A STUDY OF THE IGNITION LAG

OF

SPONTANEOUS ROCKET PROPELLANTS

Thesis by

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INTRODUCTION

The subject for this study was suggested by Dr. David Altman of the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California. Since 1942 when the Jet Propulsion Laboratory developed the red fuming nitric acid and aniline rocket motor, it has been desirable to have quantitative values for the time parameters involved in this spontaneous propellant reaction. The understanding of the combustion process in rocket combustion chambers may enable improvements to be made in rocket performance and may reduce such rocket casualties as chamber explosions caused by excessive chamber pressure.

A study of the ignition lag of a spontaneous process is inherently difficult because of the short time intervals characteristic of the process. It is not believed that the results obtained in this investigation are beyond criticism. It is hoped, however, that this investigation will assist in the understanding of the spontaneous ignition of RFNA and aniline, provide some quantitative measure of the ignition lag, and a qualitative measure of the water and temperature variables. It is regretted that it was impossible to extend the investigation to other propellant combinations.

In the following pages several conventions will appear, namely:

1. When the word acid is used, it will refer to red fuming nitric acid, with 6½% NO_2 by weight, and the acid may be written RFNA. When the acid used is not full strength, it will be indicated in the discussion.

2. The term "ignition lag" will be the time required after bringing together the two fuel components until the reaction has generated a pressure in the combustion chamber corresponding to two inches of water.

3. "Diaphragm clearance" is the distance in inches between the pressure diaphragm and the electrical contact point with which it makes contact.

4. All temperatures used are expressed in degrees Fahrenheit (°F).

5. The "trigger circuit" is considered to be the electrical circuit built into the base of the combustion chamber unit and which starts and stops the electronic timer.

SUMMARY

For this investigation, ignition lag, as previously defined, is a time required for a reaction to build up an arbitrary pressure of the order of two inches of water. This definition is of particular interest in the study of liquid rockets since the rate of pressure build-up from the spontaneous reaction of propellant components is important in the performance of the rocket motor. It makes possible a comparison of propellant combinations to determine which would be better so far as the time lag in reaching the critical pressure ratio is concerned.

It was found that under any one set of conditions it was possible to reproduce data consistently within ten percent. These consequently

resulted in very smooth relationships which are of a nature that was generally expected in each case.

In the investigation it was found that at temperatures near the freezing point of aniline, ignition lags were of the order of 12 to 16 milliseconds. On reaching ordinary room temperatures the lag was reduced by a factor of three or four. Beyond this range the effect of temperature change was not so pronounced, and the curve tends to straighten out (see Figure 3). A temperature increase of 80 degrees beyond 100 degrees F produces a decrease of only 14 percent in ignition lag.

For the effect of dilution of the RFNA with water, two relationships were obtained--one by dropping acid into aniline, the other by reversing the two components. These relationships are plotted in Figure 2 and show that a small percentage of water as an impurity in acid will produce little noticeable effect on ignition. This should be of interest to those working with acid-aniline motors in the field. It is believed that the correct values of ignition lag for mixture ratios of a motor lie between the two curves plotted. For relatively pure acid and commercial grade aniline, 3 to 5 milliseconds were required to build up a pressure of two inches of water in a chamber of 2.655 liters volume.

By using several burettes of different tip sizes, it was shown that drops having volumes of more than about 0.0475 milliliters produced approximately the same ignition lags. Two curves, one for acid into aniline and the other for aniline into acid, are plotted in Figure 1 and give the relationship between drop volume and ignition lag. There is an almost constant difference of about two milliseconds between these two curves, which seems to be characteristic of which component is dropped into the other.

REVIEW OF PREVIOUS INVESTIGATIONS

The ignition lag of spontaneous binary liquid propellants for rockets has been the subject of fairly wide investigation in this country and in Germany. Among these investigations the following studies have been brought to the attention of the authors. In this country it is believed that the first attempt to investigate the ignition lag of red fuming nitric acid and aniline was undertaken at the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.* For these tests, the two components were poured together by a remote control method, and the resulting reaction recorded on movie film at sixty-four frames per second. Combustion was considered to occur when the flame was observed, and the number of exposures between the mixing of the components and the observation of the flame was a quantitative measure of the time interval. Equal volumes of the propellant components were used, ranging from 10 cc to 25 cc. Widely dissimilar volumes were then mixed (1 cc in 10 cc, and 1 cc in 20 cc). In all cases the ignition was prompt and the measured lag was between 0.08 and 0.12 seconds. The report indicated that the investigation did not show that any one set of conditions (volume ratio and sequence) was better than another. However, the results did show that when one drop of aniline was added to a large pool of acid the reaction was more prompt than when a drop of acid was added to an excess of fuel. This point is of particular interest for the investigations described later in this report do not confirm this observation.

Recently the Kellogg Company of New York has undertaken a study of the combustion of red fuming nitric acid and 76% aqueous hydrazine. For this work a glass rocket motor was used in conjunction with a camera. It is

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*W. B. Powell and N. Kaplan; "Rocket Motor Starting Characteristics," Galcit Pro. 1, Report No. 24; July 1944.

believed that these tests indicate an ignition lag of the order of 10 to 20 milliseconds with these fuels used in a process closely approximating actual operating conditions. No report of the Kellogg work has as yet been made available.

Two groups of German investigators followed the same procedure that was used in the investigation to be described later. Essentially it was necessary to measure the interval between the mixing of the components and the actual ignition. Both groups used two photoelectric cells to do this. A drop of one component was allowed to fall past one cell located over a cup containing the other component. The drop interrupted the light to the cell and started the timer. A second photocell picked up the light given off during the reaction and indicated the combustion point to the timer. By comparing the time intervals the ignition delay was ascertained. The I. G. Farbenindustrie Aktiengesellshaft, Ludwigshafen on the Rhine, used a drum recorder and spark trace to measure the ignition interval. The other group used a Belfinger electronic timer. The latter group would measure intervals of two ranges, 80 and 240 milliseconds, with an accuracy of one millisecond. No complete translated reports of the quantitative results reached by these two groups of investigators are available to the authors at present.*

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* ZWB/UM/Re/2551 General Aspects and Requirements for the Testing Apparatus. JPL Library.

BMW/EZV/857/44 2265-522 Instrument to Measure Ignition Lag of Rocket. Bilginger. JPL Library.

DESCRIPTION OF APPARATUS

Combustion Chamber and Mechanical Accessories

A. Physical construction:

The combustion chamber is a circular cylinder of stainless steel construction mounted vertically on a base plate. The base plate carries thumb screws for alignment of the apparatus. The combustion chamber is covered with a detachable top which is secured in place by thumb screws.

The top carries integral with it a tube on the top of which is a clamp for the burette. Figure 9 shows this clearly. An annular lucite section provides a means of visually observing the drop formation on the tip of the burette. Thumb screws are provided on the burette holder to shift the horizontal alignment of the burette. The cover is also pierced by an opening for a safety plug. The cover carries a spirit level to indicate horizontal alignment of the cover.

The combustion chamber proper houses a light source and on the opposite side a photoelectric cell, a small eye port, a receptacle for the pressure pick-up, and openings for a thermocouple connection and scavenging air. On the bottom of the chamber directly on the center line and under the burette is the cup (Figure 11).* This cup is held in place on a vertical lug. The cup itself has a vertical nib upon which the falling drop impinges to assist in breaking up the droplet.

B. Operation:

When the cover is secured in place and the apparatus correctly aligned the burette at the top of the cover is directly over the small nib in the cup at the bottom of the combustion chamber (Figure 4). When a drop is released it falls through the tube and impinges on the nib of the cup. Just before it strikes the nib, the drop passes through the focus of a light beam and energizes the trigger circuit to start the timer. The pressure wave generated by the reaction strikes the pressure pick-up diaphragm, closing the circuit and stopping the timer.

*Designed by Mr. Bernard Helfand.

Trigger Circuit and Timer

The trigger circuit is built under the base of the ignition chamber and forms one complete unit as shown in Figure 10. This circuit is the circuit that starts the timer just before the two fuel components are brought together, and stops the timer when the required pressure is reached in the combustion chamber. The only connections between this unit and the timer are electrical. The trigger circuit draws its power from the chronoscope power supply.

The included wiring diagram, Figure 7, shows the trigger circuit. The two triode sections of the 6SN7 tube are used in an Eccles-Jordan circuit triggered through the pressure pick-up and associated amplifier sections of the 6SL7. The final 6SL7 amplifier stage feeds into the chronoscope. This stops the chronoscope by applying bias when the 6SL7 is conducting. This condition occurs when the diaphragm receives the ignition pressure wave or may be mannally done by a push button located on the base plate of the combustion chamber.

The chronoscope is started when the final 6SL7 is not conducting, this condition occurring when the falling drop initiates a pulse from the photo-cell.

The electronic timer is a Berkeley Chronoscope, Model TIM-D, manufactured by the Berkeley Scientific Company, Berkeley, California. This instrument is pictured in the right side of Figure 8. It is a direct reading instrument calibrated in milliseconds, and having a full scale range from 1 to 3000 milliseconds. The scale is shifted by a selector switch on the front panel. The timer itself consists essentially of a constant current device (pentode vacuum tube) which charges a condenser through a resistance when the holding bias is removed. The charge on the condenser is measured by a vacuum tube voltmeter. This charge is directly proportional to the current which is allowed to flow and to the value of the resistance through which it flows. The vacuum tube voltmeter is calibrated in milliseconds and is mounted on the front panel for direct reading.

During the investigation it was not possible to completely check the manufacturer's calibration of the Chronoscope. The timer was roughly checked with a synchronous motor and appeared to be accurate.

PROCEDURE

Briefly, the procedure followed was to fill the combustion cup with one component and the burette with the other component. The combustion chamber cover was then secured in place, the diaphragm clearance set, and the timer checked on zero. One drop was manually discharged from the burette and allowed to drop into the combustion cup. The falling drop started the timer just before the two fuel components made contact. The resulting pressure from the reaction stopped the timer. The ignition lag was then directly observed on the timer meter. The fumes were then scavenged from the chamber with low pressure air, the cover removed, and the cup cleaned and refilled. The previous procedure was then repeated.

The more detailed steps followed are tabulated in the Appendix. Included as a part of the tabulated procedure are the steps followed to check the diaphragm zero and the method of checking a new diaphragm installed in the pressure pick-up.

Since so many variables were encountered in the experiment, great care had to be taken to reproduce the conditions as nearly as possible on each run. In the course of the investigation it was found that variations in the following would cause inconsistencies in the data:

(a) Drop size

A decrease in drop size produced a non-linear increase in the ignition lag if the drop volume was below about 0.0475 ml. Figure 1 shows this dependence. This relationship will be discussed later. A single burette was used throughout to obtain all data except that plotted in Figure 1.

(b) Amount of liquid (or surface level) in cup

The effect of this was eliminated by pipetting 1.4 cc of liquid into the cup each time. This brought the level of the liquid about one-third the way up the curved part of the nib in the cup, which had to be cleaned after each run to remove contaminated fuel and carbon ash.

(c) Clearance between pressure pick-up diaphragm and electrical contact

The dependence between diaphragm clearance and ignition lag is typically shown in Figure 5. The diaphragm could be made as sensitive as was desired by decreasing the diaphragm clearance. A static pressure increase of the order of a fraction of an inch of water could be made to close the circuit. This pressure is plotted against diaphragm clearance for a typical diaphragm in Figure 6.

(d) Variations in characteristics of one diaphragm from another

Several different diaphragms had to be used during the investigation since they were easily deformed or even ruptured by some reactions. Two or three drops of acid from the burette into the aniline at one time produced a reaction that was sufficiently violent to cause deformation. Several runs were made with hydrogen-peroxide and hydrazine-hydrate which reacted with such violence that the diaphragm was ruptured. An unexplained detonation of acid-aniline occurred near the end of the investigation, although the same procedure and component volumes had been used for over 200 continuous readings with no unusual pressures. The fact that different diaphragms gave different readings with the same clearance set is probably explained by variations in stress in the diaphragm which was cut from a sheet of 0.001 inch stainless steel. This could not be avoided since the pressure pick-up was made on the "job." When it became necessary, the diaphragm was changed and tightened in place by hand. When taking up on the retaining rings the diaphragm was perforce placed under a slight amount of stress. Any change in stress distribution could

change the diaphragm characteristics and, indeed, there is reason to believe that this does occur. Consequently each diaphragm had to be calibrated to give a standard reading under standard conditions. This was done by mounting the electrical contact on a spring loaded screw so that the clearance could be set as desired. In later investigations it is strongly suggested that a commercial pressure pick-up be used, preferably one employing a corrugated metal diaphragm. It is believed that this would minimize the difficulties encountered with the diaphragm in this investigation.

(e) Alignment

The apparatus was aligned so that the burette was directly over the nib in the cup. This minimized splashing and insured the same degree of mixing of the two components. It was noticed that if the drop impinged slightly on the side of the nib the carbon ash formed in the reaction would be asymmetrical, the ash deposit would not be the same for succeeding runs, and the ignition delays so measured would not be consistent. Thus it was concluded that the degree of mixing was not constant. After alignment the apparatus was mounted on a heavy steel base plate and was held firmly in place on a laboratory desk by a large C-clamp.

(f) Technique

In studying the dependence of ignition lag on temperature only the temperature of the aniline, and necessarily of the cup, was varied. The difficulties inherent in controlling the temperature of the liquid in the burette, and of controlling the drop temperature at the moment of mixing were too great to overcome at this time. It was felt that the effect of the temperature of the small drop would be small as compared with the effect of the temperature of the much larger volume of liquid in the cup. Figure 3 shows the range studied from the freezing point of aniline to 180°F. An iron-constantan thermocouple was placed in the liquid in the cup and a temperature reading taken an instant before the ignition occurred.

For the higher temperatures it was found that the fumes from the hot aniline quickly reduced the light intensity to such an extent that the photo-cell would not be energized by the falling drop. (The photo-cell was tripped by a sudden change in light density.) Consequently low pressure air was injected to reduce the fumes before the run. The same scavenging process was necessary for acid in the cup even at ambient temperature. Furthermore, when the acid was heated, nitrogen dioxide (NO_2) was given off very rapidly and therefore the true concentration of the acid for the runs at various temperatures could not be determined. This rapid fuming of the acid was the reason that data was not obtained for dropping aniline into acid at varying temperatures.

As mentioned before, one occurrence during the investigation lacks explanation. One drop of aniline into concentrated acid at room temperature apparently detonated. Fortunately this occurred on the last run in obtaining data for a curve of drop size against ignition lag. The explosion sounded like a gun shot, blew the rubber safety plug out, and ruptured the pressure diaphragm. Very little acid entered into the reaction since its level was apparently unchanged in the cup.

For runs under similar conditions variations found in data of the order of ten percent can be attributed to a combination of the following:

(a) unavoidable variations in drop size;

(b) minor variations in temperature;

(c) errors in resetting the diaphragm clearance each time;

(d) possible variations in the electronic circuit used in measuring such short durations.

In connection with this last point, a synchronous motor set-up is being planned by the Electronics Section of JPL to give a method of checking the dependability of the readings on the different scales of the commercial timer when used in conjunction with the Eccles-Jordan multi-vibrator.

Two corrections to the readings obtained had to be applied: first, the time required for the drop to fall from the point where the light beam was cut to the surface of the liquid, a distance of 0.85 cm; second, the time required for the pressure wave to travel from the cup to the pressure diaphragm, a distance of 9.5 cm. This last time correction was made assuming the pressure wave moved at sonic velocity. This total correction amounted to 3.69 milliseconds, and has been subtracted from all original data that appear in this paper.

RESULTS

Interpretation of Drop Volume Curve

Figure 1 gives the variation of ignition lag as a function of drop volume. The characteristic of the curves indicate that drop volume has little effect on ignition lag after a drop volume of approximately 0.0475 milliliters is exceeded. It will be noted that when dropping aniline into an excess of oxidizer the ignition lag was approximately two milliseconds greater than when dropping acid into excess of fuel. This difference in ignition lag appears to be characteristic of the two methods of uniting the propellant components. The same phenomenon will be noted when discussing the ignition lag as a function of the percentage of water in the acid. The true ignition lag of equal volumes of acid and aniline probably lies about midway between the two curves.

It is interesting to note that when the acid was dropped into the aniline a deposit of heavy carbon ash was formed around the nib in the cup. When the aniline was dropped into the acid, no ash was noticeable either on the nib or in the remaining acid since there was an excess of oxidizer.

The interpretation of this curve must be tempered by recalling how the ignition lag was measured. The lag was taken as the interval between the passage of a drop past a light beam and the receipt of the pressure wave of known intensity

by a pressure diaphragm. The pressure rise is slower because of the small drop size and not because the mechanics of ignition are slower. However, because we have defined the ignition lag as the time required to build up a specified pressure in the chamber, it is believed that the curve is valid.

The drop volume for each set of readings was determined solely by the size of the burette tip used. Actually the drop volumes used as abscissae are mean volumes. The drop volume was determined by measuring the volume of fifty drops and taking the average. Actually in the laboratory it could be seen that the size of the drops from the same burette varied slightly. It will be recalled that one group of German investigators used a vacuum to accurately reproduce drops of equal volume for each run. This is a refinement that, while perhaps increasing the accuracy of individual readings, would probably not change the average of the results obtained.

Interpretation of Water Concentration Curve

The variation of ignition lag as a function of the percentage of water by weight in the acid is given in Figure 2. At zero concentration of water, it will be noted that the difference in time between dropping the acid into aniline, and the aniline into the acid was approximately 1.7 milliseconds. Previously when investigating the effect of drop size this difference in time was ascertained to be two milliseconds. This slight difference is still within the ten percent range of experimental accuracy.

Of particular interest is the difference in slope of the two curves at low concentrations. The aniline into the acid relationship is practically flat, which is about what was expected because, although the oxidizer was reduced in strength, there was still an excess of oxidizer, and the pressure build-up was only slightly affected. By similar reasoning, the ignition lag at the higher water content was still not so pronounced as for dropping the diluted acid into an excess of fuel.

The investigation was carried to a water content in the acid of 12½% by weight. When the water content in the acid exceeded this amount, no reaction strong enough to trip the timing mechanism occurred when acid was dropped into aniline. When aniline was dropped into diluted acid with more than 12½% water content only very erratic reactions could be obtained. In this connection previous observations of cup tests using very dilute acid and aniline showed only slow, spasmodic reactions with no evidence of flame. It is expected that by mixing equal quantities of aniline and diluted acid, data obtained would lie between the two curves and could possibly be extended to include greater dilutions.

Discussion of Ignition Lag as a Function of Temperature

Figure 3 shows the variation of the ignition delay with a change in temperature of the aniline. It is particularly important to note that while the temperature of the fuel was varied, the oxidizer was at 76°F. Consequently, it is not considered that this relationship is a complete picture of the effect of temperature on ignition lag. It is desirable to establish a similar relationship in which the temperature of both components were varied, and, in addition, one showing a reverse of the process by dropping aniline into acid. The physical limitations of the apparatus coupled with the volatile nature of the acid at high temperatures prevented such studies.

Figure 3, then, must be considered as a guide to the relative trend of the acid-aniline reaction at various temperatures. For the technique employed it is believed that the results are reliable. Perhaps the portion of the curve at temperatures exceeding 120° would be of the least value in predicting the performance of the fuels in actual use in rocket motors. The data were the most

difficult to obtain in this region. At elevated temperatures the problem of aniline fumes frequently made the photo-cell useless. The components burned with a clear yellow flame, leaving no carbon ash in the cup at the higher temperatures, showing that the reaction proceeded to completion.

Limitations of the Results

As a satisfactory standard of accuracy in this experiment it was decided to strive for a reproducibility of ±10%. Actually the observed data were well within this range except when the water content of the acid was too high. However, when the correction for dead time was subtracted from the observed ignition lag indicated by the timer, the percentage variation of the results increased particularly for the shorter time intervals. The corrected data were still within the ±10% variation limit.

All of the results contained in this thesis were based on the assumption that the ignition lag was the interval between the passage of a drop of one component past a photo-cell and the generation of sufficient pressure in a closed chamber to close a sensitive pressure element. No consideration was given to the time required for the appearance of the flame. It is believed that the complete ignition delay study should include a study of the relative intervals between the generation of the pressure and the appearance of the flame. There is reason to believe that the appearance of the flame follows the pressure rise and that, therefore, the rate of pressure rise to some critical value is a parameter that should be considered in the study of starting characteristics of liquid motors.

All observations were conducted at atmospheric pressure. To conduct these tests at any other pressure would require extensive alterations of the present apparatus or the design of a new one.

The greatest problem to overcome was the one of obtaining a duplication of data. The greater portion of the time consumed in this study was spent attempting to reproduce any previous result when the conditions were duplicated. It was arbitrarily decided after much testing that dropping a drop of 0.0475 ml volume of fresh acid into 1.4 cc of aniline at about 76°F should produce an ignition lag of about 4.5 milliseconds with a diaphragm clearance of 0.026 inch. This would cause a static pressure of the order of 1.9 inches of water to close the pressure contact. When diaphragms were renewed the new one was required to reproduce these values if they were to be used. Under these conditions it was possible to check previous data, and the agreement of ignition lag readings was very satisfactory. It is therefore believed that if the diaphragm characteristics are constant and the chemical properties of the components do not change, this apparatus will produce consistent results for any given set of conditions.

APPENDIX

Tabulated Procedure

The following is a brief outline of the procedure followed:

A. For a normal reading:

1. With burette containing one component, clean combustion cup and fill with 1.4 cc of the other component.
2. Insert thermocouple in component in combustion cup.
3. Replace cover on combustion chamber.
4. Close all pressure outlets to combustion chamber.
5. Close diaphragm contact until contact is made and then back off, high to low, to desired diaphragm clearance.
6. Clear electronic circuit by pressing button on combustion chamber base.
7. Take thermocouple reading for temperature and record.
8. Turn on timer.
9. Drop one drop of component from burette.
10. Record timer reading and turn off timer.
11. Scavenge fumes from combustion chamber with low pressure air.
12. Open combustion chamber and repeat above steps.

B. Method of checking diaphragm zero:

1. Remove combustion chamber cover.
2. Place timer selector switch on full scale, 3000 milliseconds.
3. Clear electronic circuit with manual push button.
4. Break light beam to trip trigger circuit.
5. Turn on timer.
6. By means of setting knob on diaphragm contact gradually decrease clearance until timer needle is stopped, showing closed circuit.

7. Observe graduated scale under diaphragm setting knob. This is the setting when the clearance between the diaphragm and contact point is zero.

8. Repeat this procedure several times to be sure the zero setting so ascertained is correct.

C. Method of checking new diaphragm:

1. Be sure that diaphragm is firmly secured by retaining ring in the pressure element with no lost motion.

2. Insert pressure pick-up in combustion chamber.

3. Follow procedure under "B" above to determine zero setting.

4. Back contact off one graduation of scale (0.026" clearance).

5. Using burette containing RFNA(6½%) and drop volume of 0.0475 ml, follow procedure outlined in "A" above. The aniline is placed in the cup for this procedure.

6. The reading obtained should be of the order of 8.5 milliseconds, ±10%.

7. Steps 5 and 6 should be repeated until it is obvious that consistent readings of the desired value are produced. Should the reading not average 8.5 milliseconds, the following should be checked:

   (a) that acid has not become weak by being exposed to atmosphere in burette too long.

   (b) that diaphragm clearance is correct.

   (c) that diaphragm is clean and is firmly secured.

8. If the desired reading of 8.5 milliseconds is still not achieved, a new diaphragm should be installed and the entire process repeated until the correct readings are obtained.

Data Sheet

Drop Volume as a Function of Ignition Lag in Milliseconds
(See Figure 1)

I. Acid (RFNA) into Aniline 3-25-47

Burette No.	III	II	V	IV	I
Drop Volume, ml	.0425	.048	.0625	.0675	.08
Run 1	4.8	4.3	4.3	4.3	3.8
2	5.5	4.1	3.8	4.2	3.3
3	4.7	3.3	3.9	4.2	3.4
4	5.1	4.3	3.9	4.1	3.3
5	4.6	4.1	3.6	3.8	3.2
6	4.8	4.2	3.6	3.5	3.5
Average	4.9	4.1	3.9	4.0	3.4

II. Aniline into Acid (RFNA) 3-25-47

Burette No.	III	II	V	IV	I
Drop Volume, ml	.0425	.048	.0625	.0675	.08
Run 1	7.4	7.2	5.8	6.8	5.8
2	6.3	5.8	5.8	5.9	6.1
3	6.8	5.8	6.3	6.0	6.6
4	6.5	6.3	6.3	6.6	6.1
5	7.3	5.8	5.8	6.7	6.3
6	7.8	7.3	6.4	6.3	6.3
Average	7.0	6.4	6.1	6.4	6.2

Data Sheet

Concentration Vs Ignition Lag in Milliseconds
Drop Volume 0.0475
(See Figure 2)

I. Acid (RFNA) into Aniline 2-25-47

% H_2O in RFNA by weight	0	2½	5	7½	10	12½
Run 1	4.3	5.3	5.1	7.0	9.3	13.8
2	5.2	5.2	4.9	8.2	8.8	13.3
3	4.6	5.3	5.1	6.8	8.9	17.3
4	5.0	5.1	5.1	7.8	8.3	14.3
5	5.3	5.2	5.2	6.8	9.9	15.3
6	4.4	5.3	4.3	7.3	8.8	16.3
Average	4.8	5.2	5.0	7.3	7.5	15.0

II. Aniline into acid (RFNA) 3-26-47

% H_2O in RFNA by weight	0	2½	5	7½	10	12½
Run 1	2.8	4.2	7.8	12.3	20.5	15.3
2	3.8	3.9	5.8	13.3	12.6	25.3
3	3.3	3.3	8.2	12.2	18.1	15.8
4	3.0	3.4	7.2	12.3	19.3	22.3
5	3.4	4.8	6.8	12.6	21.3	42.3
6	3.3	3.5	6.8	10.5	25.3	26.3
Average	3.3	3.8	7.1	12.2	19.5	24.9

Data Sheet

Temperature of Aniline
Vs
Ignition Lag in Milliseconds
March 1947
(Drop Vol. 0.0475 ml)
(See Figure 3)

Run	Temperature °F	Ignition Lag	Run	Temperature °F	Ignition Lag
1	81	3.6	31	178.0	3.3
2	81.5	3.6	32	148.0	2.8
3	62.5	4.5	33	122.0	3.2
4	53.0	5.9	34	116.5	3.8
5	49.5	5.8	35	111.0	3.9
6	49.0	8.3	36	106.5	2.8
7	55.5	5.6	37	80.5	4.3
8	57.0	6.6	38	79.0	4.0
9	52.0	6.8	39	75.0	5.1
10	60.5	5.3	40	76.5	5.4
11	59.0	5.6	41	80.0	6.2
12	65.0	5.1	42	81.5	4.4
13	69.0	5.6	43	80.5	4.2
14	72.0	4.7	44	50.5	6.8
15	74.5	4.6	45	36.0	8.8
16	75.5	5.0	46	40	9.3
17	79.0	4.3	47	25.5	11.8
18	82.5	3.8	48	42.5	8.5
19	106.0	3.6	49	54.0	7.3
20	160.0	3.0	50	36.0	12.8
21	128.0	3.3	51	26.0	9.9
22	108.5	3.5	52	22.0	12.8
23	106.5	3.1	53	32.0	15.5
24	102.0	3.6	54	37.5	9.9
25	102.0	3.6	55	33.0	13.8
26	99.0	4.3	56	42.5	9.8
27	98.5	3.7	57	51.0	7.8
28	96.5	4.0	58	57.5	7.1
29	121.0	3.6	59	61.0	6.3
30	119.0	3.4			

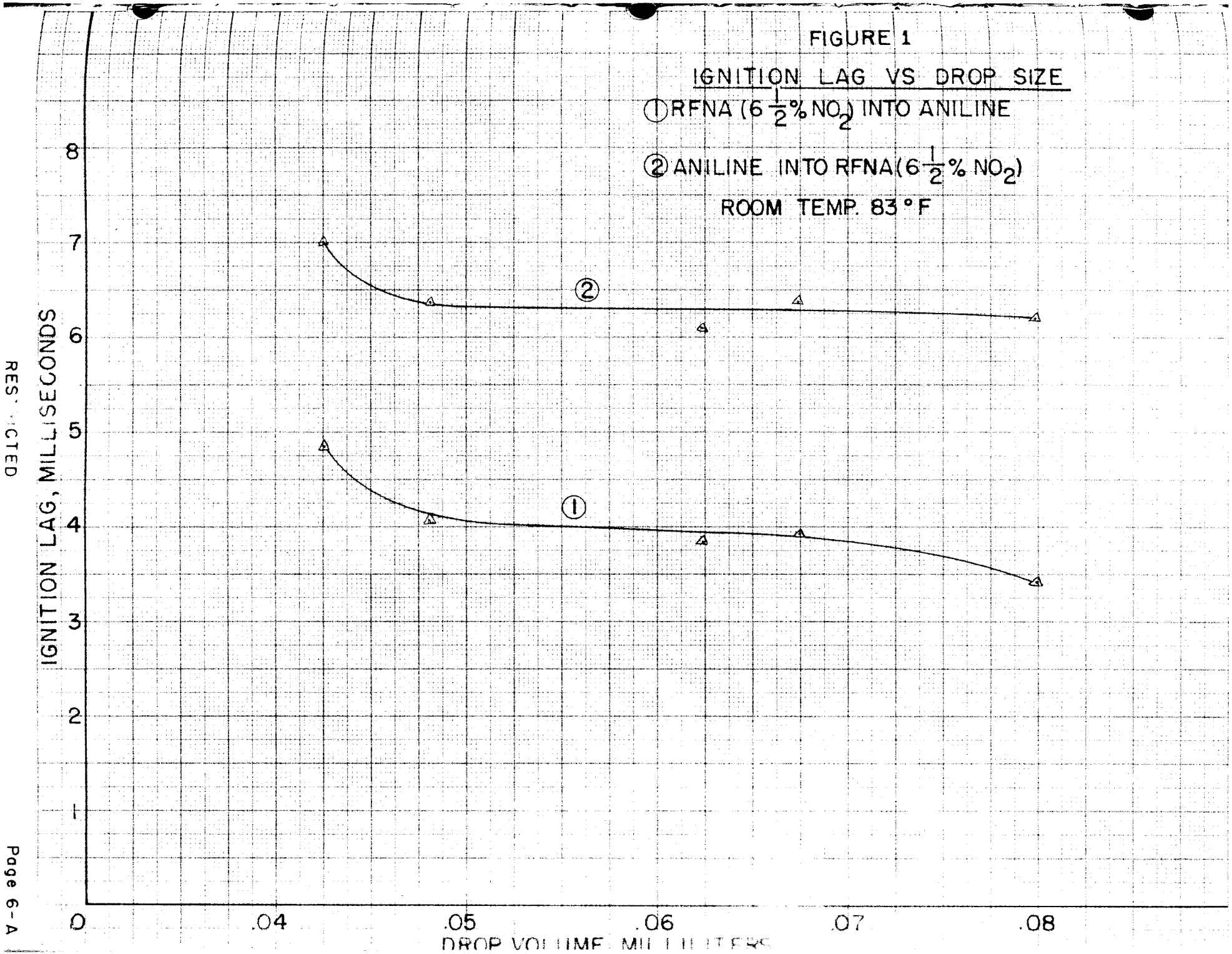


FIGURE 1
IGNITION LAG VS DROP SIZE
① RFNA (6 1/2% NO2) INTO ANILINE
② ANILINE INTO RFNA (6 1/2% NO2)
ROOM TEMP. 83°F
IGNITION LAG, MILLISECONDS
8
7
6
5
4
3
2
1
0
.04
.05
.06
.07
.08
DROP VOLUME, MILLILITERS
②
①

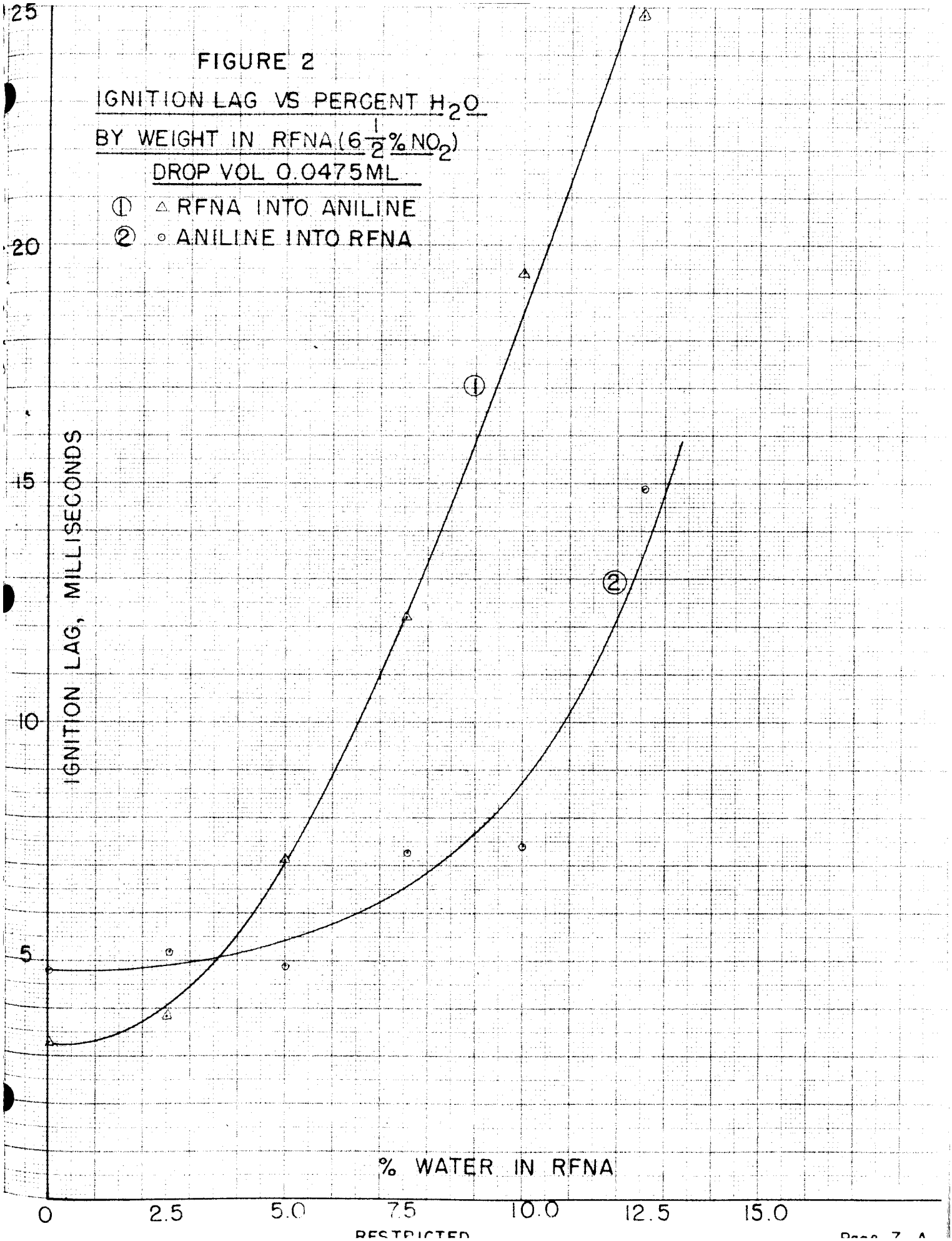
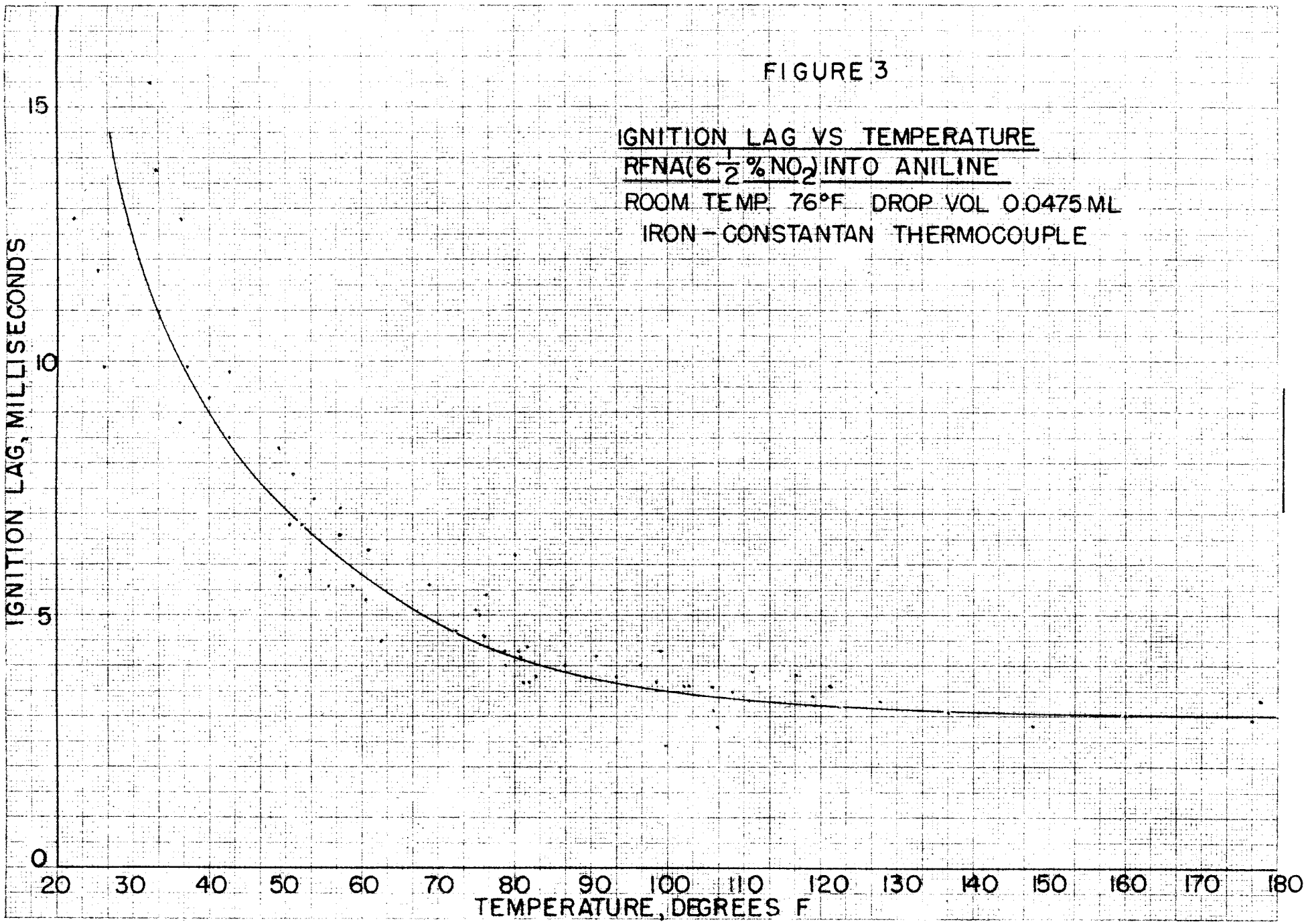


FIGURE 2
IGNITION LAG VS PERCENT H_2O
BY WEIGHT IN RFNA ($6\frac{1}{2}$% NO_2)
DROP VOL 0.0475ML
① △ RFNA INTO ANILINE
② ○ ANILINE INTO RFNA
IGNITION LAG, MILLISECONDS
25
20
15
10
5
0
2.5
5.0
7.5
10.0
12.5
15.0
% WATER IN RFNA

FIGURE 3

IGNITION LAG VS TEMPERATURE
RFNA($6\frac{1}{2}$ % NO_2) INTO ANILINE
ROOM TEMP. 76°F DROP VOL 0.0475 ML
IRON – CONSTANTAN THERMOCOUPLE



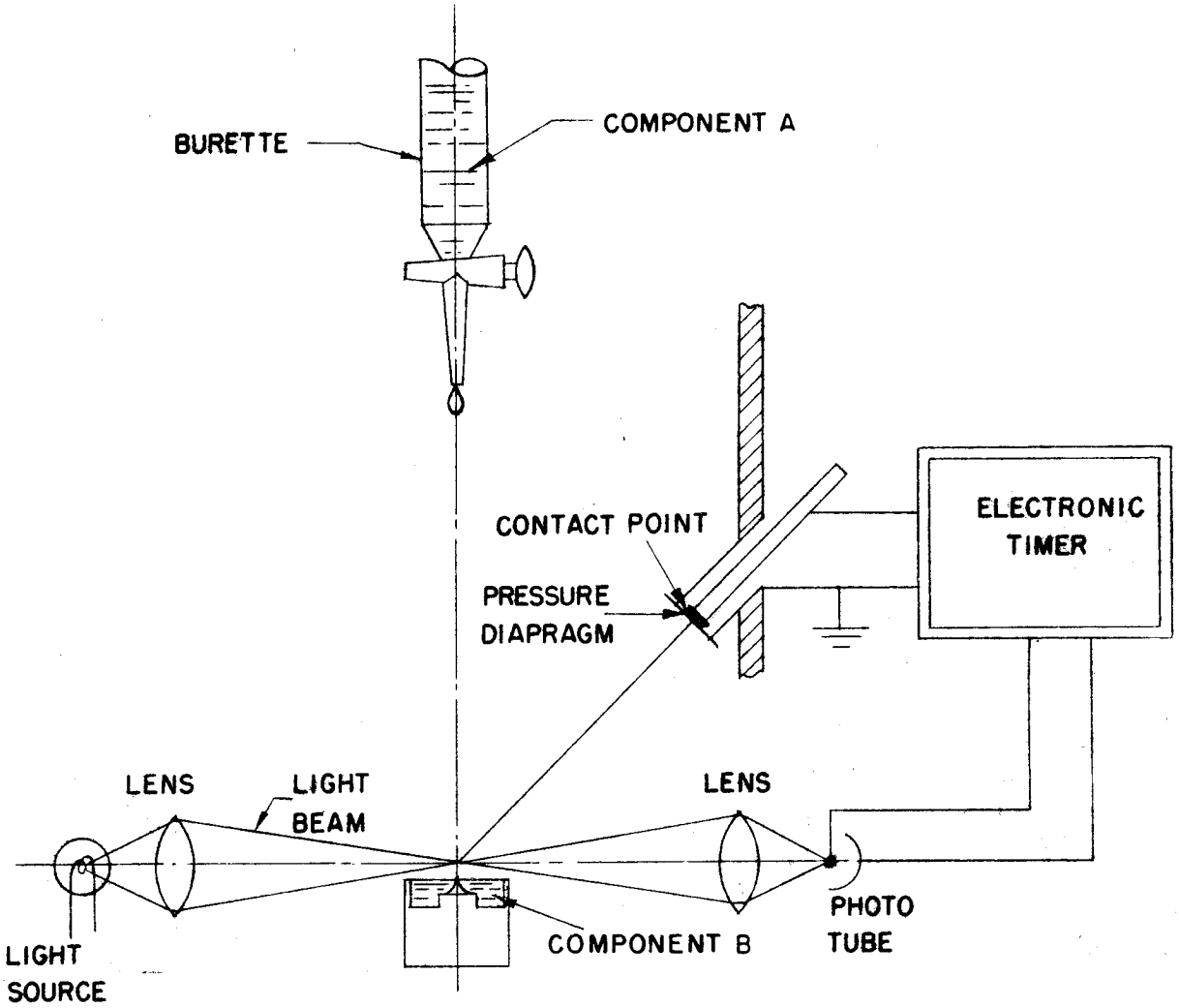


FIGURE 4

SCHEMATIC DIAGRAM
OF
IGNITION DELAY APPARATUS

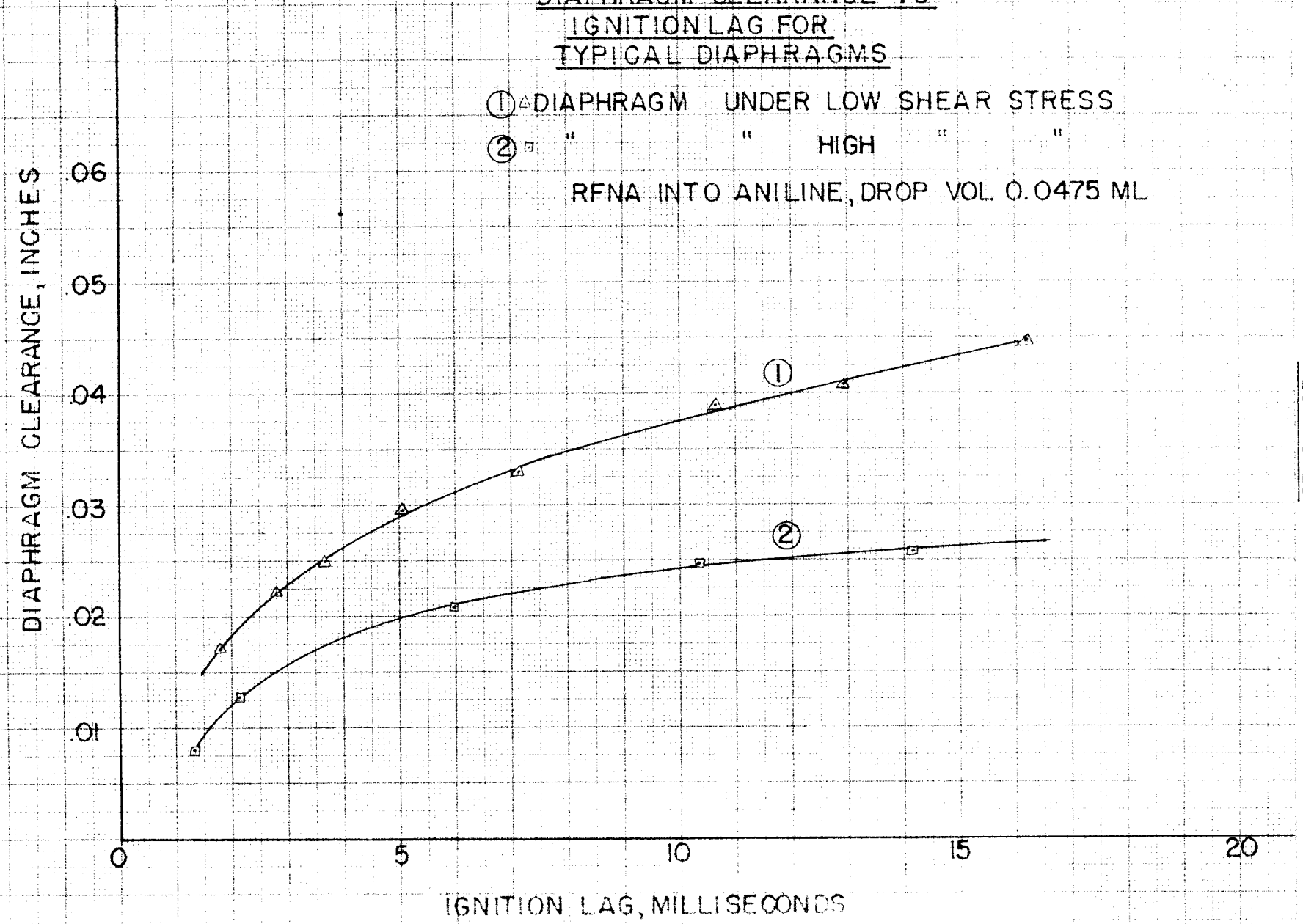
FIGURE 5

DIAPHRAGM CLEARANCE VS IGNITION LAG FOR TYPICAL DIAPHRAGMS

① △ DIAPHRAGM UNDER LOW SHEAR STRESS

② □ " " HIGH " "

RFNA INTO ANILINE, DROP VOL. 0.0475 ML



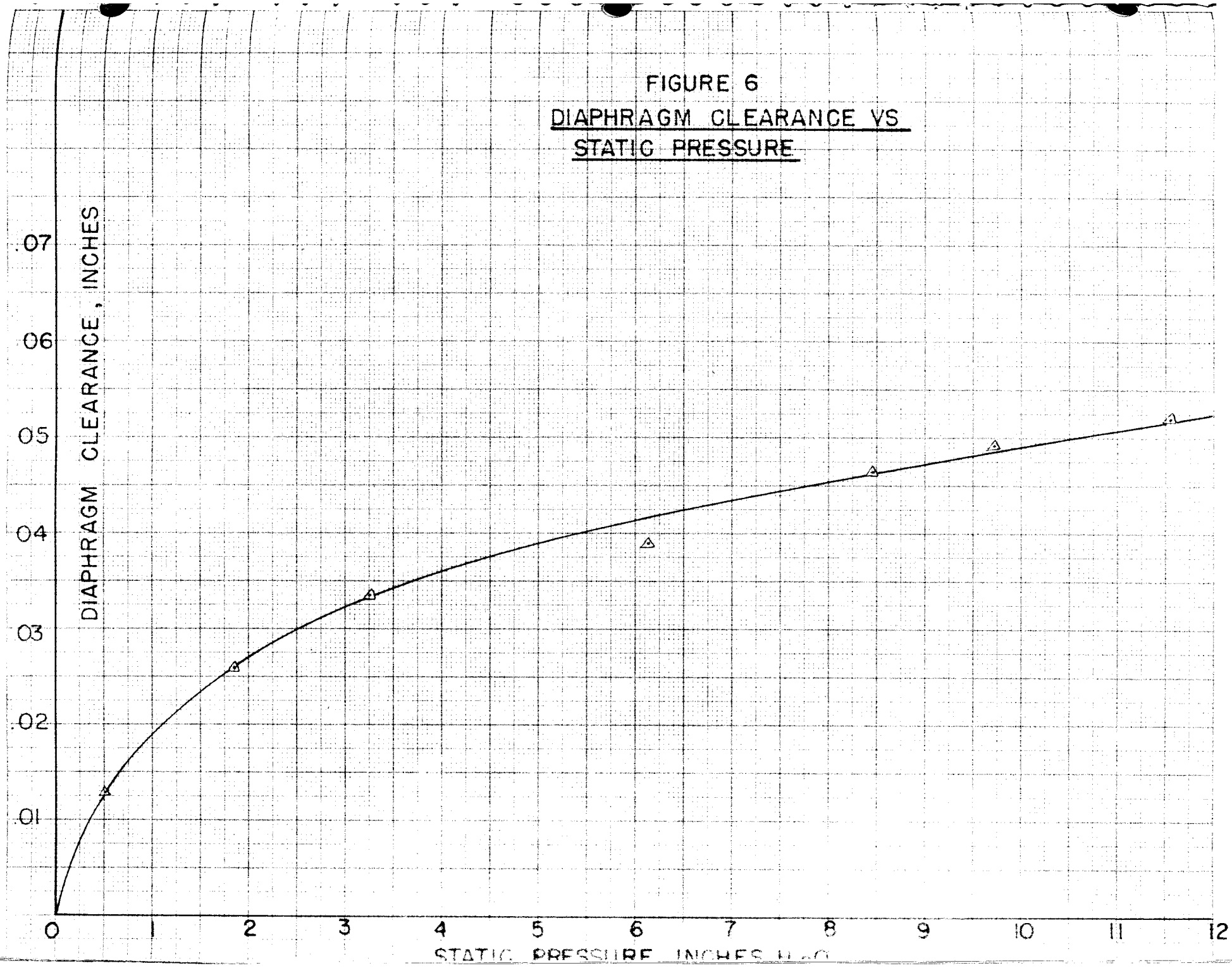


FIGURE 6
DIAPHRAGM CLEARANCE VS
STATIC PRESSURE
DIAPHRAGM CLEARANCE, INCHES
.07
06
05
04
03
02
01
0
1
2
3
4
5
6
7
8
9
10
11
12
STATIC PRESSURE INCHES W.G.

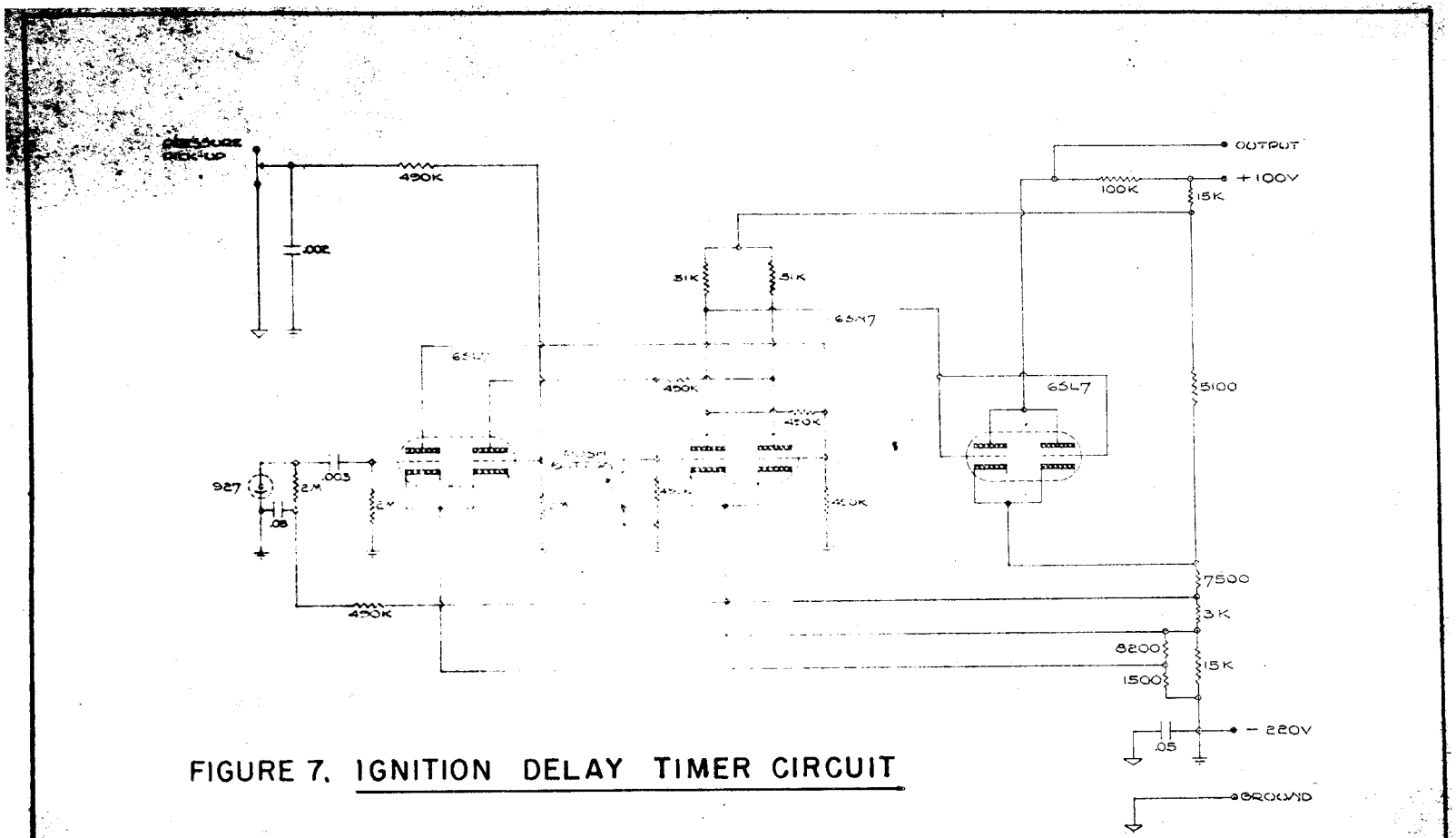


FIGURE 7. IGNITION DELAY TIMER CIRCUIT

Note

⏚ CHASSIS GROUND

⏚ FLOATING GROUND

JET PROPULSION LABORATORY, CALTECH — CALIFORNIA INSTITUTE OF TECHNOLOGY

PROJECT DESIGNATION 4 SECTION 9 PROJECT CLASSIFICATION

IGNITION DELAY TIMER

1670

156

IGNITION DELAY APPARATUS

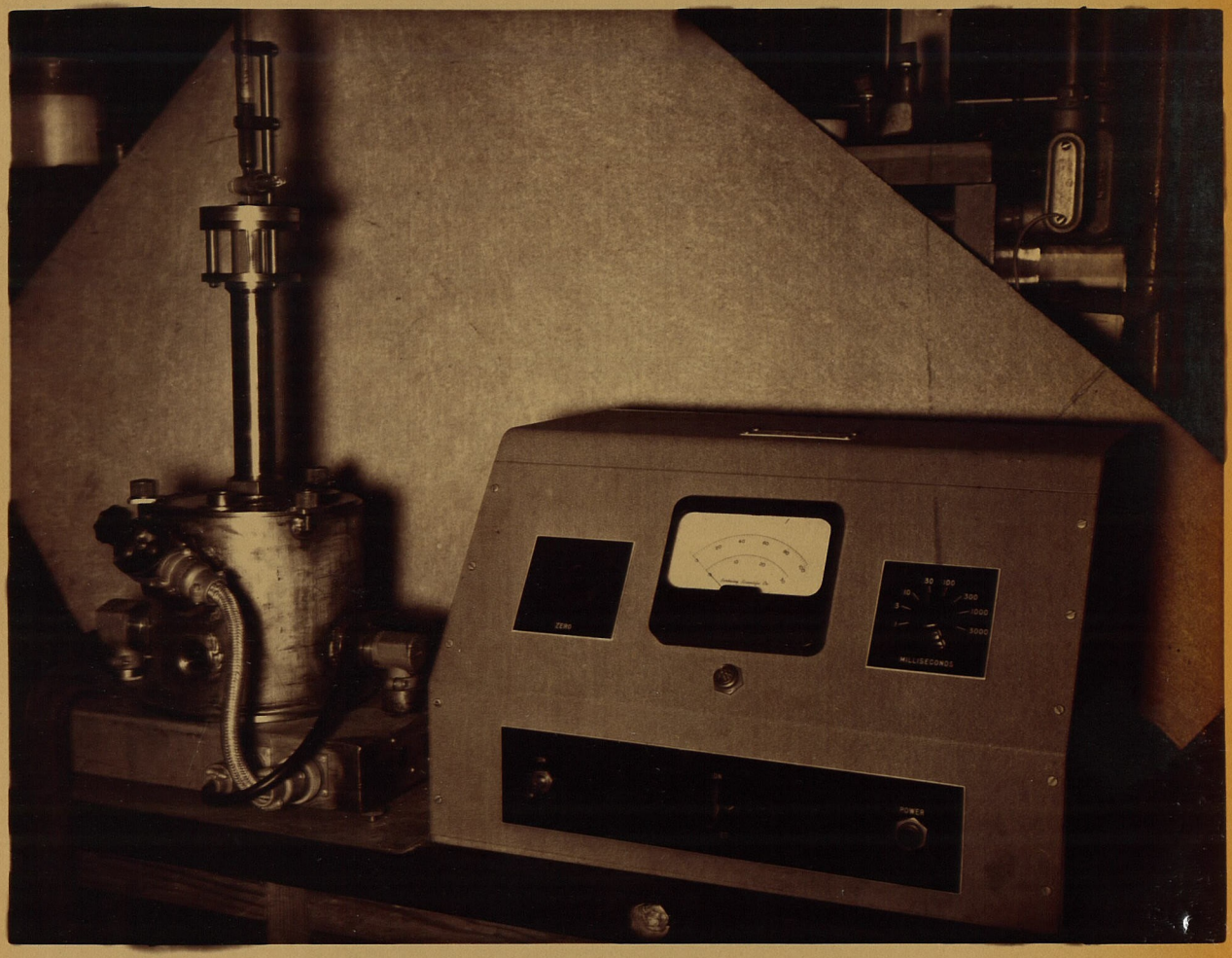


FIGURE 8. ASSEMBLED APPARATUS

IGNITION DELAY APPARATUS

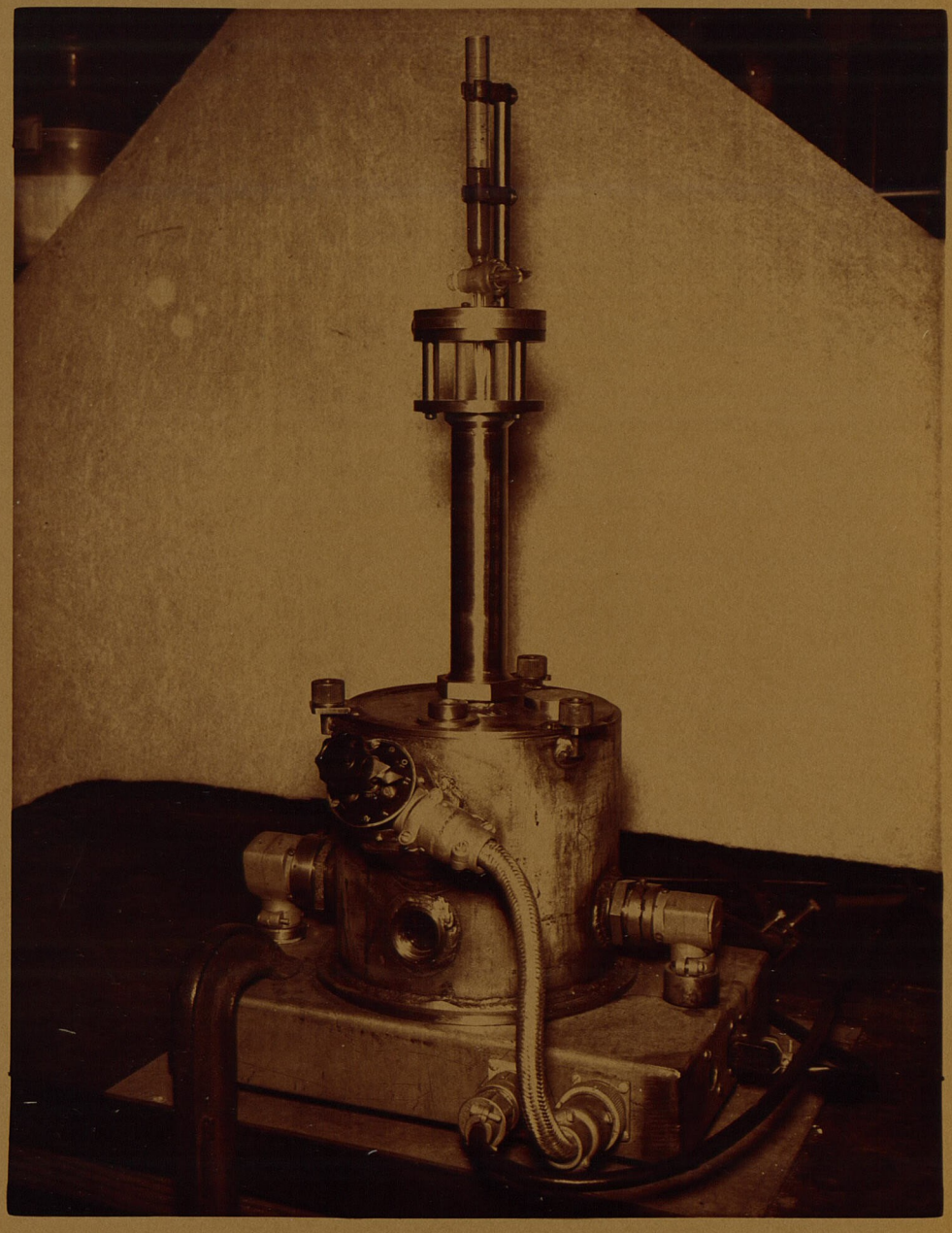


FIGURE 9. ASSEMBLED COMBUSTION CHAMBER

IGNITION DELAY APPARATUS

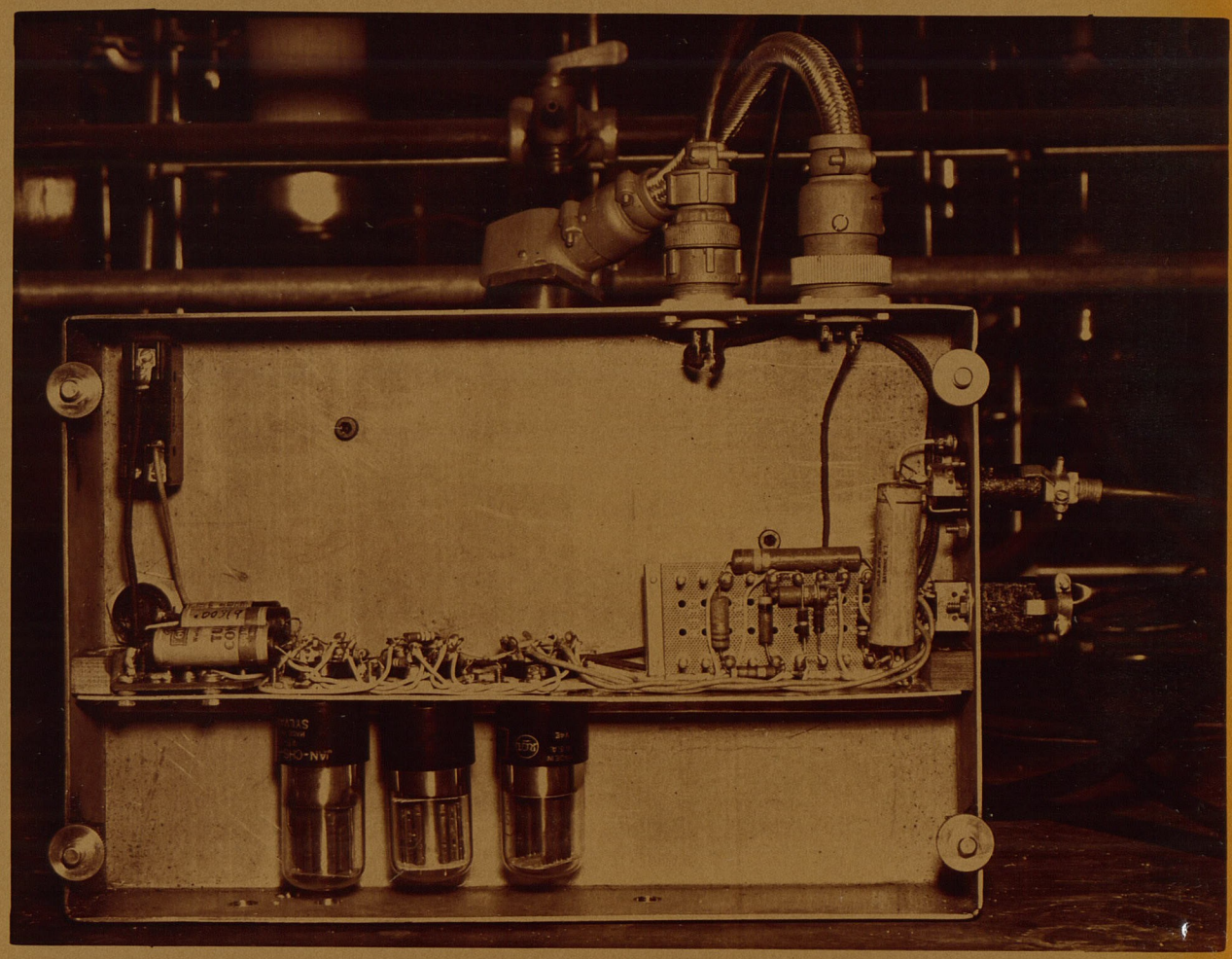


FIGURE 10. BOTTOM VIEW OF COMBUSTION CHAMBER UNIT SHOWING TRIGGER CIRCUIT

IGNITION DELAY APPARATUS

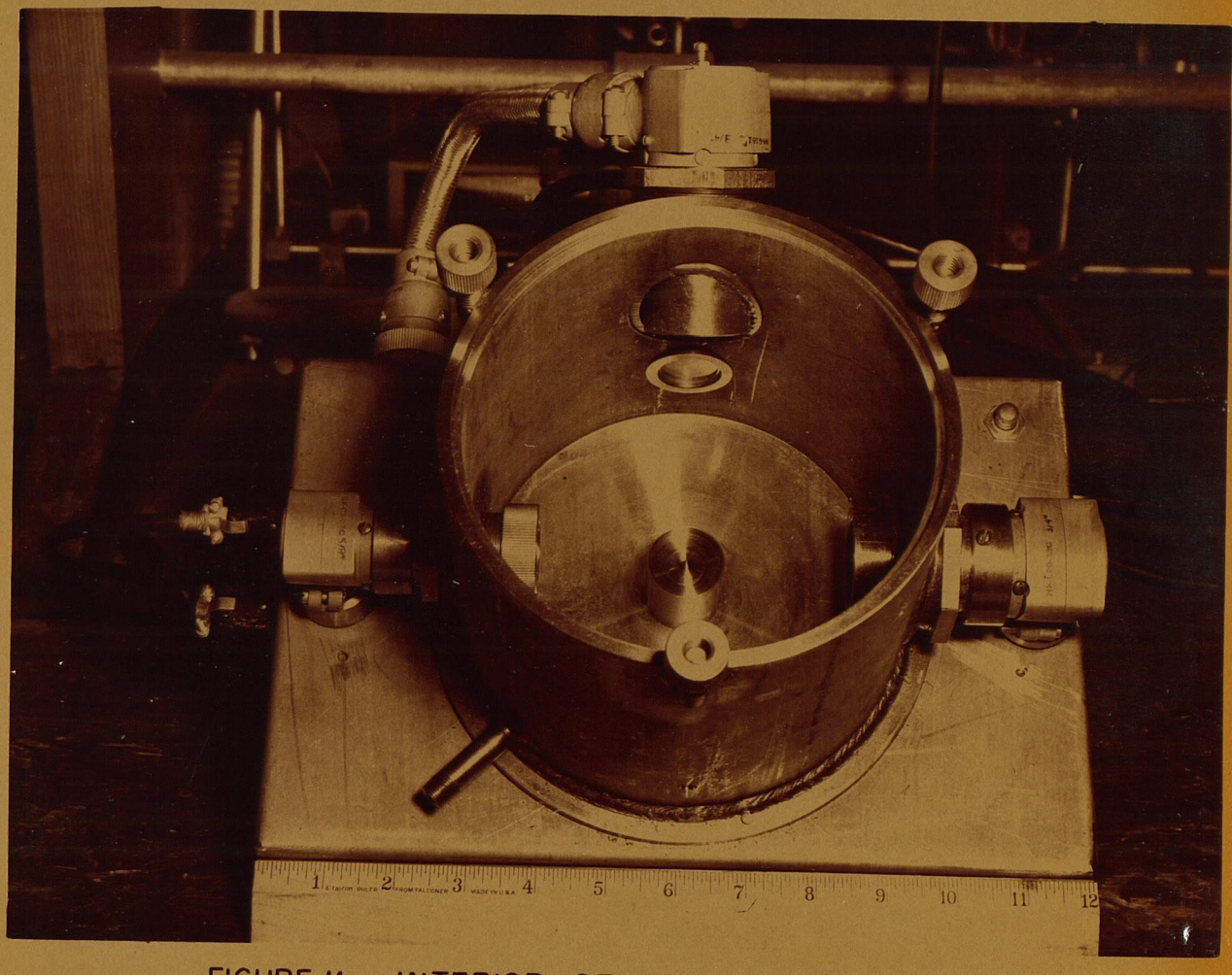


FIGURE 11 . INTERIOR OF COMBUSTION CHAMBER