

DEMONSTRATING ASPECTS  
OF SMALL ENGINE OPERATION

A PROJECT REPORT  
SUBMITTED IN PARTIAL FULFILLMENT  
OF THE REQUIREMENTS FOR  
SENIOR HONORS PROJECT

by  
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I recommend this project for acceptance by the Honors Program of Ball State University for graduation with honors.

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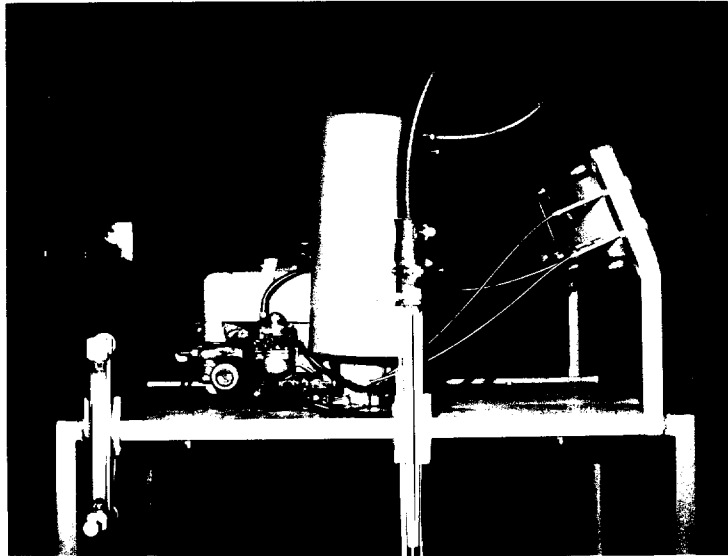
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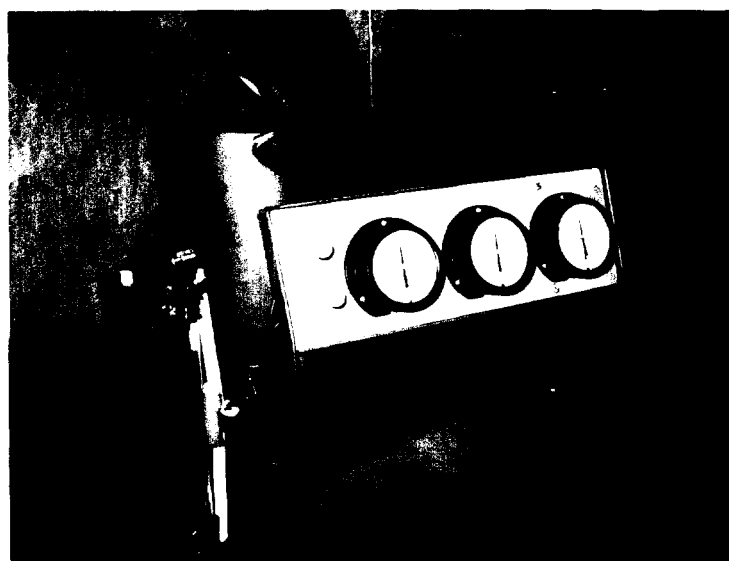
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## THE PROJECT



Engine mounted on test stand showing air intake pressure connections, fuel and air flow rotameters, and surge tank.



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Engine mounted on test stand showing the compound gauges used for measuring pressures in the air induction system.

## STATEMENT OF THE PROJECT

Although the various operating conditions of a small gasoline engine are easily discussed, they are not so easily demonstrable. The teaching aid to be constructed will be used to demonstrate the relationships between throttle-controlled engine speed, fuel and air flow, volumetric efficiency, combustion efficiency, fuel-air ratio, exhaust system temperature, and pressure conditions existing in the air induction system at various choke positions of a four cycle single cylinder engine.

A review of literature related to reciprocating internal combustion engines reveals a lack of information dealing with the relationship between throttle-controlled engine speed and the above listed factors of engine operation--especially for small gasoline engines. The project presented in this paper was designed to help fill in some of these information gaps by providing a vehicle, in the form of a four cycle small gasoline engine, for demonstrating these relationships and ascertaining information for graphic illustration of the various operating aspects of a particular engine under the conditions which follow.

## BACKGROUND INFORMATION

Although published information dealing with the various aspects of small engine operation under the conditions and in the manner with which they were dealt in this project is lacking, some information deemed helpful in defining the aspects measured and determining the validity of the results is summarized in the following paragraphs.

Obert discusses means of measuring fuel and air flow, including the use of a surge tank, for internal combustion engines<sup>1</sup> and gives an air consumption curve for a six cylinder four-stroke-cycle engine at wide open throttle.<sup>2</sup> An adapted version of the curve is reproduced in Figure I. It can be seen from Figure I that air consumption increases to a theoretical maximum at about 4500 RPM for this particular engine and then begins to drop.

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<sup>1</sup>Edward F. Obert, Internal Combustion Engines, pp. 36-38.

<sup>2</sup>Ibid., p. 437.

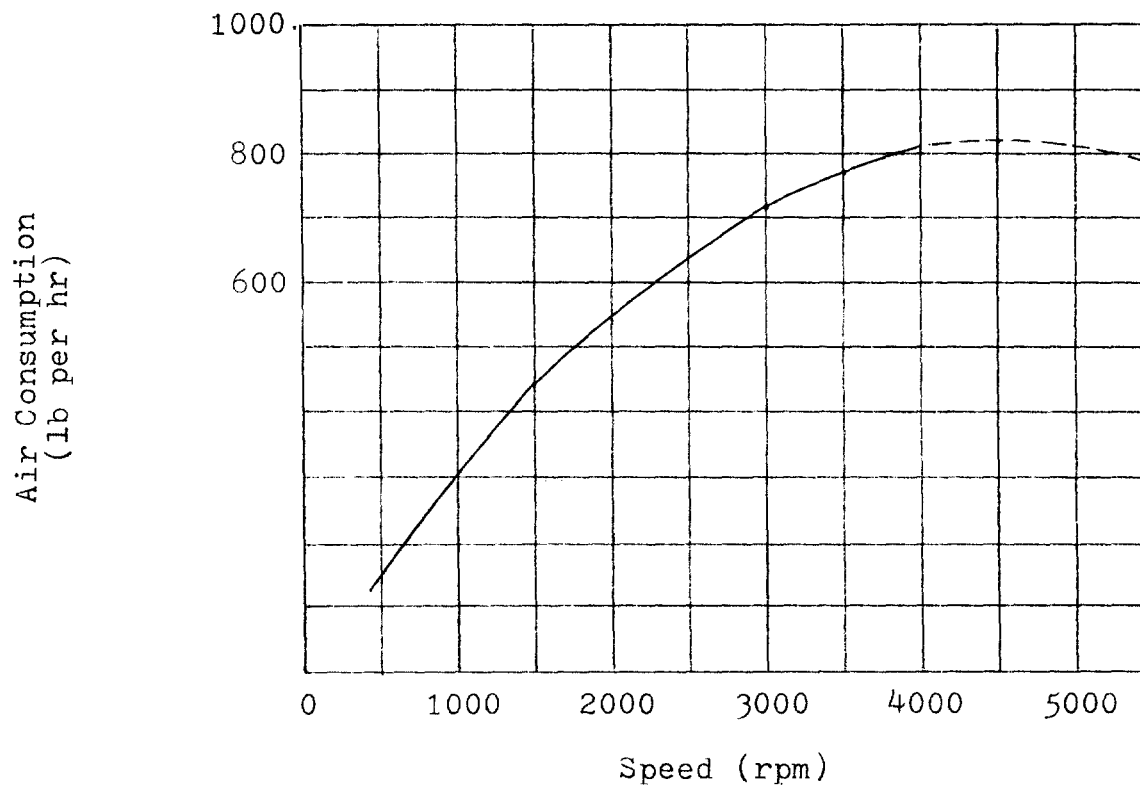


Figure I. - Air Consumption in Relation to Engine Speed

A fuel consumption curve for an eight cylinder engine is also given.<sup>1</sup> An adapted version of the curve is reproduced in Figure II. Fuel consumption for this engine increases almost linearly up to 2500 RPM and then continues to increase at a lesser rate.

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<sup>1</sup>Ibid., p. 458.

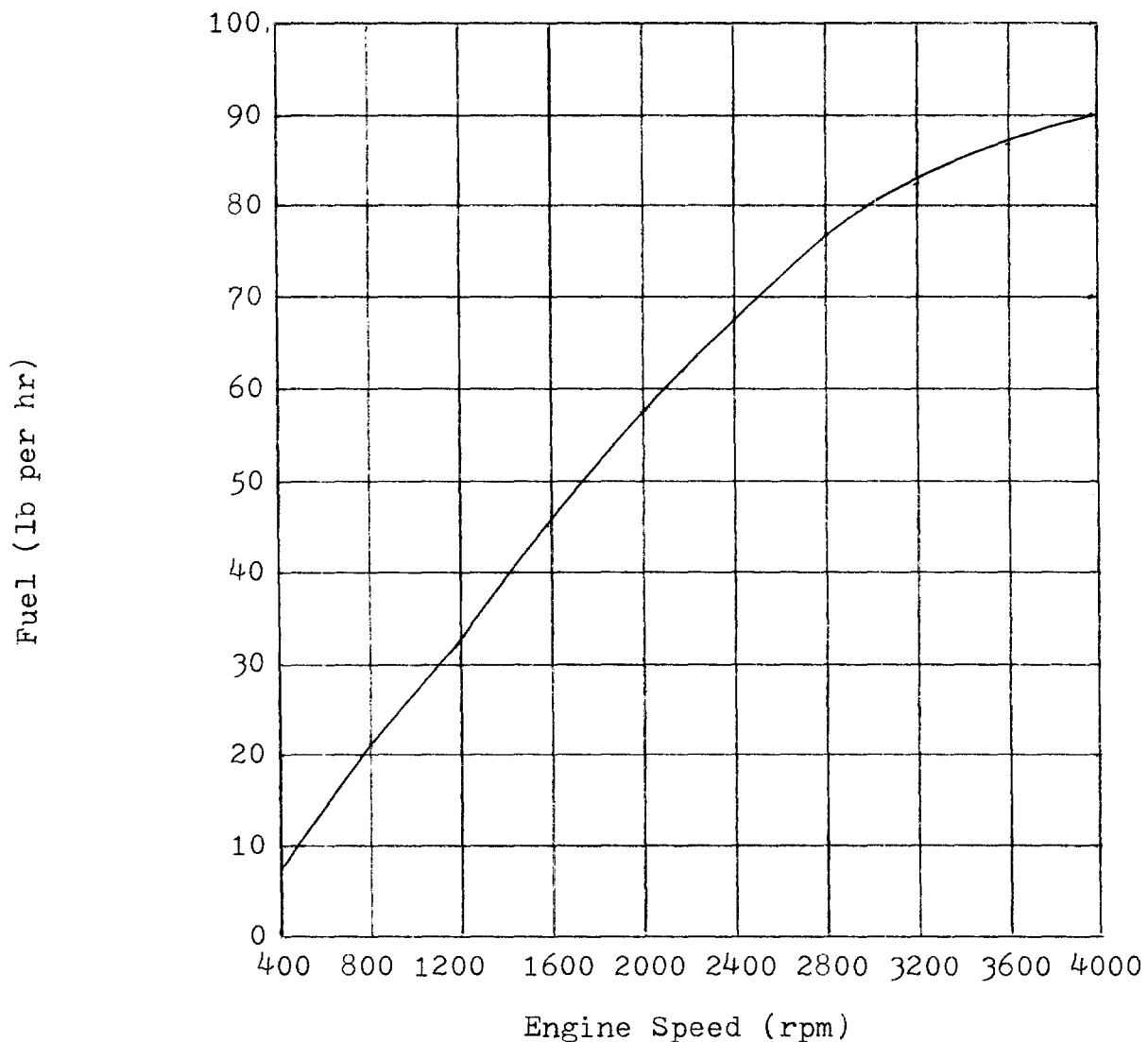


Figure II. - Fuel Consumption in Relation to Engine Speed

Crouse defines volumetric efficiency as the ratio between the amount of air-fuel mixture that actually enters the cylinder and the amount that could enter under ideal conditions, but uses the weight of air in ounces entering the cylinder during each intake stroke divided by the weight in ounces of air of the piston displacement to determine volumetric efficiency in an example. Crouse gives eighty

percent as a good volumetric efficiency for an engine running at fairly high speed, with some engines falling to fifty percent at high speeds.<sup>1</sup> Stockel defines volumetric efficiency as the total volume of the charge divided by the total cylinder volume (displacement). Stockel points out that volumetric efficiency is affected by engine speed, temperature, throttle position, intake system design, atmospheric pressure, etc., which he follows with an approximate graph of volumetric efficiency for an engine at various speeds. This graph is reproduced in Figure III.<sup>2</sup>

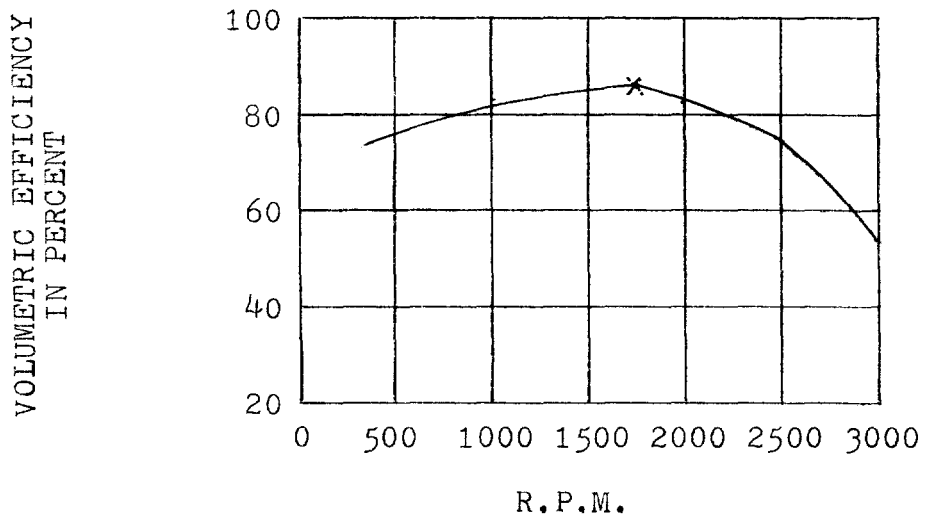


Figure III. - Volumetric Efficiency in Relation to Engine Speed

It can be seen in Figure III that volumetric efficiency decreases markedly at high RPM. The cross marks the point of highest volumetric efficiency.

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<sup>1</sup>William H. Crouse, Automotive Mechanics, p. 72.

<sup>2</sup>Martin W. Stockel, Auto Mechanics Fundamentals, p. 8-5.

Obert defines volumetric efficiency as the weight of air in pounds inducted per intake stroke divided by the theoretical weight of air in pounds to fill engine displacement volume under atmospheric pressure.<sup>1</sup>

The Sun Tune-Up Handbook gives desirable combustion efficiencies for various automobile engine speeds--these are listed in TABLE 1.<sup>2</sup>

TABLE 1

DESIRABLE COMBUSTION EFFICIENCIES FOR  
VARIOUS AUTOMOBILE SPEEDS

| RPM  | Combustion Efficiency |
|------|-----------------------|
| idle | 72% to 76%            |
| 800  |                       |
| 1000 | 78% to 82%            |
| 1200 |                       |
| 1500 |                       |
| 1800 |                       |
| 2000 | 84% to 88%            |
| 2200 |                       |

These combustion efficiencies are given over a relatively low speed range. The combustion efficiency increases twelve percent over the given range.

Obert defines the fuel-air ratio as pounds of fuel per time  $t$  divided by pounds of air per time  $t$ .<sup>3</sup>

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<sup>1</sup>Obert, Engines, p. 43.

<sup>2</sup>Sun Electric Corporation, pp. 46-47.

<sup>3</sup>Obert, op. cit.

The Small Engines Service Manual gives approximate fuel-air mixture ratio requirements for different operating conditions which are reproduced in TABLE 2.<sup>1</sup>

TABLE 2

FUEL-AIR MIXTURE RATIO REQUIREMENTS FOR  
DIFFERENT ENGINE OPERATING CONDITIONS

|                          | Fuel (lb.) | Air (lbs.) |
|--------------------------|------------|------------|
| Starting, cold weather   | 1          | 7          |
| Accelerating             | 1          | 9          |
| Idling (no load)         | 1          | 11         |
| Part open throttle       | 1          | 15         |
| Full load, open throttle | 1          | 13         |

Notice that the fuel-air ratio becomes leaner up to full load, open throttle.

Crouse's graph of the fuel-air ratio requirements of an automobile engine at different car speeds is given in Figure IV.<sup>2</sup> This graph provides a curve for fuel-air ratio requirements. Notice that the data given in Figure IV, though slightly different, is very similar to that in TABLE 2.

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<sup>1</sup>Kenneth F. Long, editorial director, p. 5.

<sup>2</sup>Crouse, Mechanics, p. 151.

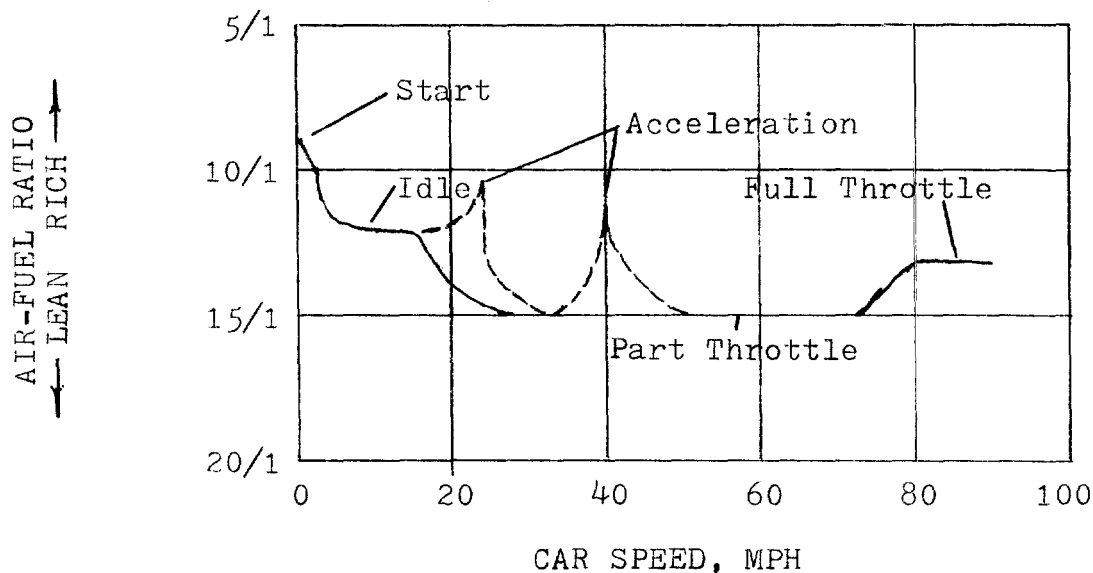


Figure VI. - Fuel-Air Ratio in Relation to Car Speed

Stockel states that the burning fuel mixture in an engine can reach a temperature of 4000 degrees Fahrenheit and normally is 2000 degrees Fahrenheit.<sup>1</sup> Kuns states that forty percent to thirty percent of the total heat given off by the liquid fuel goes to the exhaust system.<sup>2</sup>

The Small Engines Service Manual contains an illustration of typical vacuum conditions in the carburetor of a small engine operating at full throttle: two inches of mercury just prior to the venturi; six inches of mercury in the venturi; and four inches of mercury just after the venturi.

<sup>1</sup>Stockel, Mechanics, p. 4-2.

<sup>2</sup>Ray F. Kuns and Jack T. Duvall, Automotive Essentials, p. 133.

<sup>3</sup>Long, p. 5.

## DESCRIPTION

### METHOD

The engine used was a Briggs & Stratton Model Number 8B H Type Number 904046 Serial Number 23102. This is a single cylinder, four-cycle, L-Head engine with 7.75 cubic inches displacement, ignition timing ten degrees before TDC, and capable of developing two and three-quarters horsepower at 3600 RPM.

Revolutions per minute were measured using the tachometer on the Sun 77 Small Engine Tester.

Investigation proved that the most practical method of measuring fuel and air flow rates was the use of rotameters in the fuel line and air path.

The specific gravity of common regular gasoline at STP is .738; its kinematic viscosity at STP is ten centistokes. The operating temperature and pressure of the fuel was assumed to be STP and a maximum fuel flow rate of one cubic centimeter per minute was assumed to use with manufacturer's details and sizing curve to specify a rotameter with a maximum flow capacity of .165 pounds of fuel per hour.

Selected was a SK Instruments 20-7050V 1/8-15-G-5 purge rotameter with a black glass float, five inch scale of one hundred equal divisions, and an accuracy of plus or minus two percent of the full scale.

To estimate an air flow rate, the engine was assumed to have an eighty-five percent volumetric efficiency with a speed range of 0-4000 RPM. At maximum speed this would yield a maximum air flow rate equal to:

$$\frac{\text{displacement (cubic inches)} \times \text{maximum RPM} \times \text{volumetric efficiency}}{1728 \text{ cubic inches per cubic foot}}$$

or

$$\frac{7.75 \text{ cubic inches} \times 4000 \text{ RPM} \times .85}{1728 \text{ cubic inches per cubic foot}}$$

or approximately fifteen cubic feet per minute. A rotameter was selected which could measure an air flow rate up to 13.6 cubic feet per minute as being of sufficient size.

Selected was a SK Instruments Type 1827 4-HCF laboratory rotameter with a 43-J float, 250 millimeter scale, one inch inside diameter hose connections, and an accuracy of plus or minus two percent of maximum flow. A chart was also secured which converted the scale readings to flow rate in ounces per minute.

A surge tank of approximately 285 cubic inches was built and inserted between the air flow rotameter and the air

induction system to smooth out the air flow through the rotameter for a more accurate reading. This was done because the air flow on a single cylinder engine is intermittent and causes the rotameter float to fluctuate quite widely if a surge tank is not present.

The volumetric efficiency of the engine was determined by the following series of calculations:

$$\frac{\text{RPM}}{2} = \text{number of intake strokes per minute}$$

\*\*\*\*\*

cylinder air capacity (ounces) =

$$\frac{\text{displacement (cubic inches)}}{1728 \text{ cubic inches per cubic foot}} \times 1.29152 \frac{\text{ounces per cubic foot}}{\text{cubic foot}}$$

or

cylinder air capacity =

$$\frac{7.75 \text{ cubic inches}}{1728 \text{ cubic inches per cubic foot}} \times 1.29152 \frac{\text{ounces per cubic foot}}{\text{cubic foot}}$$

$$= .00579 \text{ ounces}$$

\*\*\*\*\*

$$\text{air intake (ounces)} = \frac{\text{air flow rate (ounces per minute)}}{\text{number of intake strokes per minute}}$$

$$\text{volumetric efficiency} = \frac{\text{air intake (ounces)}}{\text{cylinder air capacity (ounces)}} \times 100$$

example:

$$\text{number of intake strokes per minute} = \frac{3200}{2} = 1600$$

$$\begin{aligned} \text{air intake (ounces)} &= \frac{5.0 \text{ ounces per minute}}{1600 \text{ intake strokes per minute}} \\ &= .00315 \end{aligned}$$

$$\text{volumetric efficiency} = \frac{.00315 \text{ ounces}}{.00579 \text{ ounces}} \times 100 = 58\%$$

Combustion efficiency was measured using the Combustion Efficiency Tester on the Sun 1120 Electronic Engine Tester. This scale is based on the complete burning of fuel at any given ratio of fuel and air. Fuel-air ratio was also read directly from this scale.

Exhaust system temperature was measured using an Alnor Pyrolance manufactured by Illinois Testing Laboratories. The scale ran from 0-2500 degrees Fahrenheit.

The estimated temperature of the burning fuel mixture was derived from the exhaust system temperature which was taken as thirty-five percent of the total heat.

Compound gauges were used to measure pressure and/or vacuum at various points in the air induction system. Gauges were finally chosen which had a range from thirty

inches of mercury vacuum to fifteen pounds per square inch gauge pressure in order to measure any pressure that was above or below atmospheric. Three Ashcroft 101<sup>4</sup> Duraguage gauges with one percent accuracy, three and one-half inch dials, one-quarter inch NPT back flush mountings, and bronze Bourdon tubes were used. The air intake system was tapped for gauge placement in three places: between the choke and throttle; at the throttle; and between the throttle and intake valve.

The oil used in the engine during the tests was Quaker State Super Blend SAE 10W-20W-30 HD MS. The fuel used was Sunoco 200 (regular) gasoline.

A counterweight weighing 5.65 pounds was used on the end of the crankshaft to help level out the power impulses produced during combustion and thus reduce vibration, erratic engine operation and consequent erratic test results.

## FINDINGS

TABLE 3 following gives results of a test run with the choke fully open and readings obtained at RPM settings which could be measured on the small engine tachometer used to the greatest degree of accuracy (nearest one hundred RPM) and held constant for a time long enough for all readings to be taken for a particular speed. This turned out to be a middle speed range.

Fuel and air flow rates, volumetric efficiency, combustion efficiency, and pressure readings are all dependent upon temperature, barometric pressure, and relative humidity. These variable conditions are noted for the time the test was run. Since the instruments were calibrated for STP conditions, however, the findings following are uncorrected for the variable conditions. These corrections, though not negligible, would be small and would probably vary for various engine speeds.

Another correction should be noted for fuel flow rate. The rotameter was calibrated for fuel of a given specific gravity and kinematic viscosity, but the actual specific gravity and kinematic viscosity of the fuel used was quite probably not that specified for rotameter calibration.

Again the correction would be small and variable for various engine speeds.

Figures for fuel flow rate are approximate due to the variation in accuracy for rotameter readings at the low flow rates for the particular speeds the test included. The flow rates given are from a manufacturer's suggested method of approximating these rates from data given for higher flow rates. The rotameter used, which actually should have been smaller to measure these lower flow rates accurately, would, however, be of just the right size for measuring flow rates for higher engine speeds-- though this was not done because these would have to be instantaneous readings.

TABLE 3

## TEST RESULTS FOR ENGINE RUNNING WITH OPEN CHOKE

Test Conditions: Barometric Pressure - 29.86 in. Hg  
 Temperature - 82° F. Relative Humidity - 55%

| RPM  | Fuel Flow Rate (lb./hr.) | Air Flow Rate (cfm) | Air Flow Rate (oz./min.) | Volu-metric Effi-ciency (%) | Combus-tion Effi-ciency (%) | Fuel-Air Ratio (lb./lb.) | Exhaust System Temperature (°F.) |
|------|--------------------------|---------------------|--------------------------|-----------------------------|-----------------------------|--------------------------|----------------------------------|
| 2000 | .001                     |                     |                          |                             | 80                          | 1/13.4                   | 450                              |
| 2100 | .001                     | 1.2                 | 1.6                      | 26                          | 81                          | 1/13.4                   | 500                              |
| 2200 | .001                     | 1.6                 | 2.1                      | 31                          | 82                          | 1/13.6                   | 700                              |
| 2300 | .001                     | 1.4                 | 1.8                      | 27                          | 82                          | 1/13.6                   | 700                              |
| 2400 | .001                     | 1.4                 | 1.8                      | 26                          | 81                          | 1/13.4                   | 750                              |
| 2500 | .001                     | 1.4                 | 1.8                      | 25                          | 81                          | 1/13.4                   | 750                              |
| 2600 | .001                     | 1.6                 | 2.1                      | 27                          | 81                          | 1/13.4                   | 750                              |
| 2700 | .001                     | 1.6                 | 2.1                      | 26                          | 81                          | 1/13.4                   | 750                              |
| 2800 | .002                     | 1.6                 | 2.1                      | 26                          | 82                          | 1/13.6                   | 800                              |
| 2900 | .002                     | 1.8                 | 2.3                      | 28                          | 82                          | 1/13.6                   | 800                              |
| 3000 | .001                     | 1.8                 | 2.3                      | 28                          | 81                          | 1/13.4                   | 800                              |
| 3100 | .001                     | 2.0                 | 4.6                      | 51                          | 82                          | 1/13.6                   | 800                              |
| 3200 | .001                     | 2.2                 | 5.0                      | 54                          | 82                          | 1/13.6                   | 850                              |
| 3300 | .003                     | 2.4                 | 5.5                      | 58                          | 82                          | 1/13.6                   |                                  |

TABLE 3 (con.)

| RPM  | Esti-<br>mated<br>Temper-<br>ature of<br>Burning<br>Fuel<br>Mixture<br>(°F.) | Pressure<br>between<br>Choke and<br>Throttle<br>(" in. Hg<br>vacuum -<br># lb./sq.<br>in.) |     | Pressure<br>at Throttle<br>(" in. Hg<br>vacuum -<br># lb./sq.<br>in.) |     | Pressure<br>between<br>Throttle<br>and Intake<br>Valve (" in.<br>Hg vacuum -<br># lb./sq. in.) |                                  |
|------|--|--|-----|---|-----|--|----------------------------------|
|      |  | Hi   | Low | Hi  | Low | Hi   | Low                              |
| 2000 | 1350   | 0  | 0   | 0   | 0   | 15 <sup>+</sup> #  | 14 <sup>1</sup> / <sub>2</sub> # |
| 2100 | 1400   | 0  | 0   | 0   | 1"  | 6#   | 20"                              |
| 2200 | 2000   | 0  | 0   | 0   | 1"  | 2#   | 12"                              |
| 2300 | 2000   | 0  | 0   | 0   | 0   | 3#   | 15"                              |
| 2400 | 2150   | 0  | 0   | 0   | 0   | <sup>1</sup> / <sub>2</sub> #  | 10"                              |
| 2500 | 2150   | 0  | 0   | 0   | 0   | <sup>1</sup> / <sub>2</sub> #  | 10"                              |
| 2600 | 2150   | 0  | 0   | 0   | 0   | 0  | 9"                               |
| 2700 | 2150   | 0  | 0   | 0   | 0   | 1"   | 9"                               |
| 2800 | 2300   | 0  | 0   | 0   | 0   | 0  | 9"                               |
| 2900 | 2300   | 0  | 0   | 0   | 0   | 1"   | 8"                               |
| 3000 | 2300   | 0  | 0   | 0   | 0   | 1"   | 8"                               |
| 3100 | 2300   | 1#   | 0   | 0   | 0   | 2"   | 6"                               |
| 3200 | 2450   | 0  | 1"  | 0   | 0   | 2"   | 6"                               |
| 3300 | 2450   | 0  | 1"  | 0   | 0   | 2"   | 6"                               |

Graphs following in Figures V-XV make the findings recorded in TABLE 3 more easily interpretable.

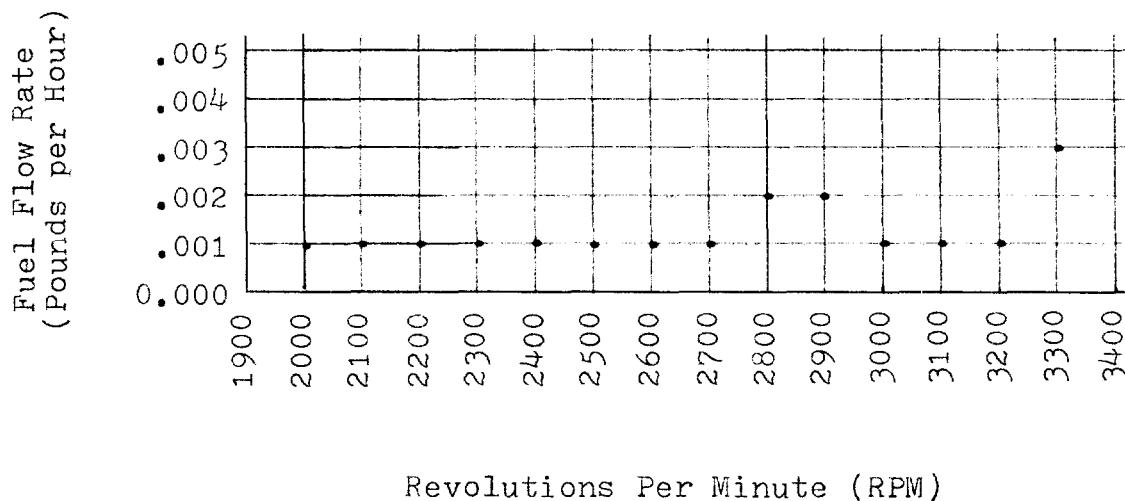


Figure V. - Fuel Flow Rate in Relation to Engine Speed

From Figure V, it can be seen that fuel consumption generally increased over the speed range of the test.

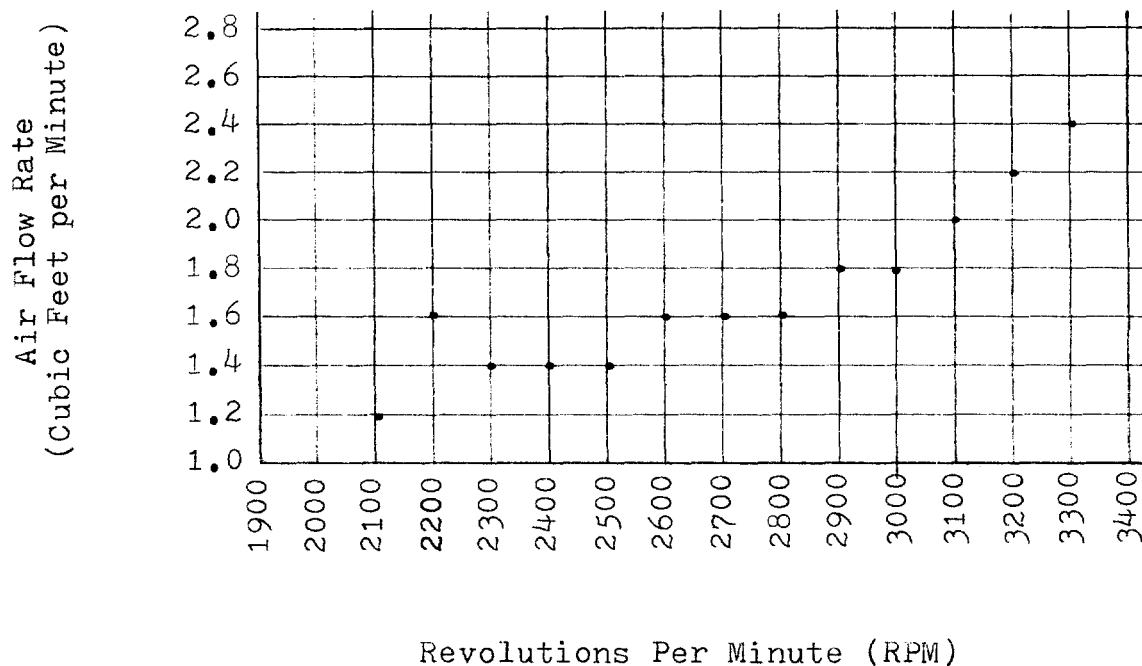


Figure VI. - Air Flow Rate in Relation to Engine Speed

Figure VI shows that over the speed range of the test, air consumption increased, which was expected.

Figure VII relates the same information as Figure VI, air flow rate, only in ounces per minute instead of cubic feet per minute. The flow rate in ounces per minute is needed for calculation of the engine's volumetric efficiency.

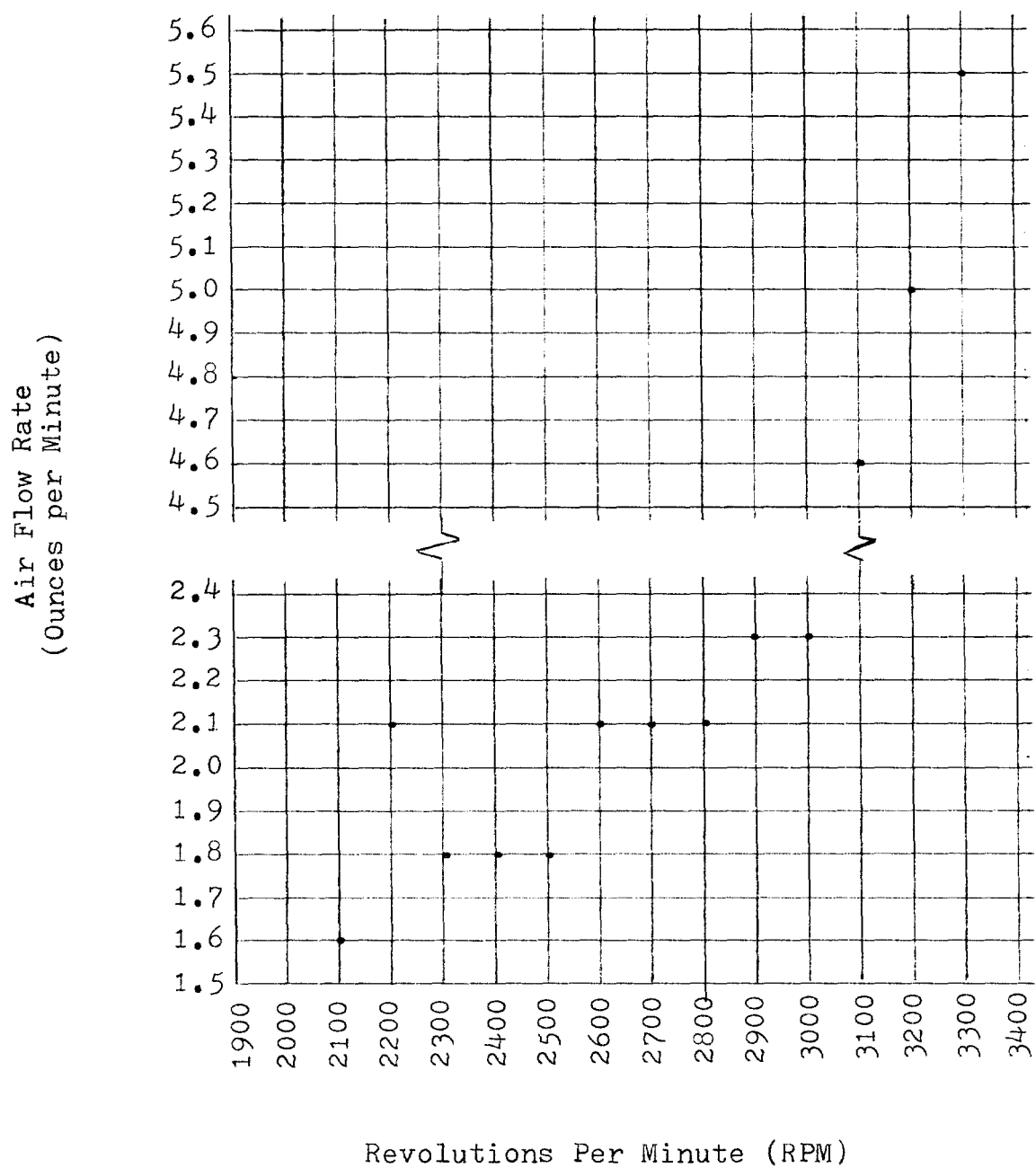


Figure VII. - Air Flow Rate in Relation to Engine Speed

Note the break in the graph in Figure VII to facilitate the graphing of the broad range of results.

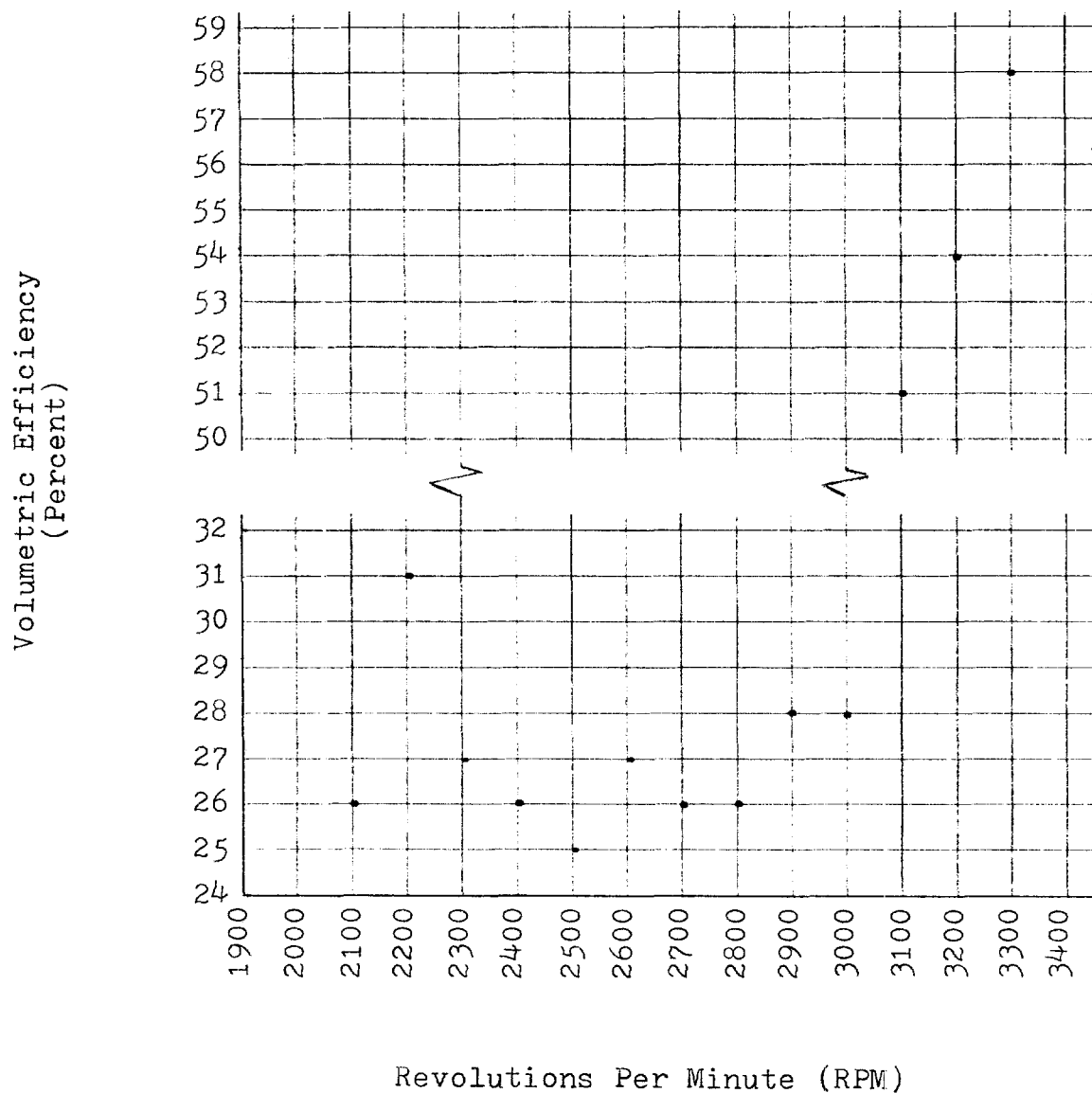


Figure VIII. - Volumetric Efficiency in Relation to Engine Speed

Volumetric efficiency, as shown in Figure VIII, can generally be said to increase over the speed range of the test. The values for volumetric efficiency are, however, extremely low at the low end of the speed range, compared

to larger engines. As no information concerning the volumetric efficiency of a single cylinder engine is available, however, the reason for this result is speculative. Possibly this result represents actual volumetric efficiency of the small engine. Possibly something was wrong with the set-up for measurement.

Note that in Figure VIII the graph has been broken to present the broad range of results.

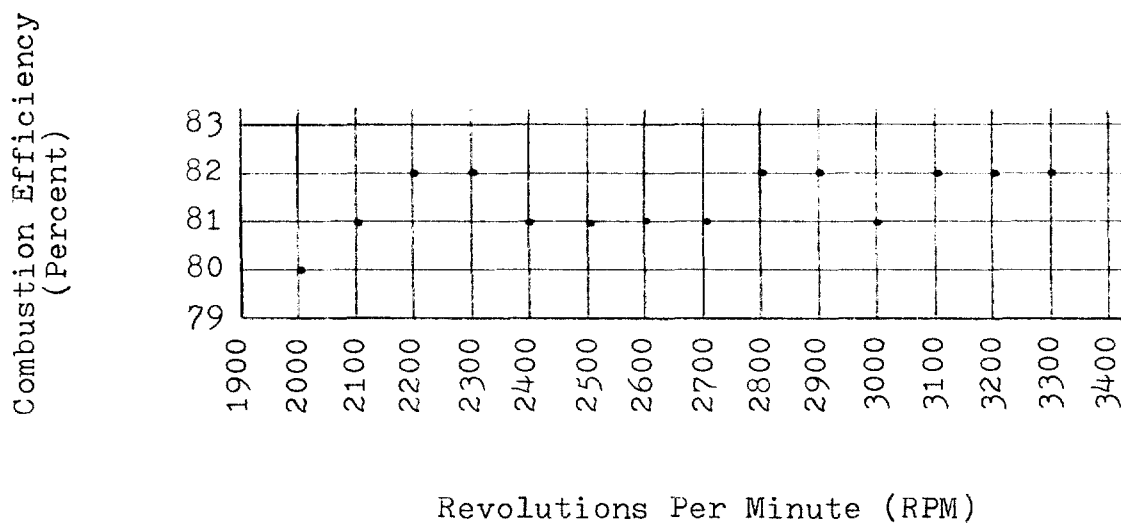


Figure IX. - Combustion Efficiency in Relation to Engine Speed

Combustion efficiency, as seen in Figure IX, for the speeds of the test is a couple of percentage points lower than for an automobile engine running at the same speeds.

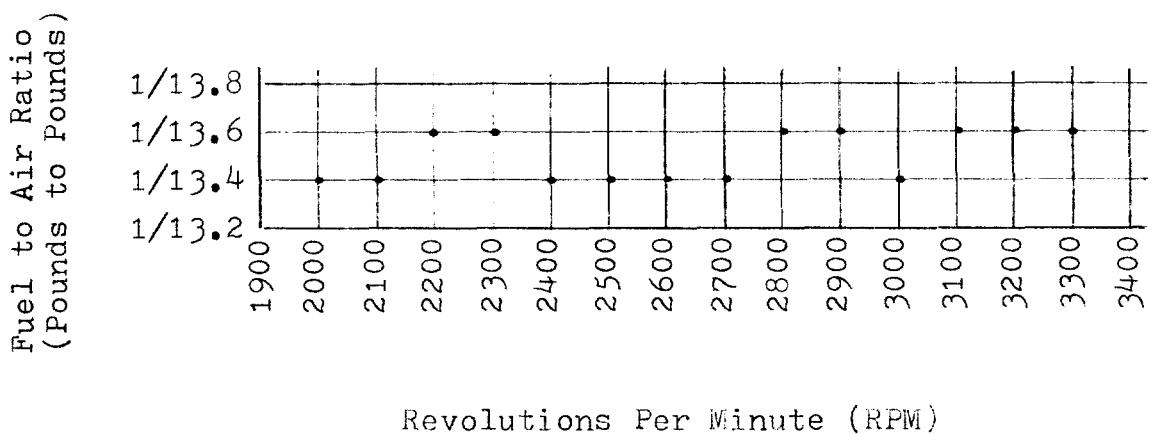


Figure X. - Fuel to Air Ratio in Relation to Engine Speed

From Figure X, fuel-air ratio seems to be about what was expected from the data available.

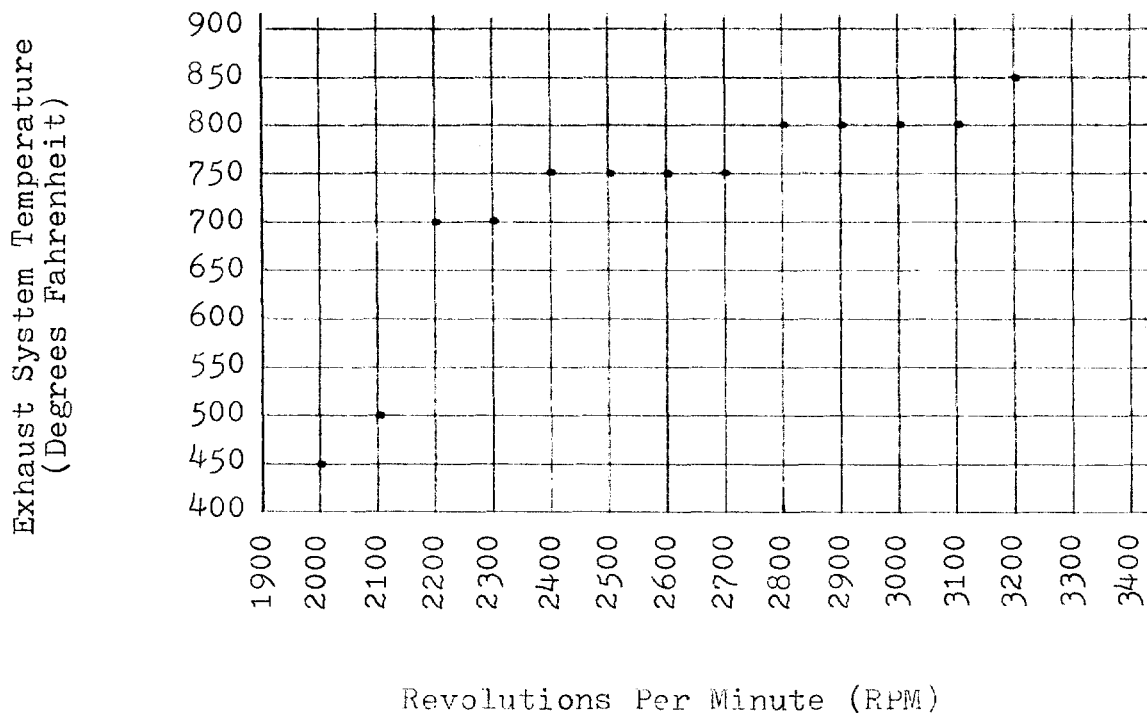


Figure XI. - Exhaust System Temperature in Relation to Engine Speed

Estimated temperature of the burning fuel mixture, Figure XII, determined from measurement of exhaust system temperature, Figure XI, seems to be in line with information available for temperatures of burning fuel.

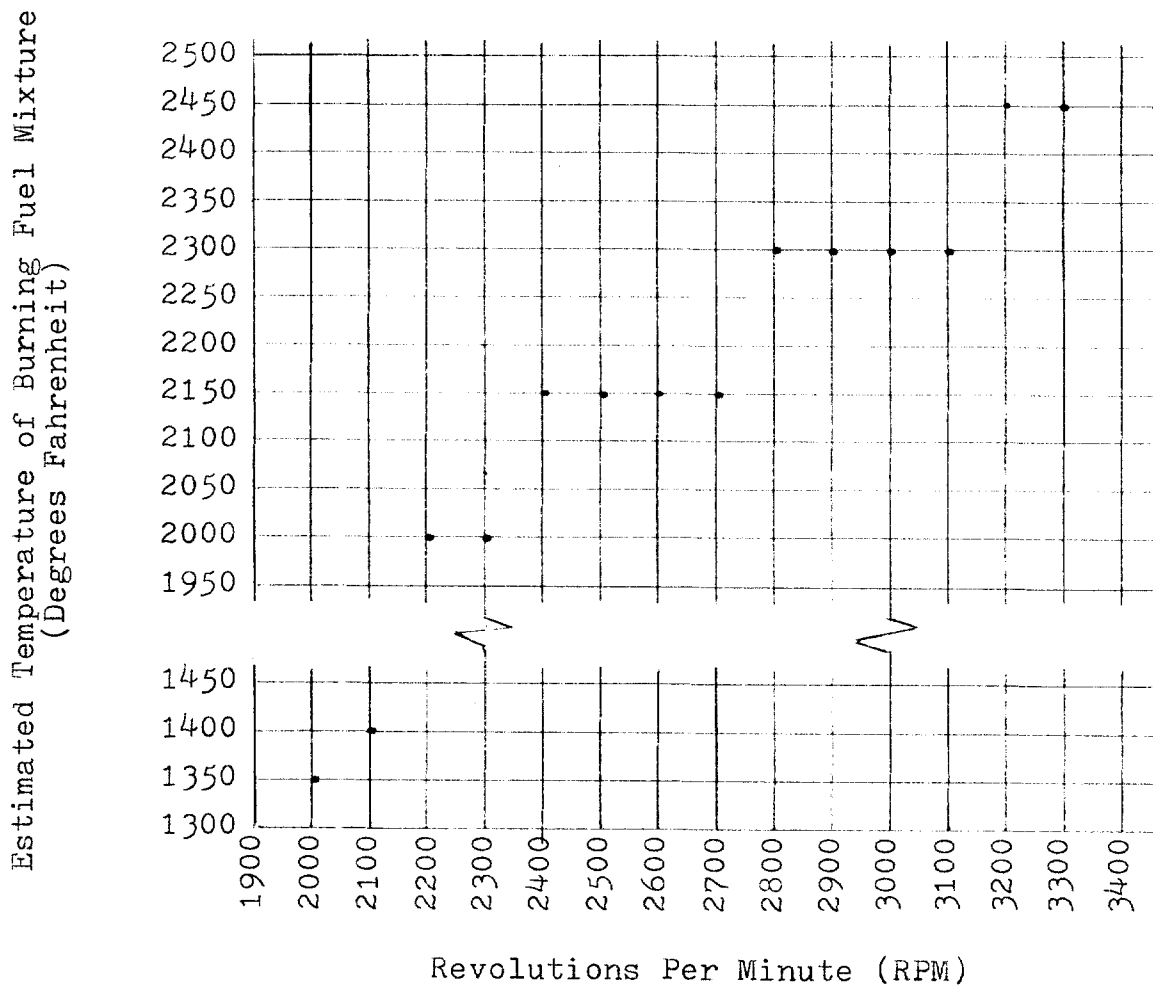


Figure XII. - Estimated Temperature of Burning Fuel Mixture in Relation to Engine Speed

Note in Figure XII that the graph has been broken to accommodate the range of data.

Findings of pressure conditions in the air induction

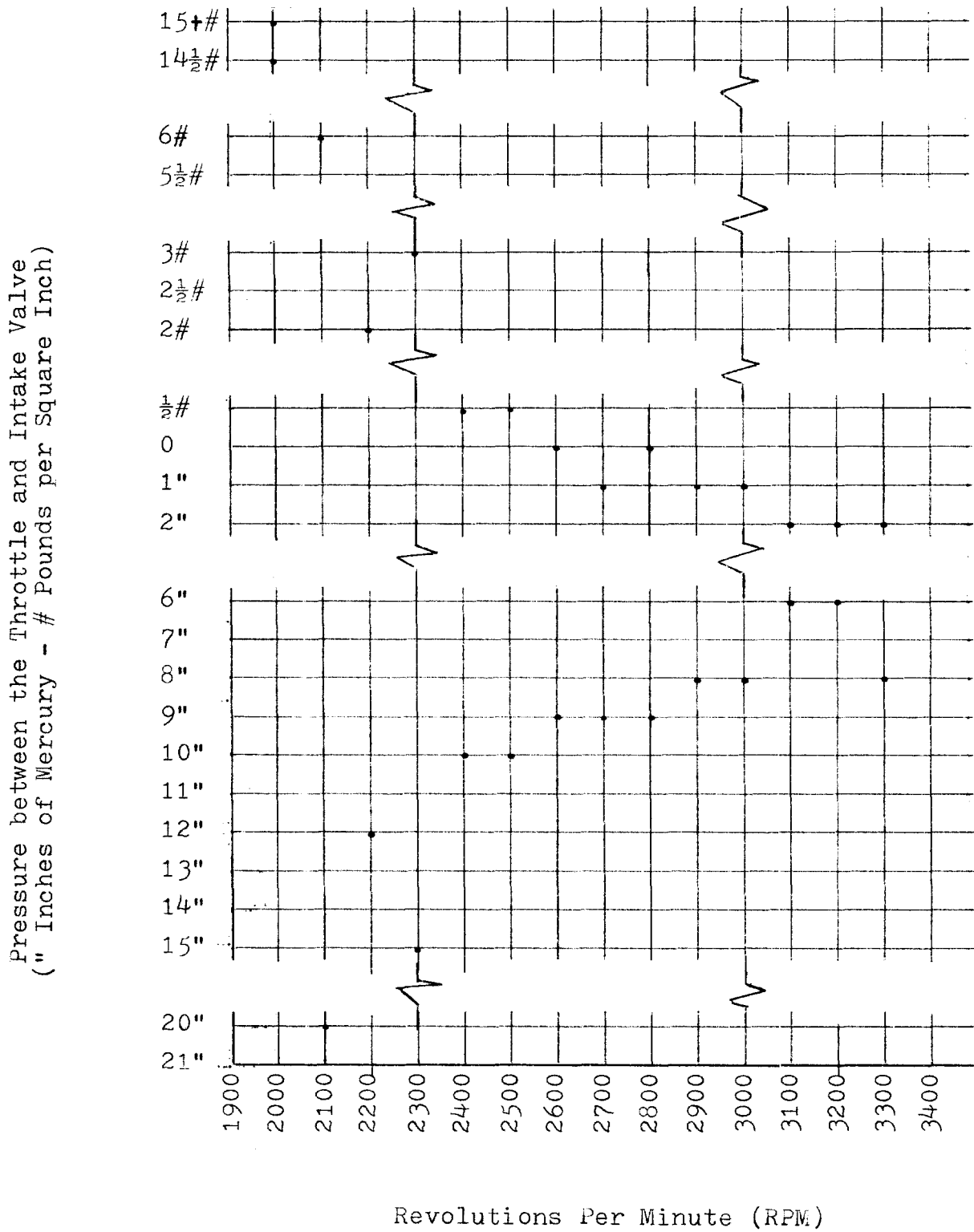


Figure XIII. - Pressure between the Throttle and Intake Valve in Relation to Engine Speed

Pressure at the Throttle  
 ("Inches of Mercury -  
 # Pounds per Square Inch)

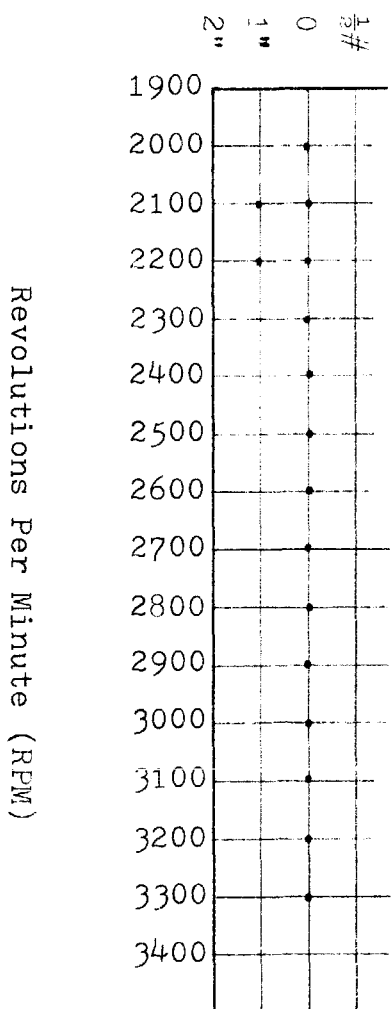


Figure XIV. - Pressure at the Throttle in Relation to Engine Speed

Pressure between the Choke and Throttle  
 (" Inches of Mercury -  
 # Pounds per Square Inch)

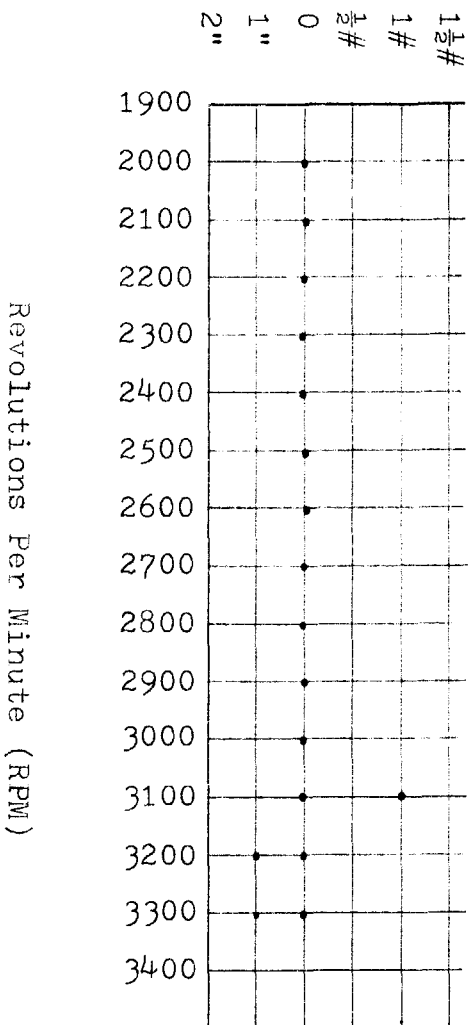


Figure XV. - Pressure between the Choke and Throttle in Relation to Engine Speed

system seem high for positions between the choke and throttle, Figure XV, and at the throttle, Figure XIV. It is difficult to determine whether this is due to faulty instrumentation, faulty set-up, or actually represents existing pressure conditions. The conditions indicated, however, are possible in light of the data available. Pressures between the throttle and intake valve, Figure XIII, seem high at low engine speeds, but this probably can be accounted for by fuel mixture being pushed back out of the cylinder past the intake valve during the compression stroke, which would be noticeable at low RPM where the valve is open for a relatively longer period of time.

Note the **breaks** in the graph in Figure XIII to accommodate the wide range of data.

## EVALUATION

This writer's experience with the project was very beneficial as it was necessary to review small engine fundamentals, learn about various operating aspects of an engine and their relationships to each other, determine measuring apparatus and units of measurement, and delineate the testing conditions and determine validity of tests.

Outside of this, the project now seems of limited value. A commercially available unit which includes a dynamometer and fuel and air flow measuring devices seems to be much more sophisticated for the aspects covered, although the approach is different and the aspects covered not as broad.

It seems now, although the project accomplishes its aims, that it is really on a springboard to redevelopment. Some sort of improvement is yet needed in the control of, determining the correction factors needed for, or re-instrumentation required for eliminating the variables still present, as the project now hinges upon findings of questionable accuracy. Better methods are needed for controlling the tests themselves, as ways to better control engine speed and extend tests over a wider speed spectrum for broader conclusions.

To make the project a really self-contained teaching aid, more instrumentation needs to be added to the project rather than using that available on other pieces of test equipment--tachometer, temperature measuring device, combustion efficiency tester, for example.

## SUMMARY AND CONCLUSIONS

The findings provide experimental data to graphically illustrate the relationship between throttle-controlled engine speed, fuel and air flow, volumetric efficiency, combustion efficiency, fuel-air ratio, exhaust system temperature, and pressure conditions in the air induction system of a small engine. When the engine is running, immediate operating conditions can be observed. The project thus provides an opportunity for the student to see the various operating aspects of a small engine.

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## APPENDIX

### APPENDIX A. GLOSSARY

Bourdon tube - a mechanical device that changes shape when pressure is applied

BDC - bottom dead center - the lower limit of piston movement

displacement - the volume that the piston displaces as it moves from top dead center to bottom dead center or  $\frac{\pi d^2 L}{4}$  where d is the cylinder bore and L the length of the piston stroke

kinematic viscosity - the ratio of absolute viscosity (a measure of the resistance of a fluid to internal deformation) to the mass density - expressed in centistokes

rotameter - a gauge that consists of a graduated glass tube containing a free float for measuring the flow of a fluid

RPM - revolutions per minute

SAE - Society of Automotive Engineers

APPENDIX B. FUEL FLOW CHART FOR POUNDS PER HOUR



**SK Instruments**

A DIVISION OF SCHUTTE & KOERTING COMPANY  
 CORNWELLS HEIGHTS, PENNSYLVANIA 19020

CUSTOMER DR. RICHARD L. GUNDEL  
 ORDER NO. \_\_\_\_\_ ITEM 6'  
 S&K ORDER NO. \_\_\_\_\_ DATE JUL 24, 1971  
 MEASURED FLUID 1.000

|                |               |                       |              |        |
|----------------|---------------|-----------------------|--------------|--------|
| TYPE           | <u>1.00</u>   | OPERATING PRESSURE    |              | TEMP   |
| TUBE NO.       | <u>17-110</u> | OPERATING TEMPERATURE |              | °C     |
| FLOAT NO.      | <u>1.00</u>   | OPERATING DENSITY     | <u>1.000</u> | GMS/CC |
| FLOAT MATERIAL | <u>1.00</u>   | DENSITY AT STP        |              | GMS/CC |
| REFERENCE NO.  | <u>1.00</u>   | OPERATING VISCOSITY   | <u>1.00</u>  | CS     |

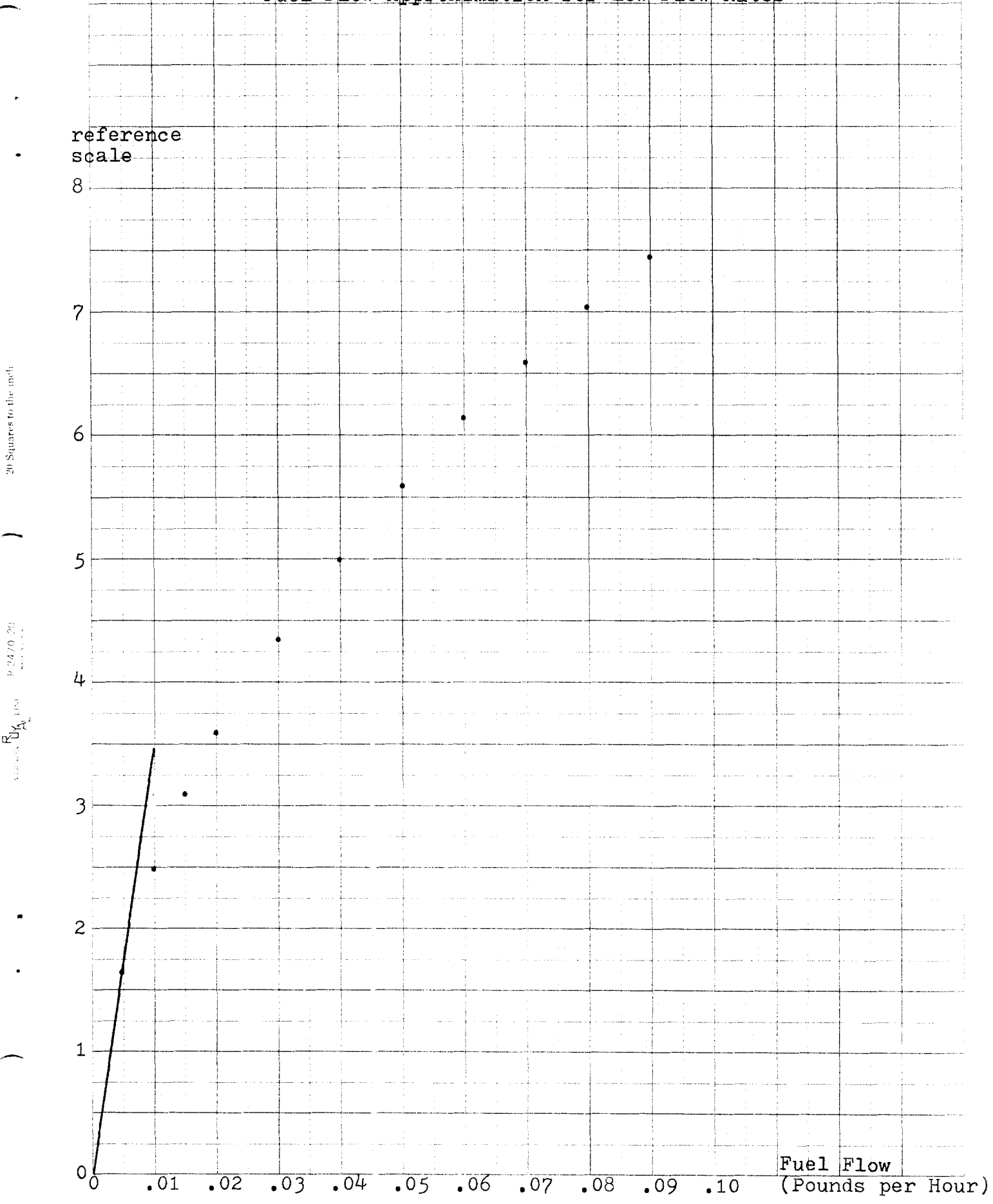
| REFERENCE SCALE | FLOW  | REFERENCE SCALE | FLOW  |
|-----------------|-------|-----------------|-------|
| 1.0             | 1.00  | 1.0             | 1.00  |
| 1.1             | 1.10  | 1.1             | 1.10  |
| 1.2             | 1.20  | 1.2             | 1.20  |
| 1.3             | 1.30  | 1.3             | 1.30  |
| 1.4             | 1.40  | 1.4             | 1.40  |
| 1.5             | 1.50  | 1.5             | 1.50  |
| 1.6             | 1.60  | 1.6             | 1.60  |
| 1.7             | 1.70  | 1.7             | 1.70  |
| 1.8             | 1.80  | 1.8             | 1.80  |
| 1.9             | 1.90  | 1.9             | 1.90  |
| 2.0             | 2.00  | 2.0             | 2.00  |
| 2.1             | 2.10  | 2.1             | 2.10  |
| 2.2             | 2.20  | 2.2             | 2.20  |
| 2.3             | 2.30  | 2.3             | 2.30  |
| 2.4             | 2.40  | 2.4             | 2.40  |
| 2.5             | 2.50  | 2.5             | 2.50  |
| 2.6             | 2.60  | 2.6             | 2.60  |
| 2.7             | 2.70  | 2.7             | 2.70  |
| 2.8             | 2.80  | 2.8             | 2.80  |
| 2.9             | 2.90  | 2.9             | 2.90  |
| 3.0             | 3.00  | 3.0             | 3.00  |
| 3.1             | 3.10  | 3.1             | 3.10  |
| 3.2             | 3.20  | 3.2             | 3.20  |
| 3.3             | 3.30  | 3.3             | 3.30  |
| 3.4             | 3.40  | 3.4             | 3.40  |
| 3.5             | 3.50  | 3.5             | 3.50  |
| 3.6             | 3.60  | 3.6             | 3.60  |
| 3.7             | 3.70  | 3.7             | 3.70  |
| 3.8             | 3.80  | 3.8             | 3.80  |
| 3.9             | 3.90  | 3.9             | 3.90  |
| 4.0             | 4.00  | 4.0             | 4.00  |
| 4.1             | 4.10  | 4.1             | 4.10  |
| 4.2             | 4.20  | 4.2             | 4.20  |
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| 4.4             | 4.40  | 4.4             | 4.40  |
| 4.5             | 4.50  | 4.5             | 4.50  |
| 4.6             | 4.60  | 4.6             | 4.60  |
| 4.7             | 4.70  | 4.7             | 4.70  |
| 4.8             | 4.80  | 4.8             | 4.80  |
| 4.9             | 4.90  | 4.9             | 4.90  |
| 5.0             | 5.00  | 5.0             | 5.00  |
| 5.1             | 5.10  | 5.1             | 5.10  |
| 5.2             | 5.20  | 5.2             | 5.20  |
| 5.3             | 5.30  | 5.3             | 5.30  |
| 5.4             | 5.40  | 5.4             | 5.40  |
| 5.5             | 5.50  | 5.5             | 5.50  |
| 5.6             | 5.60  | 5.6             | 5.60  |
| 5.7             | 5.70  | 5.7             | 5.70  |
| 5.8             | 5.80  | 5.8             | 5.80  |
| 5.9             | 5.90  | 5.9             | 5.90  |
| 6.0             | 6.00  | 6.0             | 6.00  |
| 6.1             | 6.10  | 6.1             | 6.10  |
| 6.2             | 6.20  | 6.2             | 6.20  |
| 6.3             | 6.30  | 6.3             | 6.30  |
| 6.4             | 6.40  | 6.4             | 6.40  |
| 6.5             | 6.50  | 6.5             | 6.50  |
| 6.6             | 6.60  | 6.6             | 6.60  |
| 6.7             | 6.70  | 6.7             | 6.70  |
| 6.8             | 6.80  | 6.8             | 6.80  |
| 6.9             | 6.90  | 6.9             | 6.90  |
| 7.0             | 7.00  | 7.0             | 7.00  |
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| 7.2             | 7.20  | 7.2             | 7.20  |
| 7.3             | 7.30  | 7.3             | 7.30  |
| 7.4             | 7.40  | 7.4             | 7.40  |
| 7.5             | 7.50  | 7.5             | 7.50  |
| 7.6             | 7.60  | 7.6             | 7.60  |
| 7.7             | 7.70  | 7.7             | 7.70  |
| 7.8             | 7.80  | 7.8             | 7.80  |
| 7.9             | 7.90  | 7.9             | 7.90  |
| 8.0             | 8.00  | 8.0             | 8.00  |
| 8.1             | 8.10  | 8.1             | 8.10  |
| 8.2             | 8.20  | 8.2             | 8.20  |
| 8.3             | 8.30  | 8.3             | 8.30  |
| 8.4             | 8.40  | 8.4             | 8.40  |
| 8.5             | 8.50  | 8.5             | 8.50  |
| 8.6             | 8.60  | 8.6             | 8.60  |
| 8.7             | 8.70  | 8.7             | 8.70  |
| 8.8             | 8.80  | 8.8             | 8.80  |
| 8.9             | 8.90  | 8.9             | 8.90  |
| 9.0             | 9.00  | 9.0             | 9.00  |
| 9.1             | 9.10  | 9.1             | 9.10  |
| 9.2             | 9.20  | 9.2             | 9.20  |
| 9.3             | 9.30  | 9.3             | 9.30  |
| 9.4             | 9.40  | 9.4             | 9.40  |
| 9.5             | 9.50  | 9.5             | 9.50  |
| 9.6             | 9.60  | 9.6             | 9.60  |
| 9.7             | 9.70  | 9.7             | 9.70  |
| 9.8             | 9.80  | 9.8             | 9.80  |
| 9.9             | 9.90  | 9.9             | 9.90  |
| 10.0            | 10.00 | 10.0            | 10.00 |

COMPUTED BY THE DATA PROCESSING SYSTEM

**CALIBRATION CHART**

APPENDIX C. FUEL FLOW APPROXIMATION FOR LOW FLOW RATES <sup>37</sup>

Fuel Flow Approximation for Low Flow Rates



APPENDIX D. AIR FLOW CHART FOR CUBIC FEET PER MINUTE

10-6-60

# CALIBRATION CHART

TUBE NO. 4-HCF      FLOAT NO. 43-J      SCH - 6046

CUSTOMER \_\_\_\_\_

## CORRECTIONS FOR NEW OPERATING CONDITIONS

### FOR LIQUID

IF OPERATING VISCOSITY AND/OR SPECIFIC GRAVITY ARE DIFFERENT FROM THOSE LISTED ON SCALE "A" REFER TO FACTORY FOR CORRECTED CALIBRATION.

### FOR GAS

IF OPERATING CONDITIONS ARE DIFFERENT FROM THOSE LISTED ON SCALE "B" MULTIPLY FLOWS LISTED ON SCALE "B" BY APPLICABLE CORRECTION FACTOR AS LISTED BELOW.

| CORRECTION FACTOR FOR: |   | VOLUMETRIC UNITS |                  | GRAVIMETIC UNITS |
|------------------------|---|------------------|------------------|------------------|
|                        |   | FREE             | ACTUAL           |                  |
| PERFECT GAS            | PRESSURE  | F <sub>1</sub>   | 1/F <sub>1</sub> | F <sub>1</sub>   |
|                        | TEMPERATURE                                     | F <sub>2</sub>   | 1/F <sub>2</sub> | F <sub>2</sub>   |
|                        | SP. GR. FOR NEW GAS                             | F <sub>3</sub>   | F <sub>3</sub>   | 1/F <sub>3</sub> |
| IMPERFECT GAS          | PRESSURE &/OR TEMPERATURE &/OR SPECIFIC GRAVITY | F <sub>5</sub>   | F <sub>4</sub>   | 1/F <sub>4</sub> |

SPECIFIC GRAVITIES OF GASES ARE REFERRED TO AIR AT 14.7 PSIA & 70°F AS 1.0

$$F_1 = \sqrt{\frac{P_2 + 14.7}{P_1 + 14.7}} \quad F_2 = \sqrt{\frac{T_1 + 460}{T_2 + 460}} \quad F_3 = \sqrt{\frac{G_1}{G_2}} \quad F_4 = \sqrt{\frac{G_3}{G_4}} \quad F_5 = \frac{G_1}{G_2} \sqrt{\frac{G_4}{G_3}}$$

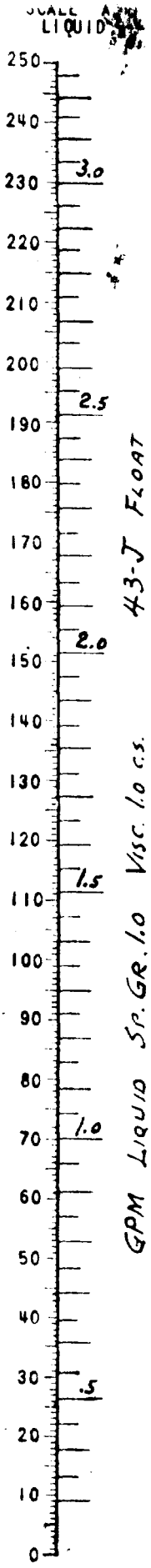
- P<sub>1</sub> = PRESSURE (PSIG) LISTED ON SCALE B.
- P<sub>2</sub> = PRESSURE (PSIG) FOR WHICH CORRECTION IS TO BE MADE.
- T<sub>1</sub> = TEMPERATURE (°F) LISTED ON SCALE B.
- T<sub>2</sub> = TEMPERATURE (°F) FOR WHICH CORRECTION IS TO BE MADE.
- G<sub>1</sub> = SP. GR. OF GAS LISTED ON SCALE "B" AT S.T.P.
- G<sub>2</sub> = SP. GR. OF NEW GAS FOR WHICH CORRECTION IS TO BE MADE AT S.T.P.
- G<sub>3</sub> = SP. GR. OF GAS LISTED ON SCALE "B" AT O.T.P.
- G<sub>4</sub> = SP. GR. FOR WHICH CORRECTION IS TO BE MADE AT O.T.P.

S.T.P. = 14.7 PSIA AND 70°F  
O.T.P. = OPERATING TEMPERATURE AND PRESSURE

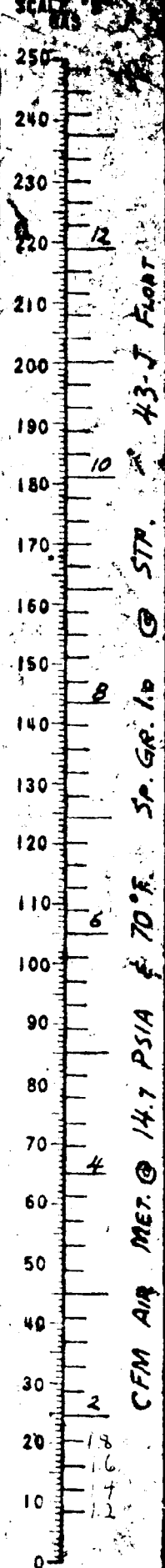
# Schutte and Koerting COMPANY

INSTRUMENT DIVISION

CORNWELLS HEIGHTS, BUCKS COUNTY, PENNSYLVANIA



43-J FLOAT  
GPM LIQUID SP. GR. 1.0 VISC. 1.0 c.s.



43-J FLOAT  
CFM AIR MET. @ 14.7 PSIA & 70°F SP. GR. 1.0 @ S.T.P.

APPENDIX E. AIR FLOW CHART FOR OUNCES PER MINUTE

**CALIBRATION CHART**

TUBE NO. *4 HCF*      FLOAT NO. *43-J*      SCH *71-53233/c*

CUSTOMER

**CORRECTIONS FOR NEW OPERATING CONDITIONS**

**FOR LIQUID**

IF OPERATING VISCOSITY AND/OR SPECIFIC GRAVITY ARE DIFFERENT FROM THOSE LISTED ON SCALE "A" REFER TO FACTORY FOR CORRECTED CALIBRATION.

**FOR GAS**

IF OPERATING CONDITIONS ARE DIFFERENT FROM THOSE LISTED ON SCALE "B" MULTIPLY FLOWS LISTED ON SCALE "B" BY APPLICABLE CORRECTION FACTOR AS LISTED BELOW.

| CORRECTION FACTOR FOR: |   | VOLUMETRIC UNITS |         | GRAMS PER MINUTE |
|------------------------|---|------------------|---------|------------------|
|                        |   | FREQ.            | ACTUAL  |                  |
| PERFECT GAS            | PRESSURE  | $F_1$            | $1/F_1$ | $F_1$            |
|                        | TEMPERATURE                                     | $F_2$            | $1/F_2$ | $F_2$            |
|                        | SPEC. GR. FOR NEW GAS                           | $F_3$            | $F_3$   | $1/F_3$          |
| IMPERFECT GAS          | PRESSURE &/OR TEMPERATURE &/OR SPECIFIC GRAVITY | $F_5$            | $F_4$   | $1/F_4$          |

SPECIFIC GRAVITIES OF GASES ARE REFERRED TO AIR AT 14.7 PSIA & 70°F AS 1.0

$$F_1 = \sqrt{\frac{P_2 + 14.7}{P_1 + 14.7}} \quad F_2 = \sqrt{\frac{T_1 + 460}{T_2 + 460}} \quad F_3 = \sqrt{\frac{G_1}{G_2}} \quad F_4 = \sqrt{\frac{G_3}{G_4}} \quad F_5 = \frac{G_1}{G_2} \sqrt{\frac{G_4}{G_3}}$$

- $P_1$  = PRESSURE (PSIG) LISTED ON SCALE B.
- $P_2$  = PRESSURE (PSIG) FOR WHICH CORRECTION IS TO BE MADE.
- $T_1$  = TEMPERATURE (°F) LISTED ON SCALE B.
- $T_2$  = TEMPERATURE (°F) FOR WHICH CORRECTION IS TO BE MADE.
- $G_1$  = SP. GR. OF GAS LISTED ON SCALE "B" AT S.T.P.
- $G_2$  = SP. GR. OF NEW GAS FOR WHICH CORRECTION IS TO BE MADE AT S.T.P.
- $G_3$  = SP. GR. OF GAS LISTED ON SCALE "B" AT O.T.P.
- $G_4$  = SP. GR. FOR WHICH CORRECTION IS TO BE MADE AT O.T.P.

S.T.P. = 14.7 PSIA AND 70°F  
O.T.P. = OPERATING TEMPERATURE AND PRESSURE

**Schutte and Koerting COMPANY**

**INSTRUMENT DIVISION**

CORNWELLS HEIGHTS, BUCKS COUNTY, PENNSYLVANIA

