TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 434

INFLUENCE OF SEVERAL FACTORS ON IGNITION LAG IN A COMPRESSION-IGNITION ENGINE

By Harold C. Gerrish and Fred Voss
Langley Memorial Aeronautical Laboratory

Washington
November, 1932

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE NO. 434

INFLUENCE OF SEVERAL FACTORS ON IGNITION LAG IN A COMPRESSION-IGNITION ENGINE

By Harold C. Gerrish and Fred Voss

SUMMARY

This investigation was made to determine the influence of fuel quantity, injection advance angle, injection valve-opening pressure, inlet-air pressure, compression ratio, and engine speed on the time lag of auto-ignition of a Diesel fuel oil in a single-cylinder compression-ignition engine as obtained from an analysis of indicator diagrams. Three cam-operated fuel-injection pumps, two pump cams, and an automatic injection valve with two different nozzles were used. Ignition lag was considered to be the interval between the start of injection of the fuel as determined with a Stroborama and the start of effective combustion as determined from the indicator diagram, the latter being the point where 4.0×10^{-6} pound of fuel had been effectively burned.

For this particular engine and fuel it was found that: (1) for a constant start and the same rate of fuel injection up to the point of cut-off, a variation in fuel quantity from 1.2×10^{-4} to 4.1×10^{-4} pound per cycle has no appreciable effect on the ignition lag; (2) injection advance angle increases or decreases the lag according to whether density, temperature, or turbulence has the controlling influence; (3) increase in valve-opening pressure slightly increases the lag; and (4) increase of inlet-air pressure, compression ratio, and engine speed reduces the lag.

INTRODUCTION

Considerable attention has been given during the past ten years to the delay period, usually termed "ignition lag," occurring in compression-ignition engines between injection and burning of the fuel. This lag is found to occur when fuel is burned in bombs, on heated surfaces, and in internal-combustion engines. This lag is of considerable importance in regard to engine performance. If the delay is too long, a large quantity of fuel will be ignited simultaneously with the consequent liability of breakage of engine parts. Burning of the fuel immediately upon injection would permit combustion to be controlled and the desired form of cycle to be obtained by controlling the rate of injection. Engine performance would be consequently improved and the life of the engine parts lengthened.

No particular factor has been definitely shown to control ignition lag, although various factors influence it. A survey of the recent literature shows that the chemical composition of the fuel has a greater effect than any of its physical properties. However, the lag may be influenced by mechanical and thermal means.

The purpose of this investigation was to determine by analyses of indicator diagrams taken from a compression-ignition engine the influence of fuel quantity, injection advance angle, injection valve-opening pressure, inlet-air pressure, compression ratio, and engine speed on the time lag of auto-ignition of a Diesel fuel oil. This time lag is considered as the interval between the appearance of the spray at the fuel-injection valve nozzle and the time when analysis of the indicator diagram shows that an arbitrary weight of fuel has been effectively burned. In speaking of fuel burned or of combustion, "effective" will be implied and will mean the combustion of the quantity of fuel deducible from the indicator diagrams and will not include that dissipated as heat losses. This investigation was conducted by the National Advisory Committee for Aeronautics during the spring of 1932.

APPARATUS AND METHOD

For this analysis indicator cards were obtained from several investigations made on the N.A.C.A. universal test engine described in reference 1. The cylinder head used had a combustion chamber formed between the horizontally opposed inlet and exhaust valves as shown in Figure 1. The combustion chambers were identical for all tests except that three different spacer rings were used between the cylinder and the head to change the compression ratio. For a compression ratio of 12.6 the head shown as (a) was used; for a compression ratio of 15.3 the head shown as (b) was used.

Three fuel-injection pumps were used during this investigation. One was a Bosch pump and the others were No. 7 and No. 7-A pumps, developed at this laboratory. The Bosch pump is described in reference 2. The No. 7 pump is the pump described in reference 3. The No. 7-A pump is similar in design but has a larger plunger diameter. Two different pump cams were used with the laboratory pumps. Reference 4 shows the pump-plunger displacement resulting from the use of these cams with No. 7 pump. Two fuel-injection nozzles were used with the automatic injection valve. Both nozzles had six orifices in one plane so directed as to form a fan-shaped spray coincident with the largest section of the combustion chamber. These nozzles were designed according to the proportional-area principle described in reference 5. The orifice areas of these nozzles were slightly different, being 0.00072 and 0.00079 square inch. The nozzle having the smaller area was used for both the 12.6 and 14.8 compression-ratio tests; the other nozzle with the larger orifice area being used for the 15.3 compression-ratio tests.

The fuel used was a commercial grade of Diesel fuel oil having a specific gravity of 0.847 and a Saybolt Universal viscosity of 41 seconds at 80° F.

A 4-inch Roots-type supercharger with a pulsation-dampening tank was used in the tests of varying the inlet-air pressure.

Figure 2 shows a typical indicator diagram taken with a modified Farnboro engine indicator. (Reference 6.) The amount of fuel burned at different positions during the cycle was determined by the method described in a report on the analysis of indicator diagrams now being prepared. The time of spray start was determined by observing with a Stroborama the spray injecting into the atmosphere. It was found for the injection systems used that neither air pressure nor engine speed had an appreciable influence on the start of injection.

The investigation was divided into four sections to show the effect of: (1) variable fuel quantity, (2) variable injection advance angle (I.A.A.), (3) variable inlet-air pressure, and (4) variable speed. Tests were made under (2) for various inlet-air pressures, compression ratios, and injection valve-opening pressures. Compression ratios of 12.6, 14.8, and 15.3 and valve-opening pressures of 3,000, 4,650, and 5,600 pounds per square inch were used. The fuel quantity was varied from 1.2×10^{-4} to 4.1×10^{-4} pound per cycle; inlet-air absolute pressures from 20 to 40 inches of mercury; and engine speeds from 1,000 to 1,750 r.p.m. All test data except those for the variable speeds were taken at 1,500 r.p.m.

RESULTS AND DISCUSSION

Analysis of a large number of indicator diagrams has shown that the determination of the actual start of combustion is quite difficult. Figure 3 has been prepared to show the effect on ignition lag of considering different quantities of fuel burned as the start of combustion. An inspection of the figure shows that all curves have the same trend irrespective of the amount of fuel burned. The least quantity of fuel burned that gives the smallest variation of the time lags from a smooth curve is 4.0×10^{-6} pound. Similar results have been obtained in other indicator diagram analyses and therefore ignition lag is defined in this report as the period between the start of fuel injection and the time when 4.0×10^{-6} pound of fuel has been burned.

It is realized that the ignition lags based on this definition are longer than is the case when no fuel is burned. However, owing to the small amount of fuel that is burned during the delay period and to the composite indicator diagram being analyzed, it is difficult to obtain definite trends by considering the start of combustion to occur when smaller fuel quantities are burned.

The results of the investigation are shown in Figures 4 to 9. The figures, however, cannot be correlated because each represents a series of runs made under different engine conditions.

Fuel quantity.- Figure 4 shows the effect of fuel quantity on ignition lag. These curves were obtained under test conditions which were constant for each curve, except that the quantity of fuel injected was varied by changing the time of cut-off of the fuel spray. The curves show that for a constant start and the same rate of injection up to the point of cut-off a variation in fuel quantity from 1.2×10^{-4} to 4.1×10^{-4} pound per cycle has no appreciable effect on ignition lag.

Injection advance angle.- Figures 5 and 6 show the effect of I.A.A. on ignition lag. It will be noted that the curves in Figure 5 and those in Figure 6 for all inlet-air pressures of less than 38 inches of mercury are concave upward. Above this pressure the curves are concave downward. This reversal in trend of the curves is apparently independent of compression ratio for the same effect is noted for two compression ratios. (See fig. 6.) The variation in the ignition lag shown in the figures is probably due to combinations of the effects of density, turbulence, and temperature of the air. Neumann (reference 7) found that as the difference between the air temperature and ignition temperature of the fuel, which decreases with density, increases the ignition lag decreases and also that the lag decreases with increased turbulence. Dicksee (reference 8) found the lag to decrease by increasing the I.A.A. from 0° to 12.5° in one engine, but in another with a more definite and orderly air flow an increase of I.A.A. from 15° to 24° increased the lag.

Valve-opening pressure.- Figure 5 also shows the effect of valve-opening pressure (v.o.p.) on ignition lag for two different fuel pumps. In both cases it is seen that an increase in v.o.p. results in a slight increase in lag. Increasing the v.o.p. increases the rate of injection (reference 2) and the fineness and uniformity of atomization of the spray. (Reference 9.) An increase in the rate of injection tends to increase the lag because of the increased quantity of fuel present in the engine cylinder which requires a greater quantity of heat to be absorbed by the fuel to attain its ignition temperature. A decrease in drop size should decrease the lag because less time would be required for the smaller liquid particle to attain its ignition temperature.

Inlet-air pressure.- The effect of variable inlet-air pressure is shown in Figure 6. It will be noted that as the pressure increases the ignition lag decreases. This change was not due entirely to pressure, because the inlet-air temperature increased from 80° to 125° F. for this range of inlet-air pressure on account of the heat added to the air by supercharging. The combined effect of these two factors probably controlled the reduction in ignition lag. A cross-plot of these curves shows that ignition lag decreases lineally with increase in inlet-air pressure. For a large range of inlet-air pressures this statement is not strictly true, as shown in Figure 7. However, the deviation is small and for all practical purposes it may be concluded that ignition lag decreases lineally with increase in inlet-air pressure. These results substantiate those obtained by Mucklow (reference 10), who found that the ignition lag increased lineally as the inlet-air pressure was reduced below atmospheric, the slope of his curve increasing, however, with the power output.

Compression ratio.- Figure 8 shows the effect of compression ratio on ignition lag. It will be seen that the lag is reduced by increasing the compression ratio. The main reason for this decrease is probably the greater difference at large compression ratios between the temperature of the compressed air at ignition and the ignition temperature of the fuel. (Reference 7.) It should be recalled that during this series of tests different fuel pumps and injection nozzles were used, but it is believed that although these factors may influence the lag, their effect is small compared with that of compression ratio.

Engine speed.- Figure 9 shows that ignition lag decreases as the engine speed is increased from 1,000 to 1,750 r.p.m. The effect is due to the combination of the influence of air temperature, turbulence, and initial rate of injection. The first two factors increase with engine speed and reduce ignition lag, whereas the latter (reference 2) also increases with engine speed and, as discussed under the section on valve-opening pressure, increases the lag.

In this test, indicator diagrams were taken for engine speeds from 1,000 to 1,750 r.p.m., the I.A.A. varying from 3 to 11 crank degrees. An inspection of the unsupercharged results of Figure 6 for a compression ratio of 15.3 shows that for this range of advance angles the variation in lag is small. Therefore, the curve of lag against speed was drawn considering the advance angle to be constant.

Dicksee (reference 8) found the same effect for engine speeds above 800 r.p.m., but for lower speeds he found that the ignition lag decreased.

CONCLUSIONS

Ignition lag, when defined as the period between the start of fuel injection and the point at which analysis of the indicator diagram shows that 4.0×10^{-6} pound of fuel has been effectively burned, shows a definite trend of the influence of several engine factors.

1. For a constant start and the same rate of fuel injection up to the point of cut-off a variation in fuel quantity from 1.2×10^{-4} to 4.1×10^{-4} pound per cycle has no appreciable effect on ignition lag.

2. Injection advance angle increases or decreases the ignition lag according to whether density, temperature, or turbulence has the controlling influence.

3. Increase in valve-opening pressure slightly increases the lag.

4. Increase in inlet-air pressure, compression ratio, and engine speed reduces the lag.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., October 19, 1932.

REFERENCES

1. Ware, Marsden: Description of the N.A.C.A. Universal Test Engine and Some Test Results. T.R. No. 250, N.A.C.A., 1927.

2. Gelalles, A. G., and Marsh, E. T.: Rates of Fuel Discharge as Affected by the Design of Fuel-Injection Systems for Internal-Combustion Engines. T.R. No. 433, N.A.C.A., 1932.

3. Gerrish, Harold C., and Voss, Fred: Investigation of the Discharge Rate of a Fuel-Injection System. T.N. No. 373, N.A.C.A., 1931.

4. Spanogle, J. A., and Whitney, E. G.: The Effectiveness of a Double-Stem Injection Valve in Controlling Combustion in a Compression-Ignition Engine. T.N. No. 402, N.A.C.A., 1931.

5. Spanogle, J. A., and Foster, H. H.: Basic Requirements of Fuel-Injection Nozzles for Quiescent Combustion Chambers. T.N. No. 382, N.A.C.A., 1931.

6. Collins, John H., jr.: Alterations and Tests of the "Farnboro" Engine Indicator. T.N. No. 348, N.A.C.A., 1930.

7. Neumann, Kurt: Experiments on Self-Ignition of Liquid Fuels. T.M. No. 391, N.A.C.A., 1926.

8. Dicksee, C. B.: Some Problems Connected with High-Speed Compression-Ignition Engine Development. Jour. Roy. Aero. Soc., Sept., 1932.

9. Lee, Dana W.: The Effect of Nozzle Design and Operating Conditions on the Atomization and Distribution of Fuel Sprays. T.R. No. 425, N.A.C.A., 1932.

10. Mucklow, G. F.: The Effect of Reduced Intake-Air Pressure and of Hydrogen on the Performance of a Solid Injection Oil Engine. The Automobile Engineer, Nov., 1926.

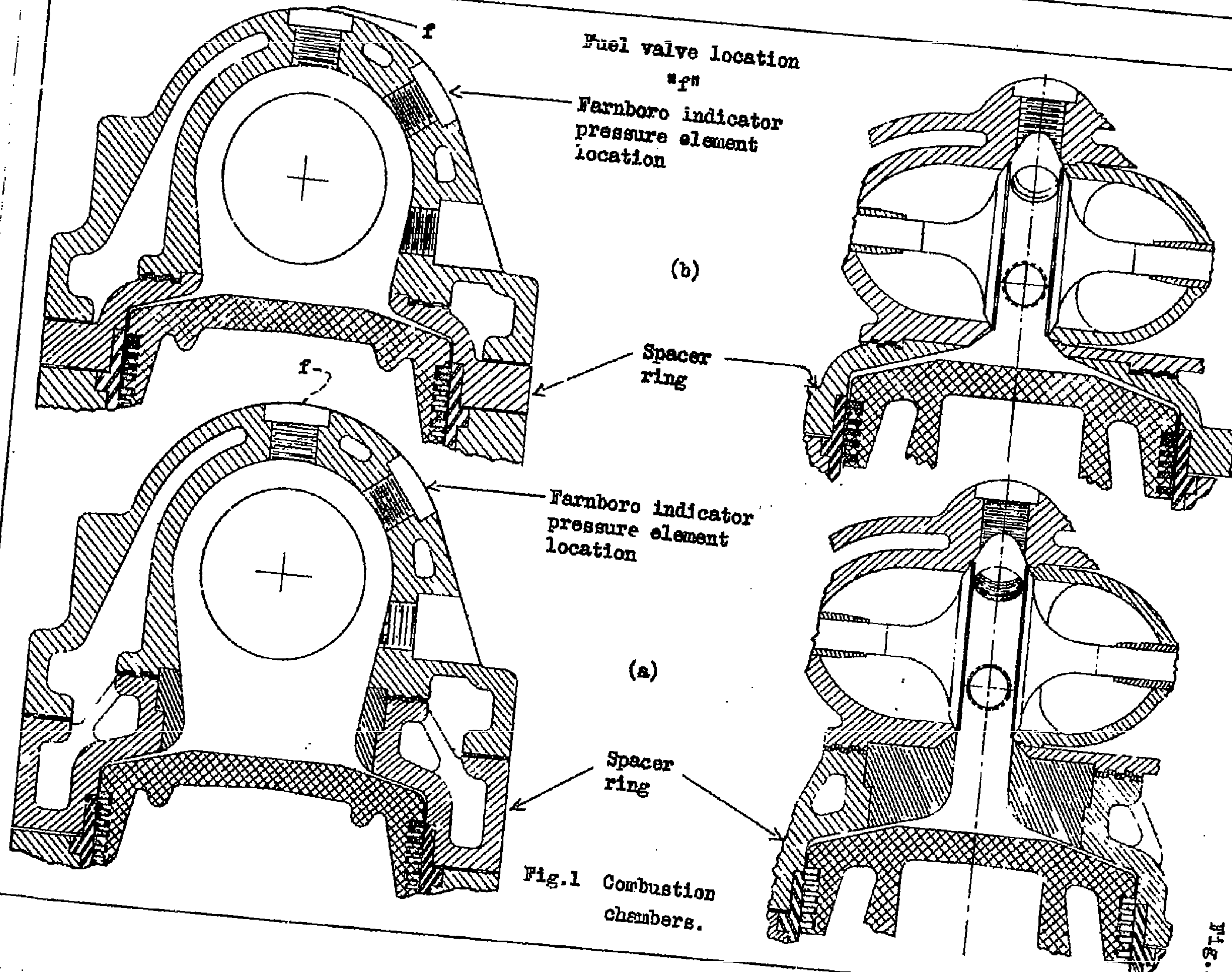

Fig.1 Combustion chambers.

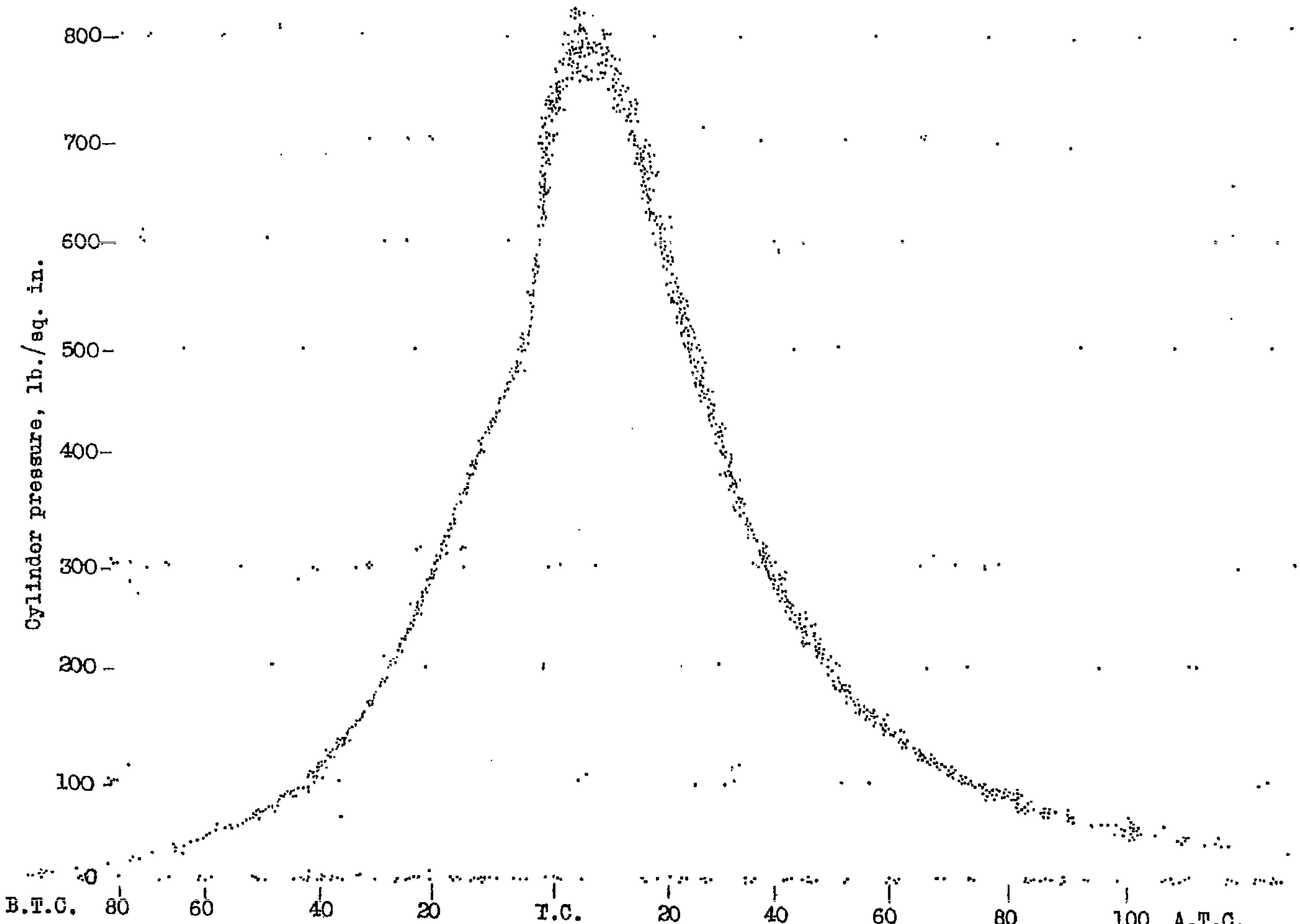

Fig.2 Indicator diagram.

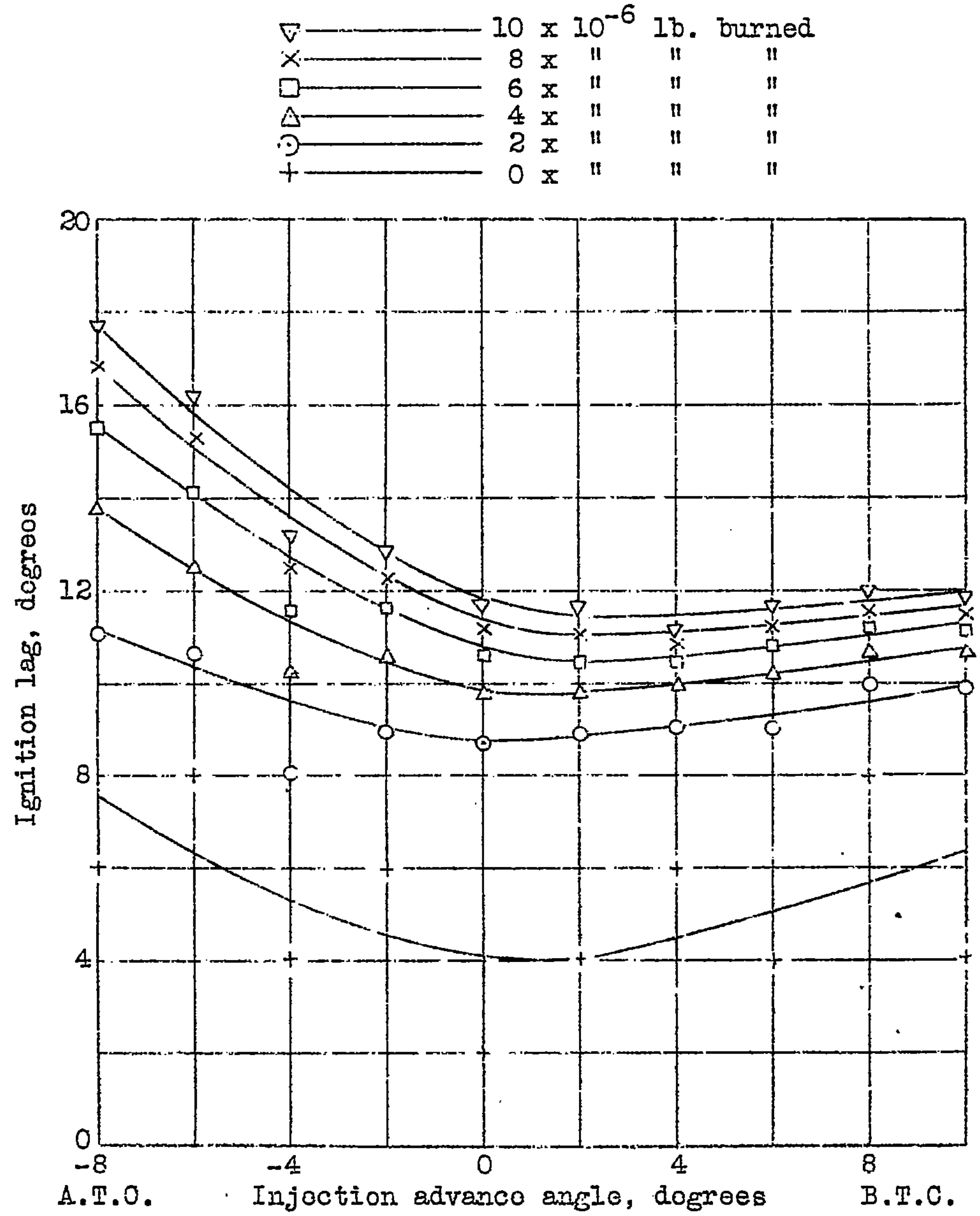

Fig.3 Ignition lag considering different quantities of fuel burned as the start of combustion.

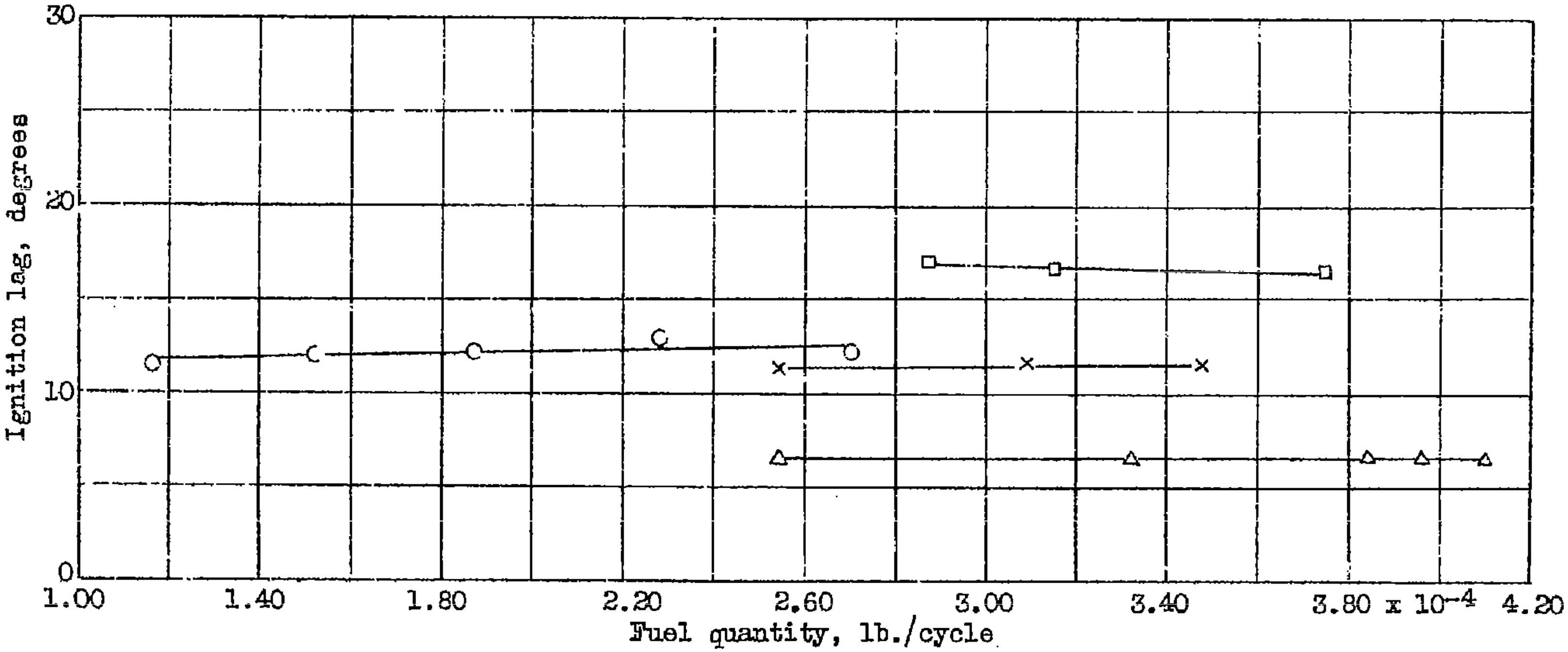

Fig.4 Effect of fuel quantity on ignition lag.

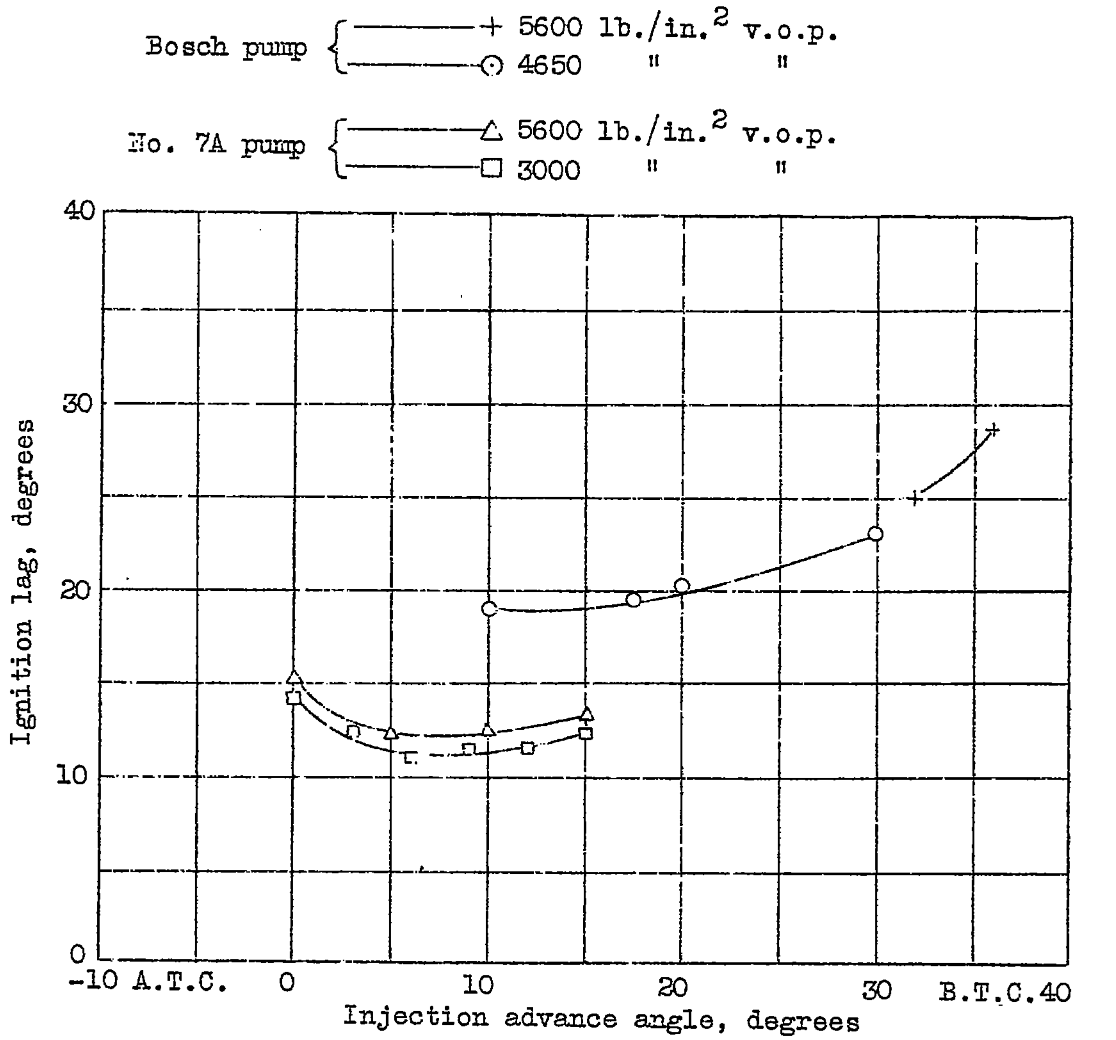

Fig.5 Effect of injection advance angle and valve-opening pressure on ignition lag.

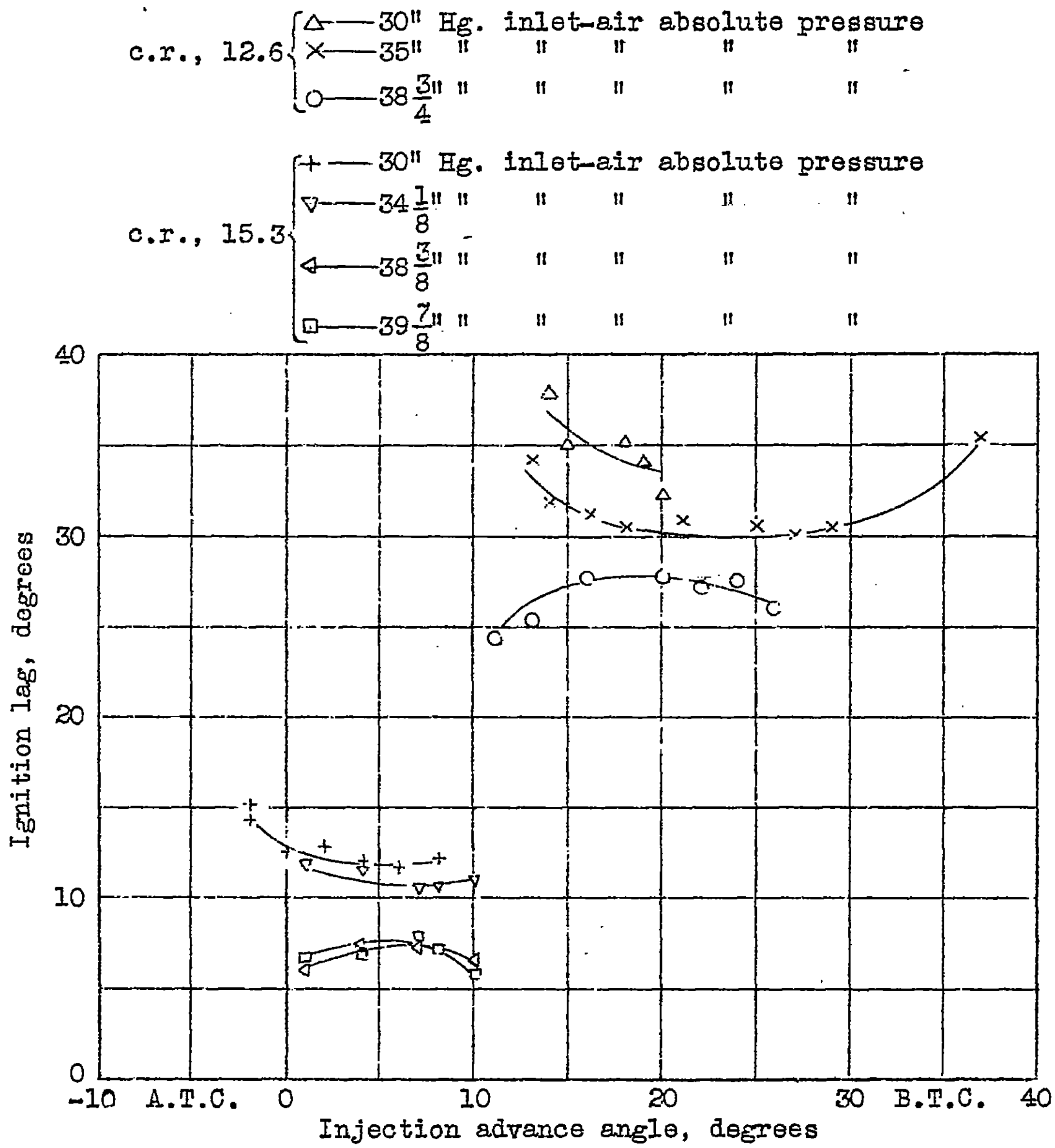

Fig.6 Effect of injection advance angle and inlet-air pressure on ignition lag.

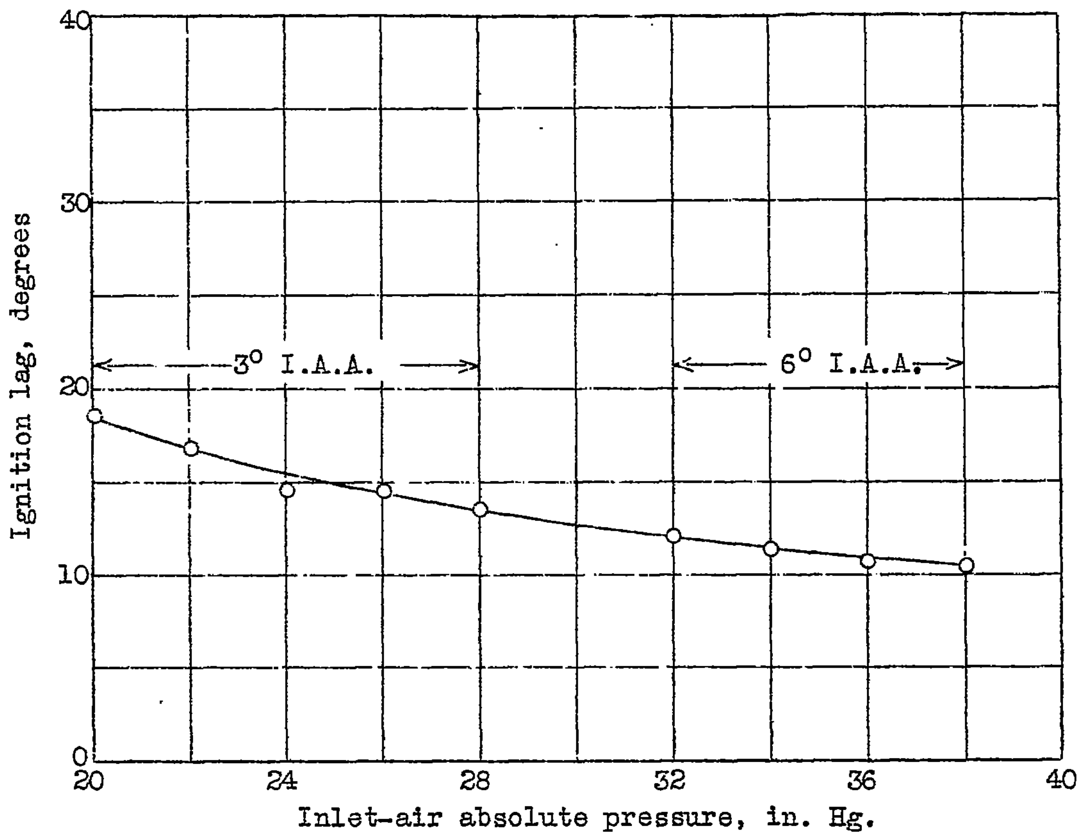

Fig.7 Effect of inlet-air pressure on ignition lag. Compression ratio, 15.3 Fuel quantity 1.96×10^{-4} to 2.33×10^{-4} lb./cycle.

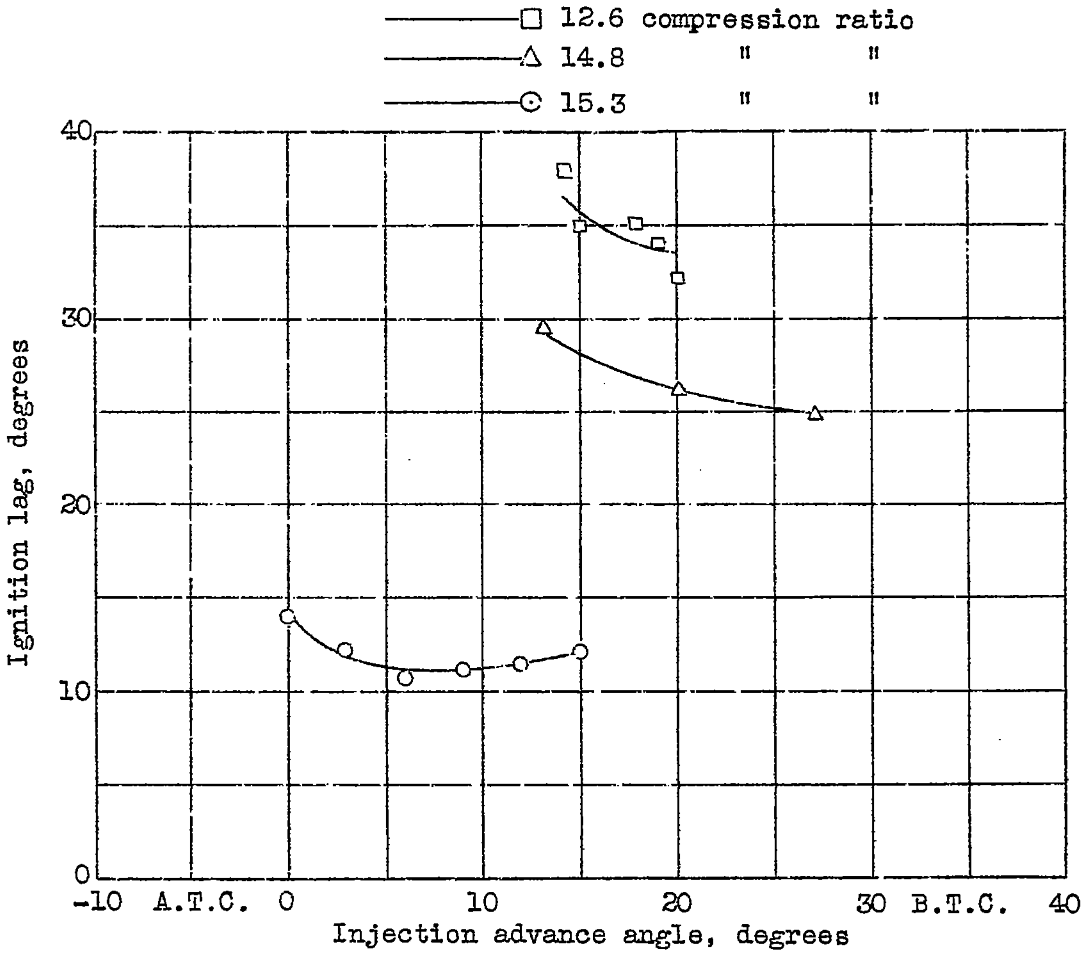

Fig.8 Effect of injection advance angle and compression ratio on ignition lag.

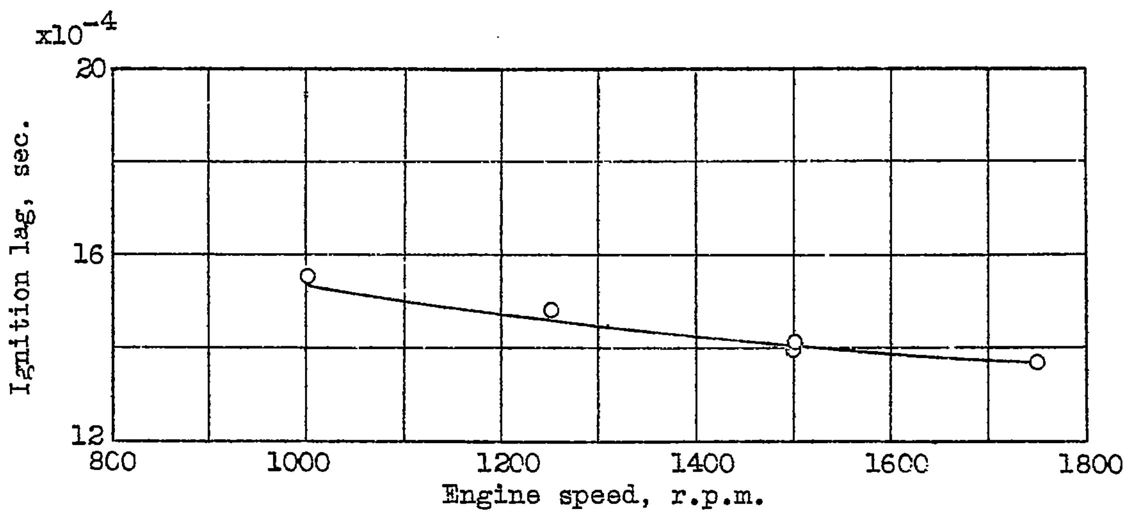

Fig.9 Effect of engine speed on ignition lag.