AN INVESTIGATION OF THE EFFECTS OF THE USE OF INDIVIDUAL THROTTLE VALVES FOR EACH CYLINDER OF A MULTI-CYLINDER INTERNAL COMBUSTION ENGINE

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by
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Approved

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LIST OF ABBREVIATIONS AND SYMBOLS

a	Area of orifice, 0.00545 square feet
A/F	Air-Fuel ratio
BHP	Brake horsepower
BP	Barometric pressure, inches of mercury
DC	Dynamometer constant, 6000
E_t	Thermal efficiency
g	Gravitational constant 116,000 feet/minute^2
H	Differential pressure drop across the micromanometer, inches of alcohol
H_a	Differential pressure drop across the micromanometer, feet of air
H_v	Heating value, 20,000 BTU/pound
K	Orifice coefficient, 0.625
L	Dynamometer load, pounds
MP	Manifold pressure, inches of mercury
Q	Air flow, cubic feet per minute
R	Gas Constant for air
RPM	Revolutions per minute
T_a	Temperature of the air, degrees Fahrenheit
T	Temperature of the air, degrees Rankine
W_a	Weight of air used for a four minute run, pounds
W_f	Weight of fuel consumed for a four minute run, pounds
W_s	Specific weight of alcohol, 49.3 pounds per cubic foot
$(W_s)_a$	Specific weight of air, pounds per cubic foot

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INTRODUCTION

Purpose:

The purpose of this investigation is to compare the efficiencies obtained at low load, using individual throttle valves for each cylinder, with those obtained using the conventional throttling method.

Objective:

It is the object of this investigation to show by means of data obtained from the operation of an Otto cycle engine that an increase in thermal efficiency can be obtained through the use of individual throttle valves so located as to enable a high pressure to be maintained in the intake manifold, thereby eliminating some of the causes of low efficiency at very light loads in the Otto cycle engine. A higher pressure at the intake manifold reduces the expansion of residual gas into the intake manifold when the intake valve opens. As a result, the work usually required fo force this gas back into the cylinder, prior to induction of the fresh charge, is decreased. Also the extra dilution of fresh charge by exhaust gas which may be pulled back into the cylinder due to valve overlap is avoided.

In the Otto cycle engine, the conventional method of governing consists of a throttle valve in the carburetor. As this valve is closed, the area through which the fresh charge must flow is progressively decreased. The pressure in the intake manifold is a function of the throttle opening and engine speed and, at a given speed, is a function of the output torque. The pressure in the cylinder at the end of the exhaust stroke, however, is approximately atmospheric at all engine loads and speeds. Consequently, opening of the intake valve causes residual gas to expand into the intake manifold, resulting in a decrease of cylinder pressure to that of the intake manifold. The entire suction stroke of the engine then occurs at manifold pressure, drawing the expanded exhaust gas back into the cylinder as well as the fresh charge of fuel and air.

This intake process is shown by path $6-6''-1$ of the theoretical throttled Otto cycle on figure 1. The cross-hatched area of this diagram represents the pumping work of the cycle and can be seen to be a function of the manifold pressure. As the load is decreased, this negative work area becomes larger while the positive work area decreases so that at very light loads, the negative work area becomes sufficiently large to cause an appreciable decrease in thermal efficiency.

By using the individual throttle valves and making the volume between each throttle and intake valve small enough to allow the pressure in that volume to build up to atmospheric between suction strokes, there is no sudden drop of pressure in the cylinder when the intake valve opens but instead a gradual decrease occurs as the suction stroke progresses, resulting in some other intake path as approximated by line 6-1 on figure 1. It is apparent that a saving of pumping work, proportional to the area between paths 6-1 and 6-6"-1, is achieved.

In effect, a comparison of the operation of the regular throttle and the special throttle valves can be shown by considering the schematic drawing of a single cylinder engine in figure 2. The chamber situated between the throttle valve and intake valve represents an infinite reservoir at a pressure equal to the intake manifold pressure. This would correspond to the condition in the intake manifold of a multi-cylinder engine with six or more cylinders where the intake strokes overlap. When the valve to this chamber is open, the pressure at the beginning of the intake stroke is that of the reservoir and the entire suction stroke occurs at that pressure, as in the case of the regular throttle of the multi-cylinder engine. on the other hand, if the valve to the chamber is closed, the pressure at the start of the intake stroke is atmospheric and gradually decreases to the reservoir pressure as the intake stroke progresses, returning to atmospheric during the three intervening strokes. This would correspond to the case of the individual throttles in a multi-cylinder engine.

Review of the Literature:

For any given speed and throttle opening, it has been determined that a definite fuel-air ratio exists which will give best-economy and another which will give best-power. Fraas says: "The most important single variable determining the fuel-air ratios for each of these conditions is the amount of residual exhaust gas which increases rapidly as the engine is throttled to an idle and materially slows down the flame speed." As a consequence of this increased dilution of fresh charge by residual gas, the relative proportion of combustible vapor is reduced. "Because of this," Fraas continues, "the best-power and best-economy mixtures under idling and low power-output conditions are considerably richer than at moderate or high power-outputs."[1] Since that part of the exhaust gas which normally expands into the intake manifold as a result of valve overlap increases the amount of residual gas, elimination of this expansion by use of the individual throttles should decrease the fuel-air ratios for best-power and best-economy in the low power range.

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[1] Fraas, A.P., Combustion Engines, McGraw-Hill Book Company, Inc., New York, 1948, p.158.

APPARATUS

Engine:

The engine used for this investigation is a four cylinder Continental Red Seal engine, model Y-69. This is an industrial engine whose specifications are as follows:

Bore (inches)..................	2.5
Stroke (inches)................	3.5
Displacement (cubic inches).....	68.7
Compression ratio..............	6.2:1

For the individual throttles, a butterfly valve was placed at the exit of each of the intake ports of the manifold with the shafts projecting vertically downward as shown in figure 5. By locating them in this manner, the pressure drop associated with throttling appears in the small volume between the individual throttle valve and the intake valve of the engine instead of in the intake manifold. Perpendicular to the extremity of each of these shafts, a lever arm was attached which was connected at the other end to a synchronizing rod for uniform adjustment. A small allowance was made for individual adjustment of these valves to permit closer control of the engine. A friction type stop was put on each shaft to prevent any movement of the valve from its intended setting.

To measure the power output, a Taylor hydraulic dynamometer was connected to the engine by means of a flexible coupling. The load on the dynamometer was measured by a Fairbanks scale. The dynamometer and scale are shown in figure 3.

The fuel system, shown in figure 4, consisted of a cross-draft carburetor with a variable jet area, a fuel pump and a two gallon can of gasoline resting on a Toledo scale which was graduated in increments of .01 pounds.

A fifty-five gallon gasoline drum was connected to the carburetor for a surge chamber to dampen the surges through the air metering equipment, thereby permitting greater accuracy in reading the manometer. At the inlet to the surge tank, a one inch diameter, sharp edged orifice was mounted in a two inch diameter pipe and pressure taps inserted according to Vena Contracta theory.[2] The pressure taps were connected to a micromanometer filled with alcohol.

An aircraft type tachometer was used to measure the RPM. Since it was designed to be run off the cam shaft and was utilized off the crank shaft, calibration with a strobotac was necessary. The only other gages used were for manifold pressure and oil pressure. A mercury filled bulb thermometer eas used to measure the outlet water temperature.

The surge chamber, micromanometer, tachometer and the gages for manifold pressure and oil pressure are shown in figure 3.

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[2] Severns, W.H. and Degler, H.E., Steam, Air and Gas Power, John Wiley and Son,. Inc., 1948, p.399.

TEST PROCEDURE

The engine was carefully checked before any data was taken to assure the best possible performance. The head and pistons were cleaned of all carbon deposits, the spark plugs were cleaned and adjusted, and a compression test showed the rings and valves to be in good condition. Lubrication was checked at frequent intervals. The engine was timed with a stroboscopic light and the distributor fastened to prevent any advancing or retarding of the spark.

By simultaneously adjusting the rate of flow of water through the dynamometer and the main throttle, the desired load and engine speed were obtained. After a sufficient warm up period to allow the engine to reach operating temperature, a series of runs was made at various air-fuel ratios, while maintaining the load and RPM constant and keeping the individual throttle valves wide open. Starting with the main jet adjusted to the leanest operating position, the RPM and load were adjusted and measurements of fuel and air consumption were taken for a four minute period. The jet was then adjusted for successively larger areas and similar readings were taken. The air-fuel ratio and efficiency for each run were computed and plotted. A similar procedure was then followed, using the special throttle valves and leaving the main throttle valve wide open. A comparison of the two curves for a given load and RPM could then be made. A total of four series was made at speeds of 1200, 1400, 1600 and 1800 RPM and with a five pound load on the dynamometer.

DISCUSSION

The principle difficulty encountered during the investigation was one of carburetion. At low speeds, the air intake velocity was relatively small, resulting in insufficient pressure drop at the jet to permit satisfactory operation. No contribution could be expected from the idling jet since it was proposed that atmospheric pressure would be present in the manifold during operation of the special valves. The problem was satisfactorily eliminated by replacing the standard carburetor with one whose throat diameter is .54 times as large, thereby increasing the throat velocity by almost two hundred and fifty percent and providing a substantial increase in the pressure drop at the throat.

To obtain an indication of the results which could be expected, a preliminary series of runs was made, consisting of varying the air-fuel ratio and measuring fuel consumption over a range of speeds with no load on the engine. Curves of fuel consumption versus air-fuel ratio indicated that the special valves required more fuel at all speeds and all air-fuel ratios. A similar comparison was made with a five pound load and the efficiency of the engine while using the special valves, in each case, was below that obtained while using the regular throttle valve. The reason for this appeared to be attributable to poor vaporization of fuel and improper mixing of the fuel and air. To confirm this theory, another test was made with a two inch vacuum in the intake manifold. This pressure drop was obtained by throttling slightly with the regular throttle, thereby providing additional turbulence as well as increased vaporization as a result of the lower pressure. An appreciable improvement resulted in the efficiency curve but not enough to equal the efficiency curve using the regular throttle. By further decreasing the manifold pressure, successive improvements were obtained and the maximum efficiency of the curve for the regular throttle was finally exceeded.

As a consequence of these results, it was decided to modify the test procedure to include the effects of throttling slightly with the main throttle in addition to the individual throttles, and to determine the manifold pressure at which maximum efficiency obtains for each speed.

RESULTS

In each of the four test groups, an improvement in thermal efficiency was achieved by using the individual throttle valves. Although the curves for these groups are not absolutely consistent in every respect, certain trends appear to be present. They are:

1. Improvements in thermal efficiency in all cases, for a given air-fuel ratio, appeared in the relatively lean region as is shown by figures 6 through 9. At no speed, did any improvement occur at an air-fuel ratio less than 11:1, whereas at the ratios above 17:1, most of the curves for the individual throttle valves showed an increase in efficiency over the curve for the regular throttle. This seems to confirm further the fact that poor mixing and vaporization was causing the lower efficiency of the engine while using the individual throttle valves. The relative improvement in thermal efficiency with increased air-fuel ratio indicates that a larger percent of the molecules of fuel found molecules of oxygen with which to combine as the amount of excess air was increased.

2. As the engine speed increased, the efficiency curve for the individual throttle valves with the regular throttle wide open more nearly equalled the curve for the regular throttle valve. This is attributable to better distribution of the fuel as a result of better atomization

and increased turbulence associated with the higher engine speed. The higher velocity of air flow and the turbulence help to keep the fuel particles in suspension, assuring less variation in air-fuel ratio from cylinder to cylinder.

3. As the speed was increased, less throttling with the main throttle was required to achieve the maximum efficiency obtainable with the individual throttle valves for that speed. This seems to indicate that the increased turbulence caused by the higher air velocity as the speed increased, decreased the need for throttling with the regular throttle, and the benefit of the additional turbulence was sooner offset by the detrimental effects of the lower manifold pressure resulting from the throttling.

CONCLUSIONS

As a consequence of the data obtained in this investigation, the following conclusions are drawn:

1. For every test group, the pumping work associated with low load operation of the Otto cycle engine was appreciably reduced by the use of individual throttle valves, resulting in a noticeable improvement in the maximum thermal efficiency.

2. Improper mixing of the fuel and air due to insufficient turbulence at low air-fuel ratios and the decreased amount of vaporization resulting from the higher manifold pressure prevented maximum benefit from being derived from the use of the individual throttle valves. Part of the saving of pumping work resulting from the higher manifold pressure had to be sacrificed for the sake of more turbulence and increased vaporization.

3. It appears reasonable, as a result of the foregoing conclusion, to further conclude that if a satisfactory method could be found to properly mix the fuel and air without resorting to use of the main throttle, the efficiency curve for the main throttle could be exceeded in the low air-fuel range, and an even greater increase of efficiency in the higher air-fuel range could safely be anticipated.

As a possible method of achieving this objective, and thereby obtaining a more accurate evaluation of the merits of the individual throttle valves, it is recommended that this investigation be continued, using natural gas or some other fuel which could be properly mixed before injection.

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APPENDIX I

Diagrams and Photographs

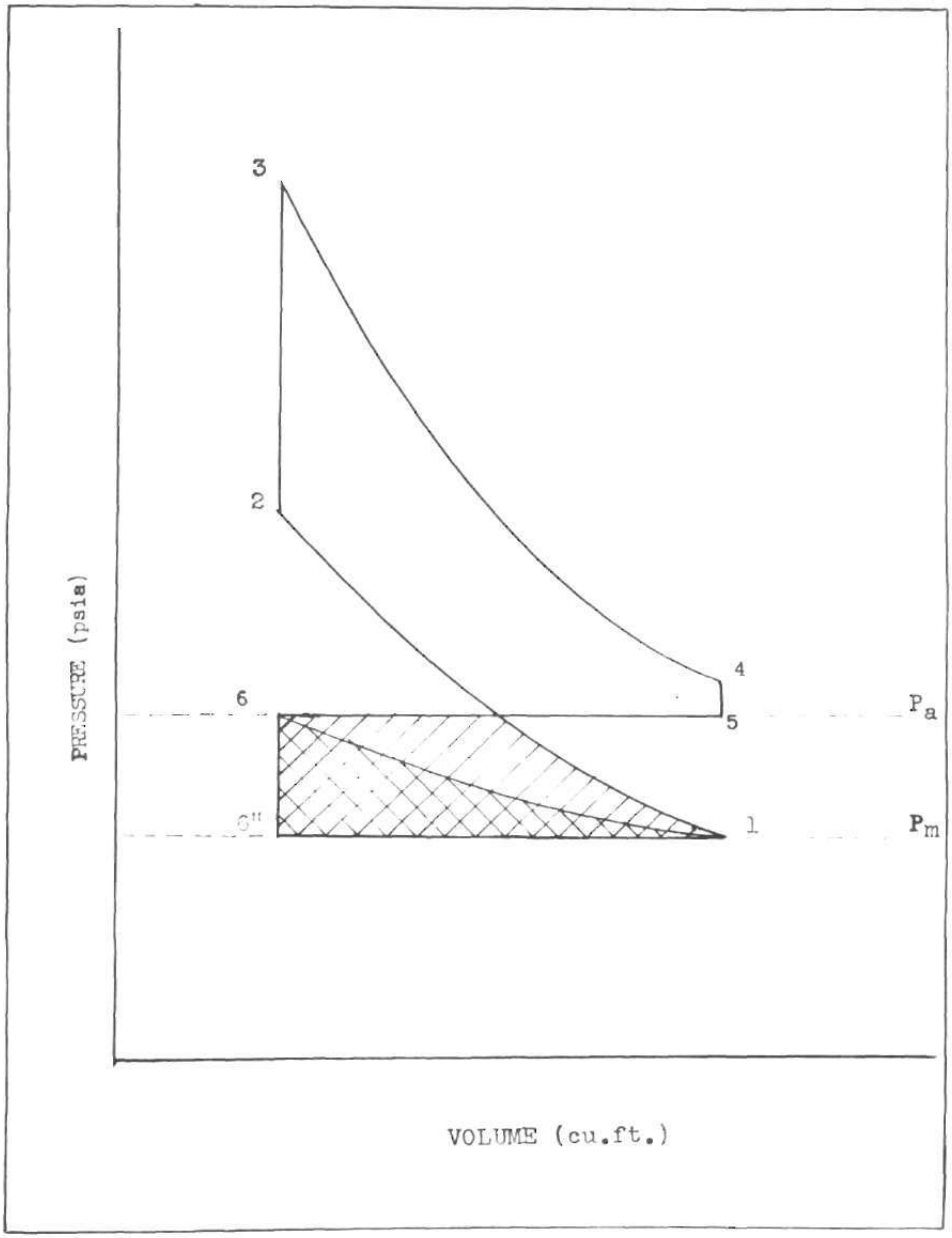


Figure 1

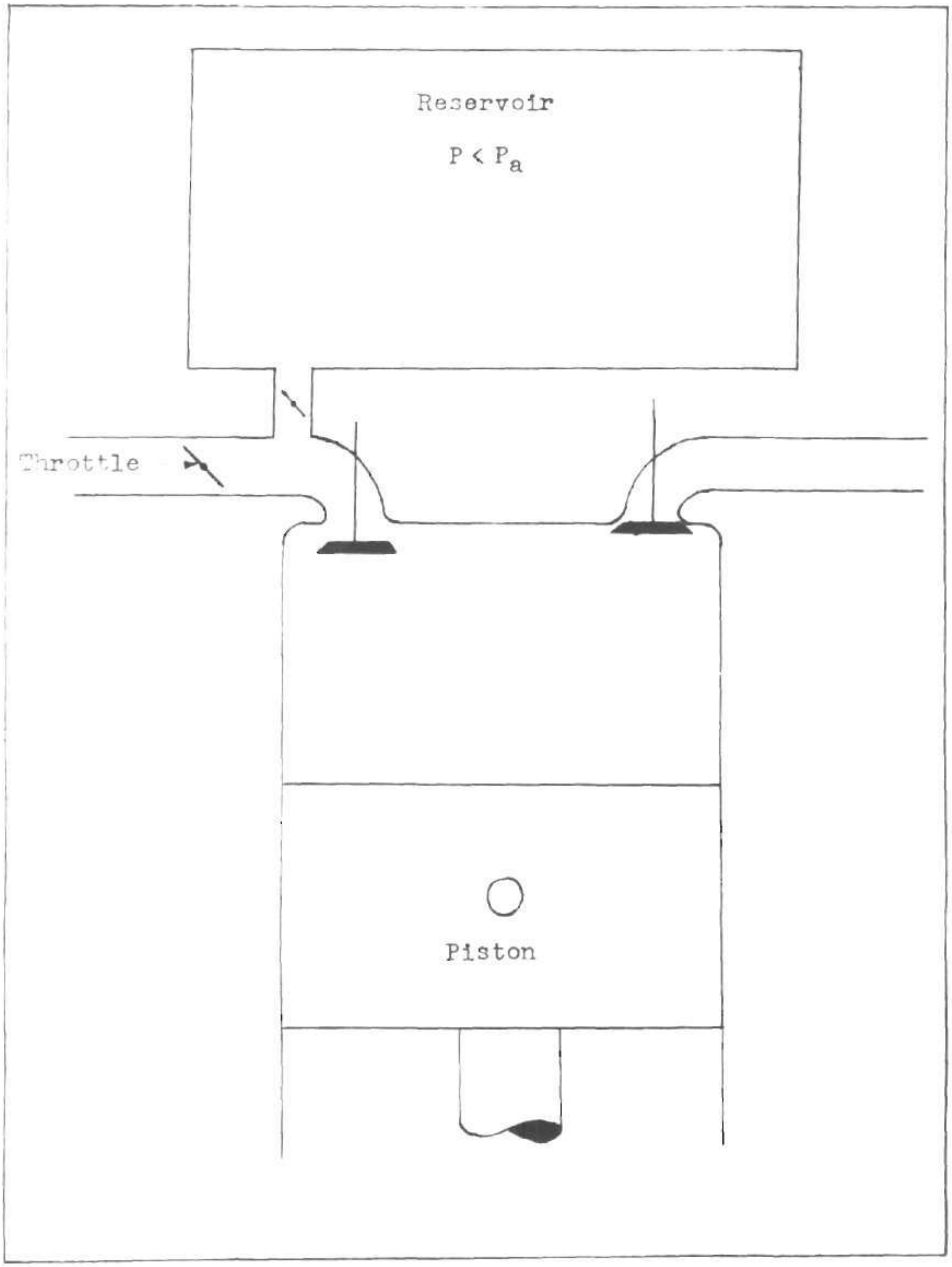


Figure 2

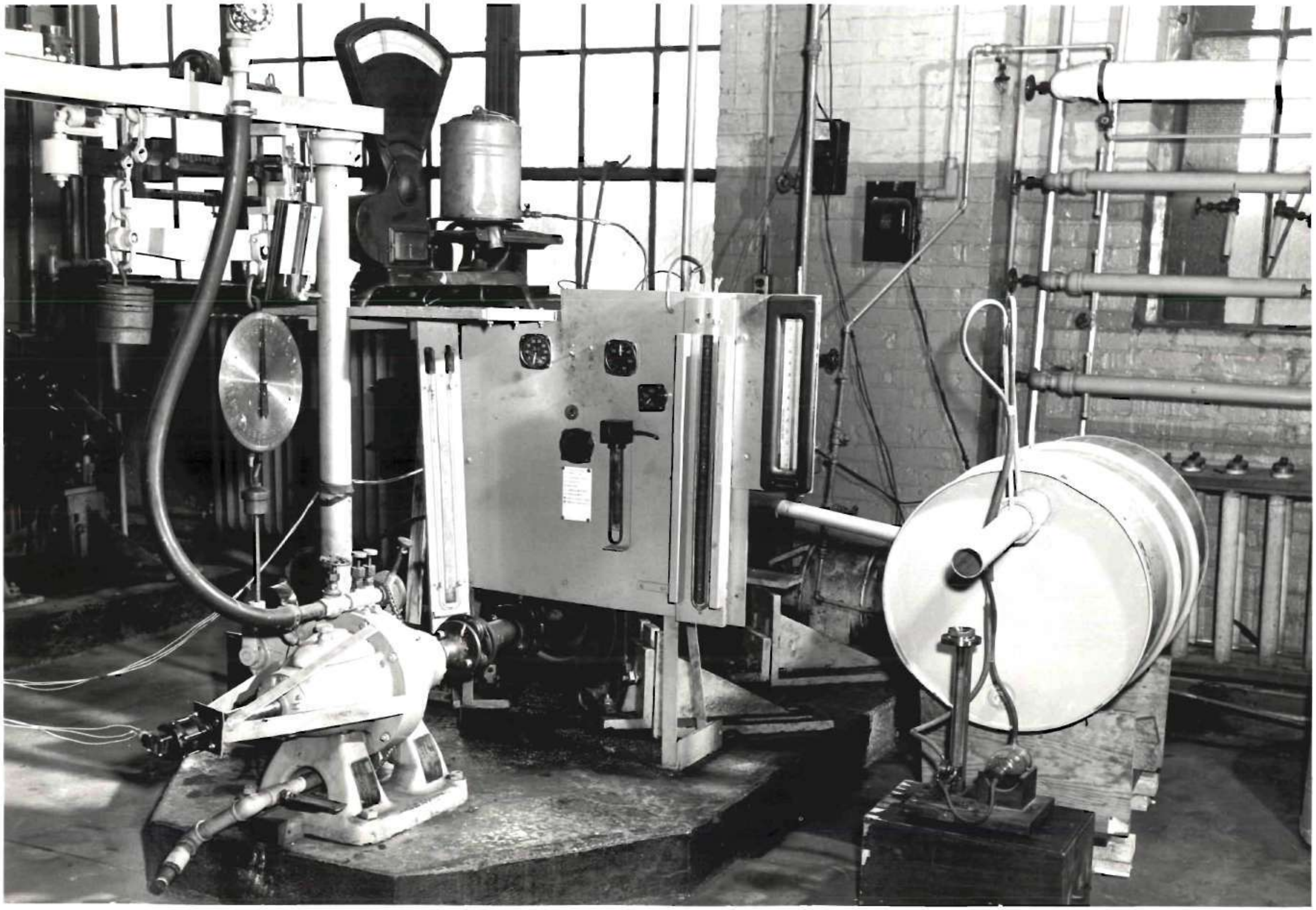


Figure 3

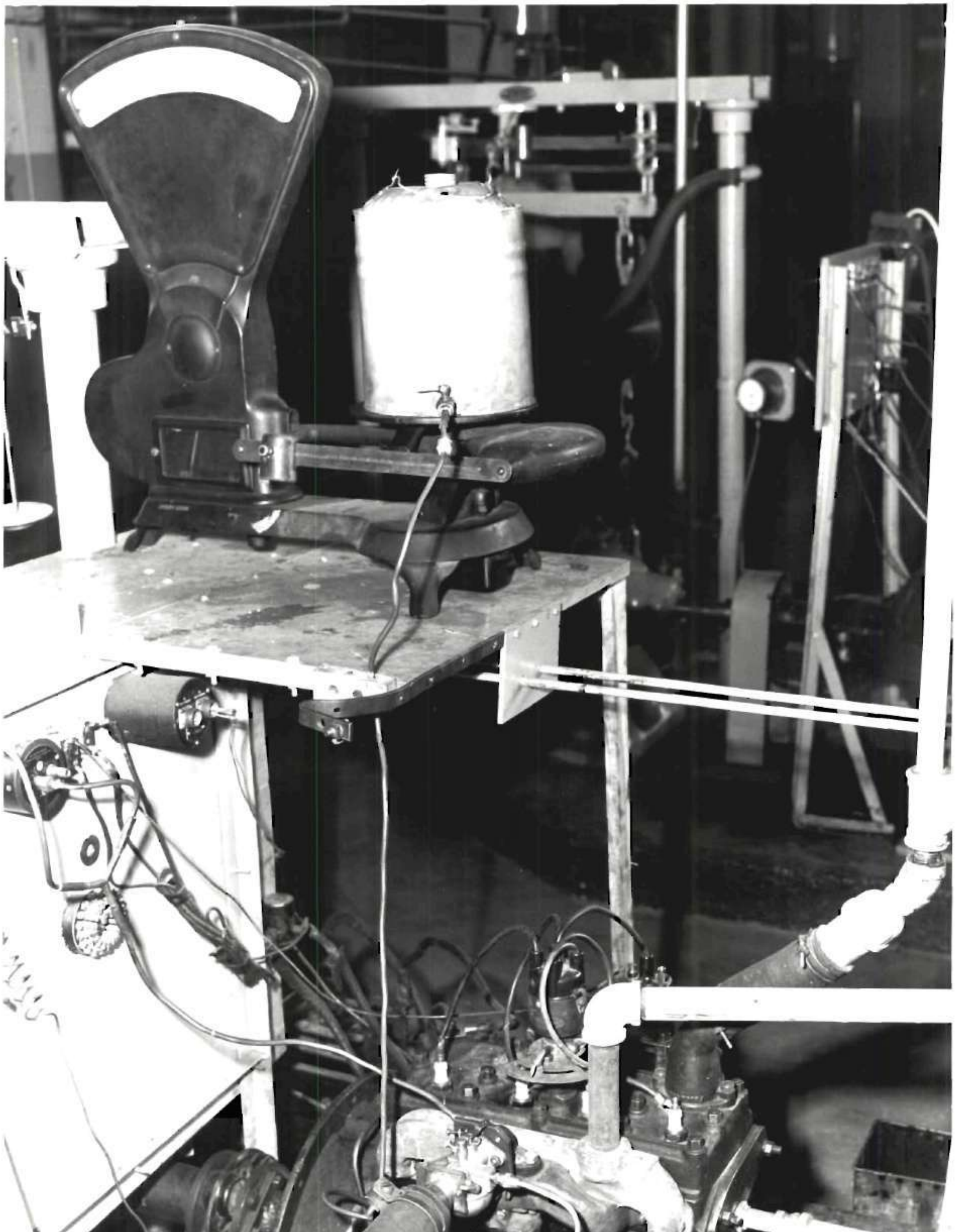


Figure 4

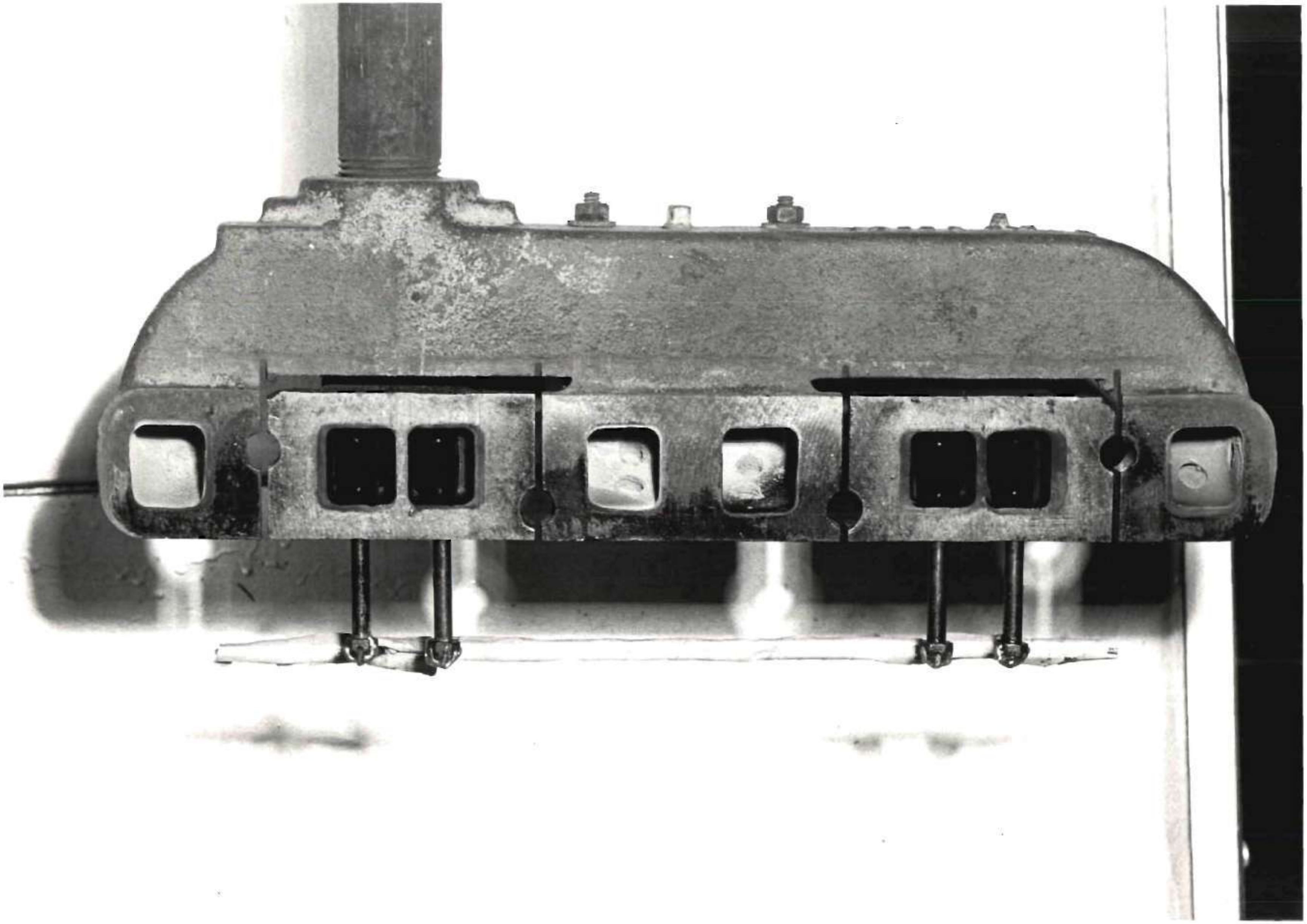


Figure 5

APPENDIX II

Tables and Curves

APPENDIX II

TABLE OBSERVED DATA REGULAR THROTTLE

Run	BP	T_a	MP	H	L	T_w	RPM
1	29.25	80	23.5	1.480	5	118	1200
2	29.25	80	19.3	0.839	5	118	1200
3	29.25	80	16.5	0.555	5	118	1200
4	29.25	80	15.0	0.424	5	118	1200
5	29.25	80	17.5	0.666	5	118	1200

OBSERVED DATA INDIVIDUAL THROTTLES

Run	BP	T_a	MP	H	L	T_w	RPM
1	29.25	80	28.5	1.430	5	119	1200
2	29.25	80	28.5	1.125	5	119	1200
3	29.25	80	28.5	0.974	5	119	1200
4	29.25	80	28.5	0.880	5	119	1200
5	29.25	80	28.5	0.907	5	119	1200

OBSERVED DATA INDIVIDUAL THROTTLES

Run	BP	T_a	MP	H	L	T_w	RPM
1	29.30	81	27.0	1.386	5	121	1200
2	29.30	81	27.0	0.825	5	121	1200
3	29.30	81	27.0	0.563	5	121	1200
4	29.30	81	27.0	0.538	5	121	1200
5	29.30	81	27.0	0.672	5	121	1200

TABLE I OBSERVED DATA INDIVIDUAL THROTTLES (Continued)

Run	BP	T_a	MP	H	L	T_w	RPM
1	29.30	81	24.0	0.833	5	121	1200
2	29.30	81	24.0	0.635	5	121	1200
3	29.30	81	24.0	0.490	5	121	1200
4	29.30	81	24.0	0.453	5	120	1200
5	29.30	81	24.0	0.647	5	120	1200

OBSERVED DATA INDIVIDUAL THROTTLES

Run	BP	T_a	MP	H	L	T_w	RPM
1	29.30	82	22.0	1.006	5	120	1200
2	29.30	82	22.0	0.507	5	120	1200
3	29.30	82	22.0	0.460	5	120	1200
4	29.30	82	22.0	0.380	5	120	1200
5	29.30	82	22.0	0.560	5	119	1200

TABLE I OBSERVED DATA INDIVIDUAL THROTTLES (Continued)

Run	BP	T_a	MP	H	L	T_w	RPM
1	29.30	80	20.0	0.870	5	119	1200
2	29.30	80	20.0	0.545	5	119	1200
3	29.30	80	20.0	0.383	5	119	1200
4	29.30	80	20.0	0.412	5	119	1200
5	29.30	80	20.0	0.515	5	119	1200

OBSERVED DATA INDIVIDUAL THROTTLES

Run	BP	T_a	MP	H	L	T_w	RPM
1	29.25	80	18.0	0.570	5	119	1200
2	29.25	80	18.0	0.470	5	118	1200
3	29.25	80	18.0	0.390	5	118	1200
4	29.25	80	18.0	0.390	5	118	1200
5	29.25	80	18.0	0.525	5	118	1200

TABLE II OBSERVED DATA REGULAR THROTTLE

Run	BP	T_a	MP	H	L	T_w	RPM
1	29.15	72	23.4	1.850	5	120	1400
2	29.15	72	18.3	0.976	5	120	1400
3	29.15	72	14.9	0.535	5	120	1400
4	29.15	72	14.5	0.510	5	120	1400
5	29.15	72	15.5	0.673	5	120	1400

OBSERVED DATA INDIVIDUAL THROTTLES

Run	BP	T_a	MP	H	L	T_w	RPM
1	29.15	72	28.4	1.670	5	120	1400
2	29.15	72	28.4	1.120	5	120	1400
3	29.15	72	28.4	1.050	5	120	1400
4	29.15	72	28.4	1.030	5	120	1400
5	29.15	72	28.4	1.250	5	120	1400

OBSERVED DATA INDIVIDUAL THROTTLES

Run	BP	T_a	MP	H	L	T_w	RPM
1	29.15	73	26.0	1.570	5	120	1400
2	29.15	73	26.0	1.167	5	120	1400
3	29.15	73	26.0	0.810	5	121	1400
4	29.15	73	26.0	0.640	5	121	1400
5	29.15	73	26.0	0.800	5	121	1400

TABLE II OBSERVED DATA INDIVIDUAL THROTTLE (Continued)

Run	BP	T_a	MP	H	L	T_w	RPM
1	29.15	73	24.0	1.480	5	121	1400
2	29.15	73	24.0	0.883	5	121	1400
3	29.15	74	24.0	0.644	5	120	1400
4	29.15	74	24.0	0.544	5	120	1400
5	29.15	74	24.0	0.691	5	120	1400

OBSERVED DATA INDIVIDUAL THROTTLES

Run	BP	T_a	MP	H	L	T_w	RPM
1	29.15	74	22.0	1.535	5	120	1400
2	29.15	74	22.0	1.130	5	119	1400
3	29.15	74	22.0	0.657	5	119	1400
4	29.15	74	22.0	0.566	5	119	1400
5	29.15	74	22.0	0.732	5	119	1400

TABLE III OBSERVED DATA REGULAR THROTTLE

Run	BP	T_a	MP	H	L	T_w	RPM
1	29.30	79	21.5	1.877	5	119	1600
2	29.30	79	16.5	0.940	5	119	1600
3	29.30	79	15.0	0.752	5	119	1600
4	29.30	79	14.8	0.684	5	119	1600
5	29.30	79	16.2	0.970	5	119	1600

OBSERVED DATA INDIVIDUAL THROTTLES

Run	BP	T_a	MP	H	L	T_w	RPM
1	29.30	79	27.0	2.930	5	119	1600
2	29.30	79	27.0	1.900	5	119	1600
3	29.30	79	27.0	1.168	5	120	1600
4	29.30	80	27.0	0.810	5	120	1600
5	29.30	80	27.0	0.880	5	120	1600
6	29.30	80	27.0	1.152	5	120	1600

TABLE III OBSERVED DATA INDIVIDUAL THROTTLES (Continued)

Run	BP	T_a	MP	H	L	T_w	RPM
1	29.30	80	26.0	1.620	5	120	1600
2	29.30	80	26.0	1.127	5	120	1600
3	29.30	80	26.0	0.740	5	120	1600
4	29.30	80	26.0	0.730	5	120	1600
5	29.30	80	26.0	0.977	5	121	1600

OBSERVED DATA INDIVIDUAL THROTTLES

Run	BP	T_a	MP	H	L	T_w	RPM
1	29.25	80	25.0	2.460	5	121	1600
2	29.25	80	25.0	1.306	5	121	1600
3	29.25	81	25.0	0.813	5	122	1600
4	29.25	81	25.0	0.660	5	122	1600
5	29.25	81	25.0	0.888	5	122	1600

TABLE IV OBSERVED DATA REGULAR THROTTLE

Run	BP	T_a	MP	H	L	T_w	RPM
1	29.20	80	21.5	2.400	5	118	1800
2	29.20	80	20.0	1.960	5	118	1800
3	29.20	80	17.0	1.270	5	118	1800
4	29.20	80	15.0	0.960	5	118	1800
5	29.20	80	16.5	1.360	5	118	1800

OBSERVED DATA INDIVIDUAL THROTTLES

Run	BP	T_a	MP	H	L	T_w	RPM
1	29.20	80	27.5	2.525	5	118	1800
2	29.20	80	28.0	1.810	5	119	1800
3	29.20	80	28.0	1.280	5	119	1800
4	29.20	81	28.0	1.410	5	119	1800
5	29.20	81	28.0	1.810	5	119	1800

OBSERVED DATA INDIVIDUAL THROTTLES

Run	BP	T_a	MP	H	L	T_w	RPM
1	29.20	81	27.0	2.810	5	119	1800
2	29.20	81	27.0	1.850	5	119	1800
3	29.20	81	27.0	1.266	5	120	1800
4	29.20	81	27.0	1.230	5	120	1800
5	29.20	81	27.0	1.575	5	120	1800

TABLE IV OBSERVED DATA INDIVIDUAL THROTTLES (Continued)

Run	BP	T_a	MP	H	L	T_w	RPM
1	29.20	81	26.0	2.710	5	120	1800
2	29.20	82	26.0	1.610	5	120	1800
3	29.20	82	26.0	1.260	5	120	1800
4	29.20	82	26.0	1.150	5	120	1800
5	29.20	82	26.0	1.570	5	120	1800

OBSERVED DATA INDIVIDUAL THROTTLES

Run	BP	T_a	MP	H	L	T_w	RPM
1	29.25	82	25.0	1.966	5	121	1800
2	29.25	82	25.0	1.330	5	121	1800
3	29.25	82	25.0	1.110	5	121	1800
4	29.25	82	25.0	1.170	5	121	1800
5	29.25	82	25.0	1.520	5	121	1800

TABLE V CALCULATED DATA REGULAR THROTTLE

Run	W_a	W_f	A/F	BHP	E_t
1	4.35	0.215	20.0	1.00	3.95
2	3.27	0.185	17.4	1.00	4.60
3	2.66	0.175	15.2	1.00	4.85
4	2.33	0.225	10.4	1.00	3.77
5	2.91	0.370	7.9	1.00	2.29

CALCULATED DATA INDIVIDUAL THROTTLES

Run	W_a	W_f	A/F	BHP	E_t
1	4.26	0.235	18.2	1.00	3.60
2	3.78	0.230	16.4	1.00	3.70
3	3.53	0.265	13.3	1.00	3.20
4	3.35	0.305	11.0	1.00	2.78
5	3.40	0.370	9.2	1.00	2.29

CALCULATED DATA INDIVIDUAL THROTTLES

Run	W_a	W_f	A/F	BHP	E_t
1	4.20	0.205	20.0	1.00	4.13
2	3.25	0.185	17.5	1.00	4.58
3	2.68	0.185	14.5	1.00	4.58
4	2.61	0.230	11.4	1.00	3.68
5	2.93	0.310	9.4	1.00	2.74

TABLE V CALCULATED DATA INDIVIDUAL THROTTLES (Continued)

Run	W_a	W_f	A/F	BHP	E_t
1	3.26	0.185	17.7	1.00	4.60
2	2.84	0.175	16.2	1.00	4.85
3	2.50	0.185	13.5	1.00	4.60
4	2.40	0.200	12.0	1.00	2.70
5	2.87	0.315	9.1	1.00	2.70

CALCULATED DATA INDIVIDUAL THROTTLES

Run	W_a	W_f	A/F	BHP	E_t
1	3.58	0.195	18.4	1.00	4.35
2	2.53	0.170	14.9	1.00	5.00
3	2.42	0.170	14.2	1.00	5.00
4	2.20	0.180	12.2	1.00	4.70
5	2.66	0.295	9.1	1.00	2.88

TABLE V CALCULATED DATA INDIVIDUAL THROTTLES (Continued)

Run	W_a	W_f	A/F	BHP	E_t
1	3.33	0.180	18.5	1.00	4.70
2	2.63	0.165	15.9	1.00	5.15
3	2.21	0.175	12.6	1.00	4.85
4	2.29	0.215	10.7	1.00	3.95
5	2.56	0.265	9.7	1.00	3.20

CALCULATED DATA INDIVIDUAL THROTTLES

Run	W_a	W_f	A/F	BHP	E_t
1	2.69	0.160	16.8	1.00	5.30
2	2.44	0.160	15.3	1.00	5.30
3	2.23	0.165	13.5	1.00	5.15
4	2.23	0.200	11.1	1.00	4.24
5	2.58	0.300	8.6	1.00	2.83

TABLE VI CALCULATED DATA REGULAR THROTTLE

Run	W_a	W_f	A/F	BHP	E_t
1	4.87	0.255	19.2	1.17	3.88
2	3.53	0.210	16.8	1.17	4.70
3	2.62	0.200	13.1	1.17	4.95
4	2.55	0.250	10.2	1.17	3.96
5	2.94	0.320	9.1	1.17	3.09

CALCULATED DATA INDIVIDUAL THROTTLES

Run	W_a	W_f	A/F	BHP	E_t
1	4.61	2.250	18.4	1.17	3.94
2	3.77	0.250	15.1	1.17	3.94
3	3.67	0.270	13.5	1.17	3.66
4	3.63	0.310	11.7	1.17	3.20
5	4.00	0.415	9.7	1.17	2.38

CALCULATED DATA INDIVIDUAL THROTTLES

Run	W_a	W_f	A/F	BHP	E_t
1	4.46	0.240	18.6	1.17	4.13
2	3.87	0.230	16.8	1.17	4.31
3	3.23	0.220	14.6	1.17	4.50
4	2.87	0.235	12.2	1.17	4.20
5	3.18	0.355	9.0	1.17	2.80

TABLE VI CALCULATED DATA INDIVIDUAL THROTTLES (Continued)

Run	W_a	W_f	A/F	BHP	E_t
1	4.35	0.235	18.5	1.17	4.22
2	3.37	0.215	15.7	1.17	4.65
3	2.87	0.215	13.3	1.17	4.65
4	2.64	0.240	11.0	1.17	4.13
5	2.98	0.335	8.9	1.17	2.95

CALCULATED DATA INDIVIDUAL THROTTLES

Run	W_a	W_f	A/F	BHP	E_t
1	4.43	0.235	18.9	1.17	4.22
2	3.80	0.215	17.6	1.17	4.60
3	2.90	0.195	14.8	1.17	5.05
4	2.69	0.220	12.2	1.17	4.50
5	3.06	0.325	9.4	1.17	3.05

TABLE VII CALCULATED DATA REGULAR THROTTLE

Run	W_a	W_f	A/F	BHP	E_t
1	4.88	0.265	18.4	1.33	4.28
2	3.46	0.220	15.7	1.33	5.13
3	3.09	0.220	14.0	1.33	5.13
4	2.95	0.260	11.4	1.33	4.35
5	3.51	0.410	8.6	1.33	2.76

CALCULATED DATA INDIVIDUAL THROTTLES

Run	W_a	W_f	A/F	BHP	E_t
1	6.10	0.315	19.4	1.33	3.60
2	4.91	0.275	17.7	1.33	4.12
3	3.85	0.245	15.7	1.33	4.60
4	3.21	0.250	12.9	1.33	4.55
5	3.35	0.310	10.8	1.33	3.65
6	3.82	0.425	9.0	1.33	2.70

TABLE VII CALCULATED DATA INDIVIDUAL THROTTLES (Continued)

Run	W_a	W_f	A/F	BHP	E_t
1	4.54	0.245	18.5	1.33	4.60
2	3.78	0.230	16.4	1.33	4.90
3	3.07	0.235	13.1	1.33	4.82
4	3.04	0.275	11.1	1.33	4.10
5	3.52	0.370	9.5	1.33	3.06

CALCULATED DATA INDIVIDUAL THROTTLES

Run	W_a	W_f	A/F	BHP	E_t
1	5.60	0.280	20.0	1.33	4.03
2	4.07	0.230	17.7	1.33	4.90
3	3.22	0.210	15.3	1.33	5.38
4	2.91	0.250	11.7	1.33	4.50
5	3.36	0.350	9.6	1.33	3.24

TABLE VIII CALCULATED DATA REGULAR THROTTLE

Run	W_a	W_f	A/F	BHP	E_t
1	5.50	0.315	17.5	1.50	4.05
2	5.00	0.300	16.7	1.50	4.25
3	4.02	0.275	14.6	1.50	4.65
4	3.50	0.300	11.7	1.50	4.25
5	4.15	0.445	9.3	1.50	2.86

CALCULATED DATA INDIVIDUAL THROTTLES

Run	W_a	W_f	A/F	BHP	E_t
1	5.65	0.290	19.5	1.50	4.40
2	4.80	0.280	17.1	1.50	4.55
3	4.03	0.295	13.7	1.50	4.32
4	4.23	0.380	11.2	1.50	3.36
5	4.80	0.490	9.8	1.50	2.60

CALCULATED DATA INDIVIDUAL THROTTLES

Run	W_a	W_f	A/F	BHP	E_t
1	5.98	0.310	19.3	1.50	4.12
2	4.85	0.280	17.3	1.50	4.55
3	4.01	0.280	14.3	1.50	4.55
4	3.95	0.360	11.0	1.50	3.54
5	4.48	0.455	9.8	1.50	2.80

TABLE VIII CALCULATED DATA INDIVIDUAL THROTTLES (Continued)

Run	W_a	W_f	A/F	BHP	E_t
1	5.88	0.300	19.6	1.50	4.25
2	4.50	0.260	17.2	1.50	5.90
3	4.00	0.275	14.5	1.50	4.65
4	3.82	0.320	11.9	1.50	4.00
5	4.47	0.480	9.4	1.50	2.65

CALCULATED DATA INDIVIDUAL THROTTLES

Run	W_a	W_f	A/F	BHP	E_t
1	5.00	0.275	18.2	1.50	4.63
2	4.10	0.255	16.1	1.50	5.00
3	3.74	0.275	13.6	1.50	4.63
4	3.85	0.360	10.7	1.50	3.54
5	4.42	0.465	9.5	1.50	2.74

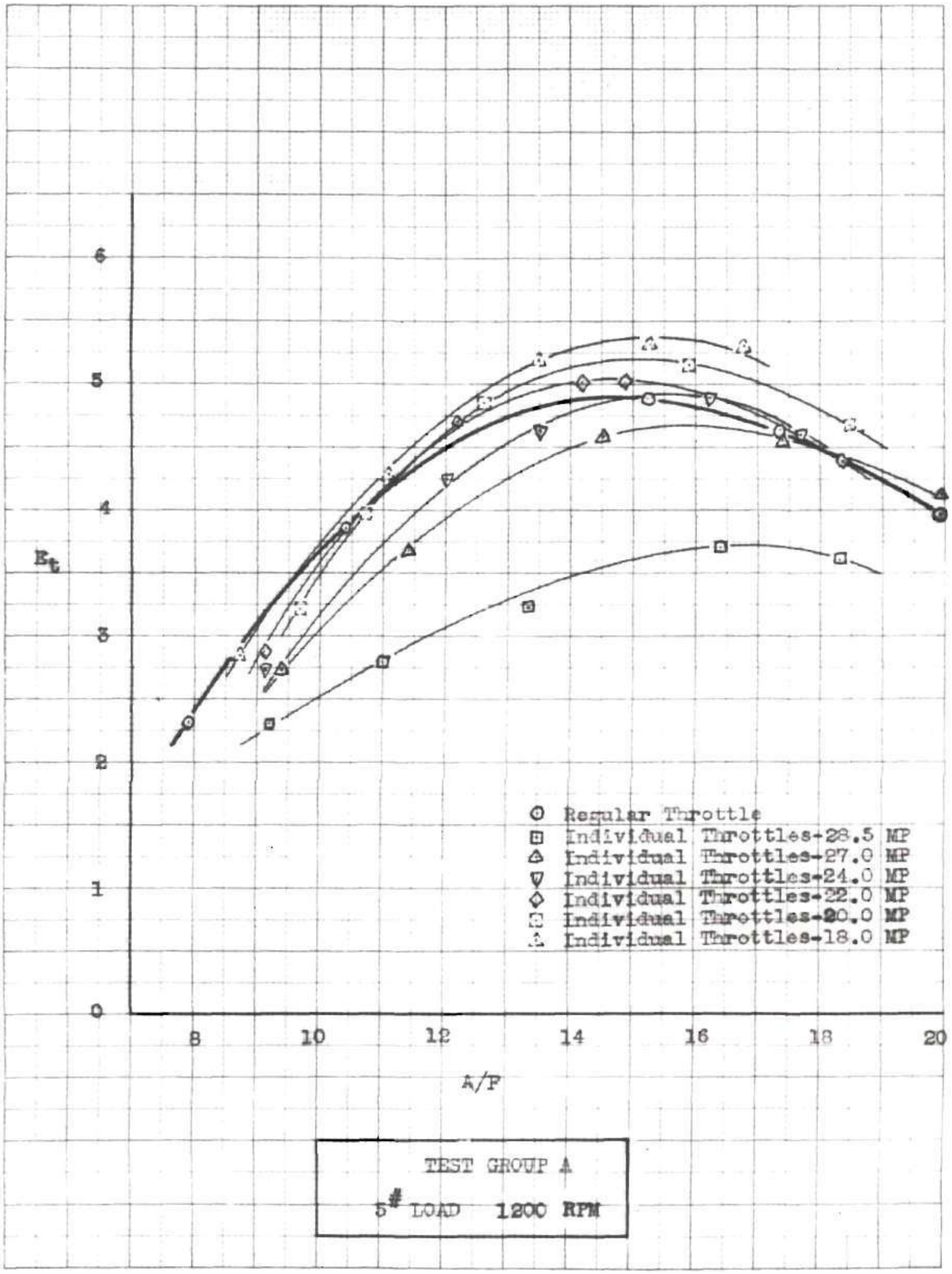

6
5
4
E_t
3
2
1
0
8
10
12
14
16
18
20
A/F
○ Regular Throttle
⊡ Individual Throttles-28.5 MP
△ Individual Throttles-27.0 MP
▽ Individual Throttles-24.0 MP
◇ Individual Throttles-22.0 MP
⊡ Individual Throttles-20.0 MP
△ Individual Throttles-18.0 MP
TEST GROUP A
5# LOAD 1200 RPM

Figure 6

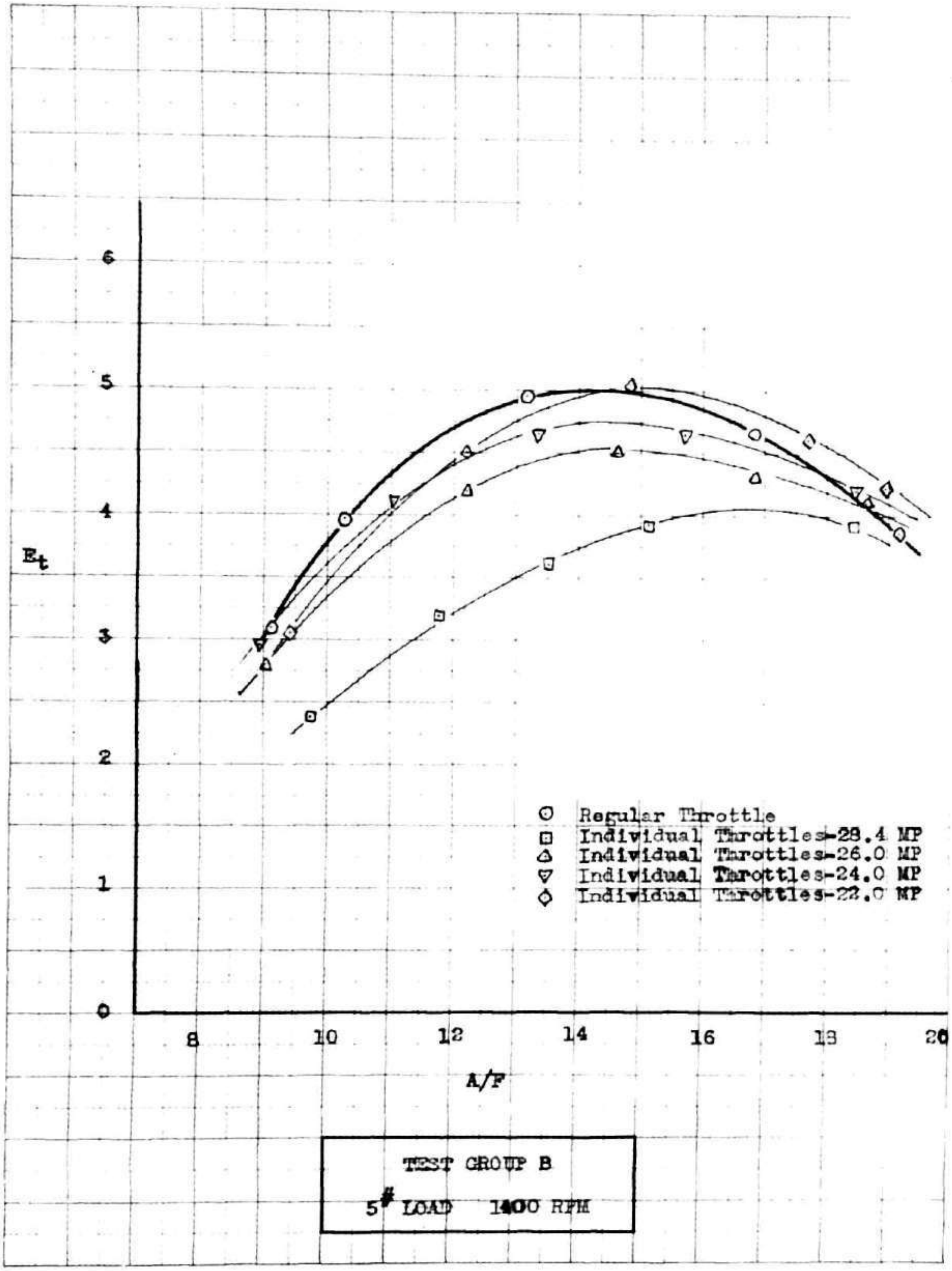
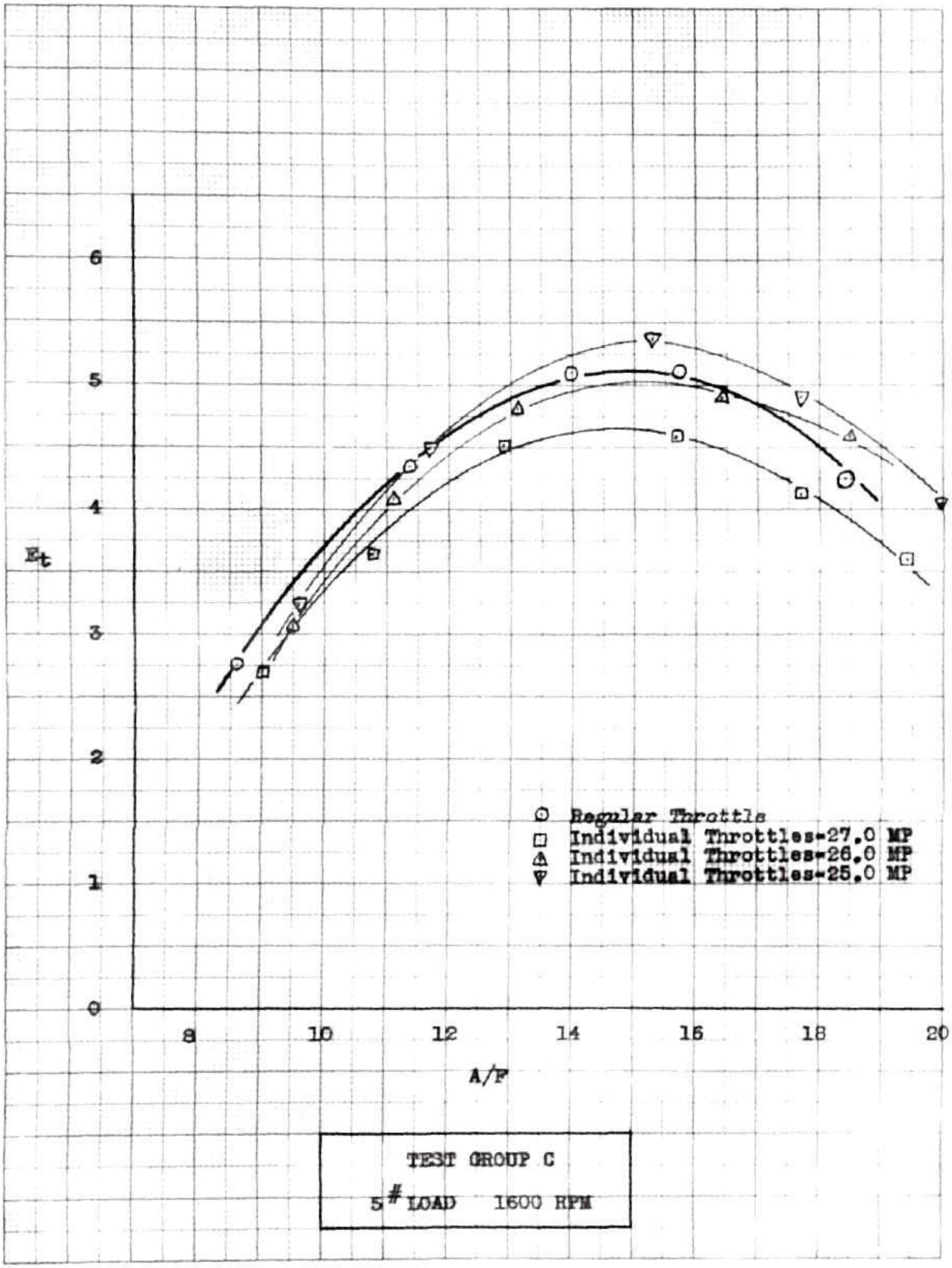

E$_t$
0
1
2
3
4
5
6
8
10
12
14
16
18
20
A/F
○ Regular Throttle
□ Individual Throttles-28.4 MP
△ Individual Throttles-26.0 MP
▽ Individual Throttles-24.0 MP
◇ Individual Throttles-22.0 MP
TEST GROUP B
5# LOAD 1400 RPM

Figure 7



6
5
4
3
2
1
0
E_t
8
10
12
14
16
18
20
A/F
⊙ Regular Throttle
□ Individual Throttles-27.0 MP
△ Individual Throttles-26.0 MP
▽ Individual Throttles-25.0 MP
TEST GROUP C
5# LOAD 1600 RPM

Figure 8

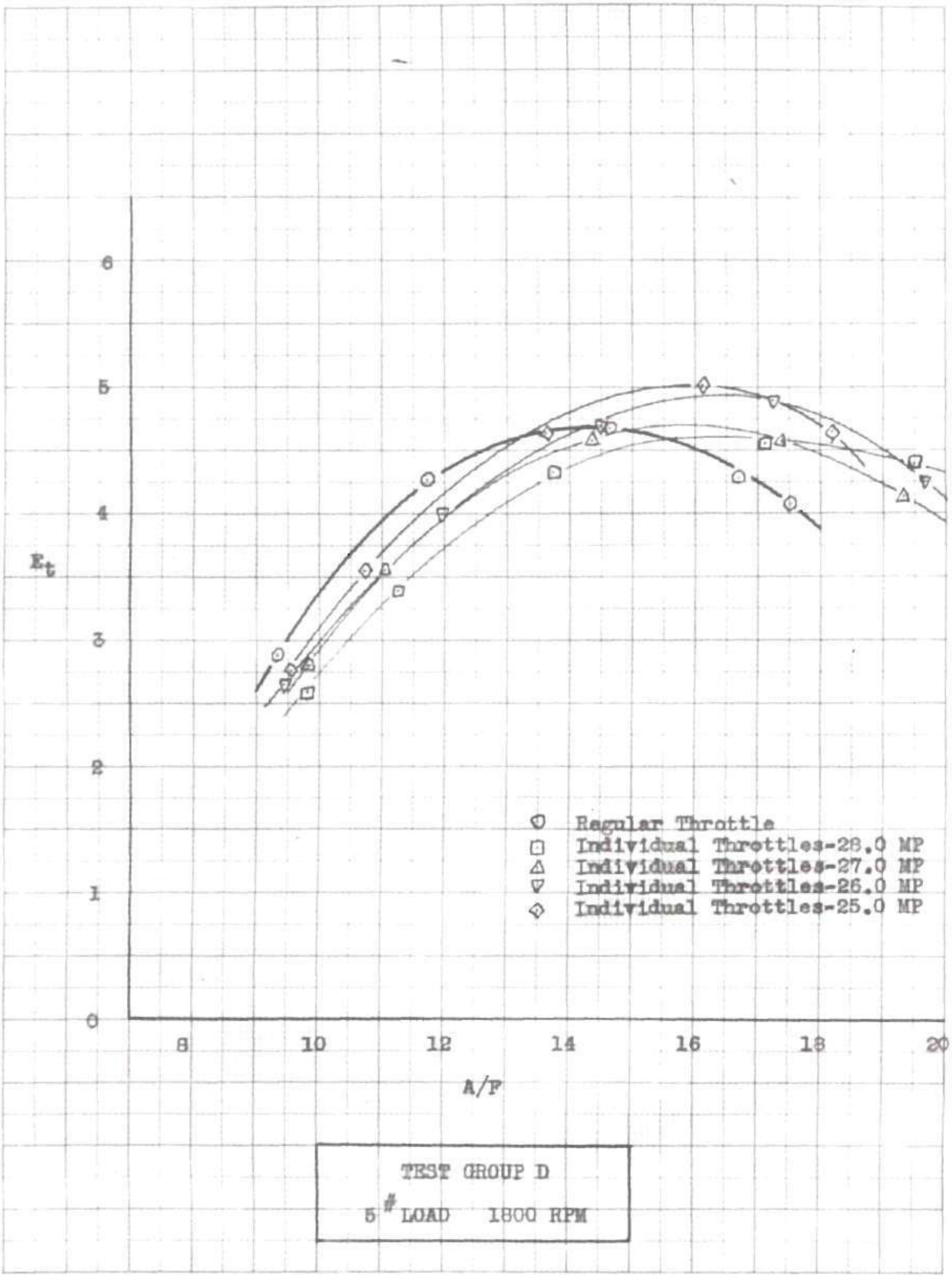

6
5
4
E_t
3
2
1
0
8
10
12
14
16
18
20
A/F
○ Regular Throttle
□ Individual Throttles-28.0 MP
△ Individual Throttles-27.0 MP
▽ Individual Throttles-26.0 MP
◇ Individual Throttles-25.0 MP
TEST GROUP D
5 # LOAD 1800 RPM

Figure 9

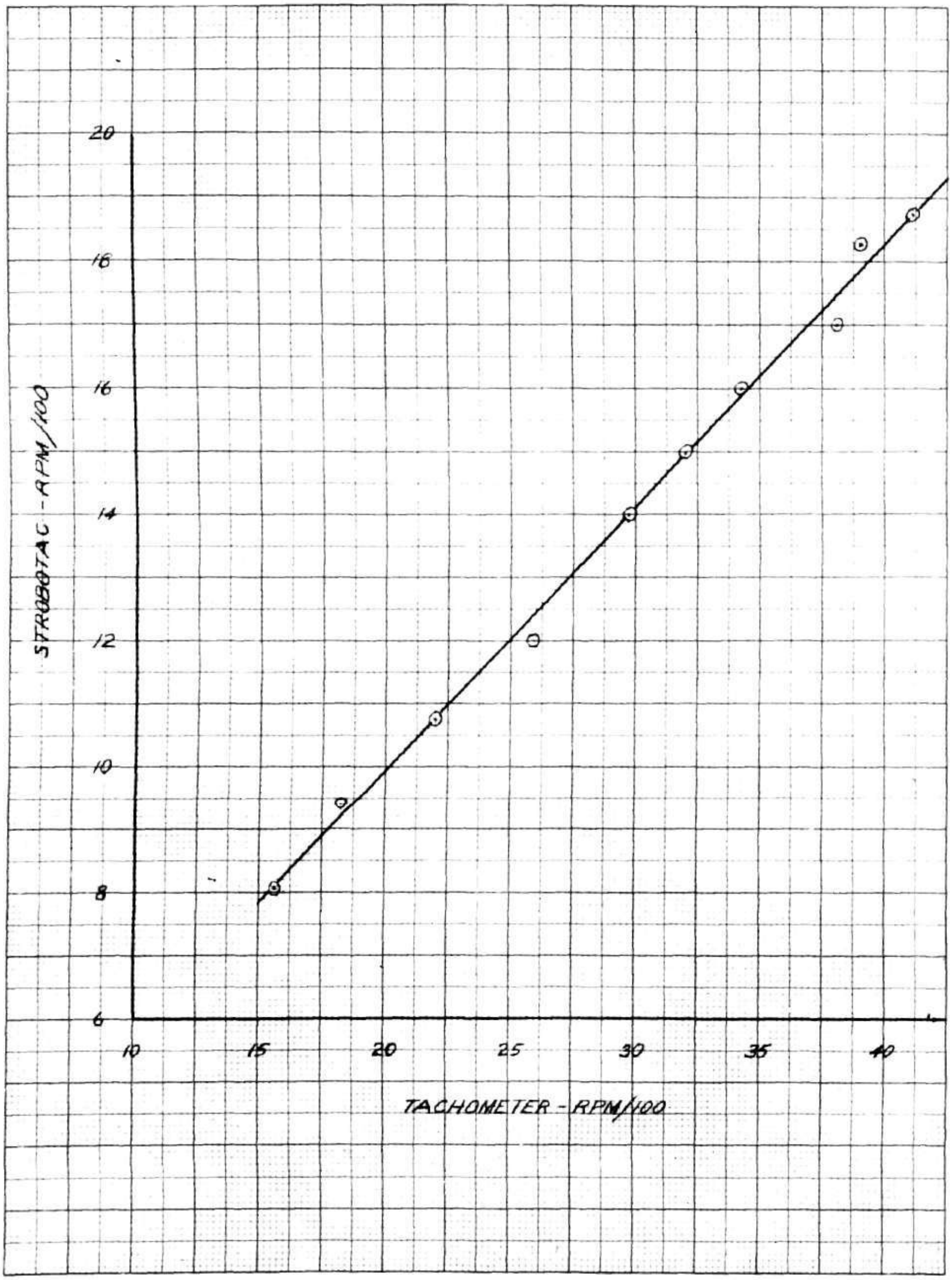

20
18
16
14
12
10
8
6
10
15
20
25
30
35
40
STROBOTAC - RPM/100
TACHOMETER - RPM/100

Figure 10

APPENDIX III

Sample Calculations

SAMPLE CALCULATIONS

BHP $\frac{\text{dynamometer load x RPM}}{6000}$

Thermal efficiency:

$$E_t = \frac{BHP \times 2545}{HV \times 15\ W_f}$$

$$E_t = \frac{1 \times 2545}{20{,}000 \times 15 \times 0.20} = 4.24\%$$

Specific weight of air:

$$(W_s)_a = \frac{BP \times 0.491}{RT}$$

$$(W_s)_a = \frac{14.3 \times 144}{53.3 \times 540} = 0.0719$$

Air flow:

$$Q = K\ a\sqrt{2\ g\ H_a}$$

$$H_a = \frac{H \times W_s}{12 \times (W_s)_a}$$

$$H_a = \frac{H \times 49.3}{12 \times 0.0719} = 56.2\ H$$

$$Q = K\ a\ \sqrt{2\ g\ 56.2\ H}$$

$$Q = 12.4\ \sqrt{H}$$

$$W_a = 12.4 \times 0.0719 \times 4\ \sqrt{H}$$

$$W_a = 3.57\ \sqrt{0.81} = 3.213$$

Air-fuel ratio:

$$A/F = \frac{W_a}{W_f}$$

$$A/F = \frac{3.213}{0.20} = 16.07$$