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MIXTURE DISTRIBUTION IN A SINGLE-ROW RADIAL ENGINE

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SUMMARY

The distribution of the fuel among the various cylinders of a Pratt and Whitney 1340 S1H1-G engine was determined by chemically analyzing samples of exhaust gas from each cylinder. The engine was operated in the 20-foot wind tunnel at different power outputs, specific fuel consumptions, and engine speeds.

The results showed that the variation in the quality of the mixture among the different cylinders was approximately 4 percent and was independent of power output, specific fuel consumption, and engine speed. The results also showed that the top cylinders operated with a lower air-fuel ratio than the bottom cylinders.

INTRODUCTION

The distribution of the fuel among the various cylinders of aircraft engines is receiving considerable attention because of its effect on fuel economy and torsional vibration. The design of the intake system may cause some of the cylinders to receive leaner mixtures than others. Carburetor adjustments made to enrich the lean cylinders will also enrich the normal mixture in the other cylinders and thus increase the fuel consumption of the engine. The variation of power generated in the cylinders also causes variation in torque and therefore engine vibration, which in some cases may be quite serious.

Considerable work has been done by other investigators on mixture distribution. (See references 1 and 2.) Their work covered the determination of the validity of various methods of investigation of mixture distribution, the importance of mixture distribution on fuel consumption, and improvements effected by various designs of manifolds and induction systems.

A direct method of determining the distribution among the various cylinders of a multicylinder engine is to measure the fuel and air entering each cylinder. The inconvenience of such procedure necessitates the adoption of indirect methods, such as noting the variation in engine power when the spark plugs of each cylinder in turn are short-circuited and analyzing indicator cards or the exhaust gases taken from the individual cylinders. Approximate determinations are sometimes made by observing the color of the exhaust flame from each cylinder and by noting the difference in temperature of the cylinder heads. The exhaust-gas method may consist of the use of an instrument that continuously indicates the quality of the mixture in each cylinder or the analysis in the laboratory of samples of exhaust gas taken from each exhaust stack. The laboratory-analysis method was used in the work covered by this paper.

This investigation was made to determine the variation in the quality of the mixture among the cylinders of a multicylinder aircraft engine and the factors that affect the mixture distribution.

APPARATUS AND METHOD

A Pratt and Whitney 1340 S1H1-G aircraft engine was used. The induction system on this engine consists of an air scoop, a carburetor, and a blower operating at 12 times engine speed. From the blower, nine tubes of equal length and diameter carry the carbureted mixture to the cylinders. The exhaust gas from one cylinder is used to heat the carburetor. Figure 1 shows the engine mounted in the 20-foot wind tunnel (reference 3) with the cowling and the controllable propeller removed.

The engine-operating conditions were as follows:

     Power - - - - - - - - 340 to 487 i.hp.

     Fuel consumption - - 0.42 to 0.59 lb./i.hp.-hr.

     Engine speed - - - 1,665 and 1,800 r.p.m.

Army Specification No. Y-3557-G gasoline having an octane rating of 87 was used as fuel for all tests. Calorimetric tests at this laboratory showed that this fuel

had a higher heating value of 19,900 B.t.u.'s per pound. The distillation characteristics of the fuel are shown in figure 2.

The exhaust-gas samples were extracted from each exhaust stack through a 1/4-inch outside-diameter tube. The first 6 feet of this tube were made of steel to withstand the high temperature of the exhaust gases; the remaining 34 feet were made of aluminum so that they could be easily led through the engine nacelle and support to the test chamber. One end of the steel tube was located in the center of the exhaust stack approximately 1 inch from the exhaust valve. The other end of the steel tube was connected to the aluminum tubing by right- and left-hand ferrules. Special care was taken to have all connections tight and no traps in the tubing for the collection of moisture.

The tubes were mounted in the test chamber so that the exhaust gases from each cylinder flowed through spacer tubes into a manifold and then to the outside of the test chamber through suitable piping. The spacer sections of tubing permitted the insertion of the sampling pipettes. A diagrammatic sketch of the set-up is shown in figure 3.

The exhaust-gas samples were collected in evacuated glass-sampling pipettes, each having a volume of approximately 250 cubic centimeters. Twenty-four of the samples were completely analyzed to establish the relation of CO_2, CO, and equivalent fuel wasted to the air-fuel ratio. The equivalent fuel wasted is the fuel equivalent of the unburned combustibles in the exhaust gases. The curves through the test points were located by the method of least squares, assuming the relations to be linear. (See fig. 4.) The equivalent fuel wasted was calculated using the heating values of combustibles given in reference 4. All other samples were analyzed only for CO_2. The CO content, the air-fuel ratio, and the equivalent fuel wasted for these samples were then obtained from figure 4.

The temperatures of the rear spark-plug bosses were determined by thermocouples and recording pyrometers. Holes were drilled in the spark-plug bosses and the thermocouples peened in place. Engine power was determined from brake-horsepower and friction-horsepower curves furnished by the engine manufacturer. The fuel consumption was determined by the use of the N.A.C.A. fuel flowmeters.

RESULTS AND DISCUSSION

Figure 5 shows the partial analysis of exhaust-gas samples taken from a single-cylinder compression-ignition engine through steel and aluminum tubing of the same size but various lengths up to that used in the main tests. These tests were made to determine whether the length of the tube had any effect on the samples. It may be seen that, irrespective of the length of the tubing used, the composition of the exhaust remained unchanged.

The time required to extract samples of the exhaust gases from all nine cylinders of the aircraft engine was approximately 5 minutes. Accordingly, a test was made to determine the constancy of the engine performance during the period of extracting samples. Figure 6 shows the results obtained from two cylinders for periods up to 12 minutes. These results show that this engine can be operated with little variation in the composition of the mixture in the cylinders during the necessary time for extracting the samples.

The distribution characteristics of this engine at various power outputs, specific fuel consumptions, and engine speeds are shown in figures 7 and 8. The curves cover the mixture range within which this engine normally operates. Each curve shows the same trend and indicates that the top cylinders operated with a lower air-fuel ratio than the bottom ones. The leaning of the bottom cylinders irrespective of power output, specific fuel consumption, and engine speed was an interesting result. An examination of the curves shows that the quality of the mixture as measured by the air-fuel ratio generally varies about 4 percent for each condition. These figures also show that, as the air-fuel ratio is increased, the CO_2 content increases and the CO content and the fuel wasted decreases.

Rabezzana and Kalmar (reference 1) analyzed the exhaust gases from each cylinder of a 6-cylinder automobile engine operating over a range of air-fuel ratios from 8 to 18. Their results show that not only is the distribution among the cylinders unaffected by the specific fuel consumption in the rich region, which is in accord with the findings of the subject research, but also that the specific fuel consumption does not affect the distribution for lean mixtures.

Figure 7 shows the results obtained with constant engine speed and constant specific fuel consumption but variable horsepower. These conditions were obtained by varying the throttle, the mixture control, and the propeller pitch setting. As would be expected, the curves show that the air-fuel ratio had to be decreased with increase in the power output for the power range investigated to maintain the desired specific fuel consumption. The effect of maintaining a constant specific fuel consumption with increase of power output on the hazard of CO poisoning is shown by the large increase in the CO content. Although the specific fuel consumption was maintained constant, the combustibles in the exhaust increased approximately 25 percent as shown by the curves of equivalent fuel wasted.

Figure 8(a) shows the results obtained from three conditions of constant power output and engine speed but variable specific fuel consumption. Increasing the specific fuel consumption decreased the CO_2 content and the air-fuel ratio but increased the CO and the percentage of fuel wasted. The bottom cylinders also showed the leanest mixture. The results of figure 8(b) were obtained for four conditions at a different power output and engine speed.

Figure 9 is a plot of the air-fuel ratios given in figure 8(b) and shows that the specific fuel consumption decreases with increase in the air-fuel ratio. These curves may be used to estimate the mixture strength in the various cylinders for the fuel-consumption range investigated. Other engine conditions may cause an appreciable change in the location of the curve.

Figure 10 shows the temperature of the rear spark-plug boss taken during the four variable-fuel-consumption runs shown in figure 8(b). These curves indicate that the temperature of each cylinder increases with the leaning of the mixture in that cylinder. The relation of temperature and mixture strength, however, varies from cylinder to cylinder. Cylinder 5 shows the leanest mixture but not the maximum temperature recorded during these runs. Cylinder 9, which has very nearly the same air-fuel ratio for the different specific fuel consumptions as the adjacent cylinder 1, has considerably lower temperatures. On the other hand, the relation between temperature and mixture strength is practically the same for cylinders 1, 3, and 7. It is concluded that, for the range of air-fuel ratios cov-

ered in this investigation, the temperature of the rear spark-plug boss is not a good indicator of the mixture strength in the cylinder.

CONCLUSIONS

The results of the investigation on a Pratt and Whitney 1340 S1H1-G engine showed that:

1. The variation in the quality of the mixture, as measured by the air-fuel ratio, among the different cylinders was independent of the power output, specific fuel consumption, and engine speed.

2. The variation in the quality of the mixture among the different cylinders was approximately 4 percent.

3. The quality of the mixture was richer in the top cylinders than in the bottom ones.

4. For a range of air-fuel ratios from 10 to 13, the temperature of the rear spark-plug boss was not a good indicator of the quality of the mixture in the cylinder.

Langley Memorial Aeronautical Laboratory,
        National Advisory Committee for Aeronautics,
            Langley Field, Va., September 15, 1936.

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       tribution in Cylinder Studied by Measuring Spark
       Plug Temperature. Auto. Ind., vol. 66, no. 12,
       March 19, 1932, pp. 450-454; and vol. 66, no. 13,
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       Tables, vol. V. McGraw-Hill Book Co., Inc., 1929,
       pp. 177-181.
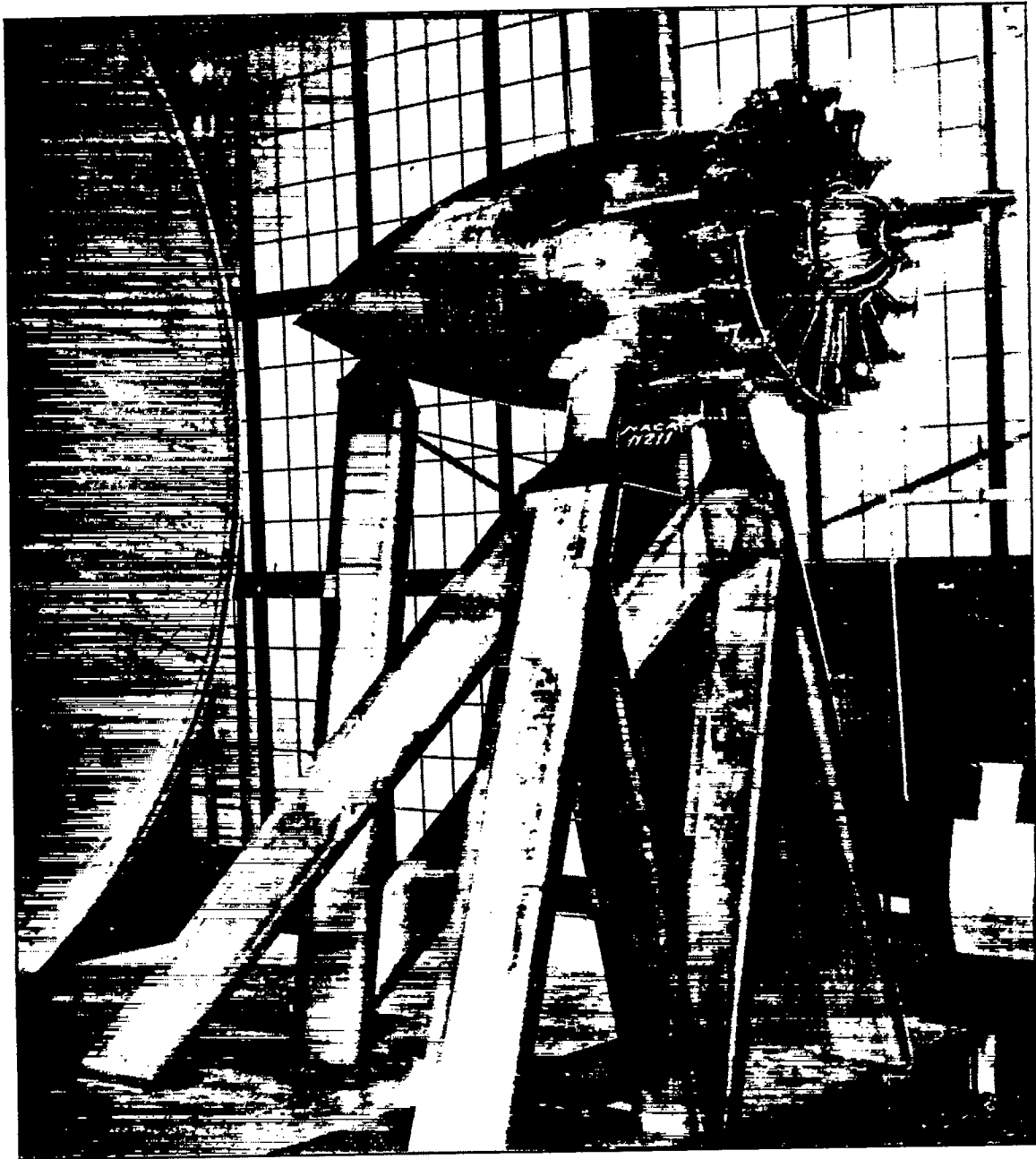
Figure 1.- Engine mounted in a 20-foot wind tunnel.
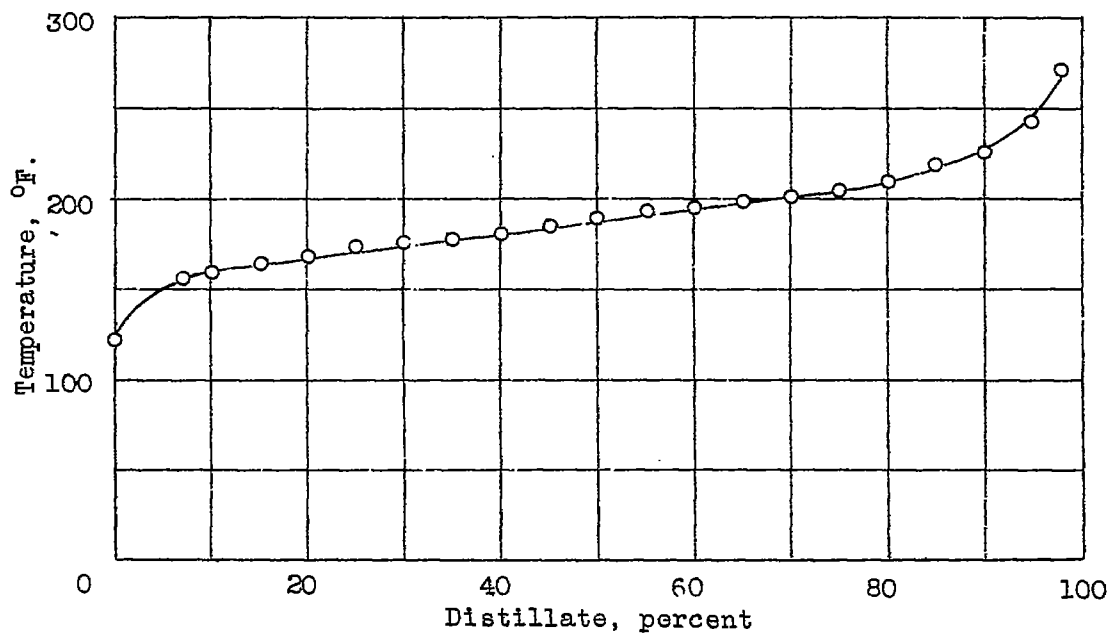
Figure 2.- Distillation curve (A.S.T.M.) for gasoline. Army specifica-
        tion No. Y-3557-G.

Fig. 3

Manometer

Pipettes

To atmosphere

Vacuum pump
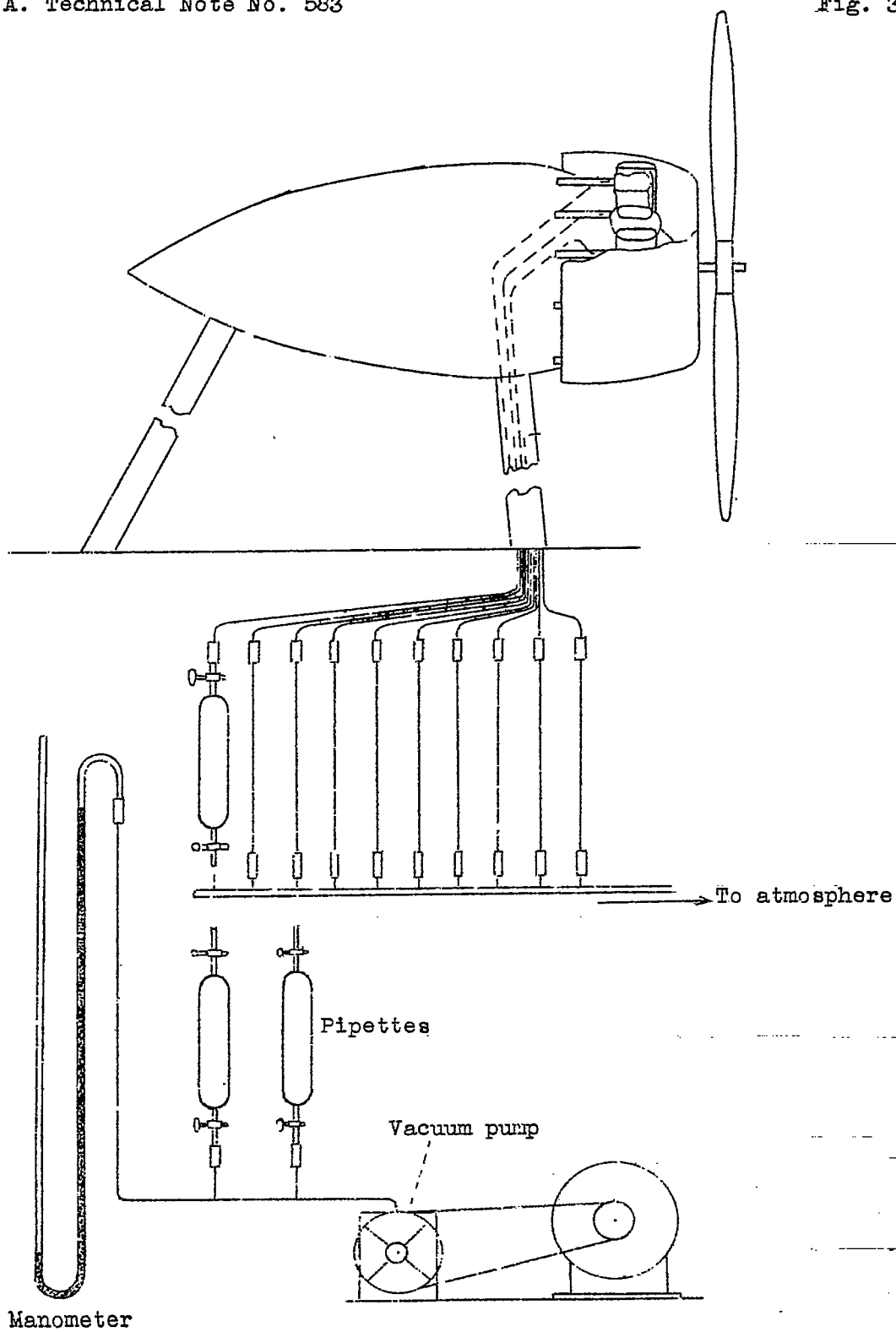
Figure 3.- Set-up of apparatus.
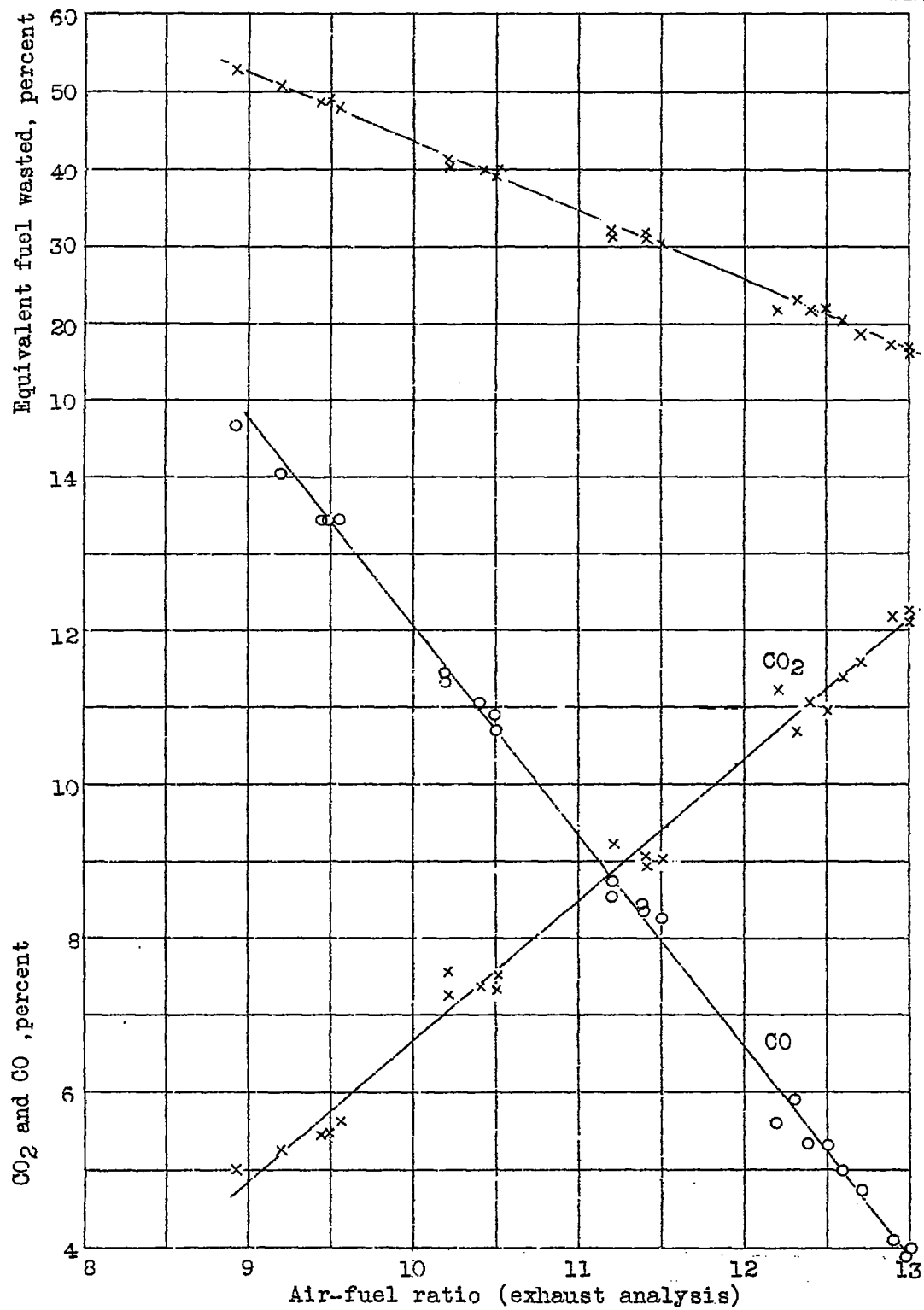
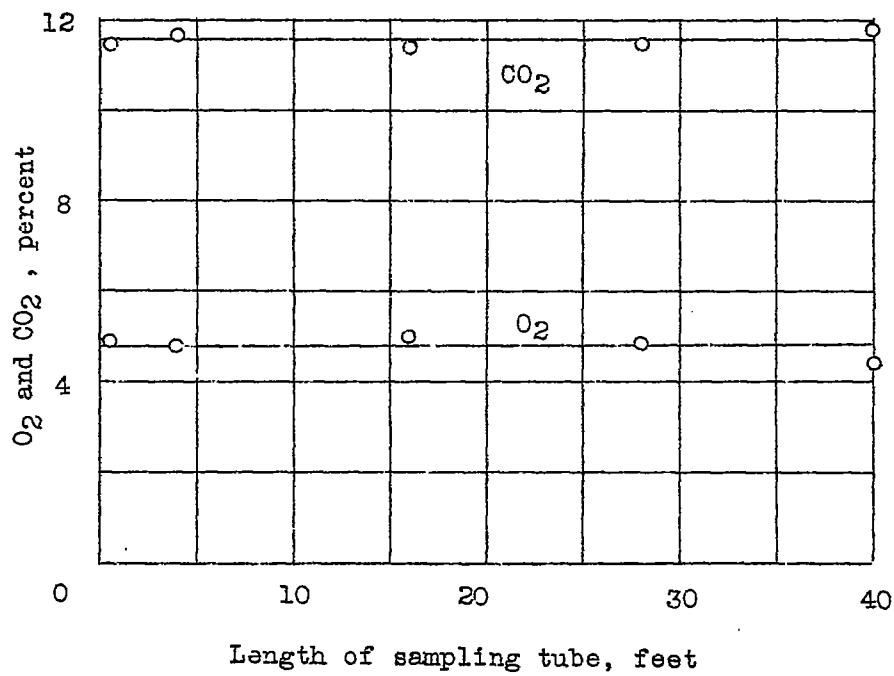Figure 4.- Relation of CO , CO$_2$, and equivalent fuel wasted to air-fuel ratio.

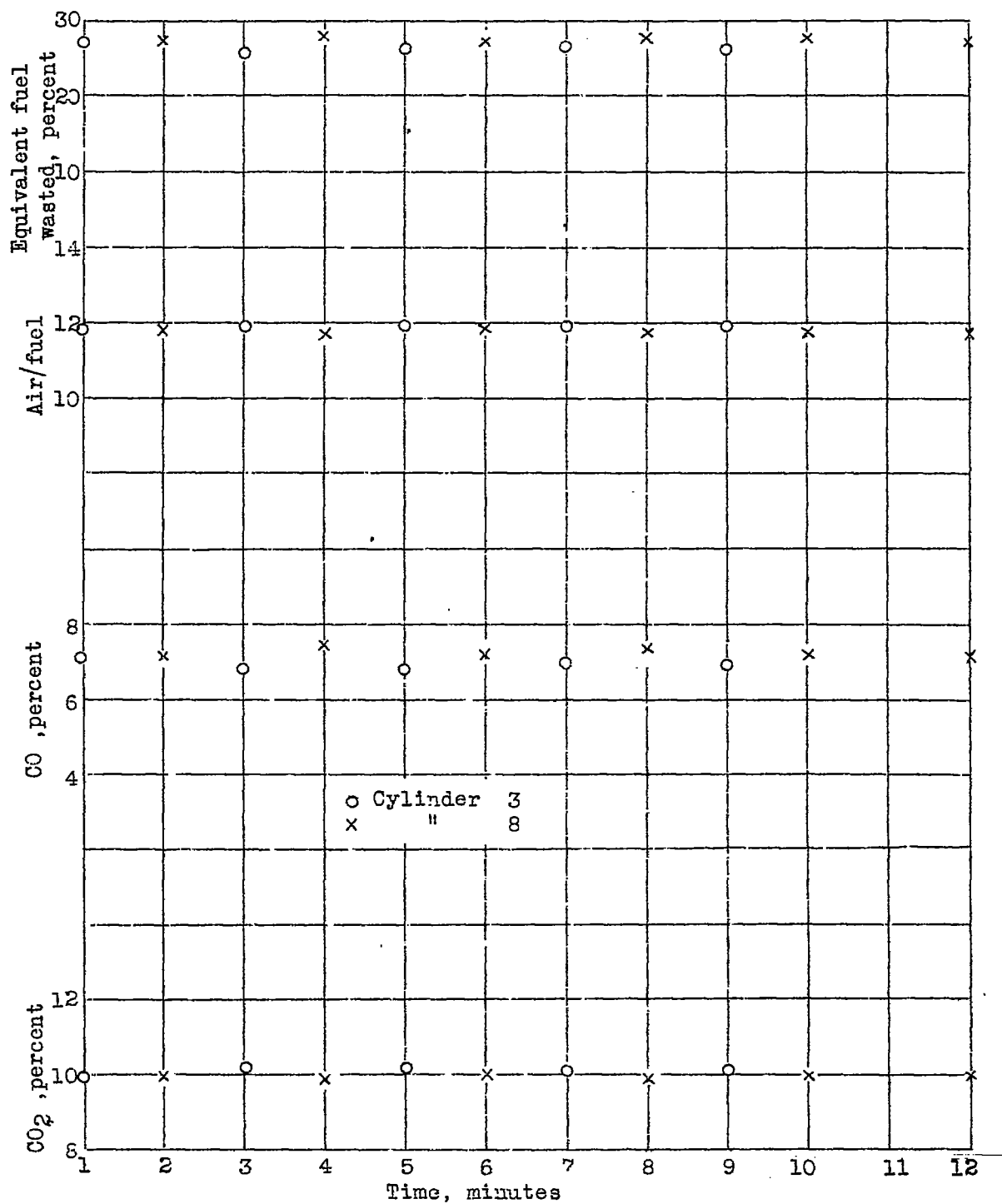Figure 5.- Effect of sampling-tube length on exhaust-
gas samples.

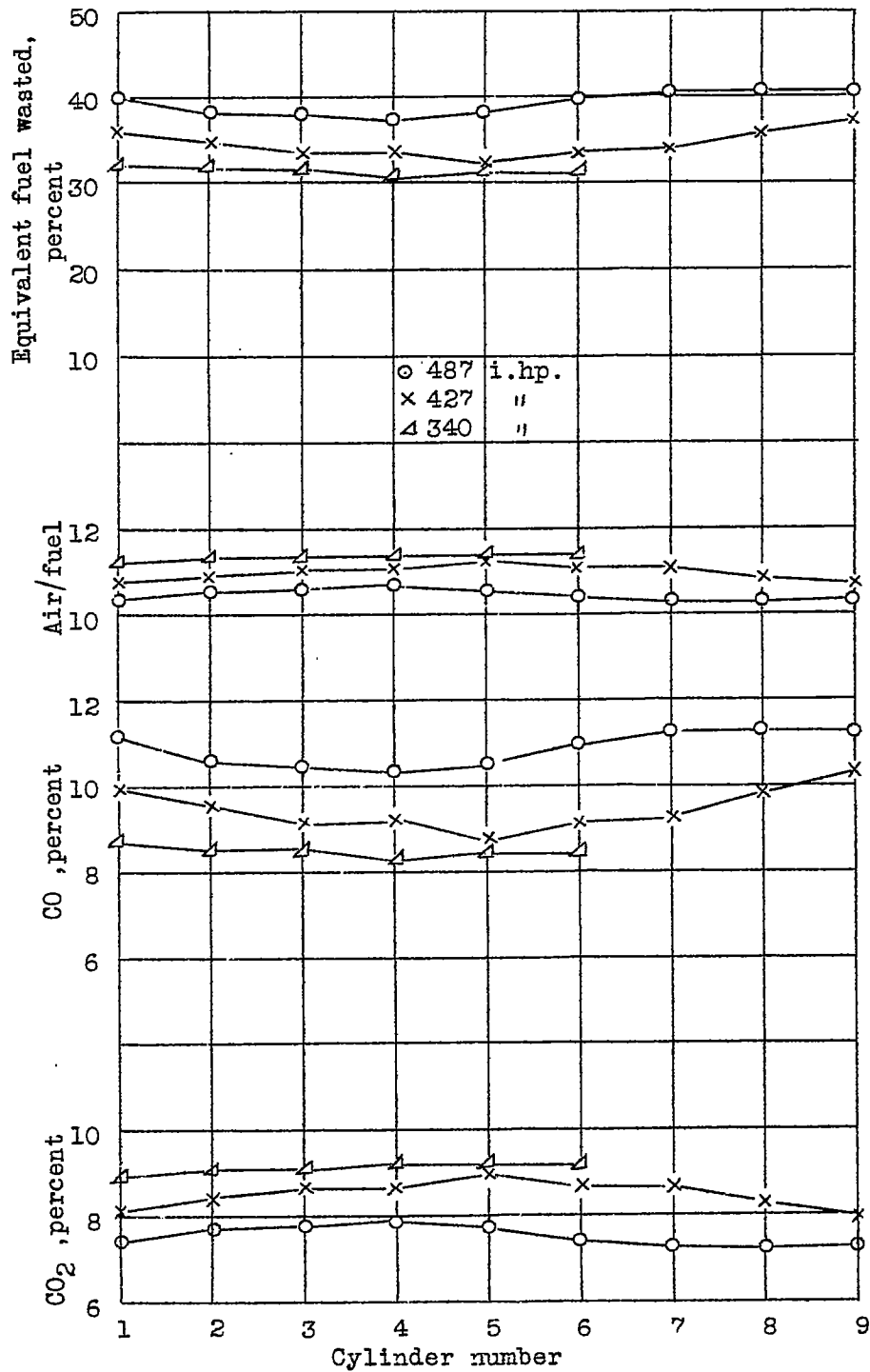Figure 6.- Constancy of exhaust-gas samples.(1,800 r.p.m., 429 i.hp.,
        0.485 lb./i.hp.-hr.)

Fig. 7

Figure 7.— Effect of engine power on distribution.
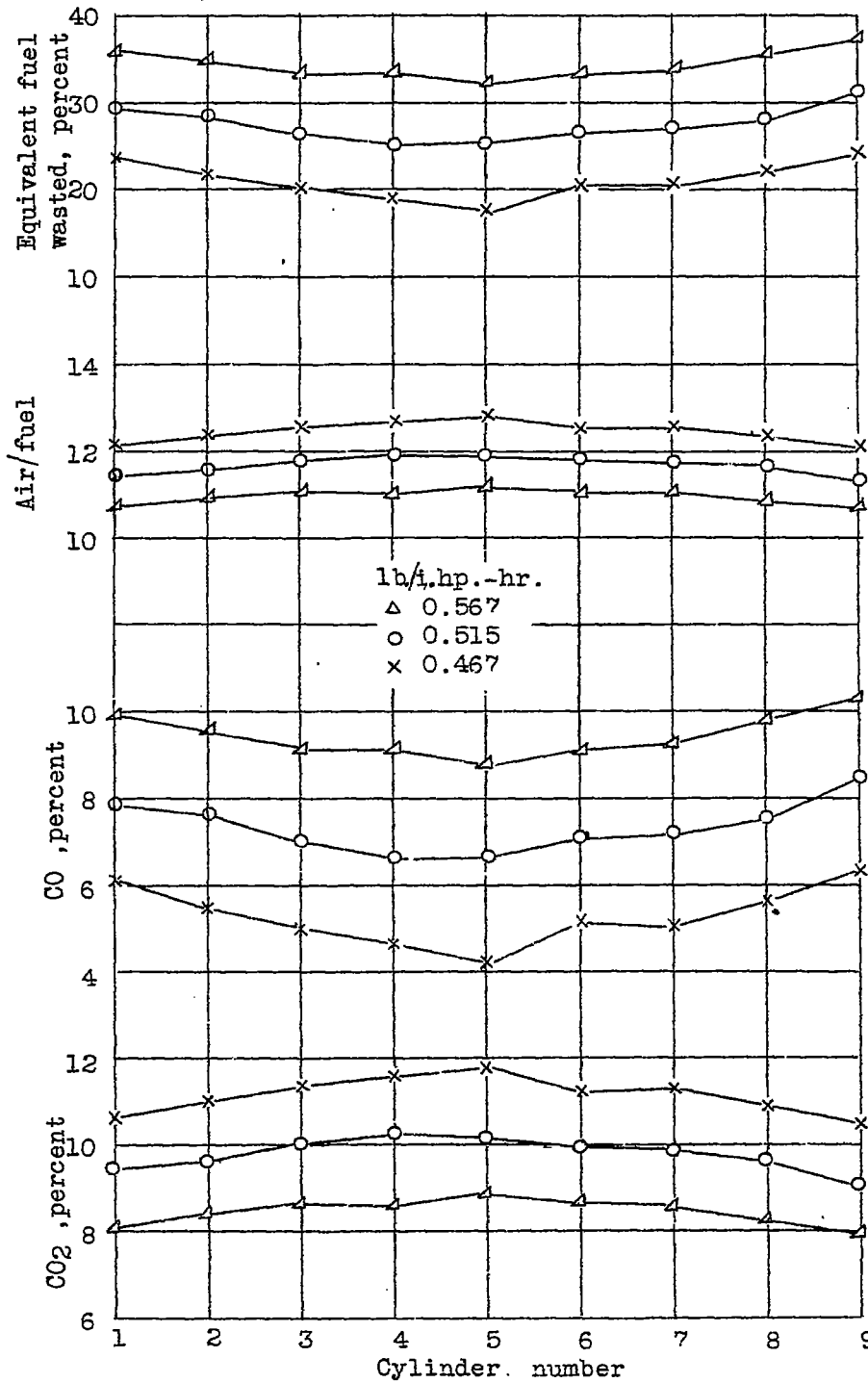(1,800 r.p.m., 0.55 to 0.58 lb./i.hp.-hr.)

Figure 8(a).- Effect of specific fuel consumption on distribution.
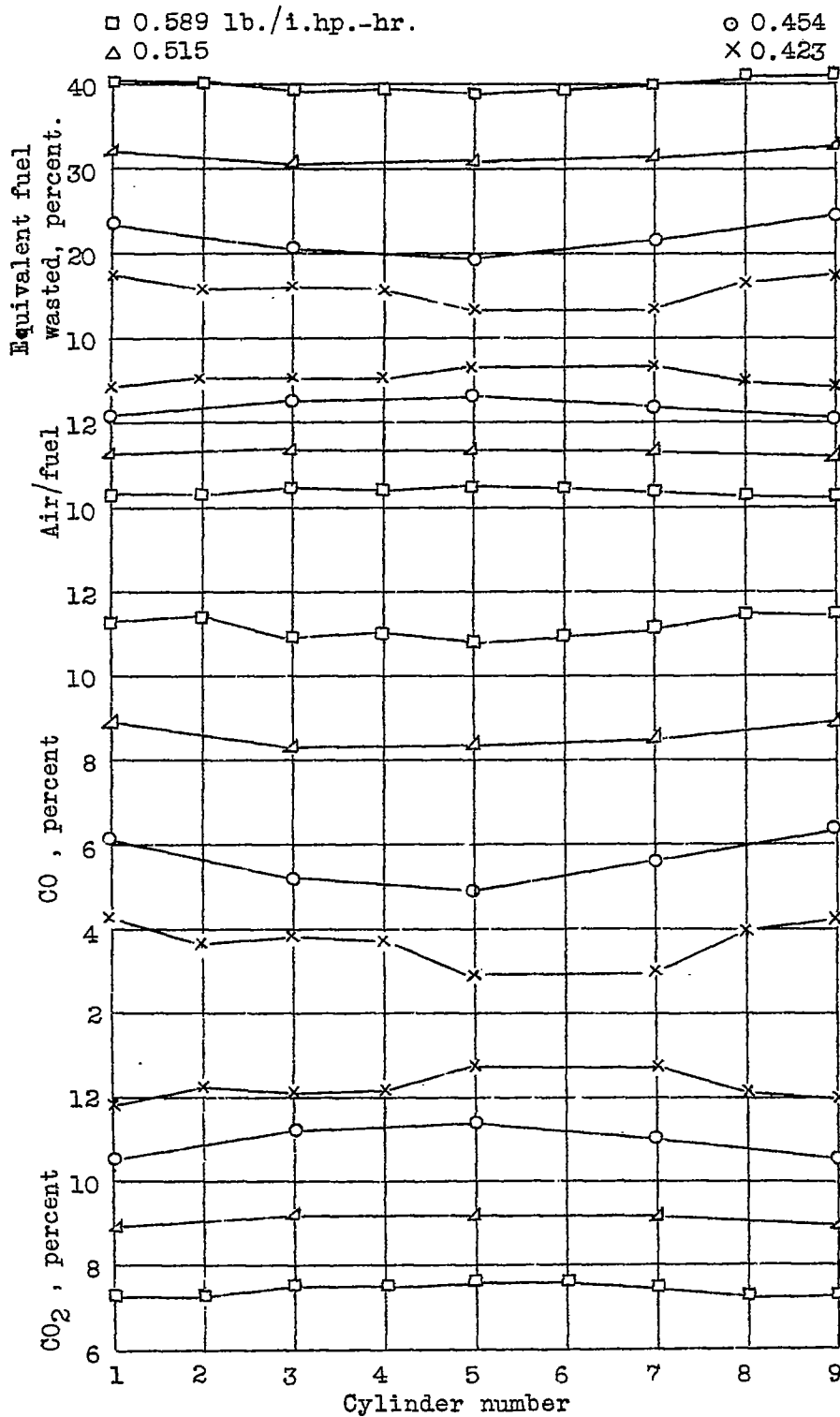(1,800 r.p.m., 422 to 429 i.hp.)

Fig. 8(b)

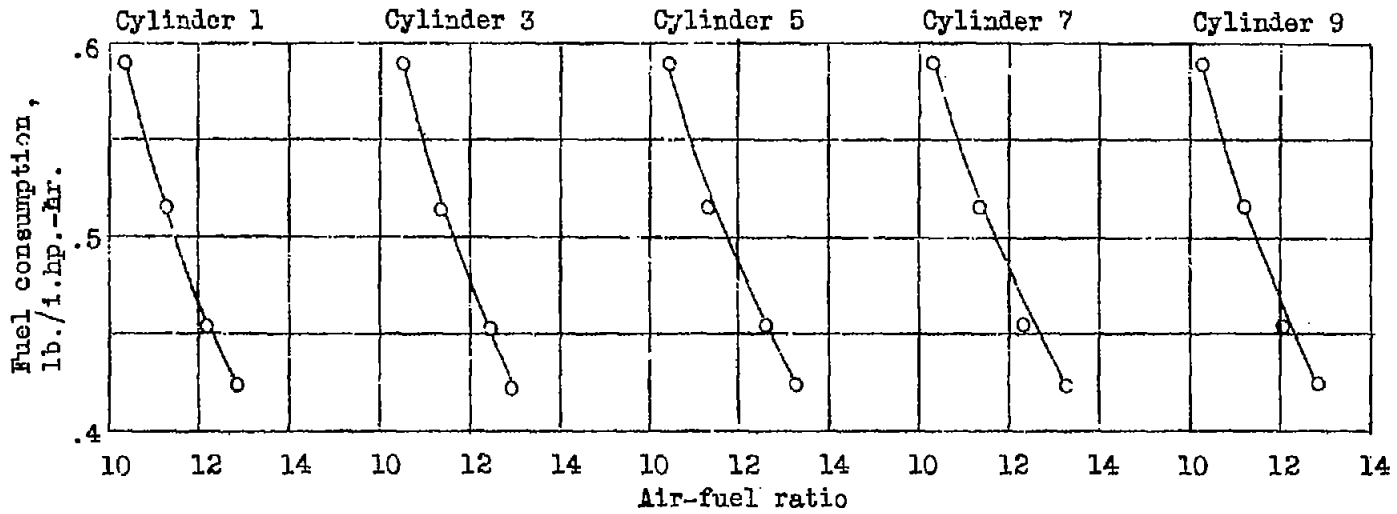Figure 8(b).- Effect of specific fuel consumption on distribution.
(1,665 r.p.m., 457 i.hp.)

Cylinder 1   Cylinder 3   Cylinder 5   Cylinder 7   Cylinder 9

Figure 9.- Effect of air-fuel ratio on specific fuel consumption.
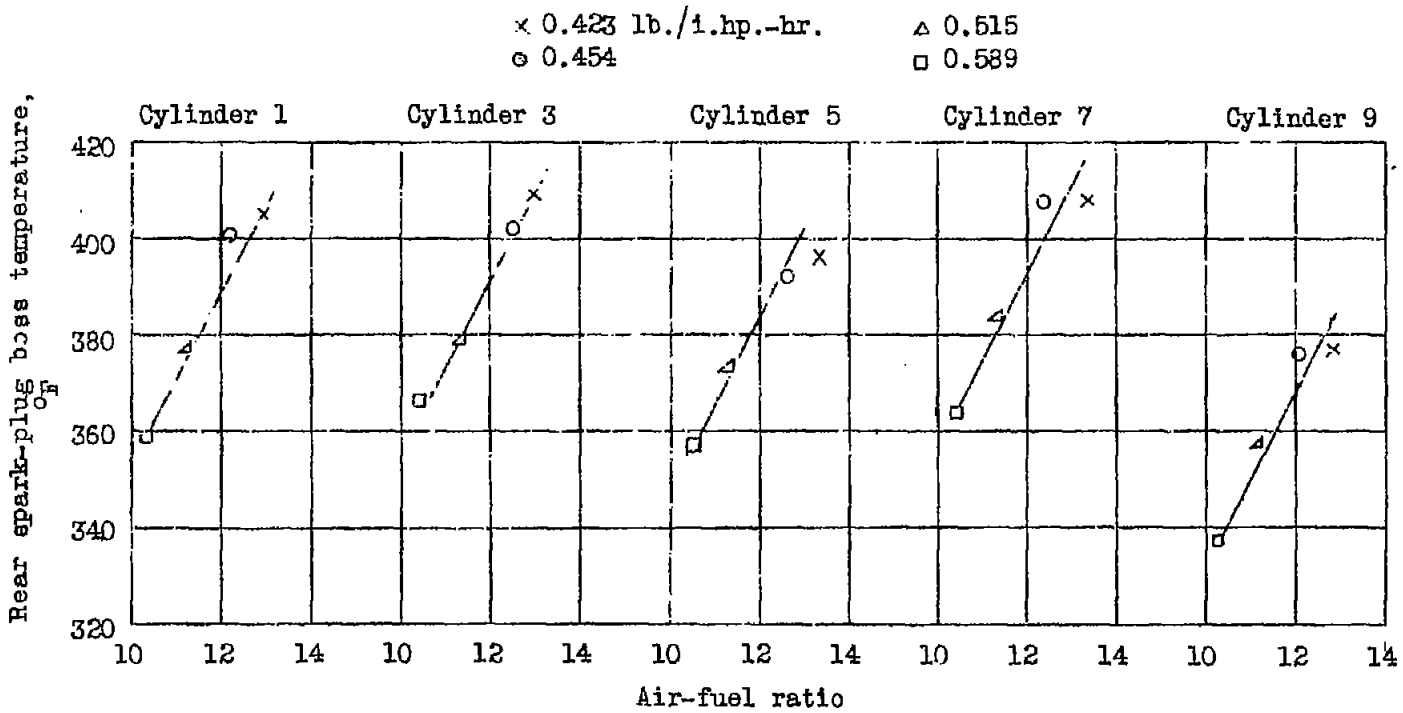(457 i. hp., 1,665 r.p.m.)

Fig. 9

Fig. 10

Figure 10.- Effect of air-fuel ratio on rear spark-plug-boss temperature.
(1,665 r.p.m., 457 i. hp.)