2} = \sqrt{\frac{T_5}{T_2}} \tag{8}$$

$$\frac{U_2}{C_1} = \frac{2}{k+1}\left(\frac{M^2_{xA}-1}{M_{xA}}\right) = 0.85\left(\frac{M^2_{xA}-1}{M_{xA}}\right) \tag{9}$$

$$\frac{t_o}{t_{fi}} = \left[1 - \frac{k_d-1}{2}\left(\frac{U_2}{C_3}\right)\right]^{\frac{k_d+1}{2(k_d-1)}} = \left[1 - 0.33\,\frac{\frac{U_2}{C_1}}{2.92}\right]^{2.02} \quad \begin{array}{l}\text{(For Helium Driver}\\ \text{at Atmos. Temp.)}\\ (k_d = 1.66)\end{array} \tag{10}$$

$$\frac{t_o}{t_{fi}} = \left[1 - 0.2\ \frac{U_2}{C_1}\right]^{3} \quad \begin{array}{l}\text{(For Nitrogen Driver}\\ \text{at Atmos. Temp.)}\\ (k_d = 1.40)\end{array} \tag{11}$$

$$\left(\frac{P_2}{P_3}\right)_{He} = \left[1 - 0.096\left(\frac{M^2_{xA}-1}{M_{xA}}\right)\right]^{5.02} \quad \text{(For Helium Driver Gas)} \tag{12}$$

$$\left(\frac{P_2}{P_3}\right)_{N_2} = \left[1 - 0.167\left(\frac{M^2_{xA}-1}{M_{xA}}\right)\right]^{7} \quad \text{(For Nitrogen Driver Gas)} \tag{13}$$

The derivation of operating time (Δt_R) as a function of the tube lengths L_R and L_d resulted in the following equation:

$$\frac{\Delta t_R C_3}{L_d} = K_1\left\{1-K_2\left(\frac{L_R}{L_d}\right)\right\} , \tag{14}$$

where

$$K_1 = \frac{2\left(M_{xB} + \frac{C_5}{C_2} - \frac{U_2}{C_2}\right)}{(1 + M_{xB})\left(\frac{t_o}{t_{fi}}\right)\left(\frac{C_5}{C_2}\right)} , \tag{15}$$

and

$$K_2 = \frac{1}{2}\left(\frac{t_o}{t_{f1}}\right)\left(\frac{C_3}{C_2}\right)\left[\left(\frac{\frac{U_2}{C_1}+\frac{C_2}{C_1}}{M_{xA}}\right) - 1\right] \quad . \qquad (16)$$

The calculated values for the significant variables are given in graphical form in Figs. 7 through 10.

Figure 7 presents significant shock tube pressure ratios and temperature ratios versus the incident shock wave Mach number (M_{xA}) as derived from Eqs. (1) through (13). Initial driver pressure (P_3) to develop a specified test chamber temperature pulse magnitude (T_5), as well as test chamber pressure magnitude (P_5) can be determined from this chart.

Figures 8 and 9 present the functions K_1 and K_2 for helium and nitrogen gas drivers for use in Eq. (14) and define operating times as a function of driver length (L_d) and receiver length (L_R).

Figure 10 presents minimum (L_R/L_d) ratios for nitrogen and helium gas drivers as a function of M_{xA}. These values have been derived from the following relationship which specifies the (L_R/L_d) value which will achieve intersection of the reflected expansion wave leading edge with the contact surface-reflected shock wave coincidence:

$$\left(\frac{L_R}{L_d}\right)_{\text{min.}} = \frac{2M_{xA}\, M_{xB}\left(\frac{C_2}{C_1}\right)}{\left(\frac{C_3}{C_1}\right)\left(\frac{t_o}{t_{f1}}\right)\left[\left(\frac{C_2}{C_1}\right)M_{xB} + M_{xA} - \frac{U_2}{C_1}\right]} \qquad (17)$$

The design of the shock tube facility has been initiated, based on these calculations. We have selected Mach 4.25 as the upper shock level for consideration inasmuch as this will heat the aerosol mixture to about 2000°C. This should be more than sufficient to achieve ignition.

The basic instrumentation will consist of two pressure pickups, a photocell, and necessary power supply, amplifiers, and display equipment. The two pressure transducers are used to measure the shock velocity. All of the phenomena associated with conditions in the shock tube are determined from this one piece of data and the initial starting conditions. The pressure

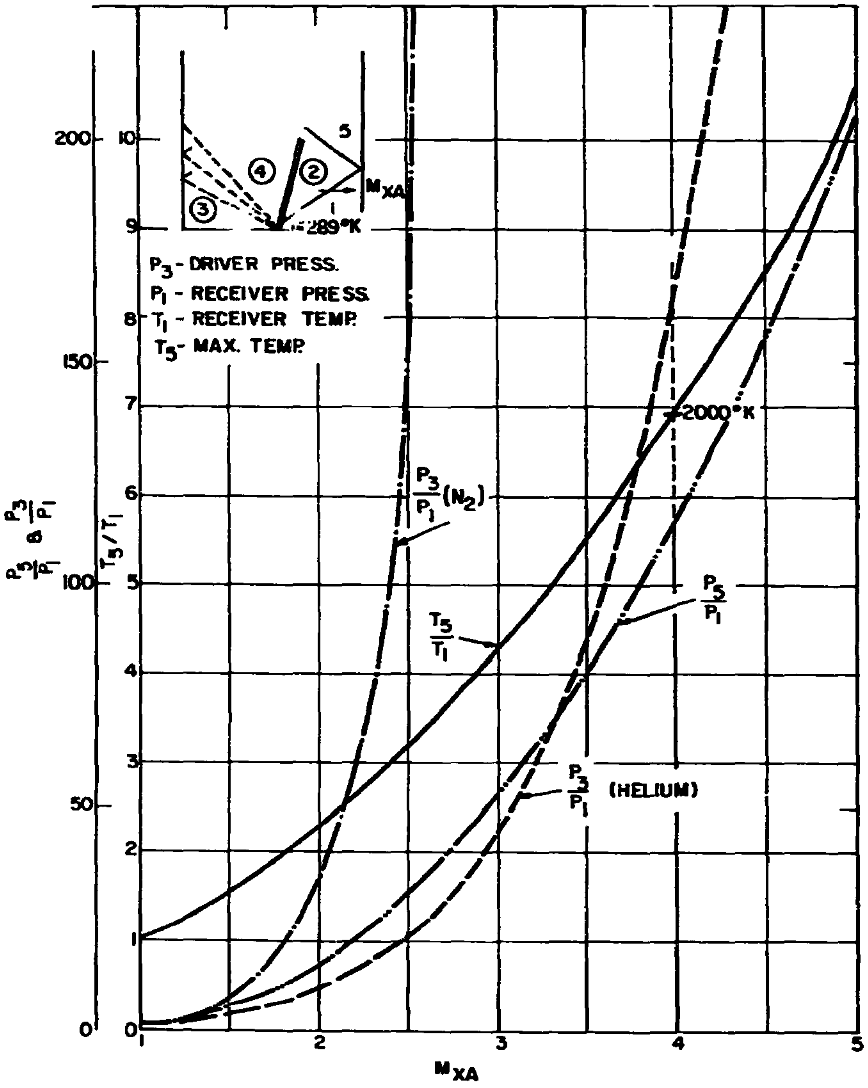

Fig. 7 - Shock Tube Pressure and Temperature Ratios vs. Incident Shock Wave Mach Number

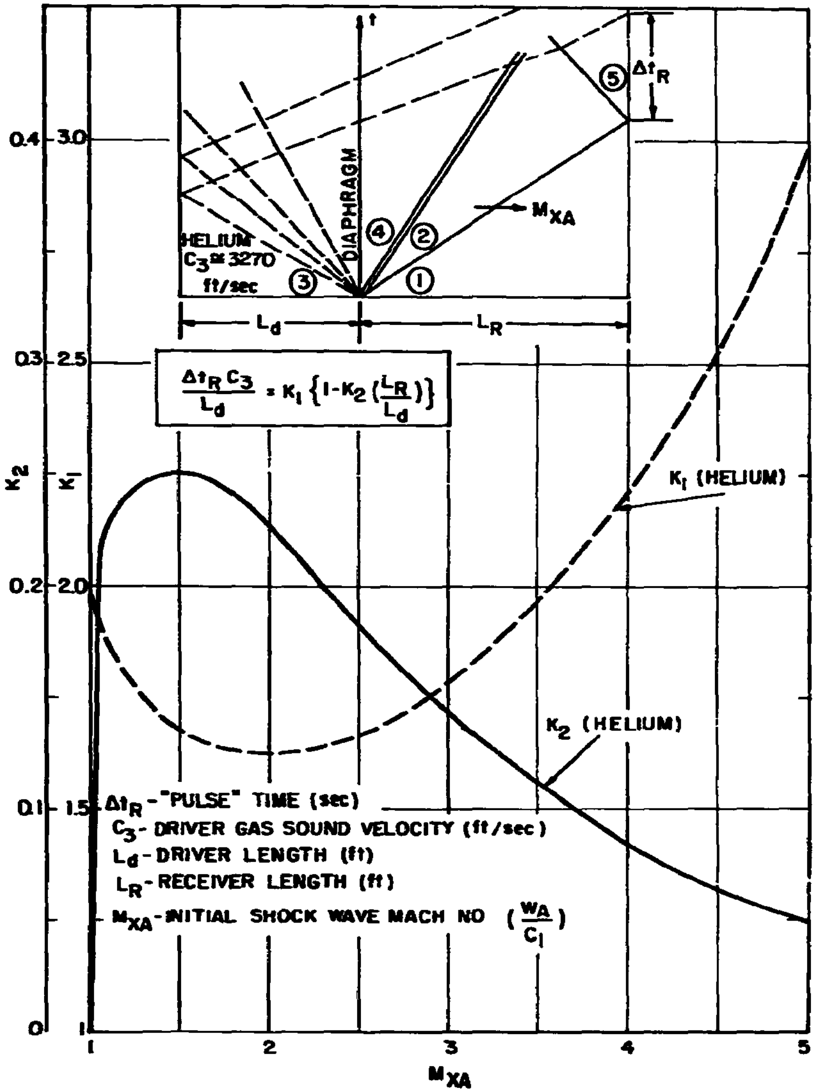

Fig. 8 - Constants for Evaluation of "Pulse" Times for Helium Driver Gas

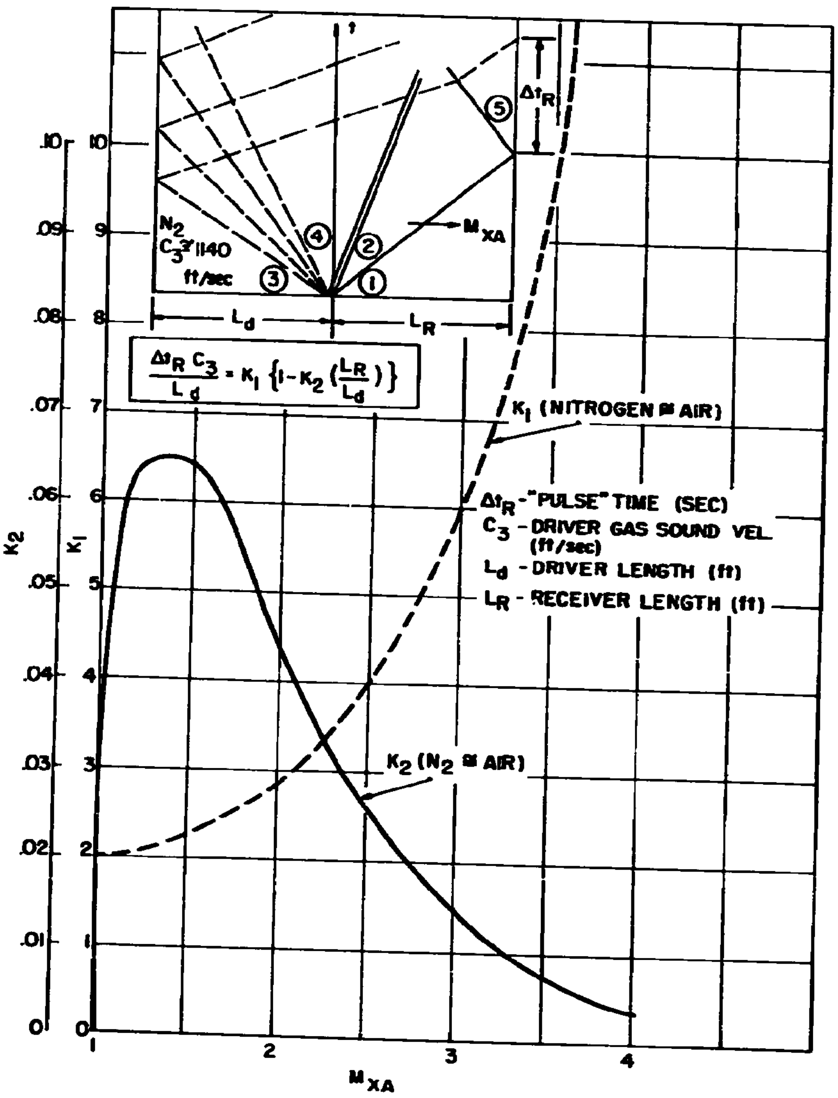

Fig. 9 - Constants for Evaluation of "Pulse" Times for Nitrogen Driver Gas

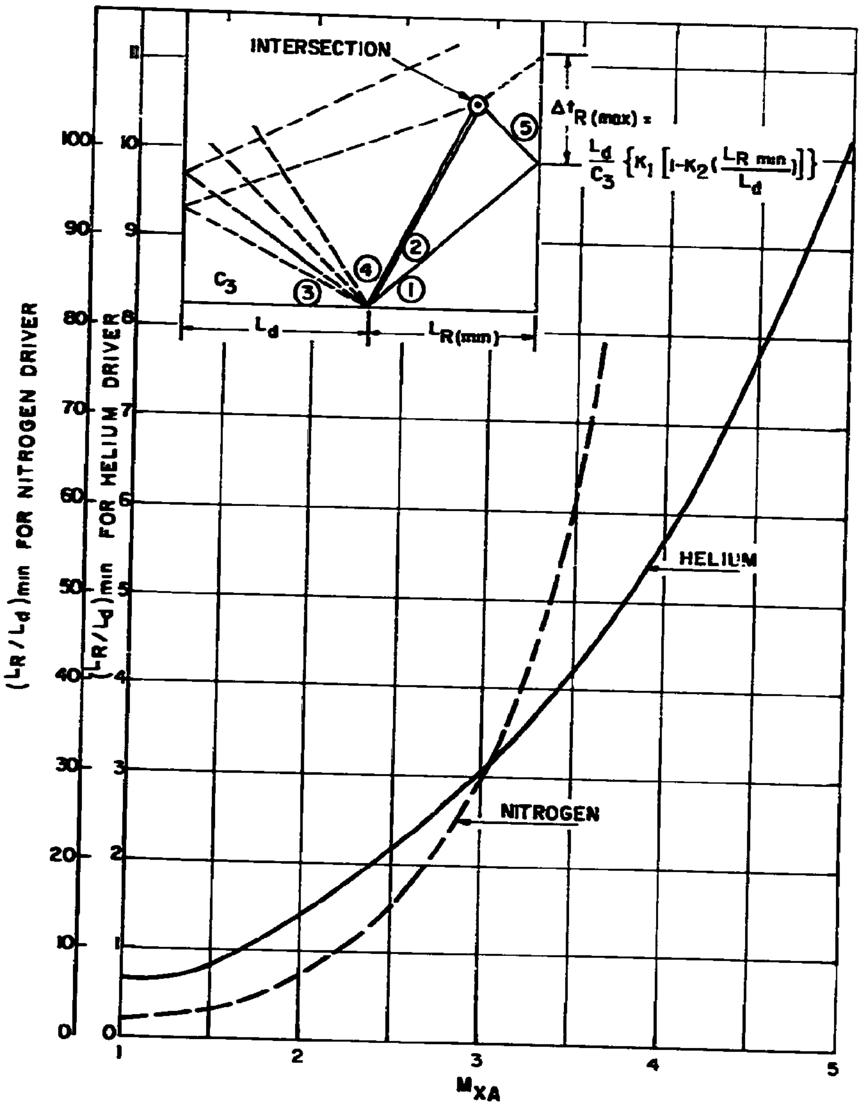

Fig. 10 - Minimum Receiver Lengths to Avoid Reflected Shock Waves From Contact Surface

transducer signals are fed to a Model 7270R Berkeley Time Interval Meter which will give a direct digital readout of the time interval between passage of the shock wave past the two transducers. The signal from the transducer nearest the receiver end of the tube will also be fed to a type RM 45A Tetronix Oscilloscope through an electronic switch. This will permit a direct observation of the pressure-time history behind the reflected shock. The oscilloscope display will be photographed with a Hewlett-Packard Model 196A Polaroid oscilloscope camera. The photocell unit is an 1P28 photomultiplier in a cathode-follower circuit. The photo cell is mounted on the receiver end of the tube and observes down the central axis of the tube. This permits observation of light output within the shock tube (ignition and/or combustion events). This signal will also be fed to the oscilloscope through an electronic switch. The electronic switch will be used to sample the input signal from two signal sources and display them on a single-beam oscilloscope on a common time base.

With the exception of the quartz piezoelectric pressure transducers, all major instrumentation will be provided by MRI. It was originally planned that available strain-type pressure gages would be used in the shock tube for event measurements. Analysis of the shock velocities required indicated that the response rate of this type gage was too slow. Consequently Kistler Instrument Corporation Model 601A transducers and Model 566 Electrostatic charge amplifiers have been purchased. This $1,740 cost represents an expense which was not in the original budget.

The shock tube is being fabricated from nominal 4.33-in. stainless steel tubing of 0.083-in. wall. The maximum over-all internal length is 20 ft., which can be distributed between the driver and receiver sections as desired. Sections are held together by bolt flange or by Marman clamps. In general, bolt flanges are used where disassembly will be infrequent.

The aerosol in the receiver section will change with time as particles coagulate and settle out. Therefore, it is desirable that the aerosol age, at the time of shock wave passage through it, be a controlled condition. To achieve this, one must be able to rupture on command the diaphragm separating the driver and receiver sections. Several methods of doing this have been used by others. Diaphragms which break at a predetermined pressure are frequently used but in this size and pressure range they cost $20 each. Sparks are used to burn holes in the diaphragm, but this might ignite the flammable mixtures. Mechanical plungers are also used to perforate the diaphragm but these can be expensive and utilize a large part of the cross-section area which interferes with the gas flow. Squibs can be used but their cost is $0.60 to $1.25 each and squibs create a spark problem. Our solution to the problem is to use a Crossman air rifle to shoot a lead pellet at the stressed diaphragm. This reduced the equipment cost to $21 and cost to rupture a diaphragm to a fraction of a cent.

Most of the shock tube components have now been fabricated. The tube is being installed in a laboratory and the necessary plumbing lines run. A complete description of the facility will be deferred until the next report.

III. PROBLEM AREAS

A number of problem areas have occurred during the course of the work to date. It is believed that a discussion of these is in order since they affect the current project status.

It was originally planned that the bulk of the experimental work would be accomplished with glycerin as a test material. Glycerin was selected as being representative of a number of properties which seemed desirable to investigate. Subsequent to initiation of the contract it was mutually agreed that the range of properties should be changed. This caused the initiation of a search for a suitable material, which was described in the first Quarterly Report. Conducting this search caused project delay and some diversion of funds.

As a result of the search, the CRDL compound that is coded QL, was selected as a suitable compromise for the factors to be studied. The use of QL has caused some unplanned-for problems and these are discussed below.

QL is of low toxicity but it has a toxic potential. It reacts with oxygen and water. It is incompatible with rubber and plastics except Teflon. It can decompose in storage with an increase in container pressure.

The toxicity and potential toxicity of QL require that due care must be exercised because of the potential hazard.

The reactivity of QL with water and oxygen requires that it be protected from the atmosphere at all times. This means that all equipment into which it is introduced must be dried and flushed if it is to remain pure for any length of time. Opening a system which contains it must be done under dry nitrogen, and then the container must be resealed under dry nitrogen. All equipment must be designed and built with this factor in mind.

The incompatibility of QL with rubber and plastics has caused a number of problems. All equipment must be designed to use Teflon gaskets and seals. This seems rather insignificant until it is realized that Teflon is a very poor substitute for an elastomer. Consequently, it is difficult to obtain a dynamic seal with it. Static seals are almost impossible with "O" rings because of Teflon's extreme cold flow tendency. However, in a number of instances we have been forced into using Teflon "O" rings for static seals.

QL is not compatible with Silastic, either, but we had to use RTV Silastic for gaskets between the end plates and plastic wall of the combustion chamber. It was originally designed and built for rubber "O" rings. A substitution of Teflon "O" rings did not work at all and a seal was not obtainable. Neither could we obtain a seal with a flat Teflon gasket. The plastic surface was just uneven enough and the strength of threads in the chamber wall was just weak enough, so that we could not bring enough pressure to bear to achieve a seal with Teflon sheet. Consequently, we constructed a mold and made two RTV Silastic gaskets. So far these are working out well.

The injection pump was designed by the manufacturer to use rubber "O" rings. We have substituted Teflon. Just obtaining correct sizes for substitution has been a problem because there seems to be a lack of correspondence in "O" ring sizes between these materials. Two of these "O" rings are very critical and both are dynamic seals. One is on the piston assembly and the other is in the check valve assembly. In fact, this latter "O" ring is the check valve. Both of these could develop into real problems if they fail to perform with QL. Some difficulty has already been experienced.

All seals in the shock tube have been designed for use with Teflon.

The tendency of QL to decompose in storage with an increase in container pressure has resulted in one accident to date. Ampoules containing 400 ml. of QL were received from CRDL. The first one opened was observed to be under a positive pressure and had a pungent, penetrating smell. On the assumption that this was normal, the ampoule was connected on to the dry, purged system as shown in Fig. 3. A nitrogen bleed was started to purge the pump overnight. The following morning Mr. Pollock examined the setup, and arrived just in time to be thoroughly sprayed by QL leaking past the plastic connection of the ampoule on the system. Later reconstruction of the events led to the conclusion that gas pressure inside the ampoule had forced the ampoule out of the connection and sprayed the material. It was bad luck that Mr. Pollock arrived just at that moment. All 400 ml. were sprayed out all over the room and equipment. Thorough decontamination of the room and equipment followed. Mr. Pollock suffered no apparent lasting ill effects from the exposure.

The accident convinced us that this must not be normal QL behavior and that the material had decomposed in storage.

We elected to purify the next ampoule of material by vacuum distillation. A vacuum distillation apparatus has been constructed for this purpose.

The desirability of having a fan in the combustion chamber to aid in mixing the gases was mentioned in earlier reports. Such a fan was constructed and installed. It was operated by a 1/4-in. drill through a gear reducer to keep the fan rpm low. The fan blade shaft was introduced into the chamber through a Teflon seal in the bottom plate. Unfortunately, the design was such that when the seal was tight enough to prevent leaks in the chamber the motor would not turn the fan blade. At present we are considering the use of a small totally-enclosed motor in the bottom of the chamber to solve this problem.

IV. PROJECT STATUS

It is difficult at this time to assess the exact project status in terms of when we will accomplish the experimental goals. There is no doubt that we are currently behind schedule. In fact, the combustion chamber studies are about four months behind schedule and the shock tube studies are three months behind the original schedule. The reasons are explained in both the first quarterly and in section III of this report.

On the positive side, the elimination of the washing in the sampling procedure should materially speed up the experimental work.

V. FUTURE WORK

The immediate work plans are to vacuum-distill the QL and prepare it for use in the combustion chamber. Particle size studies will be reinitiated using QL as the aerosol material.

The flammability limits of the detonation product gas-air mixture will be determined during the next month.

The shock tube will be installed and testing of the system initiated.

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SYMBOL LIST

P_1 = Receiver pressure

P_2 = Pressure behind incident shock

P_3 = Driver pressure

P_4 = P_2 = Pressure behind contact surface

P_5 = Pressure behind reflected shock

C_1 = Velocity sound in receiver gas

C_2 = Velocity sound in receiver gas behind incident shock

W_A = Velocity of incident shock

W_B = Velocity of reflected shock

T_1 = Receiver temperature

T_2 = Temperature behind incident shock

T_3 = Temperature of driver gas

T_4 = Temperature of driver gas during expansion

T_5 = Temperature behind reflected shock

U = Velocity of gas

t_o = Time expansion wave hits head end of driver

t_{f1} = Time at which expansion wave head, reflected from end of driver, is coincident with tail of expansion wave