PROGRESS REPORT NO. 8

DIESEL ENGINE IGNITION AND COMBUSTION

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PERIOD APRIL 1, 1966 TO DECEMBER 30, 1967

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PART I

SUMMARY

I. BACKGROUND

A program of activity to study the combustion process in supercharged diesel engines has been developed at The University of Michigan. This program is primarily concerned with the ignition delay and the effect of the several parameters on it. A special concern is given to the effect of pressure, temperature, and density of the cylinder air charge on ignition delay.

The different types of delay have been studied in detail and an emphasis is made on the pressure rise delay and illumination delay. The instruments needed for the measurement of these two delay periods have been developed and a continuous effort is being made to improve their accuracy.

This research is being made on two experimental engines. One is the ATAC high output open combustion chamber engine, and the other is a Lister-Blackstone swirl combustion chamber engine. Three fuels have been used in these tests.

II. OBJECTIVES

A. To study how gas pressure at the time of injection affects ignition delay and combustion. The effects are to be studied at pressures ranging from approximately 300 to 1000 psia.

B. To study how gas temperature at the time of injection affects ignition delay. The temperatures range from approximately 900°F to 1500°F.

C. To study various combinations of pressures and temperatures to determine whether density is an independent variable affecting ignition delay.

D. To conduct all these studies with three fuels: CITE refree grade (Mil-F-45121) fuel, diesel no. 2 fuel, and Mil-G-3056 refree grade gasoline.

III. CUMULATIVE PROGRESS

Cumulative progress has been made in the following areas:

A. Review and analysis of previous work.

B. Theoretical analysis.

C. Experimental work on Lister-Blackstone engine.

D. Comparison between the present work done on the Lister engine and previous work in bombs and engines.

E. Experimental work done on the ATAC open combustion chamber engine, using three different fuels.

Items A through D have been discussed in detail in previous progress reports. Item E will be discussed in the following paragraphs.

ITEM E: CUMULATIVE PROGRESS ON ATAC OPEN COMBUSTION CHAMBER ENGINE

The engine has been connected to an electric dynamometer. It is supercharged with shop air that has been passed through a surge tank fitted just before the engine. Another surge tank is fitted on the exhaust side. The pressures in the two tanks can be regulated to the required values.

A Kistler pressure transducer is fitted in the hole furnished by the International Harvester Company. Two more holes were drilled in the cylinder head above the piston cavity. One hole is fitted with a quartz window, and the other is fitted with a surface thermocouple.

The top dead center of the engine, as determined by the dial gage method, was found to be 1/2 crank degree past the top dead center mark engraved on the flywheel.

The degree marks are produced by a steel disk 18 in. in diameter and 1/8 in. thick, mounted on the coupling between the crankshaft and the dynamometer. Holes 1/16 in. in diameter are drilled around the periphery at 3° intervals, and larger holes, 1/8 in. in diameter, at 45° intervals. A magnetic pickup has been used to produce corresponding pips on the oscilloscope screen every 3°, with bigger pips every 45°. One of the bigger holes is aligned at top dead center.

The temperature of the inside surface of the combustion chamber is measured by a surface thermocouple placed between the inlet and exhaust valves.

The fuel-injection system is instrumented so that the start and rate of injection can be calculated from measurements of the needle lift and fuel pressure before the nozzle. The position of the plunger w.r.t., the barrel, and the injection timing are both controlled by micrometers.

An electric heater has been fitted between the critical flowmeter and the inlet surge tank. All the piping between the heater, engine, and exhaust tank are insulated by 1.5 in. thick calcium silicate pipe insulation.

The exhaust surge tank is cooled by spraying tap water into the tank. The direction of the spray is such as not to interfere with the flow of gases from the engine to the tank or with the exhaust thermocouple or smokemeter probe.

A new oscilloscope (Taktronix type 502A) and a new Polaroid camera are now in use to obtain and record the different traces for the combustion process in the engine. A special projected graticule is now in use with the camera, in order to eliminate the parallex which had been noticed before using this attachment.

The flow rate of blowby gases is measured by a flowmeter connected to the crankcase ventilation tube. An oil separater has been installed between the ventilating tube and the flowmeter to collect the oil droplets discharged with the blowby gases before reaching the flowmeter. The value of the blowby rate will be recorded together with all other data while running the engine.

The smoke produced in the exhaust of the ATAC engine is measured by a "Hartridge Smokemeter."

The different instruments used in this research project have been calibrated. These instruments are:

1. The critical flowmeter used to measure the rate of air flow into the engine.

2. Kistler pressure transducer (type 401A) together with the charge amplifier (type 655, S/N 1194). This transducer is used for measuring the gas pressure in the cylinder.

3. Kistler pressure transducer (type 601H) together with the charge amplifier (type 503, S/N 359). This transducer is used for measuring the fuel pressure before the nozzle.

4. The Bently distance detector used to measure the needle lift.

5. The surface thermocouple used to measure the inside wall surface temperature. The thermocouple output is found to agree with the standard thermocouple tables.

6. The Honeywell thermocouple (rotating disk type) used to measure the air, water, oil, and exhaust gas temperature.

Most of the computations needed for this project are now carried out on an IBM 7090 computer, in The University of Michigan Computing Center. Statistical and curve fitting procedures are made to assist in data synthesis programs, combustion analysis programs, and delay analysis programs.

IV. PROGRESS DURING THIS PERIOD

During this period the experimental work for the effect of temperature on I.D. and combustion characteristics of three different fuels have been completed. The air temperature before the inlet valve was changed over a range from 95°F to 750°F, in steps of 50°F.

Five series of runs have been made, with all the parameters held constant except the inlet air temperature and the inlet air pressure. These parameters include: the engine speed, the fuel-air ratio, the cooling water temperature, the injector opening pressure, and the injection timing. The fuels used in these tests are:

1. CITE refree grade (Mil-F-45121) fuel;
2. Diesel no. 2 fuel; and
3. Mil-G-3056 refree grade gasoline fuel.

These fuels have been purchased from the Ashland Oil and Refining Company and a copy of the certificates of analysis is given in Appendix A. Two batches of CITE fuel have been used in the experiments: Batch no. 13 dated December 3, 1965, and batch no. 19 dated March 29, 1967. The difference in their behavior in the engine is within the experimental error.

The five series of runs were made to study the following:

Series A1: Comparison between the three fuels under naturally aspirated conditions. Series A2A: Effect of temperature on I.D. of CITE fuel at constant inlet surge tank pressure of 15 in. Hg g. Series A2B: Effect of temperature on I.D. of CITE fuel at a constant mean pressure during the delay period. Series A2C: Effect of temperature on I.D. of diesel no. 2 fuel at a constant mean pressure during the delay period. Series A2D: Effect of temperature on I.D. of gasoline fuel at a constant mean pressure during the delay period. The mean pressures during the delay period were held constant for the three fuels.

All the data and results obtained from the last four series together with discussions are given in this report. The analysis of the results of Series A1, which is made to study the combustion kinetics of the different fuels under naturally aspirated conditions has not been finished yet as it includes a large amount of analytical and computational work. These results will be given in a future progress report.

In order to determine the thermodynamic state of the gases at any point in the cyle, the volume of these gases is required with the greatest accuracy possible. In order to achieve such accuracy the clearance volume of the engine was calculated and the results checked by actual measurements. The details of these computations are given in Appendix B. The swept volume is also calculated at different crank angle positions, taking into consideration the eccentricity or offset of the piston pin in the piston. The details of these computations are given in Appendix C.

The present report also includes experimental results of interest, other than the ignition delays. These are:

1. Smoke intensity in the exhaust gases.

2. Wall temperature measured on the inside surface of the combustion chamber on the centerline between the inlet and exhaust valves.

3. Maximum pressures reached in the cycle.

4. Maximum pressure gradient due to combustion.

5. The rate of change of the pressure gradient from the end of ignition delay to the point of maximum pressure gradient.

The results of the present work on the ATAC engine are compared with the previous experimental work done in engines and in bombs. For this comparison the previous data were replotted and analyzed to compute the activation energy, and compare it with the values obtained on the ATAC engine.

The results of the comparison between the present and previous data indicated that the experimental activation energy is a function of some of the physical factors in engine performance. A theoretical study of the factors that affect the activation energy is being done, in an effort to correlate between the results of different investigators under the different running conditions. These studies are still on the way and will be reported as soon as they are finished.

V. CONCLUSIONS

These conclusions are based on the tests made on the three fuels during this reporting period.

A. IGNITION DELAY ($I.D._p$)

1. For all the three fuels, the $I.D._p$ decreased continuously with the increase in temperature. A slight increase in the $I.D._p$ of CITE fuel has been noticed between 700°F and 745°F. The factors that might cause such a behavior are related to the mechanism of the chemical reactions taking place during the ignition delay.

2. The rate of decrease of the $I.D._p$ with the increase in temperature is greatest for gasoline. At a temperature of 106°F the ignition delay of gasoline is 2.142 times that of CITE fuel. But, at 700°F the ignition delay of gasoline is almost equal to that of the CITE fuel.

B. ACTIVATION ENERGY (E)

The temperature dependence of the ignition delay can be expressed in terms of an activation energy "E."* The activation energy can be considered equal to the minimum energy that should be achieved by the reactants before the start of combustion.

$$I.D._p = \frac{Ae^{E/RT}}{p^n}$$

where

A = constant

E = activation energy, Btu/lb mole

R = Universal gas constant, Btu/lb mole · °R

T = absolute temperature, °R

p = absolute pressure

n = index of pressure

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*M. E. Elliott, "Combustion of Diesel Fuel," SAE Quart. Trans. 3, 1949.

The experimental results show that the activation energy for the different fuels is as follows:

Fuel	E, Btu/lb mole
Diesel no. 2	5,230
CITE fuel	10,430
Gasoline fuel	14,780

C. NOISE

Two methods have been used to find the noise level: (1) Direct observation. (2) Analysis of the pressure crank angle traces to determine the maximum pressure gradient and its rate of change. At atmospheric temperature the highest noise level is produced with the engine running on gasoline. However, at high inlet temperatures, above 600°F, the noise level with gasoline is the same as CITE and diesel fuels.

D. SMOKE

The smoke is measured with a Hartridge smokemeter. The lowest smoke concentration is obtained with gasoline, followed by diesel no. 2 fuel. CITE fuel produced the highest smoke intensity. The high smoke level of CITE fuel is partly due to the after-injection which has been observed with this fuel.

E. TROUBLES IN ENGINE PERFORMANCE

1. The fuel leakage past the injector needle and the fuel plunger has been noticed to be excessive with CITE and gasoline fuels. This required frequent change of the lubricating oil in the fuel-pump sump, and cleaning of the injector.

2. Gasoline fuel produced a deposit over the injection system parts and required frequent cleaning.

VI. PROBLEM AREAS AND CORRECTIVE ACTION

A. FUEL LEAKAGE

Problem. Gasoline and CITE fuels have high leakage rates past fuel injection nozzle needle. In average, the rates of leakage of the different fuels are as follows:

Diesel = 0.07 litre/hr
CITE = 0.26 litre/hr
Gasoline = 0.38 litre/hr

Corrective Action. A visit was made to American Bosch Company in Springfield, Massachusetts, to discuss this problem with them. We found that they construct a special plunger barrel assembly to avoid this excessive leakage by means of a relief annulus. Buying this assembly is now under consideration.

B. DRAINAGE OF FUEL-PUMP SUMP

Problem. The drainage of lubricating oil from pump-sump was found impossible without taking the pump off the bracket.

Corrective Action. A slot is made opposite to the drainage plug. The original slot made in the bracket was on the wrong side.

C. SURFACE THERMOCOUPLE FAILURE

Problem. The thermocouple output was found faulty due to a break in the silver solder holding the top piece to the adapter.

Corrective Action. The sensing tip of the thermocouple was checked and found in good condition. A new adapter was designed and constructed to hold the top to the adapter by a screw connection thus ensuring proper operation.

D. FAILURE OF PRESSURE TRANSDUCERS

Problem. Failure occurred after 75 working hours in the fuel injection line.

Corrective Action. A spare transducer is ordered. This represented an expenditure of about $330.00 for the replacement of the faulty transducer. This cost is after a credit of $50.00 made for the trade-in.

E. FOULING OF INJECTION NOZZLE HOLES AND NEEDLE

Problem. Fouling of injection nozzle holes and needles have been noticed with CITE fuel and gasoline.

Corrective Action. A Robert Bosch nozzle cleaning kit, and a nozzle reconditioning kit were ordered and are now in use for cleaning purposes.

F. FAILURE OF 502A OSCILLOSCOPE

Problem. Lower beam of this scope was noticed not to operate properly.

Corrective Action. This was fixed in the Mechanical Analysis Laboratory of the Department of Mechanical Engineering. Spare parts and labor costs were charged to Tektronix Company.

VII. FUTURE PLANS

A. NEXT PERIOD

1. Experimental

a. To run tests on the ATAC open chamber engine, to find effect of pressure on ignition delay and combustion phenomena of CITE fuel.

b. To study the effect of speed on I.D.

c. To prepare the cooling system for the use of ethylene glycol instead of water.

2. Analytical

To study the kinetics of the combustion process as far as its effect on the ignition delay and combustion characteristics of the different fuels.

B. OVERALL

1. Experimental

a. To run tests on the ATAC open chamber engine, to find the effect of raising the coolant temperature to 250°F on ignition delay and combustion phenomena of CITE fuel.

b. To study the effect of raising the coolant temperature to 250°F on the injection process and on the engine performance in general.

2. Analytical

To analyze the data published by other investigators, on ignition delays in bombs and engines, in order to compare their results with the results of the ATAC engine.

VIII. SIGNIFICANT ACCOMPLISHMENTS

All the tests on the effect of temperature on the pressure-rise delays are completed for CITE, diesel, and gasoline fuels. The results showed that all the instruments are operating properly and showed a very good degree of reproducibility.

All the computer programs prepared for this project are ready to record, compute, and analyze the data. A comparison between the results obtained with the ATAC engine and from formulae based on previous research has also been made with the aid of the computer. This analytical work will continue. This is being done in an effort to reach general conclusions regarding the cause of the discrepancy between tests in bombs and in engines. A comparison between the results of ignition delay in different engines will also be made.

IX. PROJECT STATUS

FUNDS AND EXPIRATION DATE OF CONTRACT

Original contract July 1, 1964 to January 1, 1965	$ 23,020
Modification No. 7 Extension of contract to February 28, 1966 Addition of $18,000 to contract funds for a total of	41,020
Modification No. 8 Extension of contract to February 27, 1967 Addition of $37,000 to contract funds for a total of	78,020
Modification No. 10 Extension of contract to December 1, 1967 Addition of $45,000 to contract funds for a total of	123,020
Modification No. 12 Extension of contract to December 1, 1968 Addition of $45,000 to contract funds for a total of	168,020

PART II

EXPERIMENTAL DATA AND RESULTS

X. DATA AND RESULTS OF A SAMPLE RUN

A. RECORDED DATA (Photographs)

A sample of the traces recorded during a test on the ATAC engine are shown in Figs. 1 to 8, for run number 13, with CITE fuel.

The following are the test conditions and results for this run.

B. TEST CONDITIONS (as they Appear in Computer Sheets)

Speed = 1999 rpm
Load on dynamometer = 9.0 lb
Mass of fuel consumed, "D"* = 0.5007 lbm
Critical flowmeter orifice, "D"* = 7/32 in. dia
Time for fuel consumption = 5.79 min
Fuel leakage past injector = 0.17 liters/hr
Air pressure before flowmeter orifice = 38.1 psig
Air temperature before flowmeter orifice = 79°F
Air temperature before inlet valve = 464°F
Cooling water temperature at outlet = 167°F
Barometric pressure = 29.2 in. Hg
Surge tank pressure = 15.1 in. Hg
Exhaust temperature = 851°F
Smokemeter reading = 30 H.U.

C. RESULTS OBTAINED FROM TRACES

Minimum inside wall wurface temperature = 454°F
Temperature swing on inside surface = 47°F
Pressure at close of I.V. w.r.t. surge tank pressure = 3.0 psi
Pressure in cylinder at the start of injection, w.r.t. pressure at I.V.C. = 415 psi
Pressure at the end of ignition delay w.r.t. to pressure at start of injection = 194 psi
Start of needle lift before T.D.C. = 21.4° C.A.
End of ignition delay before T.D.C. = 13.4° C.A.

*Refer to Appendix D.2 for identification.

D. COMPUTED RESULTS

Brake horsepower = 6.0
BMEP = 33.2 psi
BSFC = 0.817 lbm/BHP hr
Fuel-air ratio = 0.0317
Air/cycle in (lbm/1000) = 2.58
Exhaust gases/cycle in (lbm/1000) = 0.11
Surge tank pressure = 21.8 psia
Volumetric efficiency = 98.0%
Temperature at I.V.C. = 477°F
Pressure of charge at start of injection = 440 psia
Density of charge at start of injection = 0.609 lbm/cu ft
Temperature of charge at start of injection = 1926°R
Average pressure during I.D. = 533 psia
Average density during I.D. = 0.707 lbm/cu ft
Average temperature during I.D. = 2010°R
$I.D._p$ = 0.667 msec

E. COMPARISON BETWEEN MEASURED $I.D._p$ WITH THAT CALCULATED FROM VARIOUS FORMULAE

TABLE 1

COMPARISON BETWEEN MEASURED $I.D._p$ WITH THAT CALCULATED FROM VARIOUS FORMULAE

Formula	Calculated $I.D._p$: Based on Conditions at Start of Injection	Calculated $I.D._p$: Based on Average Conditions During I.D.	Measured, msec
Wolfer	0.595	0.394	.667
Elliott	1.930	1.851	.667
Sitkei	1.406	1.119	.667
Tsao (at 1000 rpm)	0.924	0.702	.667

Sample of Recorded Data
ATAC - Open Chamber
Run No. 13

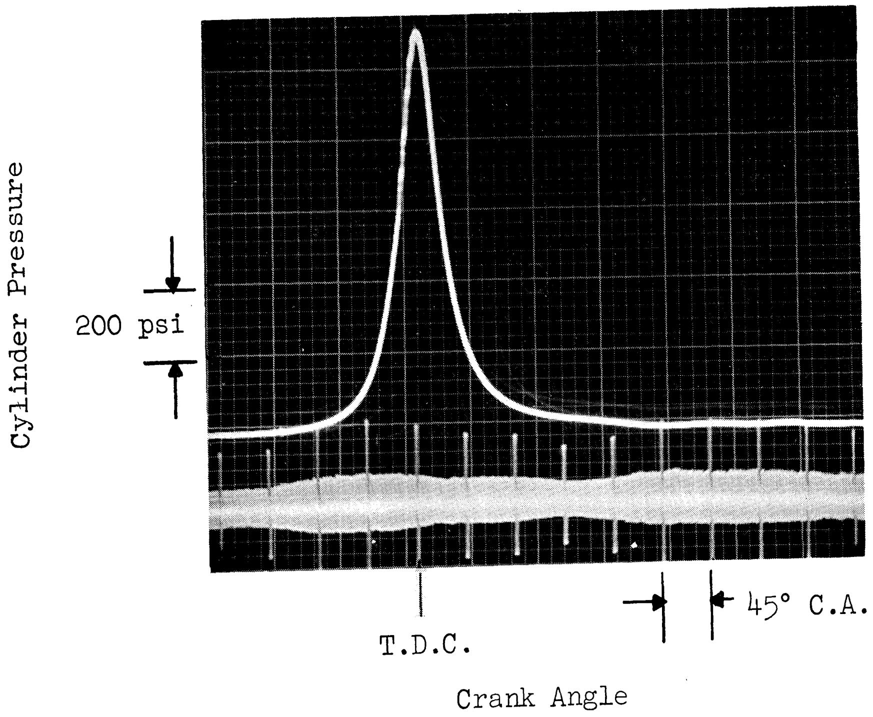


Fig. 1. Cylinder pressure for one complete engine cycle.

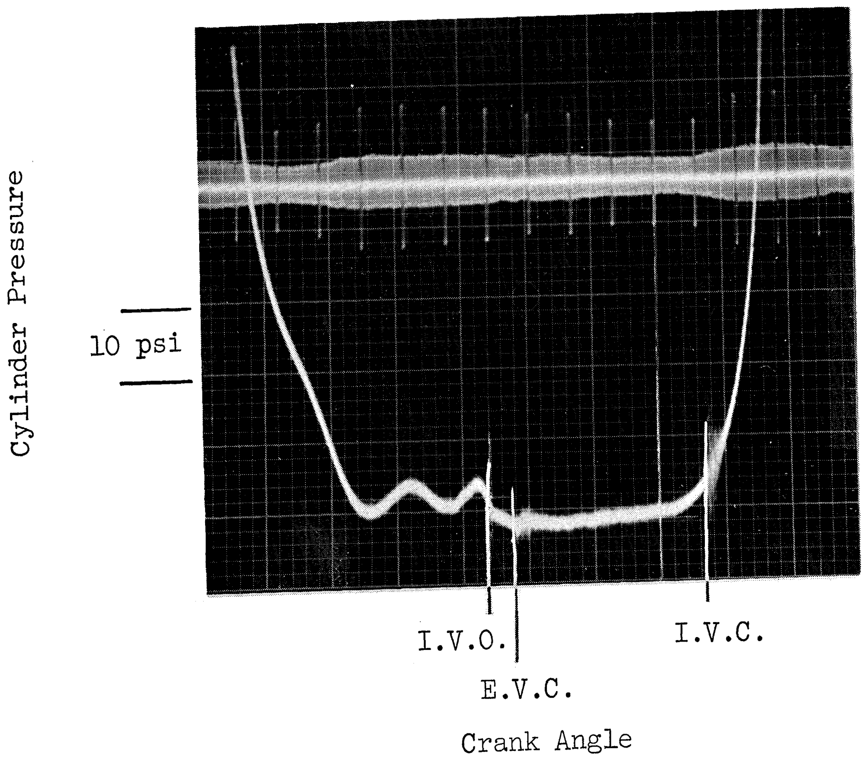


Fig. 2. Cylinder pressure for the exhaust and inlet strokes.

Sample of Recorded Data
ATAC - Open Chamber
Run No. 13

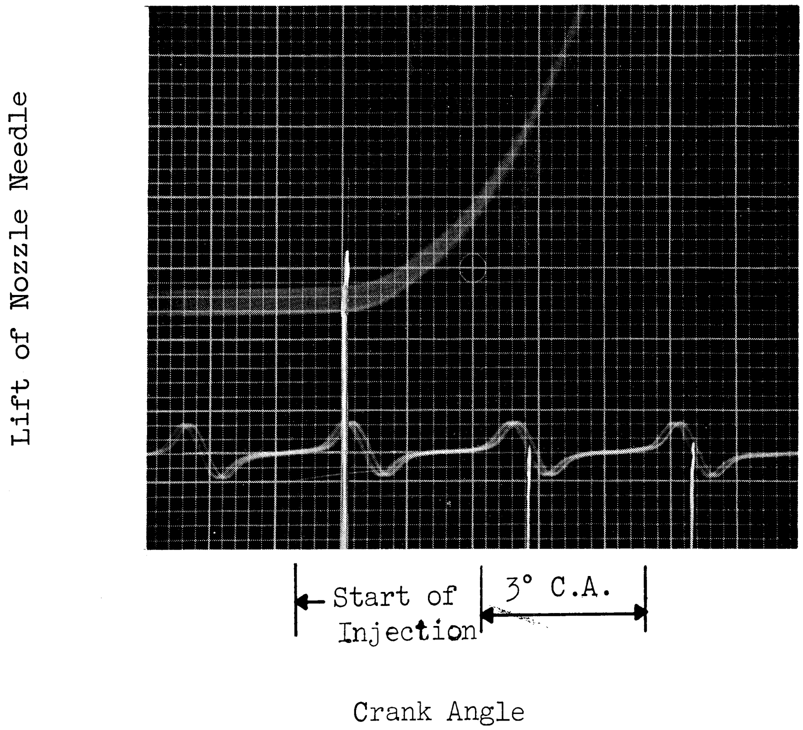


Fig. 3. Needle lift at start of injection.

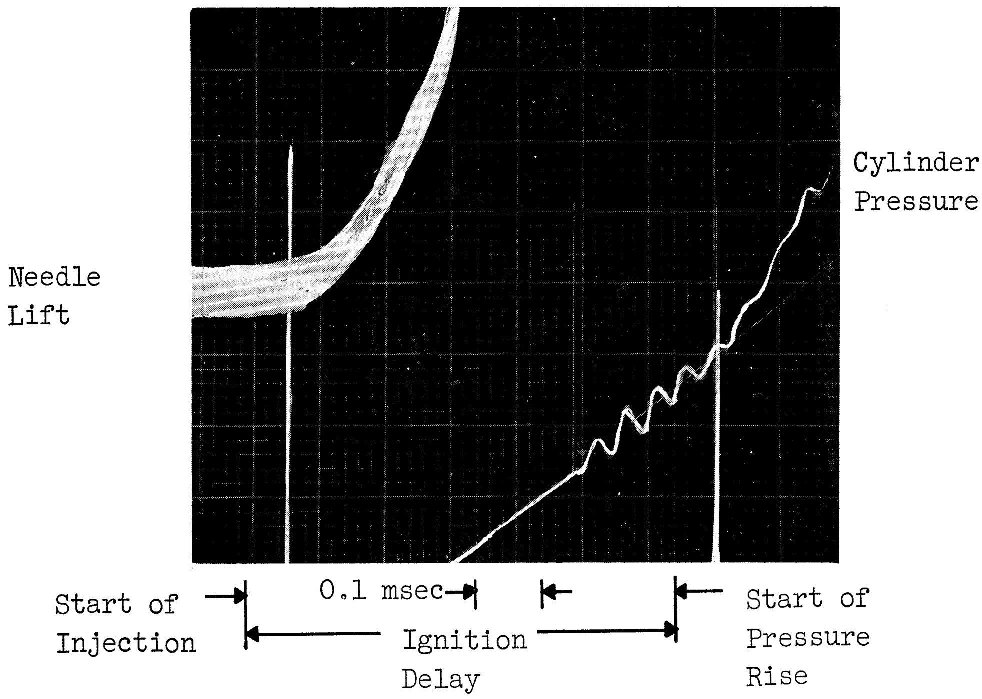


Fig. 4. Measurement of $I.D._p$ from cylinder pressure and needle lift traces.

Sample of Recorded Data
ATAC - Open Chamber
Run No. 13

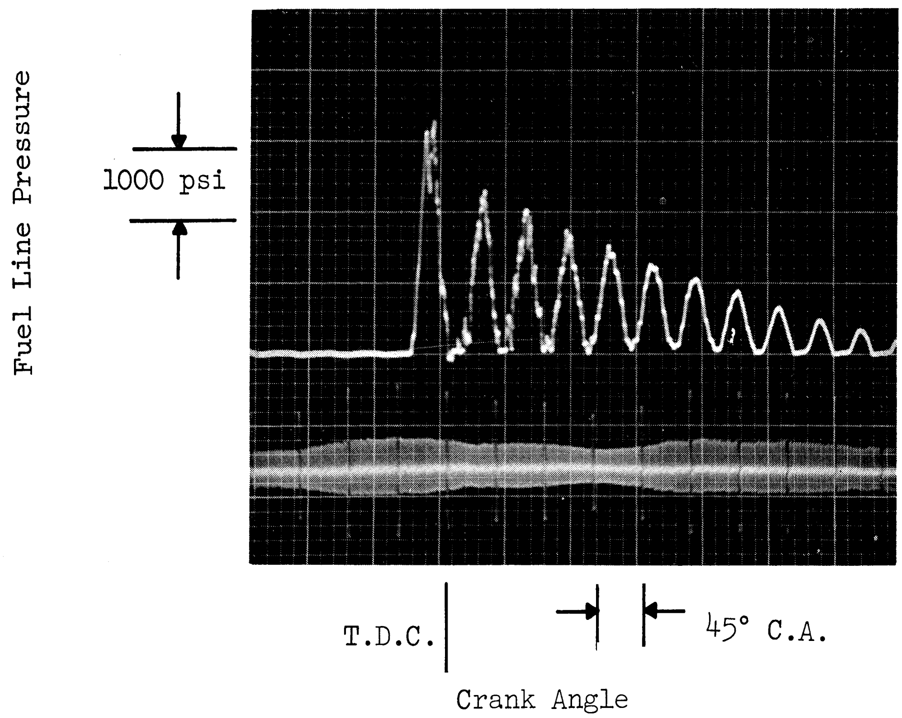


Fig. 5. Fuel line pressure.

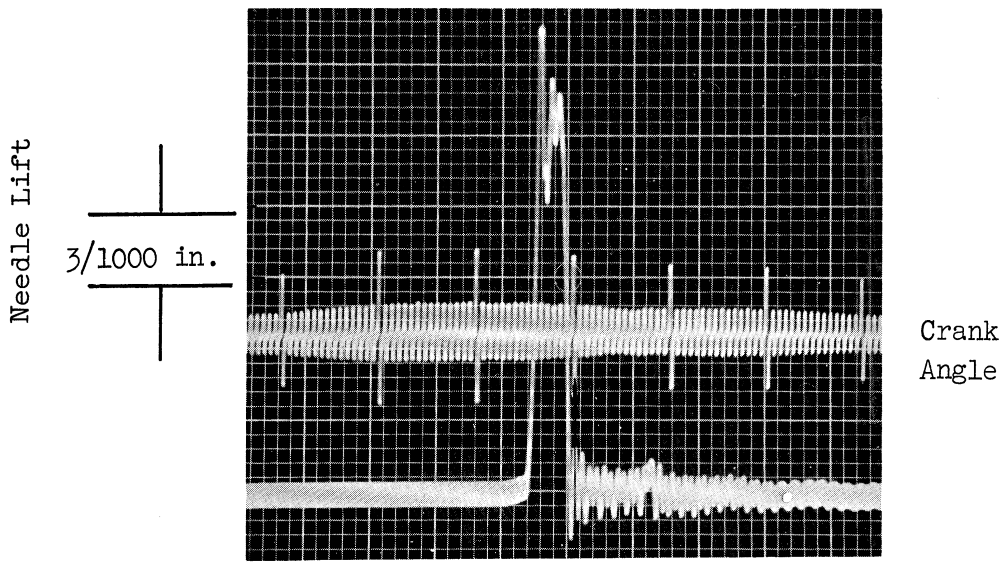


Fig. 6. Needle lift diagram.

Sample of Recorded Data
ATAC - Open Chamber
Run No. 13

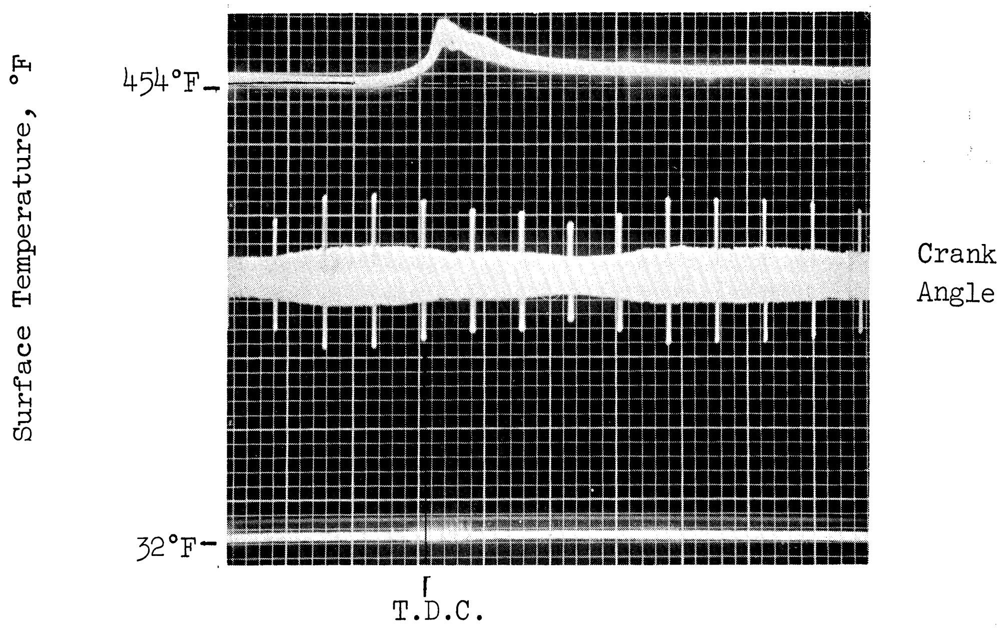


Fig. 7. Combustion chamber suriace temperature.

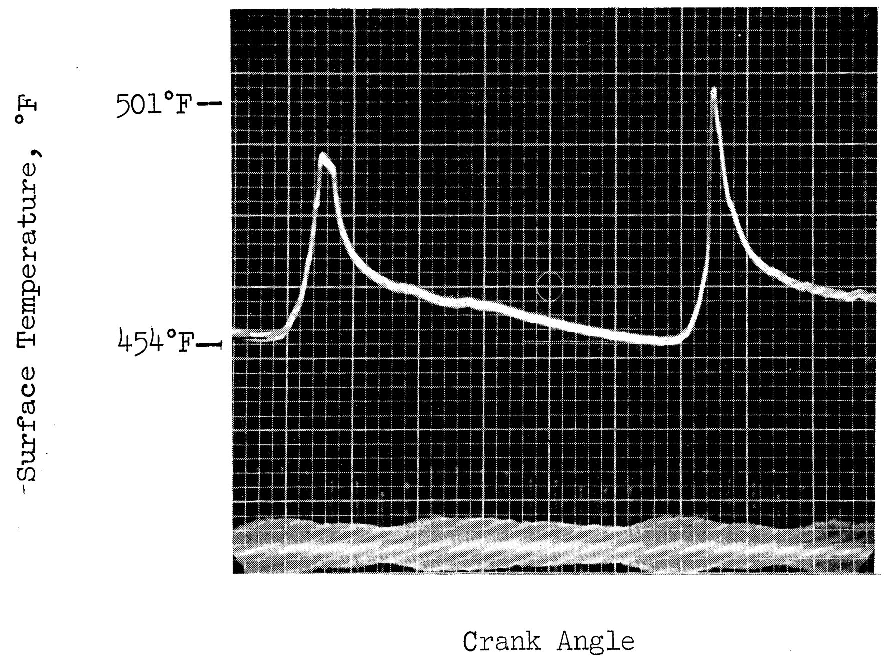


Fig. 8. Swing in wall-surface temperature.

XI. EXPERIMENTAL WORK AND RESULTS

A. SERIES A2A

Effect of Temperature on I.D.$_p$ of CITE Fuel, at Constant Inlet Surge Tank Pressure

Conditions:

Fuel = CITE refree grade (Mil-F-45121) fuel
Intake air pressure in surge tank = 15 in. Hg g
Exhaust pressure in surge tank = 15 in. Hg g
Cooling water temperature at outlet = 169°F
rpm = 2000
Fuel-air ratio = 0.0316
Injector opening pressure = 3000 psi
Injection timing (needle lift) = 21.3° BTDC

Variable:

Inlet air temperature from 97°F to 513°F.

The results of this series indicate that the pressure at the start of injection, as well as the average pressure during the ignition delay, vary with change in inlet air temperature.

An increase in the inlet air temperature from 97°F to 513°F caused a drop of 97 psi in the gas pressure at the start of injection, and a drop of 191 psi in the average pressure during the delay period. The pressure at the start of injection at different inlet temperatures is shown in Fig. 9. The corresponding average pressures are shown in Fig. 10.

The drop in pressure at higher temperatures is mainly due to the increased heat losses from the gases to the cylinder walls.

The results of this series concerning I.D. are given in Table 8 and plotted in Fig. 11, curve A. It shows that in the range of temperatures between 100°F to 501°F the ignition delay decreases continuously with increase in temperature.

It should be noted that the net change in I.D. is due to two opposing factors:

1. An increase in gas temperature which causes a decrease in ignition delay.

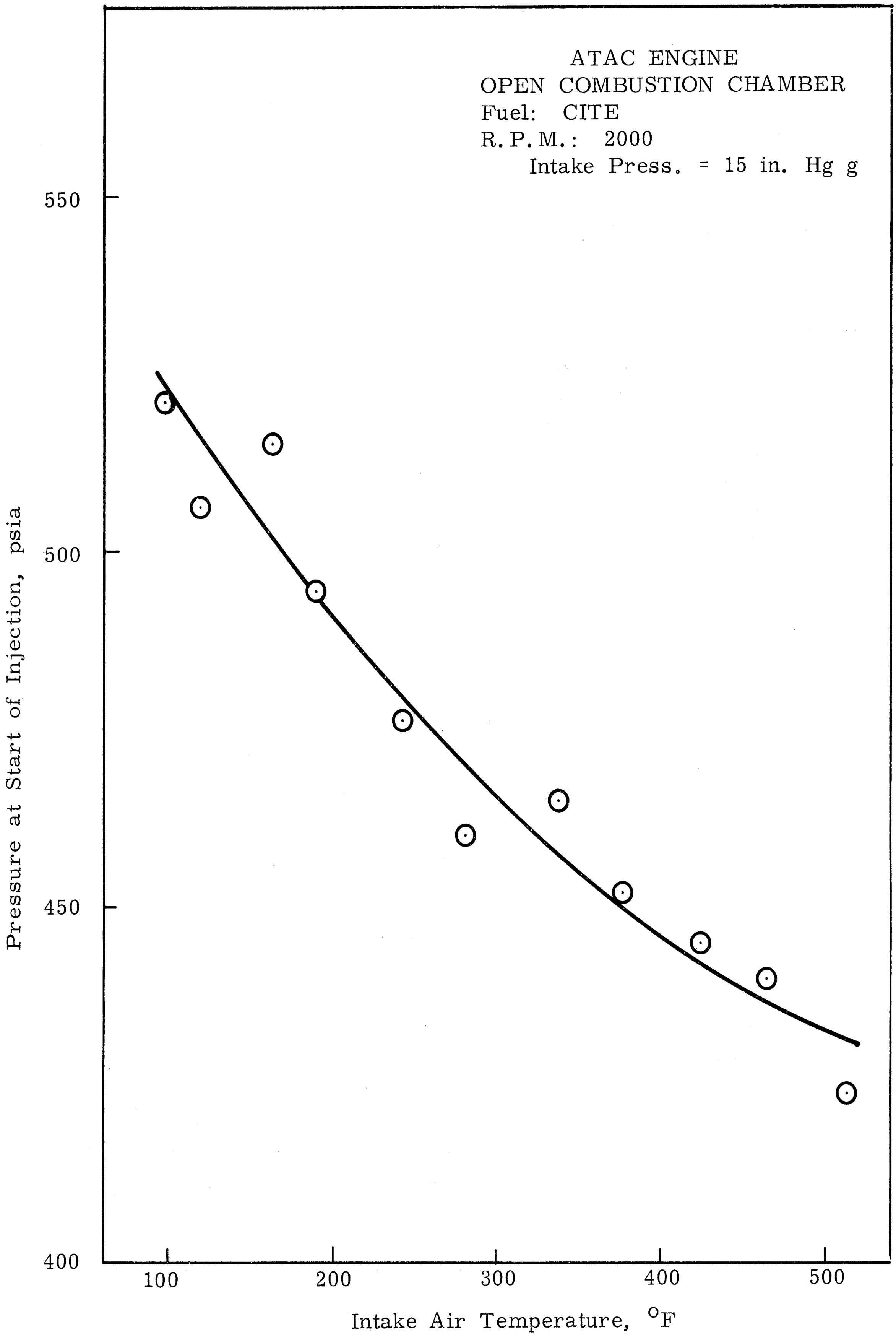


Fig. 9. Effect of intake air temperature on pressure at the start of injection (surge tank pressure = 15 in. Hg g).

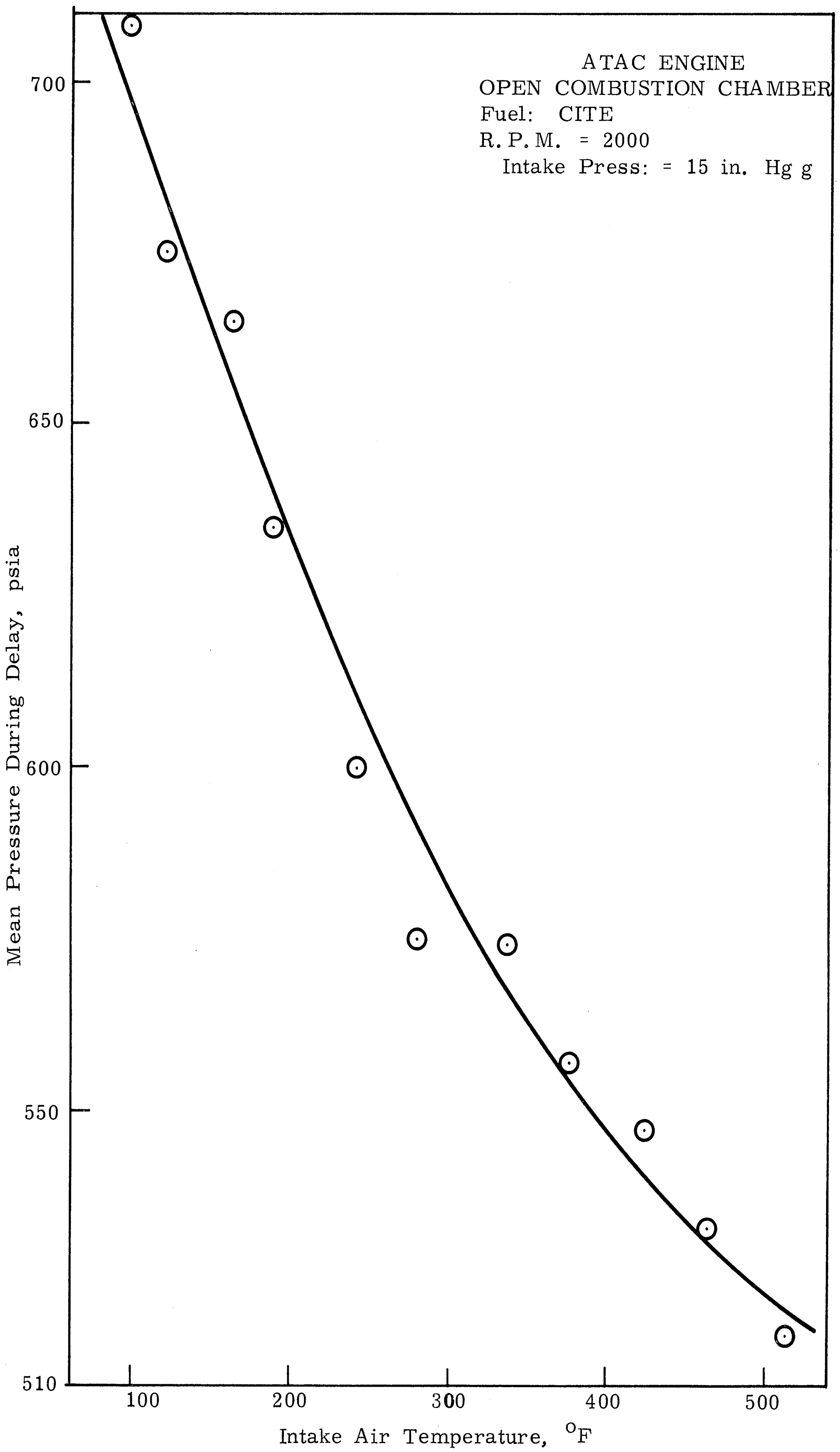


Fig. 10. Effect of intake air temperature on mean pressure during ignition delay (surge tank pressure = 15 in. Hg g).

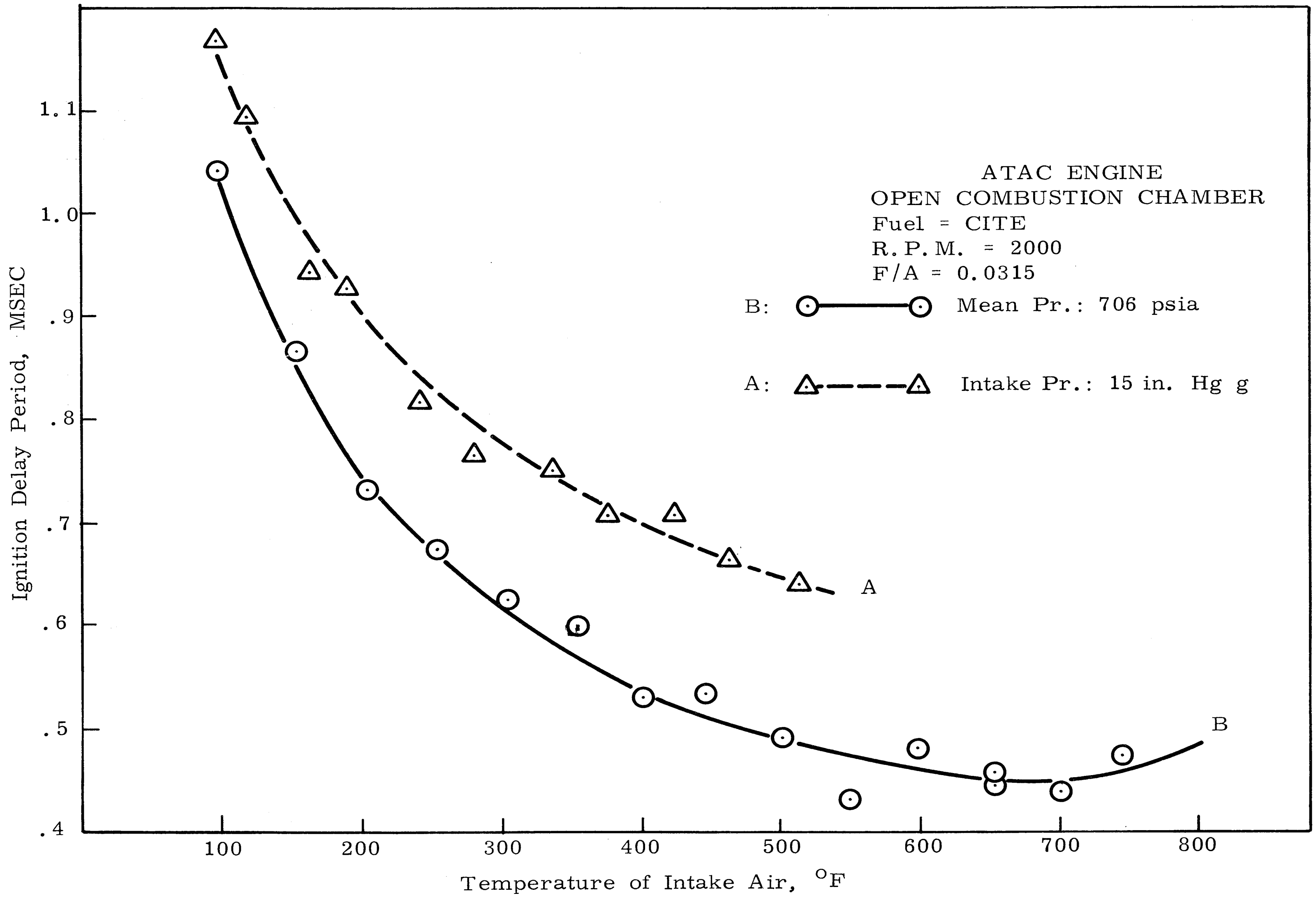


Fig. 11. Effect of temperature on I.D.$_p$ of CITE fuel.

2. A drop in gas pressure causing an increase in ignition delay.

In order to eliminate the effect of pressure on I.D., the surge tank pressure was changed in each run, such that the mean pressure during the delay period remains constant. The results of these tests are plotted in Fig. 11, curve B, and are discussed under series A2B.

Wall Surface Temperature

The temperature of the inside surface of the combustion chamber is measured by a special thermocouple placed between the inlet and exhaust valve and on the line between their two centers. A record of the surface temperatures is shown in Figs. 7 and 8, together with the crank angles.

In Fig. 7 the surface temperature is shown together with the reference temperature, which is 32°F. The minimum temperature in this photograph is 454°F. The temperature swing due to combustion as indicated in the photograph of Fig. 8, reached 47°F.

The change of the minimum surface temperature for this series is plotted in Fig. 12. It shows that the minimum temperature has changed from 354°F, at 97°F inlet air temperature, to 483°F at 513°F inlet air temperature.

B. SERIES A2B

Effect of Temperature on $I.D._p$ of CITE Fuel, at a Constant Mean Pressure During the Ignition Delay

To maintain the average pressure during the ignition delay constant, the surge tank pressure was increased with temperature. The average pressure during the delay period was kept at a constant mean value of 706 psia for all the runs of this series.

Conditions:

Fuel = CITE refree grade (Mil-F-45121) fuel
Mean pressure during delay period = 706 psia
rpm = 2000
Fuel-air ratio = 0.0315
Injector opening pressure = 3000 psi
Injection timing (needle lift) = 20.9 BTDC
Cooling water temperature at outlet = 171°F

Variables:

Inlet air temperature from 97°F to 745°F
Inlet air pressure from 15 in. Hg to 41.9 in. Hg g

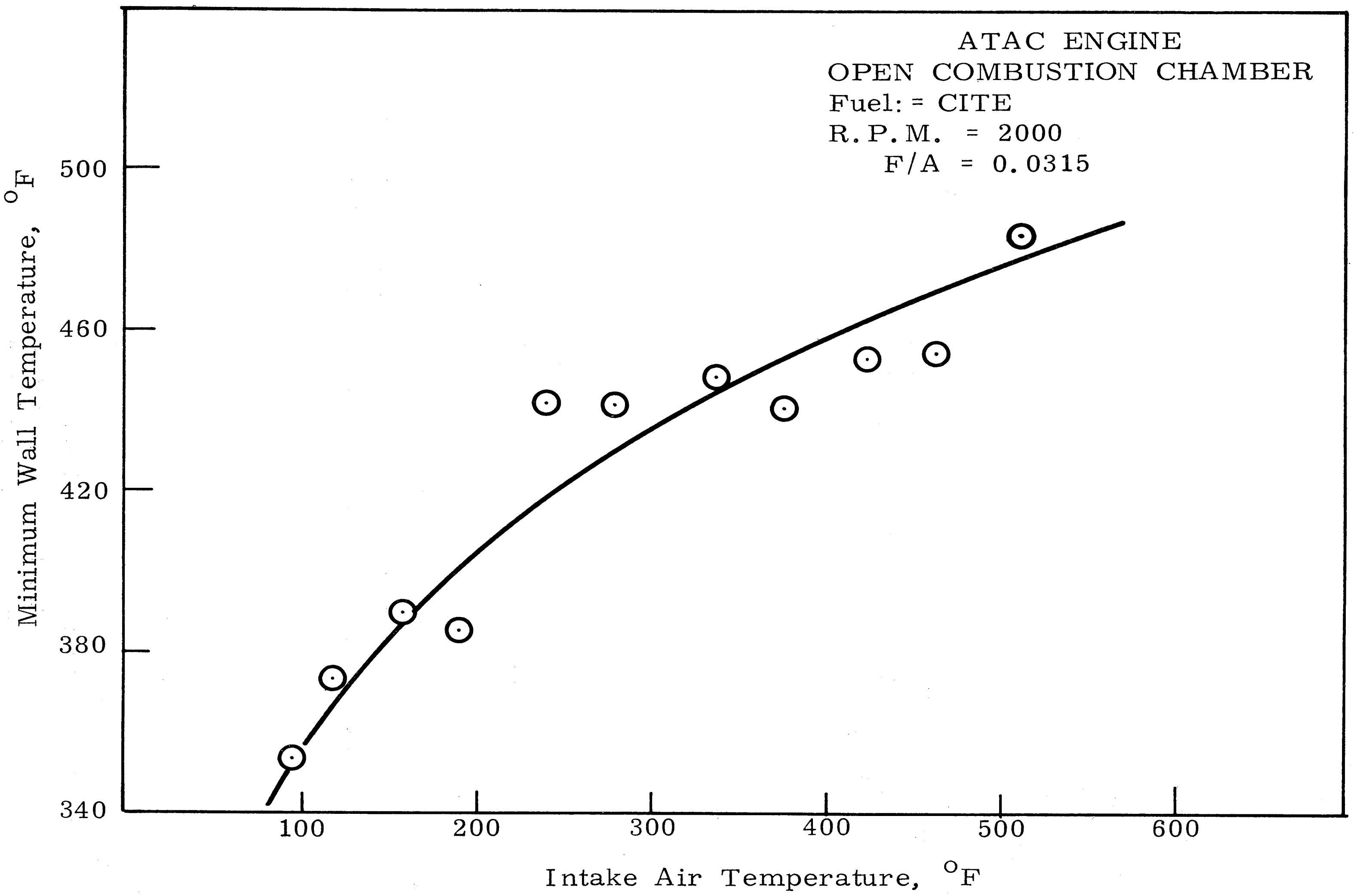


Fig. 12. Effect of intake air temperature on minimum combustion chamber wall surface temperature.

In order to keep the mean pressure at a constant value of 706 psia, the pressure in the inlet surge tank was 15 in. Hg boost at 97°F and reached 41.9 in. Hg boost at 745°F. The values of the air surge tank pressure are plotted as a function of the inlet air temperature in Fig. 13.

The results of this series of runs are plotted in Figs. 11, curve B, and Fig. 14. Figure 11, curve B, shows the results at constant average pressure together with the results at constant surge tank pressure (curve A).

The increase in ignition delays shown by curve A, above the values of curve B, are due to the lower pressures occurring during the delay period.

The results for the $I.D._p$ for CITE fuel are plotted in Fig. 14. The ignition delay decreases with increase in temperature up to about 2150°R after which it appears to increase.

Effect of Intake Air Temperature on the Volumetric Efficiency

In this report the volumetric efficiency is defined as:

$$\text{Volumetric efficiency} = \frac{\text{Actual mass flow rate}}{\text{Theoretical mass flow rate based on intake manifold conditions}}$$

The change in the volumetric efficiency at the different air temperatures, for test series A2A and A2B is shown in Fig. 15. It shows a slight drop in efficiency between 556°R and 600°R and a continuous increase with any further increase in temperature. This change is caused by the heat transfer phenomena between the air and the manifold and cylinder walls.

The change in the flow rate of air at the different temperaturs is given in Fig. 16. It shows that for series A2A the air mass is reduced by 37.4% with the increase in inlet air temperature from 97°F to 513°F. This reduction is not so great in series A2B because the inlet surge tank pressure was changed to give a constant average pressure of 706 psia during the delay period.

C. SERIES A2C

Effect of Temperature on $I.D._p$ of Diesel Fuel, at a Constant Mean Pressure During the Ignition Delay

Conditions and Variables:

These are the same as in series A2B except that the fuel used is diesel no. 2.

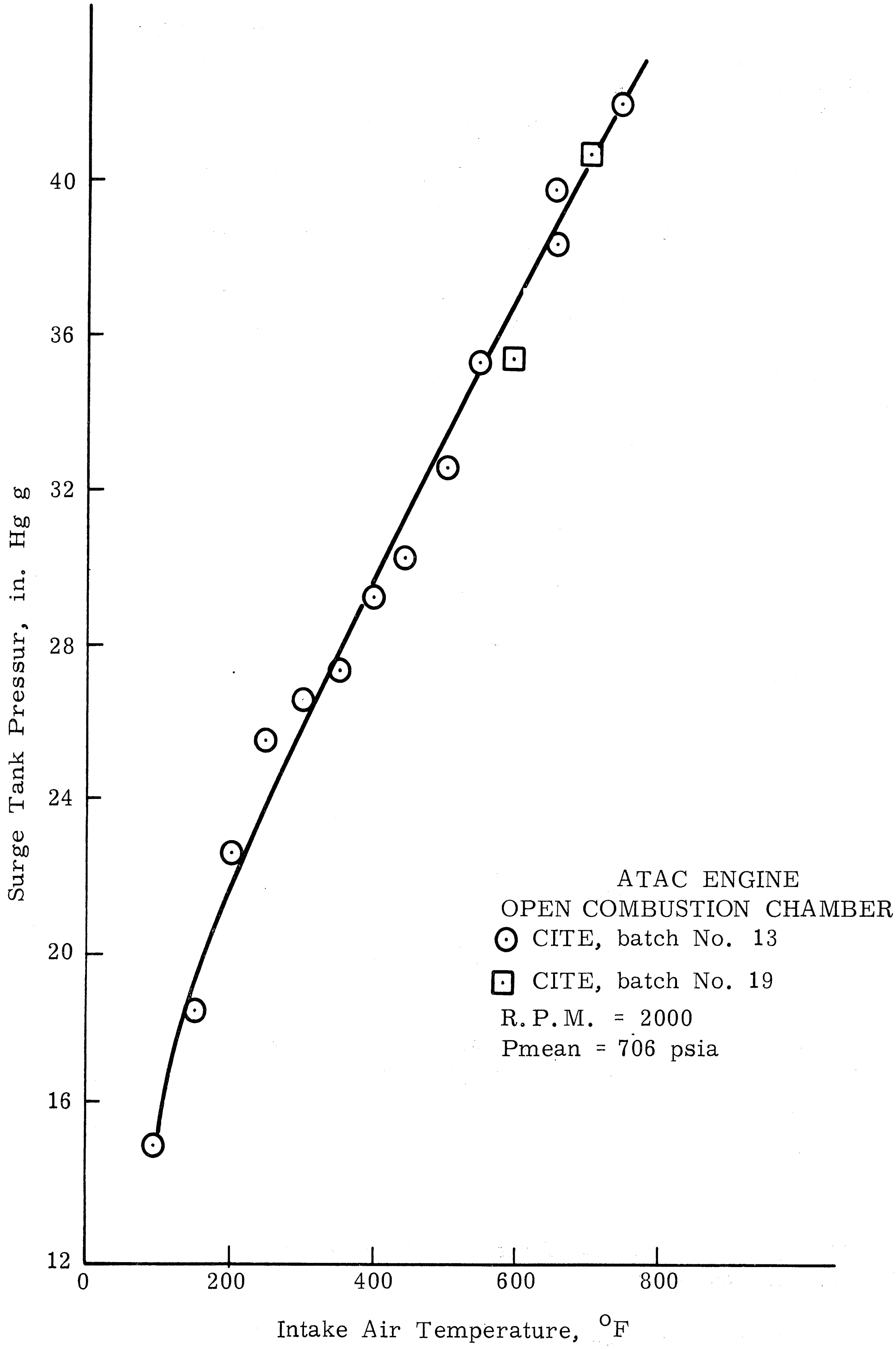


Fig. 13. Surge tank pressure at various intake temperatures, for a constant mean pressure of 706 psia during $I.D._p$.

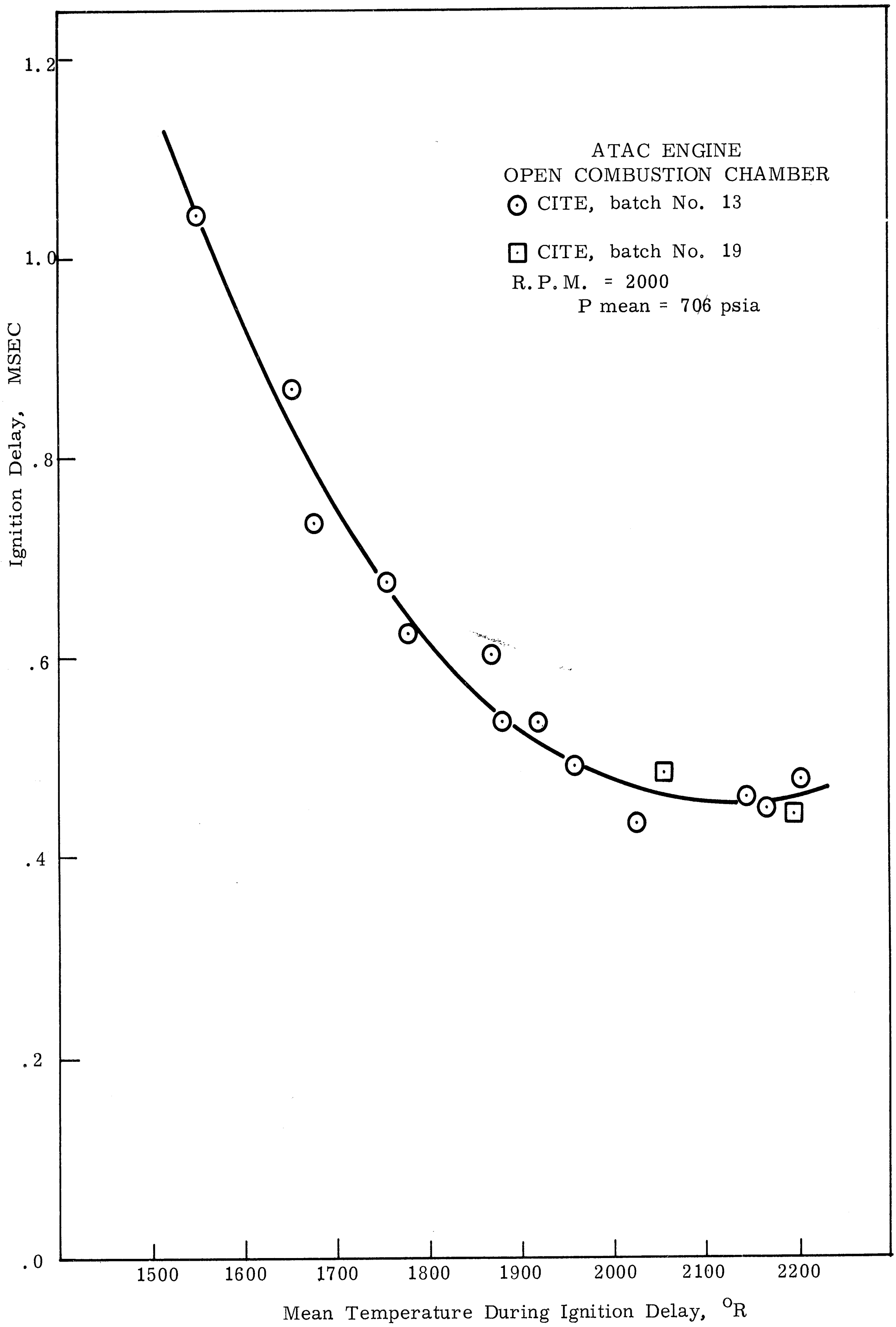


Fig. 14. Ignition delay, $I.D._p$ as a function of mean temperature during ignition delay for CITE fuel.

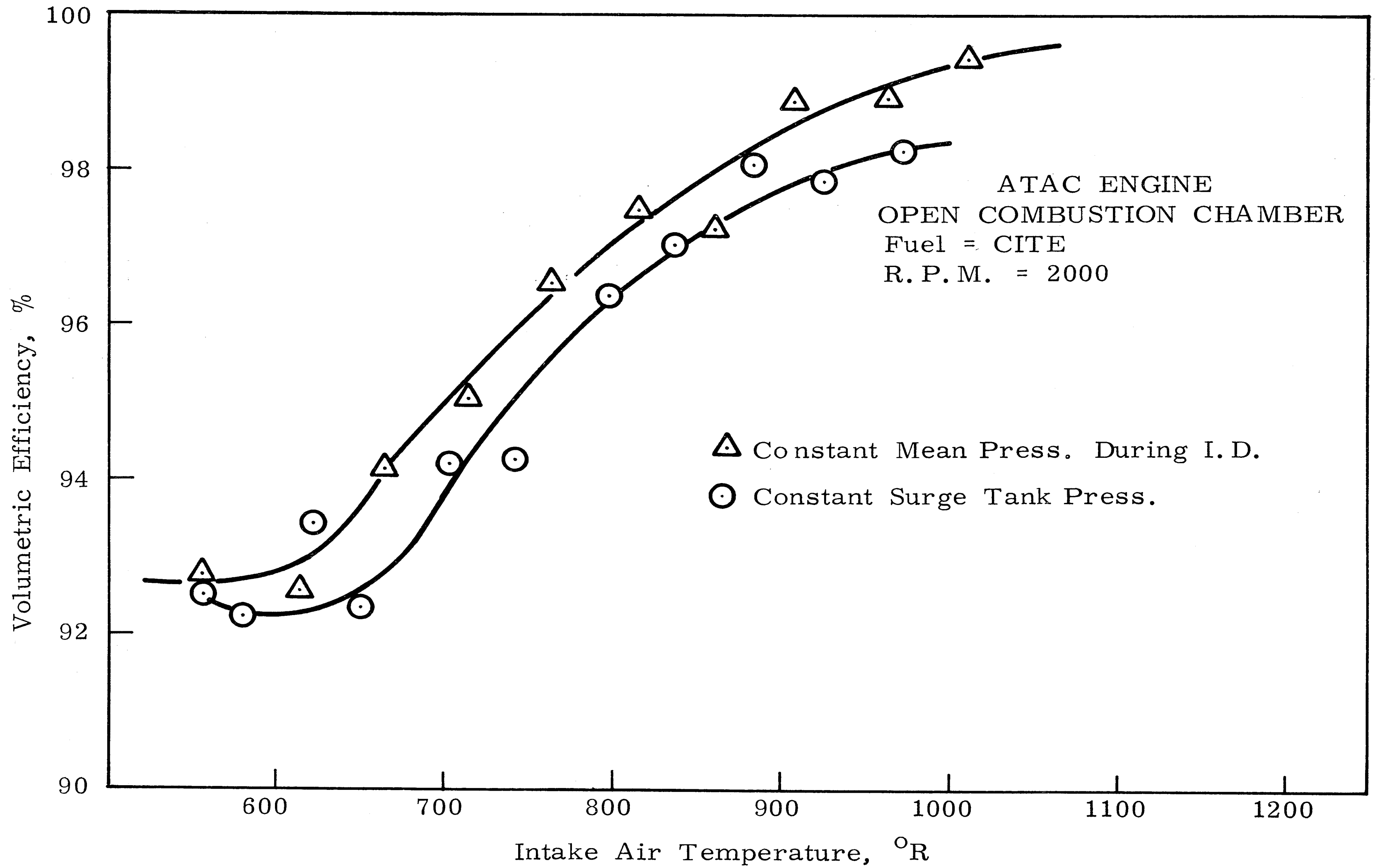


Fig. 15. Effect of intake air temperature on the volumetric efficiency.

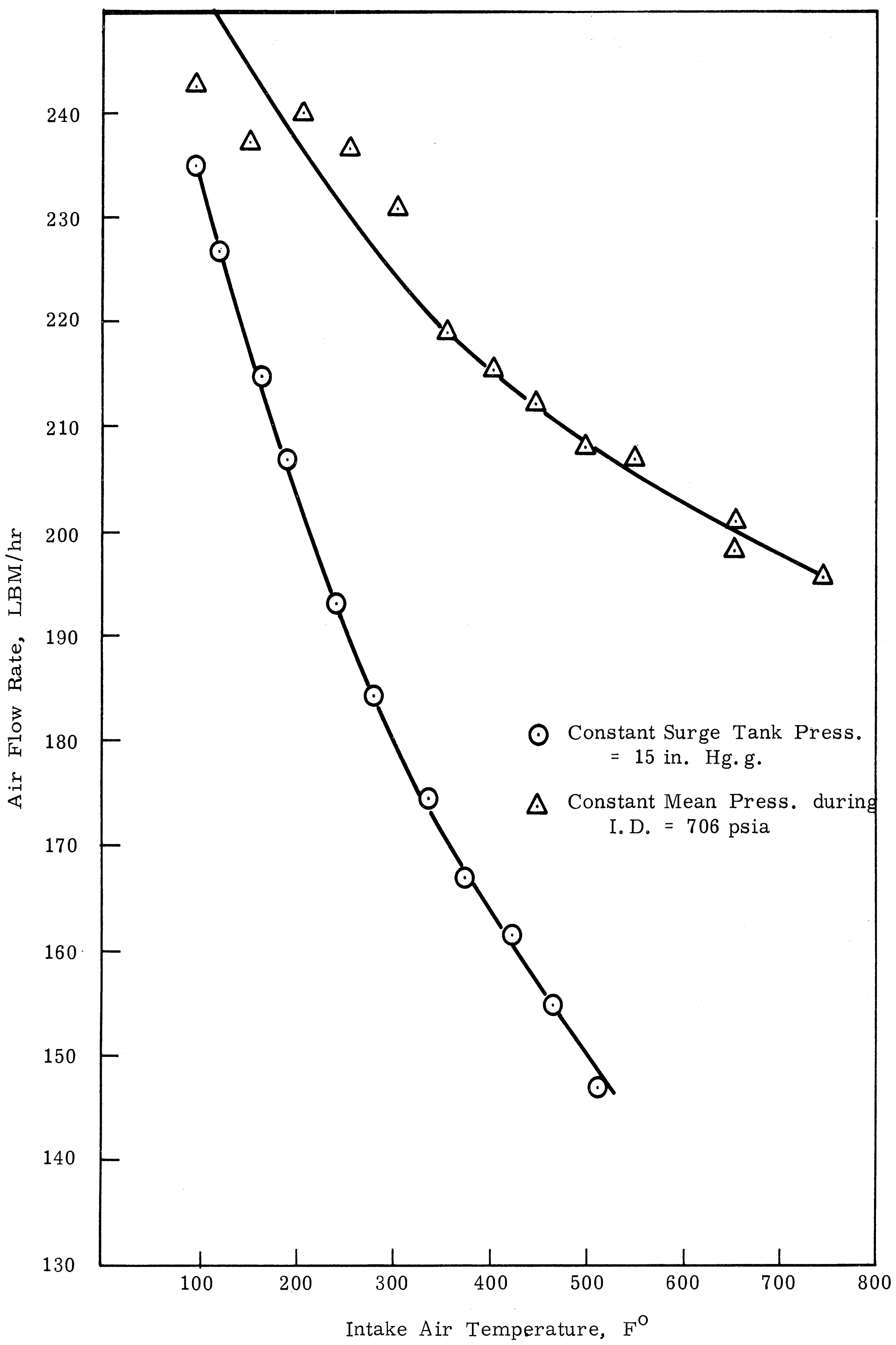


Fig. 16. Mass-flow rate at various intake air temperatures.

The results of this series of tests are shown in Fig. 17. It shows a drop of 40.3% in I.D. by an increase in the mean air temperature during I.D. from 1565°R to 2292°R.

D. SERIES A2D

Effect of Temperature on $I.D._p$ of Gasoline Fuel at a Constant Mean Pressure During the Ignition Delay

Conditions and Variables:

These are the same as in series A2B except that the fuel used is Mil-G-3056 refree grade gasoline fuel.

The results of this series of tests is shown in Fig. 18. It shows a drop of 76.2% in I.D. by an increase in the mean air temperature during I.D. from 1665°R to 2500°R.

Summary of Observations made on Gasoline Combustion

Many attempts have been made during this reporting period to examine the factors that affect the combustion of gasoline in the ATAC engine. First, in Series A1 of these tests, the engine has been run on gasoline with simulated naturally aspirated conditions. No combustion was observed. In order to obtain burning the speed was reduced to about 900 rpm, and irregular combustion was observed.

It has been interesting to note that, with atmospheric inlet air temperature, an increase of 15 in. Hg in the air pressure in the surge tank made the combustion much more regular, although the I.D. was very long.

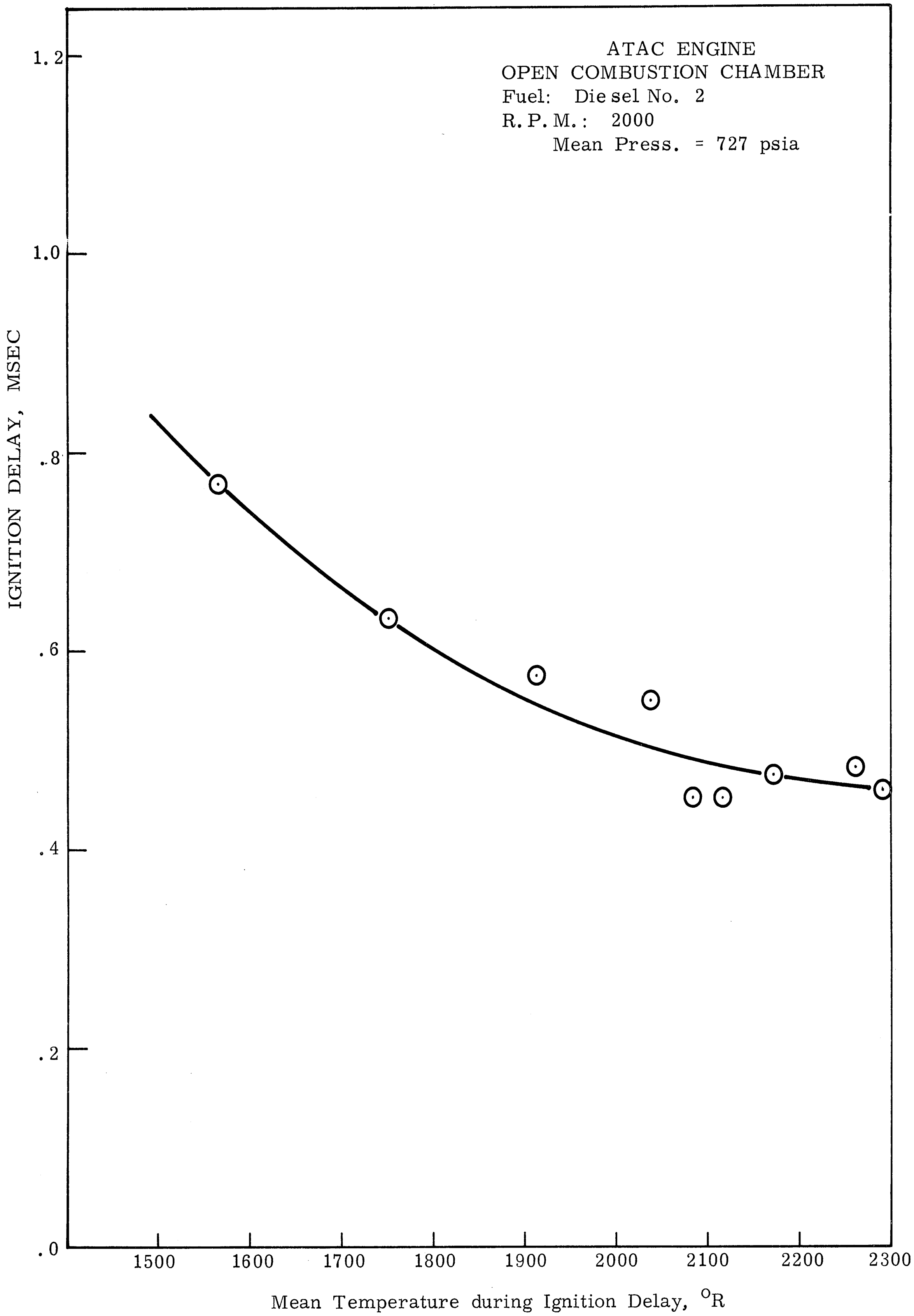


Fig. 17. Ignition delay $I.D._p$ as a function of mean temperature during ignition delay for diesel no. 2 fuel.

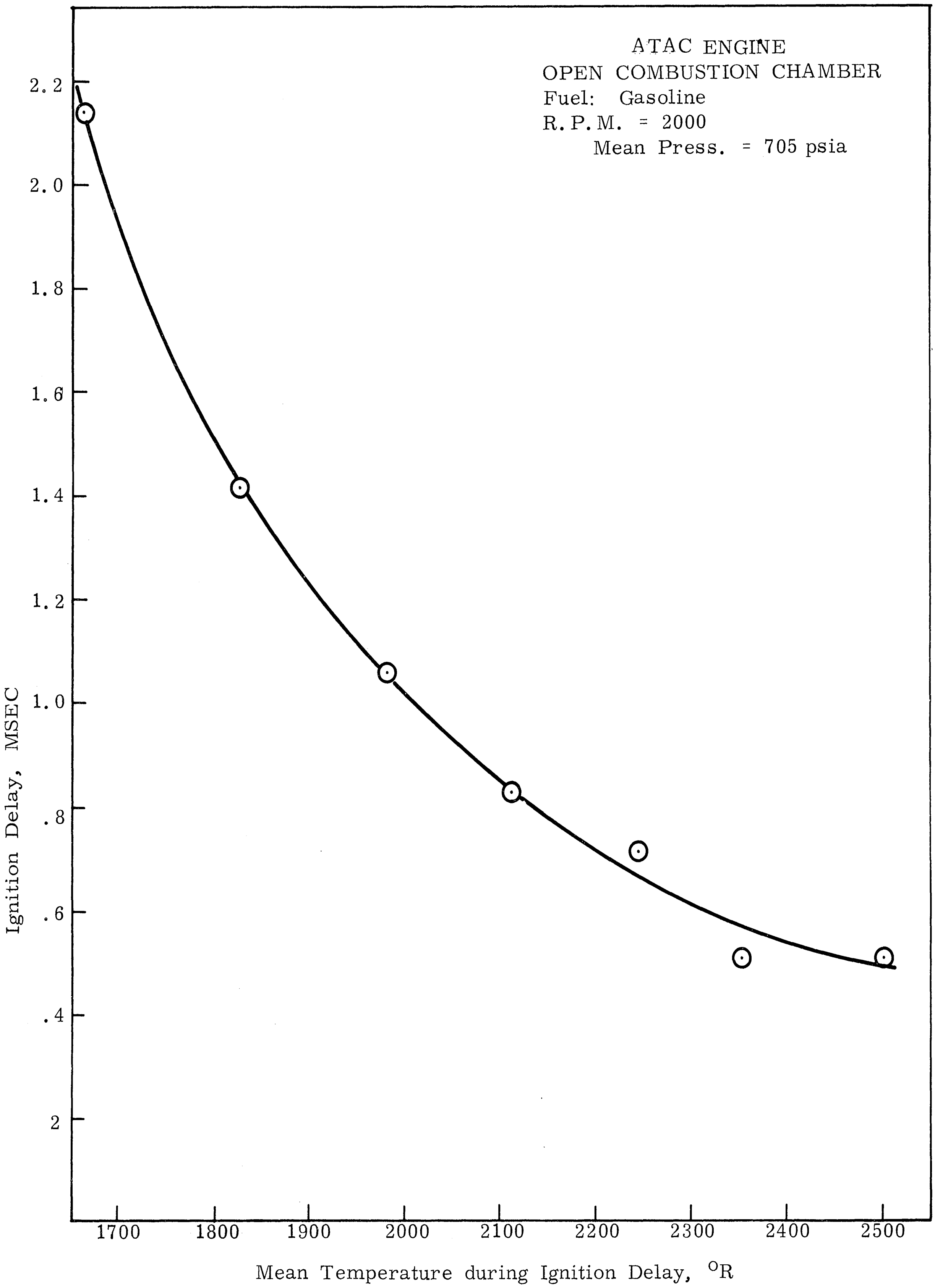


Fig. 18. Ignition delay, $I.D._p$, as a function of mean temperature during ignition delay for gasoline fuel.

XII. COMPARISON BETWEEN THE THREE FUELS

A comparison will be made between the CITE, diesel, and gasoline fuels, regarding their combustion characteristics. This comparison covers the following:

A. Delay period and activation energy

B. Noise level

1. Maximum pressure
2. Maximum pressure gradient
3. The rate of change of pressure gradient

C. Smoke intensity in exhaust

D. Specific fuel consumption.

A. DELAY PERIOD AND ACTIVATION ENERGY

To compare between three fuels, all the results of I.D. are plotted on the same diagram in Fig. 19. It shows that diesel no. 2 has the lowest ignition delay, while gasoline has the highest values.

At a temperature of 106°F the gasoline has an ignition delay of 2.142 msec, while the values for CITE and diesel are 1.0 msec and 0.752 msec, respectively. However, at an air inlet temperature of 700°F the three fuels have almost equal ignition delays of 0.45 msec.

The difference between the CITE fuel and diesel no. 2 fuel is probably not significant for inlet air temperatures above 200°F.

The values for I.D. are plotted in Figs. 20, 21, and 22 for the different fuels on a log scale versus the reciprocal of the absolute temperature. The slope of these lines gives the value of (E/R), where E is the activation energy and R is the universal gas constant. The value of the activation energy for the different fuels, as calculated from the corresponding graphs is given in Table 2.

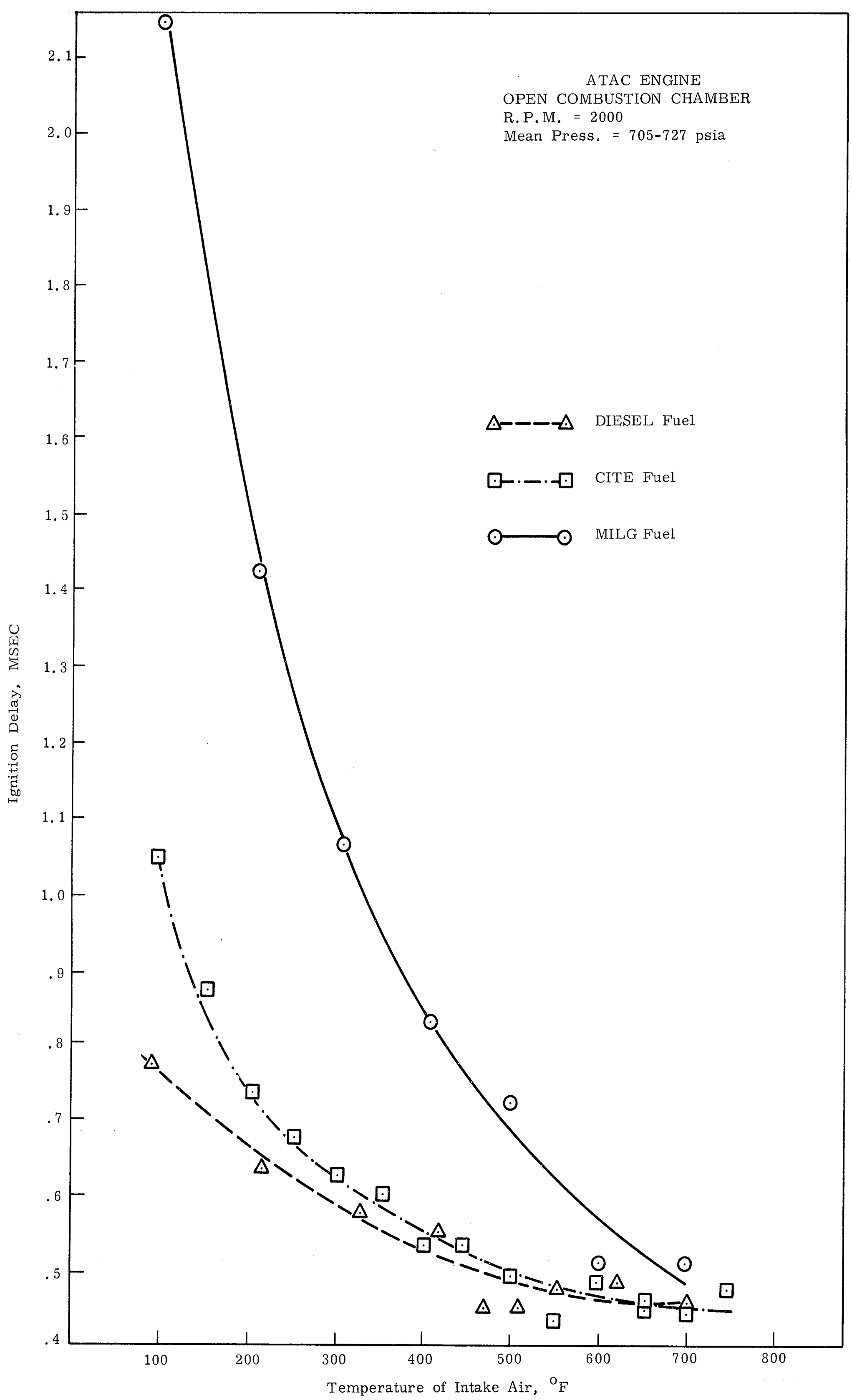


Fig. 19. Comparison between the ignition delay, $I.D._p$, of different fuels.

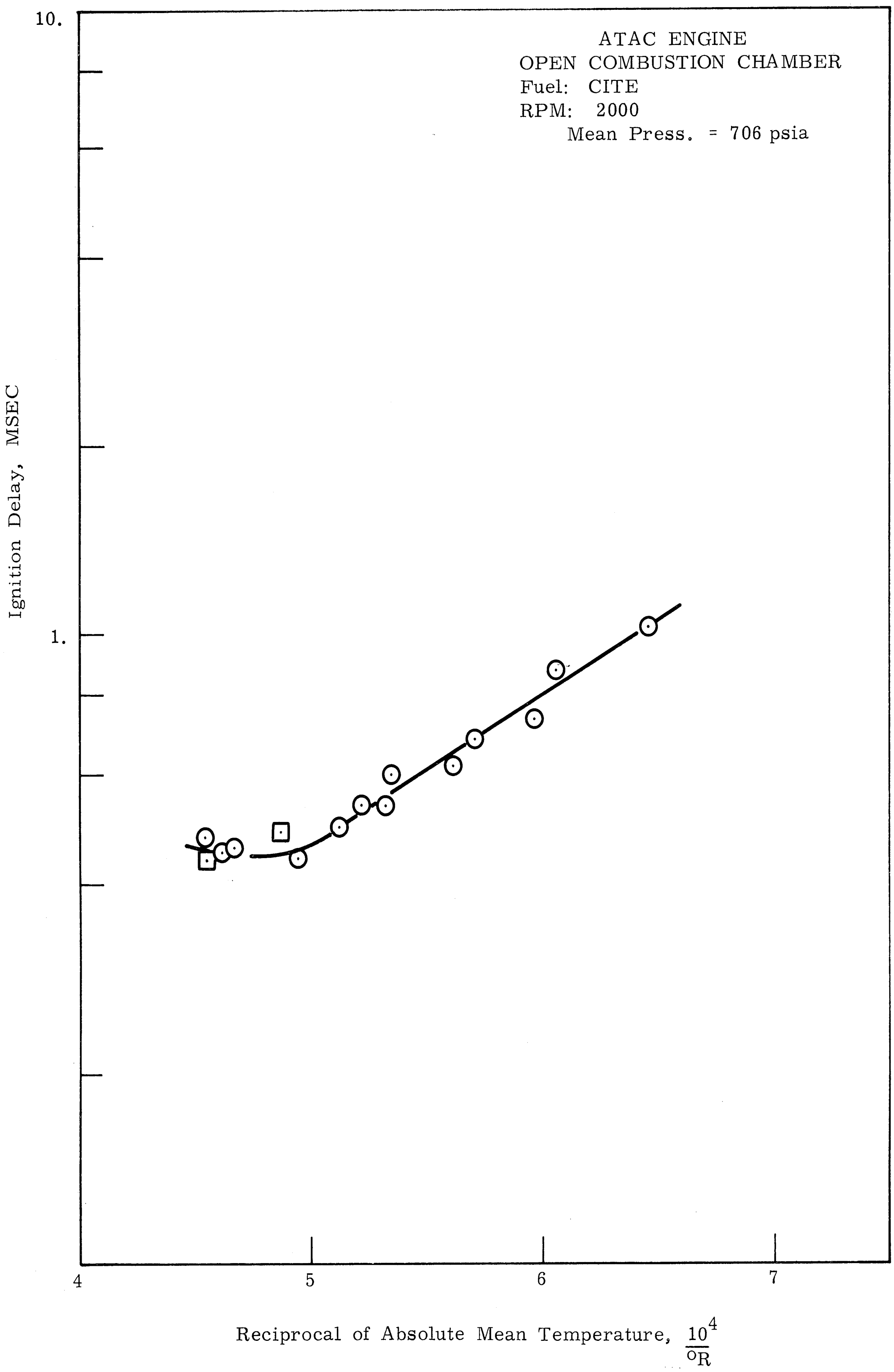


Fig. 20. Logarithm of ignition delay, I.D.$_p$, as a function of the reciprocal of the absolute mean temperature, for CITE fuel.

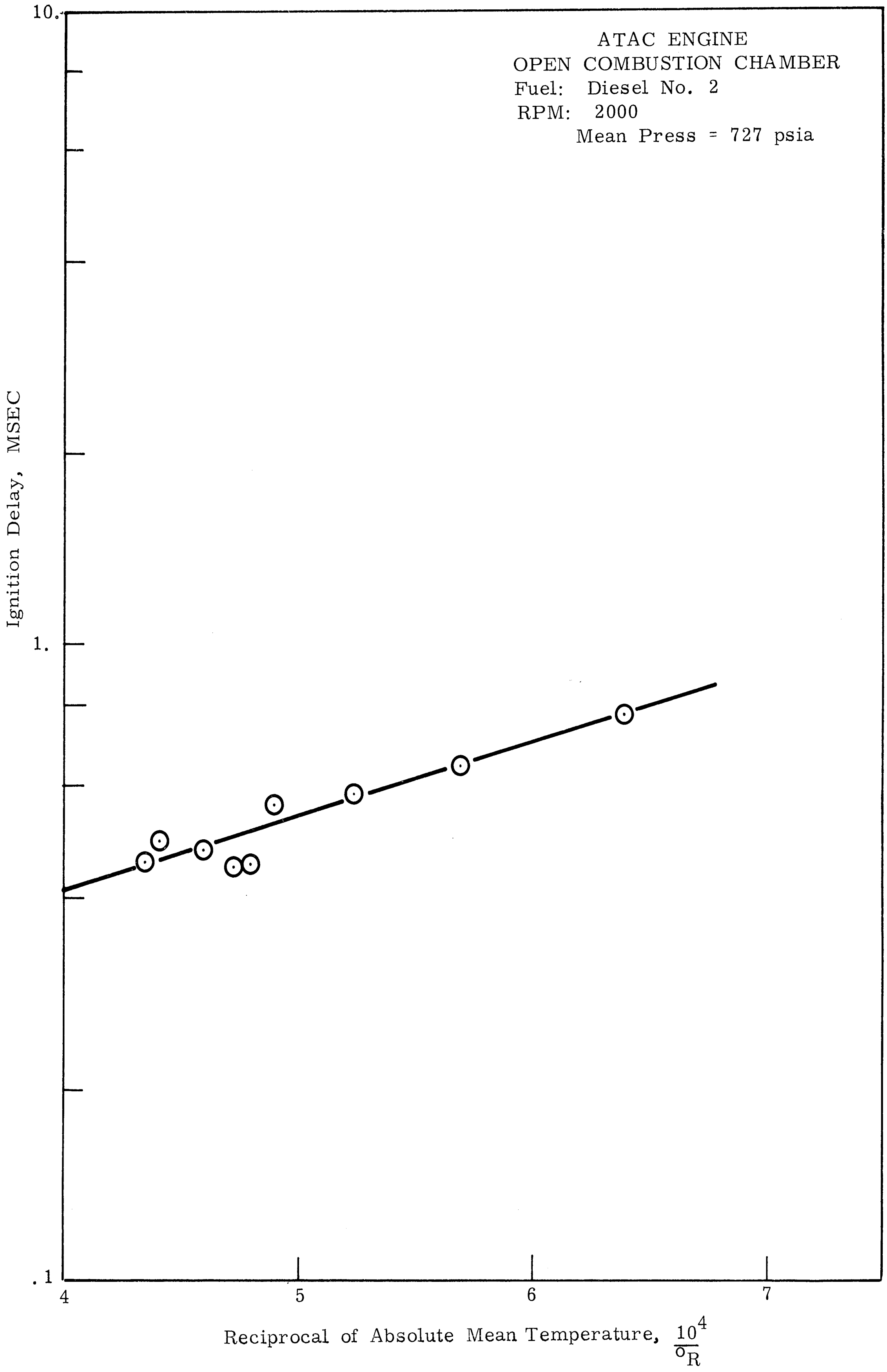


Fig. 21. Logarithm of ignition delay, I.D.$_p$, as a function of the reciprocal of the absolute mean temperature for diesel no. 2 fuel.

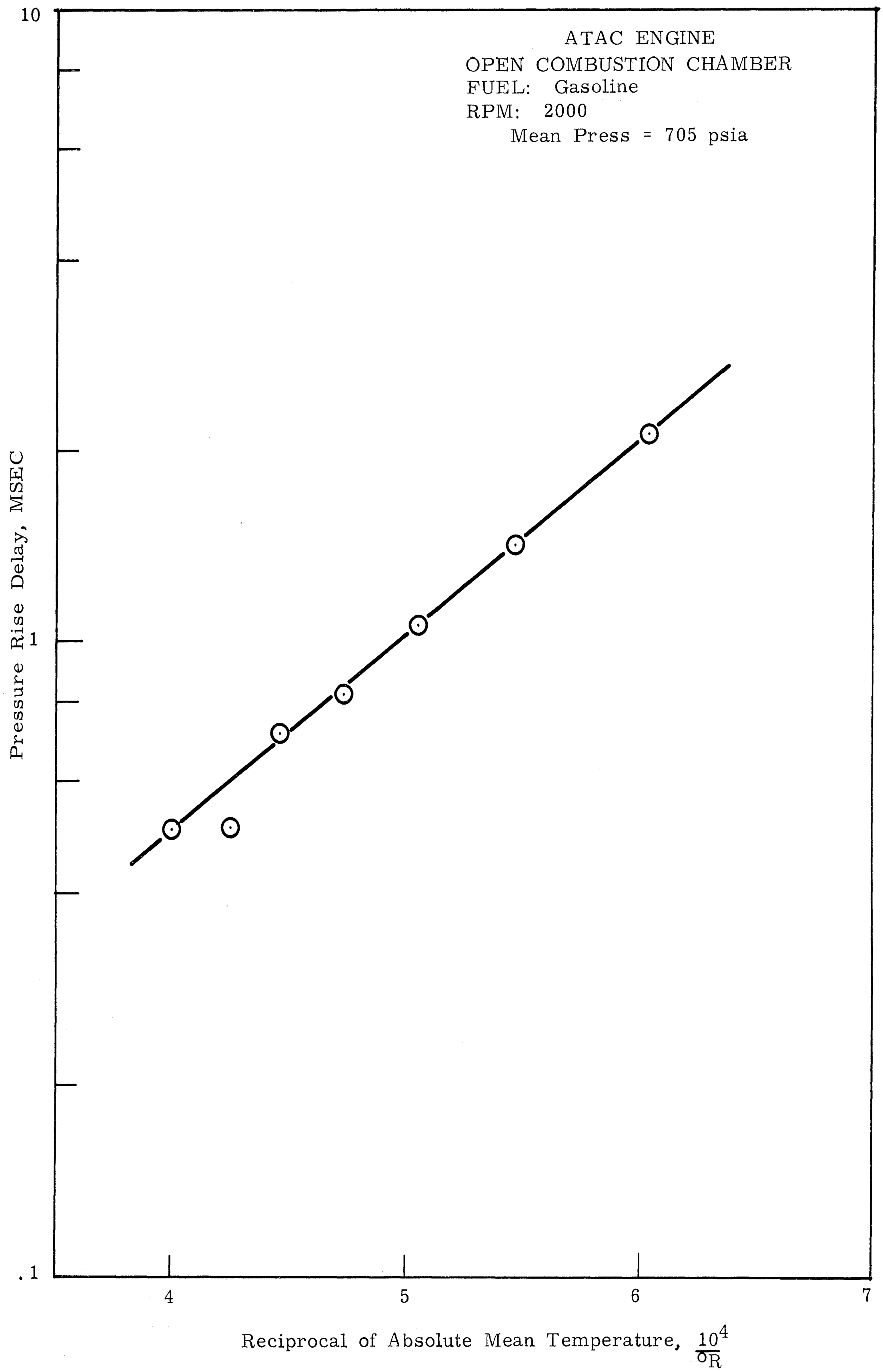


Fig. 22. Logarithm of ignition delay, I.D.$_p$, as a function of the reciprocal of the absolute mean temperature, for gasoline fuel.

TABLE 2

ACTIVATION ENERGY FOR DIFFERENT FUELS

Fuel	Activation Energy, Btu/lb mole
CITE	10,430
Diesel no. 2	5,230
Gasoline	14,780

B. NOISE LEVEL

1. Maximum Pressure

The maximum pressure reached in the cylinder near the end of the combustion process is one of the factors that affects the noise level in the diesel engine. The maximum pressures reached with the different fuels are plotted in Fig. 23 against the intake air temperature. Over the whole temperature range, the order of magnitude of the maximum pressures reached with CITE and diesel fuels is almost the same. The maximum pressure with gasoline in much higher than the other two fuels at intake temperatures below about 250°F. It is to be noticed that the maximum pressure with gasoline at 100°F is low because of the very late combustion.

2. Maximum Pressure Gradient

The maximum rate of pressure rise is among the factors that affects the noise level of the engine. The values obtained for the maximum $(dP/d\theta)$ are plotted in Fig. 24. It shows that gasoline has the highest values, which can be attributed to its long ignition delay and the large amounts of fuels accumulated in the combustion chamber at the end of the delay period. This is shown in Fig. 25 in which $(dP/d\theta)_{max}$ is plotted versus the length of ignition delay in crank angles.

3. The Rate of Change of Pressure Gradient

The rate of change of the pressure gradient with crank angles from the end of the delay period to the point of maximum $(dP/d\theta)$ is among the factors that affect the noise level and engine vibrations. Values of $(d^2P/d\theta^2)$ for the three fuels is plotted versus the intake air temperature in Fig. 26, and versus the mean temperature during the delay period in Fig. 27. The highest values of $(d^2P/d\theta^2)$ is for gasoline. The effect of the length of the I.D. on $(d^2P/d\theta^2)$ is shown in Fig. 28. From this figure it seems that the absolute length of I.D. is the main factor controlling $(d^2P/d\theta^2)$, for gasoline and CITE fuels.

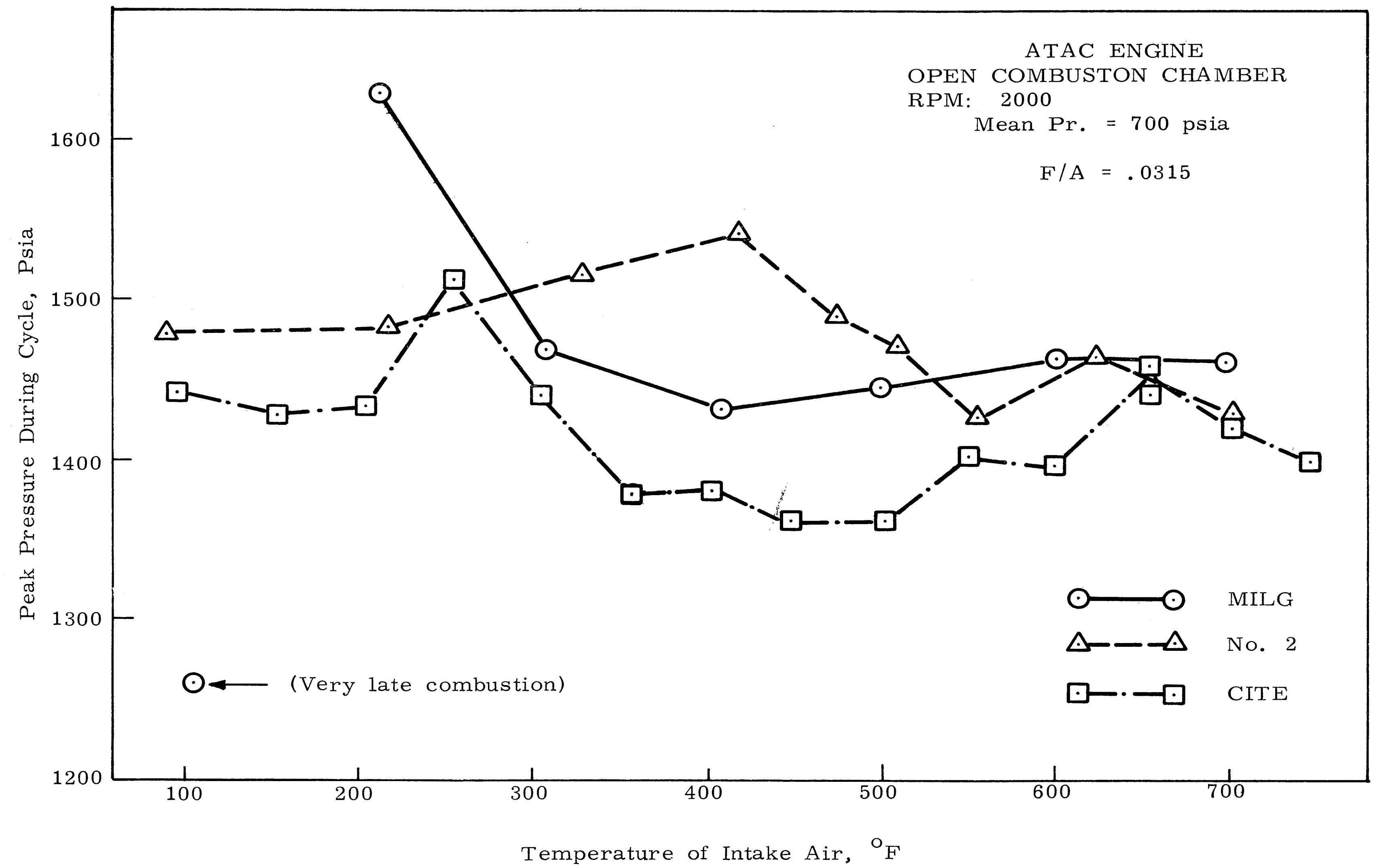


Fig. 23. Maximum cylinder pressure for different fue'

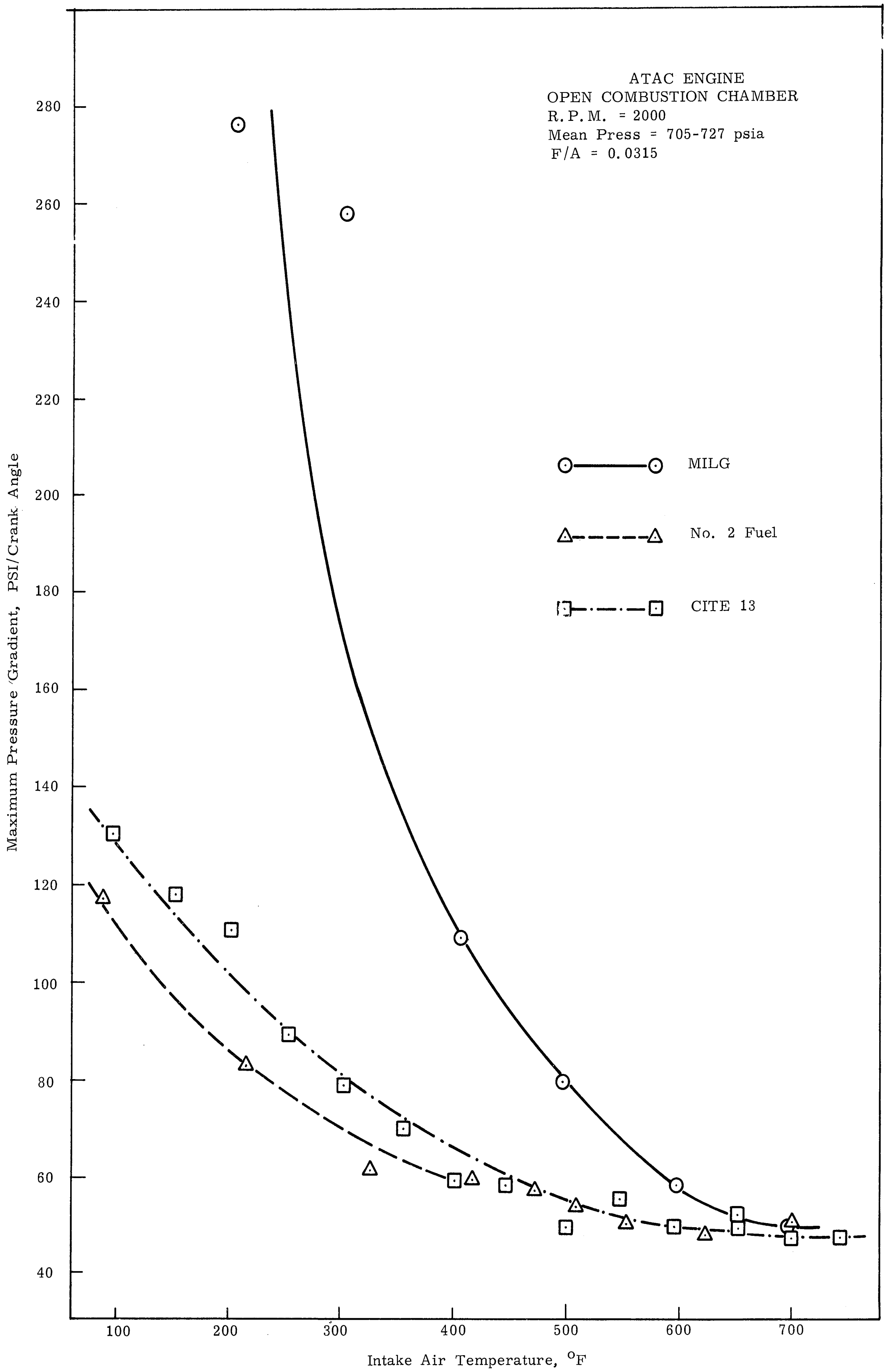


Fig. 24. Maximum pressure gradient for different fuels.

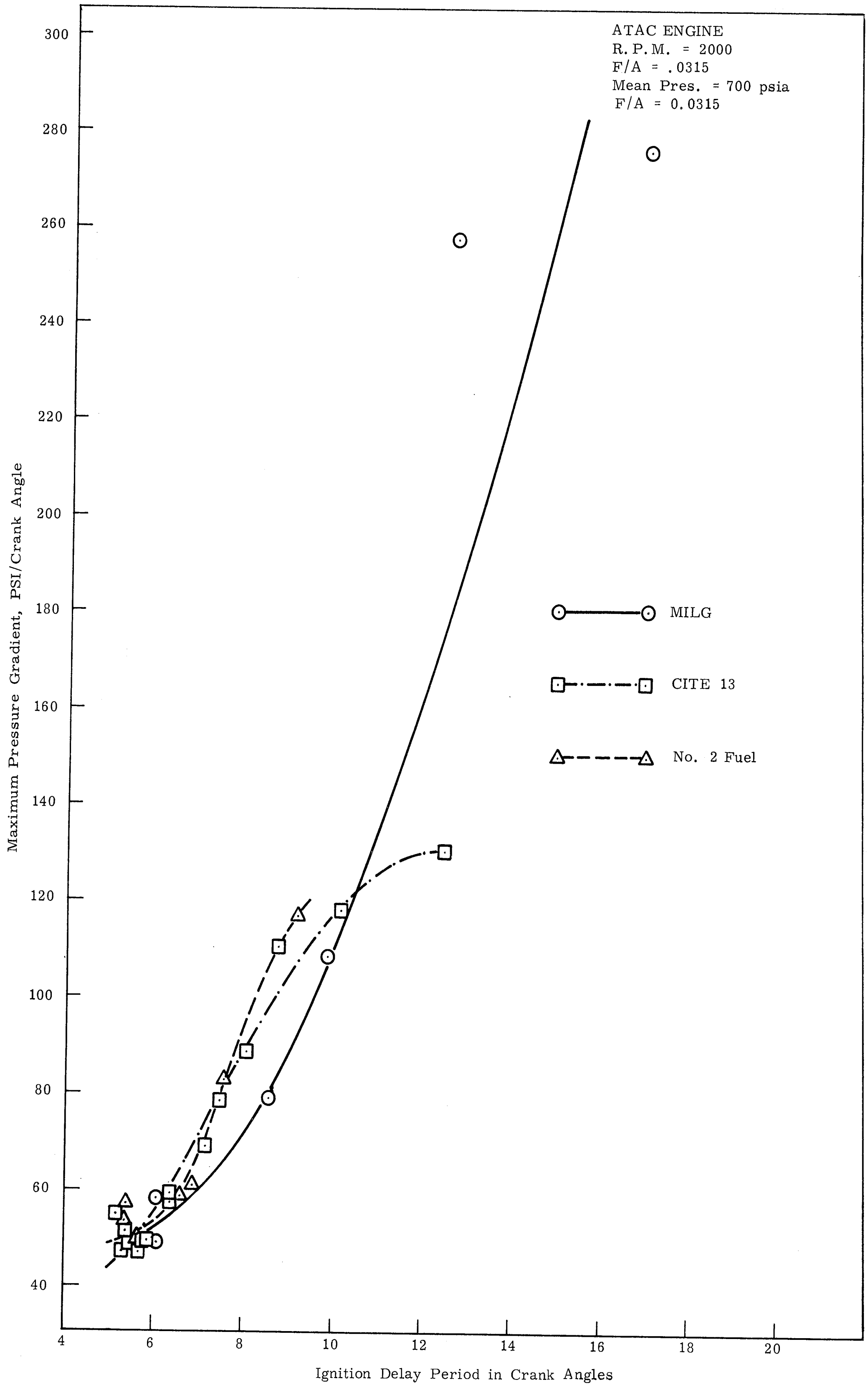


Fig. 25. Maximum pressure gradient for different fuels as a function of the length of ignition delay.

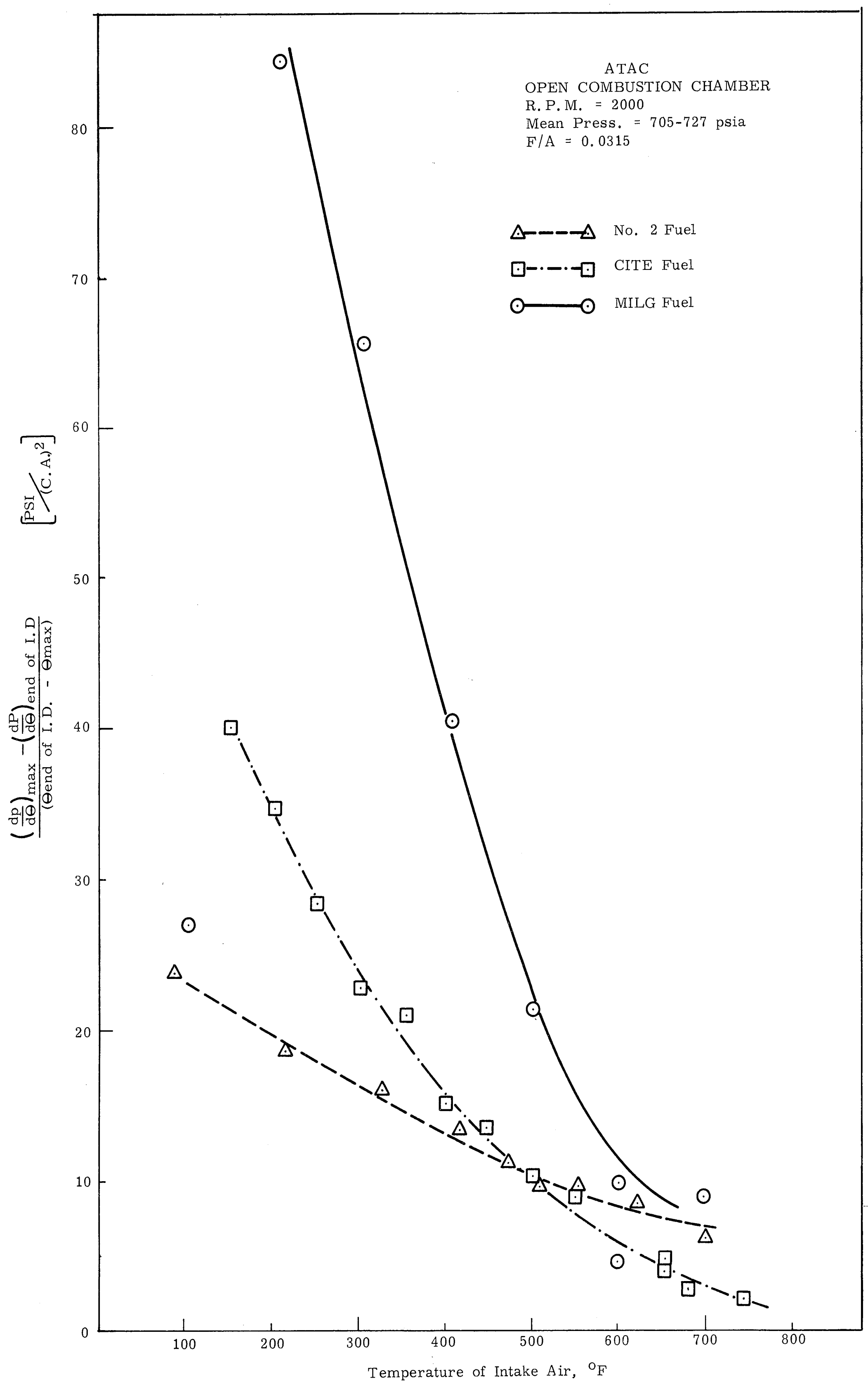


Fig. 26. Rate of change of pressure gradient for different fuels.

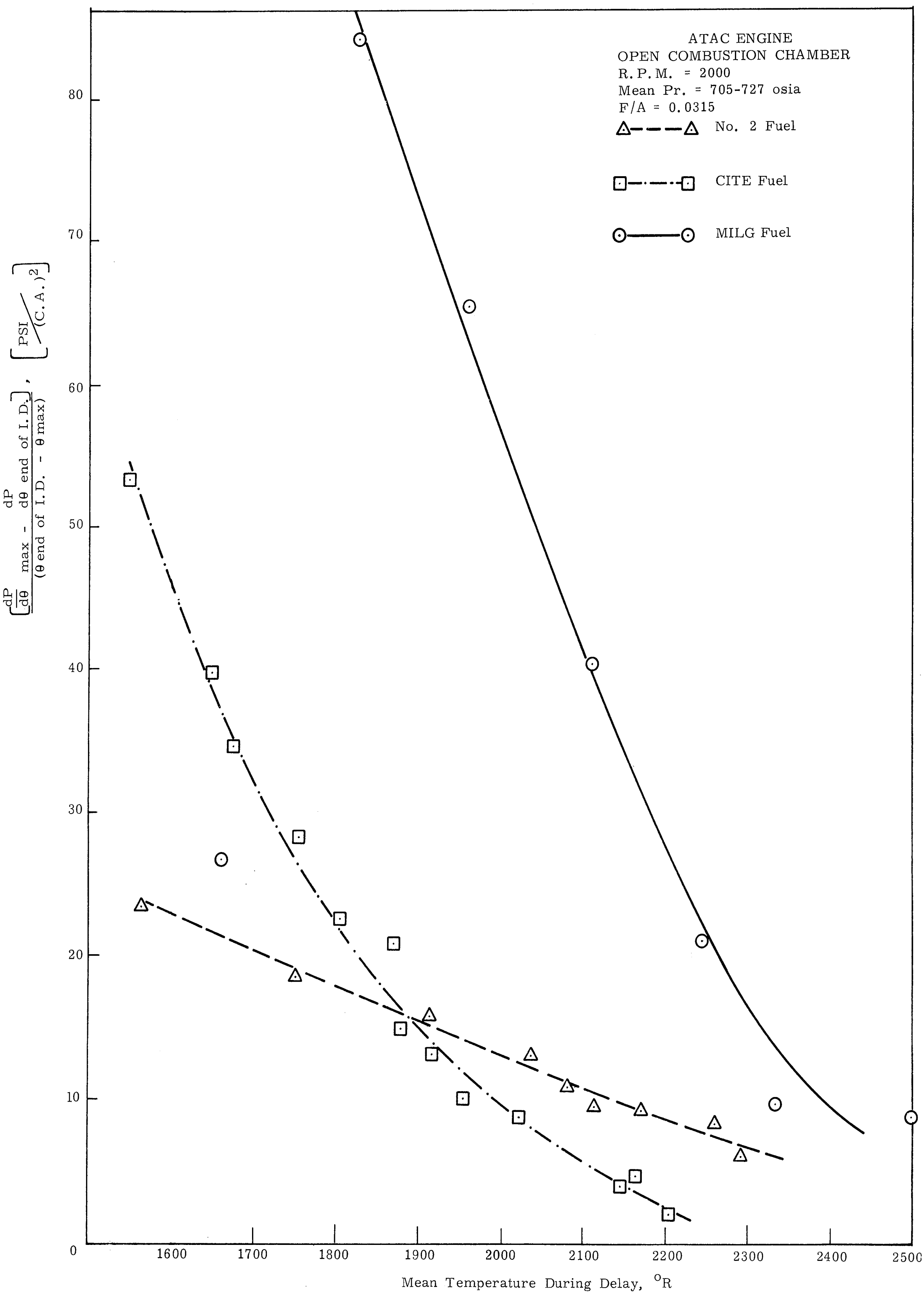


Fig. 27. Rate of change of pressure gradients for different fuels as a function of the mean temperature during ignition delay.

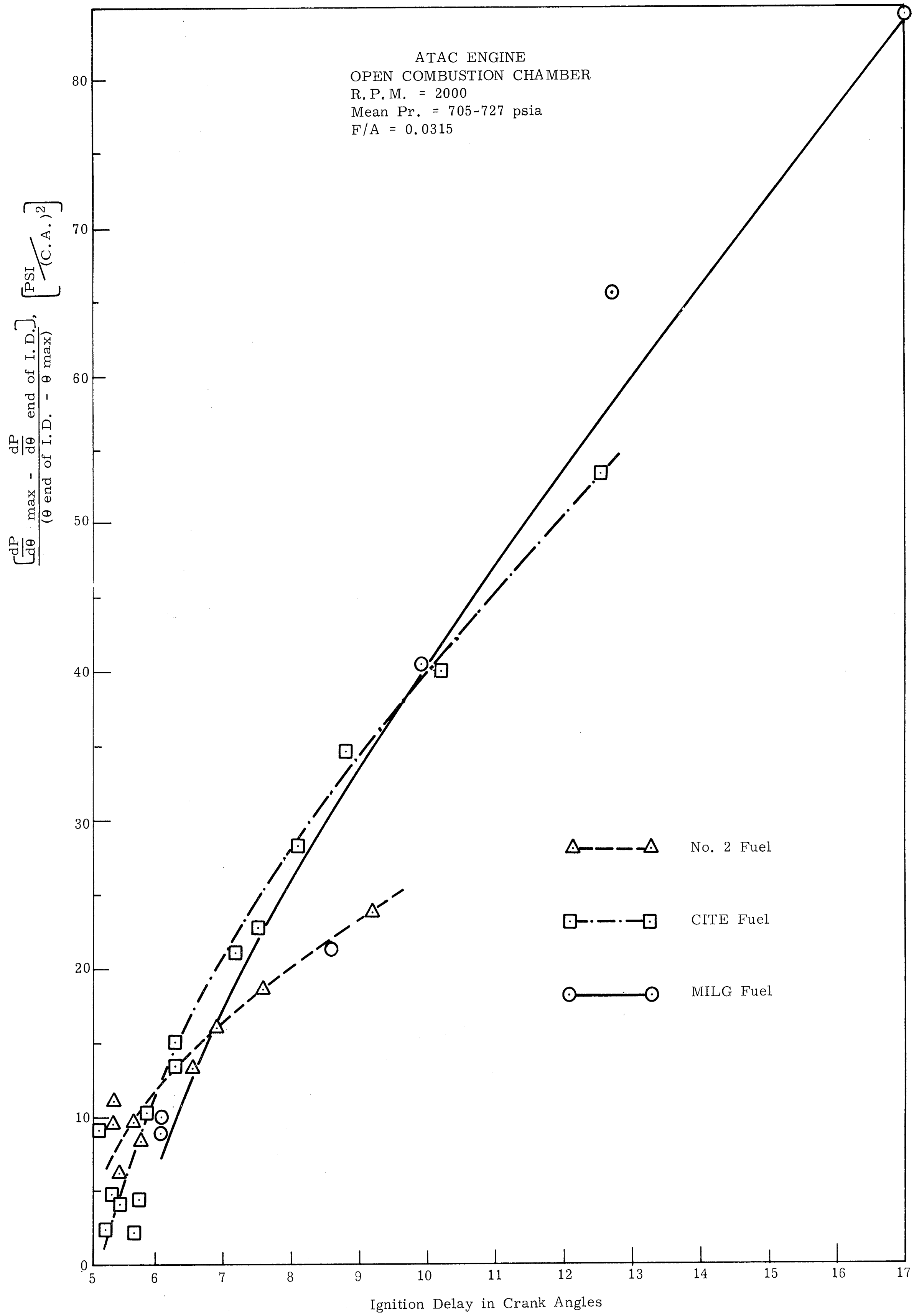


Fig. 28. Rate of change of pressure gradient for different fuels as a function of the length of ignition delay.

From this analysis it can be concluded that the phenomena of I.D. is useful in rating the different fuels in diesel engines.

C. SMOKE INTENSITY IN EXHAUST

The intensity of smoke in the exhaust gases was measured by using a "Hartridge Smokemeter," as described in Progress Report No. 7. The smokemeter readings were taken under an effective pressure of 5 in. Hg acting on the flowmeter. The results of the smokemeter readings are plotted for the three fuels in Fig. 29. It can be noticed that the CITE fuel has the highest average smoke intensity. It ranged from 40 to 71 Hartridge units. The gasoline has the lowest smoke intensity, and ranged from 6 to 19 Hartridge units. The high smoke level of CITE fuel is partly due to the after injection which has been observed with this fuel.

D. SPECIFIC FUEL CONSUMPTION

The brake specific fuel consumption for the ATAC engine is plotted in Fig. 30 against the brake mean effective pressure for different fuels. The conditions at which these data were obtained were as follows:

1. A constant fuel-air ratio of 0.0315.

2. A constant mean pressure during the ignition delay of about 700 psia. This required a change in the intake air pressure at each temperature to keep the mean pressure constant. The charge temperature and pressure before the inlet valve are shown opposite to the end points on each curve.

3. A constant speed of 2000 rpm.

4. A constant cooling water temperature at 175°F at outlet from the cylinder head.

5. A constant injection timing at 21 crank angle degrees before top dead center.

6. A constant injector opening pressure of 3000 psia.

Under the above conditions Fig. 30 shows that in the range of BMEP from 35 to 80 psi, the lowest specific consumption is obtained when the engine is run with gasoline. The highest specific fuel consumption is obtained with CITE fuel.

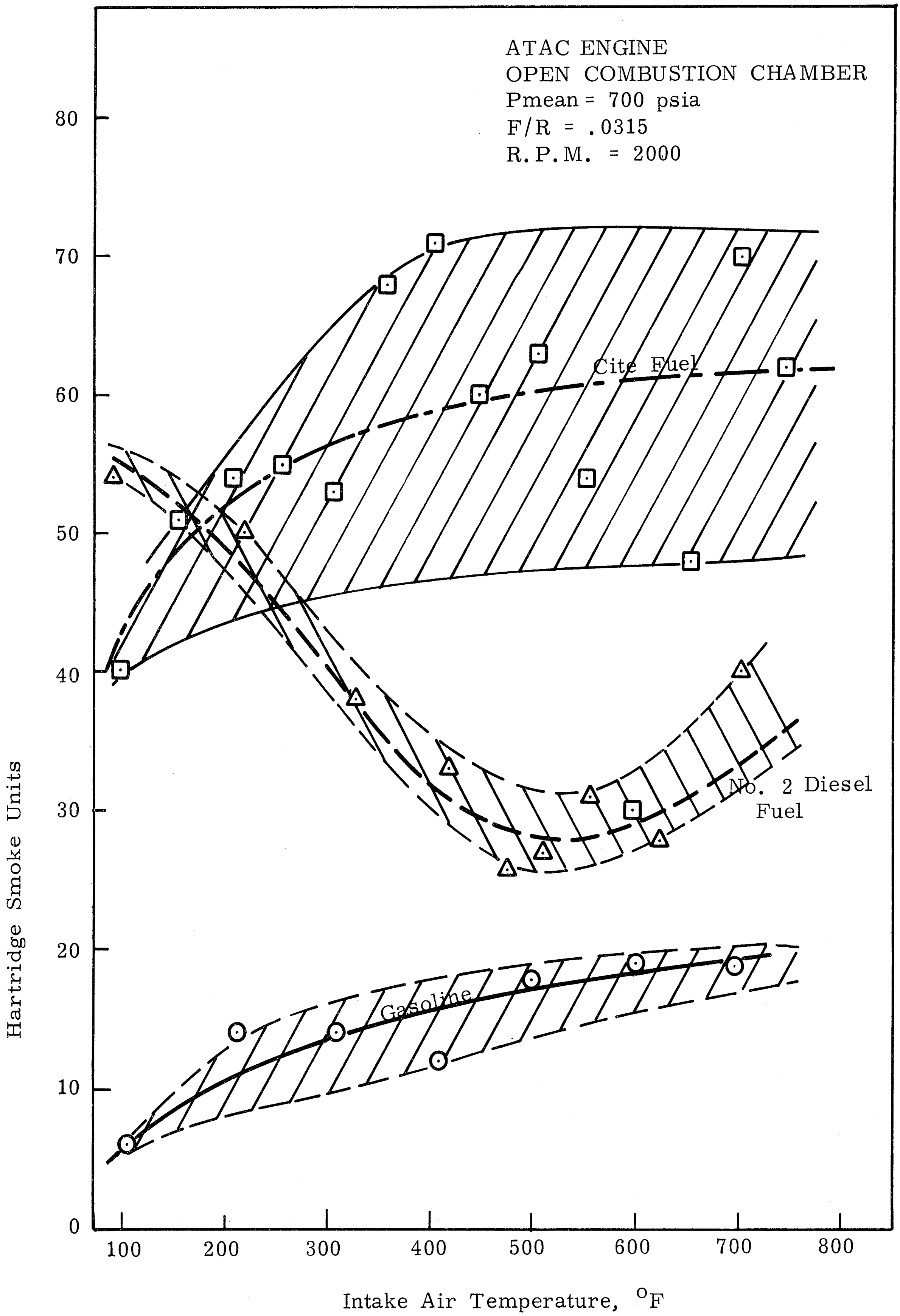


Fig. 29. Smoke intensity for different fuels.

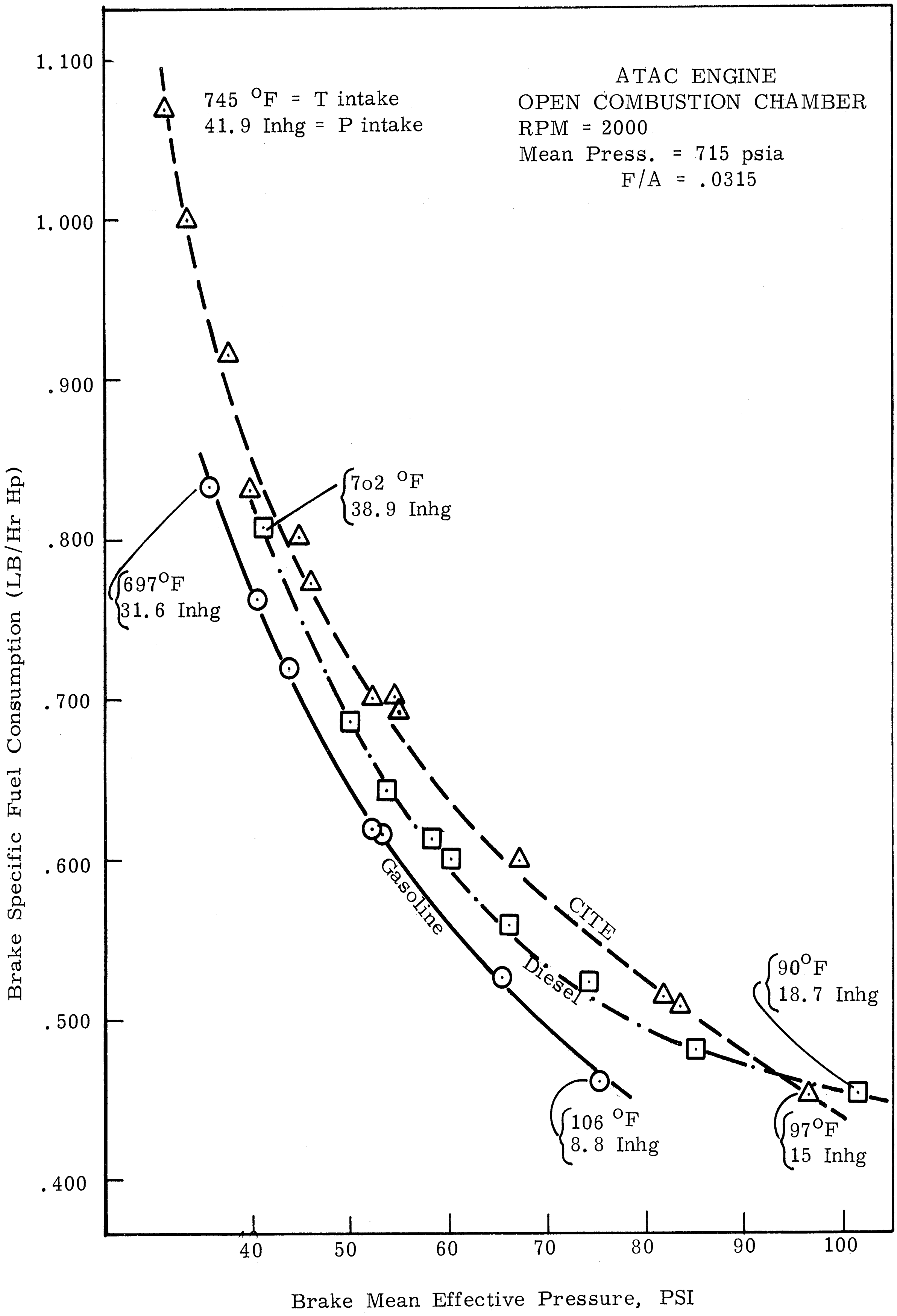


Fig. 30. Brake specific fuel consumption as a function of BMEP for different fuels (constant mean pressure during the ignition delay).

APPENDIX A

FUEL SPECIFICATIONS

The following certificates have been received from Ashland Oil and Refining Company. These are for the following fuels:

(a) Diesel fuel VV-F-800 Grade II. Dated December 29, 1965.

(b) Automotive Combat, Refree grade Mil-G-3056B. Dated September 17, 1965.

(c) CITE fuel, Mil-F-45121B Batch No. 13. Dated December 3, 1965.

(d) CITE fuel, Mil-F-45121B Batch No. 19. Dated March 29, 1967.

CERTIFICATE OF ANALYSIS

December 29, 1965

I, Eldon Sloan, certify that I am employed by Ashland Oil and Refining Company as Coordinator of Laboratories, and did supervise the following tests on Diesel Fuel VV-F-800 Grade II.

	Specification VV-F-800 Grade DF-2	Drum
Flash Point, °F, min	125	165
Cloud Point, °F, max	+15	+4
Pour Point, °F, max	+5	-5
Kinematic Vis. at 100°F, cs, min	1.8 - 6.0	2.5
Water and Sediment, % by vol., max	0.05	nil
Sulfur, %	1.00	0.11
Ash, % max	0.02	0.001
Corrosion, cu strip 3 hr at 122 ASTM No., max	3	1
Distillation, °F		
50%	Record	516
90%	675	590
End Point	725	604
Ignition Quality, Cetane No.	40	57.5
Gravity, °API	Record	39.1

ASHLAND OIL AND REFINING CO.

Eldon Sloan
Coordinator of Laboratories

CERTIFICATE OF ANALYSIS September 17, 1965

I, Eldon Sloan, certify that I am employed by Ashland Oil and Refining Company as Coordinator of Laboratories and did personally supervise the following tests on Automotive Combat, Refree Grade Mil-G-3056B dated 4 June 1958 with following exceptions and/or limits, manufactured in 737 Tank as Batch No. 4 on Sept. 17, 1965.

	Specifications Min	Specifications Max	737 Tank Batch No. 4
Distillation			
10% evap. °F	131	158	132
20% evap. °F	To be recorded		152
50% evap. °F	194	239	220
90% evap. °F	275	356	320
Residue		2%	1.0
RVP, psi	7.5	9.5	8.7
CRC Calculated Temperature			
V/L Ratio of 10	125°F	135°F	133
V/L Ratio of 30	140°F	150°F	148
Gravity			61.0
Octane Number - Motor	82	86	85.9
- Research	90	93	92.8
Gum, mg/100 ml (before wash)		4	1.2
(after wash)	To be recorded		0.8
Sulfur, % by weight		0.15	0.003
Aromatics, %	25	40	26.5
Olefins	Record		9.0
Corrosion		ASTM No. 1	1A
Metallic Lead Content			
grams/US gal	2.11	3.17	2.2
Oxidation Stability, min	480	Record	600+
Color	Equal to Standard		OK
Oxidation Inhibitor,			
lb/1000 bbl	10	10	10
Type and Amount			2,6 Ditertiary butylphenol
Metal Deactivator			
lb/1000 bbl	3	3	3 N,N'disalicylidene 1,2 Propanediamine

ASHLAND OIL AND REFINING COMPANY

Eldon Sloan
Coordinator of Laboratories

CERTIFICATE OF ANALYSIS December 3, 1965

I, Eldon Sloan, certify that I am employed by Ashland Oil and Refining Company as Coordinator of Laboratories, and did personally supervise the following tests on CITE Fuel, Mil-F-45121B manufactured in 708 Tank as Batch No. 13 on December 2, 1965.

	Mil-F-45121B Specifications Min	Max	708 Tank Batch No. 13
Gravity, °API			49.5
Distillation, °F			
Initial	130	160	156
10%	200	260	226
50%	300	375	370
90%	450	500	456
End Point		575	476
Residue, %		2	1
Loss, %		2	1
Reid Vapor Pressure	1	3	2.0
Total Sulfur, % weight	0.25	0.4	0.30
Copper Strip Corr. at 212°		1	1A
Olefin Content, vol %	2.0	5.0	2.3
Aromatic Content, vol. % (D1319)	15.0	25.0	16.2
Gum, Ext. Steam Evap. mgs/100 ml		7.0	0.6
Potential Gum, mg/100 ml		14.0	2.2
Freezing Point, °F		-67	-68
Kinematic Viscosity			
CS at 100°F	0.9		0.98
CS at -30°F		16.5	3.74
Cetane Number	35	40	38.0
Additives, lb/1000 bbl			
(a) Oxidation Inhibtor	5	9	8
(b) Metal Deactivator	1	2	2
Smoke Point, MM	17		21
Thermal Stability			
Change in pressure in 5 hr in Hg		15	0
Preheater/filter deposit 300/400°F		3	1
Water Separation Index Mod. WSIM	75		88

ASHLAND OIL AND REFINING CO.

Eldon Sloan
Coordinator of Laboratories

CERTIFICATE OF ANALYSIS

March 29, 1967

I, Eldon Sloan, certify that I am employed by Ashland Oil and Refining Company as Coordinator of Laboratories, and did personally supervise the following tests on CITE Fuel, Mil-F-45121B manufactured in 708 Tank as Batch No. 19 on March 21, 1967.

	Mil-F-45121B Specifications Min	Mil-F-45121B Specifications Max	708 Tank Batch No. 19
Gravity, °API			49.2
Distillation, °F			
Initial	130	160	134
10%	200	260	204
50%	300	375	342
90%	450	500	454
End Point		575	484
Residue, %		2	1
Loss, %		2	1
Reid Vapor Pressure	1	3	2.8
Total Sulfur, % weight	0.25	0.4	0.27
Copper Strip Corr. at 212°		1	1A
Olefin Content, vol. %	2.0	5.0	1.7
Aromatic Content, vol. % (D1319)	15.0	25.0	17.6
Gum, Ext. Steam Evap. mgs/100 ml		7.0	0.4
Potential Gum, mg/100 ml		14.0	2.2
Freezing Point, °F		-67	-73
Kinematic Viscosity			
CS at 100°F	0.9		0.95
CS at -30°F		16.5	3.5
Cetane Number	35	40	37.5
Additives, lb/1000 bbl			
(a) Oxidation Inhibitor	5	9	8
(b) Metal Deactivator	1	2	2
Smoke Point, MM	17		20
Thermal Stability			
Change in pressure in 5 hr in Hg.		15	0.3
Preheater filter deposit 300/400°F		3	1
Water Separation Index Mod. WSIM	75		90

ASHLAND OIL AND REFINING CO.

Eldon Sloan
Coordinator of Laboratories

APPENDIX B

CALCULATION OF THE CLEARANCE VOLUME

The clearance volume is computed from the dimensions of the original combuation chamber and the recesses made for the instruments. The dimensions used for these computations are shown in Figs. 31 and 32. These are obtained from engine drawings or from direct measurements made on the engine. The clearance volume constitutes of the following:

A. In piston top

1. Volume of dish = 3.6339 cu in.
2. Volume of intake value recess = 0.4101 cu in.
3. Volume of exhaust value recess = 0.1983 cu in.
4. Volume gained due to rounding of piston edge = .0048 cu in.
   Total volume of piston recesses = 4.2471 cu in.
5. Volume between piston top and cylinder head = 0.7189 cu in.
6. Volume of quartz window hole (with the quartz in place) = 0.0067 cu in.
7. Volume of pressure pickup hole = 0.0063 cu in.
8. Net volume of injector and hole = 0.0014 cu in.
9. Volume of intake valve protrusion = -0.2966.
10. Volume of exhaust valve protrusion = -0.1228.

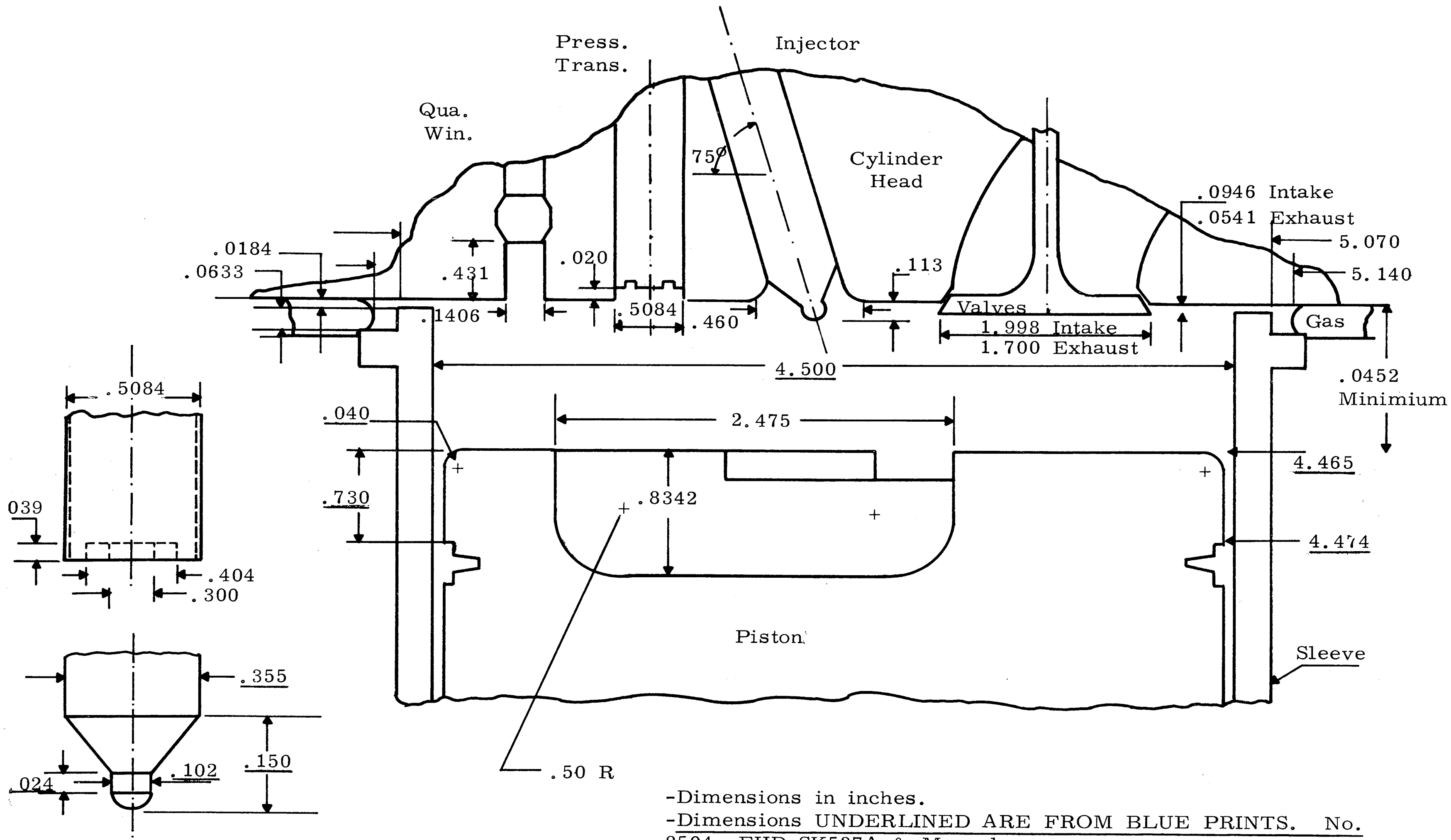
NOTE: The following volumes are excluded because they are usually full of carbon deposits:

a. Volume between piston and sleeve till the first ring = 0.1568 cu in.
b. Volume between sleeve top and cylinder head = 0.0788 cu in.
c. Volume between gasket and sleeve = 0.0459.

Total clearance volume (clean surfaces) = 4.5610 cu in.
Compression ratio (clean surfaces) = 16.692:1.

EFFECT OF CARBON DEPOSIT ON C.R.

The effect of a carbon deposit 3/1000 in. thick on the combustion chamber walls is found to increase the compression ratio from 16.692:1 to 17.116:1, or 2.54%.



-Dimensions in inches.
-Dimensions UNDERLINED ARE FROM BLUE PRINTS. No. 8504, EHD-SK537A & Manual

Fig. 31. Details of ATAC engine open combustion chamber.

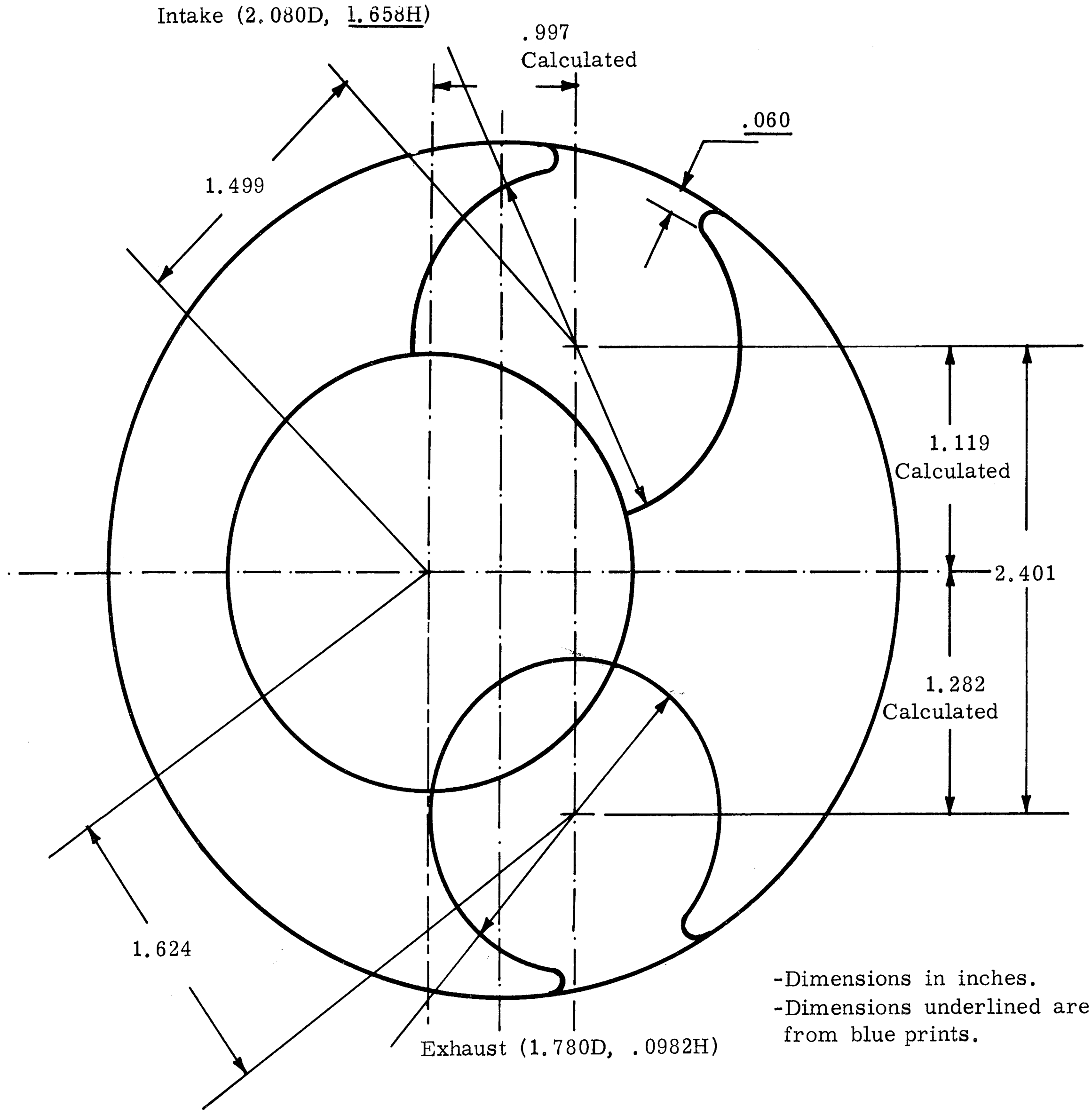


Fig. 32. Details of recesses in ATAC engine piston.

COMPRESSION RATIO USED IN COMPUTATIONS

Upon checking the surface of the combustion chamber walls, after running for periods of 100 working hours, they were found to be fairly clean. For the data analysis a compression ratio of 16.692:1 is therefore used.

APPENDIX C

VOLUME-CRANK ANGLES RELATIONSHIP

The volume of gas enclosed in the ATAC engine cylinder is calculated for the different crank angle positions as follows:

$$V = V_c + V_s$$

where

V_c = clearance volume calculated in Appendix B

V_s = swept volume obtained from the piston displacement from T.D.C. position.

The formula used for computing the cylinder volume took into consideration the offset of the piston pin with respect to piston center. This offset shown in Fig. 33 is obtained from the engine drawings and amounts to 60/1000 in.

The cylinder volume is calculated for all crank angles from -180° to +180°. To facilitate any further programming on the computer, the cylinder volume and the rate of change of volume w.r.t. crank angles are calculated and tabulated for intervals of 1/10° crank angle. A summary of these are shown in Tables 3 and 4.

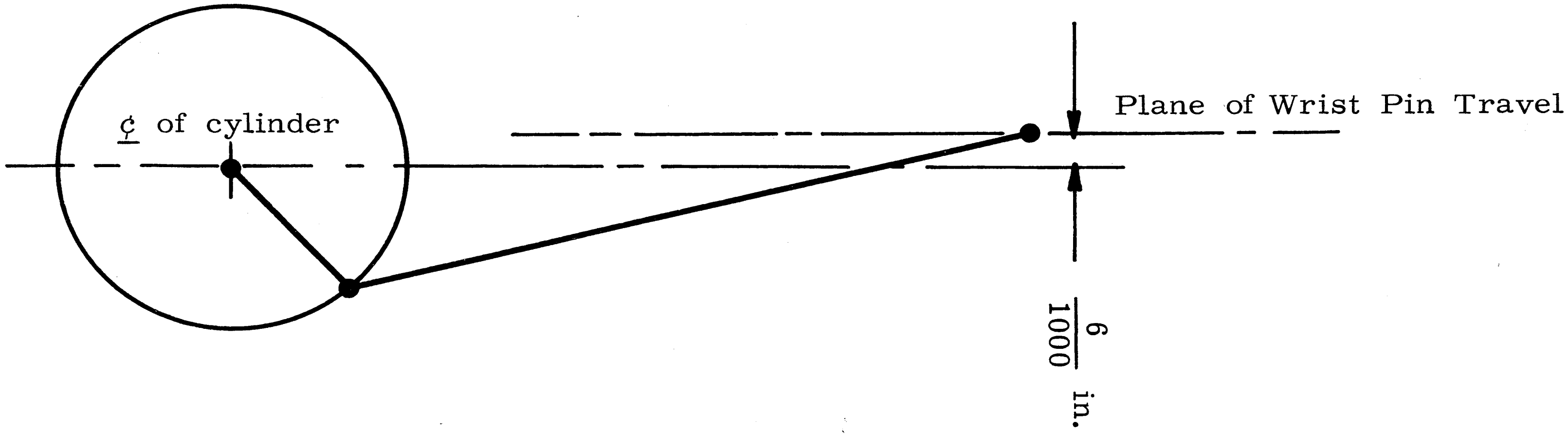


Fig. 33. ATAC engine two-bar mechanism.

TABLE 3

ATAC ENGINE CYLINDER VOLUME AND GRADIENTS AT CRANK ANGLES
FROM 0 TO 180°, COMPRESSION STROKE

C.R. = 16.692:1

Angle Θ Measured from T.D.C.

Angle Θ, deg	Volume, cu in.	Volume Gradient	Angle Θ, deg	Volume, cu in.	Volume Gradient	Angle Θ, deg	Volume, cu in.	Volume Gradient
0	4.5610	.0000						
2	4.5882	-.0272	62	27.1041	-.6188	122	62.6310	-.4576
4	4.6699	-.0544	64	28.3487	-.6255	124	63.5322	-.4435
6	4.8060	-.0815	66	29.6056	-.6312	126	64.4048	-.4291
8	4.9960	-.1085	68	30.8729	-.6359	128	65.2484	-.4144
10	5.2398	-.1352	70	32.1485	-.6396	130	66.0624	-.3996
12	5.5368	-.1617	72	33.4306	-.6423	132	66.8465	-.3845
14	5.8864	-.1879	74	34.7171	-.6441	134	67.6002	-.3693
16	6.2882	-.2137	76	36.0062	-.6449	136	68.3234	-.3539
18	6.7411	-.2392	78	37.2959	-.6447	138	69.0156	-.3383
20	7.2446	-.2642	80	38.5845	-.6437	140	69.6765	-.3226
22	7.7975	-.2887	82	39.8700	-.6417	142	70.3061	-.3069
24	8.3998	-.3126	84	41.1507	-.6389	144	70.9039	-.2910
26	9.0475	-.3360	86	42.4250	-.6352	146	71.4700	-.2750
28	9.7423	-.3587	88	43.6910	-.6308	148	72.0040	-.2590
30	10.4820	-.3808	90	44.9473	-.6254	150	72.5059	-.2429
32	11.2651	-.4022	92	46.1923	-.6194	152	72.9756	-.2268
34	12.0902	-.4228	94	47.4244	-.6126	154	73.4129	-.2106
36	12.9559	-.4427	96	48.6422	-.6051	156	73.8178	-.1943
38	13.8605	-.4618	98	49.8443	-.5969	158	74.1902	-.1781
40	14.8023	-.4800	100	51.0295	-.5881	160	74.5300	-.1618
42	15.7798	-.4973	102	52.1964	-.5787	162	74.8373	-.1455
44	16.7910	-.5138	104	53.3440	-.5687	164	75.1119	-.1291
46	17.8343	-.5293	106	54.4709	-.5581	166	75.3539	-.1128
48	18.9078	-.5440	108	55.5762	-.5471	168	75.5631	-.0965
50	20.0095	-.5576	110	56.6589	-.5355	170	75.7397	-.0801
52	21.1376	-.5703	112	57.7180	-.5235	172	75.8836	-.0638
54	22.2900	-.5820	114	58.7526	-.5111	174	75.9947	-.0474
56	23.4649	-.5927	116	59.7620	-.4982	176	76.0732	-.0310
58	24.6602	-.6024	118	60.7453	-.4850	178	76.1189	-.0147
60	25.8740	-.6111	120	61.7019	-.4715	180	76.1319	.0017

TABLE 4

ATAC ENGINE CYLINDER VOLUME AND GRADIENTS AT CRANK ANGLES FROM 0 TO -180°, EXPANSION STROKE

C.R. = 16.692:1

Angle Θ Measured From T.D.C.

Angle Θ, deg	Volume, cu in.	Volume Gradient	Angle Θ, deg	Volume, cu in.	Volume Gradient	Angle Θ, deg	Volume, cu in.	Volume Gradient
0	4.5610	.0000						
- 2	4.5882	.0272	- 62	27.0498	.6168	-122	62.4968	.4581
- 4	4.6699	.0544	- 64	28.2902	.6235	-124	63.3991	.4441
- 6	4.8059	.0815	- 66	29.5430	.6291	-126	64.2731	.4299
- 8	4.9958	.1084	- 68	30.8061	.6338	-128	65.1184	.4154
-10	5.2394	.1351	- 70	32.0775	.6375	-130	65.9345	.4007
-12	5.5362	.1616	- 72	33.3553	.6402	-132	66.7210	.3858
-14	5.8856	.1877	- 74	34.6376	.6419	-134	67.4774	.3707
-16	6.2869	.2135	- 76	35.9225	.6426	-136	68.2035	.3554
-18	6.7393	.2389	- 78	37.2080	.6426	-138	68.8990	.3400
-20	7.2421	.2638	- 80	38.4924	.6416	-140	69.5635	.3245
-22	7.7942	.2882	- 82	39.7739	.6397	-142	70.1969	.3089
-24	8.3946	.3121	- 84	41.0507	.6369	-144	70.7989	.2931
-26	9.0422	.3354	- 86	42.3211	.6333	-146	71.6426	.2693
-28	9.7358	.3581	- 88	43.5835	.6289	-148	71.9079	.2614
-30	10.4740	.3801	- 90	44.8362	.6237	-150	72.4147	.2454
-32	11.2555	.4013	- 92	46.0778	.6178	-152	72.8894	.2293
-34	12.0789	.4219	- 94	47.3068	.6111	-154	73.3320	.2132
-36	12.9426	.4417	- 96	48.5217	.6037	-156	73.7423	.1971
-38	13.8450	.4606	- 98	49.7211	.5956	-158	74.1204	.1809
-40	14.7846	.4788	-100	50.9038	.5869	-160	74.4660	.1647
-42	15.7595	.4960	-102	52.0685	.5777	-162	74.7792	.1485
-44	16.7681	.5124	-104	53.2140	.5678	-164	75.0599	.1322
-46	17.8085	.5279	-106	54.3393	.5574	-166	75.3081	.1159
-48	18.8789	.5424	-108	55.4432	.5464	-168	75.5237	.0997
-50	19.9774	.5560	-110	56.5247	.5350	-170	75.7067	.0833
-52	21.1021	.5686	-112	57.5830	.5232	-172	75.8571	.0670
-54	22.2510	.5802	-114	58.6172	.5109	-174	75.9748	.0507
-56	23.4223	.5909	-116	59.6264	.4982	-176	76.0599	.0344
-58	24.6138	.6005	-118	60.6098	.4852	-178	76.1122	.0180
-60	25.8236	.6092	-120	61.5669	.4718	-180	76.1319	.0017

APPENDIX D

DIGITAL COMPUTATIONS

A computer program has been developed for the present project, for the analysis of the data. The recorded information include:

(a) The experimental data obtained from the tests, (b) the results of computations based on the experimental data, and (c) a comparison between the present results and previously published data.

1. DATA RECORDING

The data recorded includes the following items, arranged according to their order, in the attached computer records:

Data Set A2A: A, stands for ATAC

2, stands for Group 2 of runs (Group 1 will be included in a future report)

A, stands for the first series in this group, in which fuel used is CITE fuel, Batch 13 or 19. Runs at constant intake surge tank pressure of 15 in. Hg g.

Data Set A2B: as set A2A, except that the mean pressure during the ignition delay is kept constant.

Data Set A2C: as set A2B, with diesel no. 2 fuel.

Data Set A2D: as set A2B, with gasoline fuel.

2. IDENTIFICATION

a. Mass of Fuel

Symbol	Mass, lbm
B	0.12667
C	0.25247
D	0.5007
E	0.9985

b. Critical Flowmeter Orifice

Symbol	Diameter of Orifice
A	3/32 in.
B	1/8
C	3/16
D	7/32
E	D and A
F	D and B
G	D and C
H	D, C, and A
I	D, C, and B
J	D, C, B, and A

TABLE 5

LIST OF SYMBOLS, HEADINGS, AND REPRESENTATIONS AS THEY APPEAR ON THE COMPUTER SHEETS OF TABLE 8

Column	Heading	Representation
1	For Run	Identification of run, serial number
2	Use W	Identification of mass used for fuel consumption measurements.
3	Use O	Identification of the orifice combination, used for air flow rate measurements (critical flowmeter).
4	Speed RPM	Engine speed, rpm.
5	Load lbs	Load, lb.
6	Fuel min	Fuel consumption time, min.
7	Fuel L/hr	Fuel leakage rate, liters/hr.
8	Air PSIG	Pressure before orifice, psig.
9	Air F	Temperature before orifice, °F.
10	Blow CFPM	Blowby rate in cu ft/min.
11	Temperatures (F) Air	Temperature of air before the inlet valve, °F.
12	Temperatures (F) Out	Temperature of cooling water at outlet from the engine, °F.
13	Temperatures (F) Min	Minimum temperature of the inside surface of the combustion chamber, °F.
14	Temperatures (F) Inc	Swing in temperature of the inside surface of the combustion chamber, °F.
15	Room In HG	Barometric pressure in room, in. Hg.
16	Surge In HG	Pressure in surge tanks, inlet and exhaust above barometric pressure, in. Hg.
17	At I VC PSI	Cylinder pressure at the point of I.V.C., above surge tank pressure, psi.
18	At INJ PSI	Cylinder pressure at the point of start of fuel injection.
19	RISE PSI	Cylinder pressure at the end of the pressure-rise delay w.r.t. pressure at start of injection.

TABLE 5 (Concluded)

Column	Heading	Representation
20	DBTDC LIFT	Point of needle lift, in crank angle degrees before T.D.C.
21	At Start of Rise	Point of start of pressure rise due to combustion, in crank angle degrees.
22	At Start of Illum	Point of start of illumination due to combustion, in crank angle degrees.
23	Exhaust F	Exhaust temperature, °F.
24	Exhaust HU	Smokemeter reading in Hartridge units.

TABLE 6

LIST OF SYMBOLS, HEADINGS, AND REPRESENTATIONS AS THEY APPEAR ON THE COMPUTER SHEETS OF TABLE 9

Column	Heading	Representation
1	Ror Run	Identification of run, serial number.
2	Brake HP	Brake horsepower.
3	BMEP PSI	Brake mean effective pressure, psi.
4	BSFC #/HR HP	Brake specific fuel consumption in lb/hr/ brake horsepower.
5	FUEL/ AIR	Fuel-air ratio.
6	Cycle (LBM/1000) AIR	Mass of air used per cycle in lbm/1000
7	Cycle (LBM/1000) BLOW	Mass of blowby gases per cycle in lbm/1000
8	Cycle (LBM/1000) EXH	Mass of exhaust gases in clearance volume/ cycle in lbm/1000.
9	SURGE PSIA	Absolute pressure in surge tank, psia.
10	EFF PCT	Volumetric efficiency, percentage.
11	At I VC F	Gas temperature at the closing of inlet valve, °F.
12	At Start of Injection Index	Index of compression from the point of inlet valve closing to start of injection.
13	At Start of Injection PSIA	Gas pressure at start of injection, psia.
14	At Start of Injection #/CU FT	Gas density at start of injection in lbm/ ft^3.
15	At Start of Injection R	Gas temperature at start of injection, °R.
16	Averaged during delay Index	Average index of compression during the ignition delay period.

TABLE 6 (Concluded)

Column	Heading	Representation
17	Averaged during delay PSIA	Average gas pressure during the ignition delay period.
18	Averaged during delay #/CU FT	Average gas density during the ignition delay period, in lbm/ft^3.
19	Averaged during delay R	Average gas temperature during the ignition delay period, °R.
20	Delay (MSEC) PRISE	Pressure-rise delay, msec.
21	Delay (MSEC) ILLUM.	Illumination delay, msec.

TABLE 7

LIST OF SYMBOLS, HEADINGS, AND REPRESENTATIONS, AS THEY APPEAR ON THE COMPUTER SHEETS OF TABLE 10

Column	Heading	Representation
1	For Run	Identification of run, serial number.
2	Experimental PRD	Experimental value of the pressure rise delay, msec.
3	Experimental Ild	Experimental value of the illumination delay, msec.
4	WOLFER START	Calculated values of ignition delay, by using Wolfer's Equation, based on pressure and temperature at start of injection.
5	WOLFER MEAN	Calculated values of ignition delay, using Wolfer's Equation, based on the mean pressure and temperature during the delay period.
6	ELLIOTT START	Calculated values of ignition delay, by using Elliott's Equation, based on the pressure and temperature at start of injection.
7	ELLIOTT MEAN	Calculated values of ignition delay, by using Elliott's Equation, based on the mean pressure and temperature during the delay period.
8	SITKEI START	Calculated values of ignition delay, by using Sitkei's Equation, based on the pressure and temperature at start of injection.
9	SITKEI MEAN	Calculated values of ignition delay, by using Sitkei's Equation, based on the mean pressure and temperature during the delay period.
10	TSAO	Calculated values of ignition delay, by using Tsao's Equation, based on the pressure and temperature at start of injection and the actual engine speed.
11	TSAO MEAN	Calculated values of ignition delay, by using Tsao's Equation, based on the mean pressure and temperature during the ignition delay and the actual engine speed.
12	TSAO at 1000 START	Same as (10), except that the speed used is 1000 rpm, instead of the actual engine speed.
13	TSAO at 1000 MEAN	Same as (11), except that the speed used is 1000 rpm, instead of the actual engine speed.

TABLE 8

COMPUTER DATA SHEET, RECORDED DATA, SERIES A2A FOR CITE FUEL

EFFECT OF INLET TEMPERATURE ON IGNITION DELAY
RUNS TAKEN AT CONSTANT INLET PRESSURE

DATA SET A2A HAVING 11 RUN(S) FOLLOWS. THE ATAC ENGINE WAS TESTED (INJECTOR OPENING PRESSURE SET AT 3000 PSIG) USING CT13 FUEL.

FOR RUN	USE W	USE O	SPEED RPM	LOAD LBS	FUEL MIN	FUEL L/HR	AIR PSIG	AIR F	BLOW CFFM	TEMPERATURES(F) AIR	OUT	MIN	INC	ROOM INHG	<SURGE INHG	<@IVC PSI	<@INJ PSI	<RIS PSI	DBTDC LIFT	AT START OF RISE	ILLUM	EXHAUST F	HU
4	E	D	2000	17.8	7.49	.27	66.0	78	-.0	97	169	354	12	28.1	15.1	4.0	496	373	21.3	7.3	-.0	804	61
5	E	D	2002	17.4	7.57	.28	63.0	80	-.0	119	172	373	11	28.7	15.0	3.4	481	341	21.2	8.1	-.0	838	63
6	E	D	1999	13.6	8.33	.25	58.9	80	-.0	163	169	390	9	28.8	15.1	3.8	490	305	20.7	9.4	-.0	842	55
7	E	D	2001	11.9	8.73	.24	56.2	80	-.0	190	169	386	-0	28.8	14.9	1.6	471	287	21.0	9.9	-.0	832	-0
8	E	D	2000	17.1	9.28	.20	51.3	77	-.0	242	170	422	53	28.9	15.0	2.6	452	255	21.4	11.6	-.0	784	31
9	E	D	2000	15.7	9.74	.20	48.2	78	-.0	281	170	422	47	29.0	14.9	3.7	435	238	21.9	12.7	-.0	793	35
10	C	D	2000	12.9	5.18	.18	44.8	78	-.0	337	168	448	48	28.9	15.0	3.2	440	225	21.3	12.3	-.0	805	52
11	C	D	2001	10.6	5.46	.24	42.5	79	-.0	376	169	441	47	28.9	15.0	3.0	427	219	21.5	13.0	-.0	788	28
12	D	D	1999	9.9	5.58	.20	40.2	77	-.0	424	169	454	48	29.3	15.0	3.7	420	210	21.2	12.7	-.0	842	40
13	C	D	1999	9.0	5.79	.17	38.1	79	-.0	464	167	454	47	29.2	15.1	3.0	415	194	21.4	13.4	-.0	851	30
14	C	D	2001	8.2	6.11	.17	35.6	79	-.0	513	171	483	46	29.3	15.0	3.4	399	194	21.7	14.0	-.0	866	40
AVERAGES			2000	13.1	7.21	.22	49.5	79	-.0	291	169	421	37	28.9	15.0	3.2	448	258	21.3	11.3	-.0	822	44
RMS ERRS			1	3.3	1.58	.04	9.9	1	-.0	136	1	38	17	.3	.1	.6	31	58	.3	2.2	-.0	27	13

TABLE 9

COMPUTER DATA SHEET, COMPUTATION RESULTS, SERIES A2A FOR CITE FUEL

H/C RATIO = 1.992/1, DENSITY AT 60 = 48.79 #/CUFT, CLEARANCE VOLUME = 4.5610 CUIN, COMPRESSION RATIO = 16.69/1, IVC = 128 DBTDC

FOR	BRAKE	BMEP	BSFC	FUEL/	CYCLE(LBM/1000)			SURGE	EFF	@IVC	AT START OF INJECTION				AVERAGED DURING DELAY				DELAY(MSEC)	
RUN	HP	PSI	#/HRHP	AIR	AIR	BLOW	EXH	PSIA	PCT	F	INDEX	PSIA	#/CUFT	R	INDEX	PSIA	#/CUFT	R	PRISE	ILLUM
4	11.9	65.7	.635	.0320	3.92	-.00	.11	21.2	92.1	176	1.408	521	.917	1510	1.221	708	1.176	1592	1.167	-.000
5	11.6	64.2	.640	.0328	3.78	-.00	.11	21.5	91.2	191	1.399	506	.887	1516	1.224	675	1.122	1594	1.091	-.000
6	9.1	50.2	.747	.0315	3.58	-.00	.11	21.6	92.7	239	1.386	515	.859	1595	1.253	665	1.053	1676	.942	-.000
7	7.9	43.9	.813	.0312	3.45	-.00	.11	21.5	93.5	200	1.418	494	.818	1606	1.240	635	1.001	1682	.925	-.000
8	11.4	63.1	.536	.0316	3.22	-.00	.12	21.6	93.9	277	1.389	476	.756	1677	1.273	600	.906	1758	.817	-.000
9	10.5	57.9	.555	.0316	3.07	-.00	.12	21.6	94.4	347	1.364	460	.708	1732	1.292	575	.841	1817	.767	-.000
10	8.6	47.6	.539	.0316	2.90	-.00	.11	21.6	96.0	376	1.364	465	.685	1807	1.264	574	.810	1885	.750	-.000
11	7.1	39.1	.720	.0305	2.78	-.00	.12	21.6	96.6	402	1.359	452	.654	1840	1.327	557	.767	1934	.708	-.000
12	6.6	36.5	.764	.0313	2.69	-.00	.11	21.8	97.8	465	1.329	445	.639	1859	1.304	547	.748	1947	.709	-.000
13	6.0	33.2	.817	.0317	2.58	-.00	.11	21.8	98.0	477	1.340	440	.609	1926	1.297	533	.707	2010	.667	-.000
14	5.5	30.2	.846	.0314	2.45	-.00	.11	21.8	98.3	538	1.323	424	.574	1970	1.377	517	.664	2077	.641	-.000
MEAN	8.7	48.3	.701	.0316	3.13	-.00	.11	21.6	95.0	335	1.371	473	.737	1731	1.279	599	.890	1816	.835	-.000
ERRS	2.2	12.3	.102	.0005	.48	-.00	.00	.2	2.4	121	.030	31	.113	154	.045	60	.166	160	.166	-.000

TABLE 10

COMPUTER DATA SHEET, COMPARISON WITH PREVIOUS WORK, SERIES A2A FOR CITE FUEL

FOR	EXPERIMENTAL		WOLFER		ELLIOT		SITKEI		TSAO		TSAO @ 1000	
RUN	PRD	ILD	START	MEAN	START	MEAN	START	MEAN	START	MEAN	START	MEAN
4	1.167	-.000	1.607	.841	2.542	2.381	2.536	1.641	.054	-.249	1.904	1.499
5	1.091	-.000	1.633	.884	2.530	2.377	2.573	1.694	.031	-.264	1.908	1.516
6	.942	-.000	1.213	.696	2.375	2.241	2.108	1.476	-.289	-.615	1.655	1.317
7	.925	-.000	1.231	.722	2.356	2.231	2.139	1.511	-.347	-.659	1.650	1.321
8	.817	-.000	1.033	.623	2.240	2.124	1.922	1.398	-.698	-1.053	1.476	1.168
9	.767	-.000	.918	.561	2.159	2.049	1.795	1.326	-1.007	-1.395	1.351	1.055
10	.750	-.000	.741	.476	2.061	1.972	1.579	1.219	-1.446	-1.795	1.163	.916
11	.708	-.000	.706	.441	2.022	1.922	1.542	1.177	-1.671	-2.119	1.100	.830
12	.709	-.000	.685	.438	2.001	1.909	1.518	1.174	-1.797	-2.209	1.063	.811
13	.667	-.000	.595	.394	1.930	1.851	1.406	1.119	-2.254	-2.645	.924	.702
14	.641	-.000	.563	.358	1.887	1.795	1.371	1.073	-2.606	-3.142	.846	.594
MEAN	.835	-.000	.993	.585	2.191	2.077	1.863	1.346	-1.094	-1.468	1.367	1.066
ERRS	.166	-.000	.367	.173	.222	.198	.411	.203	.881	.942	.361	.306

TABLE 11

COMPUTER DATA SHEET, RECORDED DATA, SERIES A2B FOR CITE FUEL

EFFECT OF GAS TEMPERATURE ON IGNITION DELAY WITH CITE FUEL (BATCH 13)
RUNS TAKEN AT CONSTANT MEAN PRESSURE DURING DELAY

DATA SET A2B HAVING 13 RUN(S) FOLLOWS. THE ATAC ENGINE WAS TESTED (INJECTOR OPENING PRESSURE SET AT 3000 PSIG) USING CT13 FUEL.

FOR RUN	USE W O	SPEED RPM	LOAD LBS	FUEL MIN	FUEL L/HR	AIR PSIG	AIR F	BLOW CFPM	TEMPERATURES(F) AIR	OUT	MIN	INC	ROOM<SURGE<@IVC<@INJ<RIS ROOM INHG	SURGE INHG	IVC PSI	INJ PSI	RIS PSI	DBTDC LIFT	AT START OF RISE	ILLUM	EXHAUST F	HU
15	E D	2001	26.1	7.32	.18	67.9	79	-.0	97	170	-0	-0	29.4	15.0	4.5	503	343	21.1	8.6	-.0	729	40
16	E D	2000	22.2	7.51	.23	66.0	78	-.0	154	168	-0	-0	29.3	18.4	4.8	536	300	20.8	10.4	-.0	768	51
17	E D	2000	22.2	7.46	.23	66.9	78	-.0	205	167	-0	-0	29.2	22.5	3.8	553	265	20.8	12.0	-.0	795	54
18	E D	2000	22.6	7.44	.23	65.8	76	-.0	255	174	-0	-0	29.2	25.4	3.6	572	253	20.9	12.8	-.0	838	55
19	E D	2000	18.2	7.71	.30	64.0	77	-.0	304	169	-0	-0	29.2	26.5	4.5	572	229	20.8	13.3	-.0	900	53
20	E D	2000	14.8	8.05	.30	60.0	78	-.0	356	171	-0	-0	29.2	27.0	4.4	573	223	20.5	13.3	-.0	928	68
21	E D	2001	14.9	8.22	.24	59.1	82	-.0	402	175	-0	-0	29.2	29.1	4.4	556	202	20.9	14.5	-.0	968	71
22	E D	2000	14.2	8.44	.28	58.0	82	-.0	447	170	-0	-0	29.2	30.2	4.7	559	203	20.9	14.5	-.0	967	60
23	E D	2001	12.2	8.66	.24	56.7	83	-.0	501	174	-0	-0	29.1	32.5	4.6	565	183	20.8	14.9	-.0	976	63
24	E D	2000	12.5	8.68	.28	56.3	83	-.0	550	173	-0	-0	29.1	35.2	5.0	582	167	20.8	15.6	-.0	1012	54
26	E D	1999	10.8	9.22	.31	54.5	89	-.0	654	172	-0	-0	29.1	39.7	4.0	603	176	21.0	15.6	-.0	1027	-0
28	E D	2000	10.9	8.78	.29	53.6	90	.8	654	168	-0	-0	29.2	38.3	5.2	579	172	21.4	15.9	-.0	1024	48
27	E D	2000	8.6	9.08	.28	53.0	93	-.0	745	172	-0	-0	29.0	41.9	3.1	582	189	21.5	15.8	-.0	1105	62
AVERAGES		2000	16.2	8.20	.26	60.1	82	.8	410	171	-0	-0	29.2	29.4	4.4	564	223	20.9	13.6	-.0	926	57
RMS ERRS		1	5.3	.64	.04	5.2	5	.0	197	2	-0	-0	.1	7.8	.6	24	52	.3	2.1	-.0	109	8

EFFECT OF GAS TEMPERATURE ON IGNITION DELAY WITH CITE FUEL (BATCH 19)
RUNS TAKEN AT CONSTANT MEAN PRESSURE DURING DELAY

DATA SET A2B HAVING 2 RUN(S) FOLLOWS. THE ATAC ENGINE WAS TESTED (INJECTOR OPENING PRESSURE SET AT 3000 PSIG) USING CT19 FUEL.

FOR RUN	USE W O	SPEED RPM	LOAD LBS	FUEL MIN	FUEL L/HR	AIR PSIG	AIR F	BLOW CFPM	TEMPERATURES(F) AIR	OUT	MIN	INC	ROOM<SURGE<@IVC<@INJ<RIS ROOM INHG	SURGE INHG	IVC PSI	INJ PSI	RIS PSI	DBTDC LIFT	AT START OF RISE	ILLUM	EXHAUST F	HU
29	E D	2000	11.3	8.58	.44	54.1	98	.7	598	172	-0	-0	29.1	35.4	3.6	580	175	20.3	14.5	-.0	978	30
30	E D	1999	9.1	8.84	.41	52.6	82	.8	701	171	-0	-0	29.2	40.6	6.5	595	169	21.1	15.8	-.0	1042	70
AVERAGES		2000	10.2	8.71	.42	53.3	90	.7	650	172	-0	-0	29.1	38.0	5.0	588	172	20.7	15.1	-.0	1010	50
RMS ERRS		0	1.1	.13	.01	.7	8	.0	52	0	-0	-0	.0	2.6	1.5	8	3	.4	.6	-.0	32	20

TABLE 12

COMPUTER DATA SHEET, COMPUTATION RESULTS, SERIES A2B FOR CITE FUEL

H/C RATIO = 1.992/1, DENSITY AT C = 48.79 #/CUFT, CLEARANCE VOLUME = 4.5610 CUIN, COMPRESSION RATIO = 16.69/1, IVC = 128 DBTDC

FOR	BRAKE	BMEP	BSFC	FUEL/	CYCLE(LBM/1000)			SURGE	EFF	@IVC	AT START OF INJECTION				AVERAGED DURING DELAY				DELAY(MSEC)	
RUN	HP	PSI	#/HRHP	AIR	AIR	BLOW	EXH	PSIA	PCT	F	INDEX	PSIA	#/CUFT	R	INDEX	PSIA	#/CUFT	R	PRISE	ILLUM
15	17.4	96.3	.453	.0325	4.04	-.00	.12	21.8	92.4	183	1.391	529	.953	1475	1.230	699	1.193	1550	1.041	-.000
16	14.8	81.9	.513	.0320	3.95	-.00	.13	23.4	92.7	245	1.381	564	.944	1586	1.220	711	1.141	1651	.867	-.000
17	14.8	81.9	.516	.0319	3.99	-.00	.14	25.4	93.6	260	1.380	582	.956	1617	1.234	711	1.124	1677	.733	-.000
18	15.1	83.4	.508	.0324	3.94	-.00	.14	26.8	94.2	298	1.379	602	.942	1696	1.237	725	1.095	1755	.675	-.000
19	12.1	67.1	.598	.0314	3.85	-.00	.14	27.4	96.4	353	1.357	604	.924	1735	1.218	715	1.062	1786	.625	-.000
20	9.9	54.6	.702	.0316	3.65	-.00	.13	27.6	96.8	400	1.349	605	.887	1811	1.242	714	1.014	1868	.600	-.000
21	9.9	55.0	.692	.0319	3.59	-.00	.14	26.6	96.9	441	1.331	589	.860	1818	1.290	687	.971	1880	.533	-.000
22	9.5	52.4	.699	.0312	3.54	-.00	.14	29.2	98.7	476	1.322	593	.849	1855	1.289	691	.958	1917	.533	-.000
23	8.1	45.0	.800	.0312	3.47	-.00	.14	30.3	98.8	521	1.312	600	.837	1904	1.259	689	.935	1957	.491	-.000
24	8.3	46.1	.771	.0310	3.45	-.00	.14	31.6	99.0	574	1.304	619	.833	1972	1.272	700	.920	2023	.433	-.000
26	7.2	39.8	.829	.0297	3.35	-.00	.15	33.8	98.9	638	1.310	641	.805	2114	1.243	726	.892	2165	.450	-.000
28	7.3	40.2	.871	.0320	3.30	.05	.15	33.2	99.5	669	1.294	617	.782	2097	1.229	701	.869	2146	.458	-.000
27	5.7	31.7	1.068	.0313	3.26	-.00	.15	34.8	101.1	671	1.304	620	.770	2141	1.286	712	.858	2205	.475	-.000
MEAN	10.8	59.6	.694	.0315	3.65	.05	.14	28.8	96.8	441	1.340	597	.873	1832	1.250	706	1.002	1891	.609	-.000
ERRS	3.5	19.6	.169	.0007	.27	.00	.01	3.8	2.7	161	.033	27	.064	202	.025	12	.107	198	.174	-.000

H/C RATIO = 1.999/1, DENSITY AT 60 = 48.84 #/CUFT, CLEARANCE VOLUME = 4.5610 CUIN, COMPRESSION RATIO = 16.69/1, IVC = 128 DBTDC

FOR	BRAKE	BMEP	BSFC	FUEL/	CYCLE(LBM/1000)			SURGE	EFF	@IVC	AT START OF INJECTION				AVERAGED DURING DELAY				DELAY(MSEC)	
RUN	HP	PSI	#/HRHP	AIR	AIR	BLOW	EXH	PSIA	PCT	F	INDEX	PSIA	#/CUFT	R	INDEX	PSIA	#/CUFT	R	PRISE	ILLUM
29	7.5	41.7	.827	.0315	3.30	.05	.15	31.7	98.8	580	1.307	615	.813	2009	1.214	701	.907	2054	.483	-.000
30	6.1	33.6	1.002	.0309	3.28	.05	.15	34.3	99.5	748	1.273	636	.786	2148	1.227	718	.870	2195	.442	-.000
MEAN	6.8	37.6	.915	.0312	3.29	.05	.15	33.0	99.2	664	1.290	626	.800	2078	1.220	709	.888	2125	.463	-.000
ERRS	.7	4.1	.088	.0003	.01	.00	.00	1.3	.4	84	.017	10	.014	69	.006	9	.018	70	.021	-.000

TABLE 13

COMPUTER DATA SHEET, COMPARISON WITH PREVIOUS WORK, SERIES A2B FOR CITE FUEL

FOR	EXPERIMENTAL		WOLFER		ELLIOT		SITKEI		TSAO		TSAO @ 1000	
RUN	PRD	ILD	START	MEAN	START	MEAN	START	MEAN	START	MEAN	START	MEAN
15	1.041	-.000	1.802	.985	2.621	2.460	2.738	1.805	.175	-.091	2.009	1.618
16	.867	-.000	1.121	.692	2.391	2.280	1.986	1.468	-.245	-.496	1.627	1.349
17	.733	-.000	.979	.641	2.337	2.240	1.820	1.407	-.372	-.610	1.528	1.289
18	.675	-.000	.736	.500	2.210	2.127	1.534	1.235	-.738	-.980	1.309	1.106
19	.625	-.000	.658	.468	2.154	2.087	1.440	1.195	-.931	-1.141	1.217	1.046
20	.600	-.000	.536	.382	2.056	1.990	1.290	1.086	-1.339	-1.581	1.049	.886
21	.533	-.000	.544	.389	2.048	1.978	1.302	1.096	-1.392	-1.667	1.044	.874
22	.533	-.000	.493	.354	2.006	1.939	1.238	1.050	-1.596	-1.876	.966	.804
23	.491	-.000	.432	.325	1.952	1.899	1.159	1.012	-1.885	-2.116	.866	.734
24	.433	-.000	.358	.278	1.886	1.840	1.061	.948	-2.274	-2.501	.734	.622
26	.450	-.000	.258	.203	1.766	1.728	.924	.843	-3.162	-3.374	.494	.404
28	.458	-.000	.279	.219	1.779	1.742	.954	.866	-3.089	-3.287	.526	.435
27	.475	-.000	.256	.194	1.746	1.701	.922	.830	-3.379	-3.666	.460	.351
MEAN	.609	-.000	.650	.433	2.073	2.001	1.413	1.142	-1.556	-1.799	1.064	.886
ERRS	.174	-.000	.420	.219	.254	.222	.496	.271	1.114	1.109	.451	.373

FOR	EXPERIMENTAL		WOLFER		ELLIOT		SITKEI		TSAO		TSAO @ 1000	
RUN	PRD	ILD	START	MEAN	START	MEAN	START	MEAN	START	MEAN	START	MEAN
29	.483	-.000	.333	.260	1.852	1.813	1.028	.924	-2.516	-2.697	.670	.572
30	.442	-.000	.245	.195	1.741	1.707	.906	.832	-3.397	-3.586	.445	.363
MEAN	.463	-.000	.289	.228	1.796	1.760	.967	.878	-2.957	-3.141	.558	.468
ERRS	.021	-.000	.044	.033	.056	.053	.061	.046	.440	.445	.112	.104

TABLE 14

COMPUTER DATA SHEET, RECORDED DATA, SERIES A2C FOR DIESEL FUEL

EFFECT OF GAS TEMPERATURE ON IGNITION DELAY WITH NO. 2 DIESEL FUEL
RUNS TAKEN AT CONSTANT MEAN PRESSURE DURING DELAY

DATA SET A2C HAVING 9 RUN(S) FOLLOWS. THE ATAC ENGINE WAS TESTED (INJECTOR OPENING PRESSURE SET AT 3000 PSIG) USING NO.2 FUEL.

FOR RUN	USE W	O	SPEED RPM	LOAD LBS	FUEL MIN	L/HR	AIR PSIG	F	BLOW CFFM	TEMPERATURES(F) AIR	OUT	MIN	INC	ROOM< INHG	SURGE< INHG	@IVC< PSI	@INJ< PSI	RIS PSI	DBTDC LIFT	AT START OF RISE	ILLUM	EXHAUST F	HU
41	E	D	2000	27.5	7.13	.06	74.1	73	.8	90	173	-0	-0	29.4	18.7	4.6	560	276	21.1	11.9	8.7	740	54
36	E	D	2000	23.0	7.96	.08	66.5	87	.9	217	168	-0	-0	29.2	23.2	4.5	568	237	21.0	13.4	11.0	803	50
33	E	D	2000	20.1	8.46	.04	61.5	81	.8	328	170	-0	-0	29.3	26.7	6.3	583	230	21.0	14.1	11.4	850	38
34	E	D	2000	17.9	8.89	.04	58.5	86	.9	418	170	-0	-0	29.3	29.8	6.8	596	221	21.0	14.4	14.6	888	33
37	E	D	2000	16.3	9.02	.06	56.5	77	.8	474	171	-0	-0	29.0	31.9	4.8	606	171	21.0	15.6	14.7	909	26
43	E	D	2000	15.8	9.11	.07	56.3	83	.8	509	171	-0	-0	29.0	33.4	5.2	607	173	21.1	15.7	14.0	917	27
39	E	D	2000	14.5	9.40	.09	53.5	80	.7	555	171	-0	-0	29.0	33.4	4.8	602	182	21.0	15.3	14.9	944	31
40	E	D	2000	13.5	9.43	.10	52.9	87	.8	623	169	-0	-0	29.0	36.9	4.1	612	192	21.2	15.4	15.7	985	28
44	D	C	2001	11.2	4.88	.07	73.0	87	.8	702	170	-0	-0	29.0	38.9	5.5	597	180	21.4	15.9	16.1	997	40
AVERAGES			2000	17.8	8.25	.07	61.4	82	.8	435	170	-0	-0	29.1	30.3	5.2	592	207	21.1	14.6	13.5	893	36
RMS ERRS			0	4.8	1.38	.02	7.6	5	.1	184	1	-0	-0	.2	6.1	.8	17	34	.1	1.2	2.4	79	10

TABLE 15

COMPUTER DATA SHEET, COMPUTATION RESULTS, SERIES A2C FOR DIESEL FUEL

H/C RATIO = 1.837/1, DENSITY AT 60 = 51.60 #/CUFT, CLEARANCE VOLUME = 4.5610 CUIN, COMPRESSION RATIO = 16.69/1, IVC = 128 DBTDC

FOR	BRAKE	BMEP	BSFC	FUEL/	CYCLE(LBM/1000)			SURGE	EFF	@IVC	AT START OF INJECTION				AVERAGED DURING DELAY				DELAY(MSEC)	
RUN	HP	PSI	#/HRHP	AIR	AIR	BLOW	EXH	PSIA	PCT	F	INDEX	PSIA	#/CUFT	R	INDEX	PSIA	#/CUFT	R	PRISE	ILLUM
41	18.3	101.4	.452	.0316	4.37	.05	.13	23.6	91.1	178	1.408	588	1.031	1513	1.208	722	1.223	1565	.767	1.033
36	15.3	84.8	.481	.0312	3.94	.06	.14	25.7	92.8	295	1.381	598	.937	1694	1.244	713	1.080	1751	.633	.833
33	13.4	74.1	.523	.0314	3.72	.05	.14	27.5	95.4	431	1.344	617	.887	1845	1.291	728	1.010	1913	.575	.800
34	11.9	66.0	.559	.0313	3.55	.06	.15	29.0	96.4	525	1.328	632	.851	1972	1.273	739	.963	2037	.550	.533
37	10.9	60.1	.601	.0313	3.48	.05	.15	29.9	97.4	513	1.349	641	.834	2040	1.210	724	.924	2083	.450	.525
43	10.5	58.3	.612	.0312	3.45	.05	.15	30.6	97.8	553	1.338	643	.825	2070	1.218	727	.914	2114	.450	.592
39	9.7	53.5	.643	.0312	3.32	.05	.15	30.6	98.6	579	1.337	637	.798	2123	1.222	726	.889	2172	.475	.508
40	9.0	49.8	.686	.0314	3.27	.05	.15	32.4	98.1	623	1.336	648	.781	2205	1.238	742	.872	2261	.483	.458
44	7.5	41.3	.807	.0316	3.18	.05	.15	33.3	99.4	724	1.302	636	.756	2236	1.247	723	.839	2292	.458	.441
MEAN	11.8	65.5	.596	.0314	3.59	.05	.15	29.2	96.3	491	1.347	627	.856	1966	1.239	727	.968	2021	.538	.636
ERRS	3.2	17.6	.103	.0002	.35	.00	.01	2.9	2.6	158	.029	20	.081	227	.027	8	.114	226	.101	.193

TABLE 16

COMPUTER DATA SHEET, COMPARISON WITH PREVIOUS WORK, SERIES A2C FOR DIESEL FUEL

FOR	EXPERIMENTAL		WOLFER		ELLIOT		SITKEI		TSAO		TSAO @ 1000	
RUN	PRD	ILD	START	MEAN	START	MEAN	START	MEAN	START	MEAN	START	MEAN
41	.767	1.033	1.377	.897	2.535	2.430	2.259	1.703	.041	-.146	1.817	1.560
36	.633	.833	.747	.516	2.213	2.132	1.547	1.255	-.729	-.965	1.317	1.120
33	.575	.800	.481	.336	2.016	1.943	1.220	1.025	-1.520	-1.821	.973	.800
34	.550	.533	.349	.253	1.886	1.828	1.048	.913	-2.261	-2.548	.729	.590
37	.450	.525	.298	.237	1.825	1.790	.979	.891	-2.683	-2.851	.610	.523
43	.450	.592	.280	.222	1.800	1.765	.954	.870	-2.871	-3.049	.562	.475
39	.475	.508	.256	.200	1.759	1.724	.921	.839	-3.228	-3.423	.482	.394
40	.483	.458	.216	.168	1.701	1.664	.865	.792	-3.771	-3.997	.361	.274
44	.458	.441	.210	.164	1.680	1.645	.856	.787	-4.016	-4.245	.321	.237
MEAN	.538	.636	.468	.333	1.935	1.880	1.183	1.008	-2.337	-2.561	.797	.664
ERRS	.101	.193	.359	.224	.264	.240	.432	.281	1.291	1.286	.466	.408

TABLE 17

COMPUTER DATA SHEET, RECORDED DATA, SERIES A2D FOR GASOLINE FUEL

EFFECT OF GAS TEMPERATURE CN IGNITION DELAY WITH MILG FUEL
RUNS TAKEN AT CONSTANT MEAN PRESSURE DURING DELAY

DATA SET A2D HAVING 7 RUN(S) FOLLOWS. THE ATAC ENGINE WAS TESTED (INJECTOR OPENING PRESSURE SET AT 3000 PSIG) USING MILG FUEL.

FOR RUN	USE W	O	SPEED RPM	LOAD LBS	FUEL MIN	FUEL L/HR	AIR PSIG	AIR F	ELCW CFPM	TEMPERATURES(F) AIR	OUT	MIN	INC	ROOM<SURGE<@IVC<@INJ<RIS ROOM INHG	SURGE INHG	@IVC PSI	@INJ PSI	RIS PSI	DBTDC LIFT	AT START OF RISE	ILLUM	EXHAUST F	HU
52	E	D	2001	20.4	8.80	.33	54.0	89	.8	106	169	-0	-0	28.9	8.8	4.1	446	336	21.0	-4.7	-5.0	724	6
53	E	D	2001	17.7	8.82	.36	53.0	87	.9	212	172	-0	-0	28.9	14.8	6.2	483	390	21.0	4.0	3.5	760	14
54	D	D	2000	14.3	4.58	.42	49.5	93	.7	308	170	-0	-0	29.0	17.0	5.6	505	326	20.8	8.1	6.4	797	14
55	D	D	2000	14.2	4.62	.40	48.5	86	.8	408	172	-0	-0	29.0	21.9	5.0	529	281	21.1	11.2	10.7	875	12
56	D	D	1999	11.9	4.75	.39	46.6	90	.9	499	172	-0	-0	29.0	25.0	5.0	549	252	21.0	12.4	13.4	907	18
57	D	D	1999	11.0	4.84	.39	46.0	86	1.0	600	169	-0	-0	29.0	29.6	5.4	576	189	21.0	14.9	15.1	946	19
58	D	C	2001	9.7	4.99	.40	62.5	90	.9	697	172	-0	-0	29.0	31.6	5.9	581	188	21.0	14.9	16.0	1008	19
AVERAGES			2000	14.2	5.91	.38	51.4	89	.9	404	171	-0	-0	29.0	21.2	5.3	524	280	21.0	8.7	8.6	860	15
RMS ERRS			1	3.5	1.84	.03	5.3	2	.1	196	1	-0	-0	.0	7.6	.6	46	71	.1	6.5	7.0	96	4

TALBE 18

COMPUTER DATA SHEET, COMPUTATION RESULTS, SERIES A2D FOR GASOLINE FUEL

H/C RATIO = 2.141/1, DENSITY AT 60 = 45.87 #/CUFT, CLEARANCE VOLUME = 4.5610 CUIN, COMPRESSION RATIO = 16.69/1, IVC = 128 DBTDC

FOR	BRAKE	BMEP	BSFC	FUEL/	CYCLE(LBM/1000)			SURGE	EFF	@IVC	AT START OF INJECTION				AVERAGED DURING DELAY				DELAY(MSEC)	
RUN	HP	PSI	#/HRHP	AIR	AIR	BLOW	EXH	PSIA	PCT	F	INDEX	PSIA	#/CUFT	R	INDEX	PSIA	#/CUFT	R	PRISE	ILLUM
52	13.6	75.3	.461	.0316	3.31	.05	.10	18.5	90.7	213	1.402	469	.786	1587	1.138	710	1.129	1665	2.141	2.166
53	11.8	65.3	.526	.0316	3.27	.06	.12	21.5	91.8	370	1.349	511	.779	1743	1.172	717	1.039	1827	1.416	1.458
54	9.5	52.8	.617	.0318	3.09	.05	.12	22.6	94.1	434	1.356	533	.743	1908	1.177	696	.931	1982	1.058	1.200
55	9.5	52.4	.619	.0319	3.06	.05	.13	25.0	95.2	498	1.356	559	.730	2037	1.207	696	.875	2112	.825	.867
56	7.9	43.9	.719	.0321	2.96	.06	.13	26.5	95.9	578	1.348	581	.710	2174	1.208	703	.833	2244	.717	.634
57	7.3	40.6	.762	.0317	2.94	.07	.14	28.8	97.0	669	1.333	610	.708	2293	1.234	702	.794	2353	.509	.492
58	6.5	35.8	.831	.0322	2.79	.06	.14	29.8	97.1	780	1.319	617	.672	2441	1.217	708	.754	2500	.508	.416
MEAN	9.4	52.3	.648	.0318	3.06	.06	.12	24.7	94.5	506	1.352	554	.733	2026	1.193	705	.908	2098	1.025	1.033
ERRS	2.3	13.0	.121	.0002	.17	.01	.01	3.8	2.3	176	.024	50	.038	281	.030	7	.125	273	.543	.580

TABLE 19

COMPUTER DATA SHEET, COMPARISON WITH PREVIOUS WORK, SERIES A2D FOR GASOLINE FUEL

FOR	EXPERIMENTAL		WOLFER		ELLIOT		SITKEI		TSAO		TSAO @ 1000	
RUN	PRD	ILC	START	MEAN	START	MEAN	START	MEAN	START	MEAN	START	MEAN
52	2.141	2.166	1.398	.665	2.390	2.258	2.341	1.435	-.265	-.559	1.741	1.317
53	1.416	1.458	.786	.420	2.144	2.037	1.616	1.135	-1.032	-1.358	1.272	.963
54	1.058	1.200	.493	.304	1.948	1.876	1.248	.984	-1.984	-2.258	.894	.689
55	.825	.867	.353	.235	1.827	1.767	1.060	.889	-2.786	-3.073	.643	.485
56	.717	.634	.260	.184	1.722	1.675	.931	.816	-3.688	-3.944	.419	.300
57	.509	.492	.201	.155	1.644	1.610	.845	.774	-4.474	-4.704	.248	.165
58	.508	.416	.159	.124	1.563	1.534	.783	.727	-5.568	-5.769	.066	.000
MEAN	1.025	1.033	.521	.298	1.891	1.822	1.261	.966	-2.828	-3.095	.755	.560
ERRS	.543	.580	.409	.176	.272	.237	.513	.230	1.751	1.716	.550	.430