BASIC FACTORS AFFECTING SMOOTH ENGINE IDLING

by

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at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June, 1958

Signature of Author . . . . Signature redacted
Department of Mechanical Engineering
May 26, 1958

Certified by. . . Signature redacted . . . .
Thesis Supervisor

Accepted by . . . . Signature redacted . . . .
Chairman, Departmental Committee on Theses

362 Memorial Drive
Cambridge 39, Massachusetts
May 26, 1958

Professor L. F. Hamilton
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Sir:

In partial fulfillment of the requirements for the degree of Bachelor of Science in Mechanical Engineering from the Massachusetts Institute of Technology, I herewith submit this thesis entitled, "Basic Factors Affecting Smooth Engine Idling."

Respectfully submitted,

Signature redacted

Arthur S. Rosen

ABSTRACT

A study of some of the basic factors tending to increase smoothness in engine idling is presented. The primary criterion for determining the degree of idling roughness is taken to be the frequency of missing as observed on an oscilloscope screen, with the maximum departure from mean peak cylinder pressure and the inlet pressure necessary to maintain 500 rpm. idling speed as secondary characteristics. Increases in fuel-air ratio above approximately 0.07 for normal values of spark advance, increases in inlet temperature, decreases in the degree of exhaust throttling, and increases in the spark plug gap are all found to tend towards smoother engine idling.

ACKNOWLEDGMENTS

The author would like to take this opportunity to express his sincere appreciation for the counselling and support of Professor A. R. Rogowski and for the effort and assistance of the staff of the Sloan Automotive Laboratory at M. I. T.

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INTRODUCTION

In the past decade, average rated brake horsepower of the American automobile engine has more than doubled. The public has demanded performance, and performance it has gotten. This trend towards increased engine output has entailed great expenditures for research in factors tending to increase engine horsepower. Yet, in spite of this expanded research program, idling problems, often attendant to increases in power, have been neglected. Very little, indeed, is known about the subject of idling smoothness. It is for this reason that a study of the basic factors affecting smooth engine idling was undertaken.

CONCLUSIONS

Factors which were found as tending towards smoothness in engine idling were increases in fuel-air ratio (see figure 1 in Appendix) above a certain minimum (i.e. above 0.07 for moderate values of spark advance), increases in inlet temperature (see figure 2 in Appendix), decreases in exhaust back pressure (see figure 3 in Appendix), and increases in spark plug gap (again see figure 2 in Appendix). The primary criterion used to determine the smoothness of engine operation was the frequency of missing, as determined from an oscilloscope pressure versus crank angle trace (see figure 5 in Appendix).

APPARATUS, INSTRUMENTATION, AND CONTROL OF VARIABLES

A common four-stroke, single cylinder C.F.R. (Coordinating Fuel Research) engine, with bore and stroke of 3.25 inches and 4.50 inches, respectively, was used for these experiments. Compression ratio was maintained at 6.0 to 1 throughout the tests.

An idling speed of 500 rpm., maintained at this value ± 10 rpm., was selected for purposes of this investigation, being controlled by air and fuel flow rate adjustments, other conditions, including fuel-air ratio remaining fixed. Engine speed was measured by a tachometer with a drive geared so as to give a reading of four times the engine rpm.

Brake load, B.L., a quantity proportional to brake output at constant engine speed, was measured by means of a D.C. dynamometer, used in conjunction with a hydraulic scale and a mercury manometer. The dynamometer was also used in starting the engine and in running it when not idling.

Oil and cylinder jacket temperatures, controlled by introducing steam and/or water into the appropriate heat exchanger, were maintained at 150°F. and 120°F., ± 1°F. in each case, respectively. Oil pressure was steady at 55 psig. ± 1 psi., being measured by a bourdon pressure gauge.

Inlet pressure, p_i, was measured in the inlet tank by a mercury manometer and was regulated, through air flow measurements, by a throttle valve between the air flow measuring orifice and the inlet tank.

Exhaust pressure, p_E, at the exhaust tank was measured by a mercury manometer and controlled by means of a throttle valve located after the exhaust tank.

Inlet temperature, T_i, adjusted by admitting steam and/or water into a jacket which enveloped the inlet tank, was measured by a mercury thermometer located in the inlet pipe to the engine at its junction to the inlet tank. Temperature was read to $\pm 1^{\circ}F$.

Mass rate of air flow was calculated from the pressure drop, measured by a water manometer, across a standard ASME. sharp edged orifice of 0.310 inch diameter.

Mass rate of fuel flow was measured by a carefully calibrated rotameter. Fuel, its flow controlled by a throttle valve located after the rotameter, passed from the rotameter into a heat exchanger, this arrangement assisting its vaporization. It was then admitted to the inlet pipe. Fuel-air ratio was used to coordinate fuel and air flow rates.

A "hot" spark plug, its firing timing varied manually, was used, close to the inlet valve so as to be in the midst of the fresh fuel-air mixture. The plug gap was measured by means of feeler gauges.

Zero valve overlap was used throughout the experiments.

A Li indicator and oscilloscope combination, set to depict pressure versus crank angle for each cycle, was used in determining the frequency of missing. The picture was not completely synchronized, moving slowly across the screen during successive cycles. A high intensity setting was used, so that successive cycles could easily be compared. For a comparison of smooth firing and missing depictations, see figure 5 in the Appendix.

TEST PROCEDURE

A general examination of the engine during idling conditions was undertaken as a first approach to the problem, in order that a suitable method might be determined for categorizing engine idling conditions. It was during this period that the frequency of miss occurrences, as determined from an oscilloscope pressure versus crank angle representation, was selected as the major criterion for defining the degree of idling smoothness (see figure 5 in Appendix). Inlet pressure needed to maintain 500 rpm. and percent departure from the mean maximum cylinder pressure, read from the oscilloscope screen, were decided upon as secondary measures of smoothness during idling (see figures 4 and 5 in Appendix).

Primary data was then taken for varying fuel-air ratios and spark advance angles, wherein the degree of idling smoothness was evaluated through the use of the three previously discussed methods. At constant spark advance angle, after freeing the engine from the dynamometer, air and fuel flow rates were varied in the correct proportions until a steady idling speed of 500 rpm. was attained. Idling smoothness was then observed for such a point. Data for figure 1 (see Appendix) was compiled in such a fashion, keeping inlet temperature, exhaust pressure, and spark plug gap constant, as specified in the figure.

The effect of excess fuel (also in figure 1 in the Appendix), i.e., fuel-air ratios above 0.10, was next found by the same method. Spark advance angle was held constant at 30° B.T.D.C. (before top dead center) for this test.

The effect of inlet temperature variations, at a constant spark plug gap of 0.030 inch and advance angle of 30° B.T.D.C., upon idling smoothness was next explored (see figure 2 in Appendix). At each inlet temperature the lowest fuel-air ratio for an absence of missing was approximated, the value selected being much a matter of the judgment of the observer as only small differences were noted, between successive fuel-air ratios, in the oscilloscope representation.

The effect of exhaust throttling, with ignition values as used for the above experiments for determining the effect of inlet temperature, was then sought after by approximation of the minimum no-miss fuel-air ratio for each exhaust pressure tested (see figure 3 in Appendix). Results were again greatly a matter of personal judgment.

Finally, the effect of spark plug gap was found (again see figure 3 in Appendix) by repeating the tests of the effect of inlet temperature section with two new values of spark plug gap. As in the two previously mentioned cases, resulting data was inexact due to the close resemblance between successive conditions tested.

DISCUSSION OF RESULTS

The following tendencies were observed during these investigations:

1. At fuel-air ratios of 0.09 and 0.10, smooth idling was obtained throughout the range of spark advance used in these tests (50° B.T.D.C. to 10° A.T.D.C.).

2. At a fuel-air ratio of 0.08, the engine idled smoothly at values of spark advance of 30° B.T.D.C. and below, missing occasionally at values of 40° B.T.D.C. and 50° B.T.D.C.

3. At a fuel-air ratio of 0.07, missing occurred at all values of spark advance, being very frequent at an advance of 20° B.T.D.C. and below.

4. Increased fuel-air ratio above 0.10 resulted in continued smooth engine idling, up to a value of 0.13, at which point the engine would no longer run on such a mixture.

5. Idling smoothness tended to increase slightly with increased inlet air temperature.

6. Idling smoothness seemed to decrease somewhat with increased exhaust back pressure.

7. Idling smoothness tended to increase slightly with increased spark plug gap.

8. Inlet pressure necessary to maintain 500 rpm. at given conditions tended to increase slightly with decreased idling smoothness, as measured by frequency of missing.

9. Percent departure from the mean maximum cylinder pressure, as observed on the oscilloscope, seemed to increase with decreased idling

smoothness, as determined by the frequency of missing.

The decrease in idling smoothness with decreased fuel-air ratio is, more than likely, due to the lesser likelihood for there to be a suitable combustion mixture in the vicinity of the spark plug. The engine, under idling conditions, contains a greater than normal percentage of residual gases, due to the decrease in scavenging effects at low speeds. An excess amount of fuel, over that for normal operation, is necessary to induce proper combustion within the idling engine.

Increased inlet mixture temperature tends to better vaporize the incoming fuel. Thus, such a factor should tend to increase smoothness in idling. The tendency for decreased necessary minimum fuel-air ratio with increasing inlet temperature bears out this hypothesis.

Increased exhaust back pressure, on the other hand, would tend to increase the percentage of residual gases present in the combustion chamber, thus making for rougher idling characteristics. This is proven by the increased minimum fuel-air ratio necessary for smooth engine idling at increased degrees of exhaust throttling.

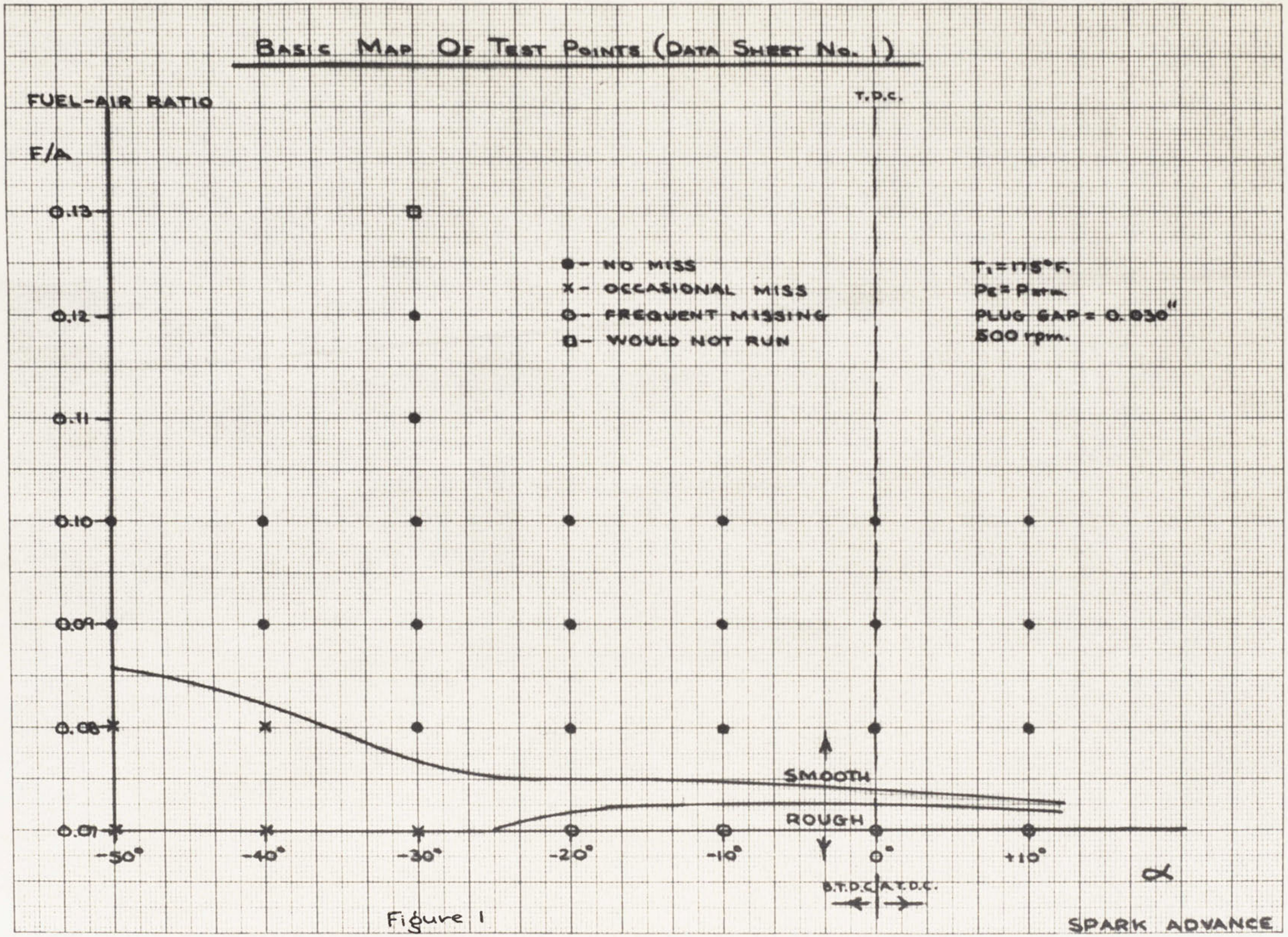
Finally, the tendency towards smoother engine idling at greater spark plug gap is explained by the more ideal combustion resulting from the greater distance which the spark must travel through the combustible mixture.

The two secondary factors measuring idling smoothness (inlet pressure needed to maintain 500 rpm. and percent departure from mean peak cylinder pressure) correlated fairly well at points of very poor idling (all indicated rough idling under such conditions). Secondary factors seemed, however, to signify roughness at other points which were taken to be smooth by the miss frequency criterion. This would indicate a greater sensitivity, or even an oversensitivity (since rough idling was recorded by secondary measuring methods under conditions at which both the missing criterion and the sensory perceptions of the observer indicated smooth idling characteristics), to any lack of idling smoothness, on the part of the secondary criteria.

SUGGESTIONS FOR FURTHER INVESTIGATION

Other factors which would, more than likely, tend to effect idling smoothness are changes in valve timing to include different degrees of overlap, alterations in spark plug location, presence of shrouding in the vicinity of the inlet valve so as to direct the flow of fresh change towards the spark plug, supercharging, and changes in compression ratio. Experimentation as to the effect of any or all of these factors upon engine smoothness would prove to be both useful and interesting. A re-evaluation of the smoothness evaluating methods presented herein in conjunction with a search for other possible criteria might be a rewarding first step in such a research undertaking.

APPENDIX



BASIC MAP OF TEST POINTS (DATA SHEET No. 1)
FUEL-AIR RATIO
F/A
T.D.C.
0.13
0.12
0.11
0.10
0.09
0.08
0.07
● - NO MISS
X - OCCASIONAL MISS
⊖ - FREQUENT MISSING
⊡ - WOULD NOT RUN
T₁ = 175°F.
Pe = Patm
PLUG GAP = 0.030"
500 rpm.
SMOOTH
ROUGH
-50°
-40°
-30°
-20°
-10°
0°
+10°
α
B.T.D.C.
A.T.D.C.
SPARK ADVANCE

Figure 1

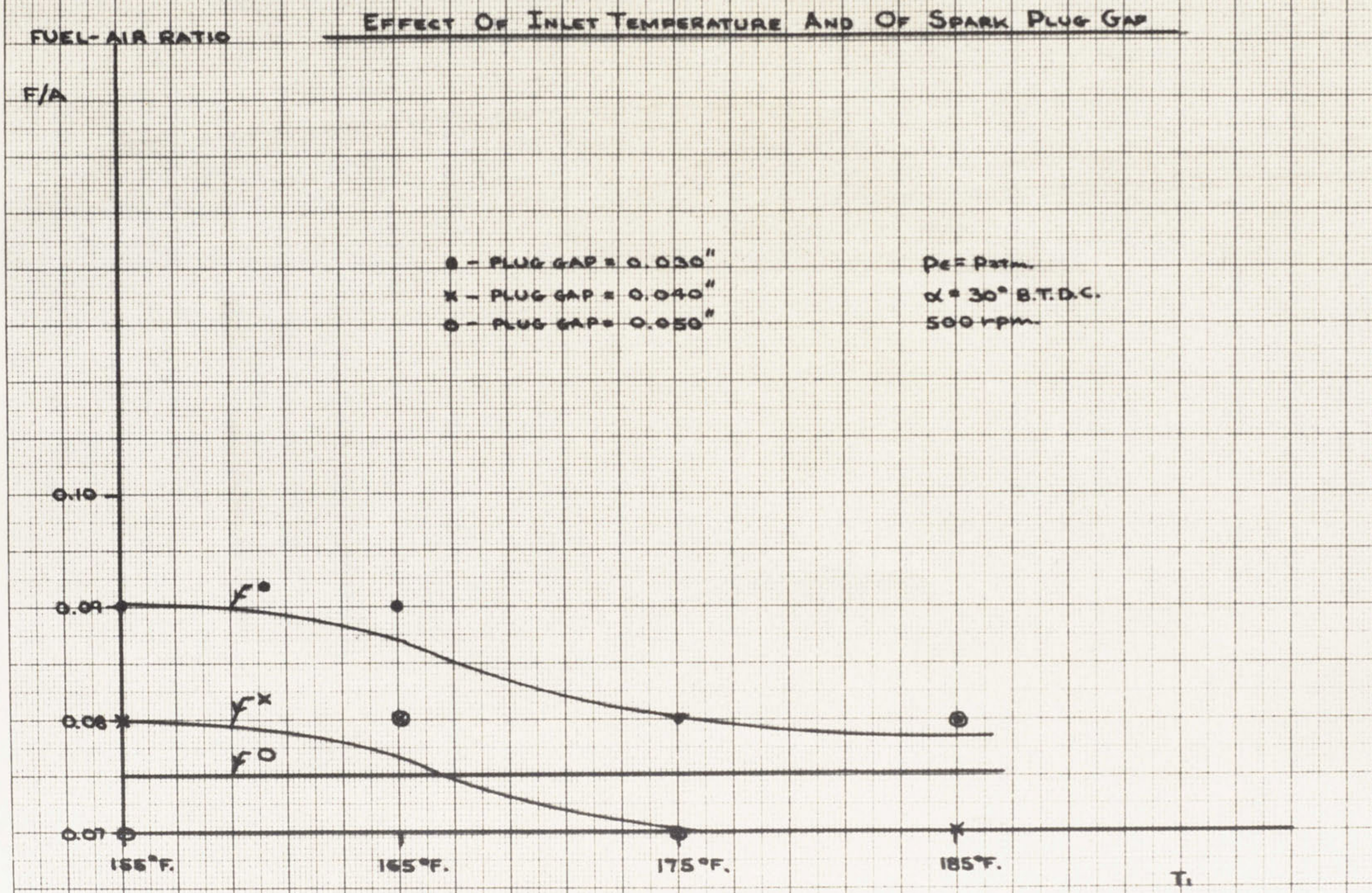

Effect Of Inlet Temperature And Of Spark Plug Gap
FUEL-AIR RATIO
F/A
● - PLUG GAP = 0.030"
✱ - PLUG GAP = 0.040"
⊙ - PLUG GAP = 0.050"
Pe = Patm.
α = 30° B.T.D.C.
500 rpm.
0.10
0.09
0.08
0.07
155°F.
165°F.
175°F.
185°F.
T₁
INLET TEMPERATURE

Figure 2

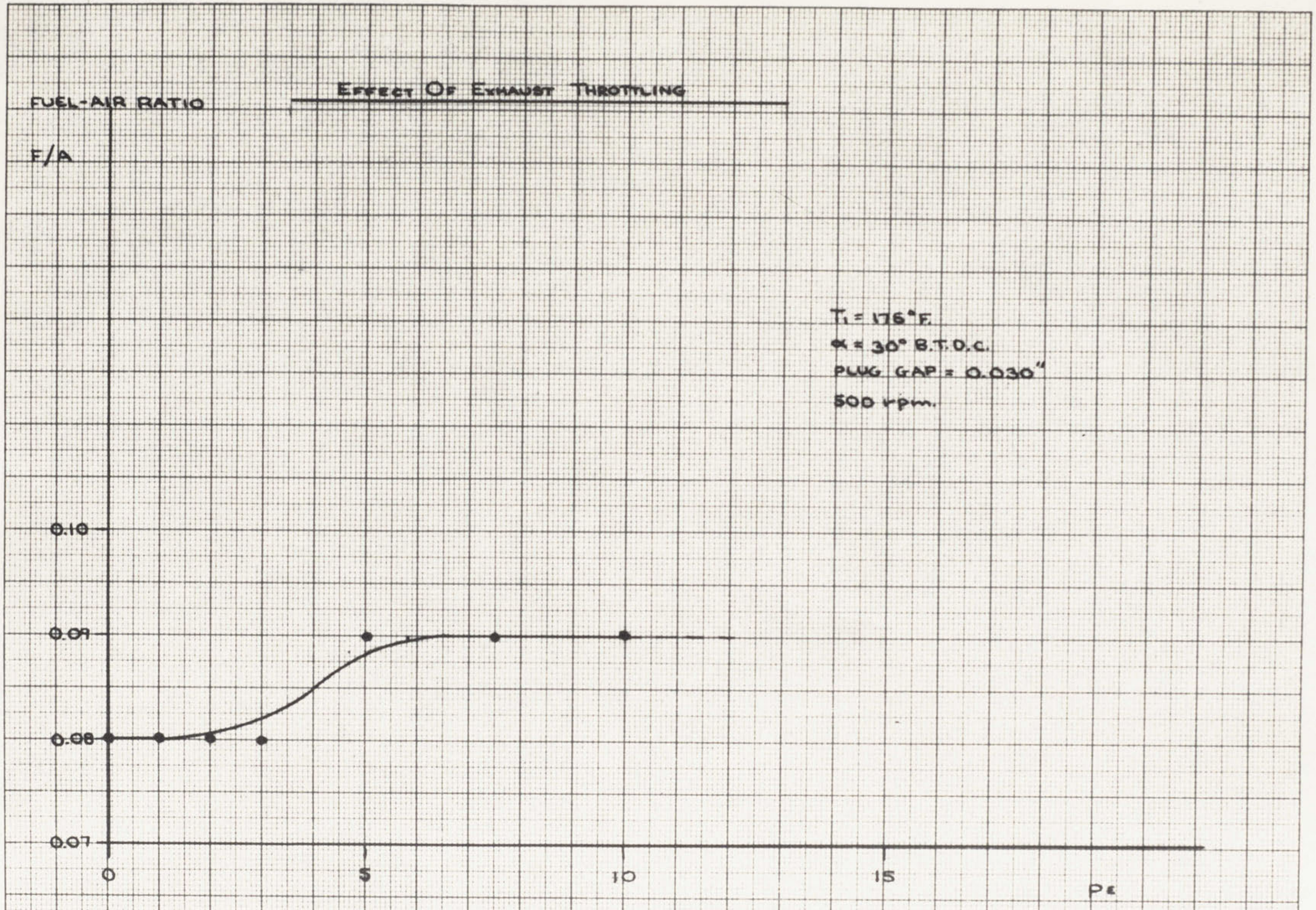

EFFECT OF EXHAUST THROTTLING
FUEL-AIR RATIO
F/A
0.10
0.09
0.08
0.07
0
5
10
15
T_1 = 176°F
α = 30° B.T.D.C.
PLUG GAP = 0.030"
500 r.p.m.
P_E
(in. Hg. above patm.)
EXHAUST PRESSURE

Figure 3

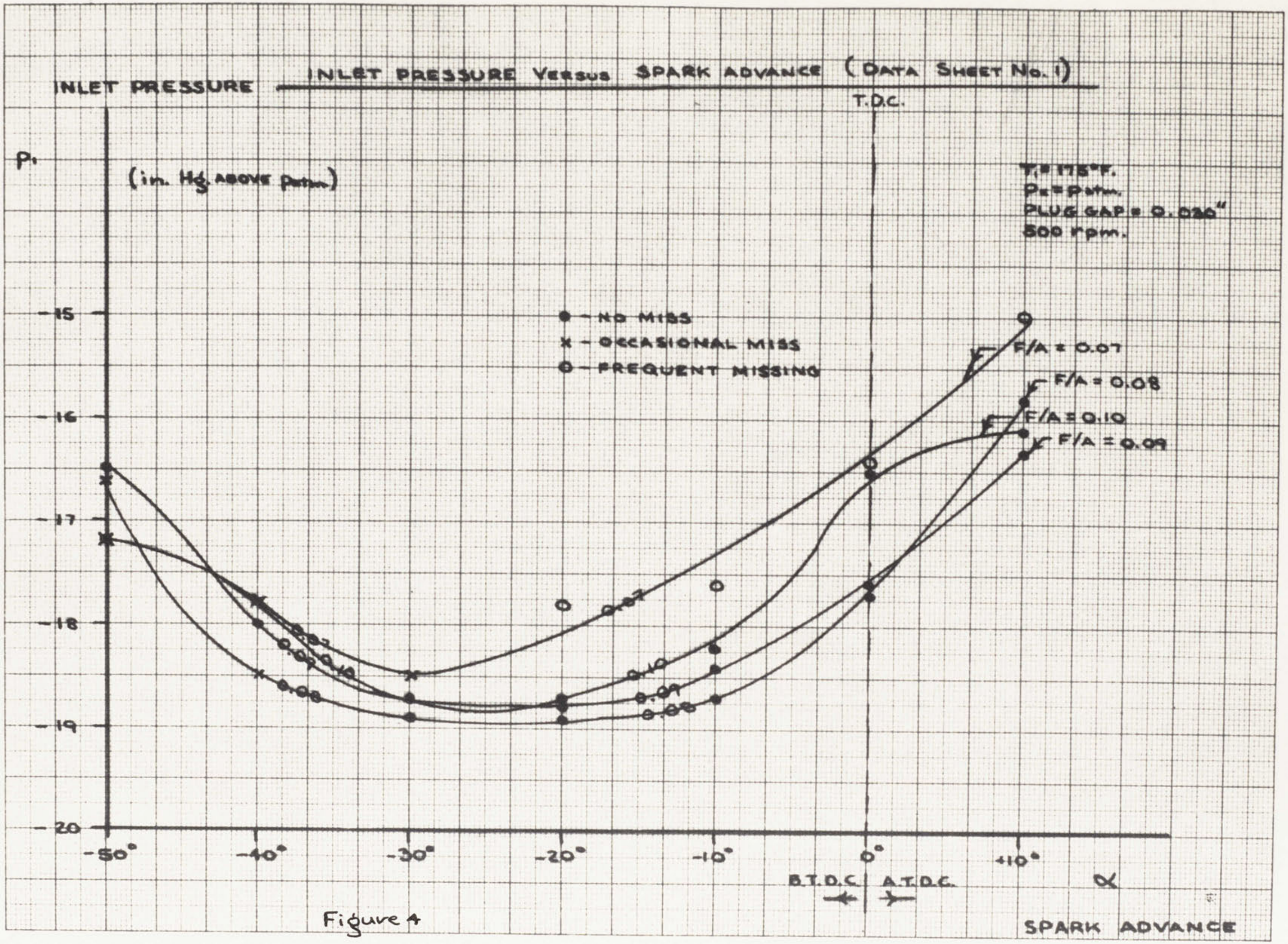

INLET PRESSURE
INLET PRESSURE Versus SPARK ADVANCE (DATA SHEET No. 1)
T.D.C.
P_1
(in. Hg. above patm)
T_1 = 175°F.
P_x = patm.
PLUG GAP = 0.020"
500 rpm.
● - NO MISS
x - OCCASIONAL MISS
o - FREQUENT MISSING
F/A = 0.07
F/A = 0.08
F/A = 0.10
F/A = 0.09
-15
-16
-17
-18
-19
-20
-50°
-40°
-30°
-20°
-10°
0°
+10°
B.T.D.C.
A.T.D.C.
α
SPARK ADVANCE

Figure 4

SUPERIMPOSED SMOOTH FIRING AND MISS OSCILLOSCOPE DIAGRAMS

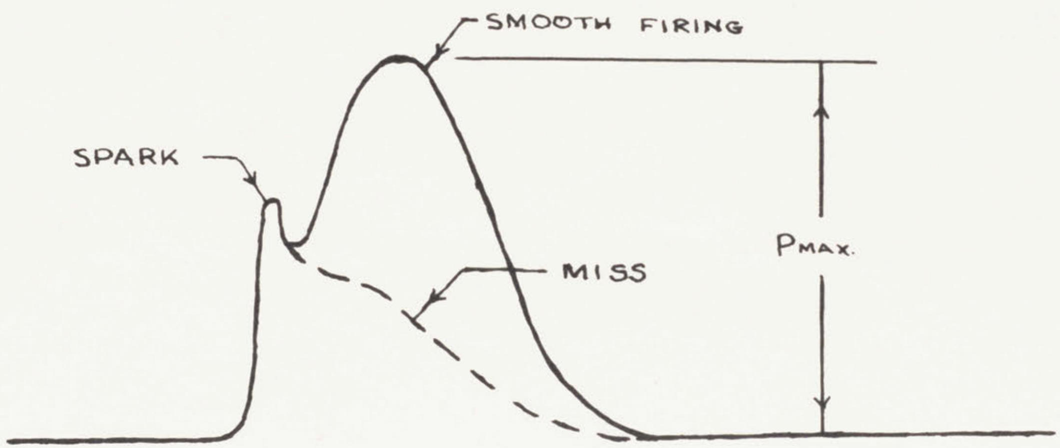


Figure 5

(pressure versus crank angle)

EXPERIMENT NO. — **TITLE** Basic Factors Affecting Smooth Engine Idling **DATE** Compiled Over Several Dates **SLOAN LABORATORY**

ENGINE C.F.R. Four-Stroke **FUEL** Gasolene **S.G.** — **WET BULB** — **DRY BULB** —

BORE 3.25" **STROKE** 4.50" **COMPRESSION RATIO** 6.0 to 1 **BAROMETER (ACT.)** — **(CORR.)** 30.10 (± 0.15) in Hg.

CONSTANTS BMEP = B.L. X BHP = $\frac{B.L. \times RPM}{}$ Data Sheet No. 1

REMARKS	~~TIME~~	RUN	RPM	B.L.	~~F.L.~~	TEMP. OIL	TEMP. JAC	OIL PRES. (gage)	P_1 (in. Hg. above atm.)	P_E	T_1	AIR CONS. (lb./sec.)	FUEL CONS. (lb./sec.)	F/A	S.A. (B.T.D.C.)	SPARK PLUG GAP	AVERAGE NUMBER OF MISSES PER MINUTE	PERCENT DEPARTURE FROM NORM. PHAS.
		1	500	1.2		150°F.	120°F.	55 p.s.i.	-17.2	0	175°F.	1.85×10^{-3}	1.85×10^{-4}	0.10	50°	0.030"	0	5
		2	↓	1.2		150°F.	120°F.	55 p.s.i.	-17.8	0	175°F.	1.70×10^{-3}	1.70×10^{-4}	0.10	40°	↓	0	10
		3	↓	1.2		150°F.	120°F.	55 p.s.i.	-18.7	0	175°F.	1.60×10^{-3}	1.60×10^{-4}	0.10	30°	↓	0	15
		4	↓	1.2		150°F.	120°F.	55 p.s.i.	-18.7	0	175°F.	1.60×10^{-3}	1.60×10^{-4}	0.10	20°	↓	0	15
		5	↓	1.1		150°F.	120°F.	55 p.s.i.	-18.2	0	175°F.	1.85×10^{-3}	1.85×10^{-4}	0.10	10°	↓	0	15
		6	↓	1.2		150°F.	120°F.	55 p.s.i.	-16.5	0	175°F.	2.15×10^{-3}	2.15×10^{-4}	0.10	0°	↓	0	50
		7	500	1.1		150°F.	120°F.	55 p.s.i.	-16.1	0	175°F.	2.20×10^{-3}	2.20×10^{-4}	0.10	A.T.D.C. 10°	0.030"	0	50
		8	500	1.1		150°F.	120°F.	55 p.s.i.	-16.5	0	175°F.	2.05×10^{-3}	1.80×10^{-4}	0.09	50°	0.030"	0	10
		9	↓	1.1		150°F.	120°F.	55 p.s.i.	-18.0	0	175°F.	1.75×10^{-3}	1.60×10^{-4}	0.09	40°	↓	0	10
		10	↓	1.1		150°F.	120°F.	55 p.s.i.	-18.7	0	175°F.	1.60×10^{-3}	1.40×10^{-4}	0.09	30°	↓	0	10
		11	↓	1.2		150°F.	120°F.	55 p.s.i.	-18.8	0	175°F.	1.60×10^{-3}	1.40×10^{-4}	0.09	20°	↓	0	10
		12	↓	1.2		150°F.	120°F.	55 p.s.i.	-18.4	0	175°F.	1.70×10^{-3}	1.60×10^{-4}	0.09	10°	↓	0	50
		13	↓	1.2		150°F.	120°F.	55 p.s.i.	-17.6	0	175°F.	1.85×10^{-3}	1.65×10^{-4}	0.09	0°	↓	0	100
		14	500	1.2		150°F.	120°F.	55 p.s.i.	-16.3	0	175°F.	2.10×10^{-3}	1.85×10^{-4}	0.09	A.T.D.C. 10°	0.030"	0	150
		15	500	1.2		150°F.	120°F.	55 p.s.i.	-16.6	0	175°F.	1.95×10^{-3}	1.60×10^{-4}	0.08	50°	0.030"	3	15
		16	↓	1.2		150°F.	120°F.	55 p.s.i.	-18.5	0	175°F.	1.65×10^{-3}	1.35×10^{-4}	0.08	40°	↓	2	20
		17	↓	1.1		150°F.	120°F.	55 p.s.i.	-18.9	0	175°F.	1.60×10^{-3}	1.35×10^{-4}	0.08	30°	↓	0	20
		18	↓	1.1		150°F.	120°F.	55 p.s.i.	-18.9	0	175°F.	1.60×10^{-3}	1.35×10^{-4}	0.08	20°	↓	0	15
~~COURSE~~		19	↓	1.1		150°F.	120°F.	55 p.s.i.	-18.7	0	175°F.	1.75×10^{-3}	1.40×10^{-4}	0.08	10°	↓	0	100
~~GROUP~~		20	↓	1.1		150°F.	120°F.	55 p.s.i.	-17.7	0	175°F.	1.85×10^{-3}	1.50×10^{-4}	0.08	0°	↓	0	100
~~NAMES~~		21	500	1.1		150°F.	120°F.	55 p.s.i.	-15.8	0	175°F.	2.10×10^{-3}	1.65×10^{-4}	0.08	A.T.D.C. 10°	0.030"	0	200
		22	500	1.1		150°F.	120°F.	55 p.s.i.	-17.2	0	175°F.	1.95×10^{-3}	1.40×10^{-4}	0.07	50°	0.030"	3	50
		23	↓	1.1		150°F.	120°F.	55 p.s.i.	-17.7	0	175°F.	1.75×10^{-3}	1.20×10^{-4}	0.07	40°	↓	5	75
		24	↓	1.1		150°F.	120°F.	55 p.s.i.	-18.5	0	175°F.	1.60×10^{-3}	1.10×10^{-4}	0.07	30°	↓	4	100
		25	↓	1.1		150°F.	120°F.	55 p.s.i.	-17.8	0	175°F.	1.85×10^{-3}	1.30×10^{-4}	0.07	20°	↓	30 to 50	100
		26	↓	1.1		160°F.	120°F.	55 p.s.i.	-17.6	0	175°F.	1.85×10^{-3}	1.35×10^{-4}	0.07	10°	↓	30 to 50	100
		27	↓	1.0		150°F.	120°F.	55 p.s.i.	-16.4	0	175°F.	2.00×10^{-3}	1.40×10^{-4}	0.07	0°	↓	30 to 50	100
		28	500	1.0		150°F.	120°F.	55 p.s.i.	-15.0	0	175°F.	2.25×10^{-3}	1.65×10^{-4}	0.07	A.T.D.C. 10°	0.030"	30 to 50	200

EXPERIMENT NO. — **TITLE** Basic Factors Affecting Smooth Engine Idling **DATE** Compiled Over Several Dates **SLOAN LABORATORY**

ENGINE C.F.R. Four-Stroke **FUEL** Gasoline **S.G.** — **WET BULB** — **DRY BULB** —

BORE 3.25" **STROKE** 4.50" **COMPRESSION RATIO** 6.0 to 1 **BAROMETER (ACT.)** — **(CORR.)** 29.75 (±0.35) in. Hg.

CONSTANTS BMEP = B.L. X BHP = $\frac{\text{B.L. x RPM}}{}$ DATA SHEET No. 2

REMARKS	TIME	RUN	RPM	B.L.	F.L.	TEMP. OIL	TEMP. JAC	OIL PRES. (GAGE)	P_1 (in. Hg above atm.)	P_E	T_1	AIR CONS. (lb./sec.)	FUEL CONS. (lb./sec.)	F/A	S.A. (B.T.D.C.)	SPARK PLUG GAP	AVERAGE NUMBER OF MISSES PER MINUTE	PERCENT DEPARTURE FROM MEAN P_{max}
		29	500	1.1		150°F	120°F	55 p.s.i.	-18.2	0	175°F	1.60×10^{-3}	1.75×10^{-4}	0.11	30°	0.030"	0	100
		30	↓	1.2		150°F	120°F	55 p.s.i.	-18.1	0	175°F	1.65×10^{-3}	2.00×10^{-4}	0.12	↓	↓	0	150
ENGINE WOULD NOT RUN AT 500 R.P.M. ON SUCH A FUEL-AIR RATIO		31	500	—		150°F	120°F	55 p.s.i.	—	0	175°F	—	—	0.13	30°	0.030"	—	—
MINIMUM F/A FOR NO MISSING		32	500	1.2		150°F	120°F	55 p.s.i.	-19.0	0	155°F	1.60×10^{-3}	1.40×10^{-4}	0.09	30°	0.030"	0	10
" " " " "		33	↓	1.2		150°F	120°F	55 p.s.i.	-19.1	0	165°F	1.60×10^{-3}	1.40×10^{-4}	0.09	↓	↓	0	5
" " " " "		34 (17)	↓	1.1		150°F	120°F	55 p.s.i.	-18.9	0	175°F	1.60×10^{-3}	1.35×10^{-4}	0.08	↓	↓	0	20
" " " " "		35	500	1.2		150°F	120°F	55 p.s.i.	-18.9	0	185°F	1.60×10^{-3}	1.35×10^{-4}	0.08	30°	0.030"	0	10
MINIMUM F/A FOR NO MISSING		36	500	1.1		150°F	120°F	55 p.s.i.	-18.4	0	155°F	1.60×10^{-3}	1.35×10^{-4}	0.08	30°	0.040"	0	75
" " " " "		37	↓	1.1		150°F	120°F	55 p.s.i.	-18.4	0	165°F	1.60×10^{-3}	1.35×10^{-4}	0.08	↓	↓	0	100
" " " " "		38	↓	1.1		150°F	120°F	55 p.s.i.	-18.4	0	175°F	1.60×10^{-3}	1.15×10^{-4}	0.07	↓	↓	0	50
" " " " "		39	500	1.1		150°F	120°F	55 p.s.i.	-18.0	0	185°F	1.60×10^{-3}	1.15×10^{-4}	0.07	30°	0.040"	0	20
MINIMUM F/A FOR NO MISSING		40	500	1.3		150°F	120°F	55 p.s.i.	-17.7	0	185°F	1.60×10^{-3}	1.15×10^{-4}	0.07	30°	0.050"	0	75
" " " " "		41	↓	1.3		150°F	120°F	55 p.s.i.	-18.3	0	175°F	1.60×10^{-3}	1.35×10^{-4}	0.08	↓	↓	0	75
" " " " "		42	↓	1.3		150°F	120°F	55 p.s.i.	-18.4	0	165°F	1.60×10^{-3}	1.15×10^{-4}	0.07	↓	↓	0	50
" " " " "		43	500	1.3		150°F	120°F	55 p.s.i.	-18.5	0	155°F	1.60×10^{-3}	1.35×10^{-4}	0.08	30°	0.050"	0	40
~~COURSE~~																		
~~GROUP~~																		
~~NAMES~~																		
MINIMUM F/A FOR NO MISSING		44 (17)	500	1.1		150°F	120°F	55 p.s.i.	-18.9	0	175°F	1.60×10^{-3}	1.35×10^{-4}	0.08	30°	0.030"	0	READINGS NOT TAKEN
" " " " "		45	↓	1.3		150°F	120°F	55 p.s.i.	-18.1	1.0	175°F	1.60×10^{-3}	1.35×10^{-4}	0.08	↓	↓	0	
" " " " "		46	↓	1.3		150°F	120°F	55 p.s.i.	-17.9	2.0	175°F	1.60×10^{-3}	1.35×10^{-4}	0.08	↓	↓	0	
" " " " "		47	↓	1.3		150°F	120°F	55 p.s.i.	-17.8	3.0	175°F	1.60×10^{-3}	1.35×10^{-4}	0.08	↓	↓	0	
" " " " "		48	↓	1.3		150°F	120°F	55 p.s.i.	-17.7	4.0	175°F	1.60×10^{-3}	1.40×10^{-4}	0.09	↓	↓	0	
" " " " "		49	↓	1.3		150°F	120°F	55 p.s.i.	-17.4	5.0	175°F	1.60×10^{-3}	1.40×10^{-4}	0.09	↓	↓	0	
" " " " "		50	↓	1.3		150°F	120°F	55 p.s.i.	-17.0	7.5	175°F	1.60×10^{-3}	1.40×10^{-4}	0.09	↓	↓	0	
" " " " "		51	↓	1.3		150°F	120°F	55 p.s.i.	-16.6	10.0	175°F	1.60×10^{-3}	1.40×10^{-4}	0.09	↓	↓	0	
VERY ROUGH IDLING DISPLAYED		52	500	1.3		150°F	120°F	55 p.s.i.	-16.0	15.0	175°F	1.60×10^{-3}	ALL	ALL	30°	0.030"	?	