AIR-FUEL RATIO AND SPARK-ADVANCE REQUIREMENTS OF SPARK-IGNITION ENGINES

By

Burton Aloit Fierstine

A THESIS

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
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THESIS

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VITA

The author was born at Memphis, Michigan on April 22, 1929. At the age of five he moved with his parents to Flint, Michigan. Elementary and college preparatory education was taken in Flint schools. The author was graduated from Flint Northern High School in 1947. Advanced schooling was taken at Flint Junior College, General Motors Institute, and Michigan State College. The author received his Bachelor of Science degree from Michigan State College in 1953.

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AN ABSTRACT

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Among the first problems encountered in the experimental development of a spark-ignition engine is the attainment of a proper air-fuel ratio and correct spark-advance for all conditions under which the engine is expected to operate. There is no purely theoretical method for predicting these values of air-fuel ratio and spark-advance for a given engine and a given set of operating conditions. Hence, these values must be determined experimentally. This investigation was conducted on a single-cylinder research type engine and on a pilot model multi-cylinder V-8 type engine intended for use in the trucking industry.

In the case of the single-cylinder engine air-fuel ratios and spark-advance requirements were determined for as many conditions of relative load and engine speed as was necessary to define the complete engine requirements. The multi-cylinder engine was investigated from the standpoint of its future use in the trucking industry. Hence, air-fuel ratios and spark-advance requirements for the V-8 engine were determined only on a basis of relative load and maximum power output at various engine speeds.

The results of this investigation have led to a series of curves which depict the air-fuel ratios and spark-advance requirements necessary for proper functioning of the test engines.

It may be concluded from these results that the engines would operate and produce a power output over a range of air-fuel ratios and

spark-advances. However, there is one spark-advance for each air-fuel ratio and engine speed which produces a maximum power output from the test engine. This is the optimum-power spark-advance for each condition of load, air-fuel ratio and engine speed. There are two air-fuel ratios which may be considered most important from the standpoint of engine operation, the one at which the engine produces a maximum power output, and the one at which the engine operates at a maximum fuel economy for the power developed.

The maximum-power air-fuel ratios and the maximum-economy air-fuel ratios were determined by investigating the effect of a change in mixture ratio on the power output of the engine. To isolate this effect it was necessary to hold constant the engine speed, intake air flow, temperature, and to maintain optimum spark-advance for each mixture ratio. The maximum-power air-fuel ratio occurs at the point of maximum power output of the engine, while the maximum-economy air-fuel ratio occurs when the rate of decline of the power output per unit of mixture-ratio, as the mixture-ratio is made more lean, equals the rate of decrease of the fuel-flow per unit of mixture-ratio. Lowering the relative load level of engine operation resulted in decreasing the power output; however, the numerical value of the maximum-power air-fuel ratio remained almost unchanged. Lowering the relative engine load required a richer mixture for maximum-economy operation, until at idle conditions the maximum-economy and maximum-power mixture ratios became the same.

The effect of variations in air-fuel ratios and spark-advance upon power output is nearly the same for all spark-ignition engines. Although operational ranges and actual numerical values will vary from engine to engine the results of this investigation can be said to define a general trend which will apply to the average spark-ignition engine.

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DESCRIPTION OF EQUIPMENT

OBJECT

The object of this investigation is to determine the effect of variations in engine speed, relative load, and intended use on the air-fuel ratios and spark-advance requirements of spark-ignition engines.

INTRODUCTION

The investigation on which this paper is based is the effect of variations in engine speed, relative load, and intended use on the air-fuel ratio and spark-advance requirements of spark-ignition engines. This investigation was carried out on two engines;one of which was a single-cylinder, variable compression ratio, research type engine, the other being a multi-cylinder, V-8 type engine intended for use in the trucking industry.

The method of solution adopted for this investigation involved the measurement of air-fuel ratios and spark-advance angles over a range of constant engine speeds, constant air flows, and at different conditions of relative load.

In the case of the single-cylinder engine air-fuel ratios and spark-advance requirements were taken at four selected engine speeds, 600, 1200, 1800 and 2400 RPM, and under conditions of approximately full load, three-quarter load, one-half load, and one-quarter load. These conditions of relative load were determined from the engine intake-air flow. At each engine speed and constant air flow the fuel flow to the engine was varied through such a range as to give a air-fuel ratio variation from approximately 8:1 on the "rich" side to 20:1 on the "lean" side. A "rich" mixture is defined as one which contains more fuel than the chemically-correct mixture ratio and a "lean" mixture one which contains less fuel than the chemically-correct mixture. At each increment of fuel flow the engine spark-advance was varied to give maximum power output for the air-fuel ratio under consideration. At each increment of fuel flow the dynamometer beam load was recorded.

The results from this investigation will show the effect of variation of engine speed and relative load on the air-fuel ratios and spark-advance requirements of the engine over the operational range used. This will then give a criterion from which can be determined the maximum-power air-fuel ratio and the maximum-economy air-fuel ratio as well as the spark-advance necessary to produce the maximum power output at these conditions.

The data obtained from the multi-cylinder V-8 engine differs from the data taken from the single-cylinder engine in that it is less complete in many respects. As was stated, the purpose of the investigation of the single-cylinder engine was to determine the complete air-fuel ratios and spark-advances necessary to define the optimum spark-advance and the maximum-power and maximum-economy mixture ratios over a range of engine speeds and relative loads. However, the multi-cylinder engine was developed with a special purpose operation in view, that is, use in the trucking industry. This then defines certain conditions under which the engine will be most liable to operate. These conditions are maximum-power at various relative loads, with maximum-power at full load the most important. Hence, the investigation of the necessary air-fuel ratios and spark-advances were carried out only far enough to determine maximum-power output.

The design operating range of the multi-cylinder engine was from 800 to 3500 RPM. Air-fuel ratios and spark-advance determinations were made at increments of engine speed throughout this range. Since the most important operating condition is full-load, spark-advance requirements were determined only for this condition, using the fuel flow which gave the maximum-power output at the various increments of engine speed. Air-fuel ratio measurements were made throughout the engine speed range at full-load, three-quarter load, one-half load, and one-quarter load. Relative load was based on the engine torque output and was obtained by multiplying the above fractions by the full-load torque output of the engine. However, the air-fuel ratio was varied only far enough to determine when the point of maximum power output had been reached. Hence, at full-load the power output of the engine would be the maximum obtainable by variation of the air-fuel ratio and spark-advance. At conditions of partial load the power output of the engine would be something less than the maximum obtainable since the spark-advance is not correct for conditions of partial load.

The results of this investigation should portray the air-fuel ratio requirements for maximum power output under varying conditions of load and speed, and the spark-advance requirements for full-load operation at various engine speeds.

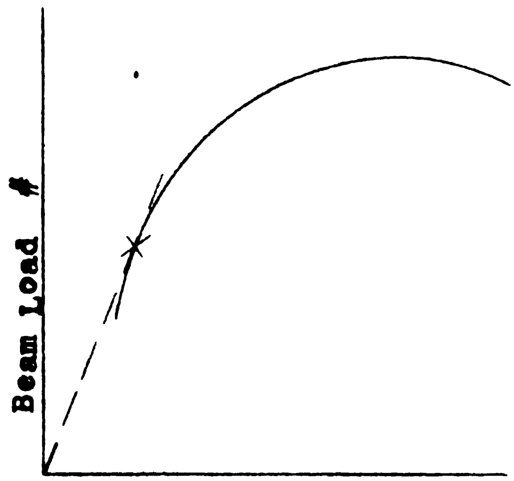
DISCUSSION OF RESULTS

Single-Cylinder Engine

The effect of air-fuel ratio on the power output of the engine at different relative loads has been portrayed in a series of curves of mixture ratio and fuel-flow versus dynamometer beam load, for a range of constant engine speeds. Each curve is drawn for a constant relative load, determined on a basis of air-flow rate, and for conditions of maximum-power or optimum spark-advance. These curves take the general shape of a decrease in beam load on either side of a maximum point, falling off rapidly as the air-fuel ratio becomes leaner than the point of maximum beam load and falling off less rapidly as the air-fuel ratio becomes richer than the point of maximum beam load. This may be explained by the fact that rich mixtures contain an excess of fuel. This excess of fuel displaces a little air, slightly decreasing the amount of oxygen available for combustion. This dilution of the mixture causes a slower combustion of the mixture and absorbs some of the combustion heat, causing a slight but noticeable decrease in the beam load and hence the power output of the engine. The mixtures leaner than the air-fuel ratio which produces a maximum beam load are diluted with an excess of air. This excess air slows the combustion rate and absorbs some of the heat of combustion and decreases the Btu per pound of air which can be produced by combustion. The combination of these effects causes a rapid drop in beam load as the air-fuel ratio grows progressively leaner.

The position of these curves is effected by relative load because the air-flow to the engine is "throttled" to attain the various load conditions. Hence, at maximum load the engine produces more power than it does at any other load. At three-quarter load it produces more power than it does at one-half load, and etc., resulting in a family of curves which are displaced vertically from one another with the maximum load being the uppermost and the least load the lowest. It should be noted that the air-fuel ratio which produces the maximum beam load for each condition of relative load is practically constant. This is explained by the fact that the conditions which cause the curve to fall off on each side of the maximum beam load point change very little as the relative load changes.

The plot of beam load as a function of the fuel-flow has provided an easy method of determining the points of maximum-power output and of maximum economy of operation for the test engine. The maximum-power output fuel-flow rate being the one which produces the maximum possible power output from the engine under the conditions at which it is operating, and the maximum-economy fuel-flow rate being the one which produces the greatest power output for the fuel consumed. Obviously, the maximum-economy is obtained by drawing a line tangent to the curve of fuel-flow versus beam load and passing through the origin. This may be proven in the following manner.



General curve of beam load as a function of fuel flow.

In order for conditions of maximum-economy to be met the ratio of

$\frac{\text{Beam Load}}{\text{Fuel-Flow Rate}}$ must be a maximum. This ratio is the slope of the tangent to any point on the curve. Hence, for maximum-economy the slope of the tangent must be a maximum. This then determines the maximum-economy fuel-flow rate and hence, the maximum-economy air-fuel mixture ratio.

In most instances of engine operation there is little reason for operating the engine on an air-fuel ratio which is leaner than the maximum-economy mixture ratio or richer than the maximum-power mixture ratio. Hence, a plot of these variables as a function of air-fuel ratio and intake air-flow has been given which shows the various maximum-power and maximum-economy mixture ratios for different engine speeds and relative loads. At the idling points the maximum-power and maximum-economy mixture ratios are the same and thus represent the intersection of the two air-fuel ratio loci curves for each constant speed. Since at higher speeds the engine's losses are greater more mixture is used to idle the engine, hence, the idle points for the various speeds do not coincide.

Probably the best criterion of engine operating economy is the amount of fuel used by the engine to produce a unit of power output. The unit of power output for most engines is the horsepower-hour. Hence, this criterion becomes the pound of fuel consumed per brake horsepower-hour. This quantity is called the "Brake Specific Fuel Consumption" and is abbreviated BSFC. A decrease in BSFC would indicate an increase in the economy of operation. Rich mixture ratios have higher values of BSFC because portions of the fuel are unburned and pass out the engine exhaust. Very lean mixture ratios, while giving a smaller fuel consumption, also result in less power output of the engine thereby increasing the BSFC. The curves of BSFC as a function of air-fuel ratio at constant engine speed, constant relative load and optimum spark-advance bear this out. It can be proven that the minimum point of each BSFC versus mixture ratio curve is the point of maximum-economy operation. If, for any given increment of air-fuel mixture ratio, the decrease in fuel flow is enough greater than the drop in the power output of the engine to cause a decrease in the ratio pounds of fuel per brake horsepower-hour, the BSFC decreases and the economy of operation increases. Since the power drops more and more rapidly as the mixture ratio becomes leaner an increment of mixture ratio is soon reached at which there is little or no change in the BSFC. For mixture ratio increments more lean than this the power output decreases more rapidly than the fuel-flow and the BSFC increases. Therefore that mixture ratio which produces the lowest value of BSFC is the maximum-economy mixture ratio for that engine speed and load.

It can be seen from the curves of BSFC versus mixture-ratio that the relative load at which the engine is operating has a decided effect on the point of maximum-economy. This may be explained by the fact that part of the energy developed by the fuel must be used to overcome the engine's internal losses. The remaining fuel produces the useful power output of the engine. These internal losses may be divided into friction losses, which vary mainly with the engine speed, and pumping losses which vary mainly as a function of the relative load level. Previous investigations have shown that the friction losses increase with the engine speed while the pumping losses increase as the relative load decreases. Thus the BSFC is less, resulting in greater fuel economy at low engine speeds and increases as the engine speed increases, while at constant engine speed the higher relative load levels produce the lowest BSFC and the lower relative loads produce higher values of BSFC. This results in a family of curves of BSFC versus mixture ratio at constant engine speed and optimum spark-advance which are displaced vertically from one another with the highest relative load having the lowest value of BSFC and the lowest relative load having the highest BSFC.

As in the case of the curves of maximum-economy and maximum-power mixture ratios plotted as a function of mixture ratio and air-flow the mixture ratio at which maximum-economy occurs decreases or becomes closer to the maximum-power mixture-ratio as the relative load decreases at constant engine speed. This occurs because of a dilution of the air-fuel mixture ratio by an inactive constituent which does not enter into the combustion process. This constituent is clearance gases which are left over from the previous combustion of the air-fuel mixture. These gases remain in the clearance volume between the top of the piston and the combustion chamber walls. Since this clearance volume is constant the amount of clearance gas remaining in the cylinder is essentially constant. Since the quantity of induced mixture varies and the clearance gas remains constant then the dilution effect of the clearance gas will vary. Thus, at low relative loads the relative clearance gas dilution is higher than at high relative loads. Hence, as the relative load decreases the air-fuel mixture ratio at maximum-economy will become richer and richer, and finally reach the maximum-power mixture ratio at idle or zero relative load.

Analysis of results in the determination of values for the spark-advance which produces the maximum-power output shows the effect of relative load, mixture ratio, and engine speed on its values, keeping the engine temperature constant. These three variables are interrelated; a change in one variable affecting the others and affecting the optimum spark-advance, abbreviated OSA. Hence, it was necessary in determining the effect of one of the three variables on OSA to hold the other two constant.

The curves of OSA as a function of relative load (in terms of air-flow-pounds per cycle) at maximum-power and the various engine speeds shows the effect of the relative purity of the mixture ratio, the relative purity being a function of the dilution effect of excess fuel, excess air, and clearance gases. These curves show that as the relative load decreases the optimum spark-advance increases, and that the optimum spark-advance increases at constant relative load as the engine speed is raised. The increase in OSA at constant speed and decreasing relative load is caused by the dilution effect of the clearance gases which decrease the flammability of the mixture. Engine speed increases OSA because the combustion of the air-fuel mixture must be started earlier if it is to go to completion shortly after the piston reaches its top-dead-center position and spread the energy release process evenly on either side of this piston-position. This is portrayed by both the plot of OSA versus relative load for maximum-power output at the various engine speeds and by the plot of OSA versus engine speed for the various relative loads at maximum-power mixture ratio.

The effect of air-fuel mixture ratio on the optimum spark-advance at the various constant engine speeds, and different relative loads is mainly a function of the relative purity of the mixture. A lean mixture is diluted with an excess of air which does not enter into the combustion but does separate the active portions of the mixture and absorbs heat from the reaction. Both of these actions decrease the rate of combustion, one by presenting an actual barrier of inert distance which impedes the progress of combustion and the other by absorbing heat from the combustion process. Hence, increasing the leanness of the mixture intensifies these effects and increases OSA. A rich mixture is diluted with excess fuel and produces the same effect although to a lesser degree.

The fuel vapor in the chemically-correct air-fuel mixture occupies only about 2% of the total mixture volume. Since the range of variation of the air-fuel ratio is small even the richest mixtures which can be used successfully in the engine will not vary greatly from this value. Hence, there is one mixture ratio for each relative load and engine speed which will be subjected to the least amount of the dilution effect and therefore will require the least amount of spark advance. As was previously discussed, the effects of the relative purity of the mixture will cause a change in OSA; with OSA increasing as the relative load is lowered at constant engine speed.

Multi-Cylinder Engine

The results obtained for the multi-cylinder engine must be approached from a slightly different angle than was used for the single-cylinder engine. However, the basic reasoning of the effect of relative load, engine speed, dilution effect, etc. will be the same for the multi-cylinder engine as it was for the single-cylinder engine.

Optimum spark-advance was determined for only full load conditions at the various engine speeds. Hence, this spark-advance is not optimum for any other conditions of load. Examination of the curve obtained shows an increase in spark-advance as the engine speed increases as did the spark-advance as a function of engine speed for the single-cylinder engine.

At full-load conditions the curves of BSFC and observed engine torque as a function of fuel-flow are shown. This shows the maximum-power output of the engine and the BSFC at this power output. These curves represent a small segment of the curves which were plotted for the single-cylinder engine and in effect determine the point of maximum power output of the engine at the various engine speeds and express the fuel consumption in terms of this power output.

Three-quarter, one-half and one-quarter load determinations were made at the appropriate constant torque output for those loads. This being the case, it was necessary to vary the throttle opening slightly to maintain the constant torque output for each engine speed. This enables the fuel consumption necessary for maximum power output to be determined on the basis of intake vacuum. Previous investigations have shown that intake vacuum is an inverse function of relative load. Hence, at low relative load the intake vacuum will be higher than at high relative load. Therefore the plotted values of intake vacuum versus BSFC and the fuel flow will determine the point of lowest relative load necessary to maintain a constant output from the engine and show what can be expected in fuel-flows at the points of lowest relative load.

This may seem to be an odd way to accomplish the determination of air-fuel ratios and spark-advances in terms of the investigation which was conducted on the single-cylinder engine. However, it must be remembered that this engine is intended for use under conditions which will call for maximum-power output almost continuously, with very little operation at conditions which might dictate the use of a maximum-economy mixture. For this reason the mixture ratio and spark-advance must be maintained at their maximum-power values at all times.

CONCLUSIONS

It may be concluded from the results of this investigation that both air-fuel ratio and spark-advance play a very important part in the determination of the maximum-power output and the economy of operation of a spark-ignition engine. It was shown that for each engine speed and constant relative load there is only one air-fuel ratio which supplies maximum-power output and one value of spark-advance which is correct or optimum for that air-fuel ratio. It was also shown that for each constant engine speed and constant relative load there is one point at which the engine is delivering a maximum amount of power for the fuel used. This maximum-economy point is a function of a value known as the Brake Specific Fuel Consumption. It was proven that the lower the value of the BSFC, the greater the economy of operation.

The level of relative load operation has probably the greatest single effect on the variations of air-fuel mixture ratio and on the spark-advance necessary for maximum power output. At the different constant engine speeds the relative load level shifts the various curves of beam load, spark-advance, and BSFC in a vertical direction, with full-load providing the greatest power output, and with decreasing values of load providing less power output. Increasing values of relative load cause a decrease in optimum spark-advance and a decrease in the BSFC, with the lowest values of load giving the highest values of OSA and BSFC.

The speed of engine operation also has a very decided effect on the power produced by the engine and on the values of BSFC and OSA. In general the slower the speed of engine operation the less was the value of OSA, BSFC, and engine power output.

From the results of the investigation conducted on the multi-cylinder engine it may be concluded that with the exception of spark-advance the air-fuel ratio has been varied to determine only the points of maximum-power output at the various engine speeds and engine output power. Optimum spark-advance was determined for only full-load operation over the speed range. It was shown from the investigation of the single-cylinder engine that this spark-advance will not be optimum for other conditions of relative load.

In general it may be concluded that air fuel ratio and spark-advance requirements have been completely determined for the single-cylinder engine over the range of engine speeds and relative loads investigated. For the multi-cylinder engine the limited range of expected operating conditions indicated that the only conditions of interest would be the maximum-power mixture ratio, and the optimum spark advance which would accompany it at full-load.

It should be pointed out that the results of this investigation apply specifically to the engines tested. However, the resulting curves which are shown can be taken as indicating a general trend for most spark-ignition engines, even though the actual numerical values will vary from engine to engine.

APPENDIX

TABLE I

SINGLE-CYLINDER ENGINE DATA SHEET

The Determination of OSA
from Beam Load

Conditions: Constant engine speed
Constant mixture ratio
Constant temperature
Full load operation

Engine Speed = 2400 RPM						
Beam Load	14.6	14.9	15.0	14.9	14.5	14.0
Spark-Advance	47°	50°	53°	56°	60°	63°

TABLE II

SINGLE-CYLINDER ENGINE DATA SHEET

Air-Fuel Ratio and Spark-Advance Data at 2400 RPM

Engine Speed RPM	Beam Load pounds	Spark Advance ° BTC	Observed Brake Horsepower	BSFC	Engine Load	Air-Flow Rate lbs./cycle	Air-Flow Rate lbs/hr.	Fuel-Flow Rate lbs./hrs.	Air-Fuel Mixture Ratio
2400	14.2	54°	6.81	1.230	Full Load		70	8.43	8.3
"	15.0	52°	7.20	0.910		.000973	70	6.55	10.7
"	14.3	52°	6.86	0.775			70	5.32	13.2
"	13.0	54°	6.24	0.749			70	4.67	15.0
"	11.4	58°	5.47	0.754			70	4.12	17.0
"	9.3	65°	4.46	0.810			70	3.61	19.4
2400	11.5	56°	5.52	1.280	3/4 Load		60	7.06	8.5
"	12.2	54°	5.86	0.949		.000834	60	5.56	10.8
"	11.6	54°	5.56	0.864			60	4.80	12.5
"	10.5	56°	5.04	0.836			60	4.21	14.3
"	8.4	62°	4.04	0.867			60	3.46	17.3
"	6.2	69°	2.98	1.103			60	3.08	19.5
2400	9.2	57°	4.42	1.287	1/2 Load		50	5.68	8.8
"	9.8	56°	4.70	0.994		.000695	50	4.67	10.7
"	9.5	56°	4.56	0.925			50	4.22	11.9
"	8.6	57°	4.13	0.909			50	3.75	13.3
"	6.7	62°	3.22	0.925			50	2.98	16.8
"	5.1	70°	2.45	1.070			50	2.62	19.1
2400	5.3	60°	2.54	1.770	1/4 Load		40	4.49	8.9
"	6.1	59°	2.93	1.278		.000556	40	3.74	10.7
"	5.9	60°	2.83	1.160			40	3.28	12.2
"	5.3	62°	2.54	1.130			40	2.87	13.9
"	4.3	65°	2.06	1.220			40	2.51	15.9
"	3.2	73°	1.51	1.462			40	2.21	18.1

TABLE III

SINGLE-CYLINDER ENGINE DATA SHEET

Air-Fuel Ratio and Spark-Advance Data at 1800 RPM

Engine Speed RPM	Beam Load pounds	Spark Advance ° BTC	Observed Brake Horsepower	BSFC	Engine Load	Air-Flow Rate lbs/cycle	Air-Flow Rate lbs/hr	Fuel-Flow Rate lbs/hr	Air-Fuel Mixture Ratio
1800	18.3	50°	6.59	1.048			58.0	6.90	8.4
"	19.3	48°	6.95	0.765	Full load	.001072	58.0	5.32	10.9
"	18.8	48°	6.76	0.697			58.0	4.71	12.3
"	17.4	49°	6.26	0.649			58.0	4.06	14.3
"	14.9	53°	5.36	0.639			58.0	3.42	16.9
"	11.9	59°	4.28	0.696			58.0	2.98	19.6
1800	14.5	54°	5.22	1.120			48.5	5.85	8.3
"	15.5	52°	5.58	0.798	3/4 load	.000899	48.5	4.45	10.9
"	14.9	52°	5.36	0.740			48.5	3.97	12.2
"	13.4	53°	4.83	0.700			48.5	3.38	14.4
"	11.1	58°	4.00	0.700			48.5	2.80	17.3
"	8.5	63°	3.06	0.788			48.5	2.41	20.1
1800	10.8	56°	3.89	1.180.			39.0	4.59	8.5
"	11.5	55°	4.14	0.872	1/2 load	.000723	39.0	3.61	10.8
"	10.9	55°	3.92	0.821			39.0	3.22	12.1
"	10.1	56°	3.63	0.791			39.0	2.87	13.6
"	8.2	60°	2.95	0.804			39.0	2.37	16.5
"	6.1	68°	2.19	0.900			39.0	1.97	19.8
1800	6.7	59°	2.42	1.380			29.5	3.32	8.9
"	7.3	58°	2.63	1.040	1/4 load	.000546	29.5	2.73	10.8
"	7.2	58°	2.59	0.962			29.5	2.49	11.9
"	6.7	59°	2.41	0.925			29.5	2.23	13.2
"	5.6	66°	2.02	0.925			29.5	1.82	16.2
"	4.2	75°	1.51	1.080			29.5	1.63	18.1

TABLE IV

SINGLE-CYLINDER ENGINE DATA SHEET

Air-Fuel Ratio and Spark-Advance Data at 1200 RPM

Engine Speed RPM	Beam Load pounds	Spark Advance ° BTC	Observed Brake Horsepower	BSFC	Engine Load	Air-Flow Rate lbs/cycle	Air-Flow Rate lbs/hr	Fuel-Flow Rate lbs/hr	Air-Fuel Mixture Ratio
1200	20.4	41°	4.90	0.940			40.0	4.60	8.7
"	21.0	40°	5.04	0.715		.00111	40.0	3.60	11.1
"	20.7	41°	4.97	0.635	Full load		40.0	3.16	12.6
"	19.1	44°	4.59	0.578			40.0	2.65	15.1
"	16.9	47°	4.06	0.572			40.0	2.32	17.2
"	14.8	51°	3.55	0.597			40.0	2.12	18.9
1200	16.3	47°	3.91	0.926			33.0	3.62	9.1
"	16.7	46°	4.01	0.740		.000918	33.0	2.97	11.1
"	16.5	46°	3.96	0.684	3/4 load		33.0	2.71	12.2
"	15.2	49°	3.65	0.608			33.0	2.22	14.9
"	13.1	53°	3.14	0.605			33.0	1.90	17.4
"	11.4	58°	2.73	0.627			33.0	1.71	19.3
1200	10.9	53°	2.62	1.150			26.5	3.01	8.8
"	11.4	51°	2.74	0.870		.000736	26.5	2.38	11.1
"	11.0	51°	2.64	0.800	1/2 load		26.5	2.11	12.5
"	10.2	53°	2.45	0.755			26.5	1.85	14.3
"	9.1	56°	2.18	0.748			26.5	1.63	16.3
"	7.1	62°	1.71	0.825			26.5	1.41	18.8
1200	7.3	57°	1.75	1.270			19.5	2.22	8.8
"	7.6	55°	1.82	0.966		.000542	19.5	1.76	11.1
"	7.2	55°	1.73	0.873	1/4 load		19.5	1.51	12.9
"	6.1	58°	1.46	0.877			19.5	1.28	15.2
"	5.2	63°	1.25	0.928			19.5	1.16	16.8
"	4.2	70°	1.01	1.040			19.5	1.05	18.6

TABLE V

SINGLE-CYLINDER ENGINE DATA SHEET

Air-Fuel Ratio and Spark-Advance Data at 600 RPM

Engine Speed RPM	Beam Load pounds	Spark Advance ° BTC	Observed Brake Horsepower	BSFC	Engine Load	Air-Flow Rate lbs/cycle	Air-Flow Rate lbs/hr	Fuel-Flow Rate lbs/hr	Air-Fuel Mixture Ratio
600	19.6	29°	2.35	0.970	Full load		19.0	2.28	8.3
"	20.3	28°	2.44	0.714		.001055	19.0	1.74	10.9
"	20.0	29°	2.40	0.608			19.0	1.46	13.0
"	19.1	33°	2.29	0.559			19.0	1.28	14.8
"	17.2	38°	2.06	0.554			19.0	1.14	16.7
"	14.4	42°	1.73	0.613			19.0	1.06	17.9
600	15.9	37°	1.91	1.005	3/4 load		15.5	1.92	8.1
"	16.5	36°	1.98	0.723		.000862	15.5	1.43	10.8
"	16.2	37°	1.94	0.630			15.5	1.22	12.6
"	14.9	42°	1.79	0.570			15.5	1.02	15.2
"	12.7	48°	1.52	0.592			15.5	0.90	17.2
"	10.5	52°	1.26	0.675			15.5	0.85	18.3
600	12.0	43°	1.44	0.993	1/2 load		12.0	1.43	8.4
"	12.2	42°	1.49	0.773		.000667	12.0	1.15	10.8
"	11.9	44°	1.43	0.671			12.0	0.96	12.5
"	9.9	52°	1.19	0.630			12.0	0.75	16.0
"	8.5	55°	1.02	0.696			12.0	0.71	16.9
"	7.7	60°	0.925	0.714			12.0	0.66	18.2
600	7.3	49°	0.876	1.255	1/4 load		9.0	1.10	8.2
"	7.7	48°	0.925	0.898		.000500	9.0	0.83	10.9
"	7.1	49°	0.852	0.775			9.0	0.66	13.6
"	5.3	58°	0.635	0.850			9.0	0.54	16.7
"	3.8	64°	0.456	1.098			9.0	0.50	18.0
"	2.8	66°	0.336	1.460			9.0	0.49	18.4

TABLE VI

MULTI-CYLINDER ENGINE DATA SHEET

Determination of Full Load Best-Power Spark-Advance

Conditions: Maximum power mixture ratio
Constant temperature
Full load operation
Engine speed constant at each RPM

Engine Speed	Observed Torque	Spark Advance	Observed Torque	Spark Advance	Observed Torque	Spark Advance
800	287.0	17°	288.0	16°	287.0	13.0°
1200	309.0	22°	310.0	21°	309.0	18.0°
1600	315.0	25.5°	316.0	24°	315.0	22.0°
1800	319.0	27.5°	320.0	26°	319.0	23.0°
2000	322.5	29.0°	323.5	27°	322.5	25.0°
2200	324.5	31.0°	325.5	29°	324.5	25.0°
2400	324.0	32.0°	325.0	30°	324.0	26.0°
2800	315.0	33.0°	316.0	31°	315.0	27.0°
3000	309.5	35.0°	310.5	32°	309.5	27.0°
3200	301.0	36.0°	302.0	33°	301.0	28.0°
3400	292.0	36.0°	293.0	33°	292.0	28.0°
3500	288.0	36.0°	289.0	33°	288.0	27.5°

TABLE VII

MULTI-CYLINDER ENGINE DATA SHEET

Full Load Operation

Engine Speed RPM	Observed Torque lb-ft	Observed Brake Horsepower	Spark Advance ° BTC	BSFC	Fuel-Flow Rate lbs/hr	Intake Vacuum in. H_2O	Throttle Opening Degrees	Air-Flow Rate lbs/hr
800	277.5	42.2	16°	0.544	23.0	1.7	W.O.T.	302.0
800	281.5	42.8	16°	0.560	24.0	1.7	W.O.T.	302.0
800	284.0	43.3	16°	0.577	25.0	1.7	W.O.T.	302.0
800	282.5	43.1	16°	0.604	26.0	1.7	W.O.T.	302.0
800	281.5	42.8	16°	0.630	27.0	1.7	W.O.T.	302.0
800	283.0	42.2	16°	0.648	28	1.7	W.O.T.	302.0
1200	303.5	69.4	21°	0.519	36.0	3.7	W.O.T.	473.0
1200	304.5	69.6	21°	0.546	38.0	3.7	W.O.T.	473.0
1200	305.5	69.8	21°	0.573	40.0	3.7	W.O.T.	473.0
1200	305.5	69.8	21°	0.587	41.0	3.7	W.O.T.	473.0
1200	304.0	69.5	21°	0.619	43.0	3.7	W.O.T.	473.0
1200	302.0	69.2	21°	0.650	45.0	3.7	W.O.T.	473.0
1600	311.0	94.7	24°	0.528	50.0	7.0	W.O.T.	652.0
1600	313.5	95.5	24°	0.545	52.0	7.0	W.O.T.	652.0
1600	314.5	95.8	24°	0.564	54.0	7.0	W.O.T.	652.0
1600	314.5	95.8	24°	0.585	56.0	7.0	W.O.T.	652.0
1600	313.5	95.5	24°	0.608	58.0	7.0	W.O.T.	652.0
1600	311.0	95.0	24°	0.631	60	7.0	W.O.T.	652

TABLE VIII

MULTI-CYLINDER ENGINE DATA SHEET

Full Load Operation

Engine Speed RPM	Observed Torque lb-ft	Observed Brake Horsepower	Spark Advance ° BTC	BSFC	Fuel-Flow Rate lbs/hr	Intake Vacuum in. H_2O	Throttle Opening Degrees	Air-Flow Rate lbs/hr
1800	314.0	107.8	26°	0.502	54.0	8.6	W.O.T.	723.0
1800	315.5	108.1	26°	0.517	56.0	8.6	W.O.T.	723.0
1800	316.5	108.5	26°	0.535	58.0	8.6	W.O.T.	723.0
1800	317.5	108.9	26°	0.551	60.0	8.6	W.O.T.	723.0
1800	316.5	108.5	26°	0.572	62.0	8.6	W.O.T.	723.0
1800	315.5	108.1	26°	0.591	64.0	8.6	W.O.T.	723.0
2000	314.0	119.7	27°	0.501	60.0	10.5	W.O.T.	806.0
2000	317.0	120.8	27°	0.514	62.0	10.5	W.O.T.	806.0
2000	318.0	121.1	27°	0.528	64.0	10.5	W.O.T.	806.0
2000	319.0	121.5	27°	0.543	66.0	10.5	W.O.T.	806.0
2000	319.0	121.5	27°	0.560	68.0	10.5	W.O.T.	806.0
2000	318.5	121.3	27°	0.576	70.0	10.5	W.O.T.	806.0
2000	318.0	121.1	27°	0.595	72.0	10.5	W.O.T.	806.0
2200	320.5	134.3	29°	0.536	72.0	12.0	W.O.T.	894.0
2200	322.0	135.0	29°	0.548	74.0	12.0	W.O.T.	894.0
2200	322.0	135.0	29°	0.564	76.0	12.0	W.O.T.	894.0
2200	321.5	134.8	29°	0.579	78.0	12.0	W.O.T.	894.0
2200	321.0	134.8	29°	0.595	80.0	12.0	W.O.T.	894.0
2200	319.5	134.1	29°	0.611	82.0	12.0	W.O.T.	894.0

TABLE IX

MULTI-CYLINDER ENGINE DATA SHEET

Full Load Operation

Engine Speed RPM	Observed Torque lb-ft	Observed Brake Horsepower	Spark Advance • BTC	BSFC	Fuel-Flow Rate lbs/hr	Intake Vacuum In. H_2O	Throttle Opening Degrees	Air-Flow Rate lbs/hr
2400	319.5	146.0	30°	0.520	76.0	14.1	W.O.T.	978.0
2400	320.0	146.2	30°	0.533	78.0	14.1	W.O.T.	978.0
2400	321.5	147.0	30°	0.545	80.0	14.1	W.O.T.	978.0
2400	321.5	147.0	30°	0.558	82.0	14.1	W.O.T.	978.0
2400	321.5	147.0	30°	0.571	84.0	14.1	W.O.T.	978.0
2400	321.0	146.8	30°	0.586	86.0	14.1	W.O.T.	978.0
2800	310.5	165.6	31°	0.513	85.0	16.3	W.O.T.	1122.0
2800	312.5	166.8	31°	0.528	88.0	16.3	W.O.T.	1122.0
2800	312.0	166.2	31°	0.547	91.0	16.3	W.O.T.	1122.0
2800	311.5	166.1	31°	0.565	94.0	16.3	W.O.T.	1122.0
2800	311.0	166.0	31°	0.585	97.0	16.3	W.O.T.	1122.0
2800	310.0	165.8	31°	0.603	100.0	16.3	W.O.T.	1122.0
3000	314.5	174.0	32°	0.517	90.0	19.8	W.O.T.	1184.0
3000	306.0	174.9	32°	0.532	93.0	19.8	W.O.T.	1184.0
3000	305.5	174.4	32°	0.550	96.0	19.8	W.O.T.	1184.0
3000	305.0	174.2	32°	0.568	99.0	19.8	W.O.T.	1184.0
3000	304.0	173.8	32°	0.587	102.0	19.8	W.O.T.	1184.0
3000	303.0	173.4	32°	0.604	105.0	19.8	W.O.T.	1184.0

TABLE X

MULTI-CYLINDER ENGINE DATA SHEET

Full Load Operation

Engine Speed RPM	Observed Torque lb/ft	Observed Brake Horsepower	Spark Advance °BTC	BSFC	Fuel-Flow Rate lbs/hr	Intake Vacuum in. H_2O	Throttle Opening Degrees	Air-Flow Rate lbs/hr
3200	295.5	180.0	33°	0.516	93.0	21.6	W.O.T.	1248.0
3200	297.5	181.2	33°	0.530	96.0	21.6	W.O.T.	1248.0
3200	298.0	181.7	33°	0.545	99.0	21.6	W.O.T.	1248.0
3200	297.0	181.0	33°	0.563	102.0	21.6	W.O.T.	1248.0
3200	296.5	180.7	33°	0.581	105.0	21.6	W.O.T.	1248.0
3200	295.5	180.5	33°	0.597	108.0	21.6	W.O.T.	1248.0
3400	286.5	185.7	33°	0.517	96.0	23.0	W.O.T.	1308.0
3400	287.5	186.1	33°	0.532	99.0	23.0	W.O.T.	1308.0
3400	288.0	186.5	33°	0.547	102.0	23.0	W.O.T.	1308.0
3400	287.0	186.1	33°	0.564	105.0	23.0	W.O.T.	1308.0
3400	287.0	186.1	33°	0.580	108.0	23.0	W.O.T.	1308.0
3400	286.5	185.7	33°	0.598	111.0	23.0	W.O.T.	1308.0
3500	283.0	188.8	33°	0.525	99.0	24.0	W.O.T.	1330.0
3500	283.5	189.0	33°	0.540	102.0	24.0	W.O.T.	1330.0
3500	284.0	192.2	33°	0.555	105.0	24.0	W.O.T.	1330.0
3500	283.0	188.8	33°	0.572	108.0	24.0	W.O.T.	1330.0
3500	282.0	188.0	33°	0.590	111.0	24.0	W.O.T.	1330.0
3500	281.0	187.8	33°		114.0	24.0	W.O.T.	1330.0

TABLE XI

MULTI-CYLINDER ENGINE DATA SHEET

Three-Quarter Load

Engine Speed RPM	Observed Torque lb-ft	Observed Brake Horsepower	Spark Advance ° BTC	BSFC	Fuel-Flow Rate lbs/hr	Intake Vacuum In. Hg.	Throttle Opening Degrees	Air-Flow Rate lbs/hr
800	213.0	32.4	16°	0.555	18.0	4.80	21.0°	298.0
800	213.0	32.4	16°	0.585	19.0	5.50	14.5°	276.0
800	213.0	32.4	16°	0.616	20.0	5.70	14.0°	243.0
800	213.0	32.4	16°	0.647	21.0	4.95	15.0°	269.0
800	213.0	32.4	16°	0.678	22.0	4.95	15.4°	283.0
800	213.0	32.4	16°	0.710	23.0	4.20	20.0°	308.0
1200	229.0	52.3	21°	0.516	27.0	5.75	26.5°	364.0
1200	229.0	52.3	21°	0.535	28.0	5.90	25.0°	347.0
1200	229.0	52.3	21°	0.555	29.0	5.95	25.0°	309.0
1200	229.0	52.3	21°	0.574	30.0	5.90	25.0°	339.0
1200	229.0	52.3	21°	0.593	31.0	5.80	26.5°	367.0
1200	229.0	52.3	21°	0.612	32.0	5.63	29.0°	392.0
1600	236.0	71.9	25°	0.515	37.0	5.60	32.0°	517.0
1600	236.0	71.9	25°	0.528	38.0	5.80	31.0°	478.0
1600	236.0	71.9	25°	0.542	39.0	6.00	30.5°	457.0
1600	236.0	71.9	25°	0.556	40.0	6.00	30.5°	468.0
1600	236.0	71.9	25°	0.570	41.0	5.90	31.0°	480.0
1600	236.0	71.9	25°	0.584	42.0	5.80	31.5°	499.0

TABLE XII

MULTI-CYLINDER ENGINE DATA SHEET

Three-Quarter Load

Engine Speed RPM	Observed Torque lb-ft	Observed Brake Horsepower	Spark Advance ° BTC	BSFC	Fuel-Flow Rate lbs/hr	Intake Vacuum in. Hg.	Throttle Opening Degrees	Air-Flow Rate lbs/hr
1800	238.0	81.5	26°	0.509	41.5	5.40	35.0°	578.0
1800	238.0	81.5	26°	0.527	43.0	5.60	34.0°	553.0
1800	238.0	81.5	26°	0.546	44.5	5.70	33.5°	531.0
1800	238.0	81.5	26°	0.564	46.0	5.70	33.5°	540.0
1800	238.0	81.5	26°	0.582	47.5	5.65	34.0°	552.0
1800	238.0	81.5	26°	0.601	49.0	5.60	34.5°	561.0
2000	239.0	91.0	27°	0.538	49.0	5.50	39.0°	640.0
2000	239.0	91.0	27°	0.560	51.0	5.60	38.0°	607.0
2000	239.0	91.0	27°	0.582	53.0	5.65	37.5°	581.0
2000	239.0	91.0	27°	0.605	55.0	5.60	37.5°	619.0
2000	239.0	91.0	27°	0.626	57.0	5.40	39.0°	641.0
2000	239.0	91.0	27°	0.648	59.0	5.15	41.0	668.0
2200	241.0	101.0	29°	0.515	52.0	5.30	39.0°	710.0
2200	241.0	101.0	29°	0.535	54.0	5.55	38.0°	659.0
2200	241.0	101.0	29°	0.555	56.0	5.55	38.0°	681.0
2200	241.0	101.0	29°	0.574	58.0	5.50	38.5°	702.0
2200	241.0	101.0	29°	0.594	60.0	5.45	39.0°	733.0
2200	241.0	101.0	29°	0.629	63.5	5.35	39.5°	770.0

TABLE XIII

MULTI-CYLINDER ENGINE DATA SHEET

Three-Quarter Load

Engine Speed RPM	Observed Torque lb-ft	Observed Brake Horsepower	Spark Advance ° BTC	BSFC	Fuel-Flow Rate lbs/hr	Intake Vacuum in. Hg.	Throttle Opening Degrees	Air-Flow Rate lbs/hr
2400	241.0	110.1	30°	0.517	57.0	5.15	43.0°	771.0
2400	241.0	110.1	30°	0.535	59.0	5.20	41.0°	743.0
2400	241.0	110.1	30°	0.554	61.0	5.25	40.5°	729.0
2400	241.0	110.1	30°	0.582	63.0	5.20	41.0°	756.0
2400	241.0	110.1	30°	0.589	65.0	5.20	41.5	781.0
2400	241.0	110.1	30°	0.618	67.0	5.20	43.5°	802.0
2800	234.0	124.9	31°	0.521	65.0	5.00	44.0°	912.0
2800	234.0	124.9	31°	0.537	67.0	5.40	43.0°	891.0
2800	234.0	124.9	31°	0.553	69.0	5.45	42.0°	859.0
2800	234.0	124.9	31°	0.568	71.0	5.45	42.0°	864.0
2800	234.0	124.9	31°	0.585	73.0	5.45	42.0°	871.0
2800	234.0	124.9	31°	0.641	80.0	5.40	43.0°	879.0
3000	229.5	131.1	32°	0.541	71.0	5.70	44.0°	964.0
3000	229.5	131.1	32°	0.557	73.0	5.75	43.5°	944.0
3000	229.5	131.1	32°	0.571	75.0	5.75	43.5°	944.0
3000	229.5	131.1	32°	0.594	78.0	5.75	43.5°	951.0
3000	229.5	131.1	32°	0.625	82.0	5.70	44.0°	958.0
3000	229.5	131.1	32°	0.665	87.0	5.65	45.5°	963.0

TABLE XIV

MULTI-CYLINDER ENGINE DATA SHEET

Three-Quarter Load

Engine Speed RPM	Observed Torque lb-ft	Observed Brake Horsepower	Spark Advance ° BTC	BSFC	Fuel-Flow Rate lbs/hr	Intake Vacuum in. Hg.	Throttle Opening Degrees	Air-Flow Rate lbs/hr
3200	223.5	136.1	33°	0.528	72.0	5.70	46.0°	1020.0
3200	223.5	136.1	33°	0.543	74.0	5.85	45.0°	991.0
3200	223.5	136.1	33°	0.565	77.0	5.90	45.0°	952.0
3200	223.5	136.1	33°	0.587	80.0	5.90	45.0°	968.0
3200	223.5	136.1	33°	0.616	84.0	5.85	45.5°	979.0
3200	223.5	136.1	33°	0.653	89.0	5.80	46.0°	987.0
3400	216.0	140.0	33°	0.543	76.0	5.85	46.5°	1064.0
3400	216.0	140.0	33°	0.564	79.0	5.95	46.0°	1015.0
3400	216.0	140.0	33°	0.585	82.0	6.00	45.5°	994.0
3400	216.0	140.0	33°	0.608	85.0	6.00	45.5°	989.0
3400	216.0	140.0	33°	0.636	89.0	5.95	46.0°	1000.0
3400	216.0	140.0	33°	0.665	93.0	5.90	47.0°	1078.0
3500	213.0	142.0	33°	0.549	78.0	5.75	47.0°	1100.0
3500	213.0	142.0	33°	0.571	81.0	6.00	46.0°	1049.0
3500	213.0	142.0	33°	0.584	83.0	6.00	46.0°	1051.0
3500	213.0	142.0	33°	0.605	86.0	6.00	46.0°	1057.0
3500	213.0	142.0	33°	0.641	91.0	5.95	46.5°	1079.0
3500	213.0	142.0	33°	0.669	95.0	5.85	47.0°	1119.0

TABLE XV

MULTI-CYLINDER ENGINE DATA SHEET

One-half Load

Engine Speed RPM	Observed Torque lb-ft	Observed Brake Horsepower	Spark Advance • BTC	BSFC	Fuel-Flow Rate lbs/hr	Intake Vacuum in. Hg.	Throttle Opening Degrees	Air-Flow Rate lbs/hr
800	142.0	21.6	16°	0.555	12.0	9.95	13.5°	184.0
800	142.0	21.6	16°	0.602	13.0	10.3	13.0°	163.0
800	142.0	21.6	16°	0.648	14.0	10.8	12.5°	159.0
800	142.0	21.6	16°	0.694	15.0	10.7	13.0°	165.0
800	142.0	21.6	16°	0.740	16.0	10.4	13.5°	177.0
800	142.0	21.6	16°	0.787	17.0	10.2	14.0	192.0
1200	153.0	35.0	21°	0.572	20.0	10.60	18.5°	276.0
1200	153.0	35.0	21°	0.600	21.0	10.75	18.0°	258.0
1200	153.0	35.0	21°	0.624	22.0	10.80	18.0°	261.0
1200	153.0	35.0	21°	0.658	23.0	10.75	18.0°	265.0
1200	153.0	35.0	21°	0.686	24.0	10.60	18.5°	272.0
1200	153.0	35.0	21°	0.716	25.0	10.35	19.0	283.0
1600	157.0	47.8	24°	0.565	27.0	10.40	23.0°	372.0
1600	157.0	47.8	24°	0.586	28.0	10.55	22.5°	367.0
1600	157.0	47.8	24°	0.606	29.0	10.60	22.5°	53.0
1600	157.0	47.8	24°	0.628	30.0	10.61	22.5°	349.0
1600	157.0	47.8	24°	0.649	31.0	10.55	22.5°	361.0
1600	157.0	47.8	24°	0.690	33.0	10.45	23.0°	383.0
1600	157.0	47.8	24°	0.774	37.0	10.25	24.0°	397.0

TABLE XVI

MULTI-CYLINDER ENGINE DATA SHEET

One-half Load

Engine Speed RPM	Observed Torque lb-ft	Observed Brake Horsepower	Spark Advance ° BTC	BSFC	Fuel-Flow Rate lbs/hr	Intake Vacuum in. Hg.	Throttle Opening Degrees	Air-Flow Rate lbs/hr
1800	159.0	54.6	26°	0.562	31.0	10.25	25.0°	429.0
1800	159.0	54.6	26°	0.586	32.0	10.35	24.5°	412.0
1800	159.0	54.6	26°	0.604	33.0	10.40	24.5°	398.0
1800	159.0	54.6	26°	0.623	34.0	10.40	24.5°	400.0
1800	159.0	54.6	26°	0.686	37.5	10.30	25.0°	415.0
1800	159.0	54.6	26°	0.732	40.0	10.25	25.5°	431.0
2000	159.5	60.8	27°	0.576	35.0	10.35	27.0°	482.0
2000	159.5	60.8	27°	0.592	36.0	10.45	26.5°	461.0
2000	159.5	60.8	27°	0.608	37.0	10.45	26.5°	463.0
2000	159.5	60.8	27°	0.641	39.0	10.40	27.0°	477.0
2000	159.5	60.8	27°	0.675	41.0	10.35	27.5°	492.0
2000	159.5	60.8	27°	0.724	44.0	10.27	28.5°	501.0
2200	161.0	67.5	29°	0.555	37.5	10.00	29.0°	543.0
2200	161.0	67.5	29°	0.578	39.0	10.20	28.5°	521.0
2200	161.0	67.5	29°	0.593	40.0	10.30	28.0°	505.0
2200	161.0	67.5	29°	0.607	41.0	10.35	28.0°	508.0
2200	161.0	67.5	29°	0.622	42.0	10.35	28.0°	512.0
2200	161.0	67.5	29°	0.652	44.0	10.30	28.5°	538.0
2200	161.0	67.5	29°	0.726	49.0	10.20	29.0°	547.0

TABLE XVII

MULTI-CYLINDER ENGINE DATA SHEET

One-half Load

Engine Speed RPM	Observed Torque lb-ft	Observed Brake Horsepower	Spark Advance ° BTC	BSFC	Fuel-Flow Rate lbs/hr	Intake Vacuum in. Hg.	Throttle Opening Degrees	Air-Flow Rate lbs/hr
2400	161.0	73.6	30°	0.591	43.5	9.90	31.0°	595.0
2400	161.0	73.6	30°	0.611	45.0	10.05	30.5°	581.0
2400	161.0	73.6	30°	0.632	46.5	10.1	30.0°	568.0
2400	161.0	73.6	30°	0.652	48.0	10.05	30.5°	579.0
2400	161.0	73.6	30°	0.680	50.0	9.90	31.0°	588.0
2400	161.0	73.6	30°	0.710	52.0	9.65	32.0°	603.0
2800	156.0	83.3	31°	0.619	51.5	10.25	32.5°	687.0
2800	156.0	83.3	31°	0.637	53.0	10.35	32.0°	659.0
2800	156.0	83.3	31°	0.655	54.5	10.35	32.0°	653.0
2800	156.0	83.3	31°	0.672	56.0	10.30	32.5°	671.0
2800	156.0	83.3	31°	0.709	59.0	10.20	33.5°	688.0
2800	156.0	83.3	31°	0.720	60.0	10.00	34.0°	698.0
3000	149.0	90.8	32°	0.595	54.0	10.45	34.0°	723.0
3000	149.0	90.8	32°	0.612	55.5	10.55	34.0°	730.0
3000	149.0	90.8	32°	0.628	57.0	10.55	34.0°	732.0
3000	149.0	90.8	32°	0.644	58.5	10.50	34.0°	734.0
3000	149.0	90.8	32°	0.672	61.0	10.50	34.0°	740.0
3000	149.0	90.8	32°	0.705	64.0	10.40	34.0°	751.0

TABLE XVIII

MULTI-CYLINDER ENGINE DATA SHEET

One-half Load

Engine Speed RPM	Observed Torque lb-ft	Observed Brake Horsepower	Spark Advance ° BTC	BSFC	Fuel-Flow Rate lbs/hr	Intake Vacuum In. Hg.	Throttle Opening Degrees	Air-Flow Rate lbs/hr
3200	149.0	90.8	33°	0.612	55.5	10.45	36.0°	758.0
3200	149.0	90.8	33°	0.628	57.0	10.55	35.5°	749.0
3200	149.0	90.8	33°	0.644	58.5	10.60	35.5°	742.0
3200	149.0	90.8	33°	0.667	60.5	10.60	35.5°	745.0
3200	149.0	90.8	33°	0.678	61.5	10.55	35.5°	756.0
3200	149.0	90.8	33°	0.699	63.5	10.40	36.0°	769.0
3400	144.0	93.3	33°	0.648	60.5	10.55	37.0°	793.0
3400	144.0	93.3	33°	0.664	62.0	10.60	36.0°	771.0
3400	144.0	93.3	33°	0.681	63.5	10.65	36.0°	759.0
3400	144.0	93.3	33°	0.708	66.0	10.60	36.0°	769.0
3400	144.0	93.3	33°	0.739	69.0	10.55	37.0°	788.0
3400	144.0	93.3	33°	0.750	70.0	10.30	37.5°	801.0
3500	142.0	95.0	33°	0.643	61.0	10.40	38.0°	841.0
3500	142.0	95.0	33°	0.674	64.0	10.55	37.5°	832.0
3500	142.0	95.0	33°	0.705	67.0	10.60	37.0°	823.0
3500	142.0	95.0	33°	0.737	70.0	10.60	37.0°	829.0
3500	142.0	95.0	33°	0.769	73.0	10.55	37.5°	836.0
3500	142.0	95.0	33°	0.800	76.0	10.45	38.0°	843.0

TABLE XIX

MULTI-CYLINDER ENGINE DATA SHEET

One-quarter Load

Engine Speed RPM	Observed Torque lb-ft	Observed Brake Horsepower	Spark Advance ° BTC	BSFC	Fuel-Flow Rate lbs/hr	Intake Vacuum in. Hg.	Throttle Opening Degrees	Air-Flow Rate lbs/hr
800	71.0	10.8	16°	0.832	9.0	15.60	9.0°	131.0
800	71.0	10.8	16°	0.879	9.5	15.75	8.0°	119.0
800	71.0	10.8	16°	0.925	10.0	15.70	8.0°	125.0
800	71.0	10.8	16°	0.970	10.5	15.60	8.5°	132.0
800	71.0	10.8	16°	1.017	11.0	15.50	9.0°	137.0
800	71.0	10.8	16°	1.065	11.5	15.42	10.0°	147.0
1200	76.5	17.5	21°	0.733	12.8	15.50	13.0°	179.8
1200	76.5	17.5	21°	0.779	13.6	16.00	12.0°	163.0
1200	76.5	17.5	21°	0.818	14.3	16.05	12.0°	154.0
1200	76.5	17.5	21°	0.847	14.8	16.00	12.0°	161.0
1200	76.5	17.5	21°	0.876	15.3	15.90	12.5°	171.0
1200	76.5	17.5	21°	0.943	16.5	15.50	14.0°	188.0
1600	78.5	24.0	24°	0.786	18.8	15.50	17.0°	252.0
1600	78.5	24.0	24°	0.815	14.5	15.80	16.0°	231.0
1600	78.5	24.0	24°	0.837	20.0	15.90	15.5°	219.0
1600	78.5	24.0	24°	0.857	20.5	15.80	16.0°	235.0
1600	78.5	24.0	24°	0.899	21.5	15.50	17.0°	251.0
1600	78.5	24.0	24°	0.938	22.5	15.25	19.0°	263.0

TABLE XX

MULTI-CYLINDER ENGINE DATA SHEET

One-quarter Load

Engine Speed RPM	Observed Torque lb-ft	Observed Brake Horsepower	Spark Advance ° BTC	BSFC	Fuel-Flow Rate lbs/hr	Intake Vacuum in. Hg.	Throttle Opening Degrees	Air-Flow Rate lbs/hr
1800	79.5	27.3	26°	0.792	21.6	15.70	17.5°	276.0
1800	79.5	27.3	26°	0.826	22.5	15.80	17.0°	263.0
1800	79.5	27.3	26°	0.844	23.0	15.80	17.0°	251.0
1800	79.5	27.3	26°	0.863	23.5	15.75	17.0°	262.0
1800	79.5	27.3	26°	0.899	24.5	15.70	17.5°	274.0
1800	79.5	27.3	26°	0.935	25.5	15.60	19.0°	281.0
2000	79.5	30.3	27°	0.777	23.5	15.75	20.0°	313.0
2000	79.5	30.3	27°	0.810	24.5	15.80	20.0°	302.0
2000	79.5	30.3	27°	0.843	25.5	15.85	19.5°	291.0
2000	79.5	30.3	27°	0.876	26.5	15.85	19.0°	283.0
2000	79.5	30.3	27°	0.909	27.5	15.80	19.5°	293.0
2000	79.5	30.3	27°	0.943	28.5	15.70	19.5°	307.0
2000	79.5	30.3	27°	0.974	29.5	15.65	20.5°	318.0
2200	80.5	33.8	29°	0.771	26.0	15.60	21.5°	342.0
2200	80.5	33.8	29°	0.800	27.0	15.70	20.5°	321.0
2200	80.5	33.8	29°	0.830	28.0	15.75	20.0°	307.0
2200	80.5	33.8	29°	0.859	29.0	15.70	20.5°	325.0
2200	80.5	33.8	29°	0.889	30.0	15.60	21.0°	335.0
2200	80.5	33.8	29°	0.918	31.0	15.33	22.0	346.0

TABLE XXI

MULTI-CYLINDER ENGINE DATA SHEET

One-quarter Load

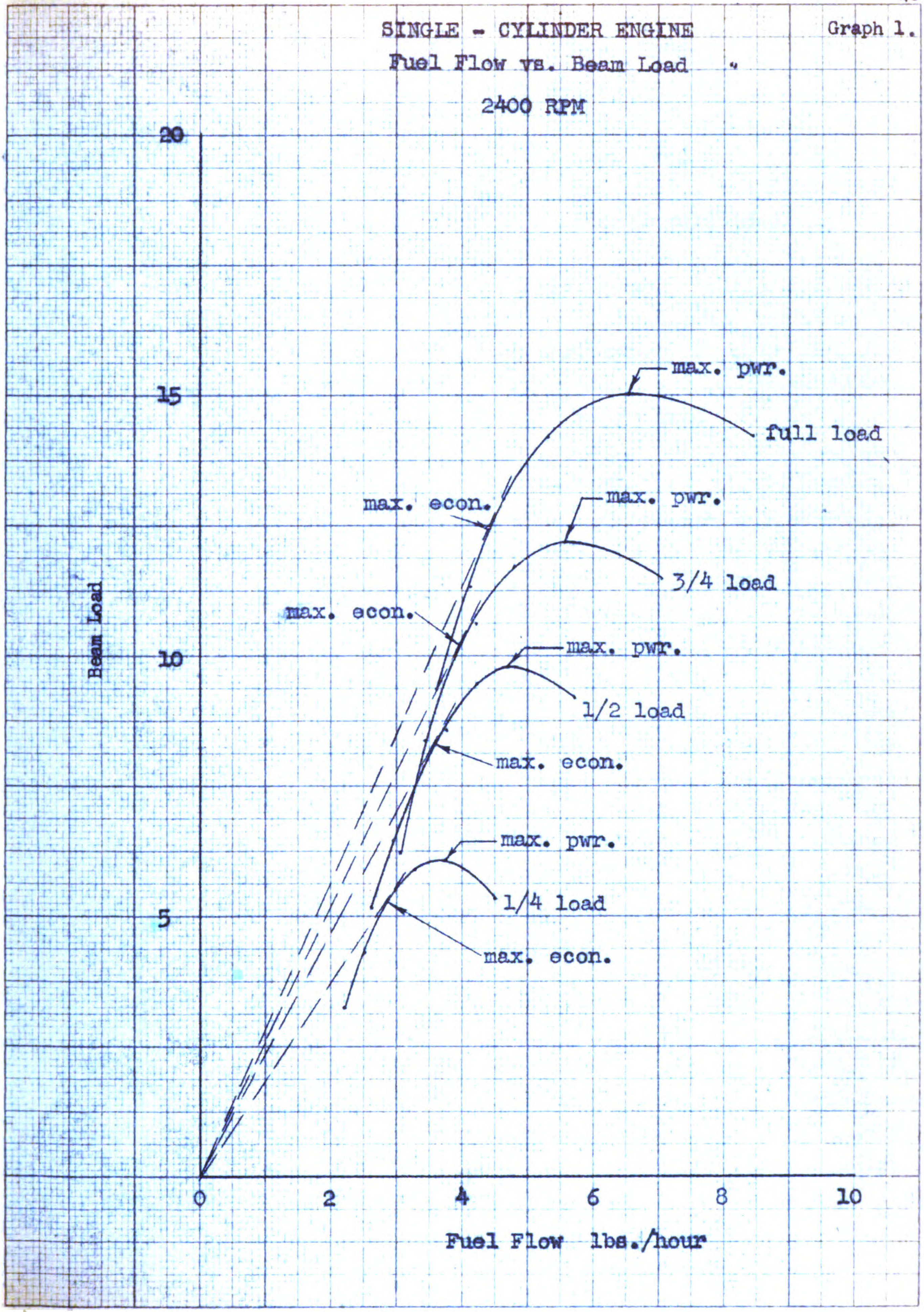
Engine Speed RPM	Observed Torque lb-ft	Observed Brake Horsepower	Spark Advance ° BTC	BSFC	Fuel-Flow Rate lbs/hr	Intake Vacuum in. Hg.	Throttle Opening Degrees	Air-Flow Rate lbs/hr
2400	80.5	36.8	30°	0.775	28.5	15.45	21.5°	377.0
2400	80.5	36.8	30°	0.802	29.5	15.50	21.5°	358.0
2400	80.5	36.8	30°	0.830	30.5	15.55	21.0°	349.0
2400	80.5	36.8	30°	0.857	31.5	15.50	21.5°	361.0
2400	80.5	36.8	30°	0.898	33.0	15.40	22.0°	381.0
2800	78.0	41.7	31°	0.791	33.0	15.10	25.5°	482.0
2800	78.0	41.7	31°	0.815	34.0	15.25	25.0°	471.0
2800	78.0	41.7	31°	0.839	35.0	15.30	24.5°	461.0
2800	78.0	41.7	31°	0.863	36.0	15.35	24.0°	449.0
2800	78.0	41.7	31°	0.899	37.5	15.30	24.5°	465.0
2800	78.0	41.7	31°	0.935	39.0	15.25	25.0°	483.0
2800	78.0	41.7	31°	1.030	43.0	15.20	26.0°	490.0
3000	76.5	43.9	32°	0.820	36.0	15.15	26.5	491.0
3000	76.5	43.9	32°	0.843	37.0	15.20	26.0	480.0
3000	76.5	43.9	32°	0.865	38.0	15.25	25.5°	468.0
3000	76.5	43.9	32°	0.890	39.0	15.25	25.5°	479.0
3000	76.5	43.9	32°	0.924	40.5	15.20	26.0°	488.0
3000	76.5	43.9	32°	1.002	44.0	15.05	27.0°	496.0

TABLE XXII

MULTI-CYLINDER ENGINE DATA SHEET

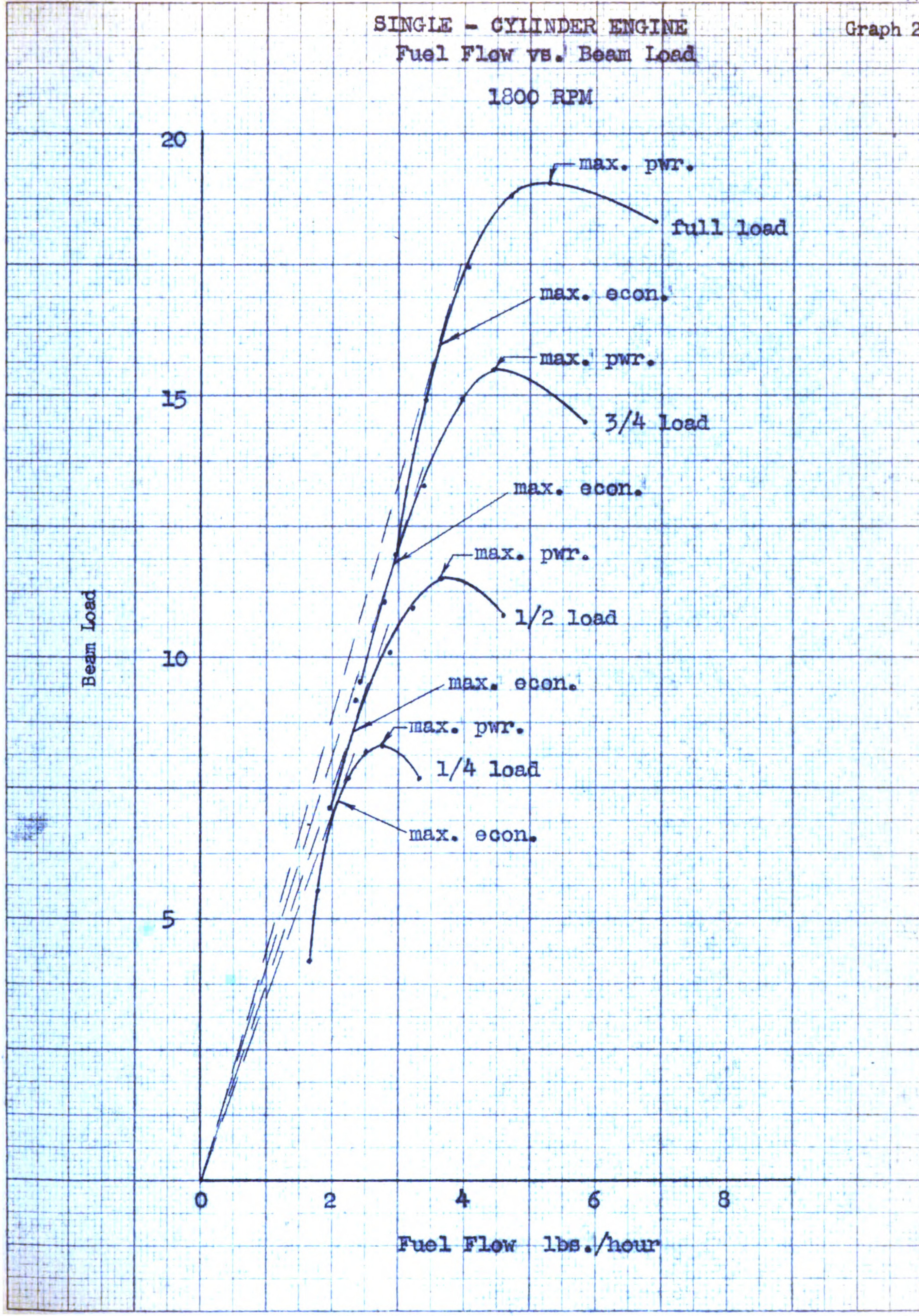
One-quarter Load

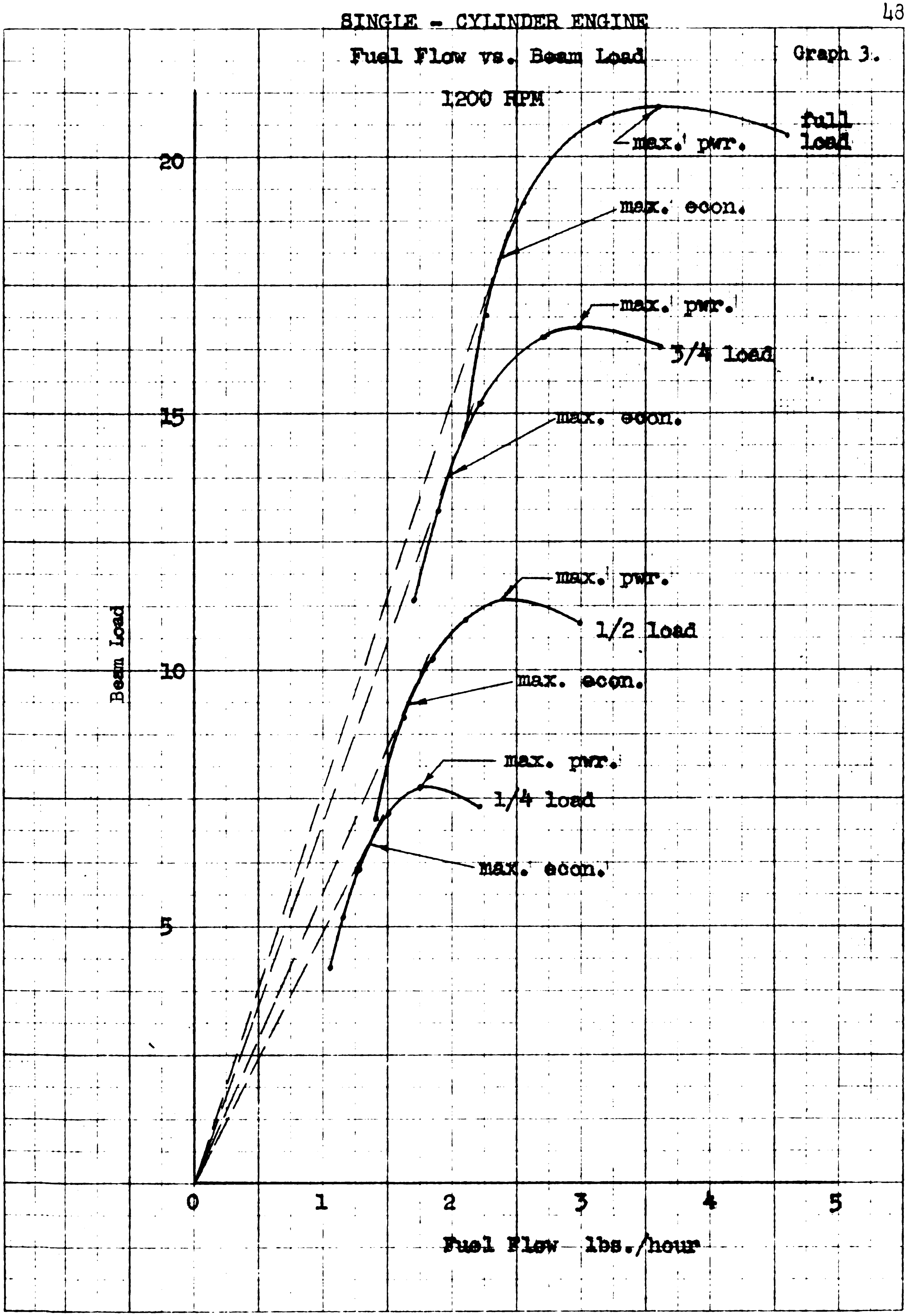
Engine Speed RPM	Observed Torque lb-ft	Observed Brake Horsepower	Spark Advance ° BTC	BSFC	Fuel-Flow Rate lbs/hr	Intake Vacuum in. Hg.	Throttle Opening Degrees	Air-Flow Rate lbs/hr
3200	74.5	45.5	33°	0.857	39.0	15.10	28.0°	534.0
3200	74.5	45.5	33°	0.880	40.0	15.25	27.5°	517.0
3200	74.5	45.5	33°	0.901	41.0	15.30	27.0°	508.0
3200	74.5	45.5	33°	0.924	42.0	15.25	27.0°	513.0
3200	74.5	45.5	33°	0.967	44.0	15.20	27.5°	531.0
3200	74.5	45.5	33°	1.055	48.0	15.0	29.0°	547.0
3400	72.0	46.8	33°	0.897	42.0	15.10	28.5°	560.0
3400	72.0	46.8	33°	0.919	43.0	15.15	28.0°	549.0
3400	72.0	46.8	33°	0.940	44.0	15.25	27.5°	541.0
3400	72.0	46.8	33°	0.972	45.5	15.20	27.5°	547.0
3400	72.0	46.8	33°	1.015	47.5	15.15	28.0°	554.0
3400	72.0	46.8	33°	1.070	50.0	15.05	29.0°	565.0
3500	71.0	47.5	33°	0.885	42.0	15.05	29.0	583.0
3500	71.0	47.5	33°	0.916	43.5	15.15	28.5	572.0
3500	71.0	41.5	33°	0.947	45.0	15.20	28.0	568.0
3500	71.0	47.5	33°	0.979	46.5	15.15	28.0	573.0
3500	71.0	47.5	33°	1.031	49.0	15.05	28.5	579.0
3500	71.0	47.5	33°	1.115	53.0	14.85	29.5	587.0



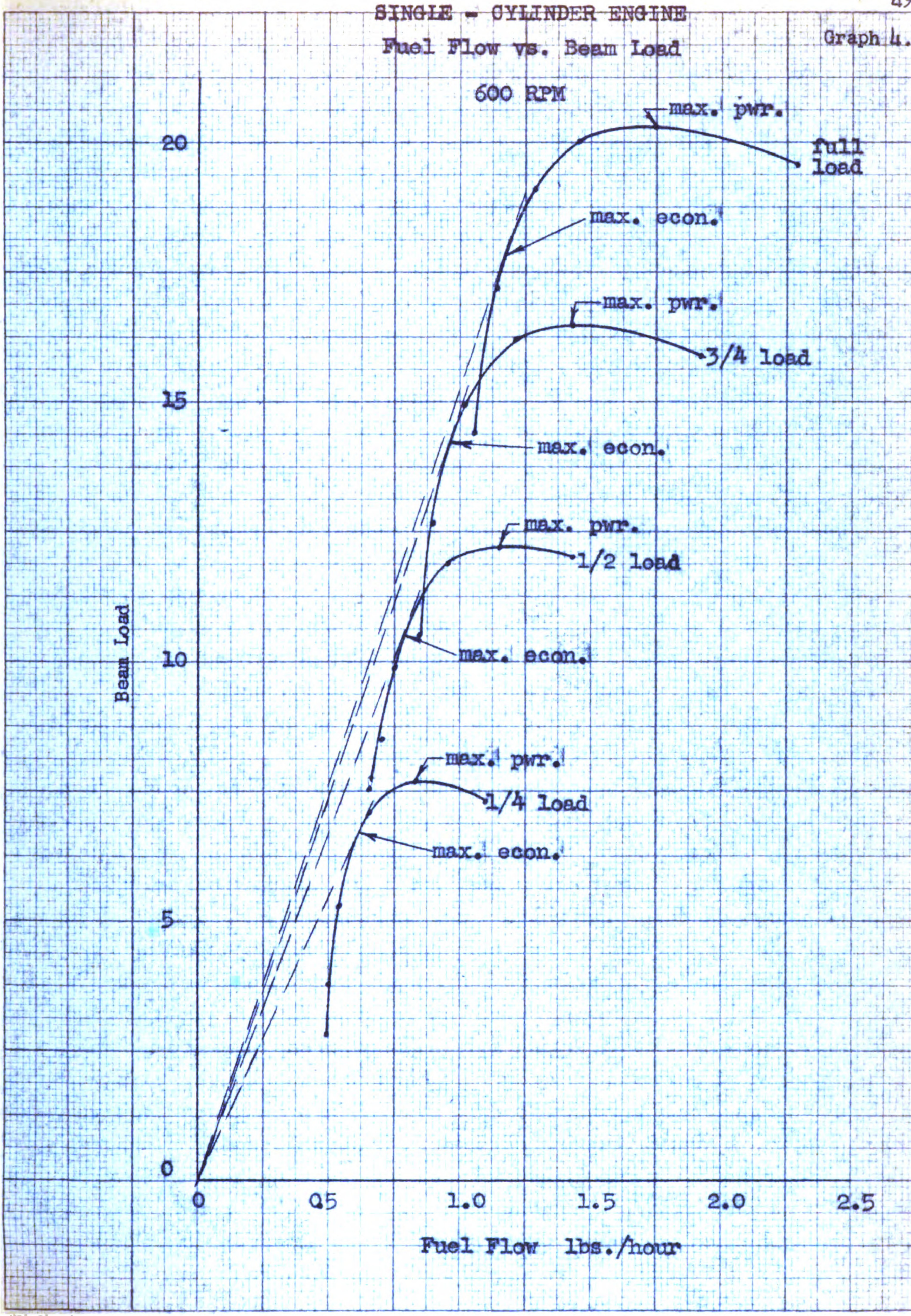
SINGLE - CYLINDER ENGINE
Graph 1.
Fuel Flow vs. Beam Load
2400 RPM
Beam Load
20
15
10
5
0
2
4
6
8
10
max. pwr.
full load
max. econ.
max. pwr.
3/4 load
max. econ.
max. pwr.
1/2 load
max. econ.
max. pwr.
1/4 load
max. econ.
Fuel Flow lbs./hour

Graph 2.

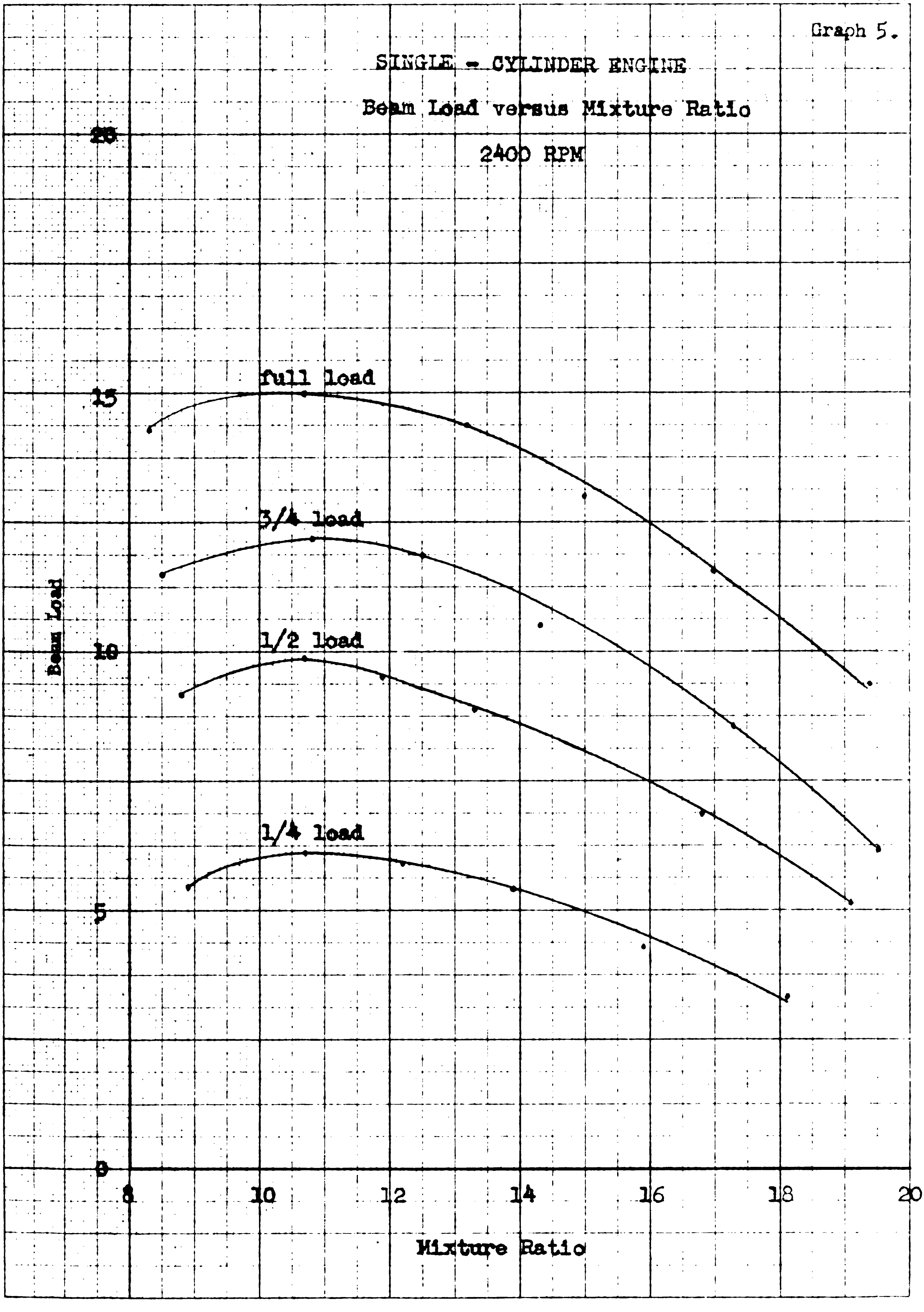

SINGLE - CYLINDER ENGINE
Fuel Flow vs. Beam Load
1800 RPM
Beam Load
Fuel Flow lbs./hour
0
2
4
6
8
5
10
15
20
max. pwr.
full load
max. econ.
max. pwr.
3/4 load
max. econ.
max. pwr.
1/2 load
max. econ.
max. pwr.
1/4 load
max. econ.

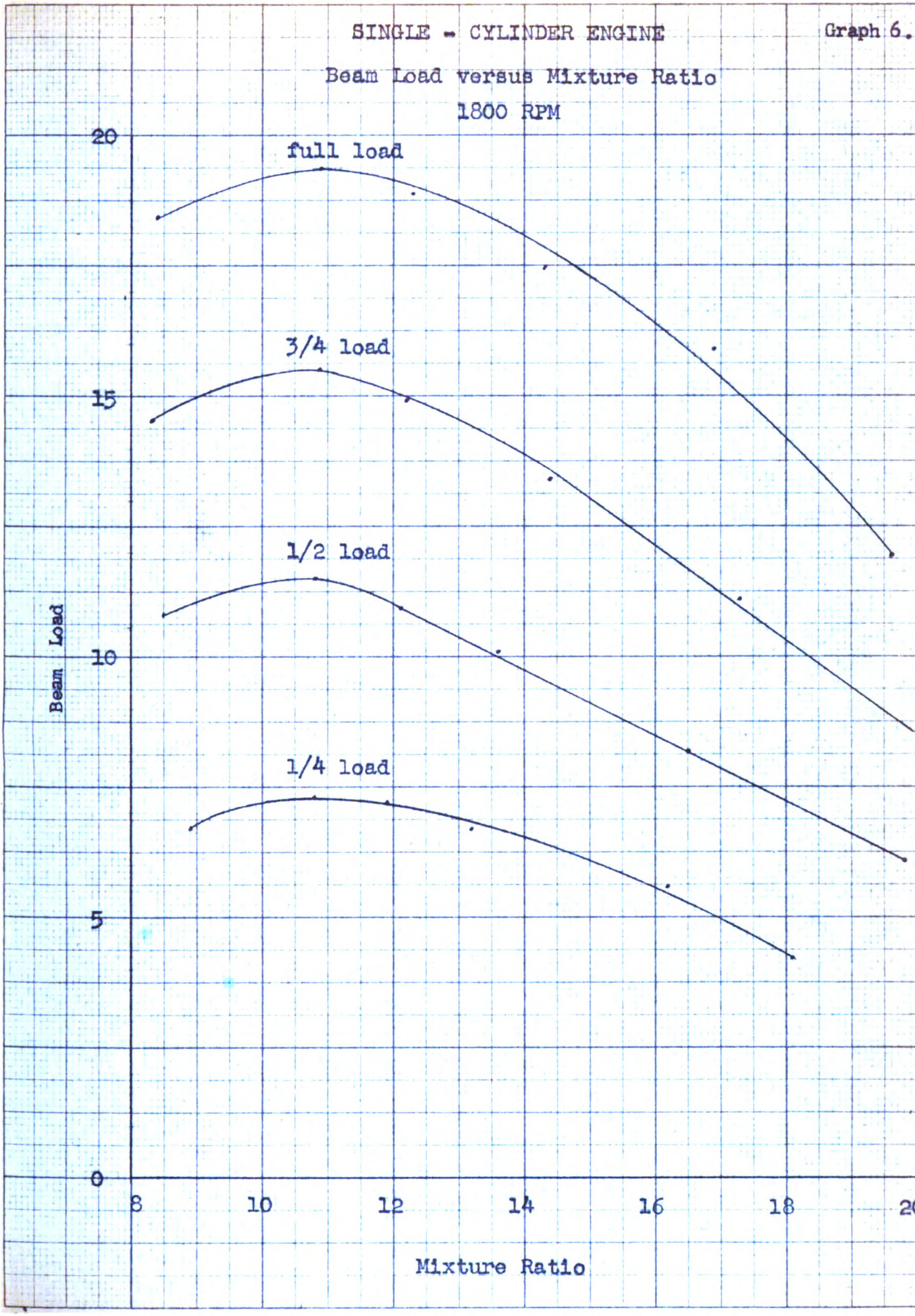

SINGLE - CYLINDER ENGINE
Fuel Flow vs. Beam Load
1200 RPM
Graph 3.
full load
max. pwr.
max. econ.
max. pwr.
3/4 load
max. econ.
max. pwr.
1/2 load
max. econ.
max. pwr.
1/4 load
max. econ.
Beam Load
20
15
10
5
0
1
2
3
4
5
Fuel Flow lbs./hour

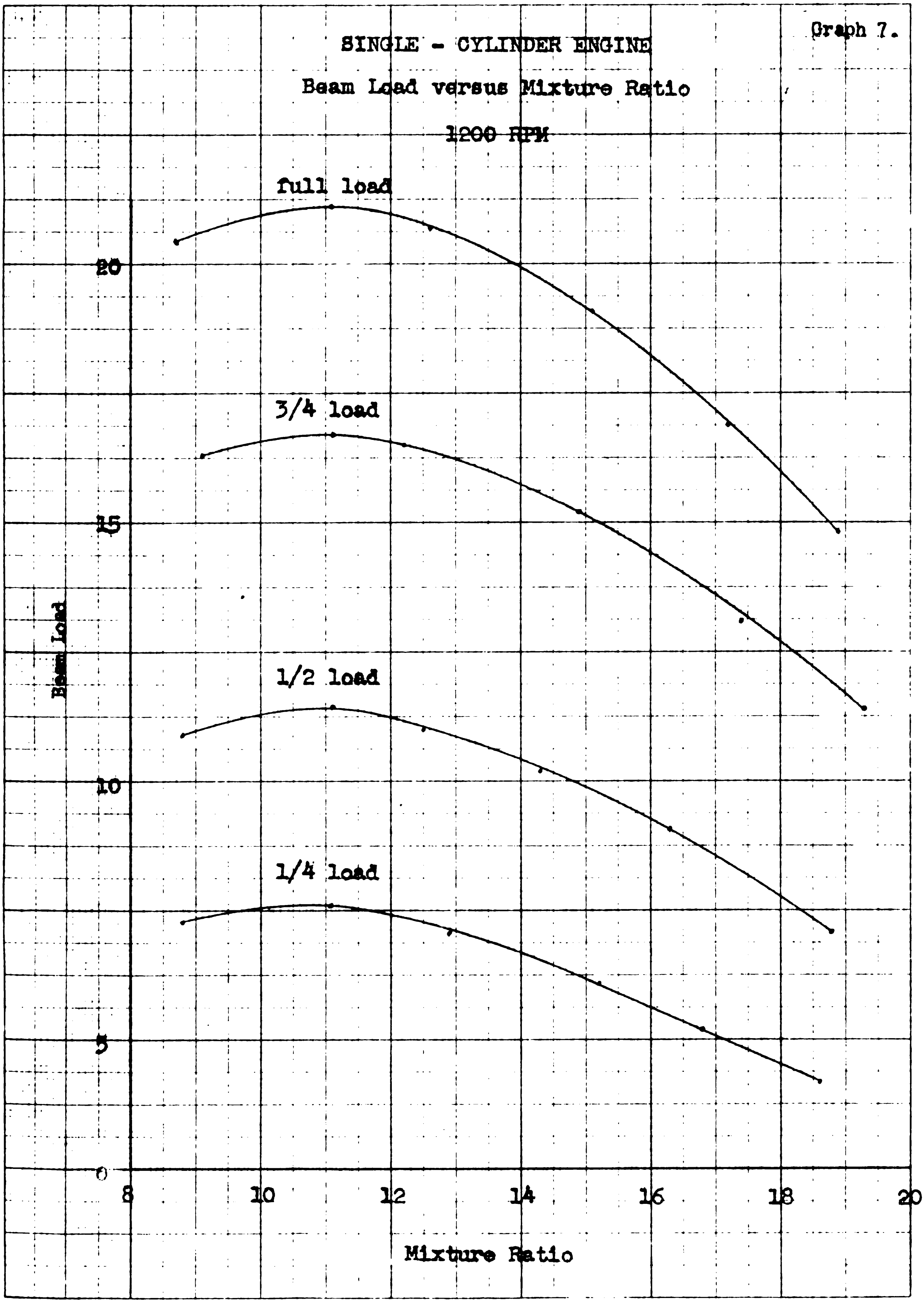
Graph 4.

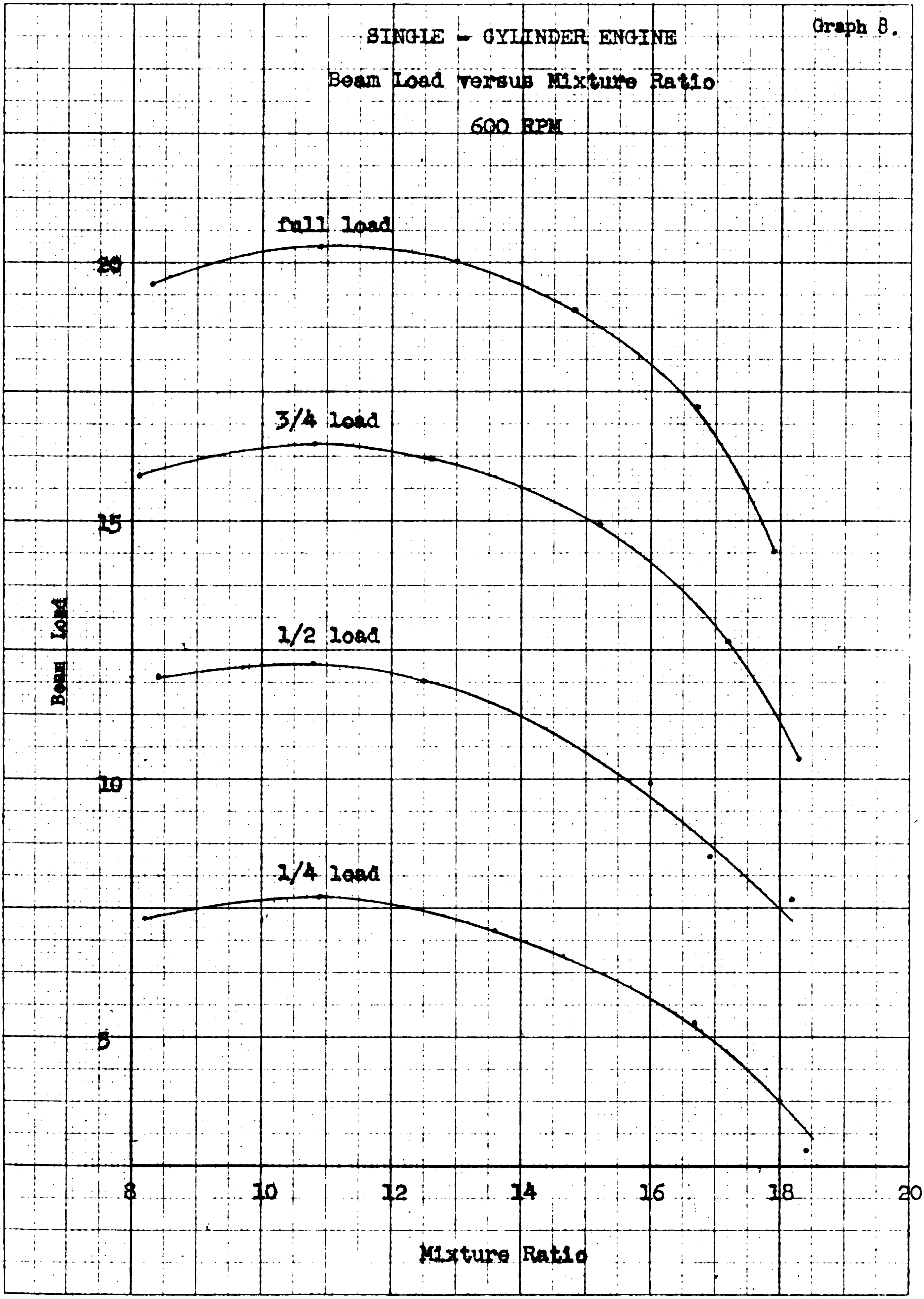

SINGLE - CYLINDER ENGINE
Fuel Flow vs. Beam Load
600 RPM
max. pwr.
full load
max. econ.
max. pwr.
3/4 load
max. econ.
max. pwr.
1/2 load
max. econ.
max. pwr.
1/4 load
max. econ.
Beam Load
0
5
10
15
20
0
0.5
1.0
1.5
2.0
2.5
Fuel Flow lbs./hour

Graph 5.


SINGLE - CYLINDER ENGINE
Beam Load versus Mixture Ratio
2400 RPM
full load
3/4 load
1/2 load
1/4 load
Beam Load
20
15
10
5
0
8
10
12
14
16
18
20
Mixture Ratio


SINGLE - CYLINDER ENGINE
Graph 6.
Beam Load versus Mixture Ratio
1800 RPM
full load
3/4 load
1/2 load
1/4 load
Beam Load
20
15
10
5
0
8
10
12
14
16
18
20
Mixture Ratio

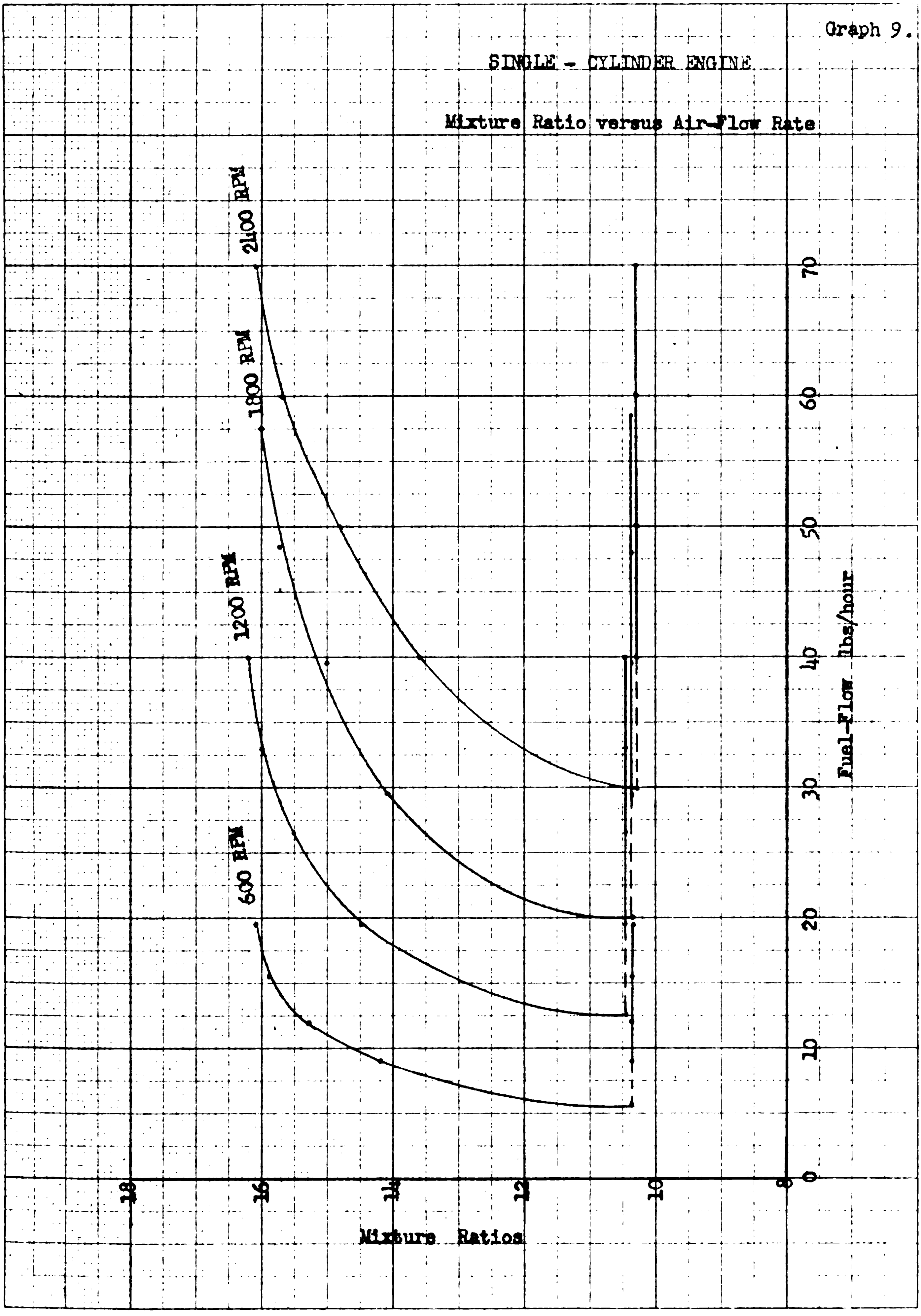

Graph 7.
SINGLE - CYLINDER ENGINE
Beam Load versus Mixture Ratio
1200 RPM
full load
3/4 load
1/2 load
1/4 load
Beam Load
20
15
10
5
0
8
10
12
14
16
18
20
Mixture Ratio


Graph 8.
SINGLE - CYLINDER ENGINE
Beam Load versus Mixture Ratio
600 RPM
full load
3/4 load
1/2 load
1/4 load
Beam Load
20
15
10
5
8
10
12
14
16
18
20
Mixture Ratio

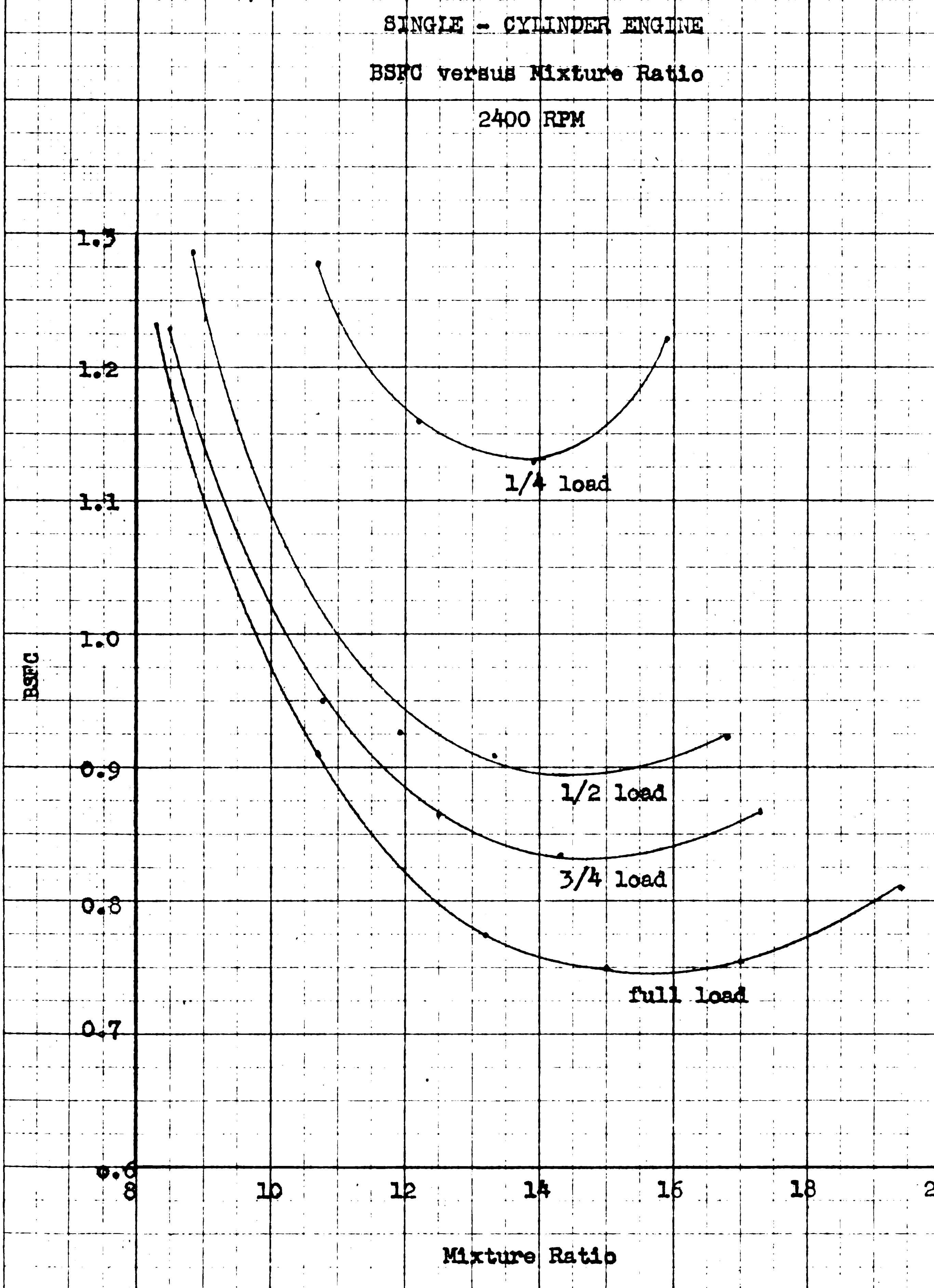
Graph 9.

SINGLE - CYLINDER ENGINE

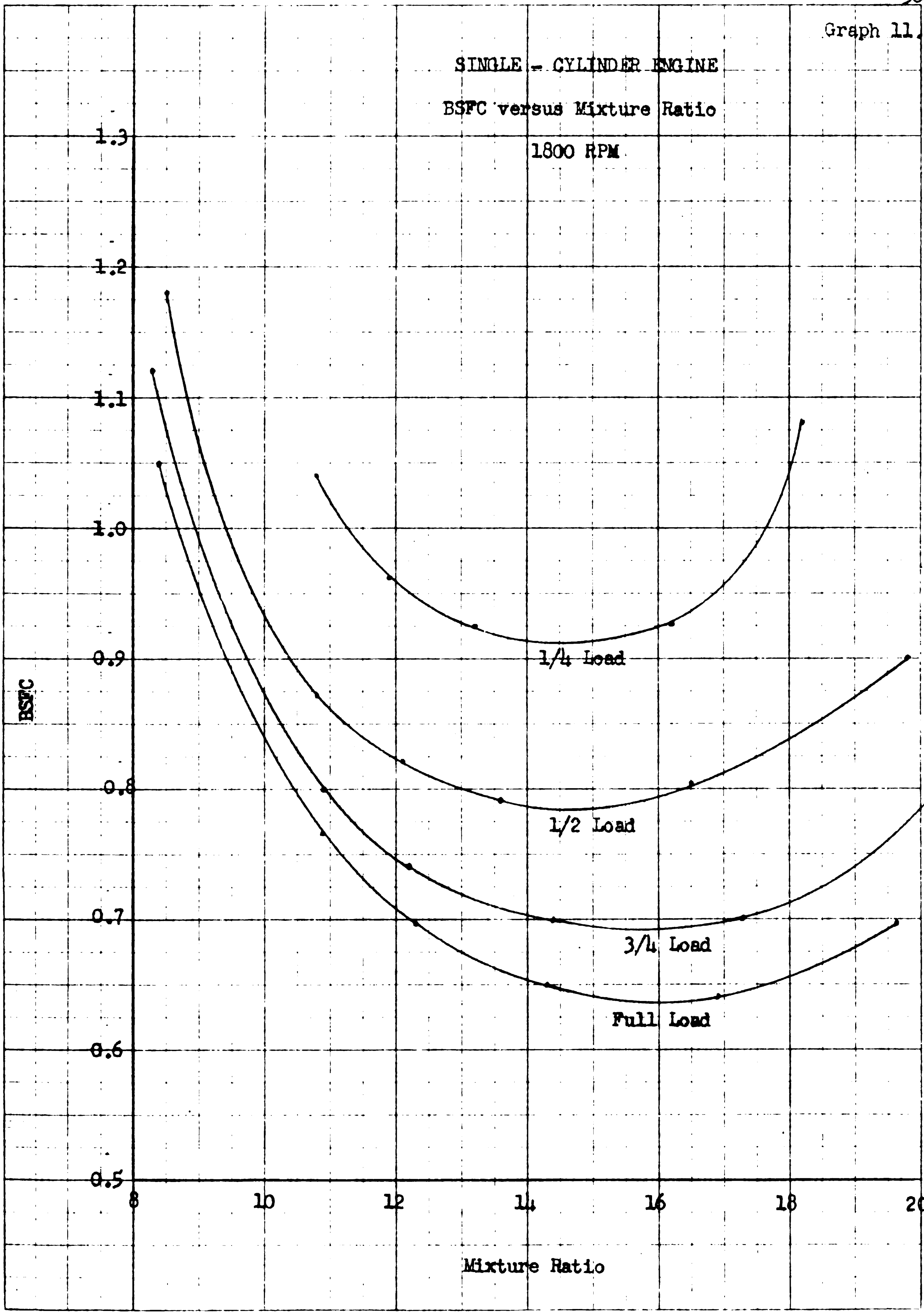
Mixture Ratio versus Air-Flow Rate



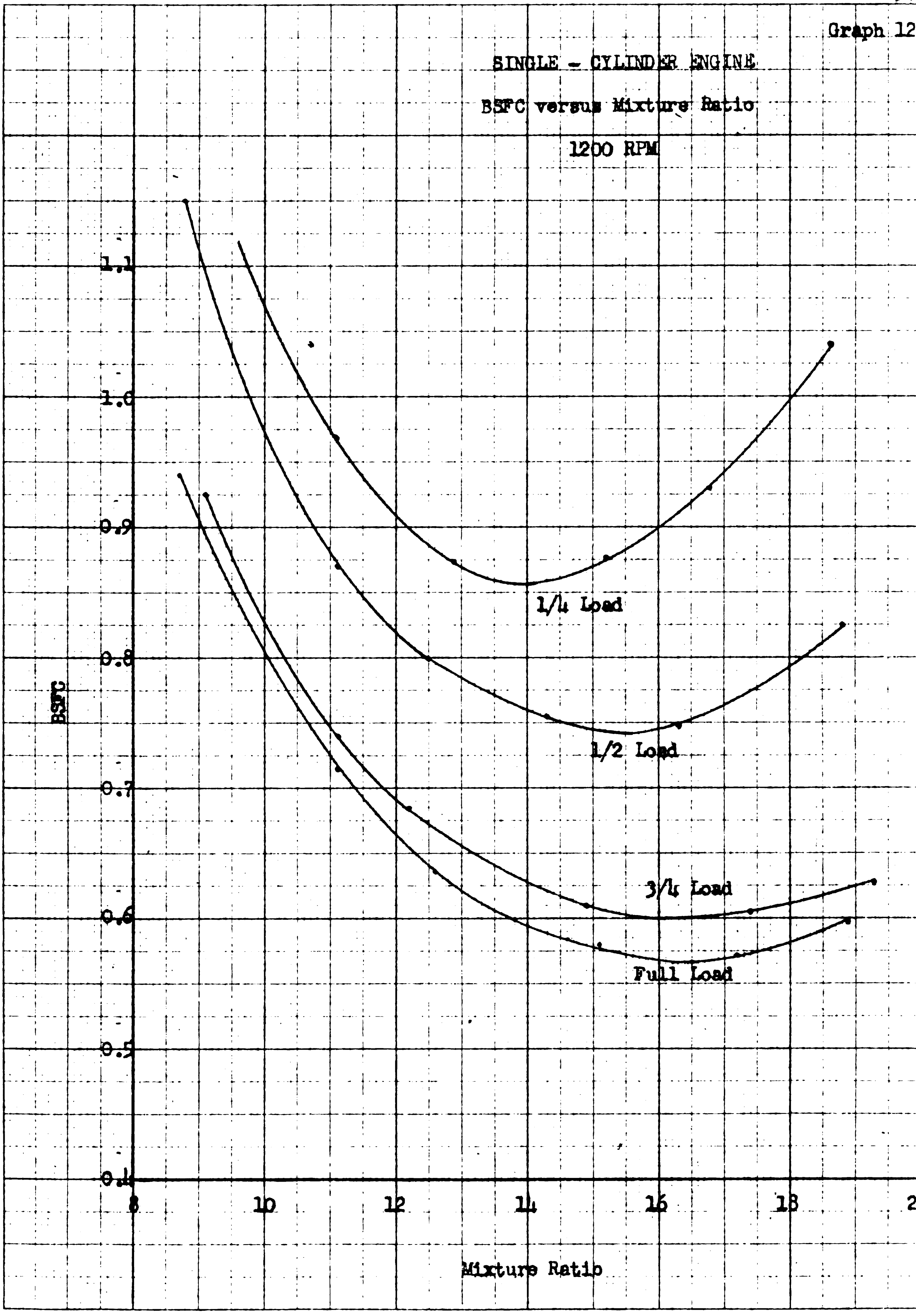
Graph 10.

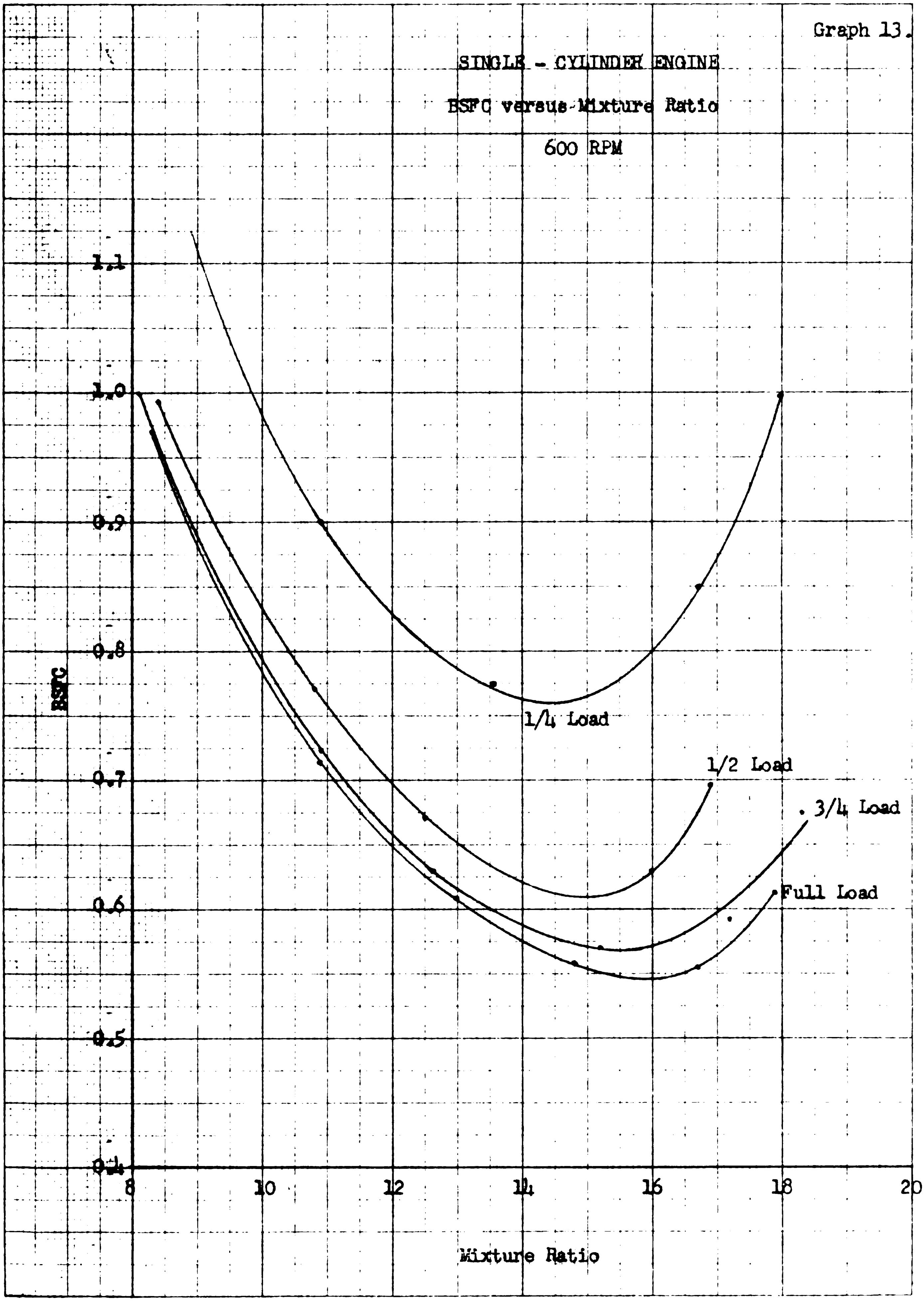

SINGLE - CYLINDER ENGINE
BSFC versus Mixture Ratio
2400 RPM
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
BSFC
1/4 load
1/2 load
3/4 load
full load
8
10
12
14
16
18
20
Mixture Ratio

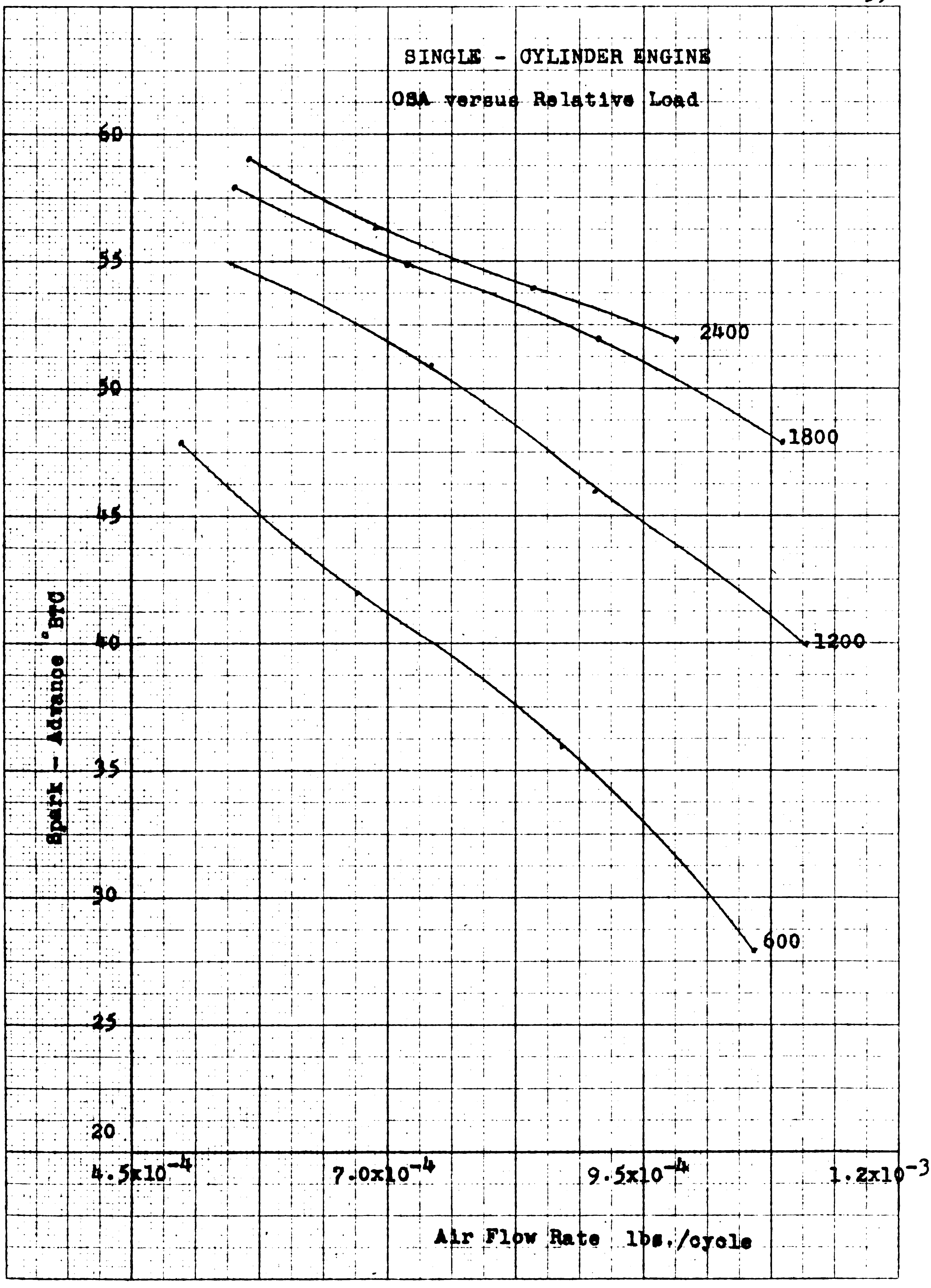
Graph 11.

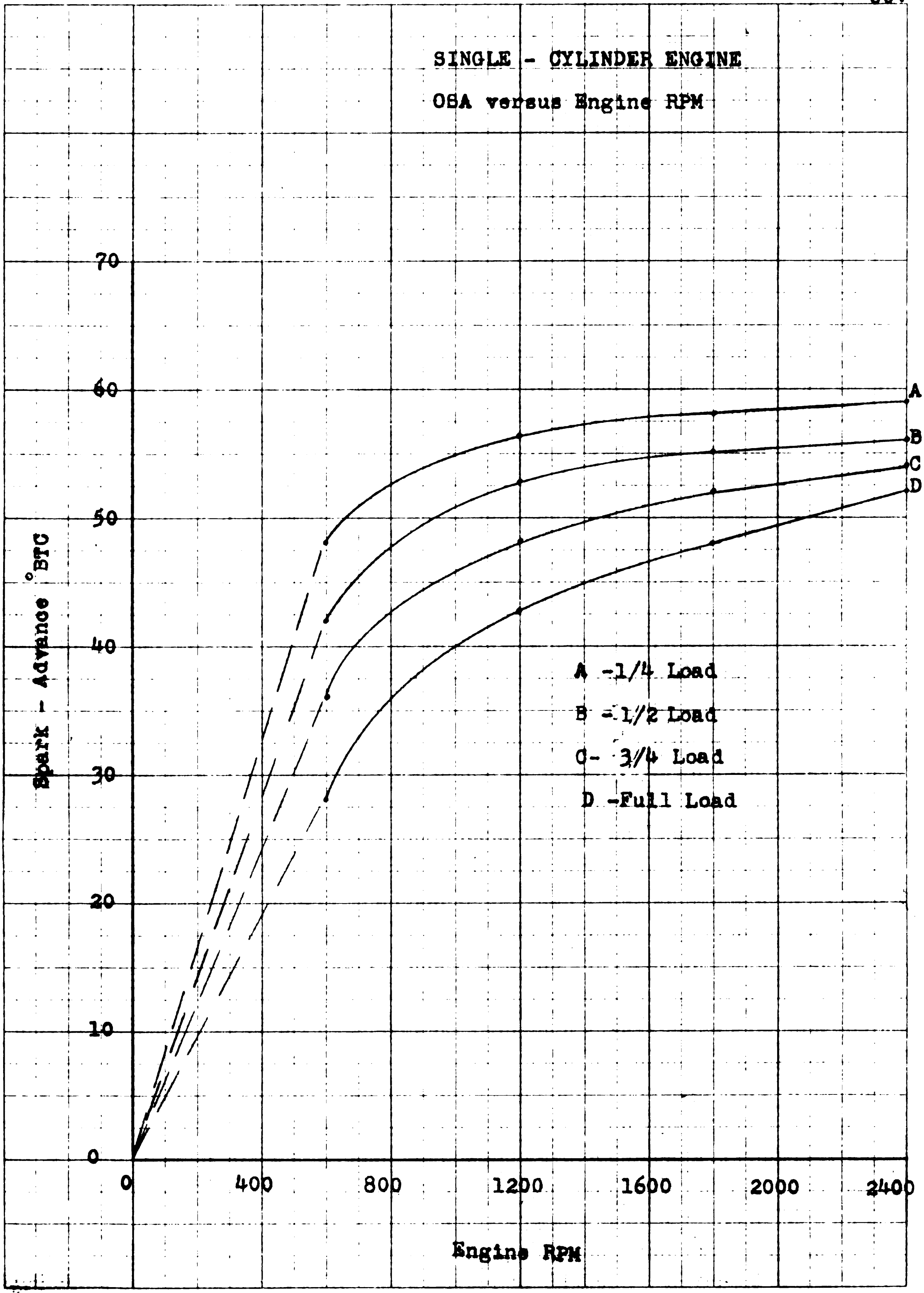

SINGLE - CYLINDER ENGINE
BSFC versus Mixture Ratio
1800 RPM
1/4 Load
1/2 Load
3/4 Load
Full Load
BSFC
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
8
10
12
14
16
18
20
Mixture Ratio

Graph 12.


SINGLE - CYLINDER ENGINE
BSFC versus Mixture Ratio
1200 RPM
BSFC
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
8
10
12
14
16
18
20
Mixture Ratio
1/4 Load
1/2 Load
3/4 Load
Full Load

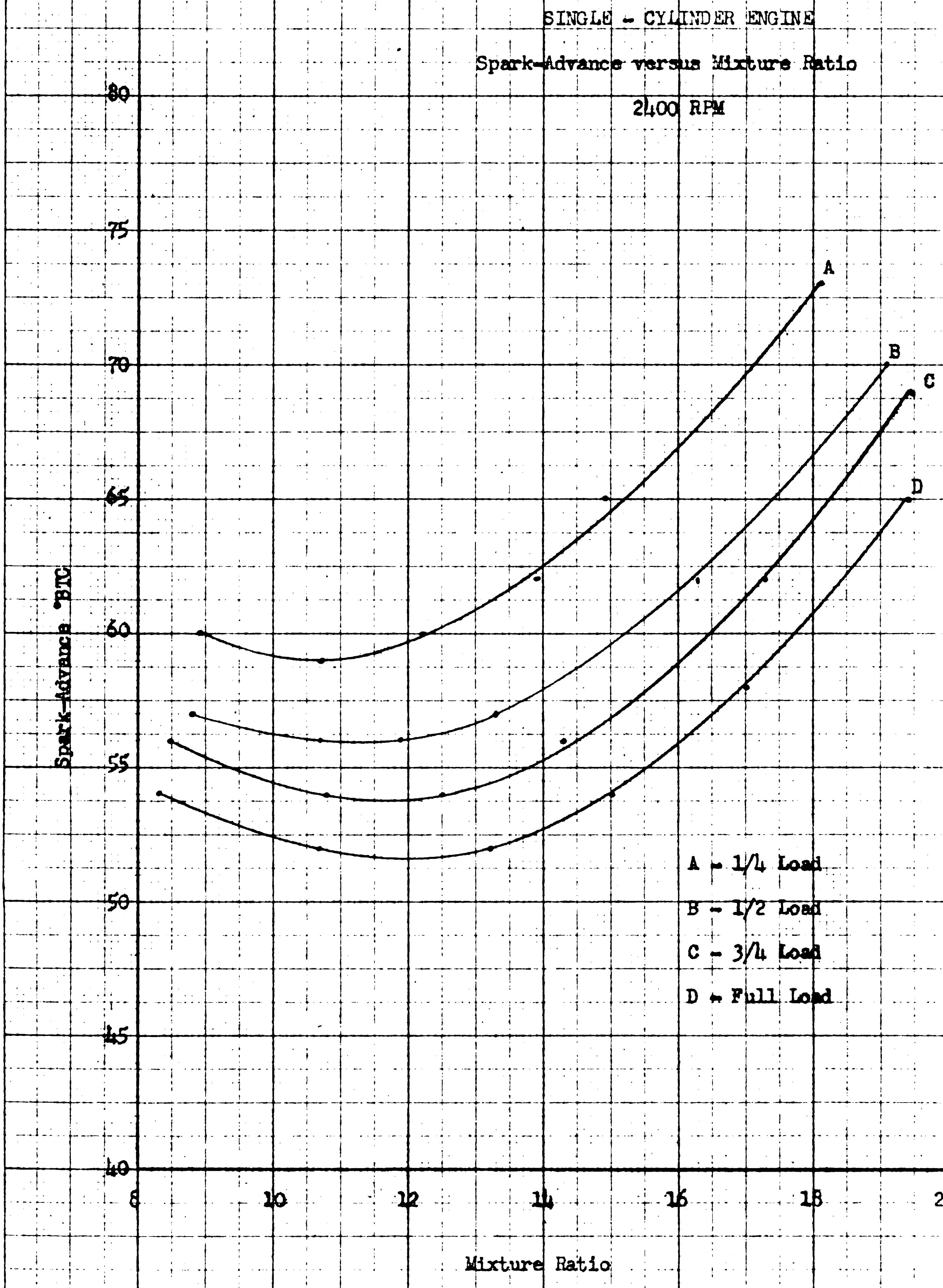

Graph 13.
SINGLE - CYLINDER ENGINE
BSFC versus Mixture Ratio
600 RPM
BSFC
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
1/4 Load
1/2 Load
3/4 Load
Full Load
8
10
12
14
16
18
20
Mixture Ratio


SINGLE - CYLINDER ENGINE
OSA versus Relative Load
60
55
50
45
40
35
30
25
20
Spark - Advance °BTC
2400
1800
1200
600
4.5x10^-4
7.0x10^-4
9.5x10^-4
1.2x10^-3
Air Flow Rate lbs./cycle

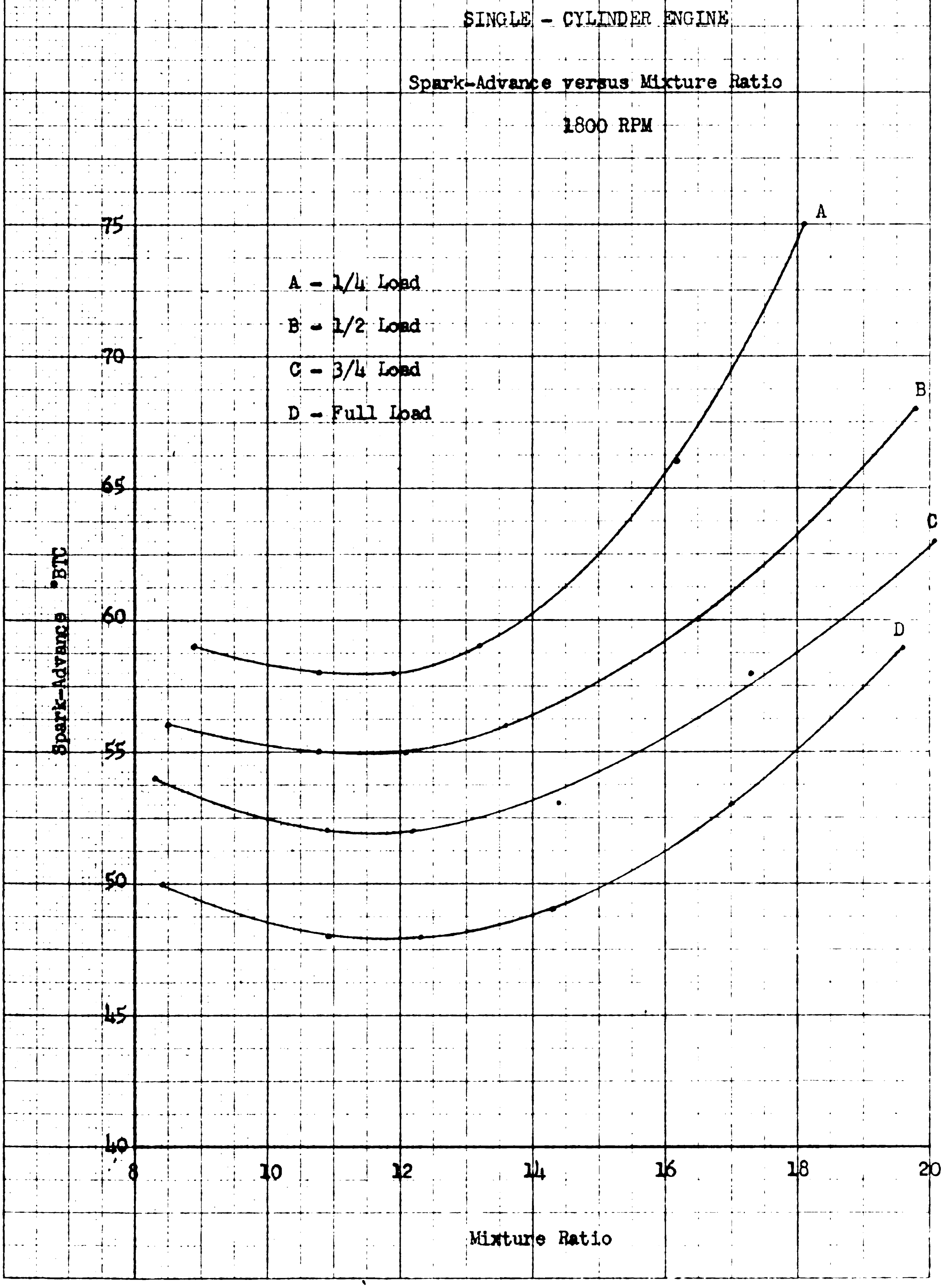


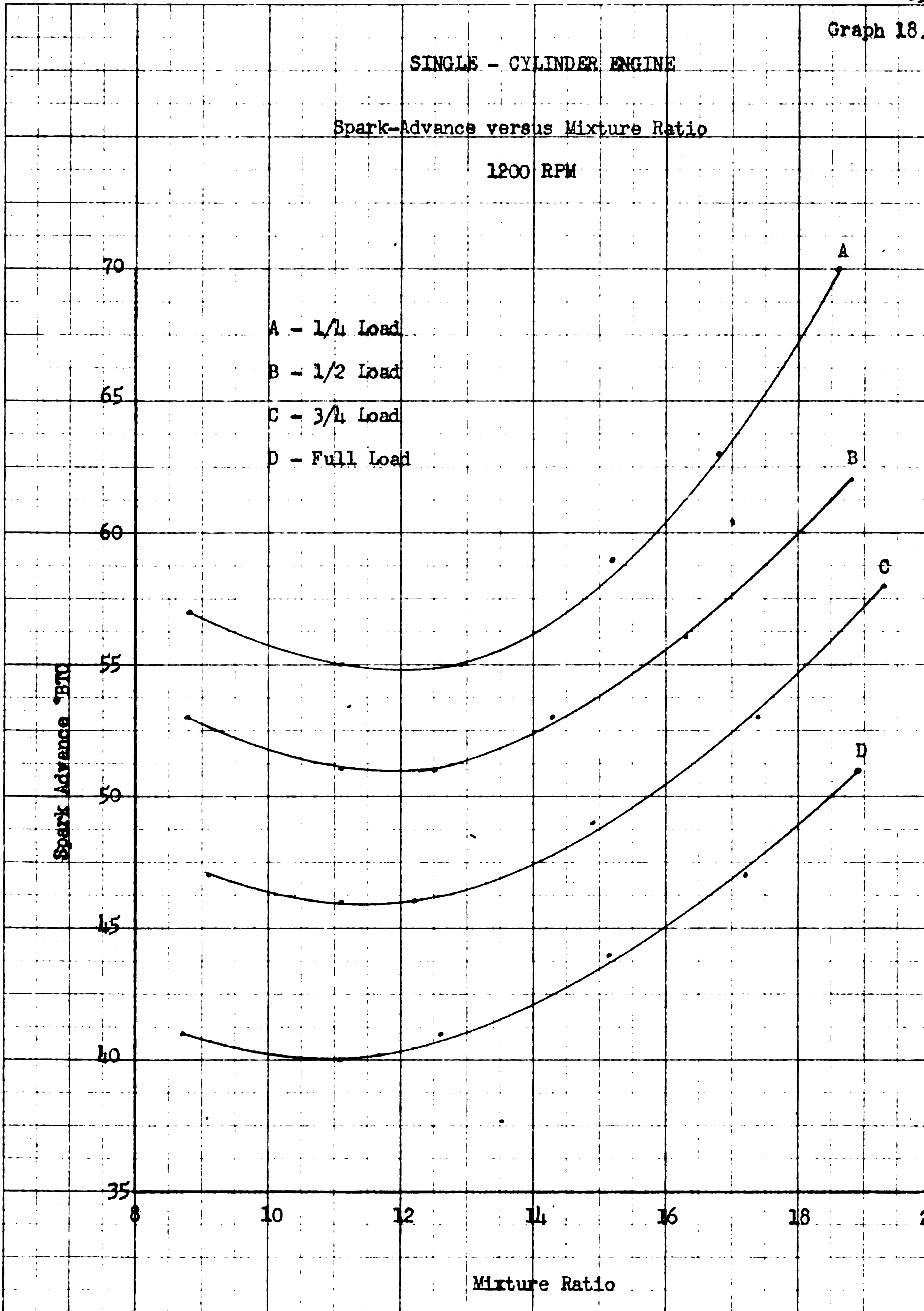
SINGLE - CYLINDER ENGINE
OSA versus Engine RPM
Spark - Advance °BTC
70
60
50
40
30
20
10
0
0
400
800
1200
1600
2000
2400
Engine RPM
A
B
C
D
A -1/4 Load
B - 1/2 Load
C- 3/4 Load
D -Full Load

Graph 16.

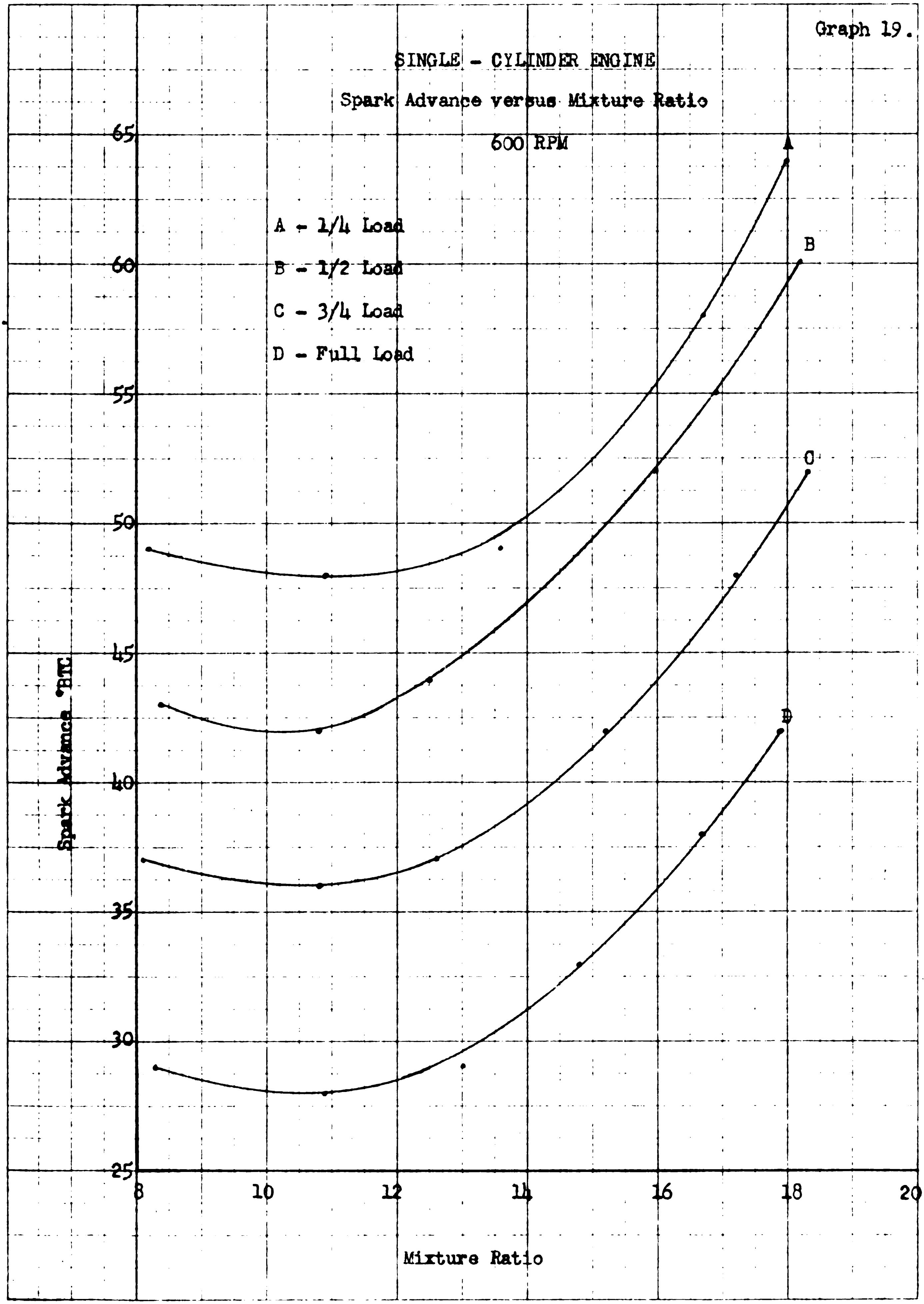

SINGLE - CYLINDER ENGINE
Spark-Advance versus Mixture Ratio
2400 RPM
Spark-Advance °BTC
80
75
70
65
60
55
50
45
40
8
10
12
14
16
18
20
Mixture Ratio
A
B
C
D
A - 1/4 Load
B - 1/2 Load
C - 3/4 Load
D - Full Load

Graph 17.

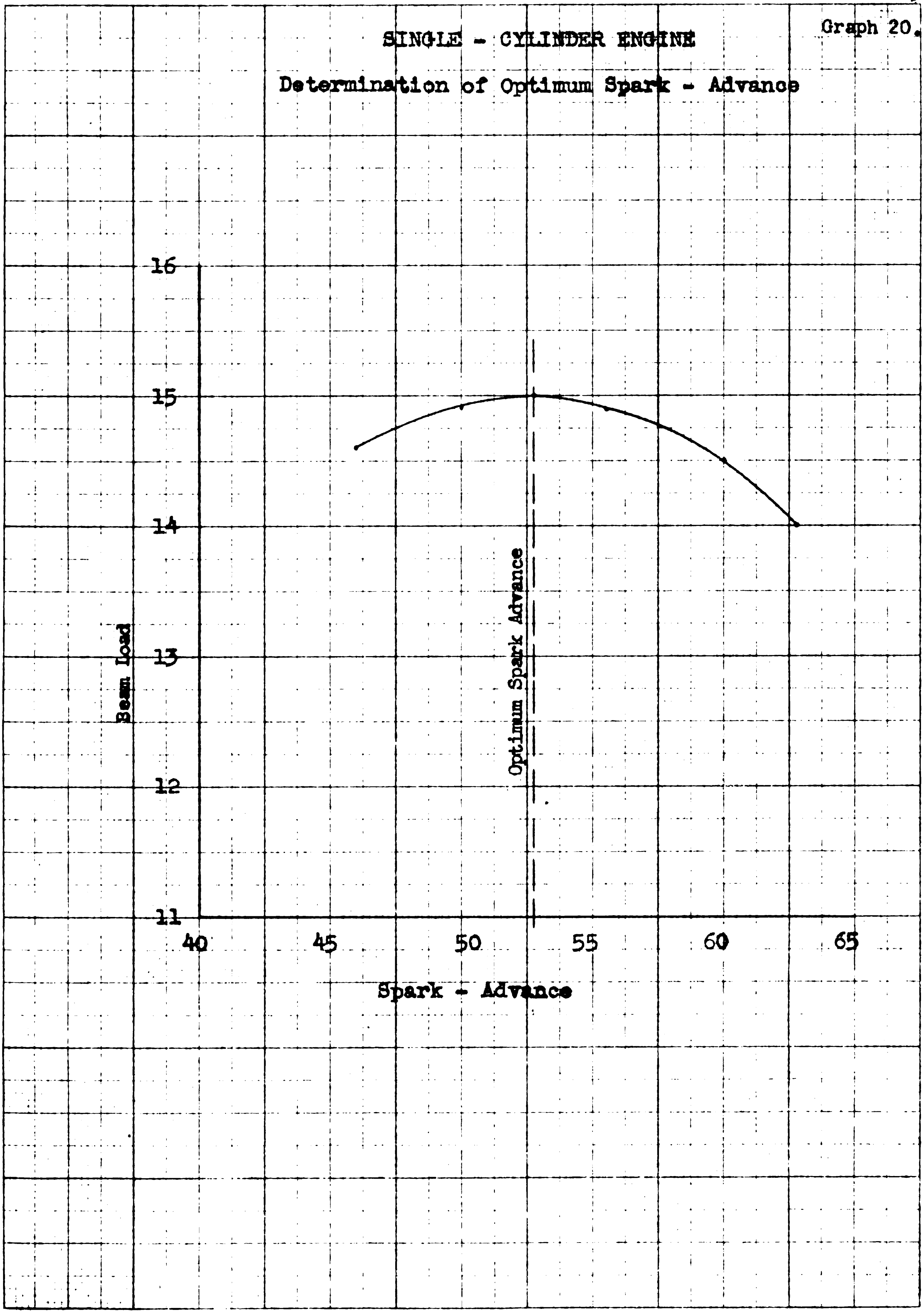

SINGLE - CYLINDER ENGINE
Spark-Advance versus Mixture Ratio
1800 RPM
A - 1/4 Load
B - 1/2 Load
C - 3/4 Load
D - Full Load
A
B
C
D
Spark-Advance °BTC
75
70
65
60
55
50
45
40
8
10
12
14
16
18
20
Mixture Ratio


Graph 18.
SINGLE - CYLINDER ENGINE
Spark-Advance versus Mixture Ratio
1200 RPM
A - 1/4 Load
B - 1/2 Load
C - 3/4 Load
D - Full Load
A
B
C
D
Spark Advance °BTC
70
65
60
55
50
45
40
35
8
10
12
14
16
18
20
Mixture Ratio

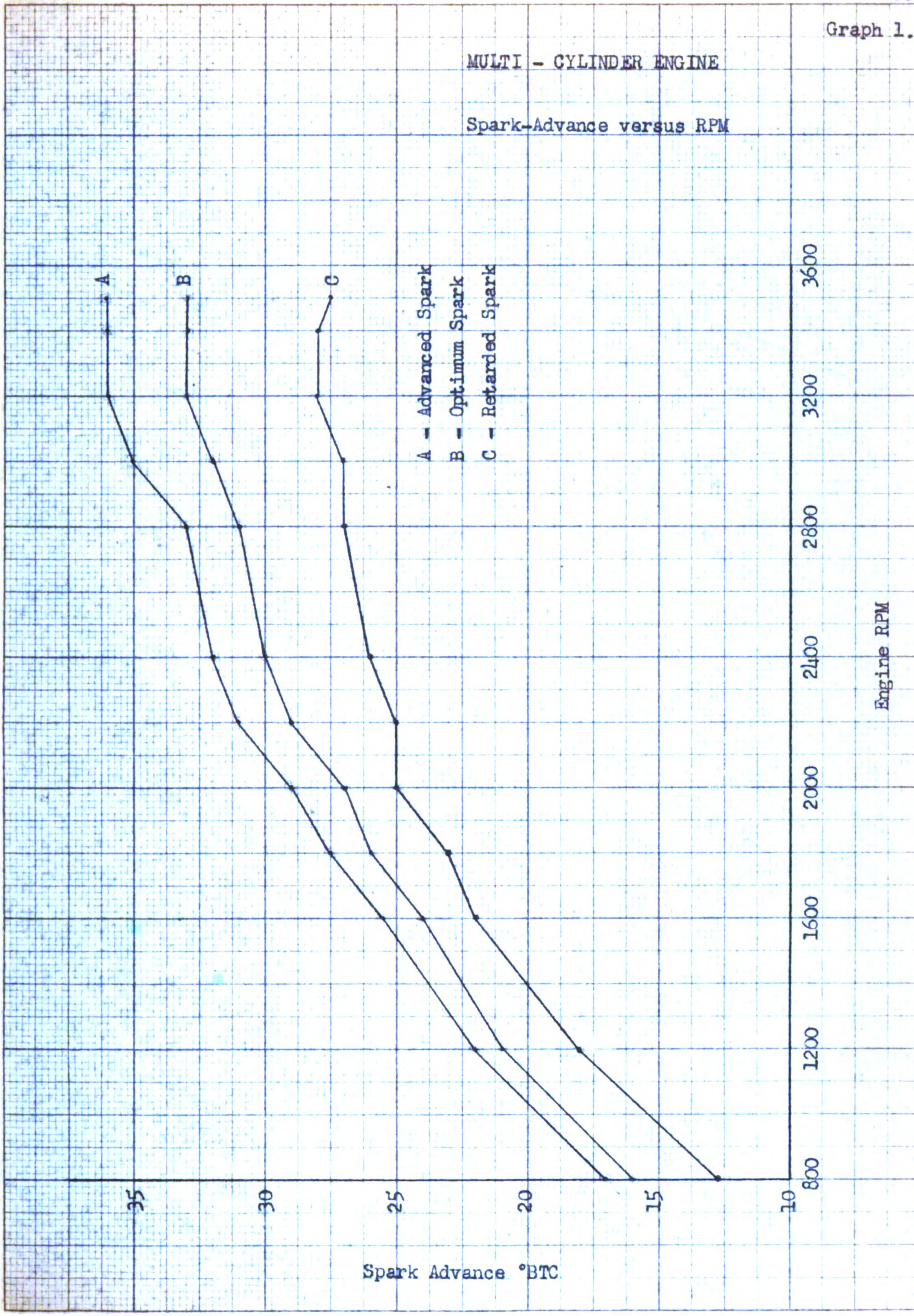
Graph 19.

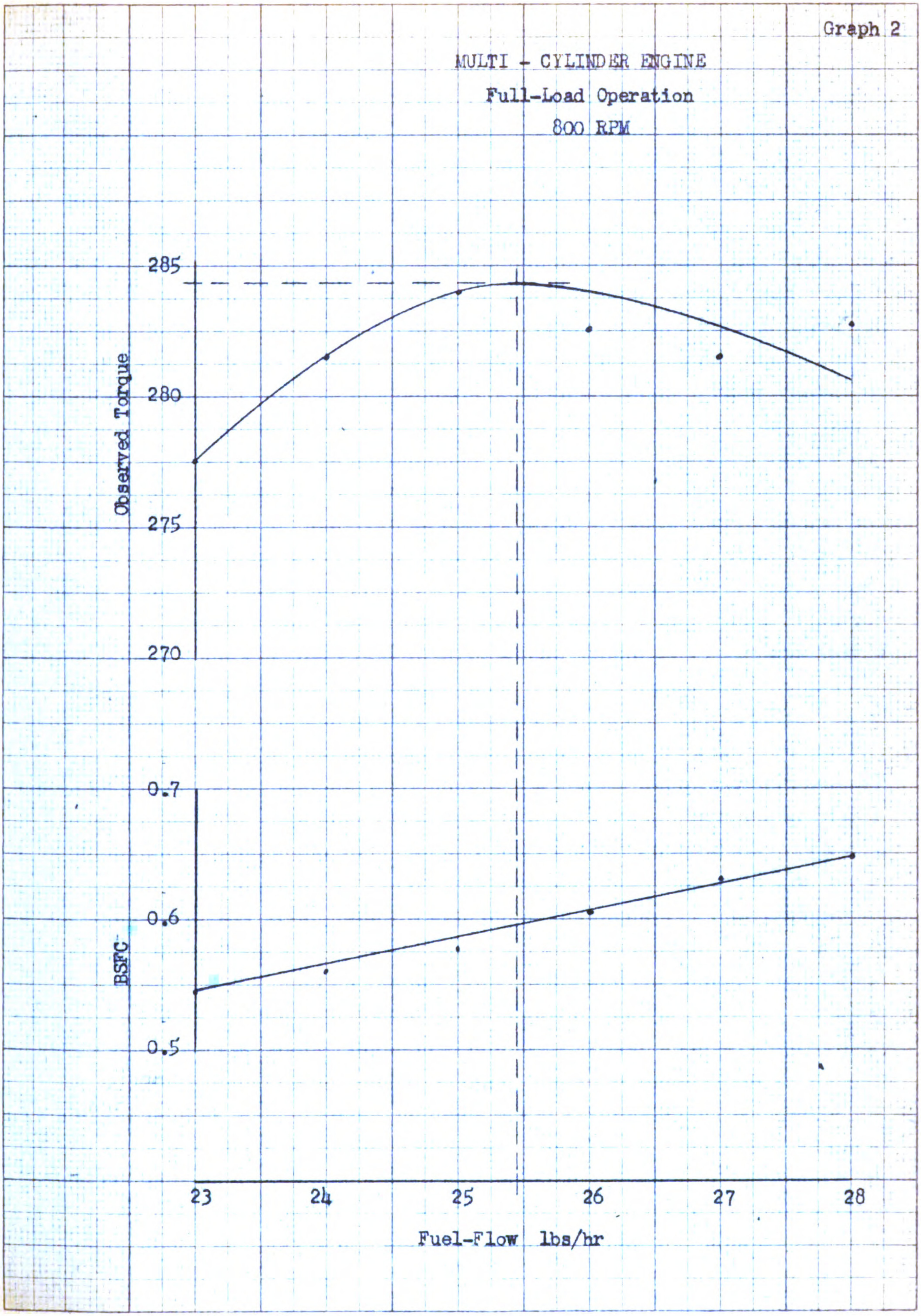

SINGLE - CYLINDER ENGINE
Spark Advance versus Mixture Ratio
600 RPM
A - 1/4 Load
B - 1/2 Load
C - 3/4 Load
D - Full Load
A
B
C
D
Spark Advance °BTC
65
60
55
50
45
40
35
30
25
8
10
12
14
16
18
20
Mixture Ratio

Graph 20.

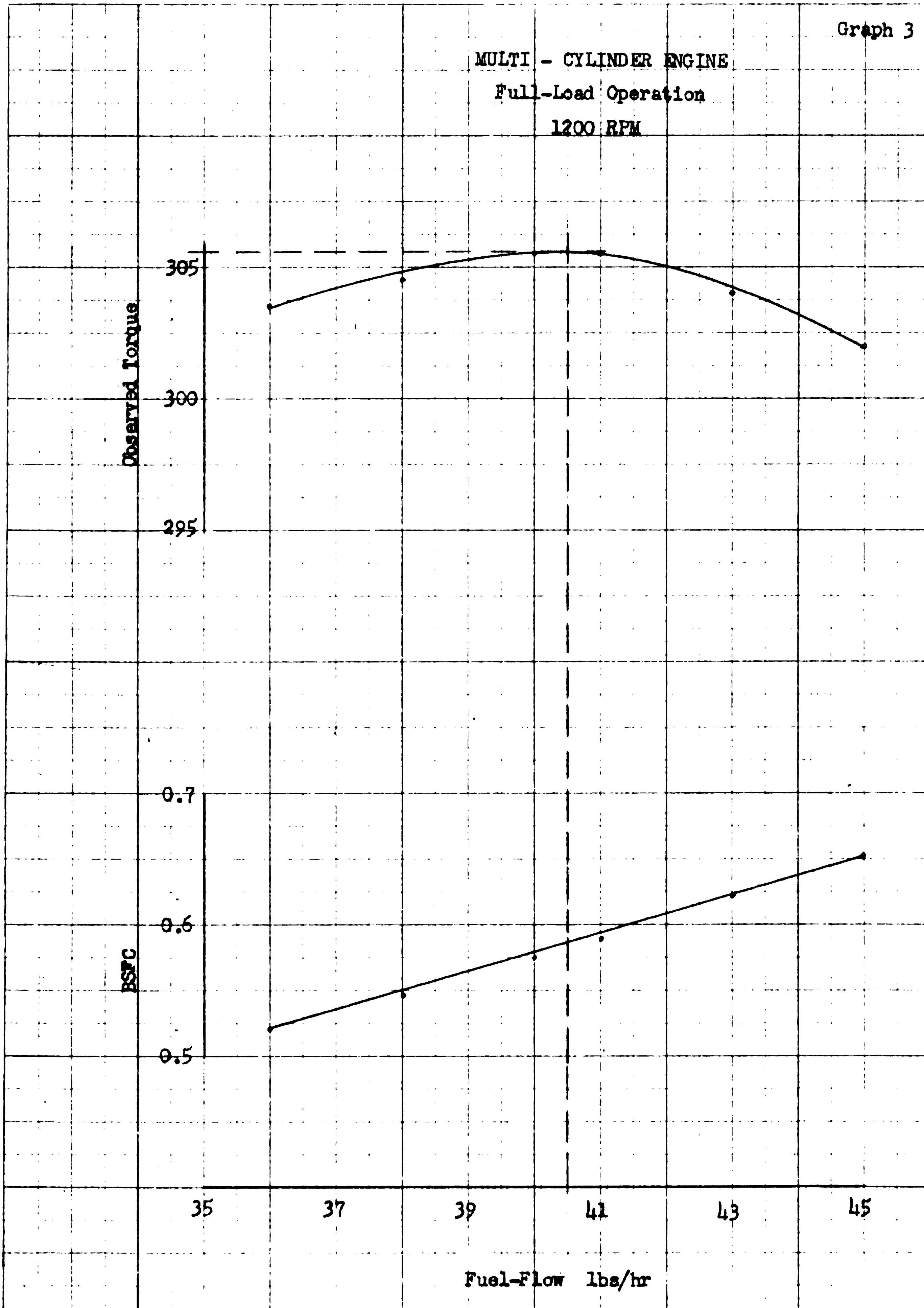

SINGLE - CYLINDER ENGINE
Determination of Optimum Spark - Advance
Beam Load
16
15
14
13
12
11
40
45
50
55
60
65
Optimum Spark Advance
Spark - Advance

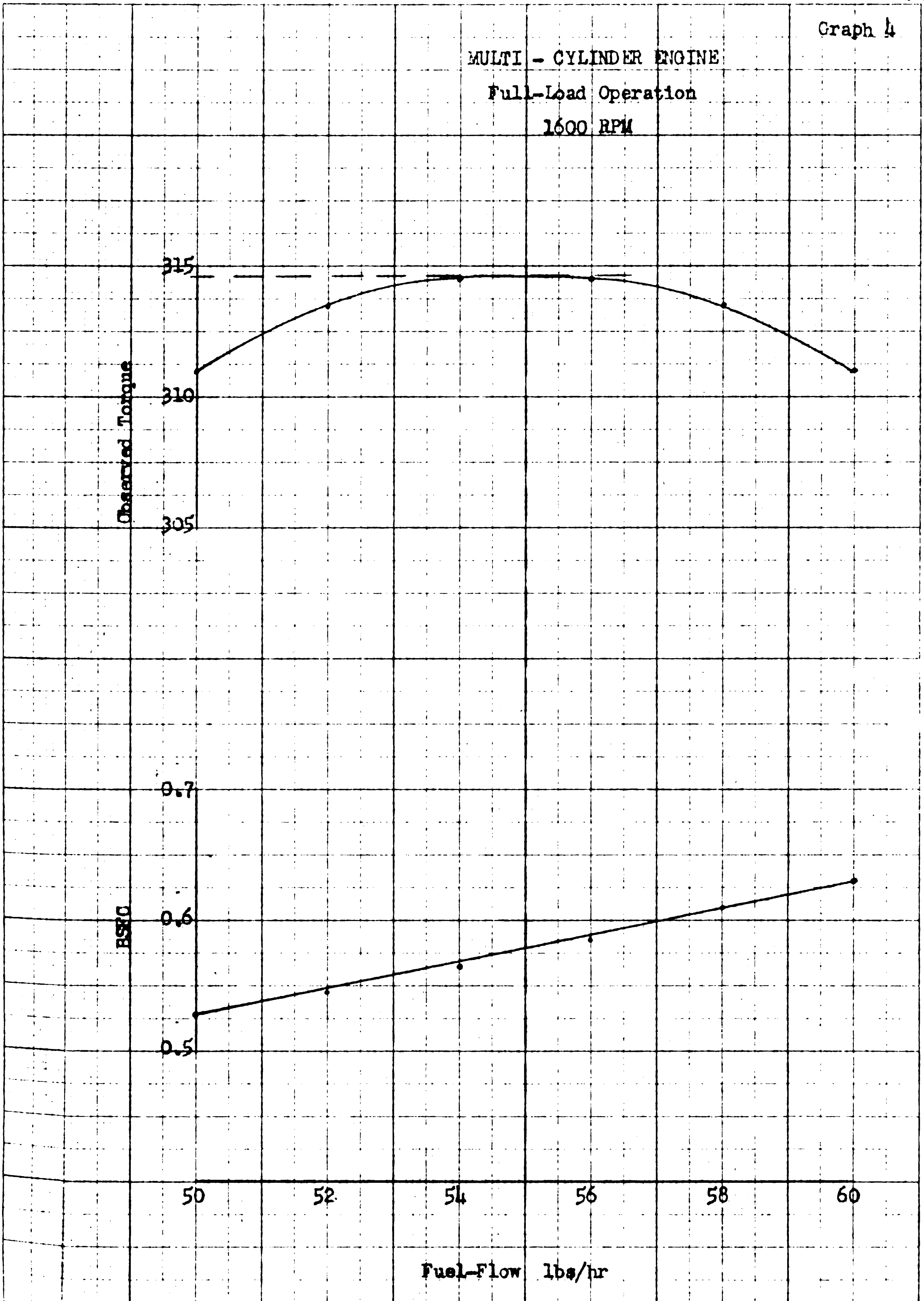
Graph 1.

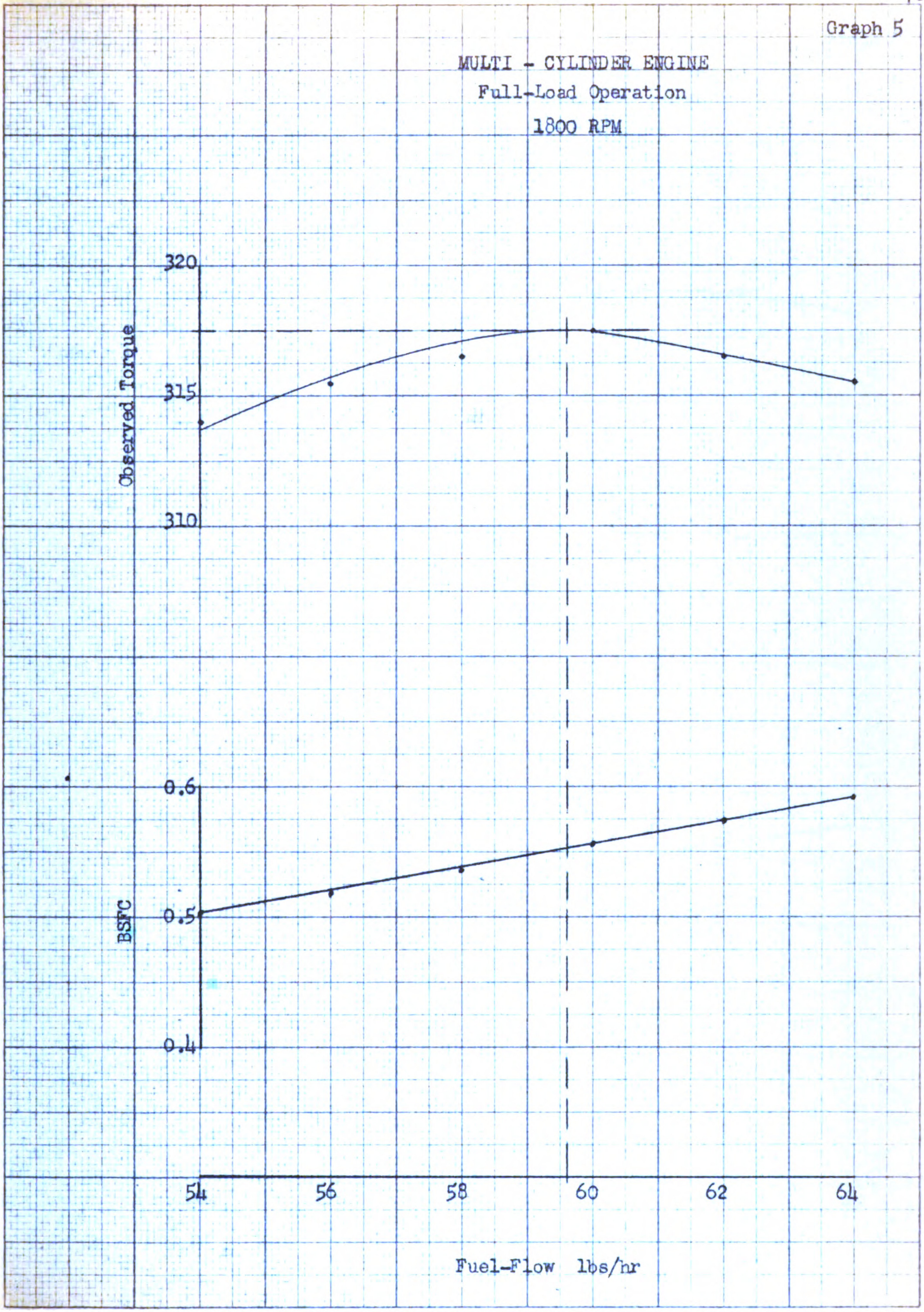

MULTI - CYLINDER ENGINE
Spark-Advance versus RPM
A - Advanced Spark
B - Optimum Spark
C - Retarded Spark
A
B
C
Engine RPM
800
1200
1600
2000
2400
2800
3200
3600
Spark Advance °BTC
10
15
20
25
30
35


Graph 2
MULTI - CYLINDER ENGINE
Full-Load Operation
800 RPM
Observed Torque
285
280
275
270
BSFC
0.7
0.6
0.5
23
24
25
26
27
28
Fuel-Flow lbs/hr

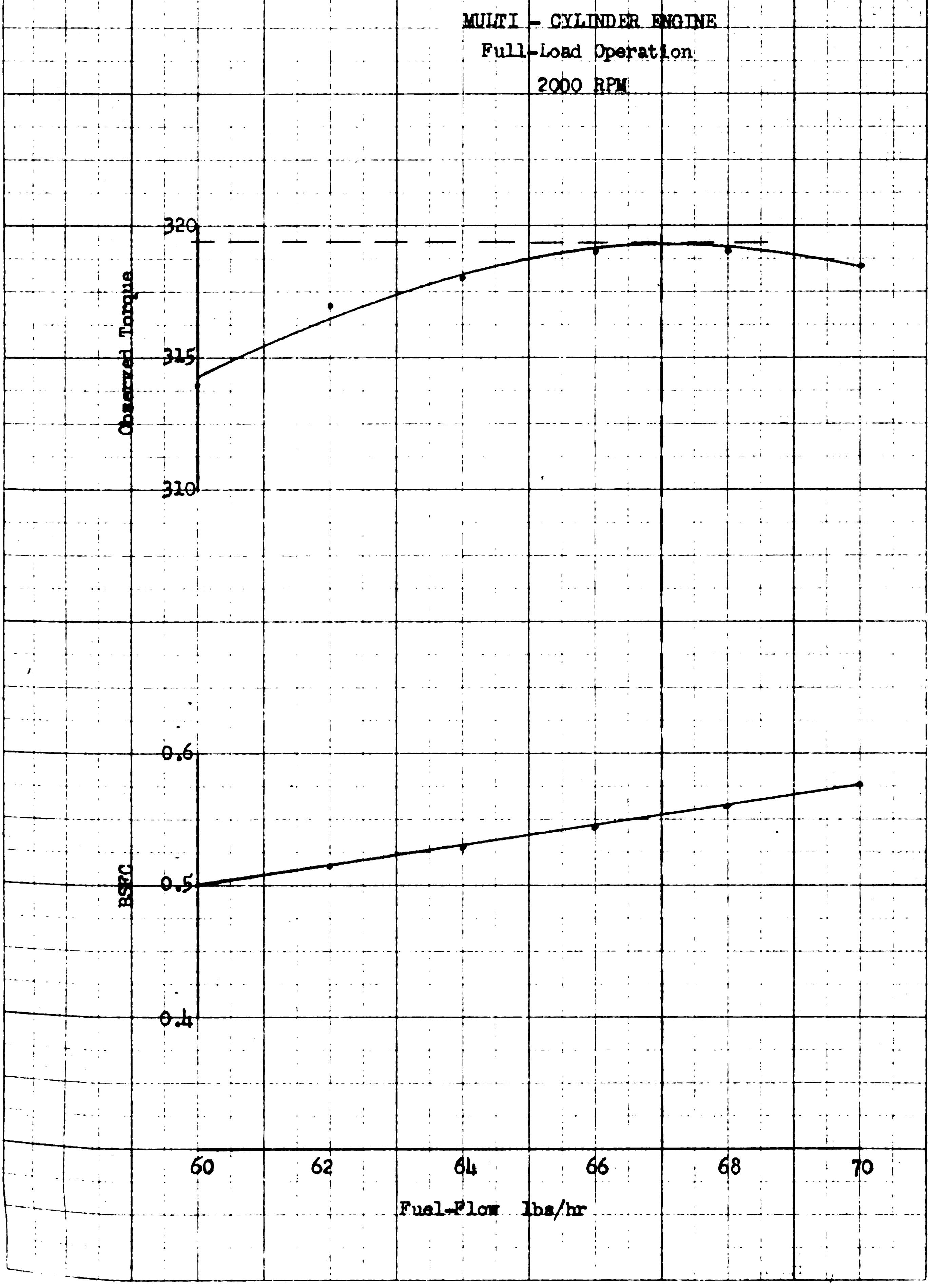
Graph 3


MULTI - CYLINDER ENGINE
Full-Load Operation
1200 RPM
Observed Torque
305
300
295
BSFC
0.7
0.6
0.5
35
37
39
41
43
45
Fuel-Flow lbs/hr

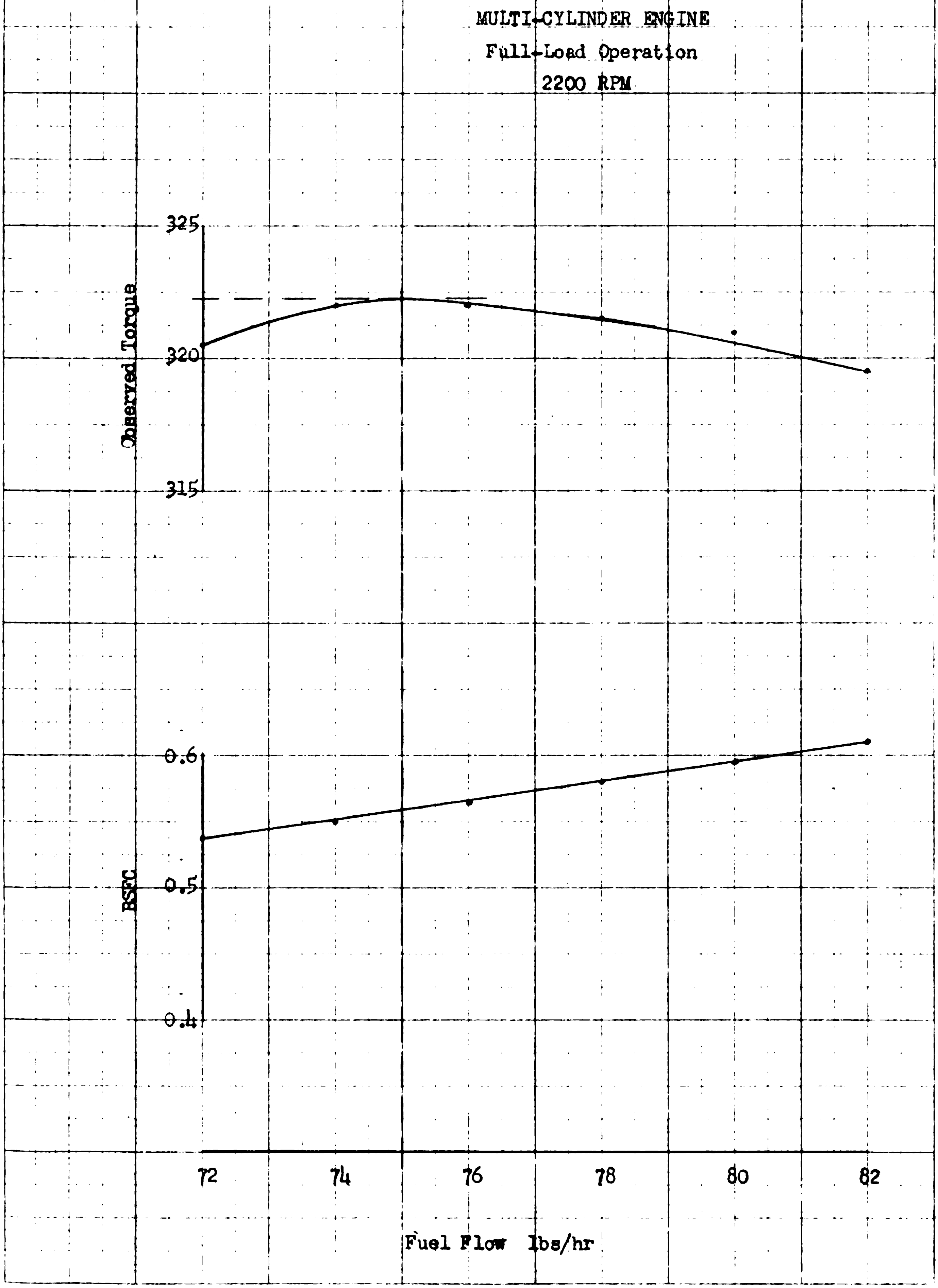

Graph 4
MULTI - CYLINDER ENGINE
Full-Load Operation
1600 RPM
Observed Torque
315
310
305
BSFC
0.7
0.6
0.5
50
52
54
56
58
60
Fuel-Flow lbs/hr

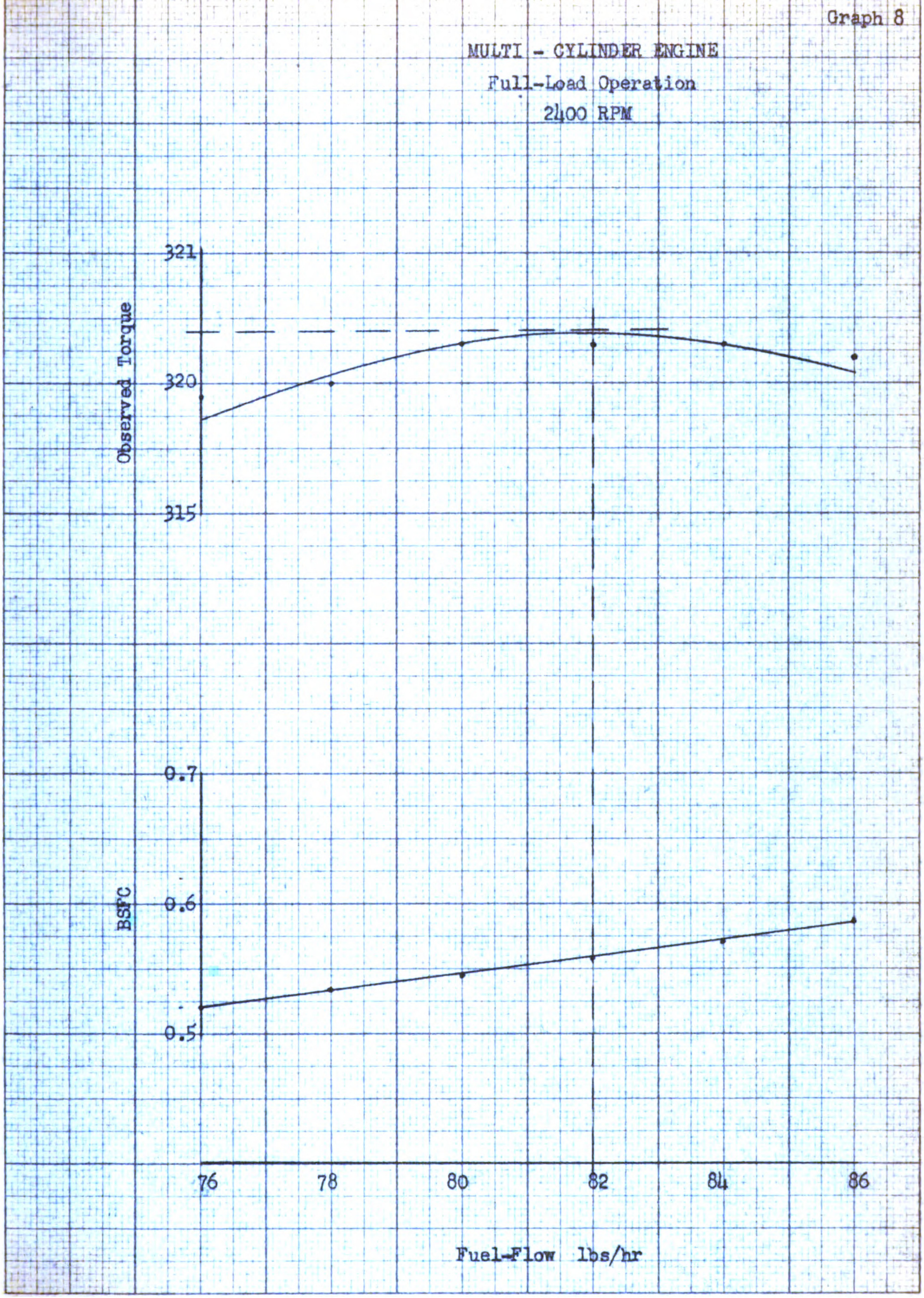

Graph 5
MULTI - CYLINDER ENGINE
Full-Load Operation
1800 RPM
320
315
310
Observed Torque
0.6
0.5
0.4
BSFC
54
56
58
60
62
64
Fuel-Flow lbs/hr

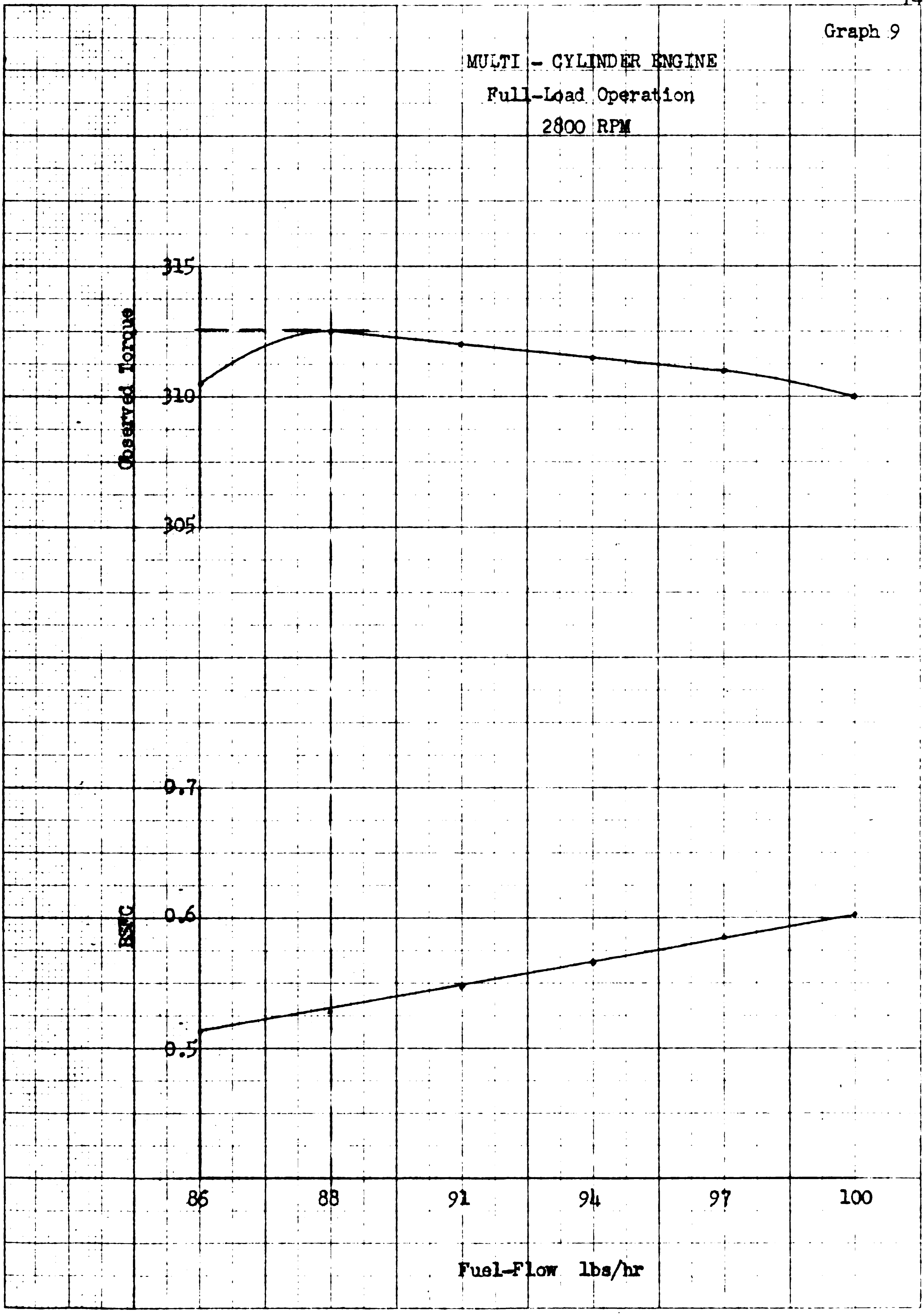
Graph 6


MULTI - CYLINDER ENGINE
Full-Load Operation
2000 RPM
Observed Torque
320
315
310
BSFC
0.6
0.5
0.4
60
62
64
66
68
70
Fuel-Flow lbs/hr

Graph 7

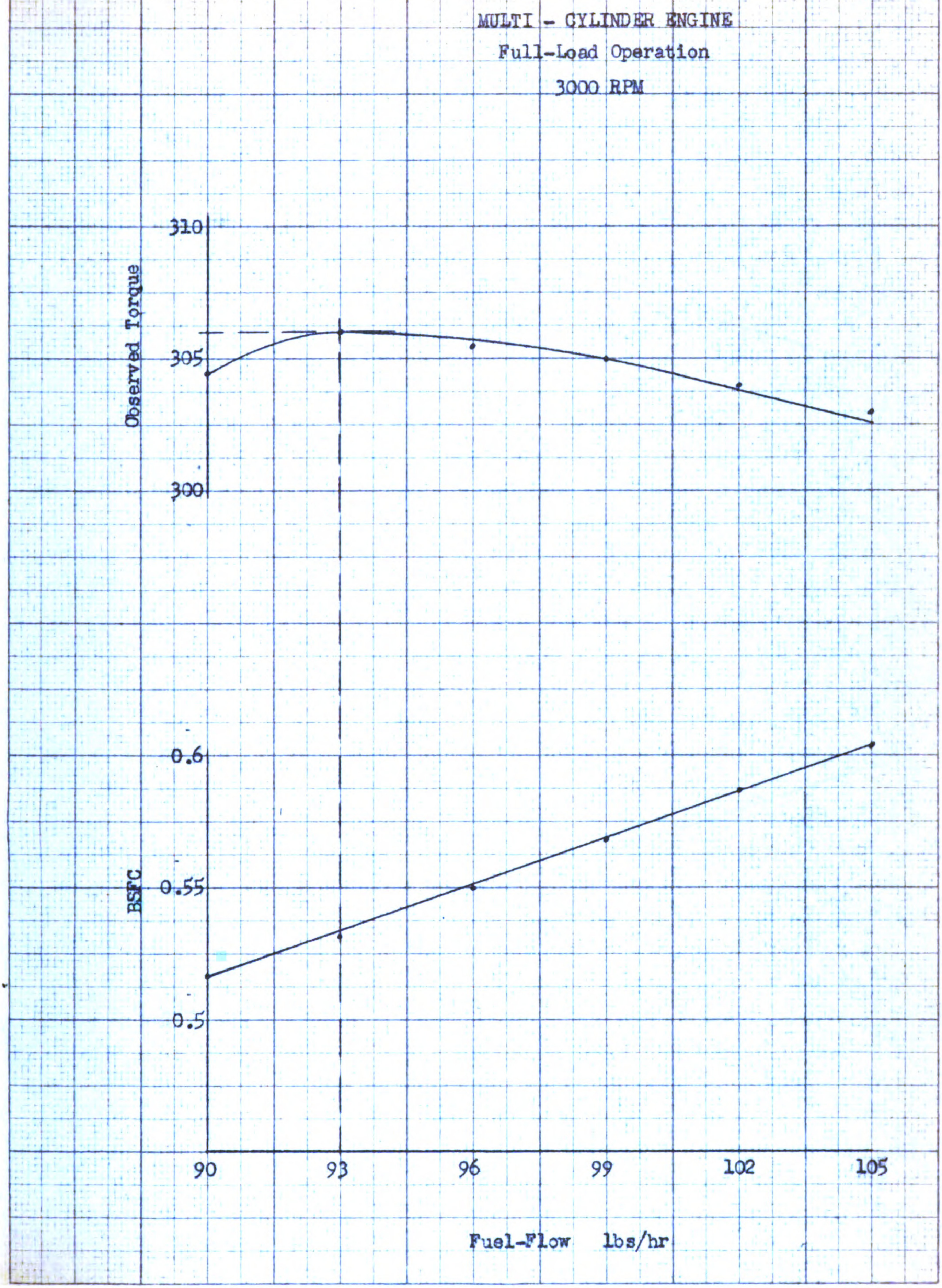

MULTI-CYLINDER ENGINE
Full-Load Operation
2200 RPM
Observed Torque
325
320
315
BSFC
0.6
0.5
0.4
72
74
76
78
80
82
Fuel Flow lbs/hr


Graph 8
MULTI - CYLINDER ENGINE
Full-Load Operation
2400 RPM
Observed Torque
321
320
315
BSFC
0.7
0.6
0.5
76
78
80
82
84
86
Fuel-Flow lbs/hr

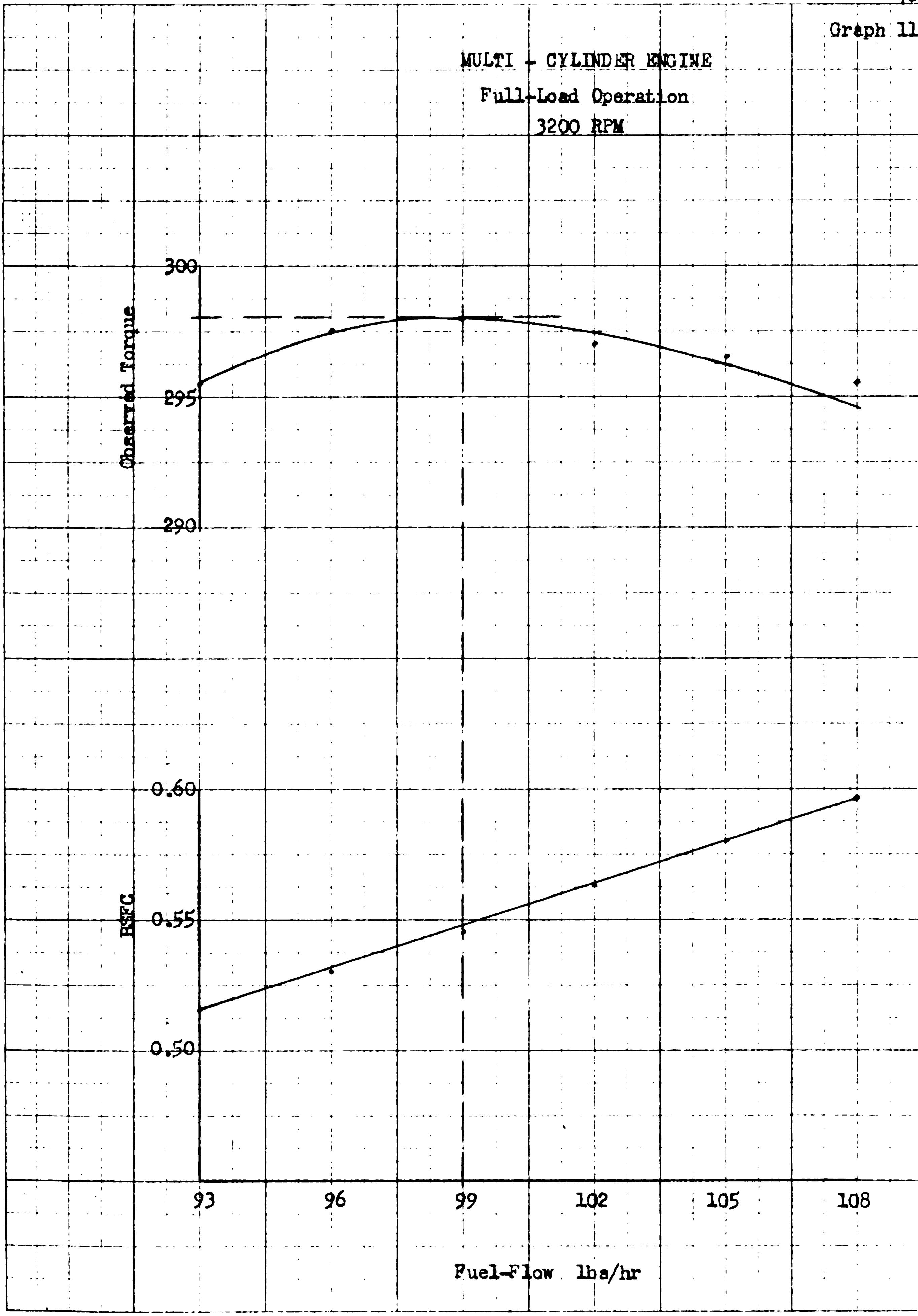


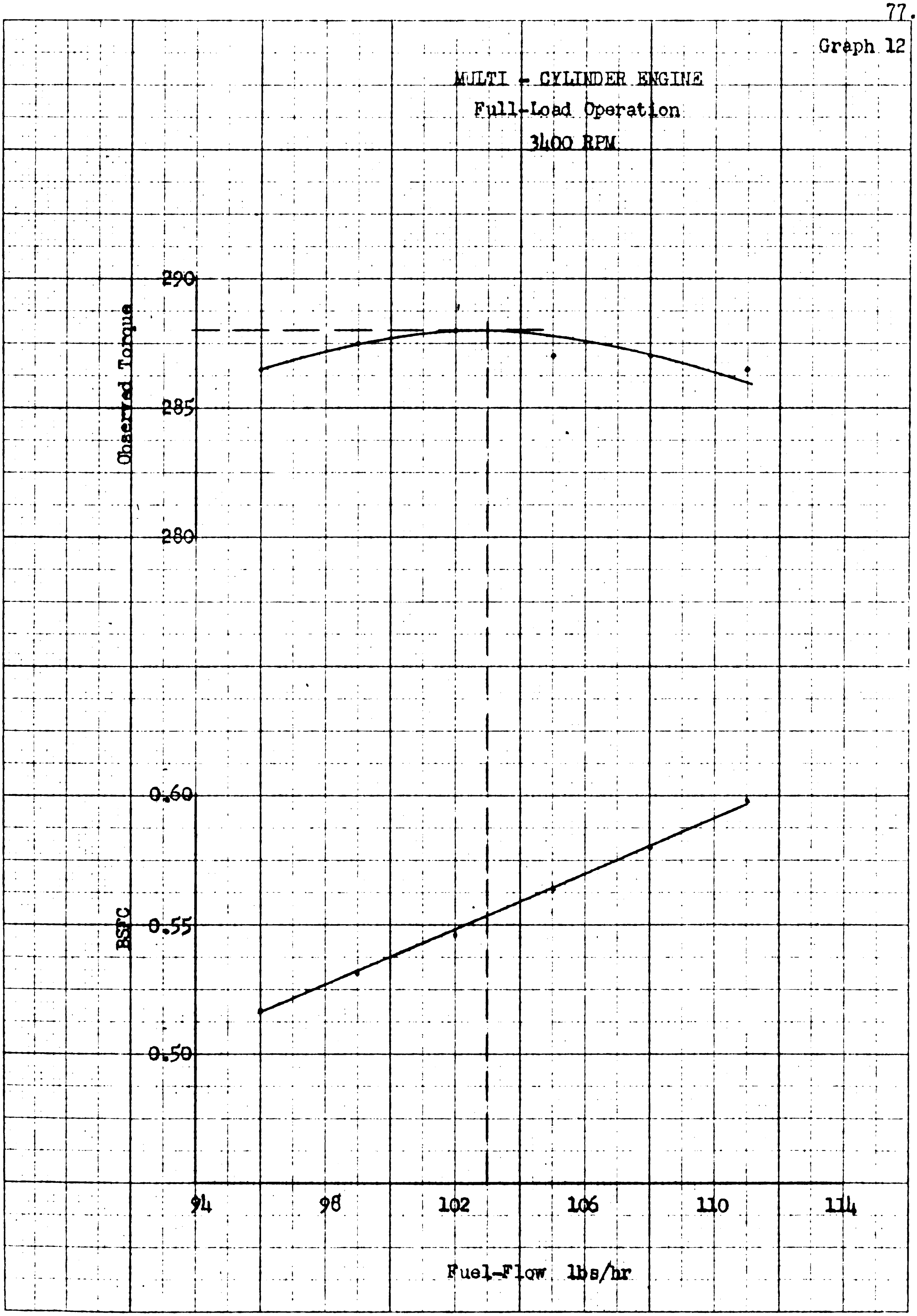
Graph 9
MULTI - CYLINDER ENGINE
Full-Load Operation
2800 RPM
Observed Torque
315
310
305
BSFC
0.7
0.6
0.5
86
88
91
94
97
100
Fuel-Flow lbs/hr

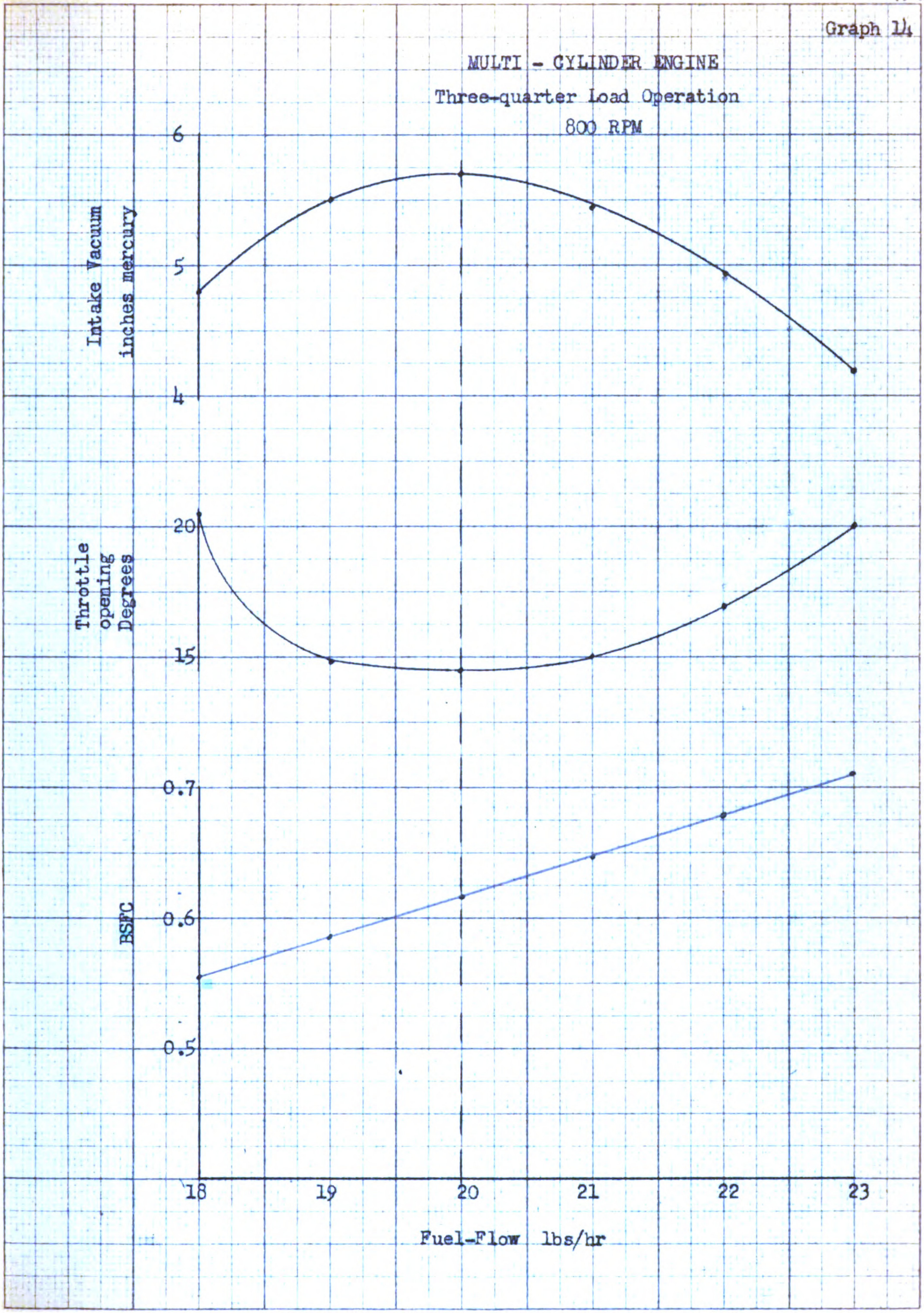
Graph 10


MULTI - CYLINDER ENGINE
Full-Load Operation
3000 RPM
Observed Torque
310
305
300
BSFC
0.6
0.55
0.5
90
93
96
99
102
105
Fuel-Flow lbs/hr

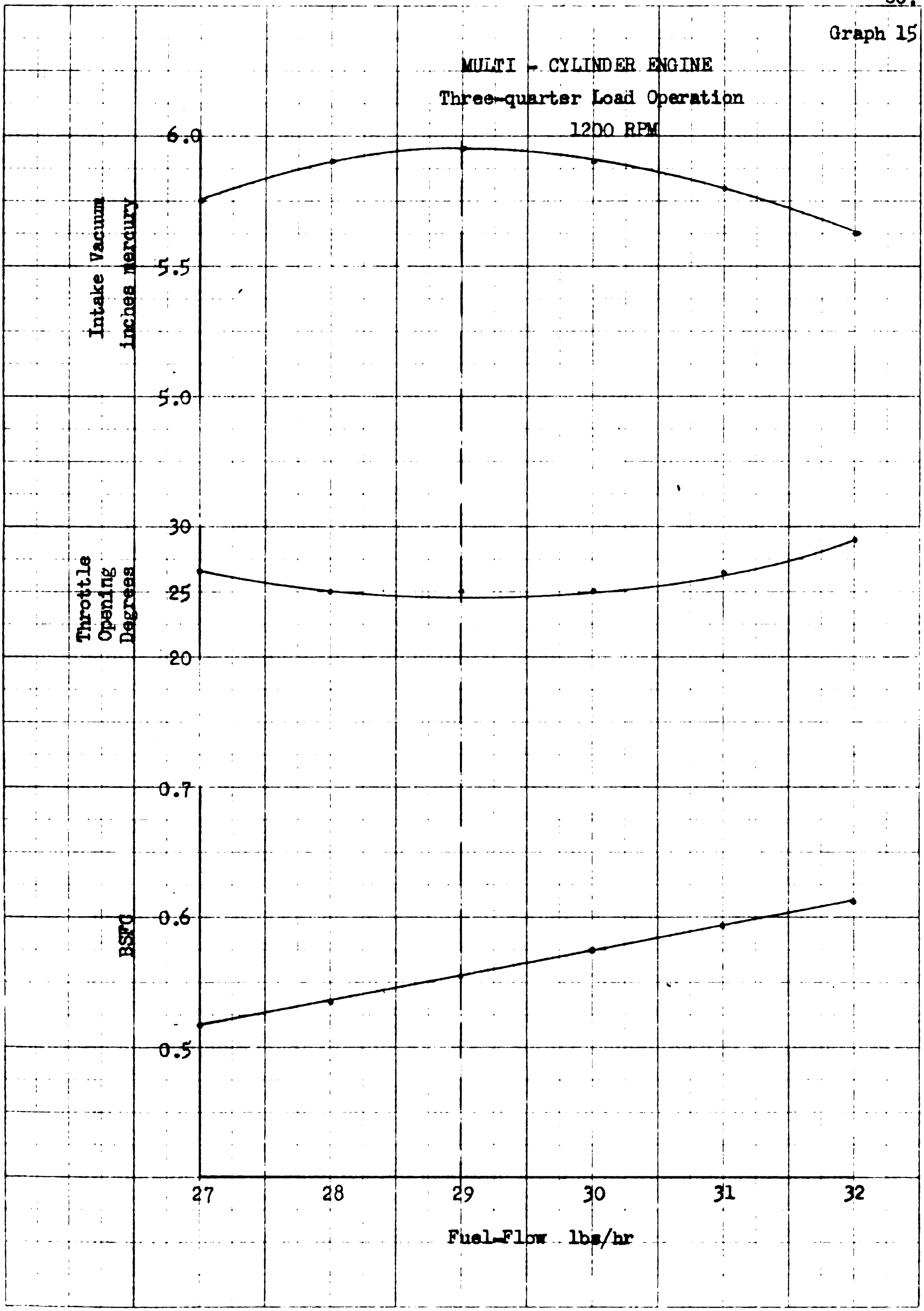
Graph 11


MULTI - CYLINDER ENGINE
Full-Load Operation
3200 RPM
Observed Torque
300
295
290
BSFC
0.60
0.55
0.50
93
96
99
102
105
108
Fuel-Flow lbs/hr

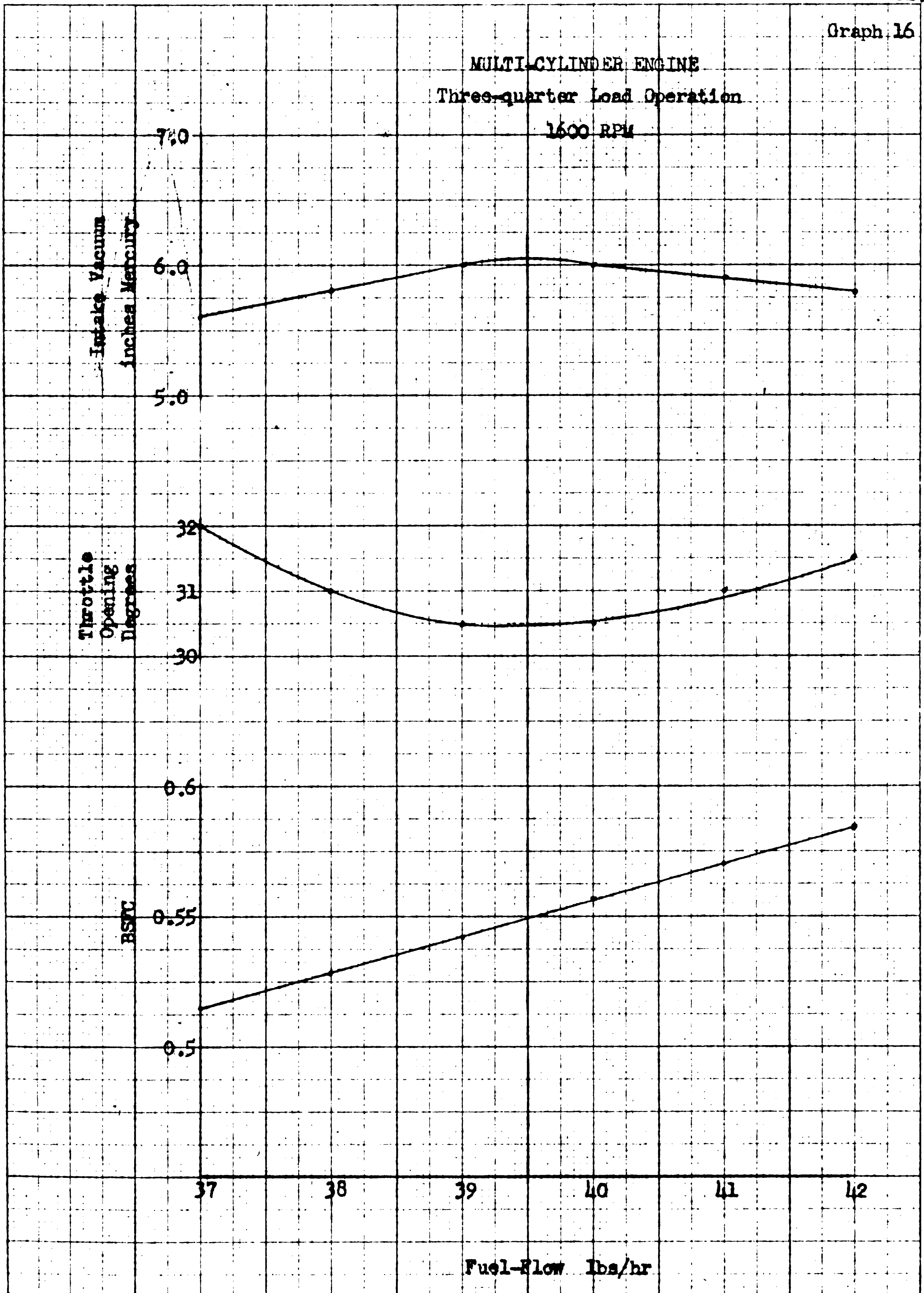

Graph 12
MULTI - CYLINDER ENGINE
Full-Load Operation
3400 RPM
Observed Torque
290
285
280
BSFC
0.60
0.55
0.50
94
98
102
106
110
114
Fuel-Flow lbs/hr

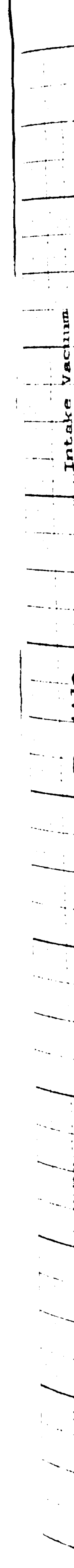

Graph 14
MULTI - CYLINDER ENGINE
Three-quarter Load Operation
800 RPM
Intake Vacuum
inches mercury
6
5
4
Throttle
opening
Degrees
20
15
BSFC
0.7
0.6
0.5
18
19
20
21
22
23
Fuel-Flow lbs/hr

Graph 15

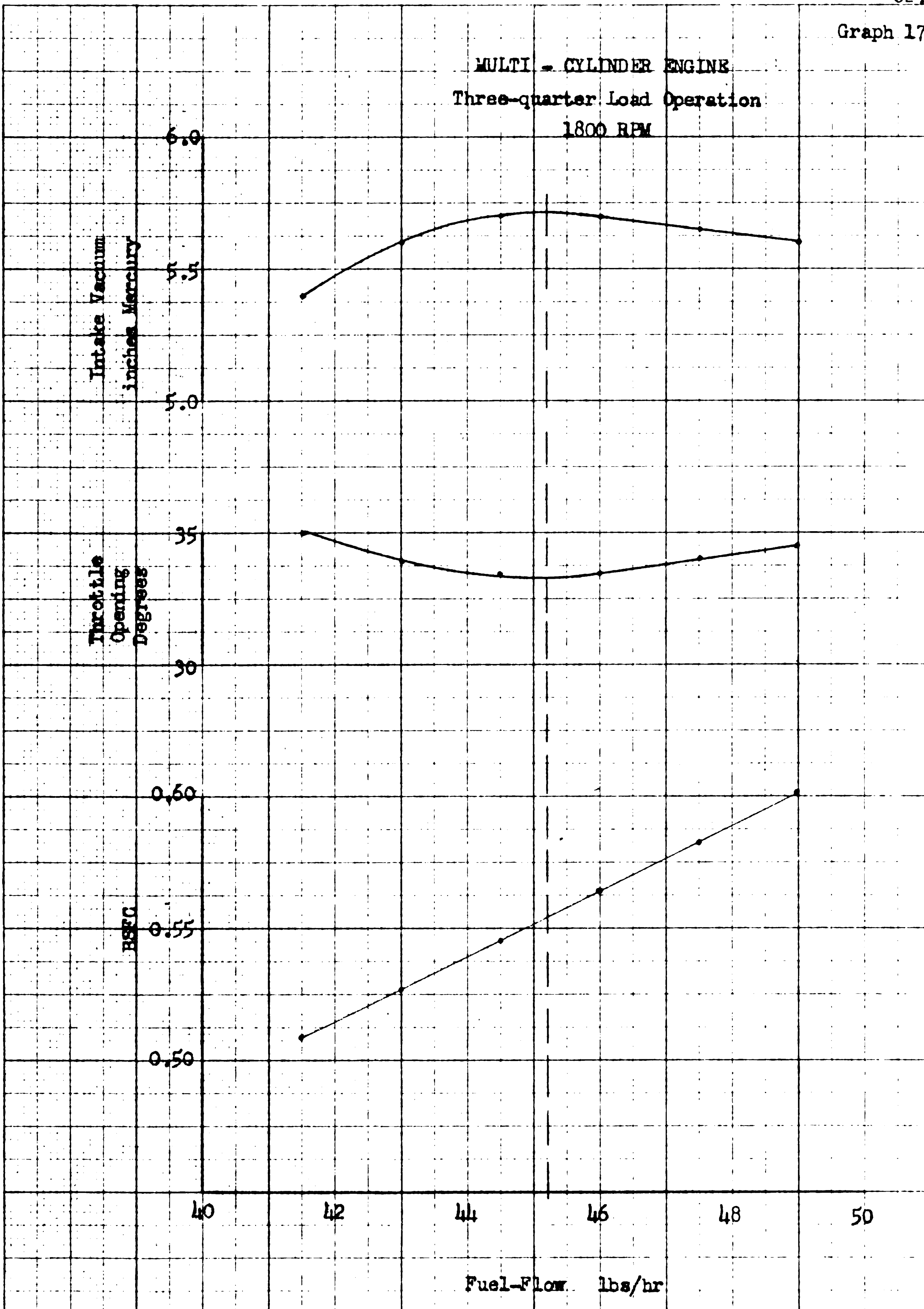

MULTI - CYLINDER ENGINE
Three-quarter Load Operation
1200 RPM
Intake Vacuum inches mercury
6.0
5.5
5.0
Throttle Opening Degrees
30
25
20
BSFC
0.7
0.6
0.5
27
28
29
30
31
32
Fuel-Flow lbs/hr

Throttle	Intake Vacuum

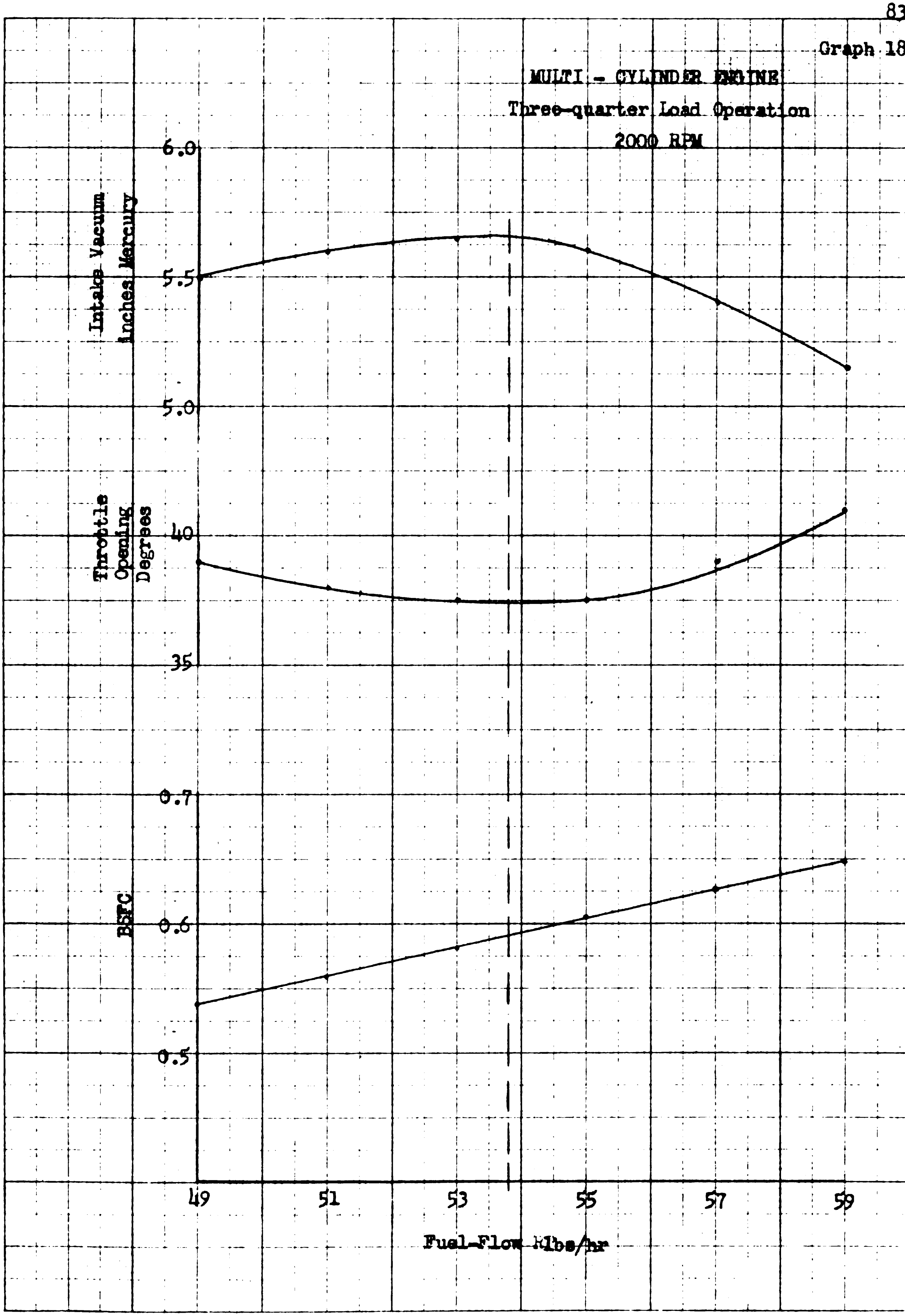

Graph 16
MULTI-CYLINDER ENGINE
Three-quarter Load Operation
1600 RPM
Intake Vacuum
Inches Mercury
7.0
6.0
5.0
Throttle
Opening
Degrees
32
31
30
BSFC
0.6
0.55
0.5
37
38
39
40
41
42
Fuel-Flow lbs/hr


Intake Vacuum

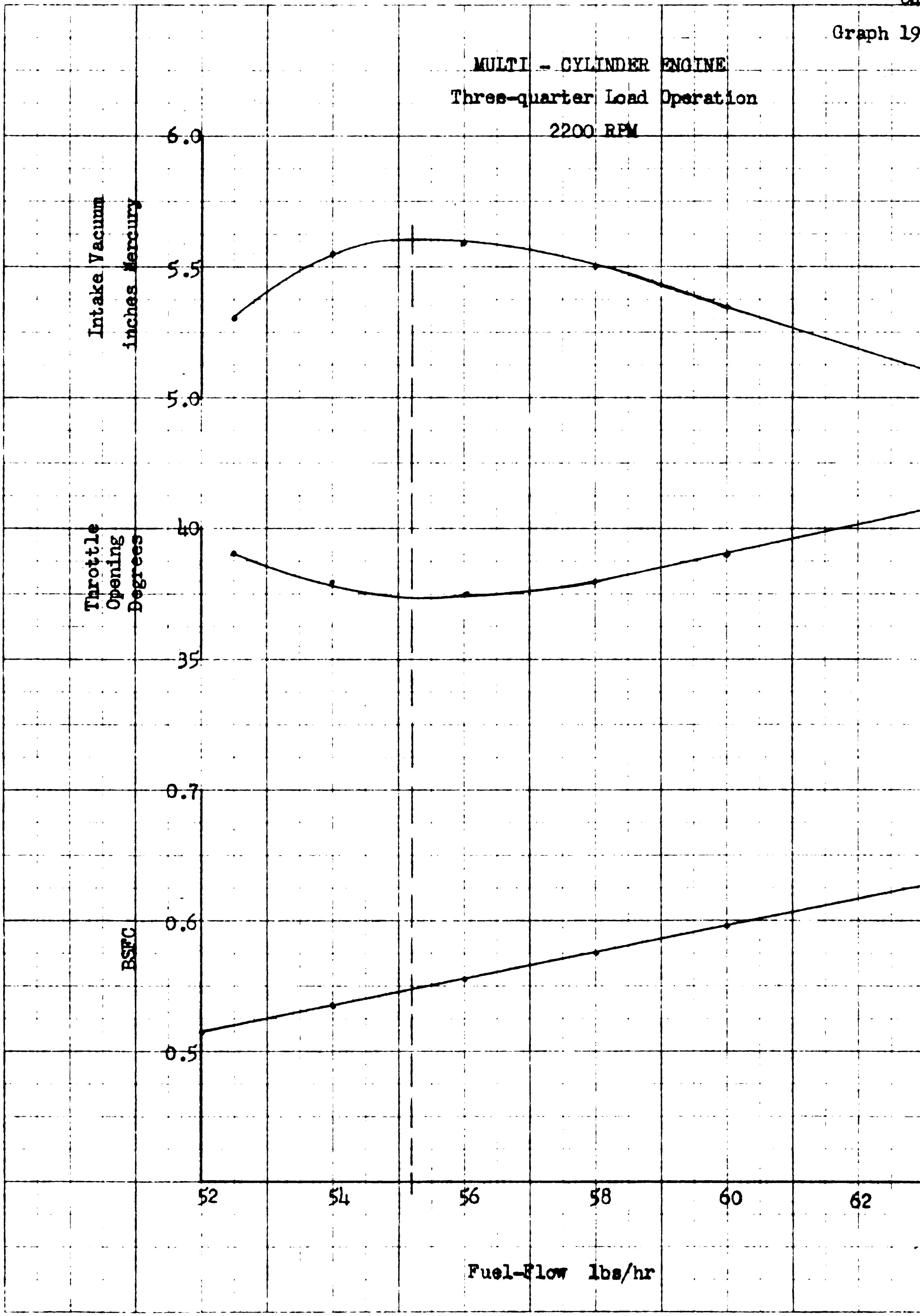
Graph 17

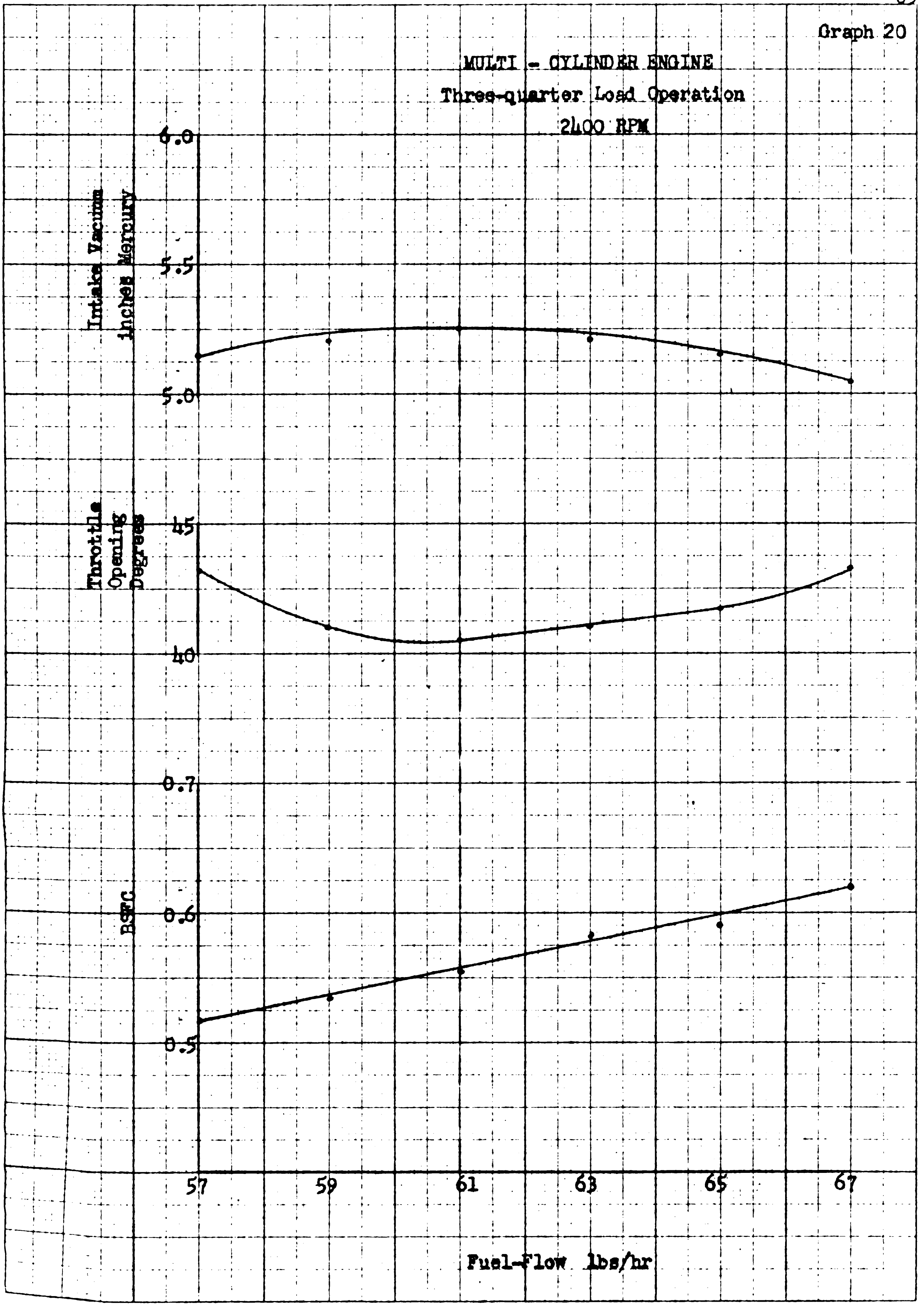

MULTI - CYLINDER ENGINE
Three-quarter Load Operation
1800 RPM
Intake Vacuum
inches Mercury
6.0
5.5
5.0
Throttle
Opening
Degrees
35
30
BSFC
0.60
0.55
0.50
40
42
44
46
48
50
Fuel-Flow lbs/hr

					Throttle		Intake Vacuum Inches Mercury	

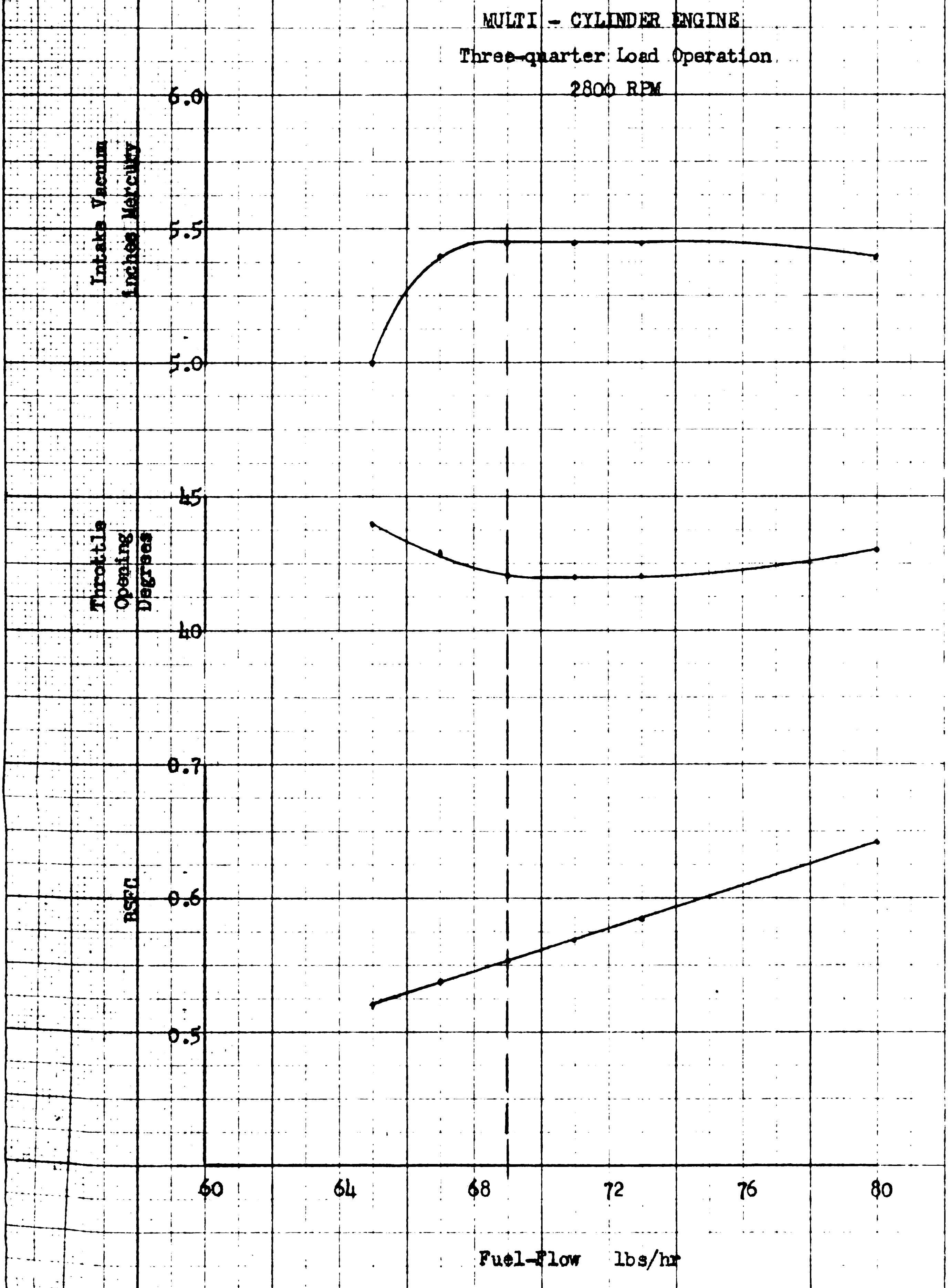

Graph 18
MULTI - CYLINDER ENGINE
Three-quarter Load Operation
2000 RPM
Intake Vacuum
Inches Mercury
6.0
5.5
5.0
Throttle
Opening
Degrees
40
35
BSFC
0.7
0.6
0.5
49
51
53
55
57
59
Fuel-Flow lbs/hr

Graph 19

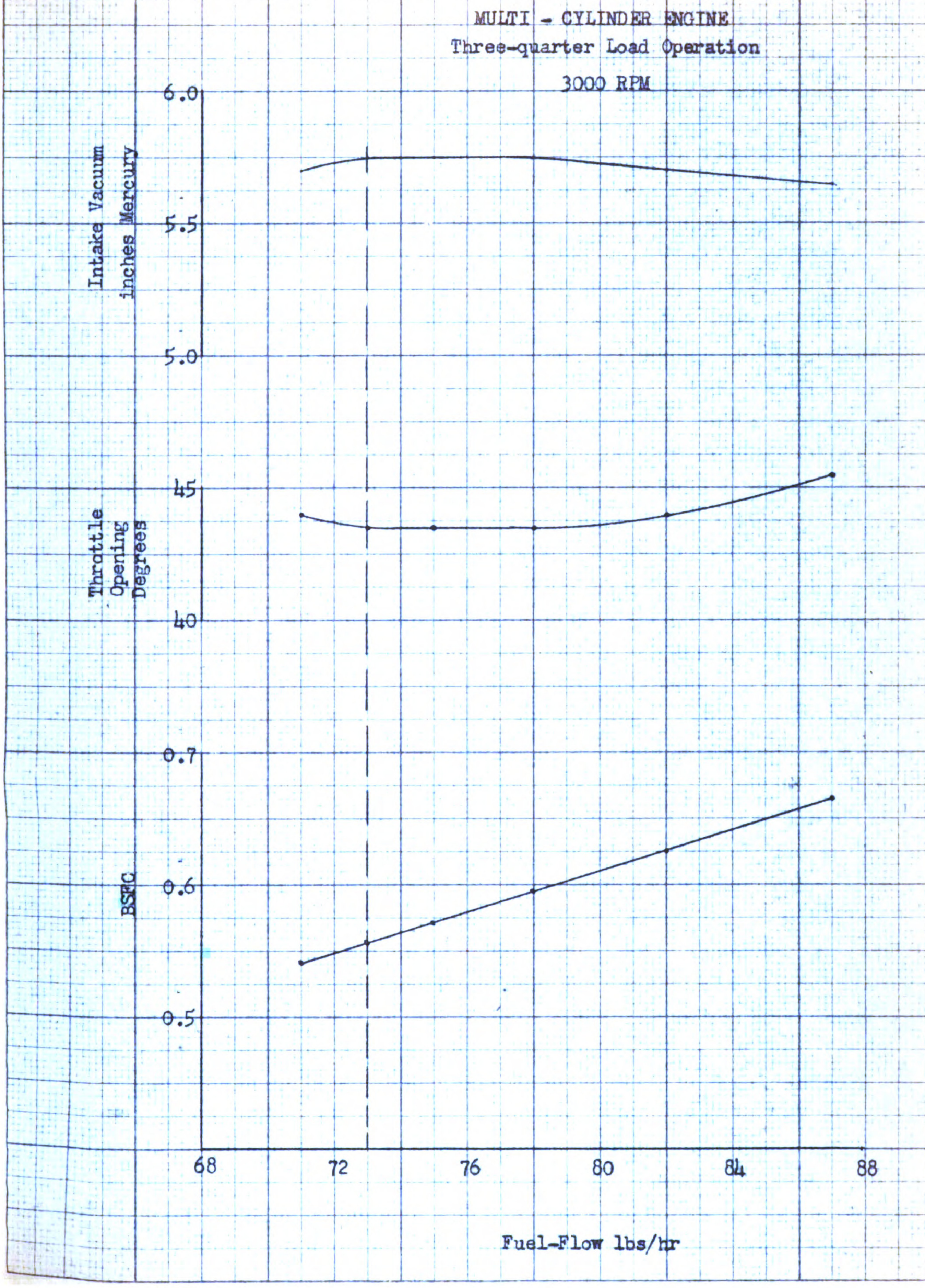

MULTI - CYLINDER ENGINE
Three-quarter Load Operation
2200 RPM
Intake Vacuum inches Mercury
6.0
5.5
5.0
Throttle Opening Degrees
40
35
BSFC
0.7
0.6
0.5
52
54
56
58
60
62
Fuel-Flow lbs/hr


Graph 20
MULTI - CYLINDER ENGINE
Three-quarter Load Operation
2400 RPM
Intake Vacuum
Inches Mercury
6.0
5.5
5.0
Throttle
Opening
Degrees
45
40
BSFC
0.7
0.6
0.5
57
59
61
63
65
67
Fuel-Flow lbs/hr

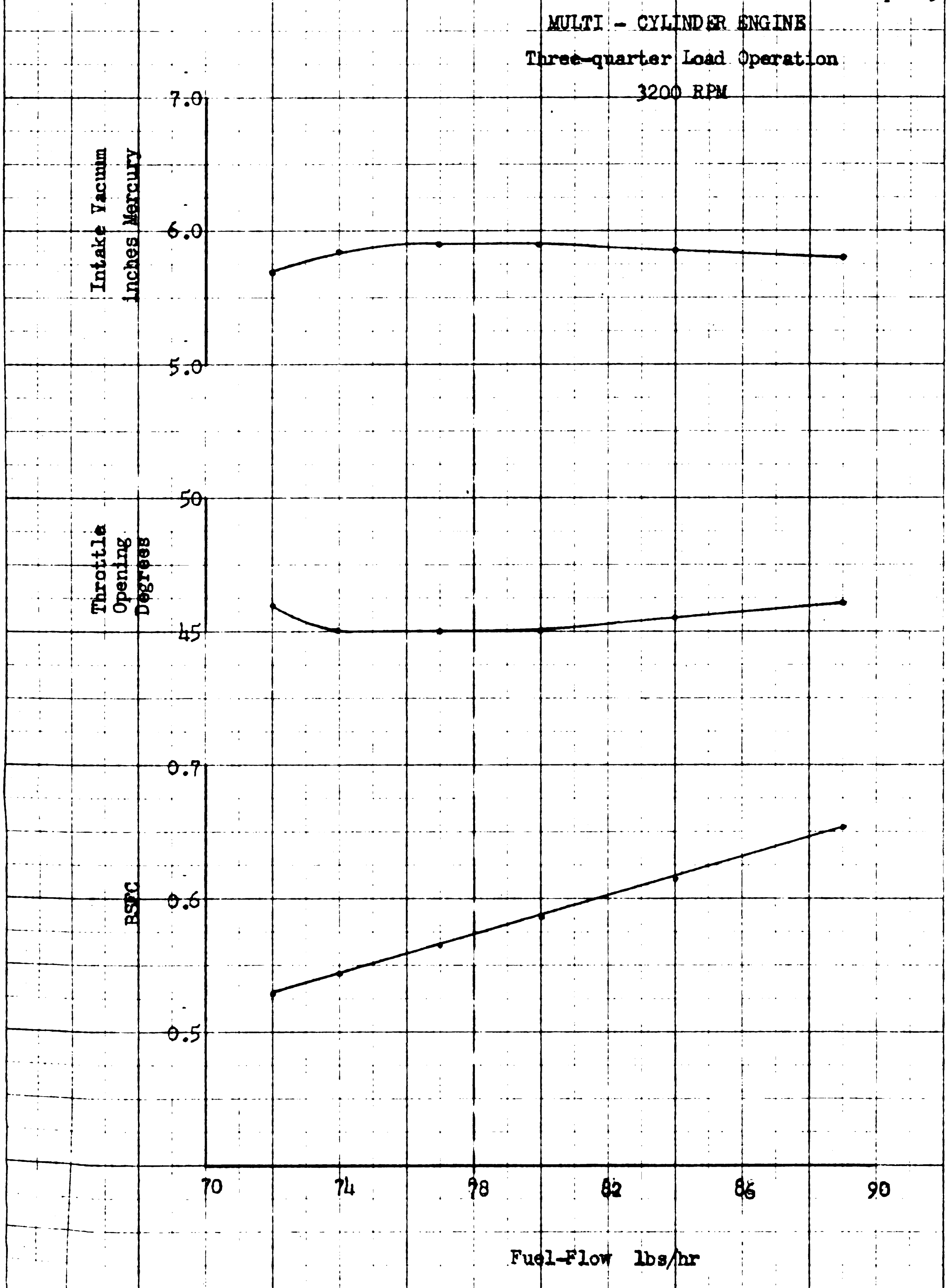
Graph 21


MULTI - CYLINDER ENGINE
Three-quarter Load Operation
2800 RPM
Intake Vacuum
Inches Mercury
6.0
5.5
5.0
Throttle
Opening
Degrees
45
40
BSFC
0.7
0.6
0.5
60
64
68
72
76
80
Fuel-Flow lbs/hr

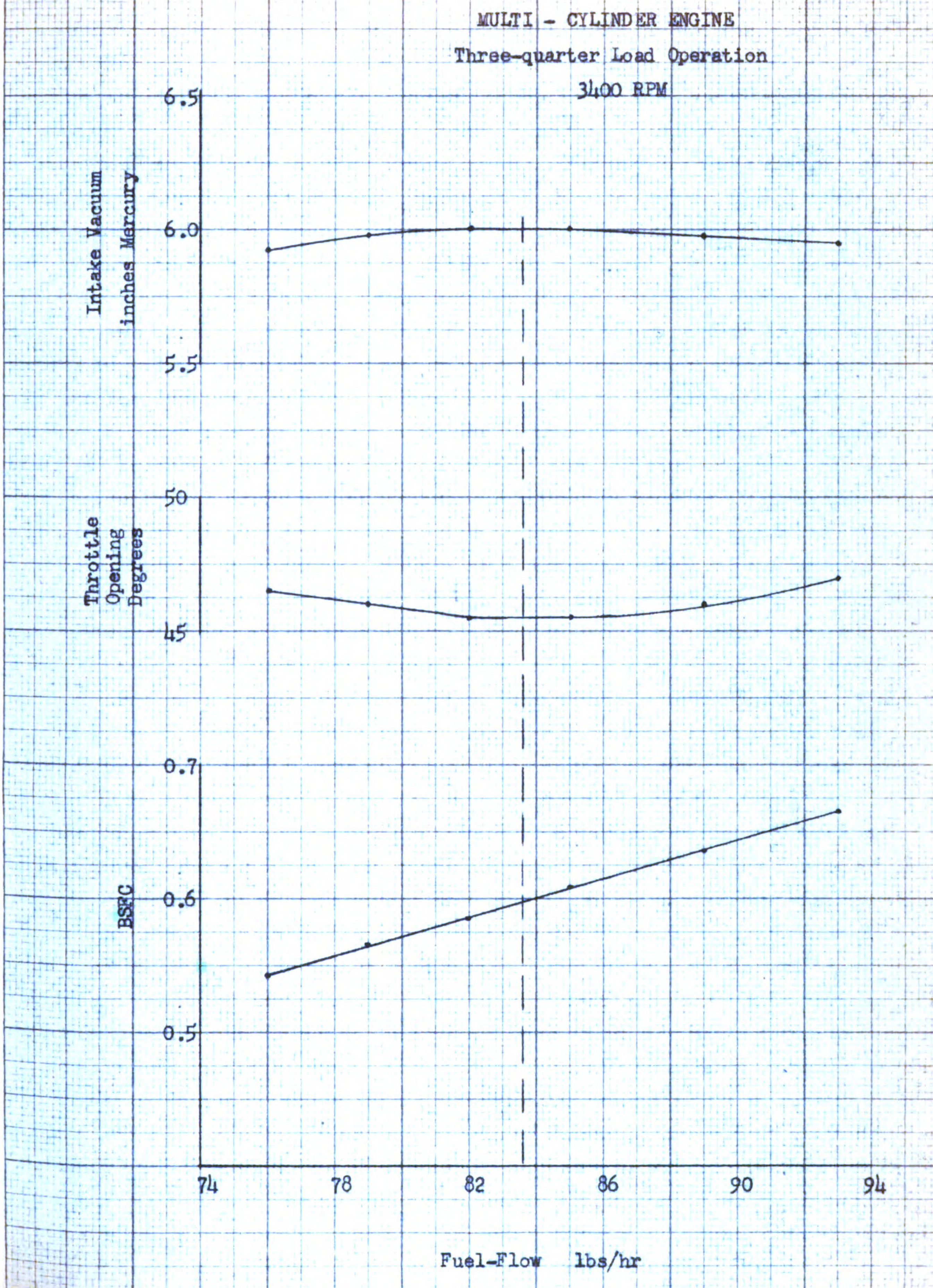
Graph 22

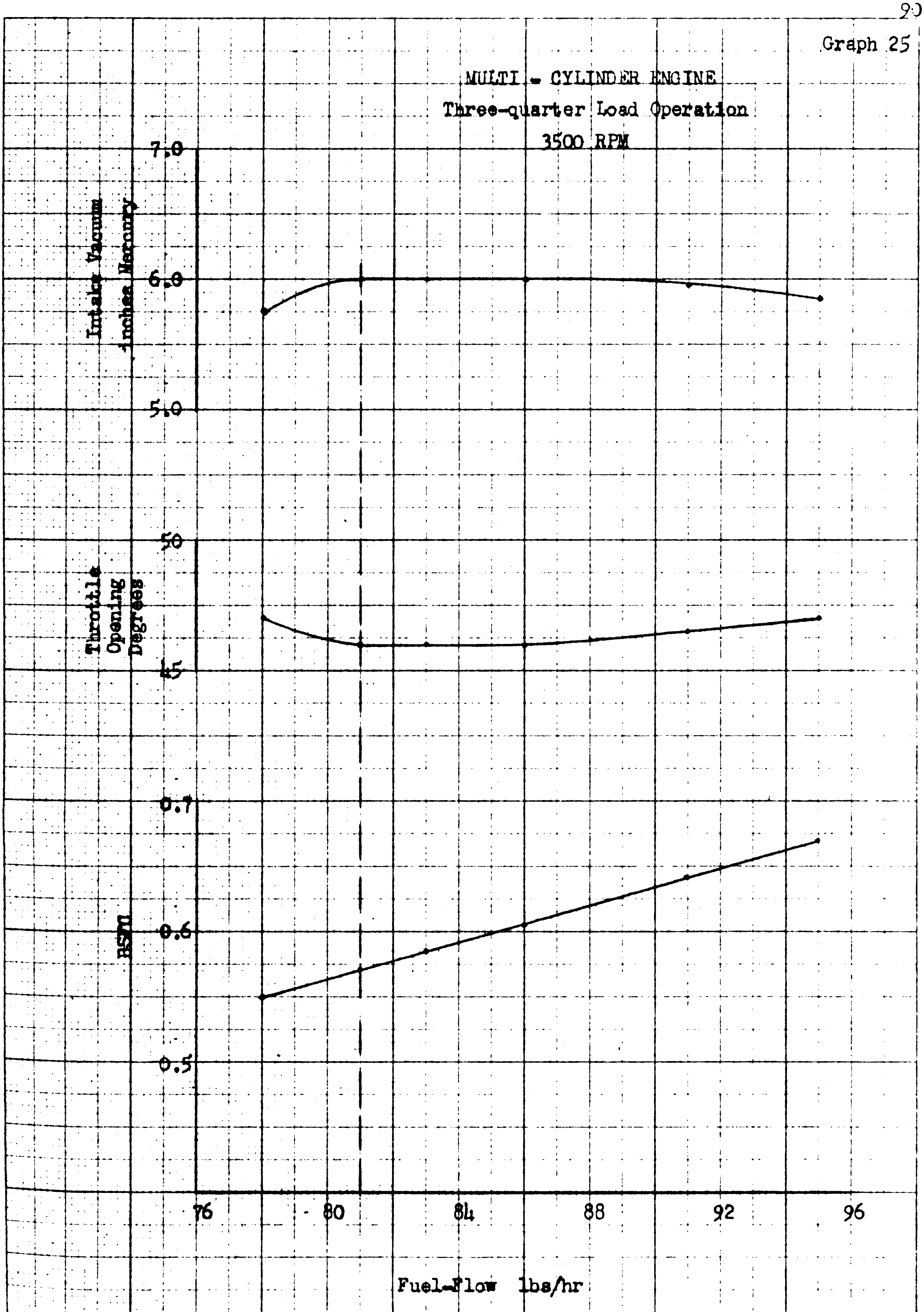

MULTI - CYLINDER ENGINE
Three-quarter Load Operation
3000 RPM
Intake Vacuum
inches Mercury
6.0
5.5
5.0
Throttle
Opening
Degrees
45
40
BSFC
0.7
0.6
0.5
68
72
76
80
84
88
Fuel-Flow lbs/hr

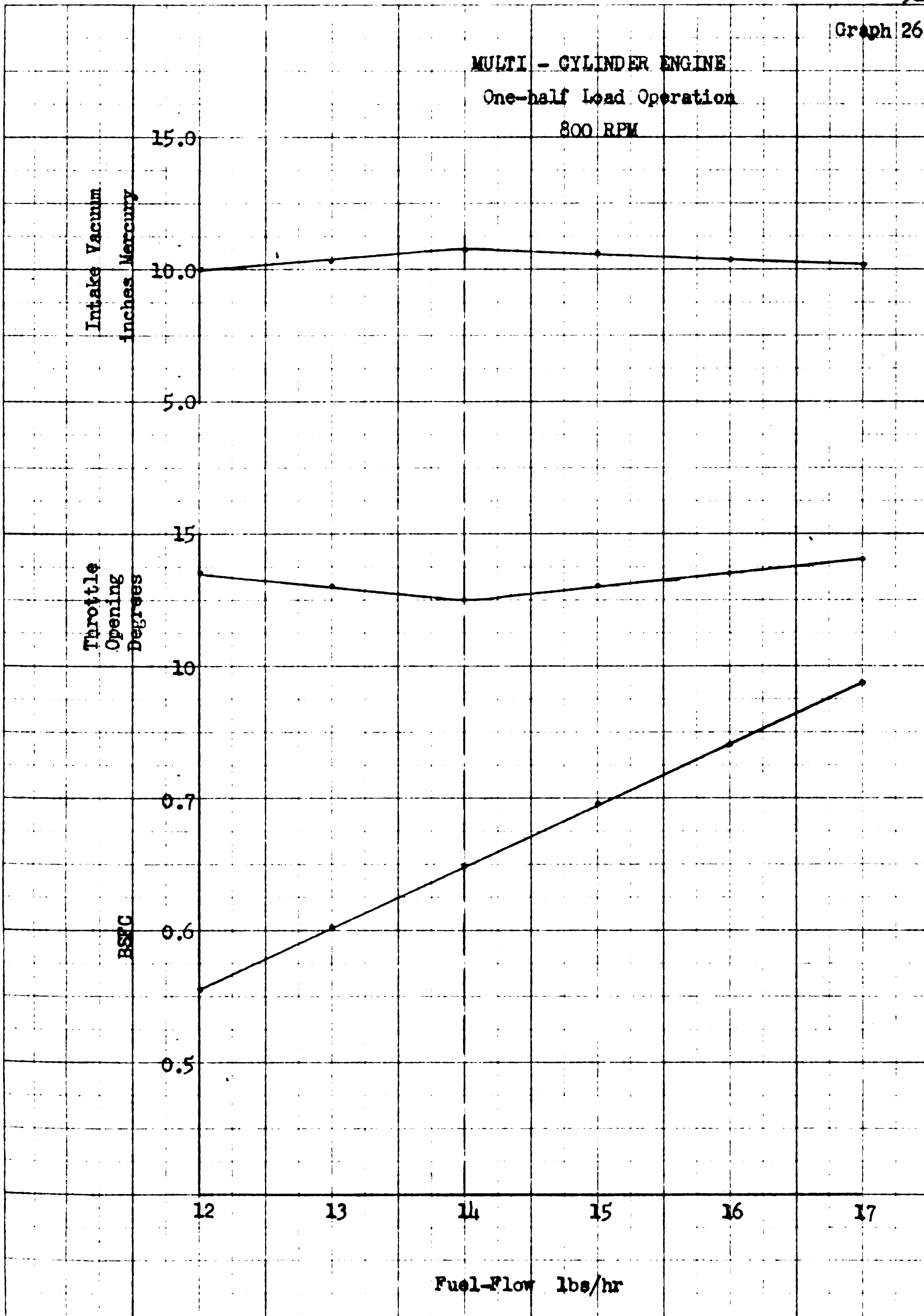
Graph 23


MULTI - CYLINDER ENGINE
Three-quarter Load Operation
3200 RPM
Intake Vacuum inches Mercury
7.0
6.0
5.0
Throttle Opening Degrees
50
45
BSFC
0.7
0.6
0.5
70
74
78
82
86
90
Fuel-Flow lbs/hr

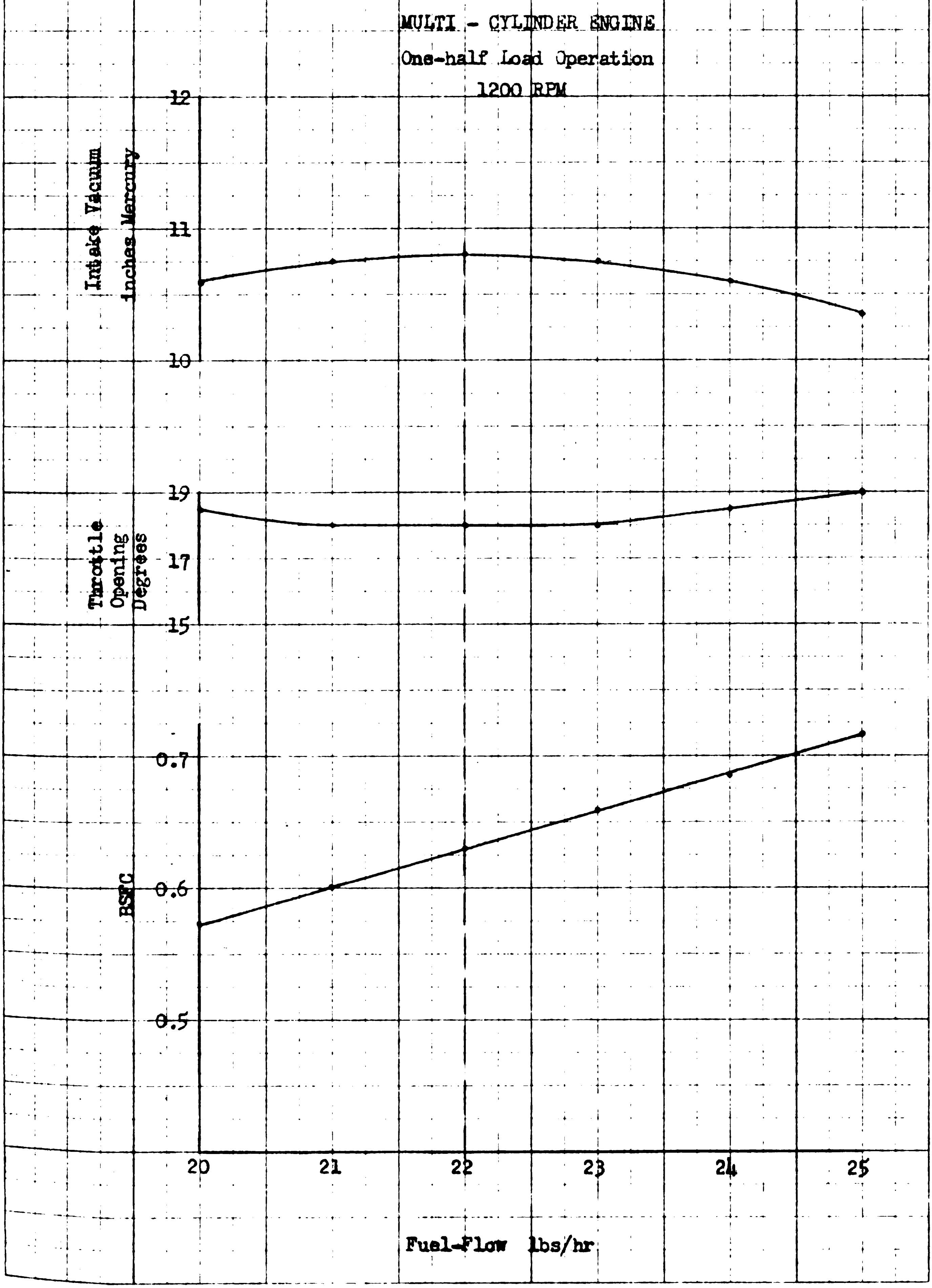
Graph 24

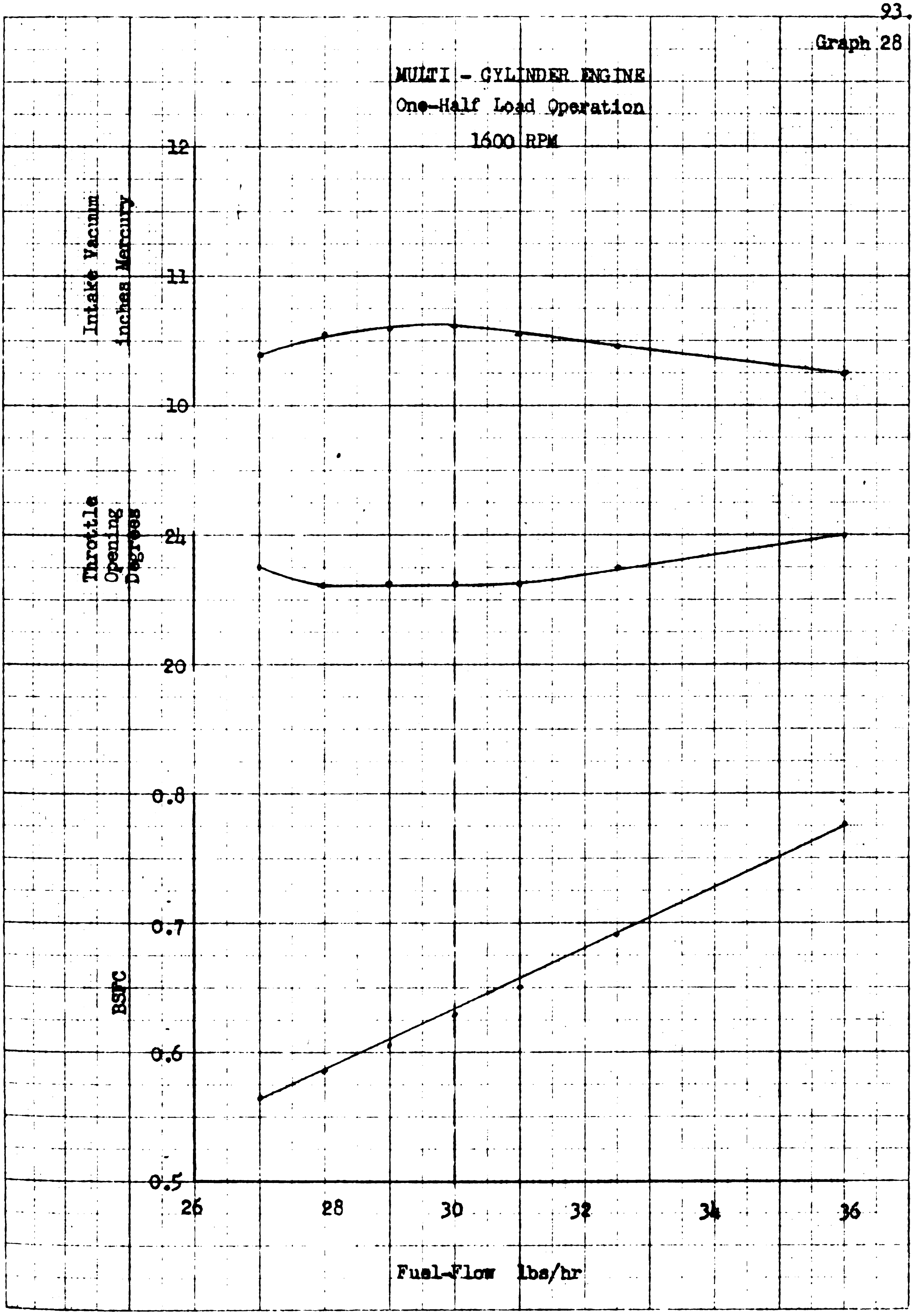

MULTI - CYLINDER ENGINE
Three-quarter Load Operation
3400 RPM
Intake Vacuum
inches Mercury
6.5
6.0
5.5
Throttle
Opening
Degrees
50
45
BSFC
0.7
0.6
0.5
74
78
82
86
90
94
Fuel-Flow lbs/hr


Graph 25
MULTI - CYLINDER ENGINE
Three-quarter Load Operation
3500 RPM
Intake Vacuum inches Mercury
7.0
6.0
5.0
Throttle Opening Degrees
50
45
BSFC
0.7
0.6
0.5
76
80
84
88
92
96
Fuel-Flow lbs/hr

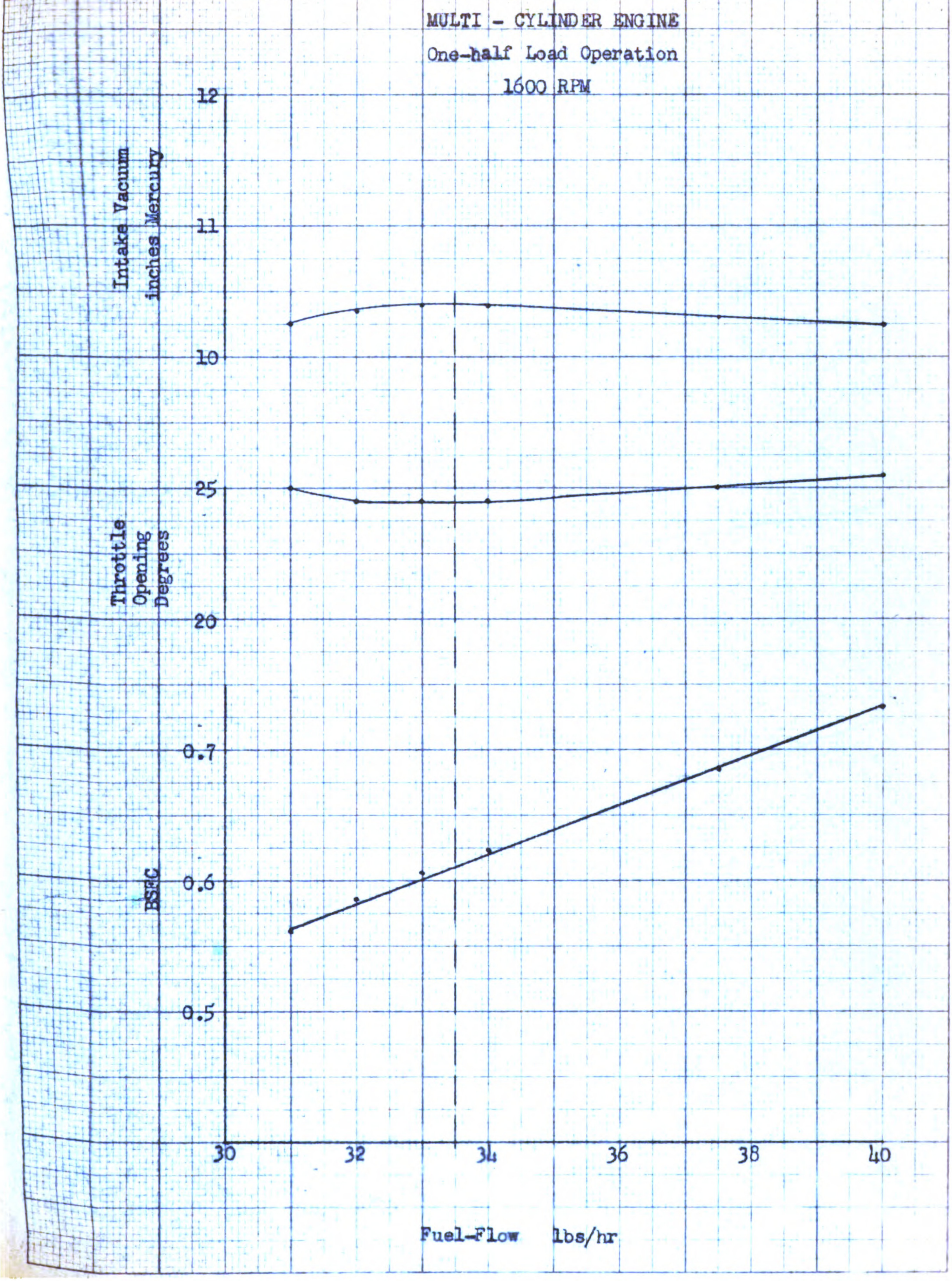

Graph 26
MULTI - CYLINDER ENGINE
One-half Load Operation
800 RPM
15.0
10.0
5.0
Intake Vacuum
Inches Mercury
15
10
Throttle
Opening
Degrees
0.7
0.6
0.5
BSFC
12
13
14
15
16
17
Fuel-Flow lbs/hr

Graph 27

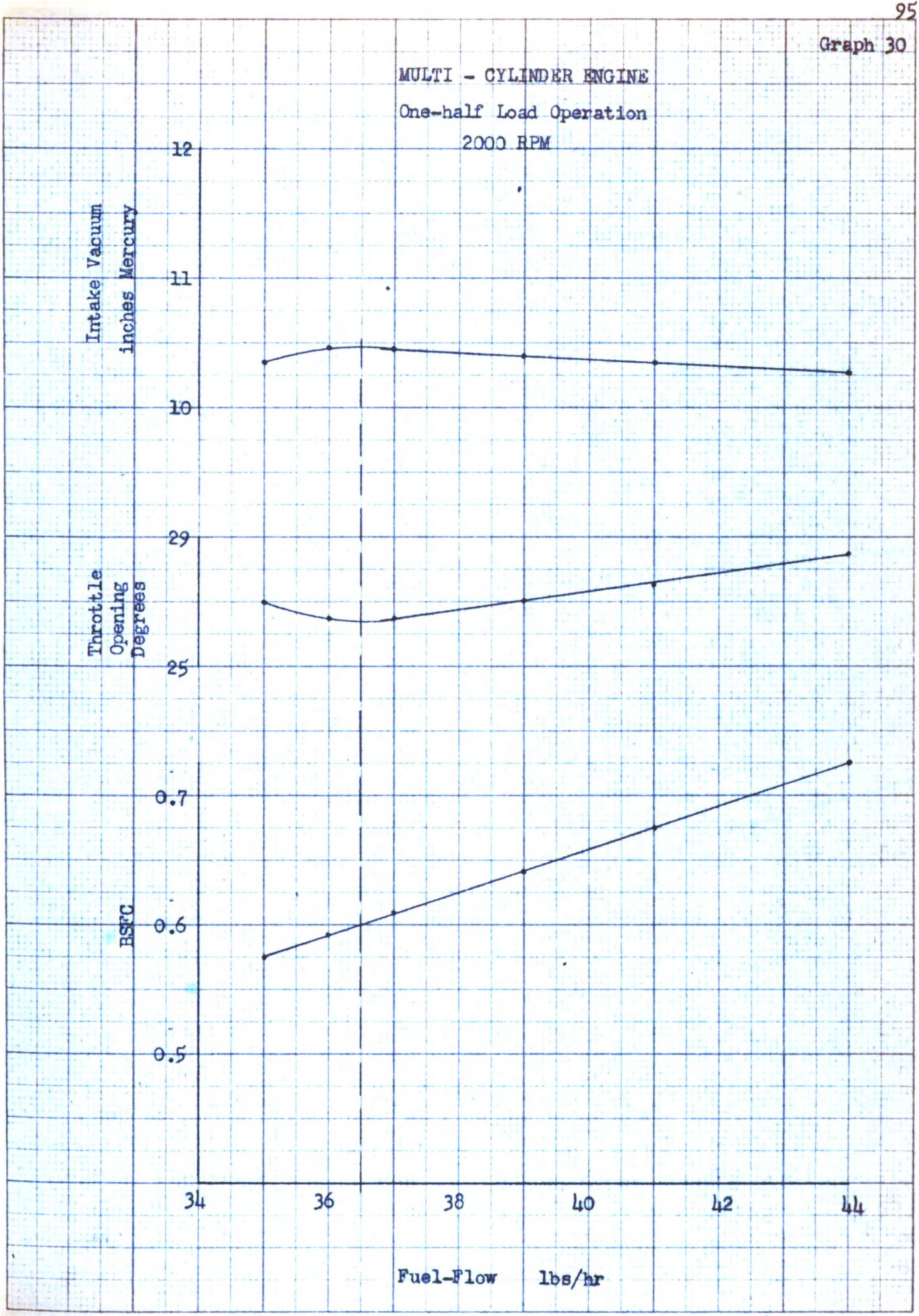

MULTI - CYLINDER ENGINE
One-half Load Operation
1200 RPM
Intake Vacuum
Inches Mercury
12
11
10
19
17
15
Throttle
Opening
Degrees
0.7
0.6
0.5
BSFC
20
21
22
23
24
25
Fuel-Flow lbs/hr

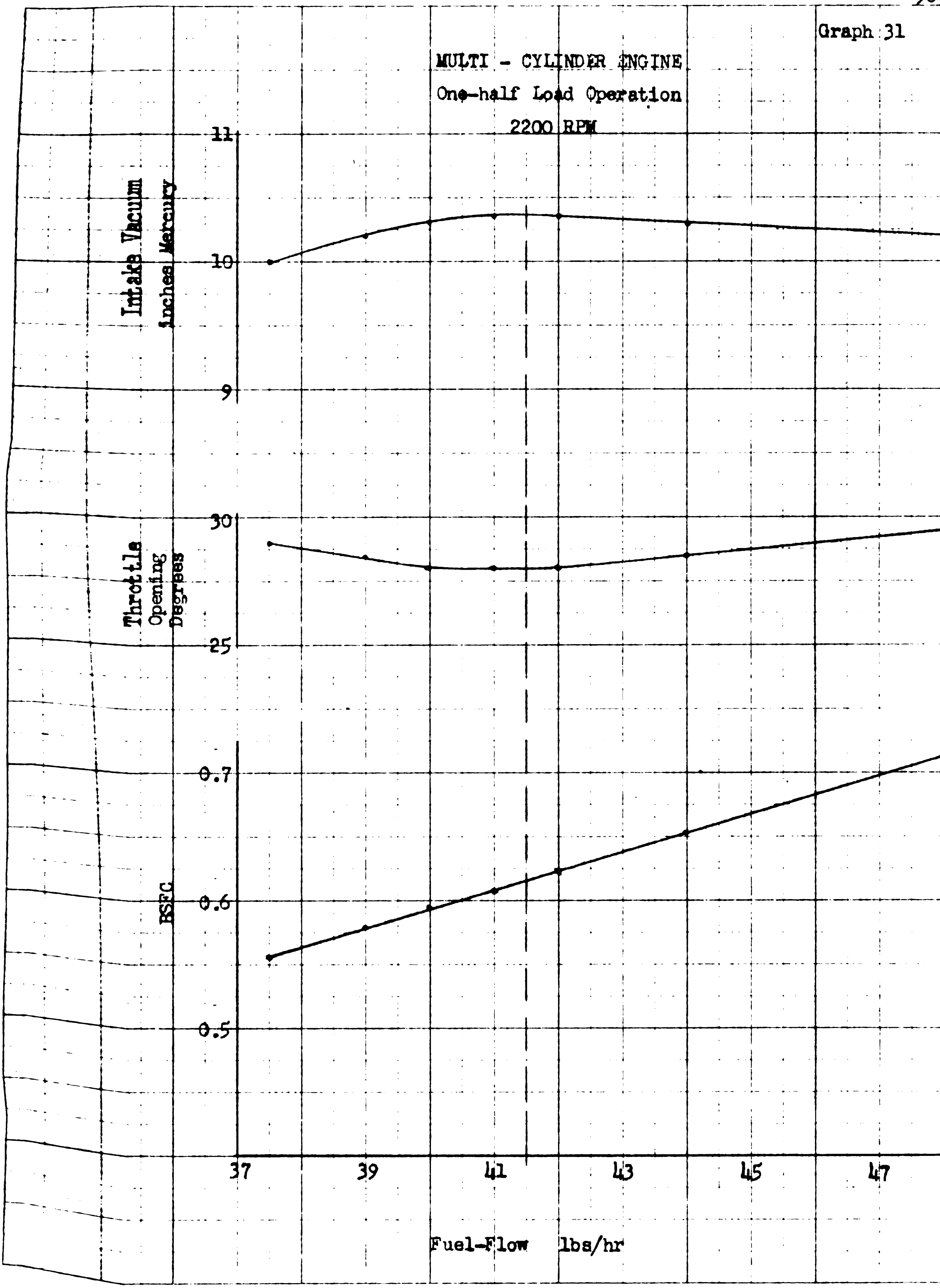

Graph 28
MULTI - CYLINDER ENGINE
One-Half Load Operation
1600 RPM
Intake Vacuum
Inches Mercury
Throttle
Opening
Degrees
BSFC
12
11
10
24
20
0.8
0.7
0.6
0.5
26
28
30
32
34
36
Fuel-Flow lbs/hr

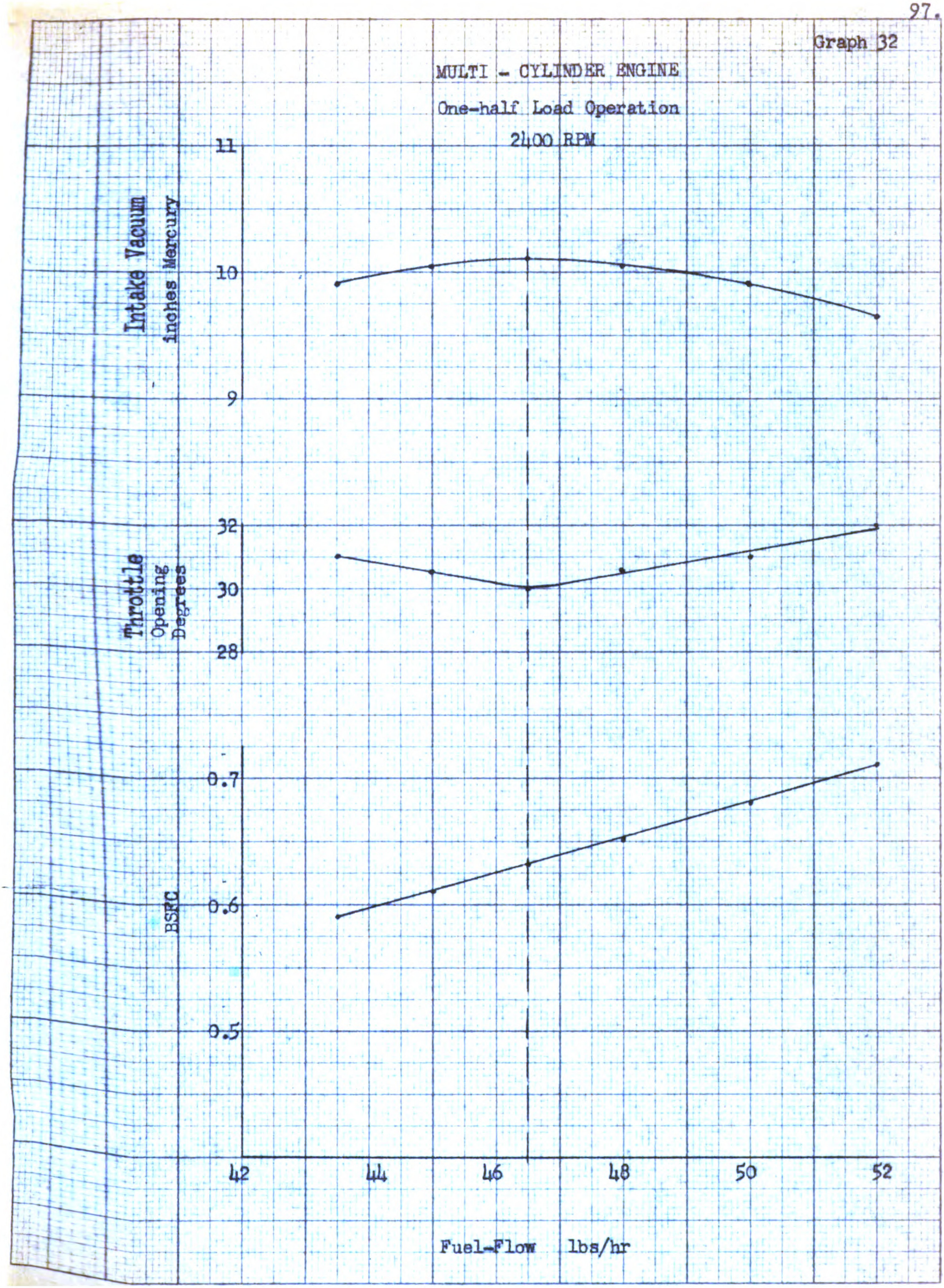
Graph 29

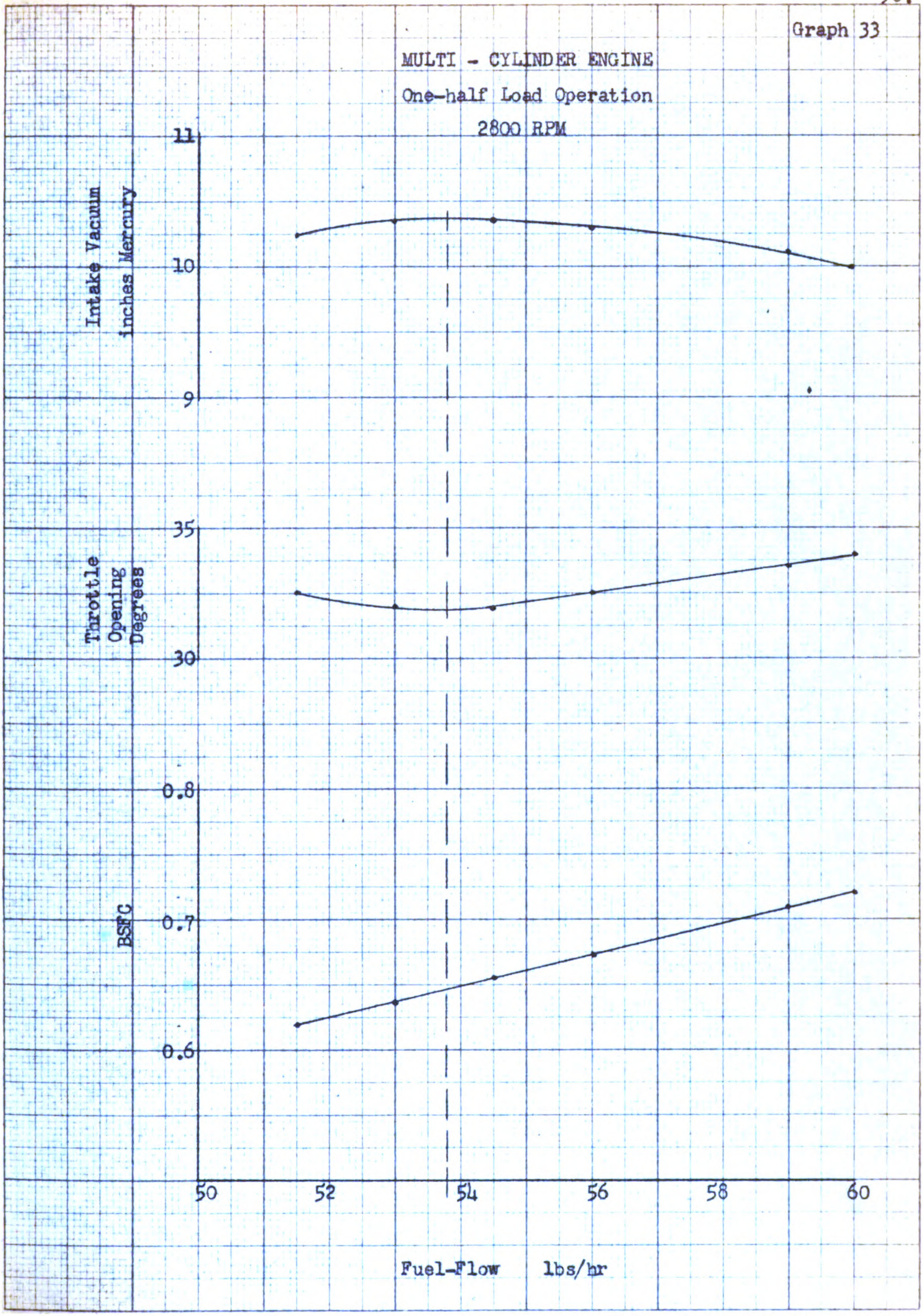

MULTI - CYLINDER ENGINE
One-half Load Operation
1600 RPM
Intake Vacuum inches Mercury
12
11
10
Throttle Opening Degrees
25
20
BSFC
0.7
0.6
0.5
30
32
34
36
38
40
Fuel-Flow lbs/hr

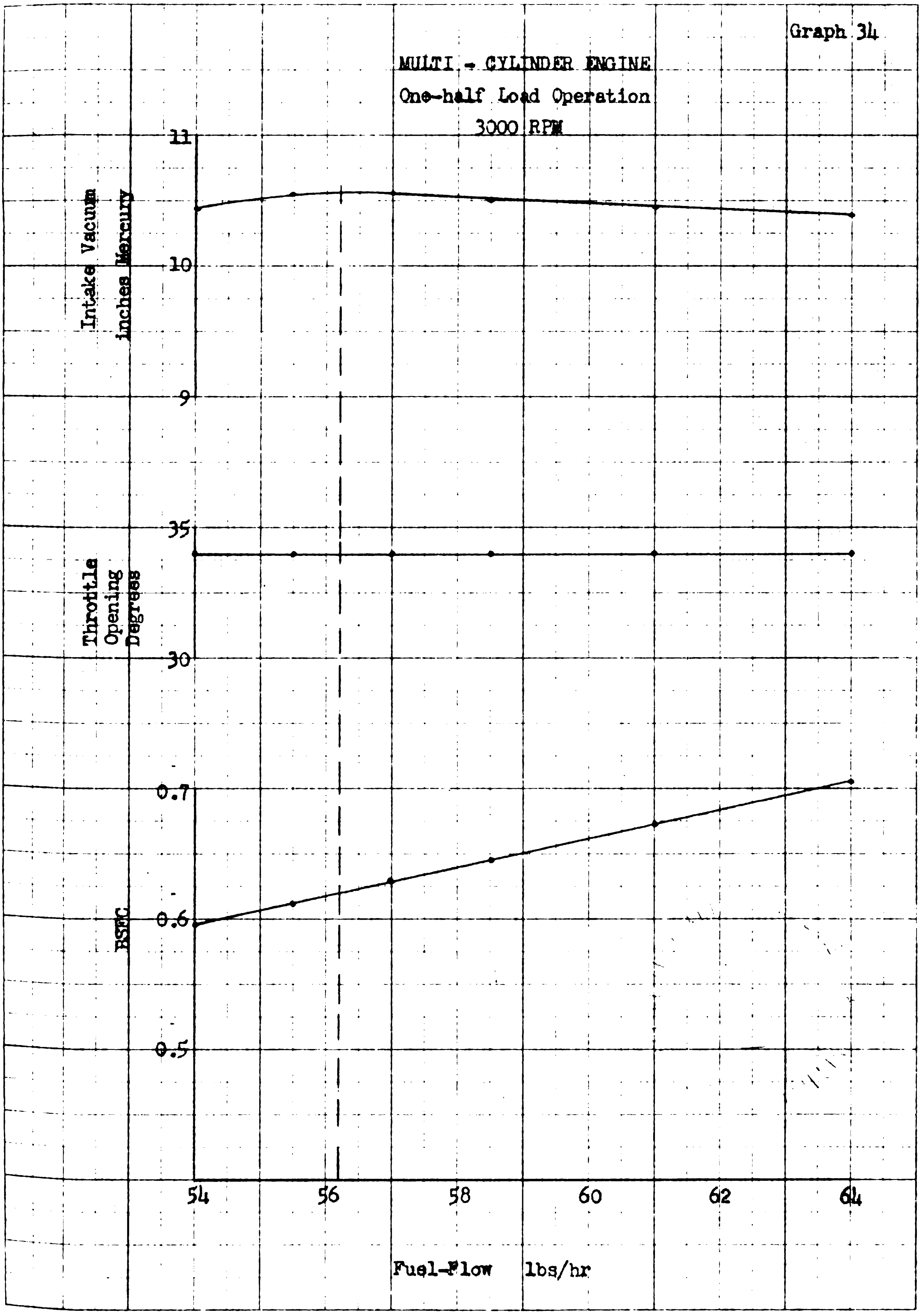
Graph 30

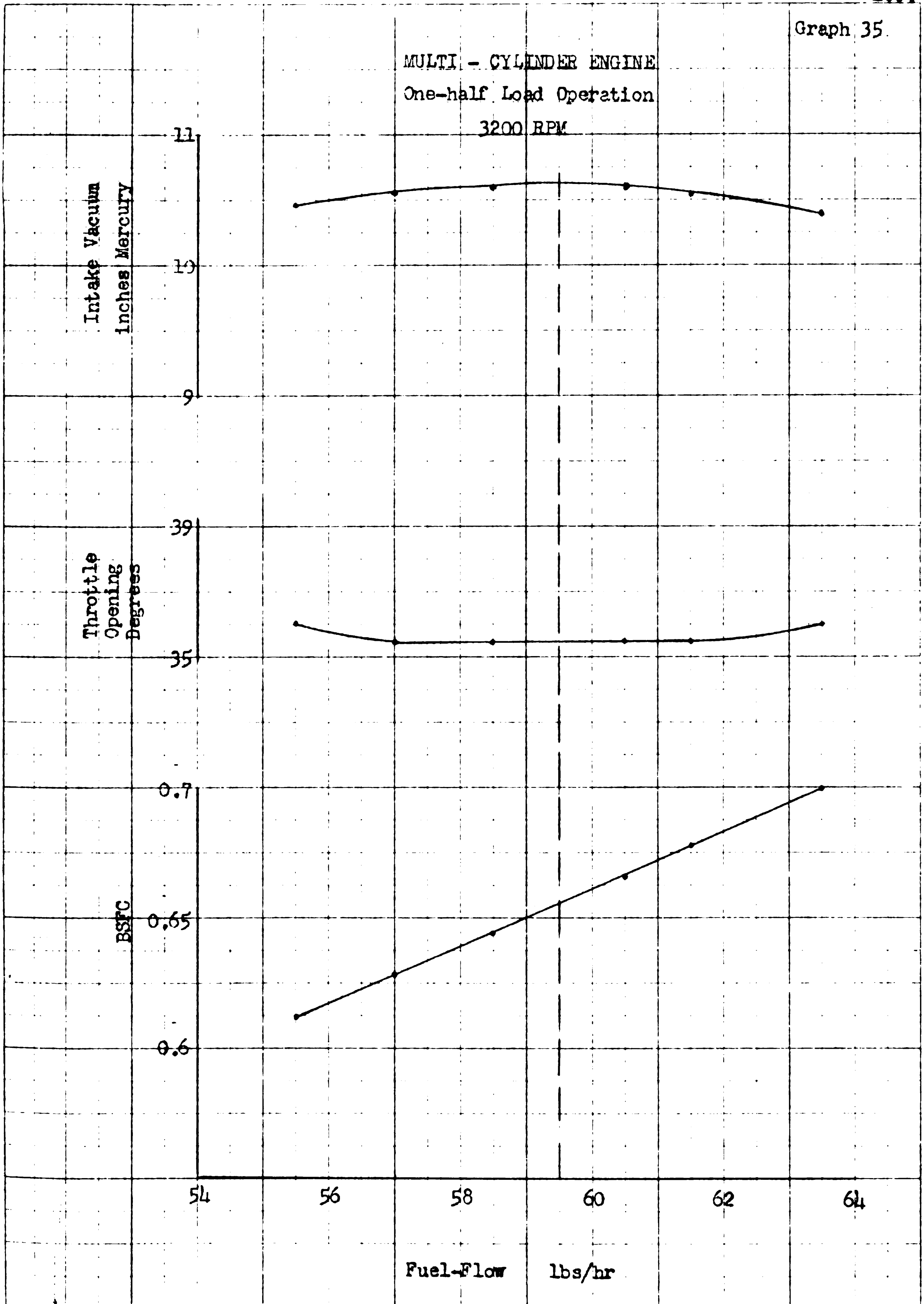

MULTI - CYLINDER ENGINE
One-half Load Operation
2000 RPM
Intake Vacuum inches Mercury
Throttle Opening Degrees
BSFC
12
11
10
29
25
0.7
0.6
0.5
34
36
38
40
42
44
Fuel-Flow lbs/hr


Graph 31
MULTI - CYLINDER ENGINE
One-half Load Operation
2200 RPM
Intake Vacuum
Inches Mercury
11
10
9
Throttle
Opening
Degrees
30
25
BSFC
0.7
0.6
0.5
37
39
41
43
45
47
Fuel-Flow lbs/hr

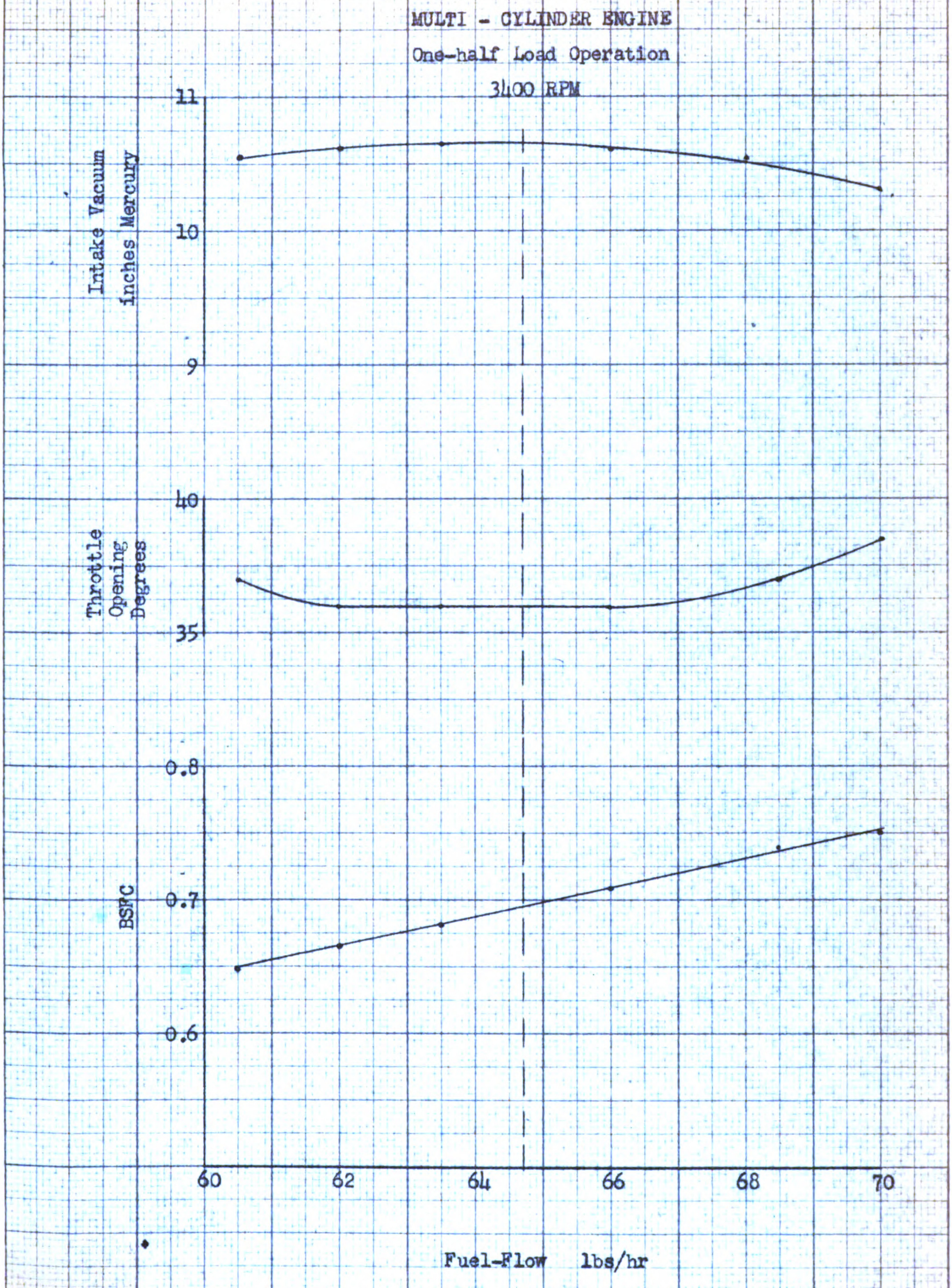

Graph 32
MULTI - CYLINDER ENGINE
One-half Load Operation
2400 RPM
Intake Vacuum
inches Mercury
11
10
9
Throttle
Opening
Degrees
32
30
28
BSFC
0.7
0.6
0.5
42
44
46
48
50
52
Fuel-Flow lbs/hr

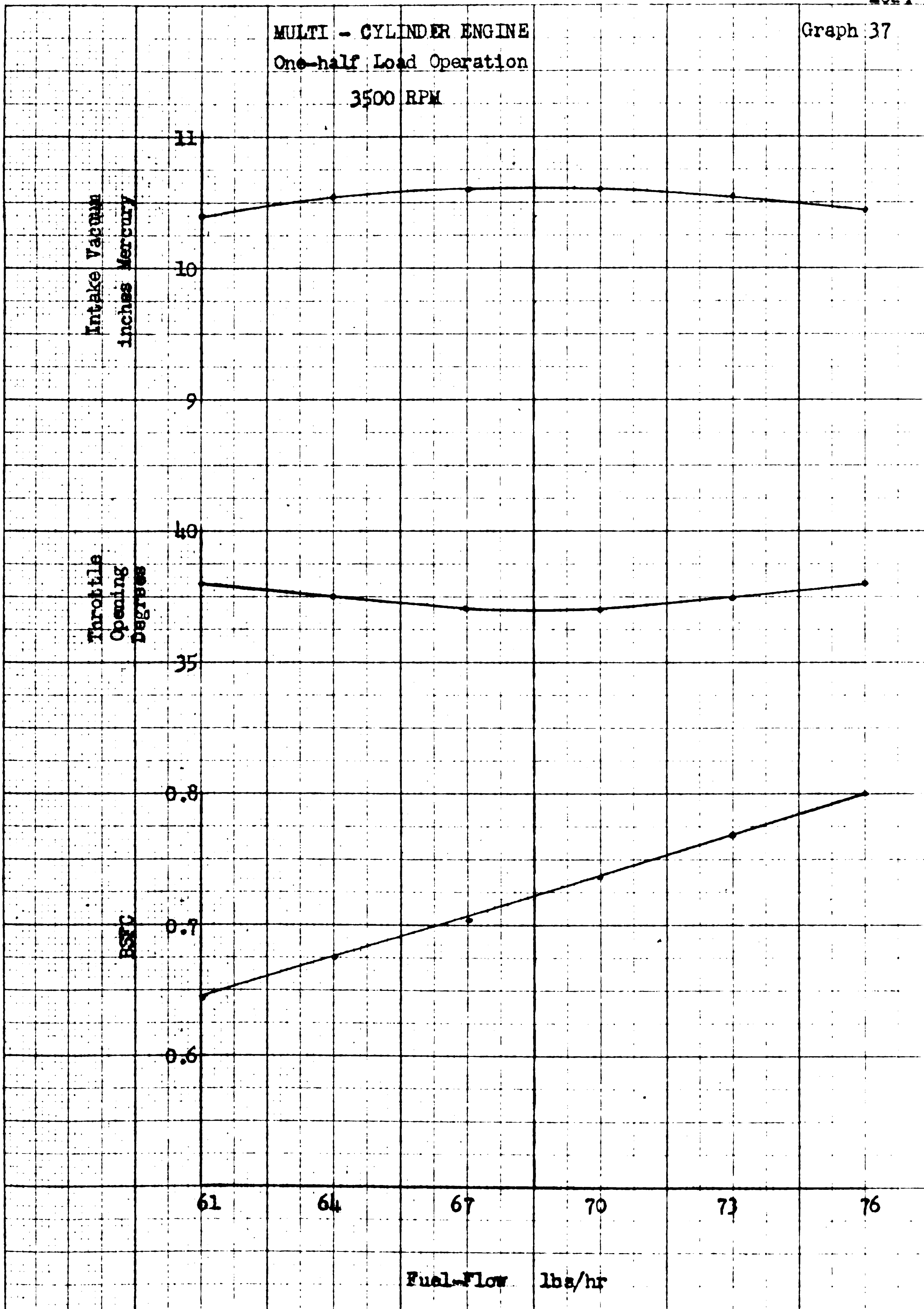

Graph 33
MULTI - CYLINDER ENGINE
One-half Load Operation
2800 RPM
Intake Vacuum
inches Mercury
11
10
9
Throttle
Opening
Degrees
35
30
BSFC
0.8
0.7
0.6
50
52
54
56
58
60
Fuel-Flow lbs/hr

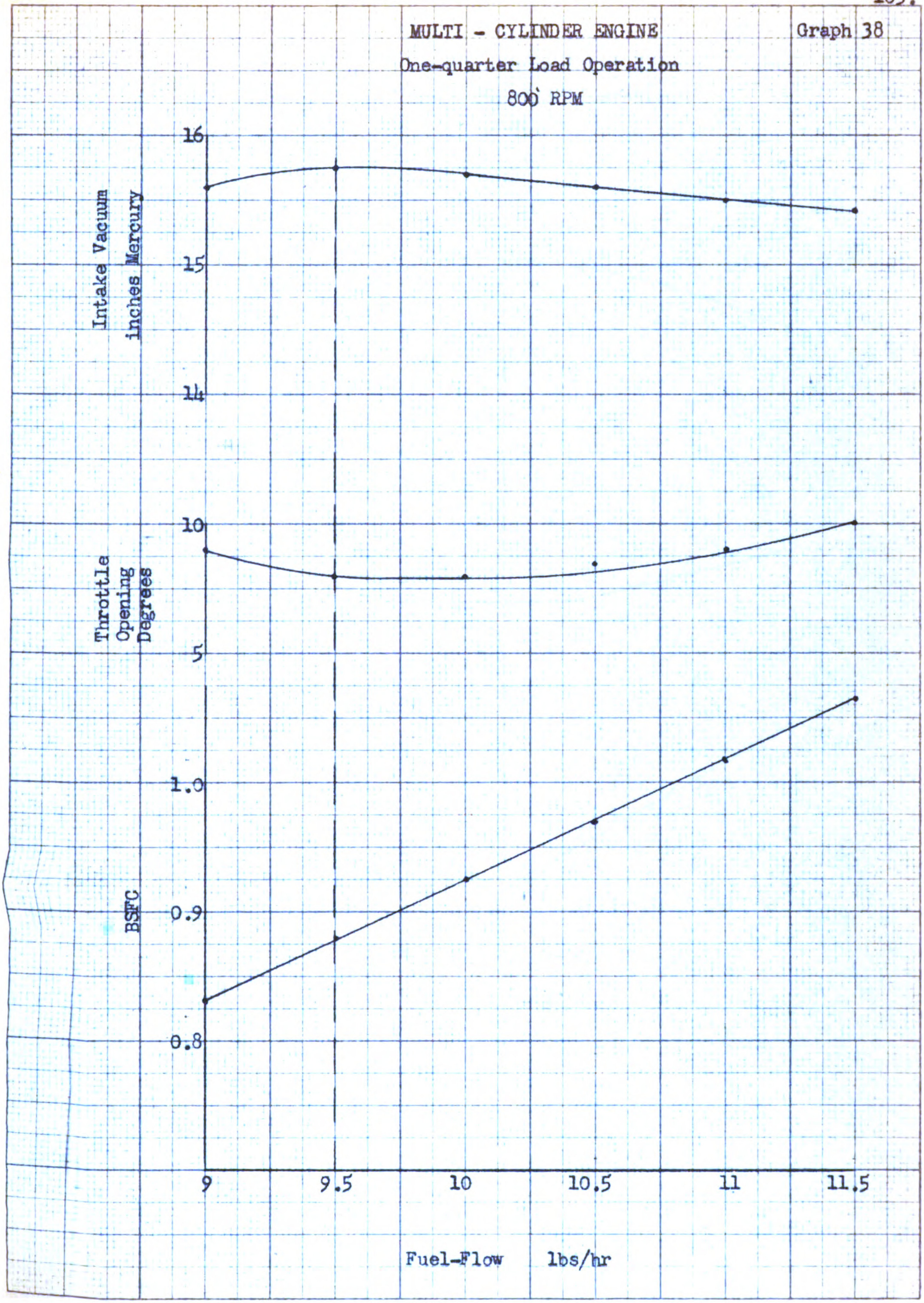

Graph 34
MULTI - CYLINDER ENGINE
One-half Load Operation
3000 RPM
Intake Vacuum inches Mercury
11
10
9
35
Throttle Opening Degrees
30
0.7
BSFC
0.6
0.5
54
56
58
60
62
64
Fuel-Flow lbs/hr


Graph 35
MULTI - CYLINDER ENGINE
One-half Load Operation
3200 RPM
Intake Vacuum
inches Mercury
11
10
9
Throttle
Opening
Degrees
39
35
BSFC
0.7
0.65
0.6
54
56
58
60
62
64
Fuel-Flow lbs/hr

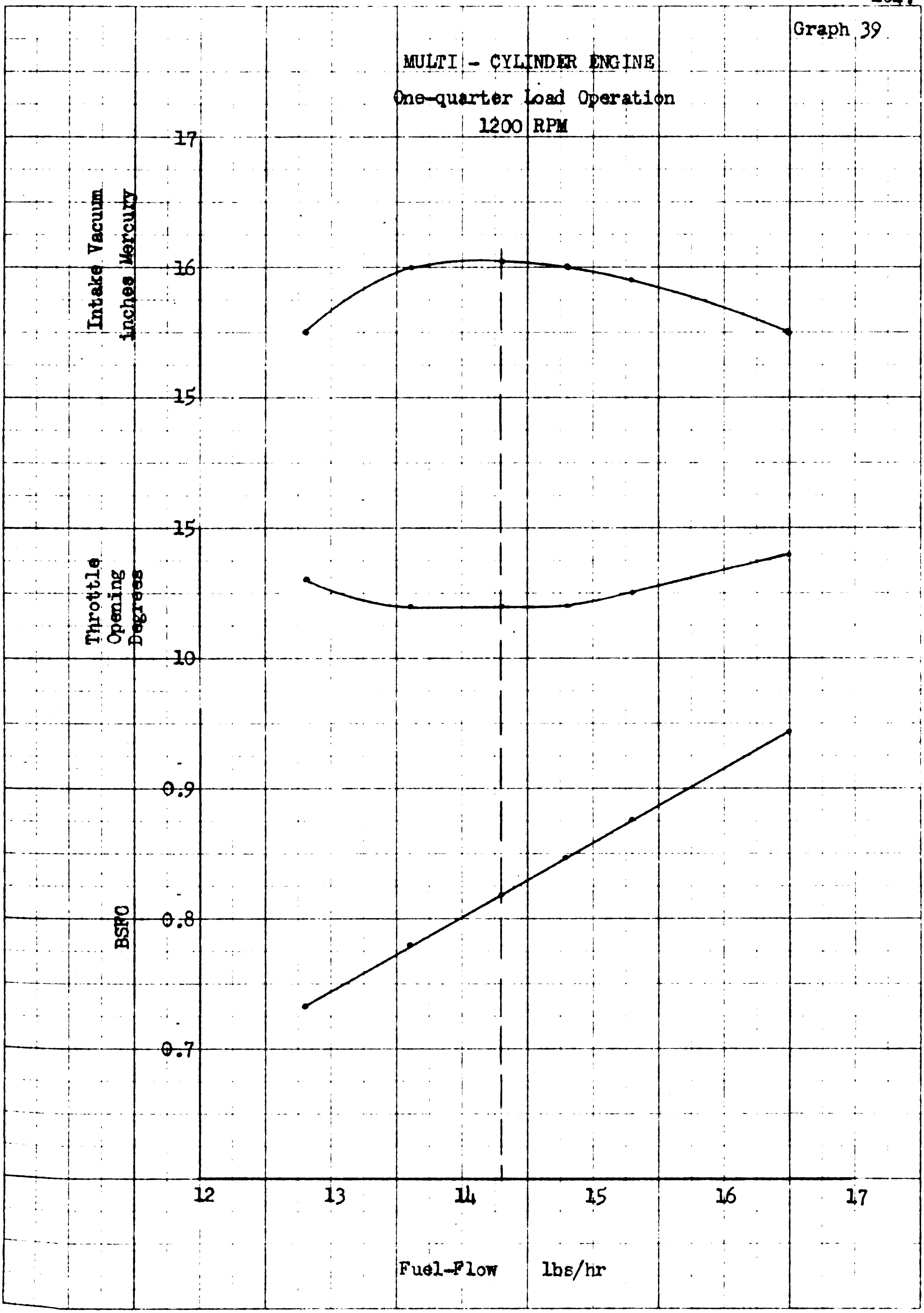
Graph 36

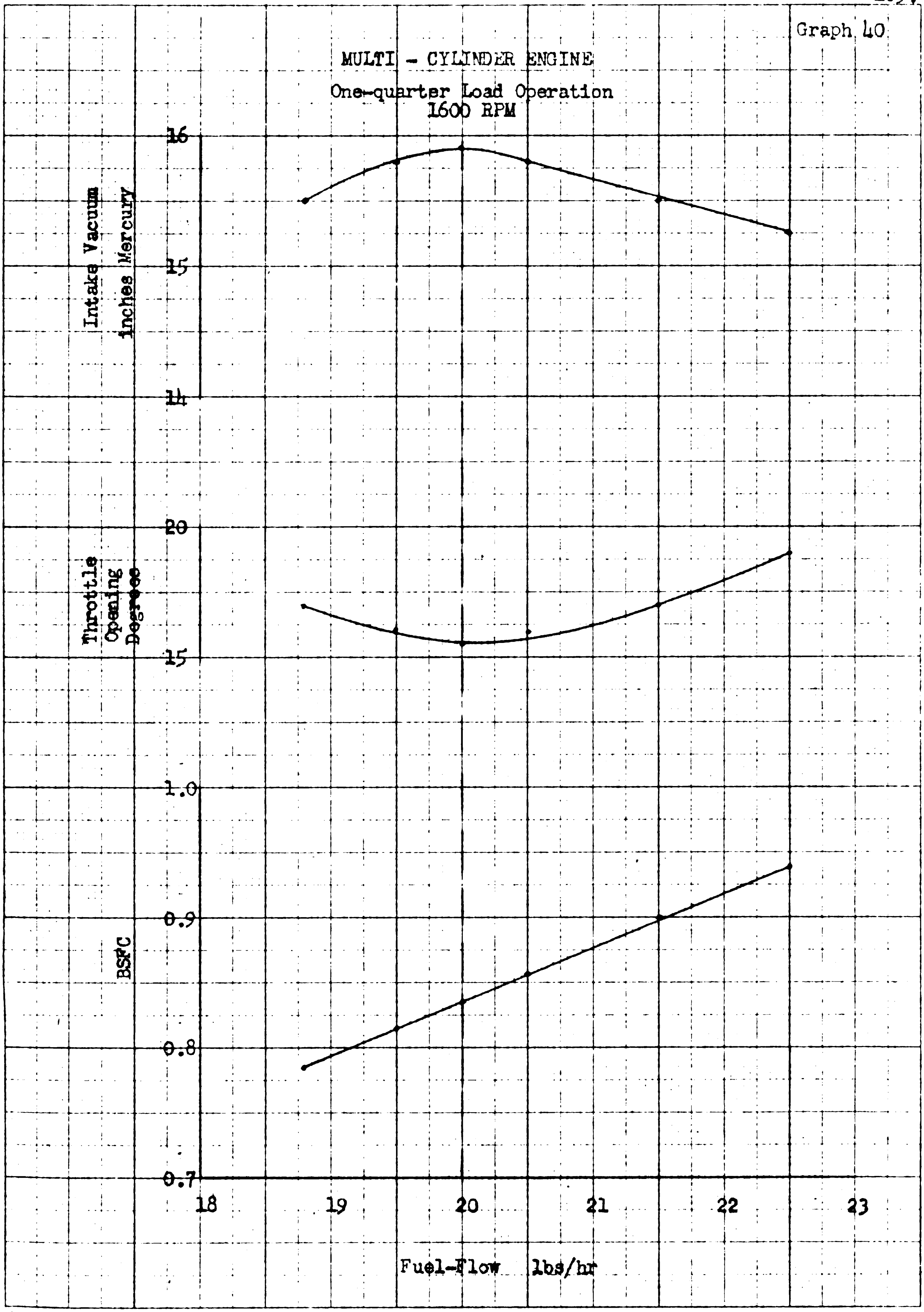

MULTI - CYLINDER ENGINE
One-half Load Operation
3400 RPM
Intake Vacuum
Inches Mercury
11
10
9
Throttle
Opening
Degrees
40
35
BSFC
0.8
0.7
0.6
60
62
64
66
68
70
Fuel-Flow lbs/hr


MULTI - CYLINDER ENGINE
One-half Load Operation
3500 RPM
Graph 37
Intake Vacuum
inches Mercury
11
10
9
Throttle
Opening
Degrees
40
35
BSFC
0.8
0.7
0.6
61
64
67
70
73
76
Fuel-Flow lbs/hr

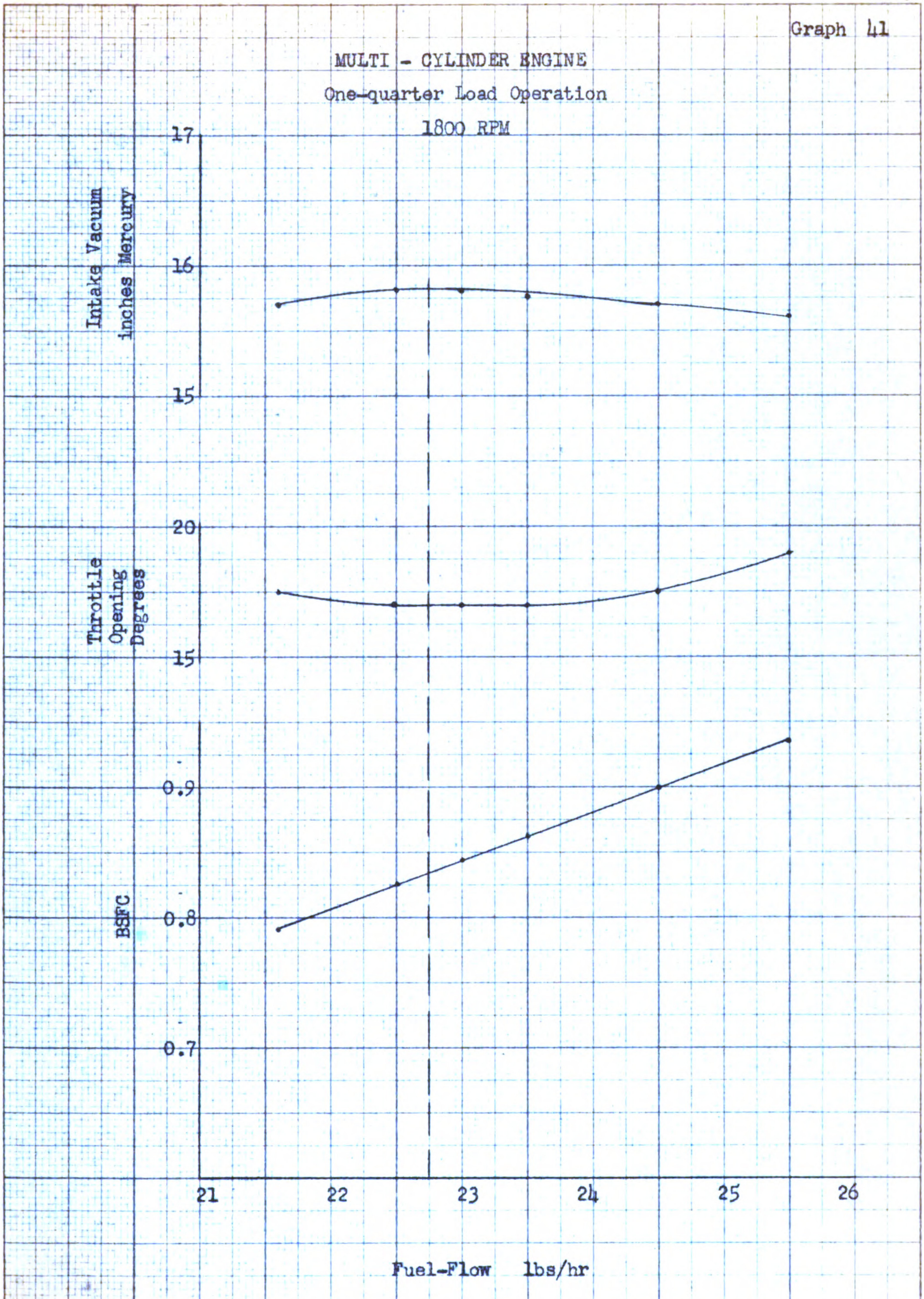

MULTI - CYLINDER ENGINE
One-quarter Load Operation
800 RPM
Graph 38
Intake Vacuum
inches Mercury
16
15
14
Throttle
Opening
Degrees
10
5
BSFC
1.0
0.9
0.8
9
9.5
10
10.5
11
11.5
Fuel-Flow lbs/hr

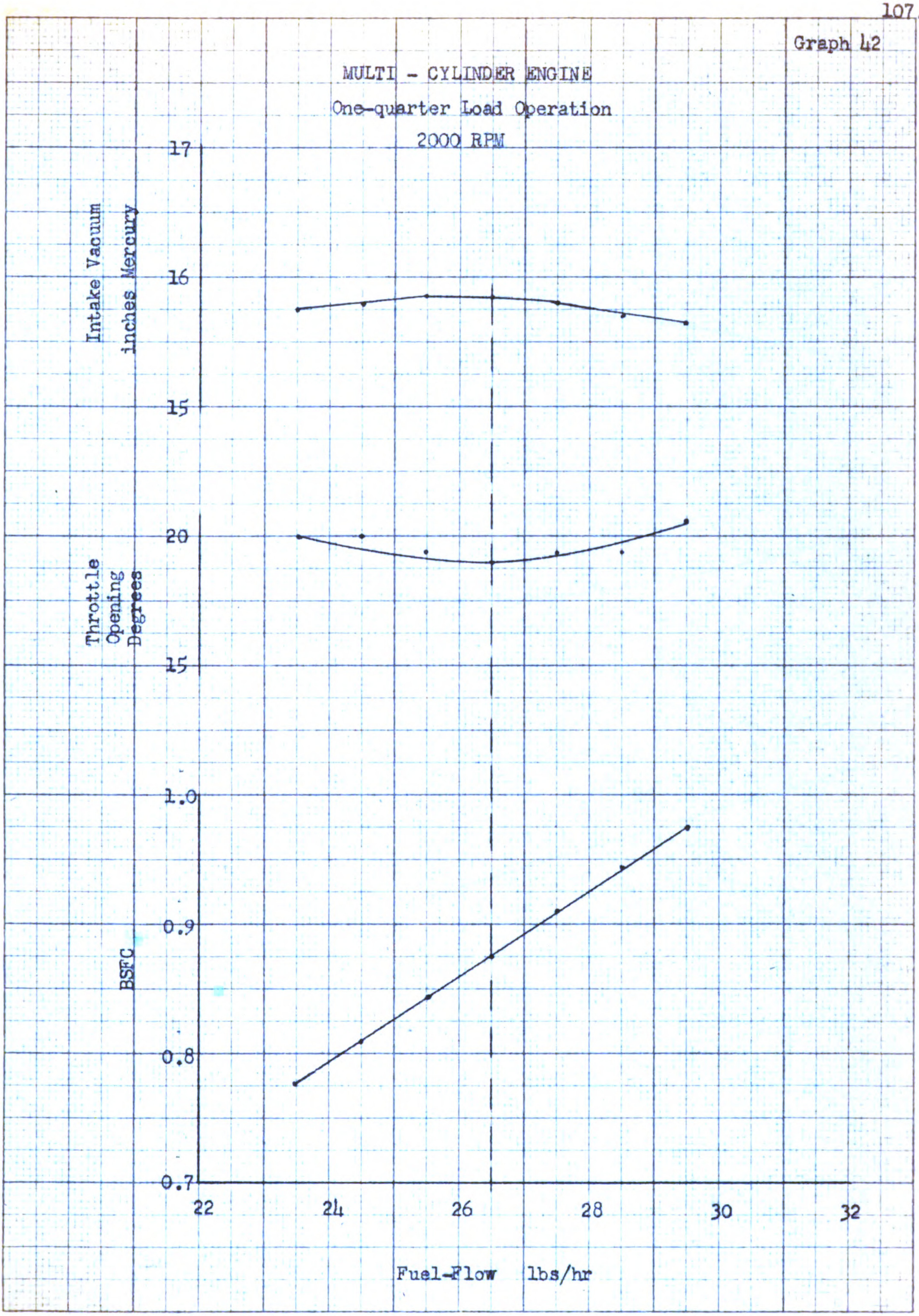
Graph 39

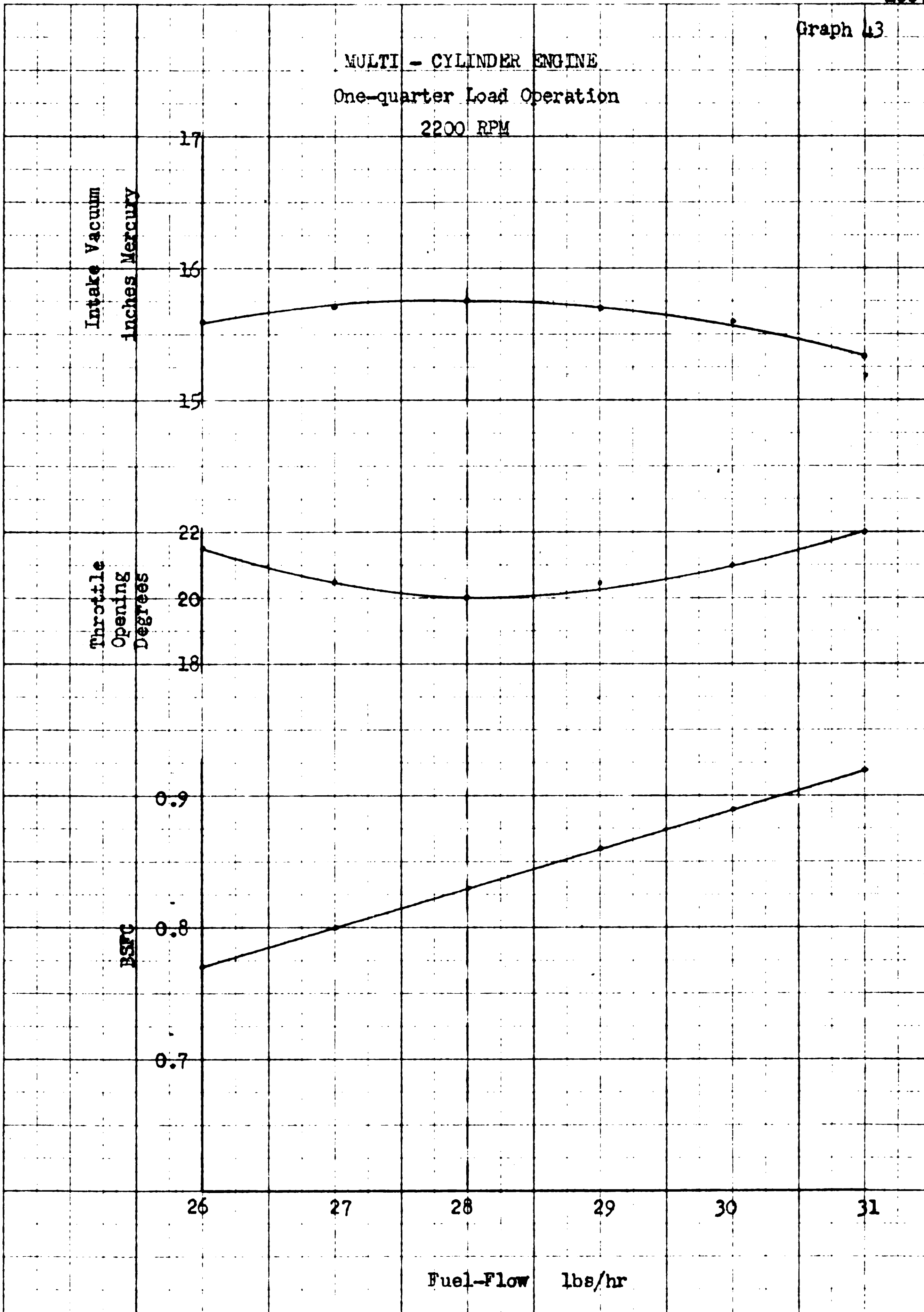

MULTI - CYLINDER ENGINE
One-quarter Load Operation
1200 RPM
Intake Vacuum
Inches Mercury
17
16
15
Throttle
Opening
Degrees
15
10
BSFC
0.9
0.8
0.7
12
13
14
15
16
17
Fuel-Flow lbs/hr


Graph 40
MULTI - CYLINDER ENGINE
One-quarter Load Operation
1600 RPM
Intake Vacuum
Inches Mercury
16
15
14
Throttle
Opening
Degrees
20
15
BSFC
1.0
0.9
0.8
0.7
18
19
20
21
22
23
Fuel-Flow lbs/hr

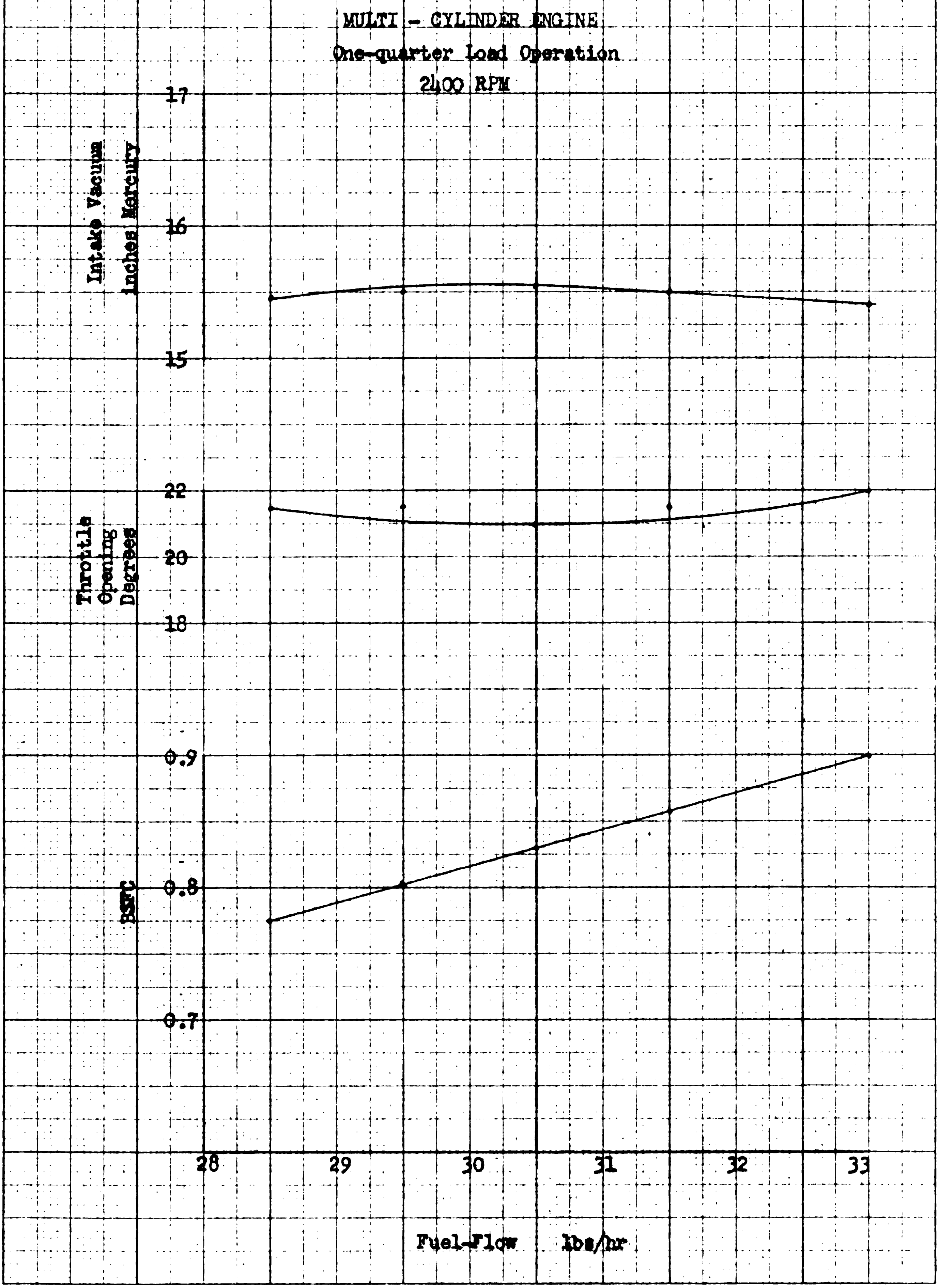
Graph 41

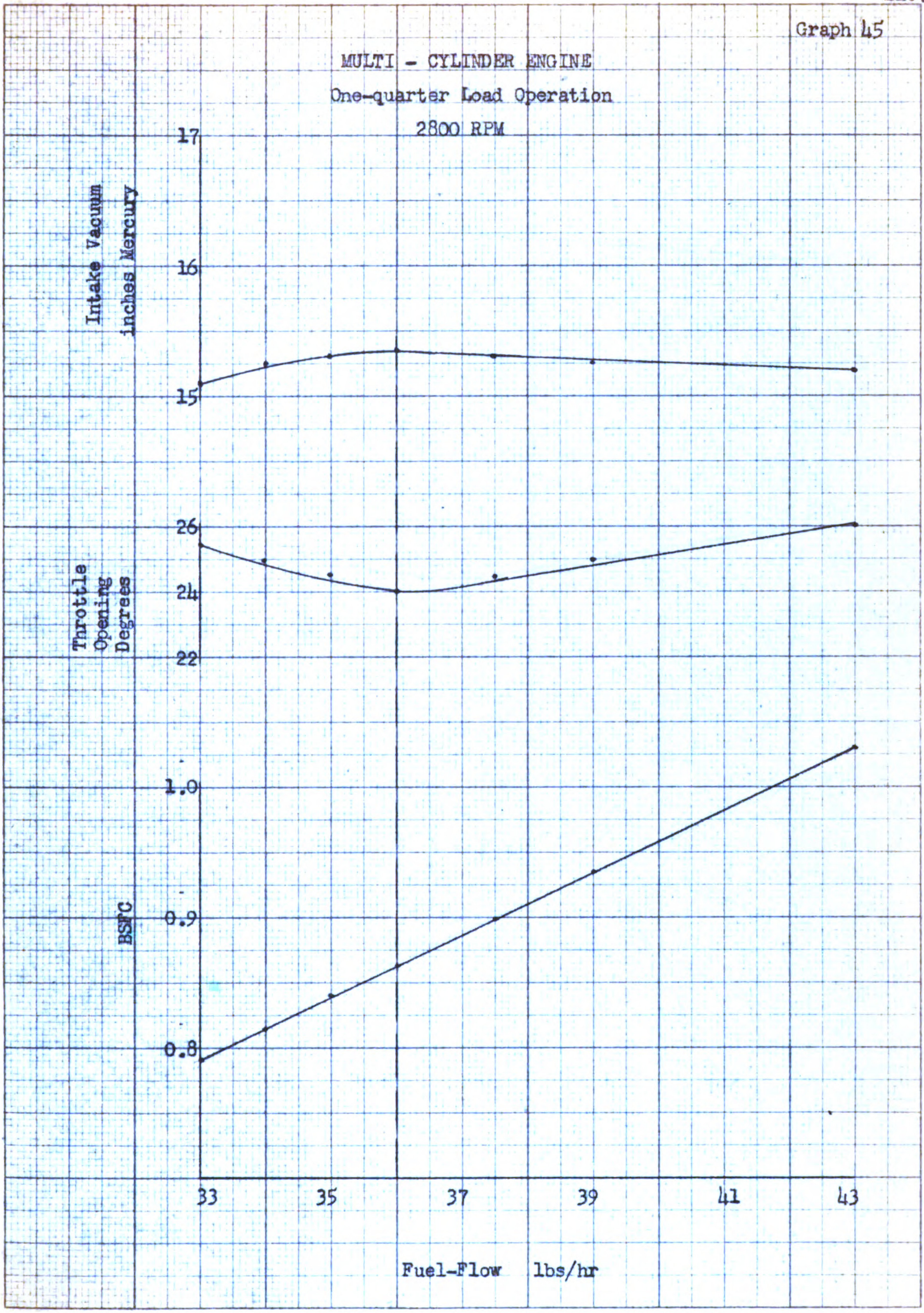

MULTI - CYLINDER ENGINE
One-quarter Load Operation
1800 RPM
Intake Vacuum inches Mercury
17
16
15
Throttle Opening Degrees
20
15
BSFC
0.9
0.8
0.7
21
22
23
24
25
26
Fuel-Flow lbs/hr

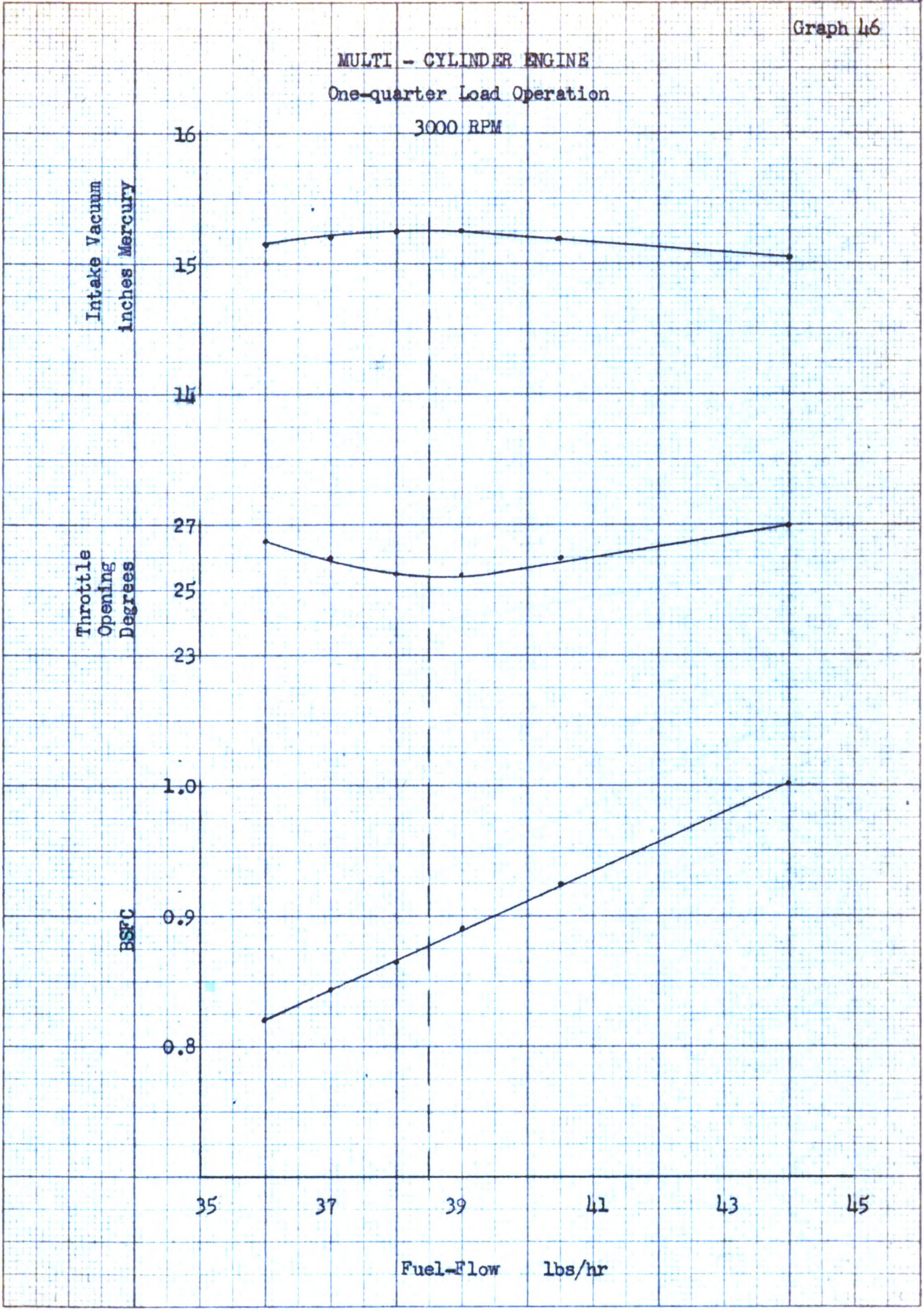

Graph 42
MULTI - CYLINDER ENGINE
One-quarter Load Operation
2000 RPM
Intake Vacuum
inches Mercury
17
16
15
Throttle
Opening
Degrees
20
15
BSFC
1.0
0.9
0.8
0.7
22
24
26
28
30
32
Fuel-Flow lbs/hr

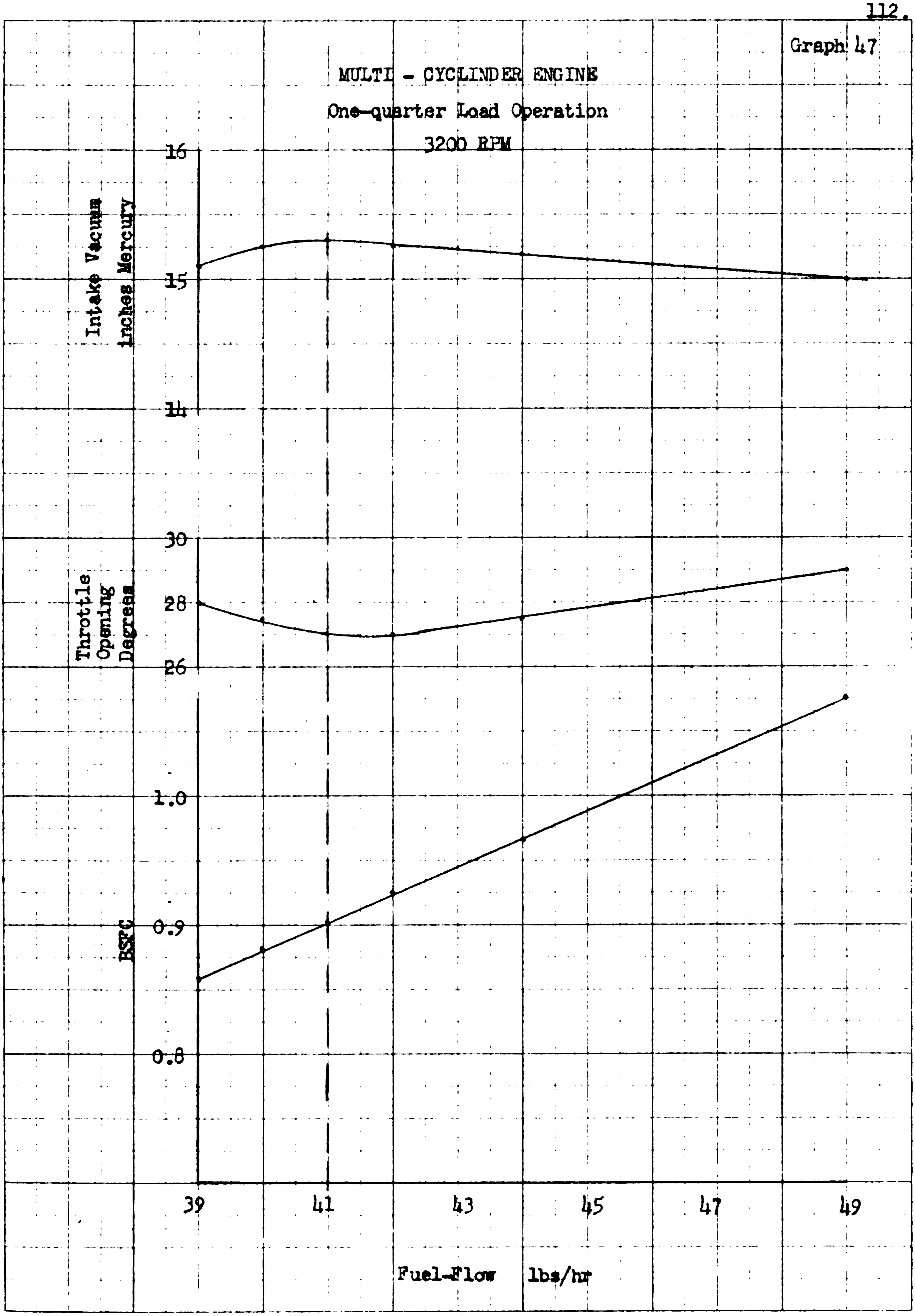

Graph 43
MULTI - CYLINDER ENGINE
One-quarter Load Operation
2200 RPM
Intake Vacuum
Inches Mercury
17
16
15
Throttle
Opening
Degrees
22
20
18
BSFC
0.9
0.8
0.7
26
27
28
29
30
31
Fuel-Flow lbs/hr

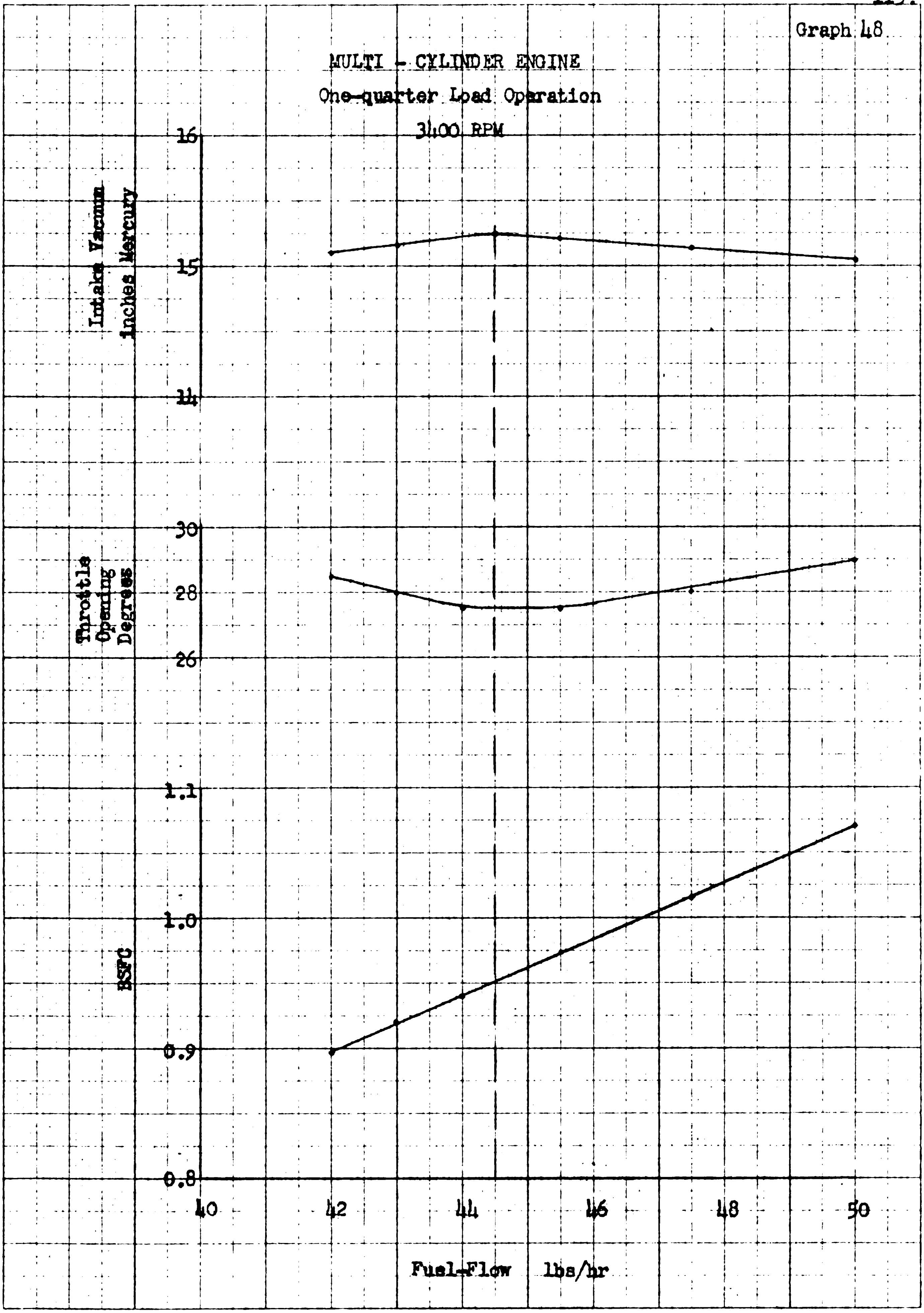
Graph 44

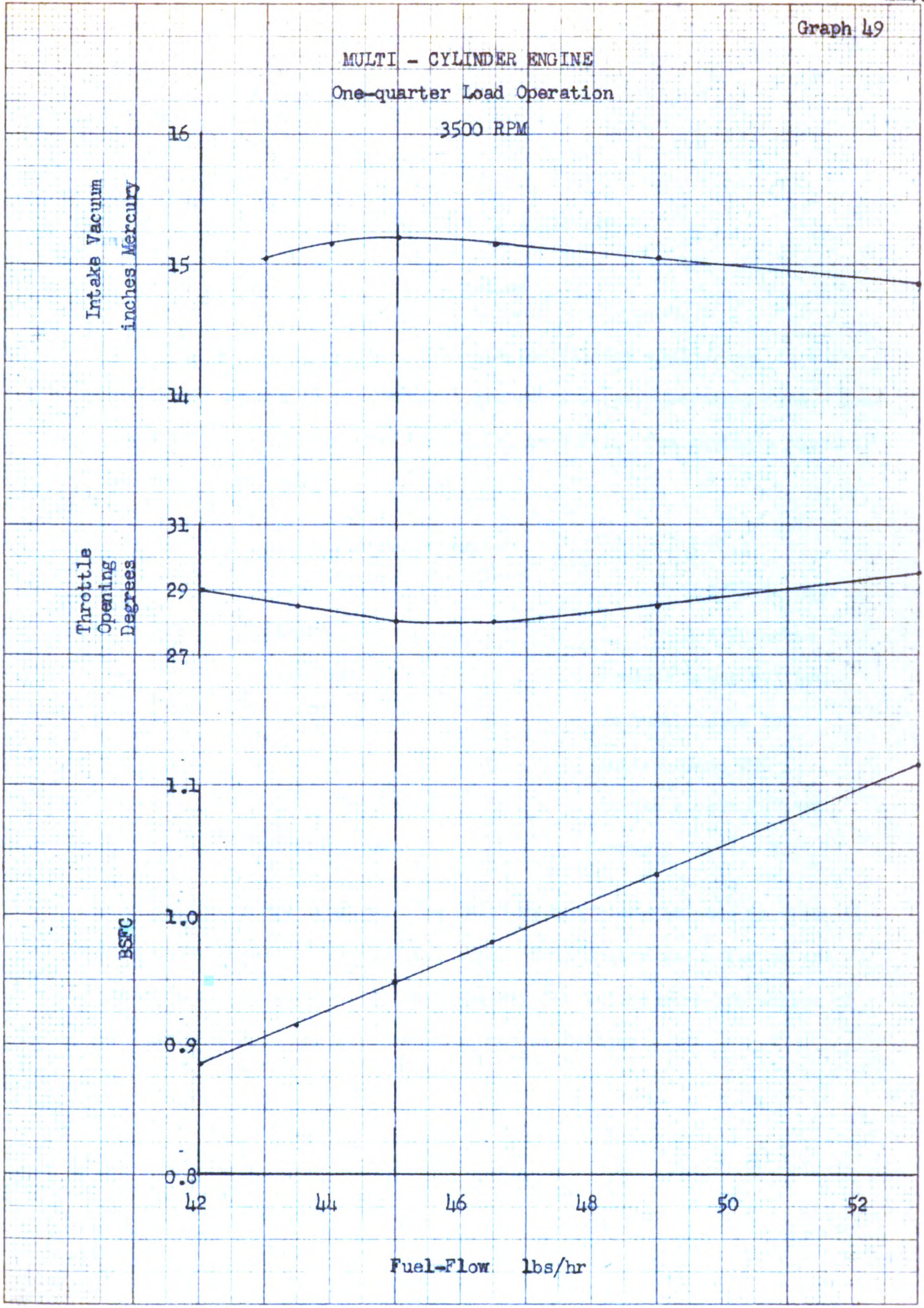

MULTI - CYLINDER ENGINE
One-quarter Load Operation
2400 RPM
Intake Vacuum
Inches Mercury
17
16
15
Throttle
Opening
Degrees
22
20
18
BSFC
0.9
0.8
0.7
28
29
30
31
32
33
Fuel-Flow lbs/hr


Graph 45
MULTI - CYLINDER ENGINE
One-quarter Load Operation
2800 RPM
Intake Vacuum
inches Mercury
17
16
15
Throttle
Opening
Degrees
26
24
22
BSFC
1.0
0.9
0.8
33
35
37
39
41
43
Fuel-Flow lbs/hr


Graph 46
MULTI - CYLINDER ENGINE
One-quarter Load Operation
3000 RPM
Intake Vacuum
inches Mercury
16
15
14
Throttle
Opening
Degrees
27
25
23
BSFC
1.0
0.9
0.8
35
37
39
41
43
45
Fuel-Flow lbs/hr


Graph 47
MULTI - CYCLINDER ENGINE
One-quarter Load Operation
3200 RPM
Intake Vacuum
inches Mercury
16
15
14
30
Throttle
Opening
Degrees
28
26
1.0
0.9
BSFC
0.8
39
41
43
45
47
49
Fuel-Flow lbs/hr


Graph 48
MULTI - CYLINDER ENGINE
One-quarter Load Operation
3400 RPM
Intake Vacuum
Inches Mercury
16
15
14
Throttle
Opening
Degrees
30
28
26
BSFC
1.1
1.0
0.9
0.8
40
42
44
46
48
50
Fuel-Flow lbs/hr


Graph 49
MULTI - CYLINDER ENGINE
One-quarter Load Operation
3500 RPM
Intake Vacuum
inches Mercury
16
15
14
Throttle
Opening
Degrees
31
29
27
BSFC
1.1
1.0
0.9
0.8
42
44
46
48
50
52
Fuel-Flow lbs/hr

DESCRIPTION OF EQUIPMENT

Engines

Single-cylinder engine. The single-cylinder engine used in this investigation was of the variable compression-ratio research type. Compression ratio was variable from 3.2:1 to 8.2:1. The engine's physical data was as follows:

test compression ratio	6.08:1
bore	3 1/16 inches
stroke	4 1/2 inches
valve timing	exhaust opens 27° BBC
	exhaust closes TDC
	intake opens TDC
	intake closes 28° ABC
manufacturer	Christy Machine Works

Multi-cylinder engine. The multi-cylinder engine used in this investigation was of the 90° V-8 type. This engine was built as an experimental pilot model to lead the way for future mass-production of similar engines. Its physical data was as follows:

compression ratio	7.25:1
bore	3 7/8 inches
stroke	4 1/8 inches
displacement	390 cubic inches
valve timing	exhaust opens 50° BBC
	exhaust closes 10° ATC
	intake opens 10° BTC
	intake closes 50° ABC

Dynamometers

The dynamometers used for this investigation were of the direct-current cradle-field type. The dynamometer used for the single-cylinder engine absorbed a maximum of ten horsepower and measured beam load by means of a Toledo scale. The dynamometer used for the multi-cylinder engine absorbed 200 horsepower and also used a Toledo scale for beam load measurements. This scale read directly in engine torque. Each dynamometer was equipped with a Standard Electric Time Company tachometer magneto for engine speed measurements.

Air-Flow Meters

Single-Cylinder engine. The air-flow meter used for the single-cylinder engine was built in the Michigan State College Automotive Laboratory. Fig. 1 shows a photograph of the unit mounted on the test engine.

The air-flow meter was based on thin-plate orifice theory for measuring the flow of gases and utilized a large "U" tank to dampen air surge. An inclined water manometer was used to measure the pressure difference between the inside of the surge chamber and the atmosphere. Suitable scales were made for each thin-plate orifice used. Fig. 2 is a photograph of the manometer with a scale in place.

The basic equation[1] for this type of air-flow meter is:

$$W = C_1 A_2 \sqrt{2g\, \delta_1 \frac{\gamma}{12} h} \times 3600$$

where
W = air flow - lbs/hour

C_1 = orifice discharge coefficient

A_2 = orifice area - square feet

g = acceleration due to gravity

δ_1 = density of dry air - lbs/cubic foot

γ = density of water - lbs/cubic foot

h = water head - inches of water

This unit was calibrated for conditions of dry air at 29.1 inches of mercury and an air temperature of 70° Fahrenheit. Hence, a deviation from these conditions will cause a change in the air flow reading of the instrument. However, the effect of these changes will be slight, particularly since the air-flow rate was held constant at each condition of engine speed and relative load. This can be proved in the following manner:

1. Diederichs and Andrae. Experimental Mechanical Engineering. Vol. I, p. 616, John Wiley and Sons, New York, N.Y.

Conditions in the Automotive Laboratory on April 11, 1954 were as follows:

barometer	30.18 inches of mercury
relative humidity	34%
temperature	73° Fahrenheit

From the Society of Automotive Engineers <u>Engine Test Code</u>, the following air correction formula is found:

$$\text{correction factor} = \frac{\text{Reference Barometer}}{(B - E)} \times \sqrt{\frac{460 + t_1}{460 + t_2}}$$

where B = actual barometer reading - inches of mercury

E = water vapor pressure - inches of mercury

t_1 = actual temperature reading - °F

t_2 = reference temperature - °F

Solution of this formula using the various values for actual and reference conditions yields an air-correction factor of 1.015. Multiplying this times the recorded air-flow rate would give the correct air-flow rate. Assuming an uncorrected air-flow rate of 20 lbs/hr. and multiplying this by 1.015 yields a corrected air-flow of 20.3 lbs/hour. In terms of percentages this variation is about 1.4%.

<u>Multi-cylinder engine</u>. The air-flow meter used for testing the multi-cylinder engine was a commercial instrument manufactured by Commercial Laboratories, Inc. This air-flow meter is based on the metering tube principle, in which an orifice area varies with the flow

rate and the pressure differential across the metering element remains constant.

The metering element consists of a vertical tapered tube containing a horizontal flat disc float which is free to move along the axis of the tube. The float area is slightly less than the smallest area of the tube cross-section. Because the tube's smallest area is at the lower end, and since the air flows upward through it, the float adjusts in height until the annular area between it and the tube is just sufficient to pass the rate of air-flow existing. There is then established a stable equilibrium in which the float weight is exactly balanced by the upward force imparted by the moving column of air. Consequently, there exists a distinct height of the float for each rate of air-flow. This position is read on a scale calibrated directly in flow rate on the front of the instrument.

The upward force on the float consists primarily of that due to the drop in static pressure of the air as it flows through the annular orifice. The float weight and float area transverse to the flow remains constant with the result that the pressure differential (p) across the float is practically constant for all equilibrium positions of the float in the tube. Thus for the orifice formula

$$Q = CA\sqrt{2gh} = CA\sqrt{2g\ p/d}$$

the quantity $\frac{CA}{d}$ varies directly as the flow rate, Q

where g = acceleration due to gravity

C = orifice coefficient

A = orifice area

d = density of dry air

Due to the design of the float tubes (C) is essentially constant. The air density (d) is independent of the float position and varies only as the density of the atmosphere. This variation is quite small as was shown for the single-cylinder engine.

This instrument is compensated for pulsations in air-flow by means of a large area flexible diaphragm. The movement of this diaphragm corresponds to the volume change between pulsations thus preventing the transmission of the pulsations to the metering circuit. Fig. 3 is a photograph of this air-flow meter.

Fuel-Flow Meters

Single-cylinder engine. The fuel-flow meter used for the single-cylinder engine was built in the Michigan State College Automotive Laboratory. This flow meter was based on pressure head difference between two columns of liquid. Fig. 4 shows a sketch of the fuel flow meter.

With this type of liquid flow meter one column of liquid is kept at the level of the supply reservoir while the second column will be at some distance below this zero level, depending on the pressure differential or head existing between them. This pressure differential or head is a function of the flow rate of the liquid through the orifice between the two tubes.

The unit was built in three stages to obtain the necessary range of fuel flows. Calibration was obtained experimentally by weighing the amount of flow over an arbitrarily set length of time. The distance which the measuring liquid level drops from zero was measured for each rate of flow. The defining relation for this calibration is

$$v = \sqrt{2gh} \qquad \text{and } Q = vA$$

where v = velocity of flow

g = acceleration due to gravity

h = pressure head

Q = flow rate

A = area of metering orifice

Since the flow rate is an exponential function of the velocity of flow a plot of flow rate versus the head difference yields a linear function when plotted on a semi-logarithmic scale. This determined the calibration for each stage of the flow meter. The instrument was calibrated before use and the flow rates were not corrected for variations in specific gravity of fuel, since these variations would be quite small.

Multi-cylinder engine. The fuel-flow meter used for test work on the multi-cylinder engine was a commercially built unit operating on the variable area principle. The unit consists of two stages which give a flow range of from 5 to 175 pounds per hour. The metering element consists of a vertical tapered tube containing a horizontal flat disc or float which is free to move along the axis of the tube. The float area is slightly less than the smallest diameter of the tapered tube cross section. Inasmuch as the tube's smallest area is at the lower end since the fuel flows upward through it, the float adjusts in height until the annular area between it and the tube is just sufficient to pass the rate of flow existing. There is then established a stable equilibrium in which the float weight is exactly balanced by the upward force impacted by the moving column of fuel. Consequently, there exists a distinct height of the float for each rate of flow. The float tube is graduated to correspond to these levels and reads directly in pounds of fuel per hour at a specific gravity of 0.72 and a temperature of 70° Fahrenheit.

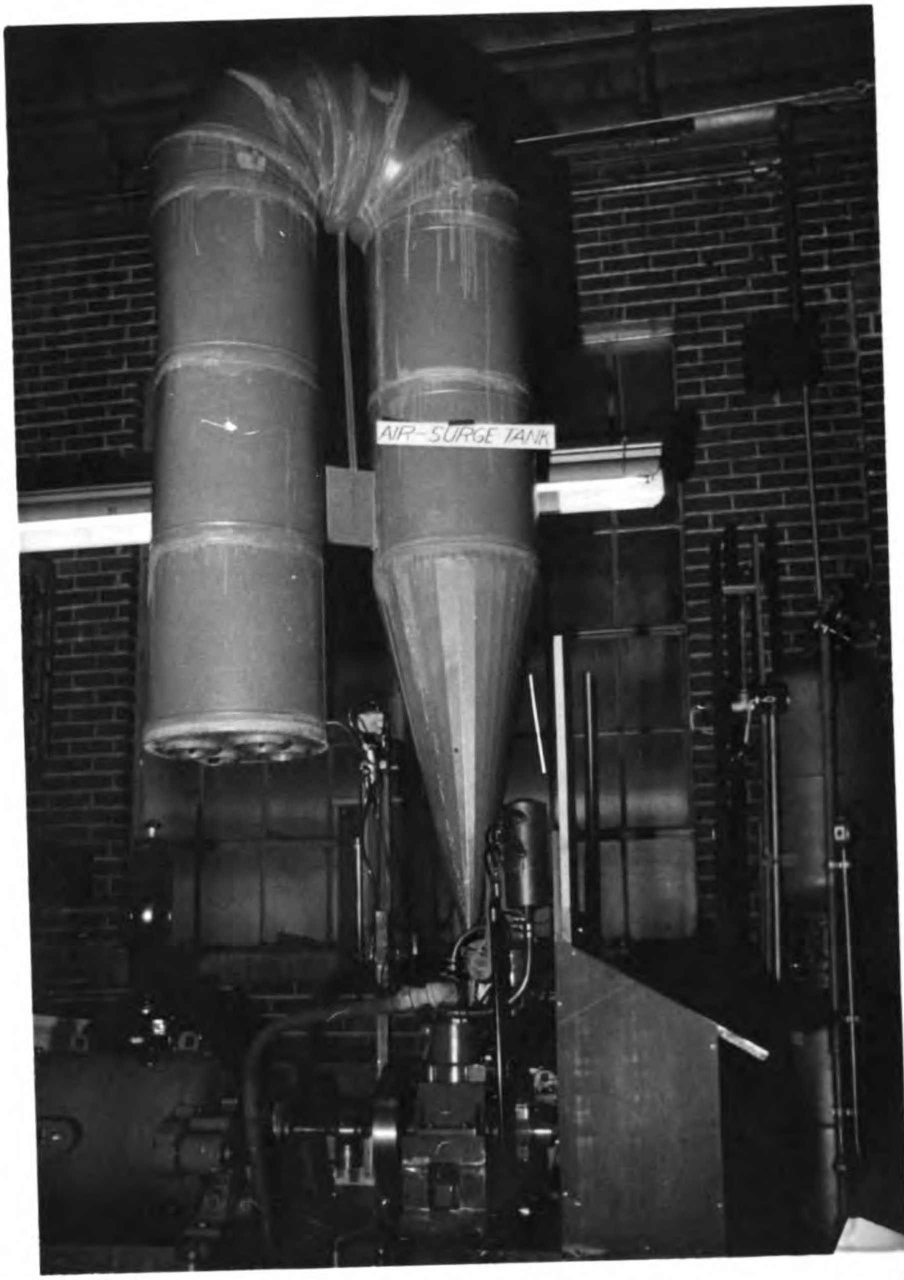


Figure 1. Single - cylinder engine air - surge tank

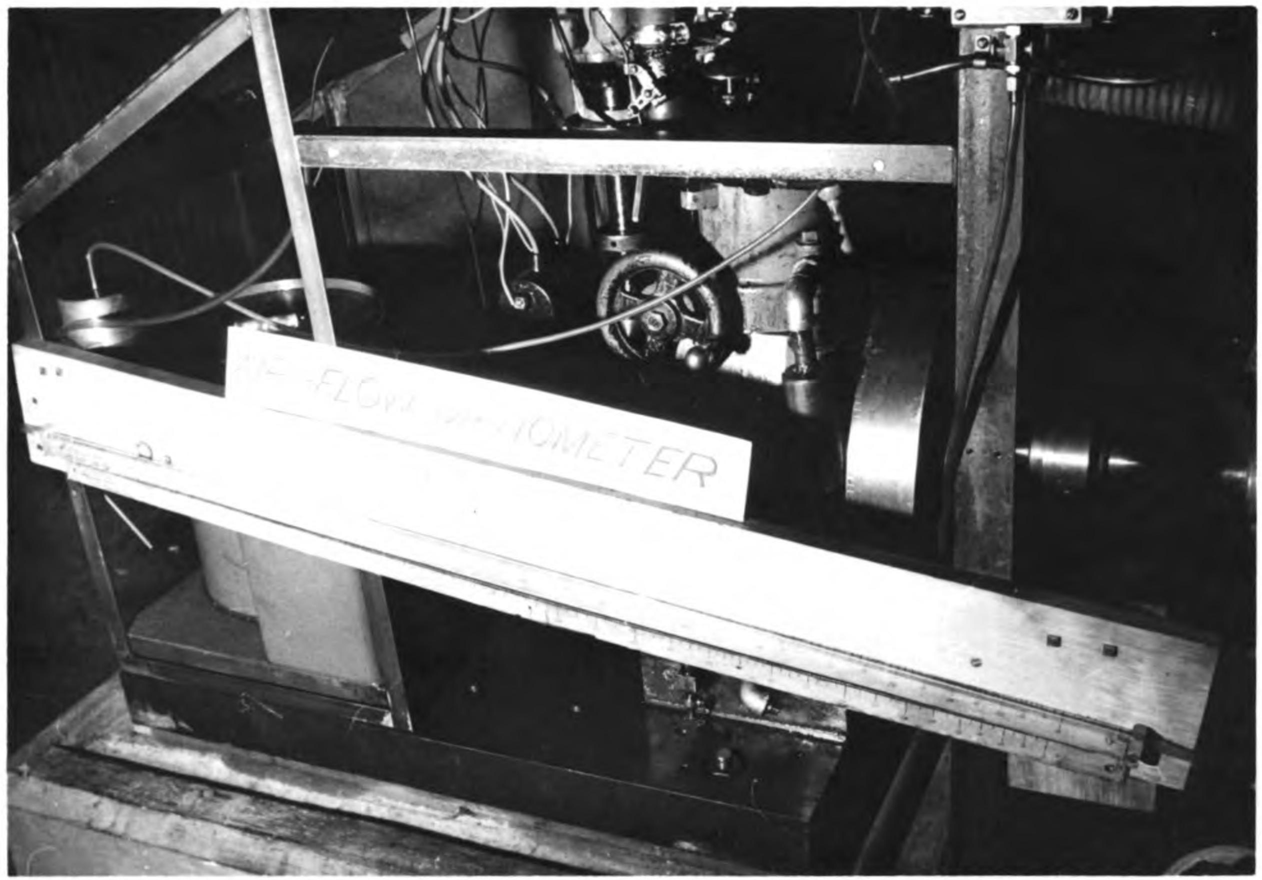


Figure 2. Single - cylinder engine air - flow manometer

COX INSTRUMENTS

AIR FLOWMETER -- TYPE 15

A Complete, Self-Contained Laboratory Unit for Measuring the Rate of Air Flow

Figure 3.

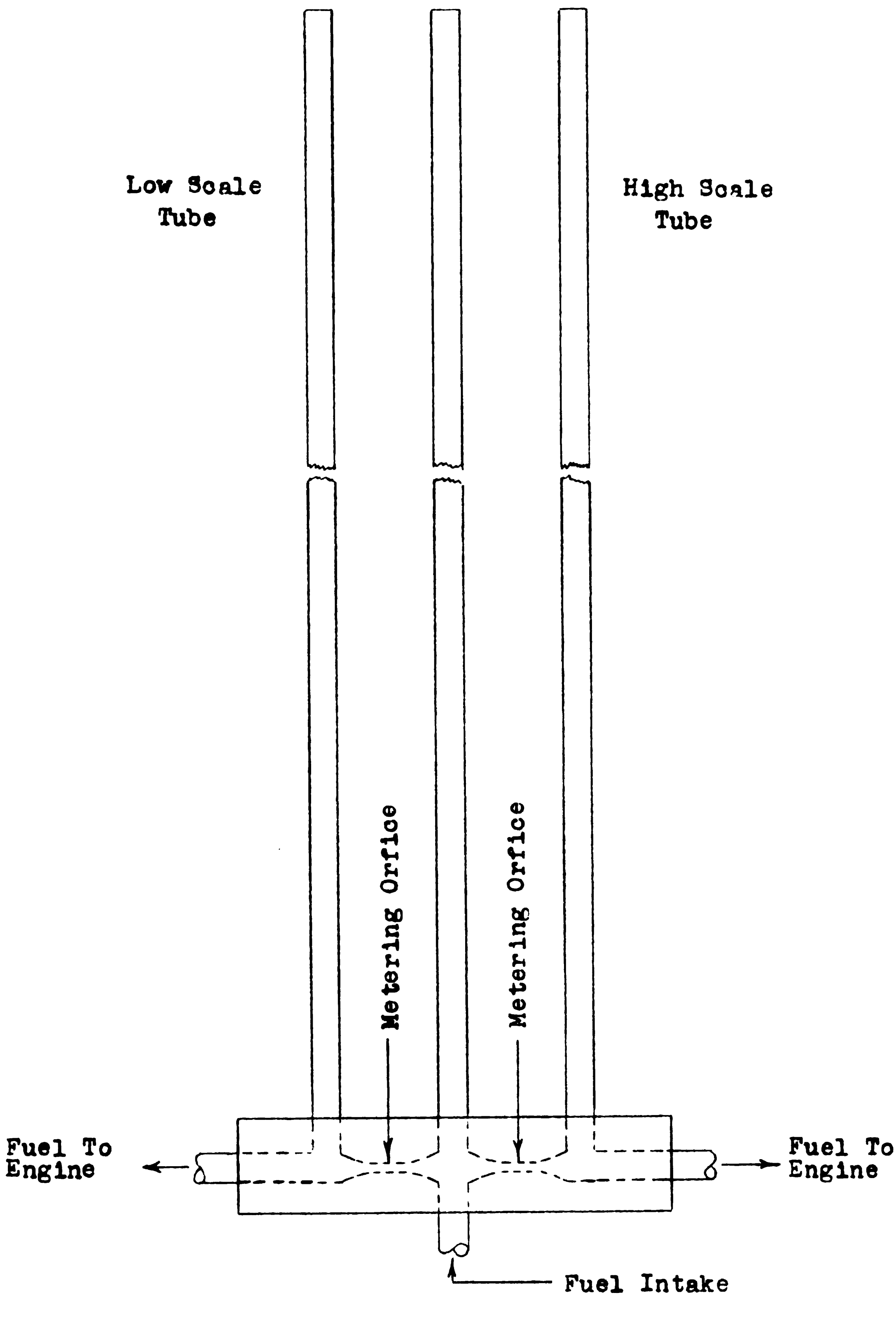


Figure 4. Schematic of fuel - flow meter for single - cylinder engine

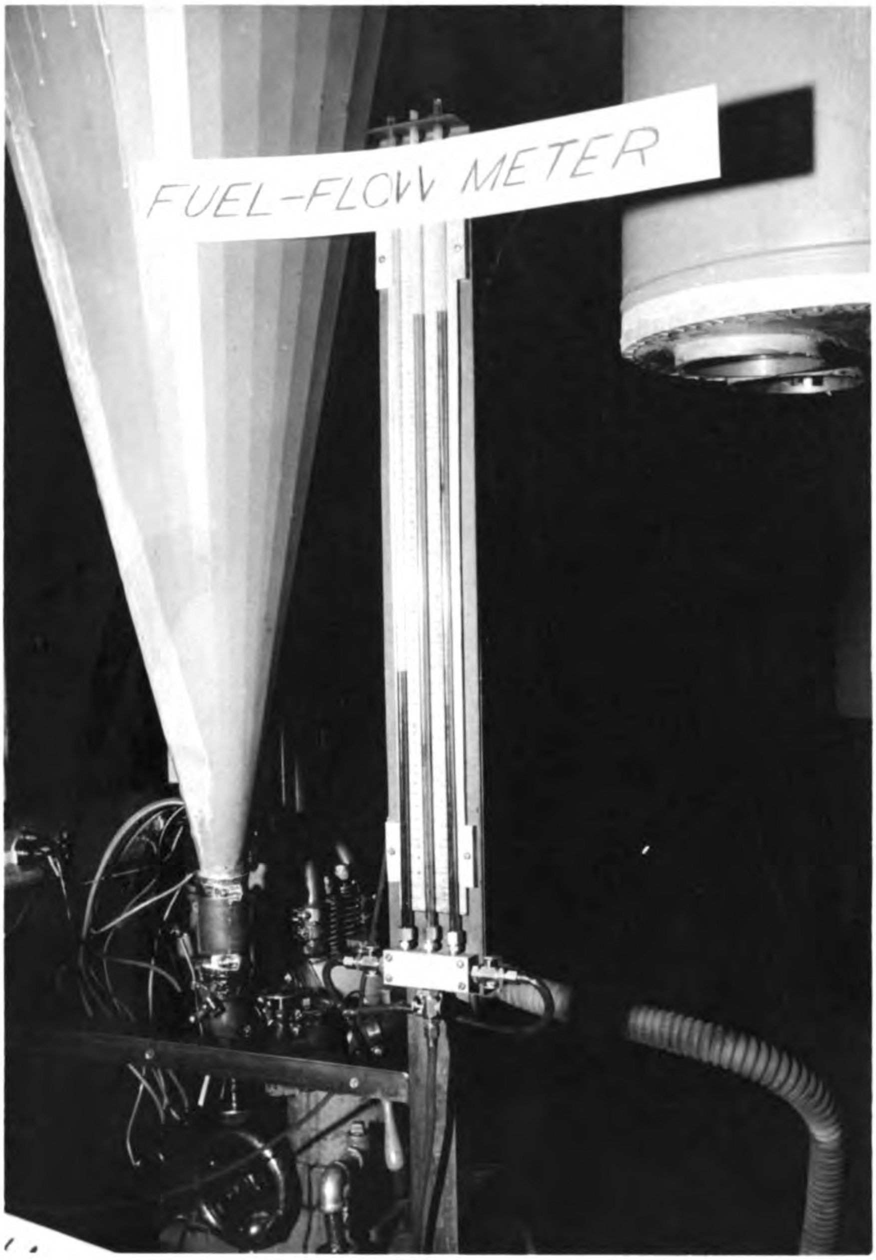


Figure 5. Single - cylinder engine fuel - flow meter

BIBLIOGRAPHY

1. Otto, L. L. Carburetion and Ignition Requirements of Spark-Ignition Engines. An Unpublished Paper.

2. Heldt, P. M. High Speed Combustion Engines, 14th ed., Nyack: P. M. Heldt, 1948.

3. Lichty, L. C. Internal Combustion Engines, 6th ed., New York: McGraw-Hill Book Co., Inc., 1951.

4. Obert, E. F. Internal Combustion Engines, 2nd ed., Scranton: International Textbook Co., 1950.

5. Diederichs, H. and Andrae, W. C. Experimental Mechanical Engineering, Vol. I, New York: John Wiley and Sons, Inc., 1930.