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RESEARCH MEMORANDUM

SPARK IGNITION OF FLOWING GASES

I - ENERGIES TO IGNITE PROPANE - AIR MIXTURES IN PRESSURE RANGE OF 2 TO 4 INCHES MERCURY ABSOLUTE

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SUMMARY

Ignition studies of flowing gases were made to obtain information applicable to ignition problems in gas-turbine and ram-jet aircraft propulsion systems operating at altitude conditions. Spark energies required for ignition of a flowing propane - air mixture were determined for pressures of 2 to 4 inches mercury absolute, gas velocities of 5.0 to 54.2 feet per second, fuel-air ratios of 0.0607 to 0.1245, and spark durations of 1.5 to 24,400 microseconds.

The results showed that at a pressure of 3 inches mercury absolute the minimum energy required for ignition occurred at fuel-air ratios of 0.08 to 0.095. The energy required for ignition increased almost linearly with increasing gas velocity. Shortening the spark duration from approximately 25,000 to 125 microseconds decreased the amount of energy required for ignition. A spark produced by the discharge of a condenser directly into the spark gap and having a duration of 1.5 microseconds required ignition energies larger than most of the long-duration sparks.

INTRODUCTION

A current combustion problem is reignition in gas-turbine and ram-jet aircraft propulsion systems. If the flame in the combustor becomes unstable and blows out, reignition, particularly at altitude conditions, is difficult or impossible with some of the ignition methods now used. Inasmuch as an electric spark discharge is used as the ignition source in many such engines, a study of the effect of gas-stream parameters on ignition was included as part of a program on fundamental studies of combustion being conducted at the NACA Lewis laboratory.

Ignition of flowing gases by electric sparks has not yet been investigated, although results of ignition of stationary or quiescent gases have been reported by numerous investigators. Some of the latest results on ignition of quiescent gas mixtures are reported in reference 1. As indicated in reference 2, larger energies are required in quiescent gas to ignite a turbulent mixture than a non-turbulent one; however, no measurement of the gas flow was made.

As the first part of the NACA research program, an investigation of spark gaps subjected to low-pressure and moving-air conditions is reported in reference 3, in which the effect of gas-stream parameters on the energy and the power dissipated in the spark with a constant ignition system is described. Various other results such as the distance that the spark moved downstream, the duration of the spark, the existence of more than one spark at high velocities, and the effect of gap spacing and electrode diameter were determined. An oscillographic method of measuring energy, power, and duration of the spark was used.

The second part of the program is an investigation of electric spark ignition of a flowing combustible mixture of propane and air and the initial results are reported herein. Minimum energies required to ignite the flowing mixture were determined for various conditions of gas pressure, gas velocity, fuel-air ratio, and duration of the spark. The basic ignition and measuring systems described in reference 3 were used, but the resistor values and condenser voltages were changed to obtain variable amounts of energy and durations of the sparks. Oscillograms of the spark discharge were obtained and were analyzed as described in reference 3.

APPARATUS AND PROCEDURE

Combustion Apparatus

The combustion apparatus, shown in figure 1, was constructed from an altitude chamber that was altered for this investigation. A predetermined amount of propane and air at room temperature was introduced into the chamber at the desired pressure, thoroughly mixed by fans, and circulated by a blower through the test section and back into the altitude chamber. The gas velocity was varied by changing the blower speed.

The test section had a 3-inch-inside diameter with a screen and a flame arrester at opposite ends to prevent the flame from passing into the chamber and causing an explosion. The volume of

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the test section was small compared with the total volume of the apparatus so that a number of ignition runs could be made without noticeably changing the mixture strength. The electrodes were 3/16-inch-diameter cylindrical rods with blunt ends and were located on the same center line perpendicular to the direction of flow. Gap spacing was 0.250 inch. Quartz windows were located at the electrode position and at a point 10 inches downstream. Appearance of flame at the downstream window was used as the criterion for ignition.

The velocity of the mixture was determined by a pitot-static tube used in conjunction with a micromanometer to measure the velocity pressure. Inasmuch as the tube was located on the center line of the test section, the results presented are in terms of the peak velocity of the mixture. The degree of turbulence of the flowing mixture was not determined.

Ignition and Measuring Systems for Long-Duration Sparks

The ignition and measuring systems shown in figure 2 are described in reference 3. The capacitance of the condenser was held constant at 0.52 microfarad. The size of the resistors and the voltage of the condenser were changed for the various runs to the values listed in table I. Switch S_3 was closed throughout this investigation.

When the desired conditions were obtained in the combustion chamber, the condenser was charged, S_1 was opened, and then the condenser was discharged by means of S_2. A number of trials were made with different condenser voltages until the ignition point was located. If the ignition point could not be found by varying the voltage, the value of resistor R_2 was adjusted to bring the point within range. The values of R_3, R_4, and R_5 were adjusted when necessary to give the desired deflections of the oscillograph beam. The value of R_1 was changed when a different spark duration was desired. As soon as the ignition voltage was determined as the average of a number of trials, the trace on the oscillograph tube was photographed and the photograph was analyzed for the duration and energy of the spark.

In some instances, especially at low condenser voltages, time lag of the spark gap was encountered; that is, time elapsed between the instant of application of the voltage across the spark gap and the occurrence of the spark. In such cases, an ultraviolet light at the electrode window irradiated the electrodes in order to reduce the lag to a negligible value.

Ignition Apparatus for Short-Duration Sparks

With the ignition and measuring systems just described, it was impossible to obtain data at spark durations as small as were desired. A somewhat different ignition apparatus was used to obtain results with short-duration sparks. A condenser was placed directly across the spark gap, charged to the breakdown voltage of the gap, and discharged into the gap. The ignition point was found by varying the capacitance of the condenser. The energy was calculated as

$$E = 1/2\ CV^2$$

where

E energy, joules

C capacitance, farads

V voltage, volts

The spark duration with this arrangement was estimated to be between 1 and 2 microseconds by observing the current wave of the discharge with an oscillograph. The voltage produced across a 1-ohm resistor in series with the spark gap was amplified and placed on the deflection plates. Timing marks were superimposed on the trace. Because the trace was faint and therefore could not be photographed, the number of timing spots was visually estimated. The resistor did not affect the ignition energy required.

RESULTS AND DISCUSSION

Results could only be obtained over a comparatively narrow range of pressure and gas velocity due to equipment limitations. The maximum pressure was limited to 4 inches mercury absolute because of the danger of flame passing through the flame arrester and screen and causing an explosion in the altitude chamber, which was not designed to withstand explosions. The maximum velocity that could be attained with the 3-inch test section was 54.2 feet per second.

In check runs at fixed values of the gas-stream parameters, the energies for ignition varied as much as 5 percent from the mean value. The ultraviolet light failed to make the results more consistent or to have any effect on the ignition energy at conditions where time lag was not encountered. The variation in ignition energy was attributed to the fact that the spark occurred at different positions on the electrode surface in the various runs.

Energy values given in table I are the minimum energies that caused ignition with the specific electrodes used and may not be equal to the minimums that could be obtained with electrodes of different geometry.

The effect of fuel-air ratio and gas velocity on the energy required for ignition are shown in figure 3 for a pressure of 3 inches mercury absolute and a spark duration of approximately 600 to 800 microseconds. The minimum energy necessary to ignite the mixture occurred at fuel-air ratios of 0.08 to 0.095, which are richer than stoichiometric. Toward both the rich-limit and lean-limit ends of the curves, the required energy began to increase rapidly. Just beyond the ends of the curves shown, the energies rose to large values, although definite values could not be determined because ignition became very erratic.

The effect of gas velocity on the energy required to ignite the mixture at various pressures was determined for a fuel-air ratio of 0.0835 and spark duration of approximately 600 to 800 microseconds. The results in figure 4 show that the energy required increased almost linearly with gas velocity and decreased with increasing pressure. At a pressure of 4 inches mercury absolute, almost three times as much energy was required for ignition at a velocity of 54.2 feet per second as was required at 5.0 feet per second.

The effect of changing the spark duration on the energy required to ignite the mixture at a fuel-air ratio of 0.0835 is shown in figure 5 for pressures of 3 and 4 inches mercury absolute each at velocities of 5.0 and 54.2 feet per second. As the spark duration was shortened from about 25,000 microseconds, the required energy decreased. At about 200 microseconds, the trace on the oscillograph tube became faint and analysis of the oscillograms was difficult. The points at 1.5 microseconds were determined by the method used for short-duration sparks in order to show the difference in amounts of energy that would be required for the two systems. The curves were not continued to these points because the current-wave shapes are different for each system.

The current-wave shape of the long-duration sparks was substantially an exponential decay, whereas the current-wave shape of the 1.5-microsecond-duration sparks was oscillatory. The energy required for the short-duration sparks was considerably higher than most of the long-duration sparks. 1134

SUMMARY OF RESULTS

The following results were obtained in the investigation to determine the minimum energy requirements to ignite a flowing combustible mixture of propane and air in the pressure range of 2 to 4 inches mercury absolute:

1. At a pressure of 3 inches mercury absolute, the minimum ignition energy occurred at fuel-air ratios of 0.08 to 0.095 with gas velocities between 5.0 and 54.2 feet per second. The required energy increased with richer and leaner fuel-air ratios.

2. The energy required for ignition increased almost linearly with increasing gas velocity in the range of 5.0 to 54.2 feet per second. The required energy increased three-fold over this velocity range at a pressure of 4 inches mercury absolute.

3. As the spark duration was shortened from about 25,000 to 125 microseconds, the energy required for ignition decreased.

4. The energy required for ignition with a spark having a duration of 1.5 microseconds, as produced by the discharge of a condenser directly into the spark gap, was considerably larger than most of the long-duration sparks.

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National Advisory Committee for Aeronautics,
Cleveland, Ohio.

REFERENCES

1. Blanc, M. V., Guest, P. G., von Elbe, Guenther, and Lewis, Bernard: Ignition of Explosive Gas Mixtures by Electric Sparks. I. Minimum Ignition Energies and Quenching Distances of Methane, Oxygen, and Inert Gases. Jour. Chem. Phys., vol. 15, no. 11, Nov. 1947, pp. 798-802.

2. Wheeler, Richard Vernon: The Inflammation of Mixtures of Ethane and Air in a Closed Vessel: The Effects of Turbulence. Jour. Chem. Soc. Trans. (British), vol. CXV, pt. I, art. VIII, 1919, pp. 81-94.

3. Swett, Clyde C., Jr.: Investigation of Spark Gaps Subjected to Altitude and Air-Velocity Conditions. NACA RM E8I17, 1948.

TABLE I - IGNITION DATA AND VALUES OF CIRCUIT COMPONENTS FOR LONG-DURATION SPARKS

Pressure (in. Hg abs.)	Spark duration (microsec)	Velocity (ft/sec)	Energy (joules)	Condenser voltage (kilovolts)	Resistor values				
					R_1 (ohms)	R_2 (ohms)	R_3 (ohms)	R_4 (ohms)	R_5 (ohms)
Fuel-air ratio, 0.0607									
3	900	5.0	0.0554	19.25	517.1	10,130	248.5	450,000	68,600
Fuel-air ratio, 0.0668									
3	800	54.2	0.0685	20.1	517.1	10,130	248.5	450,000	68,600
Fuel-air ratio, 0.0683									
3	850	5.0	0.048	11.6	517.1	10,130	248.5	450,000	68,600
	830	25.2	.0688	12.03	517.1	10,130	248.5	450,000	68,600
Fuel-air ratio, 0.0759									
3	800	54.2	0.0592	13.7	517.1	10,130	248.5	450,000	68,600
Fuel-air ratio, 0.0835									
2	666	5.0	0.0563	11.0	619.3	3485	48.85	19,670	15,670
	633	15.0	.0597	13.0	619.3	3485	48.85	19,670	15,670
	732	25.2	.0683	13.6	619.3	3485	48.85	19,670	15,670
	732	40.0	.0742	14.0	619.3	3485	48.85	19,670	15,670
	746	54.2	.0841	16.4	619.3	3485	48.85	19,670	15,670
3	133	5.0	0.0176	11.2	102.5	1996	32.44	19,660	15,660
	167	54.2	.0346	14.0	102.5	1022	24.59	19,660	15,660
	240	5.0	0.0145	7.3	166	3032	103.6	19,720	15,680
	277	54.2	.0411	15.0	166	2041	41.74	19,730	15,680
	800	5.0	0.0314	6.6	517.1	10,130	248.5	450,000	68,600
	750	15.0	.0349	7.2	517.1	10,130	248.5	450,000	68,600
	750	25.2	.0435	8.85	517.1	10,130	248.5	450,000	68,600
	800	40.0	.057	11.0	517.1	10,130	248.5	450,000	68,600
	700	54.2	.057	13.9	517.1	10,130	248.5	450,000	68,600
	3880	5.0	0.0444	5.1	5332	103,100	1784	450,000	58,300
	5000	54.2	.229	16.95	5332	103,100	1784	450,000	58,300
	24,400	5.0	0.131	7.8	26,830	279,000	7496	1.8×10^6	185,000
	24,000	54.2	.554	16.6	26,940	190,000	3044	1.8×10^6	183,000

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Fuel-air ratio, 0.0835									
4	125	5.0	0.00708	6.9	102.7	6020	183.7	19,660	15,660
	150	54.2	.0212	17.5	102.7	3486	63.1	19,660	15,660
	200	5.0	0.009	5.1	166.2	6024	183.8	19,690	15,640
	233	54.2	.0288	11.4	166.2	3033	105.9	19,690	15,640
	600	5.0	0.0144	5.85	516.6	24,900	515.5	450,000	68,700
	550	15.0	.01455	6.3	516.6	24,900	515.5	450,000	68,700
	600	25.2	.0221	7.5	516.6	24,900	515.5	450,000	68,700
	550	40.0	.0286	10.1	516.6	24,900	515.5	450,000	68,700
	650	54.2	.0417	16.83	516.6	24,900	515.5	450,000	68,700
	3250	5.0	0.0225	5.9	5335	202,900	7525	1.8×10^6	185,000
	4630	54.2	.1785	17.0	5336	164,900	2992	450,000	58,320
	21,700	5.0	0.0976	9.1	27,000	560,000	14,490	1.8×10^6	185,000
	23,300	54.2	.517	16.2	26,900	280,000	4,198	1.8×10^6	185,000
Fuel-air ratio, 0.0911									
3	800	25.2	0.0397	8.8	517.1	10,130	248.5	450,000	68,600
	800	54.2	.0646	16.2	517.1	10,130	248.5	450,000	68,600
Fuel-air ratio, 0.0987									
3	850	5.0	0.0378	6.73	517.1	10,130	248.5	450,000	68,600
	800	54.2	.0749	19.4	517.1	10,130	248.5	450,000	68,600
Fuel-air ratio, 0.1063									
3	800	25.2	0.0579	9.8	517.1	10,130	248.5	450,000	68,600
Fuel-air ratio, 0.1140									
3	850	5.0	0.0423	10.2	517.1	10,130	248.5	450,000	68,600
Fuel-air ratio, 0.1184									
3	850	25.2	0.0592	18.34	517.1	10,130	248.5	450,000	68,600
Fuel-air ratio, 0.1245									
3	850	5.0	0.0556	17.6	517.1	10,130	248.5	450,000	68,600

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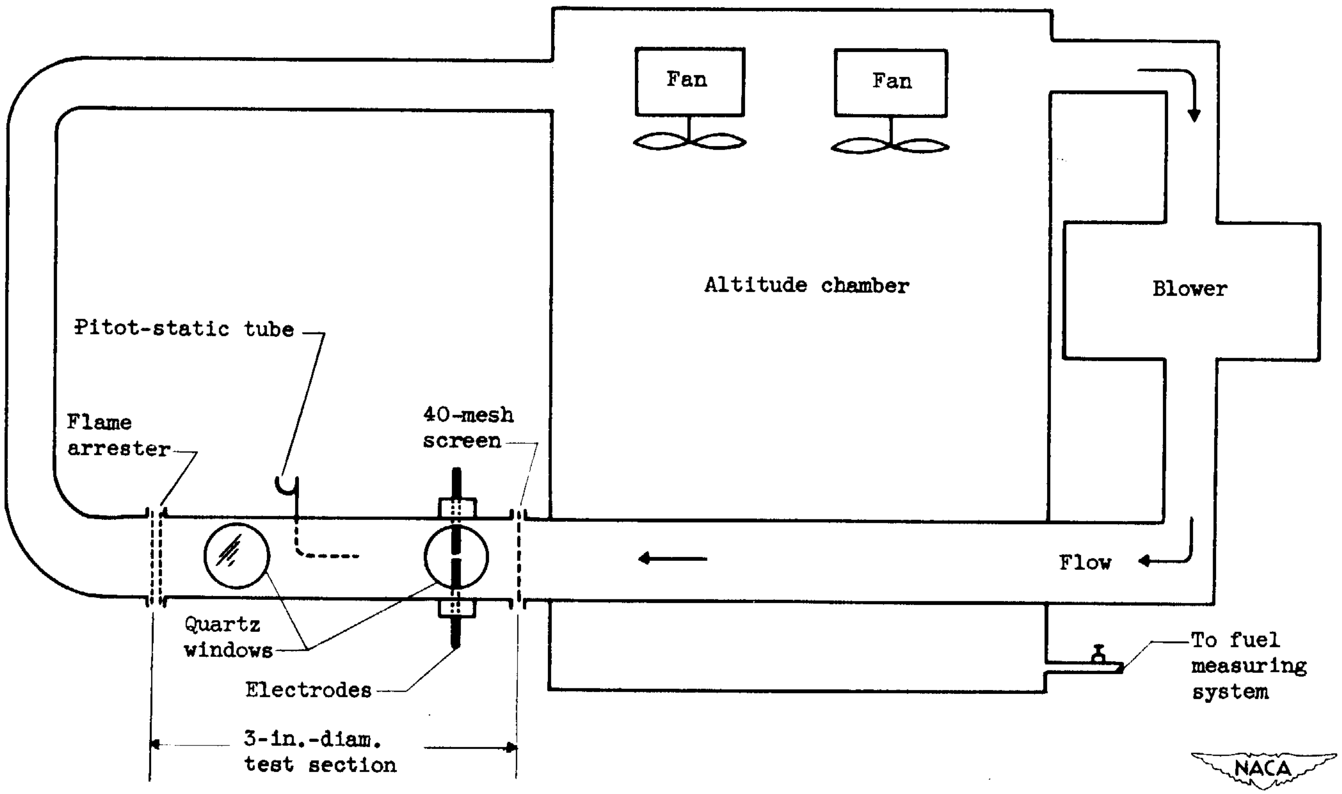

Figure 1. - Apparatus for ignition studies of flowing combustible gas.

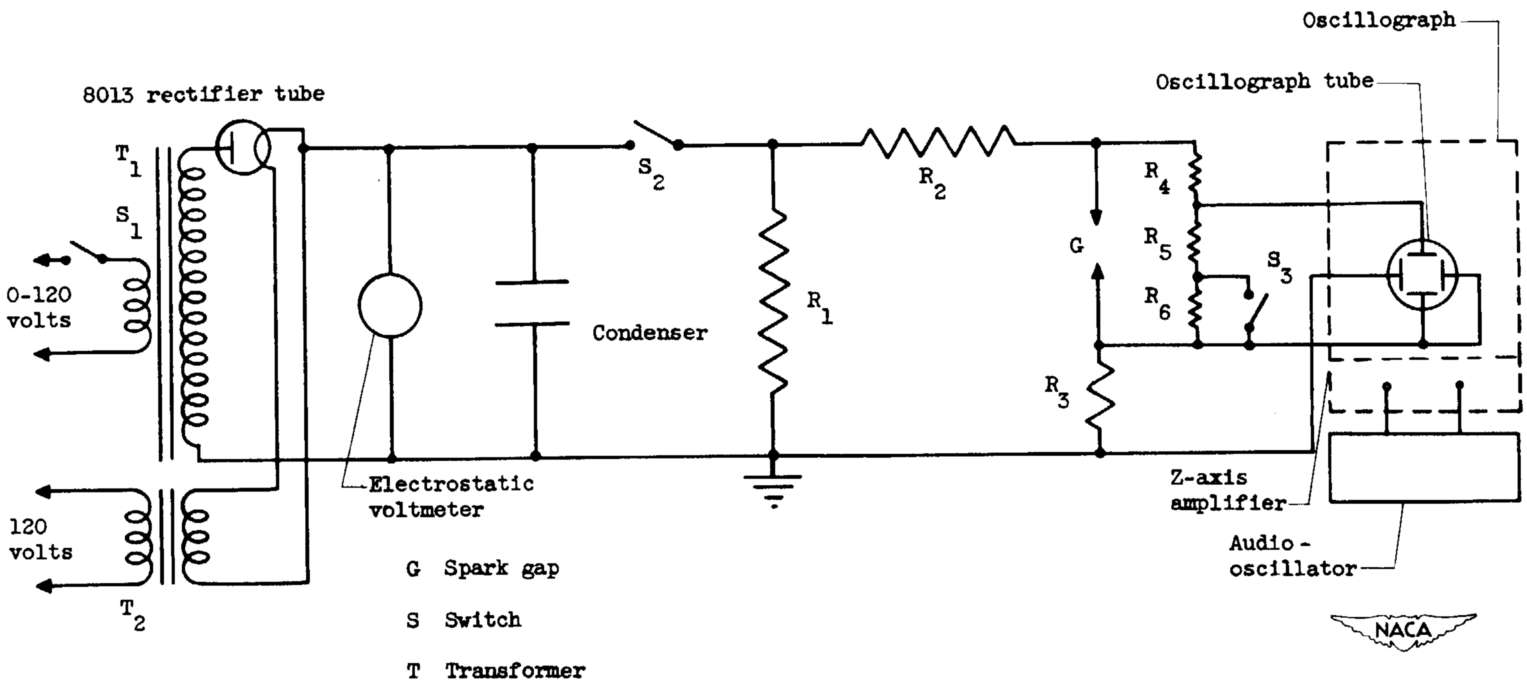

Figure 2. - Ignition and measuring systems for long-duration sparks (reference 3).

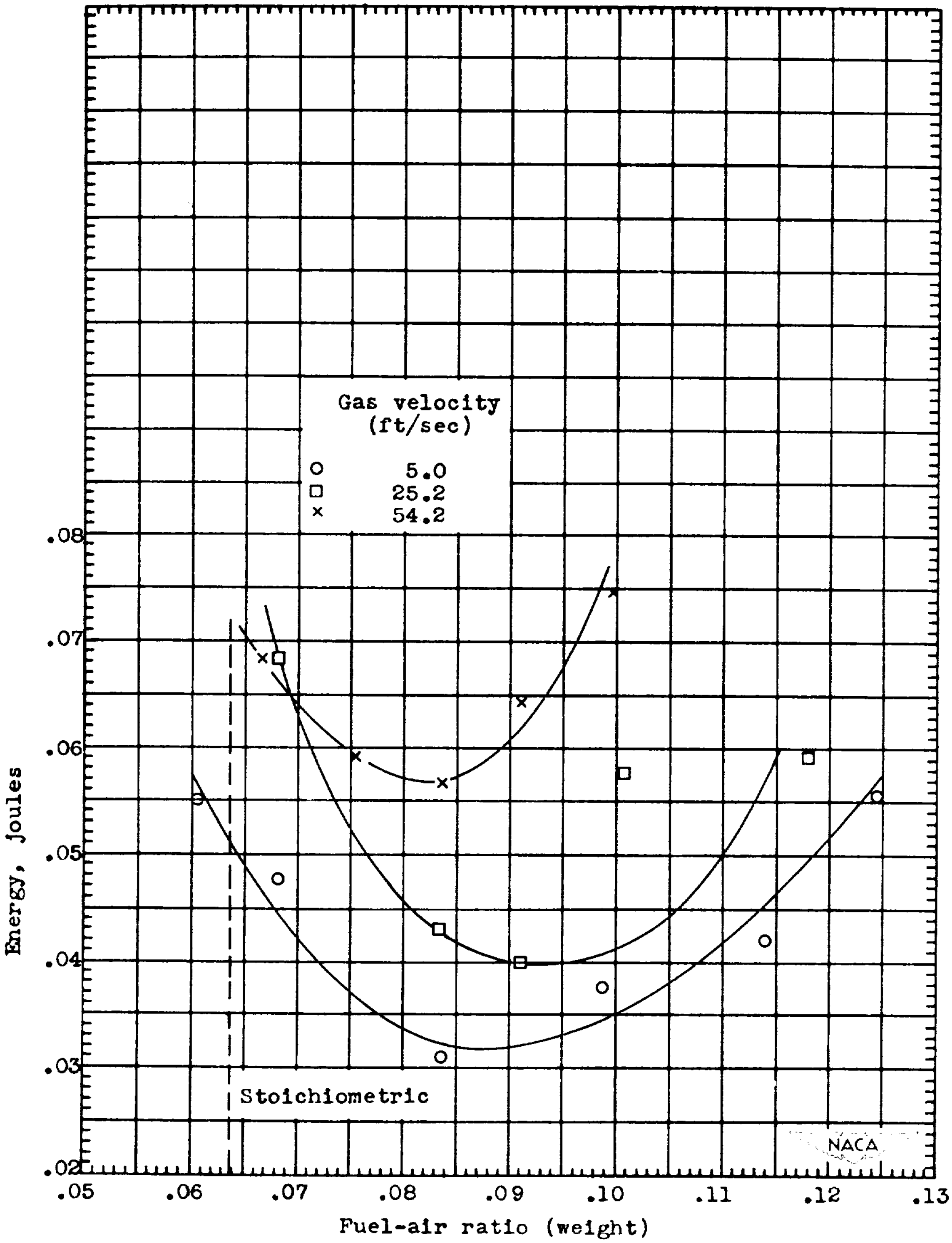

Figure 3. - Effect of fuel-air ratio and gas velocity on energy required for ignition. Pressure, 3 inches mercury absolute; spark duration, approximately 600 to 800 microseconds; temperature, 80° F.

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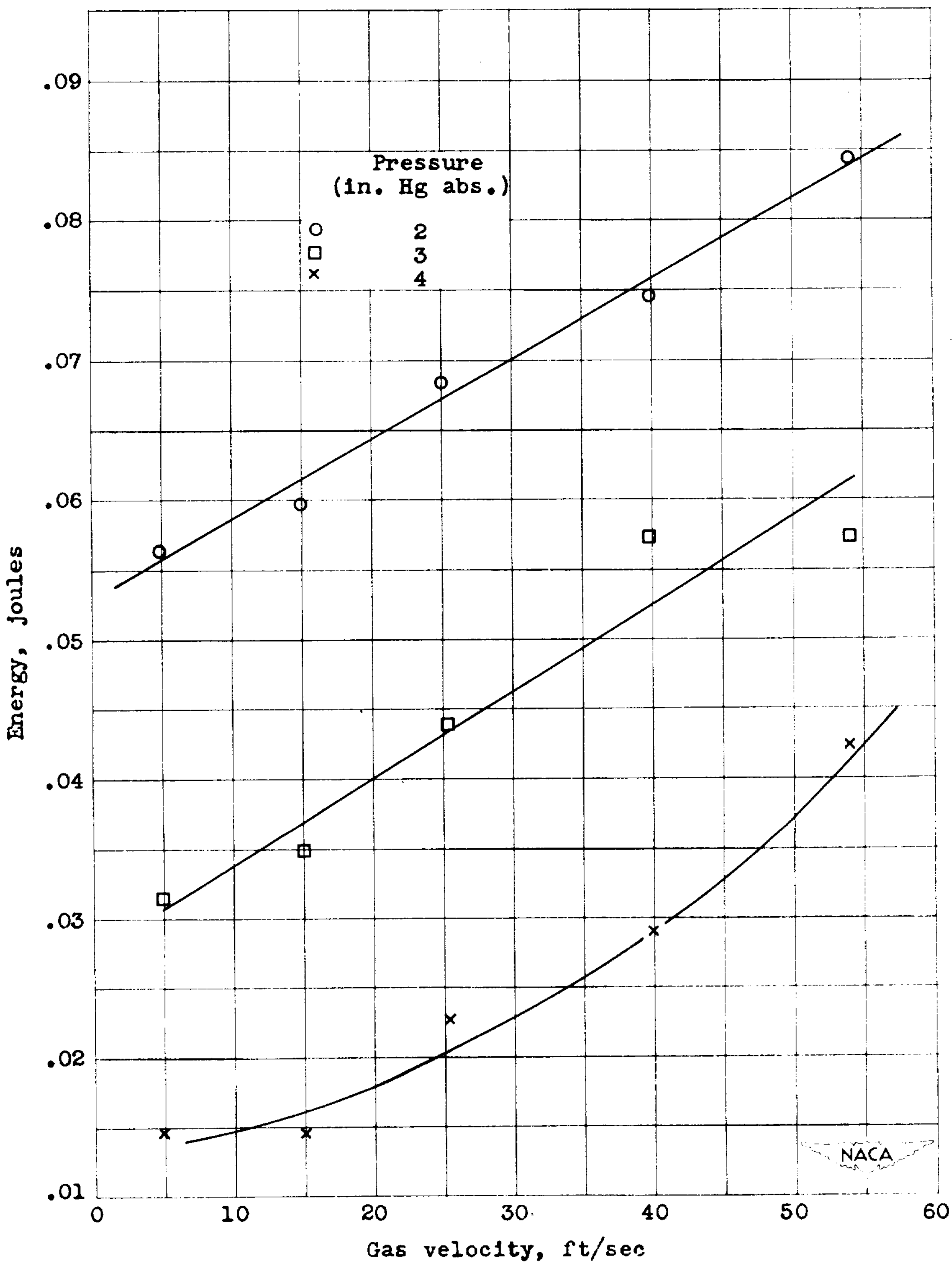

Figure 4. - Effect of gas velocity and pressure on energy required for ignition. Spark duration, approximately 600 to 800 microseconds; fuel-air ratio, 0.0835.

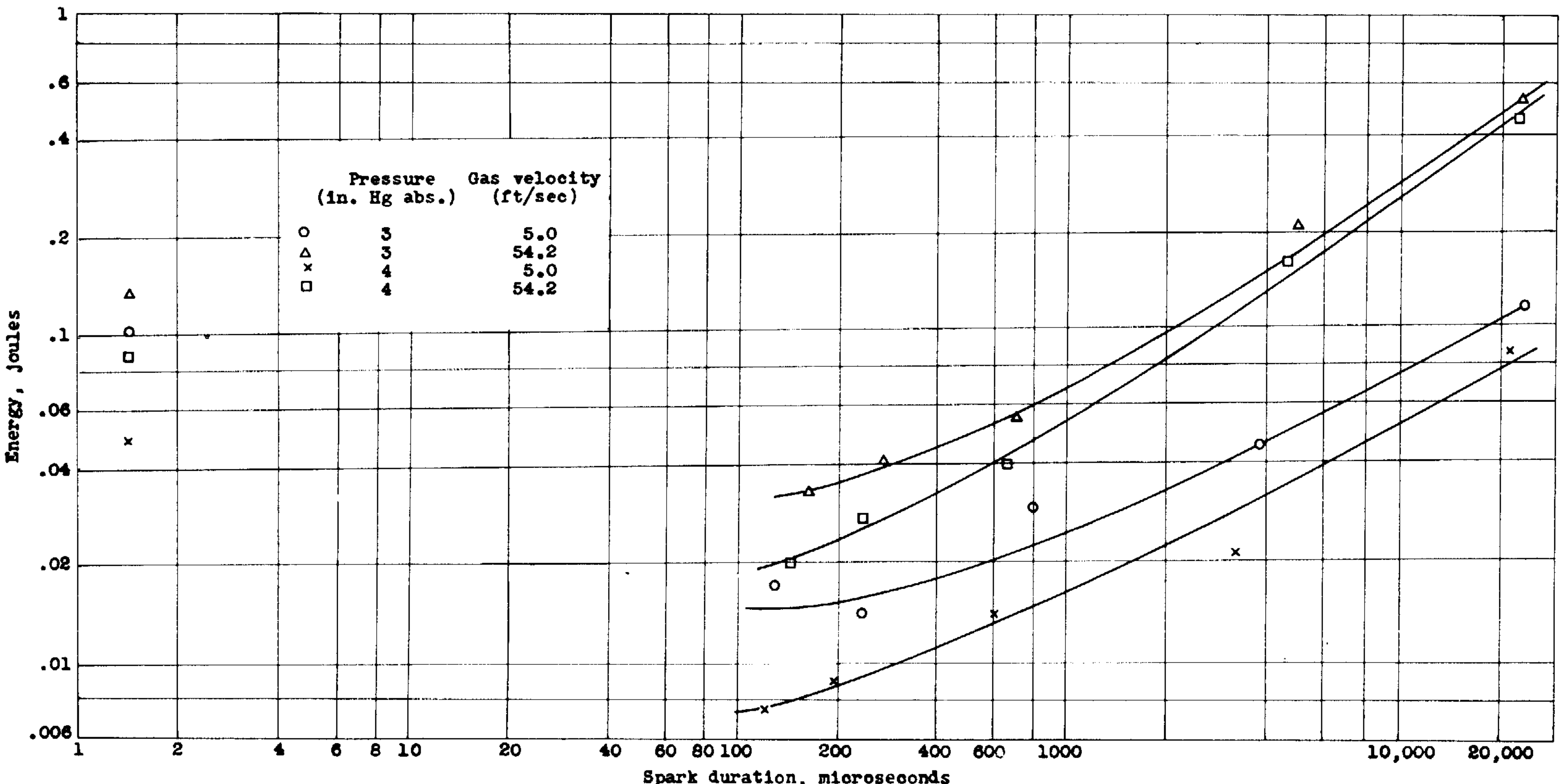

Figure 5. - Effect of spark duration on energy required for ignition. Fuel-air ratio, 0.0635.