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Technical Report

No. 13502

SPARK-IGNITED DIESEL ENGINE (U)

CONTRACT DAAE07-84-C-R047
and DAAE07-85-C-R054

NOVEMBER 1990

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) 9Y235	5. MONITORING ORGANIZATION REPORT NUMBER(S) 13502
6a. NAME OF PERFORMING ORGANIZATION COMBUSTION ELECTROMAGNETICS INCORPORATED 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION USTACOM
6c. ADDRESS (City, State, and ZIP Code) 32 Prentiss Road Arlington, MA 02174	7b. ADDRESS (City, State, and ZIP Code) Warren, MI 48397-5000
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAAE07-84-C-R047 and DAAE07-85-C-R054
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
SPARK-IGNITED DIESEL ENGINE (U)

12. PERSONAL AUTHOR(S)
WARD, MICHAEL A. V. (President)

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
FINAL	FROM 84April TO 90July	90-11-27	

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	INTERNAL COMBUSTION ENGINE IGNITION SPARK ASSISTED DIESEL ENGINES

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Conventional diesel engines suffer from problems of excessive weight and size and excessively high rates of pressure rise and peak pressure because of the requirement of very high-compression ratios for the purpose of ignition. They also lack multi fuel capability. The use of electrical or other precise ignition means obviates the dependence on high compression for ignition and would allow the diesel engine to operate at the more efficient and practical compression ratio of 12 to 1. To accomplish this, an innovative ignition system with an unusually high rate of energy delivery was used in conjunction with a modified diesel engine. This new design was found to provide approximately equal efficiency under most operating conditions other than high load, and to provide instant cold start at the more desirable compression ratio of between 11 to 12 to 1. However, problems of spark plug fouling by the fuel spray made this approach impractical for this specific application. Approaches for handling the problem of plug fouling have been suggested in this report.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL ELLSWORTH C. ADAMS	22b. TELEPHONE (Include Area Code) (313) 574-6147 22c. OFFICE SYMBOL AMSTA-RGRD

DD Form 1473, JUN 86 Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

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1.0 INTRODUCTION

This final technical report, prepared by Combustion Electromagnetics Inc., CEI, for the U.S. Army Tank-Automotive Command (TACOM), under contract DAAE07-84-C-R047 and DAAE07-85-C-R054, describes the prototype engine developed for achieving the objectives of this contract including the fuel injector and ignition system used, and the test results obtained. A Deutz F1L511D, single-cylinder, air-cooled, direct-injection diesel engine of 50 cubic-inch displacement was used as the base engine and was modified from the crankcase up into the prototype engine. The engine was tested both in its completed prototype form and in baseline form. The SuperFlow Computerized Engine Dynamometer and the Geneva APA 100 were used to conduct the tests and to collect all the required data.

2.0 OBJECTIVE

The primary goal of this work was to modify a high-power and high-energy ignition system developed by CEI (the "CEI Ignition") to be made suitable for Direct-Injection IC engines and to test it on a prototype engine of appropriate design, developed by CEI, by modifying an existing high-efficiency diesel engine. The engine would be modified to have a moderate compression ratio, no swirl, and moderate to high squish to help improve the air-fuel mixing and to speed up the burn. Cold start at the lower compression ratio would be achieved through use of the ignition. The expected results are a significant reduction in both the peak combustion pressures and in the rate of rise of pressure. This, in turn, was expected to provide a high engine efficiency, a low-heat transfer, and a multi fuel capability.

The single-cylinder prototype test engine would be designed to accommodate a central fuel injector and a dual (CEI) pulsed type discharge ignition for igniting the fuel spray and for coupling electrical energy to the flame front during the ignition and early combustion periods. The baseline and prototype engine would be dynamometer tested on a SuperFlow Computerized Engine Dynamometer Test Bed to assess both the benefits of the dual ignition system and the benefits of the engine design. The Geneva APA 100 would be used for in-cylinder measurements using a pressure transducer.

3.0 CONCLUSIONS

The new ignition and engine system was successful in meeting most of the contract objectives, but was unsuccessful in that the spark plug suffered from a persistent fouling problem due to contamination by the injected fuel. In addition, the combination of the required high spark breakdown voltage and the plug contamination made for an especially stressful environment for the ignition. This has led to the regrettable conclusion that, without further research to prove otherwise, high-power, high-energy ignition, i.e., CEI ignition, is not considered to be a practical approach at this time for controlling early-stage combustion in diesel engines. If there existed a demonstrated strong desire to pursue such an approach, then the research should include studies of fuel contamination of ceramics and possible ways to alleviate it, including the possible use of extended ceramic plugs and the possible development of a dual glow plug/spark plug.

4.0 RECOMMENDATIONS

4.1. Ignition/Engine Modifications

As stated in the "Conclusion" section, use of the CEI ignition in diesel engines is not recommended, unless work is successfully performed to develop ways to handle the combined problems of plug fouling and a very high ignition voltage requirement. However, a possible design will be presented which uses an unusually long insulator nose to minimize the plug-fouling problem, and a plug-tip location to provide a possible self-cleansing action by strong squish flow fields. Also, piston firing will be recommended to provide for the largest possible plug gap and elimination of the ground or "J" electrode.

4.2. Alternative Engines

CEI recommends taking a totally different approach in terms of engine type and design for meeting the objectives of a multi fuel direct injection engine with a high power to weight ratio; i.e., a lighter weight engine than the current diesel. Development of a low effective compression ratio two-stroke engine for this application is recommended as well as a low cost, low-pressure fuel injection system designed for early injection into a high-flow field which will promote mixing.

5.0. DISCUSSION

5.1. Background

There is a need to increase the diesel engine's capabilities for burning a variety of fuels and to reduce its weight and size. In addition, there is an advantage to reducing the engine heat transfer losses so that an air-cooling system, versus a water-cooling system, can be used. It is desired to accomplish these goals while maintaining or improving the engine efficiency, preferably while improving the engine's exhaust emission levels.

One way to achieve some of the desired goals is to better control the flame initiation process. This can be done in several ways, such as by using some electrical initiation means, e.g., a spark plug, or by using an electronically controlled fuel injection system. Electronic fuel injection still requires compression ignition as the ignition process, and therefore requires a very high compression ratio of 17:1 to 24:1, which is detrimental from the perspective of reducing engine size, weight, and heat transfer, and optimizing engine efficiency. An ignition system, on the other hand, is compatible with a lower compression ratio, including the compression ratio (CR) where best efficiency is achieved, i.e., 11 to 13 to 1 CR for the typical diesel engine. However, as was discovered in this work, the diesel-engine environment is particularly harsh for an ignition system from the perspective of plug fouling and high cylinder pressures.

However, it is clear that if the time of flame initiation can be specified as a function of engine RPM and load (as it is in a gasoline engine) and the engine can be operated at a moderate compression ratio, then the desired goals mentioned above can be met, and in addition, slightly higher engine efficiency can be achieved, as well as a substantially lower rate of rise of pressure, (one of the principal problems of the diesel engine).

5.2. Fuel Injection System

Considerable research was done on identifying suitable fuel injection nozzle characteristics for this contract. The results of this research were reported in Technical Report No. 5, which is included as part of Appendix A. The principal results related to spray pattern, including spray angle and spray traversal with time. The results indicate that a nozzle with 12 holes of approximately 0.006 inches diameter was suitable for achieving the objectives of good mixing and good utilization of the air. Such a design produced a spray which required 1.5 to 2.0 msecs to reach the spark plugs located one inch away, or approximately 20 crank angle degrees at a speed of approximately 2,000 RPM. A drawing and specification of the fuel injector tip is shown in Figure 5-1.

For the fuel pump, it was decided to use the pump that comes standard with the engine. Attempts to obtain special research type fuel injection systems from major manufacturers were unsuccessful. In fact, it was a disappointment that none of the major fuel injector manufacturers were interested in collaborating on this project. This resulted in some delays and reconsidering of approaches. In the end, as indicated in Figure 5-1, blank nozzle tips were obtained from United Technologies, Italy, and these were successfully laser drilled at a local facility. Testing with a hand-operated fuel injection pump indicated a suitable spray pattern, i.e., a circularly uniform spray pattern with good atomization. As is also indicated in Figure 5-1, the two holes located along the line joining the spark plugs were of a slightly larger diameter, i.e. 0.008" diameter, to insure that slightly more fuel mixture would be injected at the park plug sites.

Open chamber ignition of the fuel spray was not performed because of time limitations. Also, this had been investigated in the Phase I part of the contract, where it was shown that reliable ignition was achievable even at room temperature.

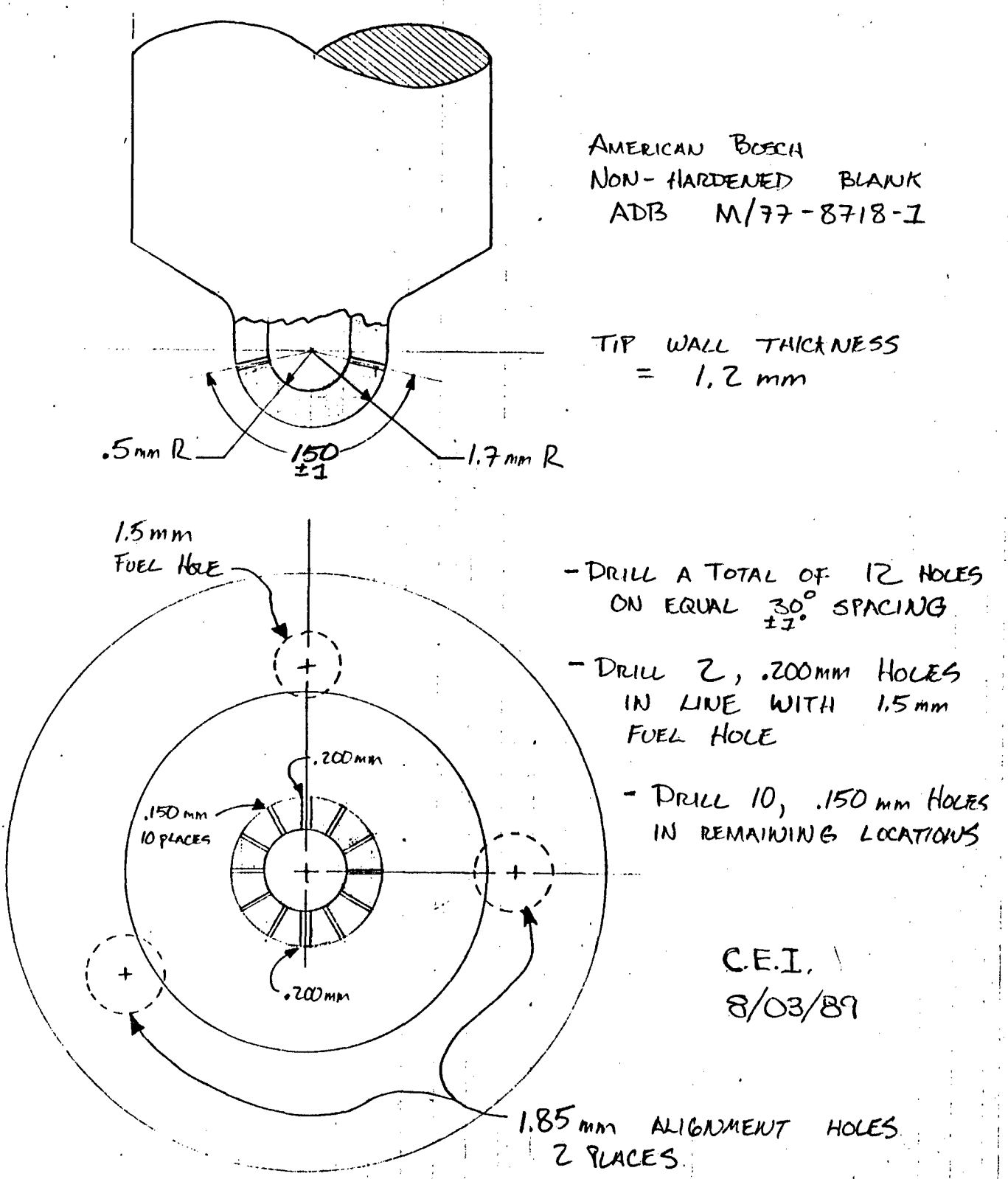


Figure 5-1. Fuel Injector Tip with Specifications

5.3. Ignition System

The ignition system used under this contract was developed by CEI which had an unusually high rate of energy delivery and the ability to deliver very rapid spark pulses in a single ignition and combustion duration.

Since the beginning of the contract, the CEI ignition went through a significant evolutionary process, to the point that when the engine tests were initiated, the ignition was near what is now deemed to be its final stage of development. One of the principal new features of the ignition was the development of a recharge circuit which delivered energy to the discharge capacitor between the very rapidly firing spark pulses of the pulse train, so that the amplitude of the spark pulses was maintained near the maximum level throughout the ignition firing period. A circuit drawing of the ignition is shown in Figure 5-2.

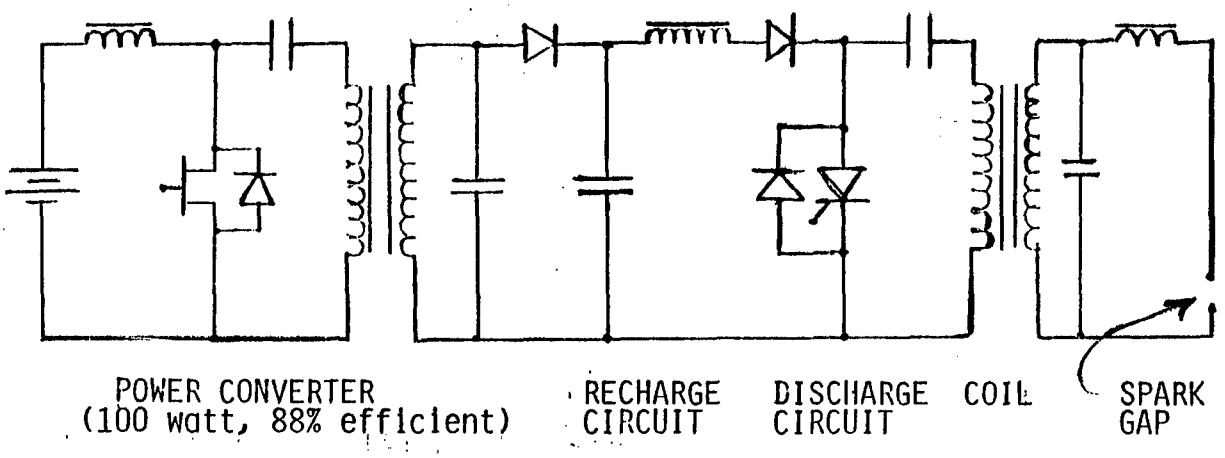
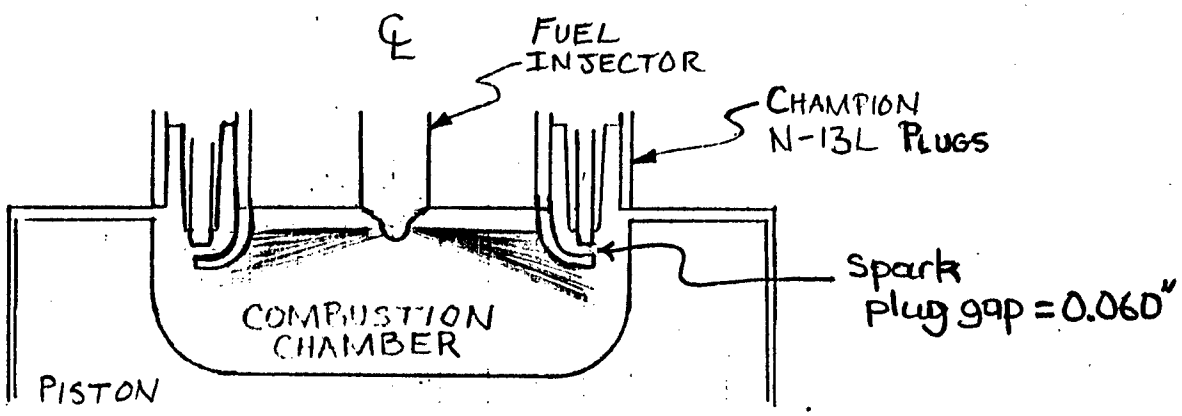


Figure 5-2. Ignition System Circuit Drawing

Two spark plugs were used in the engine, as is shown in Figure 5-3. They were placed symmetrically, one inch from the centrally located fuel injector. The objective was to initiate combustion at these two sites so that the burn time could be reduced (for a centrally located fuel injector). However, as will be discussed in Section 5.7 under "Alternatives", it is believed that most of the benefits of the ignition can be attained by the careful repositioning of both the fuel injector and the spark plug, with only one spark plug per cylinder being required. The use of one spark plug per cylinder is clearly advantageous in terms of simplicity and cost.

A typical (primary voltage) sequence of spark pulses ranges between about thirty pulses of approximately constant amplitude at low engine speeds to five pulses at high engine speeds. For the high engine speed condition, the time duration between pulses is approximately 0.25 msecs, resulting in the delivery of five ignition pulses within one millisecond. This is important given that the fuel spray velocity at the spark plug site is approximately 0.5 cm per msec, which would create five ignition sites over a length of 0.5 cm defined by the radius of the spark plug end. The first power converter that was developed for this contract work, designated as REDL3, was not used, as it was superseded by a more efficient and suitable system recently developed by CEI, shown in circuit form in Figure 5-2.



COMPRESSION RATIO	:	12 to 1
BORE x STROKE	:	3.90" x 4.13"
HEAD CLEARANCE	:	.065"
PISTON BOWL VOLUME	:	58 cc

Figure 5-3. Cross-section of Combustion Chamber

5.4. Engine Measurement Equipment

Two pieces of equipment were purchased under this contract for the purpose of performing the engine testing: An engine dynamometer with computer data acquisition capability, the SuperFlow SF 901, and equipment for measuring the in-cylinder combustion processes, the Geneva APA 100.

The SuperFlow SF 901 is a complete engine dynamometer test stand which comes with a test stand for mounting the engine and a dial for varying the torque provided by the water brake. It is suitable for at least 500 horsepower. As part of the contract, a computer terminal was purchased which permitted communication with the main electronic test stand to perform calibrations and to develop averaging schemes as part of the data acquisition.

Standard with the SuperFlow is the ability to measure typical engine parameters such as RPM, torque, power, fuel flow, air flow, brake specific fuel consumption (BSFC), manifold pressure, water temperature, and oil temperature. A sample of the data is shown in Figure 5-4. Considerable work was performed to calibrate the system and to make it suitable for the diesel engine. For fuel measurements, a back-up weighing technique had to be implemented, since it was found that the pulsations created by the fuel pump produced errors in the measurements (by the fuel flow turbine). Furthermore, the higher viscosity of the diesel fuel affected the operation of the fuel flow meter.

A large air ballast was fabricated and installed to dampen the greater air fluctuations caused by the single-cylinder engine. The undamped pulsations gave a higher apparent air-flow reading.

The APA 100 required significant troubleshooting to get it to operate to specification. However, while this was an inconvenience, the manufacturer of the unit made himself totally available in helping eliminate problems in the system. In the end, the unit was found to operate sufficiently to allow appropriate pressure versus time curves to be obtained, and to permit proper averaging between cycles of the various key parameters, principally peak pressure and rate of rise of pressure. A typical output data curve is shown in Figure 5-5. The heat output data was suspect, and it was determined as not essential for the level of study that was being performed.

COMBUSTION ELECTROMAGNETICS INC.
32 PRENTISS ROAD
Arlington, Massachusetts 02174
PHONE: (617) 641-0520

Test Number: 29
Date (M/D/Y): 12/23/88 Time (H:M:S): 09:57:38 Operator: Pollhammer
Engine description: Deutz F1L511 STOCK
Test description: 1500 RPM, MAX LOAD, Fuel #2

Test: 2.00 Seconds/Data Point Fuel Spec. Grav.: .832 Air Sensor: 4.0
Vapor Pressure: .37 Barometric Pres.: 29.38 Ratio: 1.00 TO 1
Engine Type: 4-Cycle Diesel Engine displacement: 50.0 Stroke: 4.130

Speed rpm	Trq lb-ft	Pwr Hp	FA-FB lb/hr	A1 scfm	A/F	BSFC lb/Hohr	BSAC	Man-P in Hg	Oil psi	CAT F	Fuel F	Oil Out	Wat Out
1497	21.4	6.1	2.3	21.4	42.7	.38	16.10	-51.47	.0	65	159	155	0
1505	21.1	6.0	2.2	21.5	44.9	.37	16.45	-51.47	.0	65	159	155	0
1498	21.4	6.1	2.2	21.5	44.9	.36	16.18	-51.47	.0	64	159	155	0
1495	21.7	6.2	2.3	21.5	42.9	.37	15.92	-51.47	.0	63	159	155	0
1494	21.6	6.1	2.3	21.5	42.9	.38	16.18	-51.47	.0	63	159	154	0
1498	21.4	6.1	2.4	21.5	41.1	.39	16.18	-51.47	.0	64	158	154	0
1498	21.2	6.0	2.4	21.5	41.1	.40	16.45	-51.47	.0	64	158	154	0
1496	21.4	6.1	2.7	21.5	36.6	.44	16.18	-51.47	.0	65	159	154	0
1498	21.4	6.1	2.4	21.5	41.1	.39	16.18	-51.47	.0	64	158	155	0
1501	21.0	6.0	2.3	21.5	42.9	.38	16.45	-51.47	.0	64	159	155	0
1501	21.1	6.0	2.4	21.5	41.1	.40	16.45	-51.47	.0	64	159	155	0
1493	21.6	6.1	2.2	21.5	44.9	.36	16.18	-51.47	.0	64	160	156	0
1497	21.5	6.1	2.1	21.5	47.0	.34	16.18	-51.47	.0	63	159	155	0
1491	21.6	6.1	2.3	21.5	42.9	.38	16.18	-51.47	.0	63	159	155	0
1496	21.6	6.2	2.3	21.5	42.9	.37	15.92	-51.47	.0	62	158	155	0
1501	21.0	6.0	2.4	21.5	41.1	.40	16.45	-51.47	.0	62	158	154	0
1500	21.1	6.0	2.2	21.6	45.1	.37	16.52	-51.47	.0	62	158	153	0
1497	21.5	6.1	2.4	21.6	41.3	.39	16.25	-51.47	.0	62	158	154	0
1497	21.4	6.1	2.5	21.5	39.5	.41	16.18	-51.47	.0	62	158	155	0
1496	21.4	6.1	2.6	21.5	38.0	.43	16.18	-51.47	.0	63	158	156	0
1497	21.1	6.0	2.7	21.5	36.6	.45	16.45	-51.47	.0	63	159	156	0
1499	20.9	6.0	2.5	21.5	39.5	.42	16.45	-51.47	.0	64	159	156	0
1500	21.0	6.0	2.4	21.5	41.1	.40	16.45	-51.47	.0	63	158	156	0
1502	21.0	6.0	2.3	21.5	42.9	.38	16.45	-51.47	.0	63	159	155	0
1498	21.2	6.0	2.3	21.5	42.9	.38	16.45	-51.47	.0	64	159	155	0
1502	21.0	6.0	2.4	21.5	41.1	.40	16.45	-51.47	.0	64	158	154	0
1496	21.5	6.1	2.4	21.5	41.1	.39	16.18	-51.47	.0	62	158	154	0
1494	21.2	6.0	2.3	21.5	42.9	.38	16.45	-51.47	.0	62	158	154	0
1499	21.1	6.0	2.3	21.5	42.9	.38	16.45	-51.47	.0	63	159	154	0
1497	21.4	6.1	2.2	21.5	44.9	.36	16.18	-51.47	.0	63	158	155	0
1493	21.2	6.0	2.4	21.5	41.1	.40	16.45	-51.47	.0	63	158	156	0
1497	21.2	6.0	2.3	21.5	42.9	.38	16.45	-51.47	.0	63	159	155	0
1499	21.4	6.1	2.4	21.5	41.1	.39	16.18	-51.47	.0	63	160	156	0
1501	21.6	6.2	2.4	21.5	41.1	.39	15.92	-51.47	.0	64	159	156	0
1495	21.7	6.2	2.5	21.4	39.3	.40	15.84	-51.47	.0	65	158	156	0
	21.3	6.1		21.5						64	159	156	

1st 20gr in 63.00 sec = 2.52 → 2.54 lbs/HR
2ND 20gr in 61.93 sec = 2.56

COMBUSTION ELECTROMAGNETICS, INC.

9-Jan-89
10:47:56

12-JAN-89
13:48:11

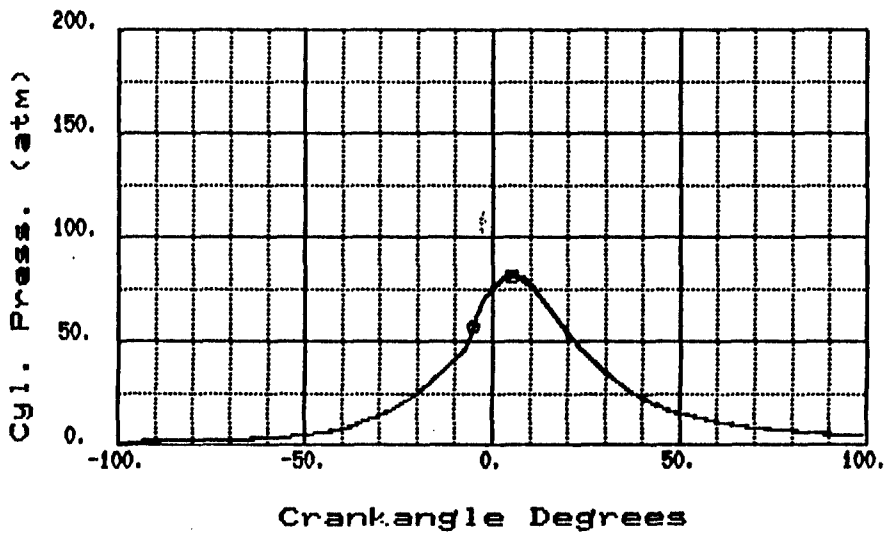
Indicated Data vs Crankangle

Engine : DEUTZ F1L 511
Cell : Superflow
Project : TACOM Baseline

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	17.00	Intake	=	328.5,-120.5
Ign Timing	=	984.0 Deg	Exhaust	=	108.5, 392.5
Engine Speed	=	1535.0 rpm	Engine Torque	=	28.48 N-m

APA100: U.S. Army Tank Automotive Command

Title f de03ja.016



DATA MARKERS :

Pmax =	80.9975
@	5.00
dPmax=	5.6322
@	-5.00

Double-triangle is valve timing.

Figure 5-5. Typical APA 100 Pressure Data

5.5. Engine Design

For the purposes of this contract work, a single-cylinder, air-cooled diesel engine was determined to be suitable. A study was conducted of readily available commercial single-cylinder engines. After careful evaluation, a Deutz F1L511D engine was selected, as this was a high-efficiency engine and therefore represented a suitably challenging baseline. The engine was of approximately 4 inch bore and stroke with an approximately 50 cubic-inch displacement. The more complete engine specifications are given below.

Bore/Stroke:	3.94/4.13 in (100/105 mm)
Displacement:	50 cubic inches (0.825 Liters)
CR:	17:1
Maximum output:	14 hp @ 3000 RPM
Maximum torque:	27 ft.lbs @ 2000 RPM
Minimum idling speed:	900 RPM
BSFC @ maximum torque:	0.385 lbs/hp-hr
Engine weight:	242 lbs (110 kg)

After some study, it was concluded that the best way to incorporate the new design was to completely replace the existing engine cylinder and cylinder head but to retain the engine's piston. The piston was modified by having the face appropriately machined to increase the bowl size for a compression ratio of approximately 12 to 1 (see Figure 5-3). A cast-iron cylinder and cylinder head were designed and fabricated to CEI specifications. With the exception of the rocker mounts, all parts were hand machined. The cylinder head was flat with vertical valves since the combustion chamber was contained entirely inside the piston. This also simplified machining of the parts.

For the combustion chamber located inside the piston, it was decided to use a high-squish combustion chamber similar to the existing one used in the engine in its baseline condition. The combustion chamber, which took the form of a bowl-in-piston, was designed such that the two spark plugs closely defined the outer edges of the bowl. The fuel injector was designed with a 150 degree included angle so that the fuel spray would move mainly against the air flow created by the squish to promote mixing of the air and fuel. This angle was also chosen so that injected fuel would reach the spark plug sites for ignition.

5.6. Engine Testing and Results

The engine was mounted on the SuperFlow computerized engine dynamometer for testing. Special mounts were made for the engine because of its high level of vibration. The mounts were made of four-inch square cross-section aluminum stock and were found to perform satisfactorily. In addition, the entire frame of the dynamometer was anchored to the floor by means of large blocks of wood spanning its width and shock-mounted to the floor through heavy duty machinery rubber mounts. These modifications were found to be sufficient to handle the engine. For pressure measurement, a water-cooled standard piezotronics pressure transducer was used, which was mounted in the cylinder head.

Initial tests were conducted to calibrate air flow and fuel flow. During these tests, it was discovered that the fuel-flow meter would not give reliable data because of pulsations in the fuel line and the high viscosity of the fuel, which was standard diesel fuel available at local gas stations. Therefore, a back-up weighing technique was devised so that when actual data was being taken, fuel consumption for a precise period of time was determined by w the time measurement.

Measurements were made at four engine speeds: 1500, 2000, 2500, and 2800 RPM. For each engine speed three load settings were taken: 10 ft. lbs, 20 ft. lbs, and a maximum load which was typically 27 ft lbs. Measurements included printing of the complete data provided by the SuperFlow engine dynamometer computer (Figure 5-4), with the fuel flow being measured independently via the weighing technique. This permitted evaluation of BSFC, for each point. In addition, the APA 100 was operated at each point to provide peak pressure and maximum rate of rise of pressure at each point (see Figure 5-5 for sample data).

Summaries of the baseline data are shown for the three torque conditions in Figures 5-6, 5-7, 5-8. The same figures show the data that were taken later with the engine in its final redesigned form.

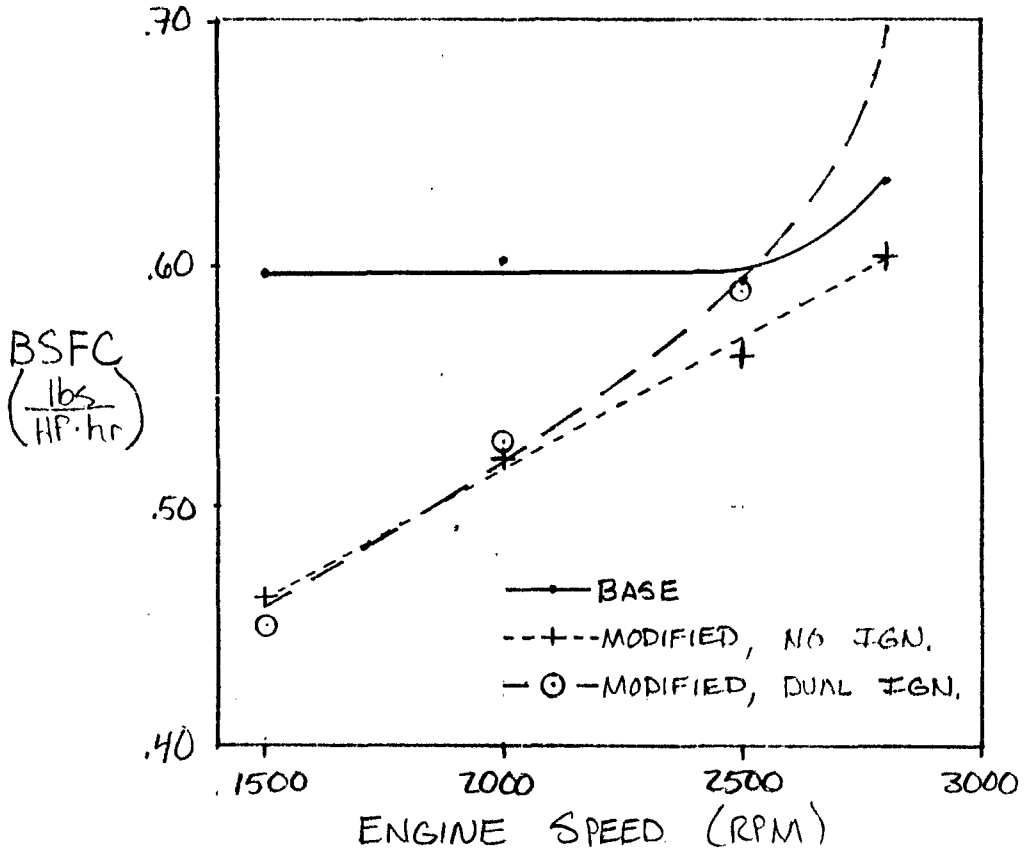


FIGURE 5-6, B.S.F.C. VERSUS R.P.M. @ 10 FT·LBS TORQUE

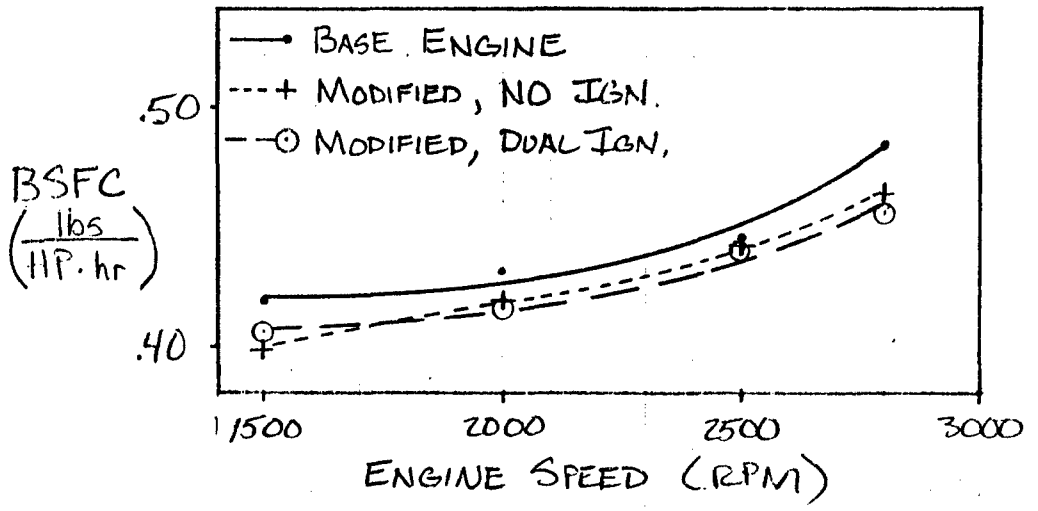


FIGURE 5-7, B.S.F.C. VERSUS R.P.M. @ 20 FT·LBS TORQUE

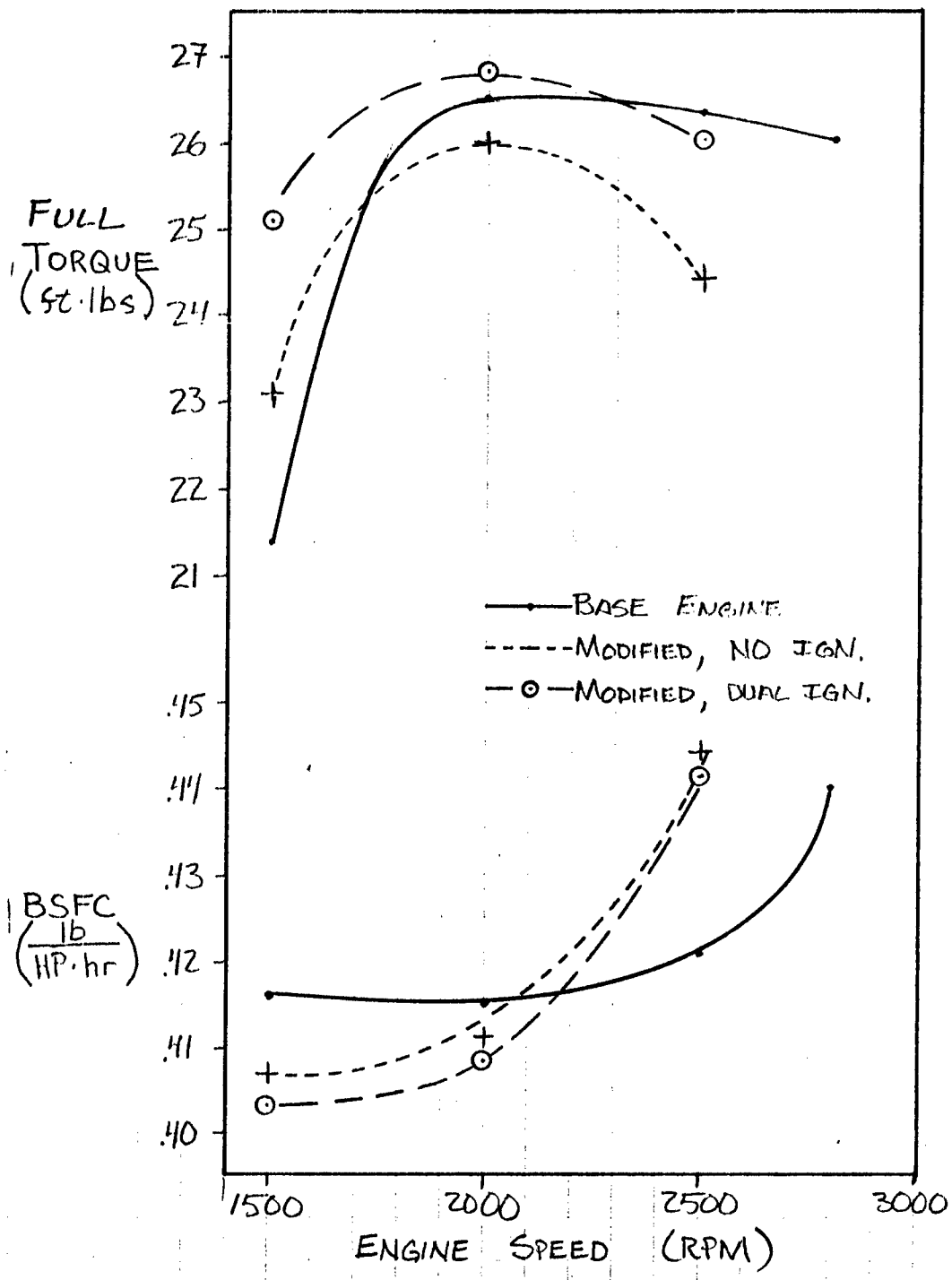


FIGURE 5-8. B.S.F.C. VERSUS R.P.M. @ FULL TORQUE

At 10 foot lbs BSFC was approximately 0.6 lbs/hp-hr over the entire speed range of 1500 RPM to 2800 RPM. At 20 ft lbs, BSFC ranged from about 0.42 to 0.48 lbs/hp-hr, increasing approximately linearly with speed. At maximum load, BSFC was between 0.41 and 0.42, similar to the 20 ft lbs case, and was constant for speeds in excess of 2000 RPM, rising somewhat at the higher speeds to a maximum BSFC 0.44 lbs/hp-hr at 2800 RPM. The torque peaked at between 2000 and 2500 RPM at between 26 and 27 ft. lbs. The data from the SuperFlow and the APA 100 (for the baseline engine) are shown in Appendix B.

After completion of the baseline tests, the engine was disassembled down to the crankcase and the new piston and cylinder heads installed. A cross section of the combustion chamber, as defined by the piston and shown with respect to the centrally located fuel injector, is shown in Figure 5-3. The dimensions of the bowl in the piston were selected to given a compression ratio of approximately 12 to 1.

Initial attempts to operate the engine with a lower compression ratio of 10 to 1 and a lip at the perimeter of the cylinder bowl were unsuccessful with the engine producing insufficient power at the higher loads and the perimeter lip interfering with the fuel spray. Hence, the selection was made for a higher compression ratio of between 11 and 12 to 1, and a modified, simpler shaped bowl-in-piston combustion chamber, shown in Figure 5-3. As with the base engine, the water-cooled pressure transducer was used and installed in the cylinder head. One of CEI's latest prototype ignitions was used.

It was found that at room temperatures without the aid of the ignition, the engine would not start at the 12 to 1 compression ratio. With the aid of the ignition, with either one or two plugs, the engine would start immediately and operate until sufficiently warm, when the ignition could be either turned off or kept on. A run of data was taken at very light load during the starting and warm-up stage with the ignition consecutively turned on and off and the APA 100 in the data-acquiring mode to determine the differences in peak pressure. The results of this test are summarized in Figure 5-9, in terms of peak pressure versus time elapsed from engine start-up for the two cases with and without ignition assist. The actual data is given in Appendix C.

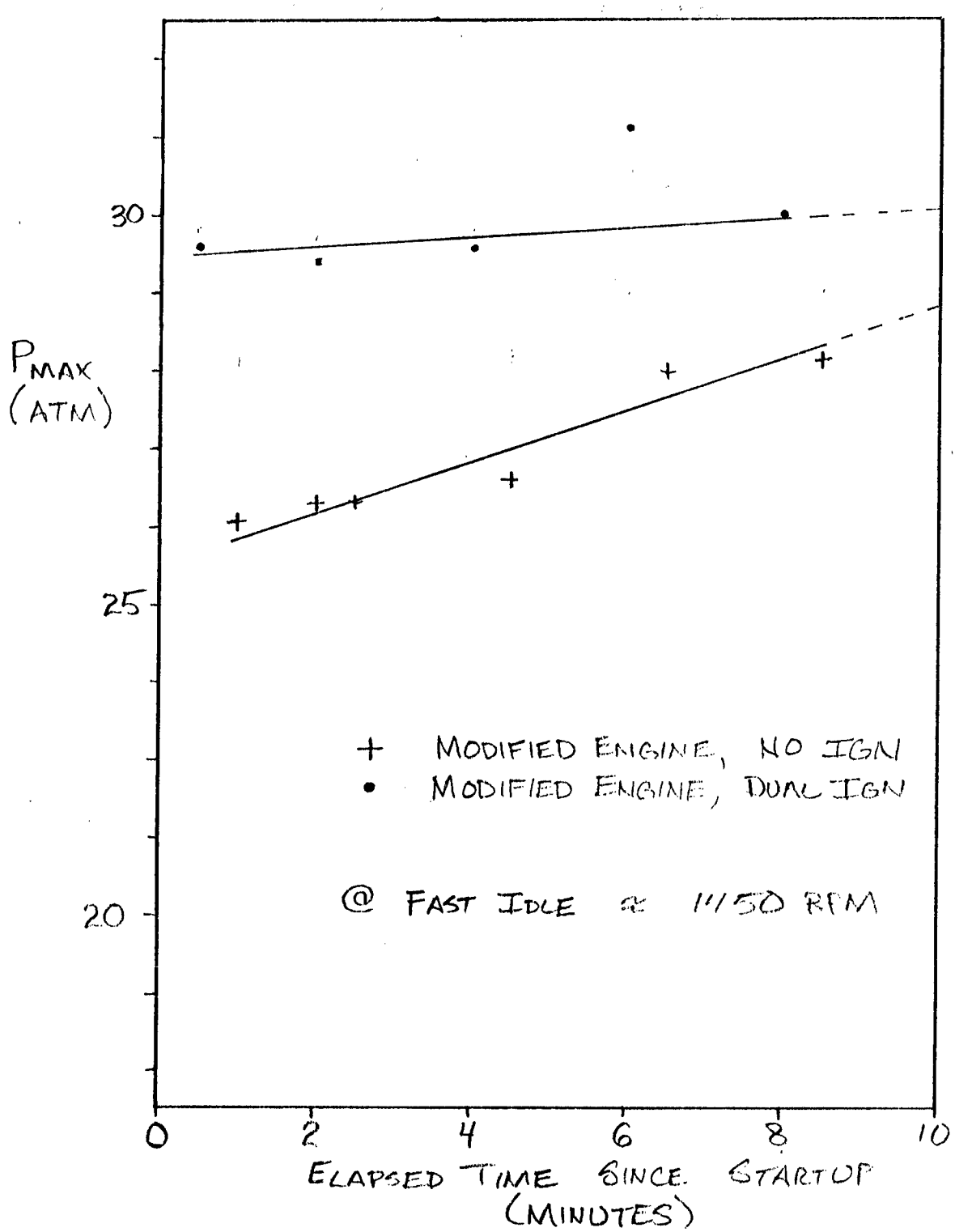


FIGURE 5-9. PEAK PRESSURE VERSUS ELAPSED TIME FROM ENGINE START-UP

As can be seen, the use of the ignition produced a substantially higher peak pressure for the first ten minutes of operation, which is desirable under the conditions of cold start, versus the conditions with the engine hot at high load where a lower peak pressure and lower rate of rise of pressure is desirable.

The engine was then run under the same conditions as the baseline at 10 and 20 ft. lbs and at full load at the four RPM conditions of 1500, 2000, 2500, and 2800 RPM. Once the engine was hot, selective data was taken with and without the ignition. The differences between the two cases were found to be small, while the differences with respect to the baseline engine were larger. Actual data of BSFC versus RPM are given for the modified engine in Figures 5-6, 5-7, 5-8, alongside the baseline data.

Plots of the maximum pressure and the maximum rate of rise of pressure for the three torque conditions are shown in Figures 5-10 through 5-15. The differences between the modified and baseline engine are remarkable, with the modified engine exhibiting, under practically all operating conditions, a peak pressure and peak rate-of-rise-of-pressure about one half that of the baseline engine. Given that the modified engine operated at comparable efficiency to the baseline engine, this data represents the achievement of one of the principle goals of this contract work. The actual data is given in Appendix D.

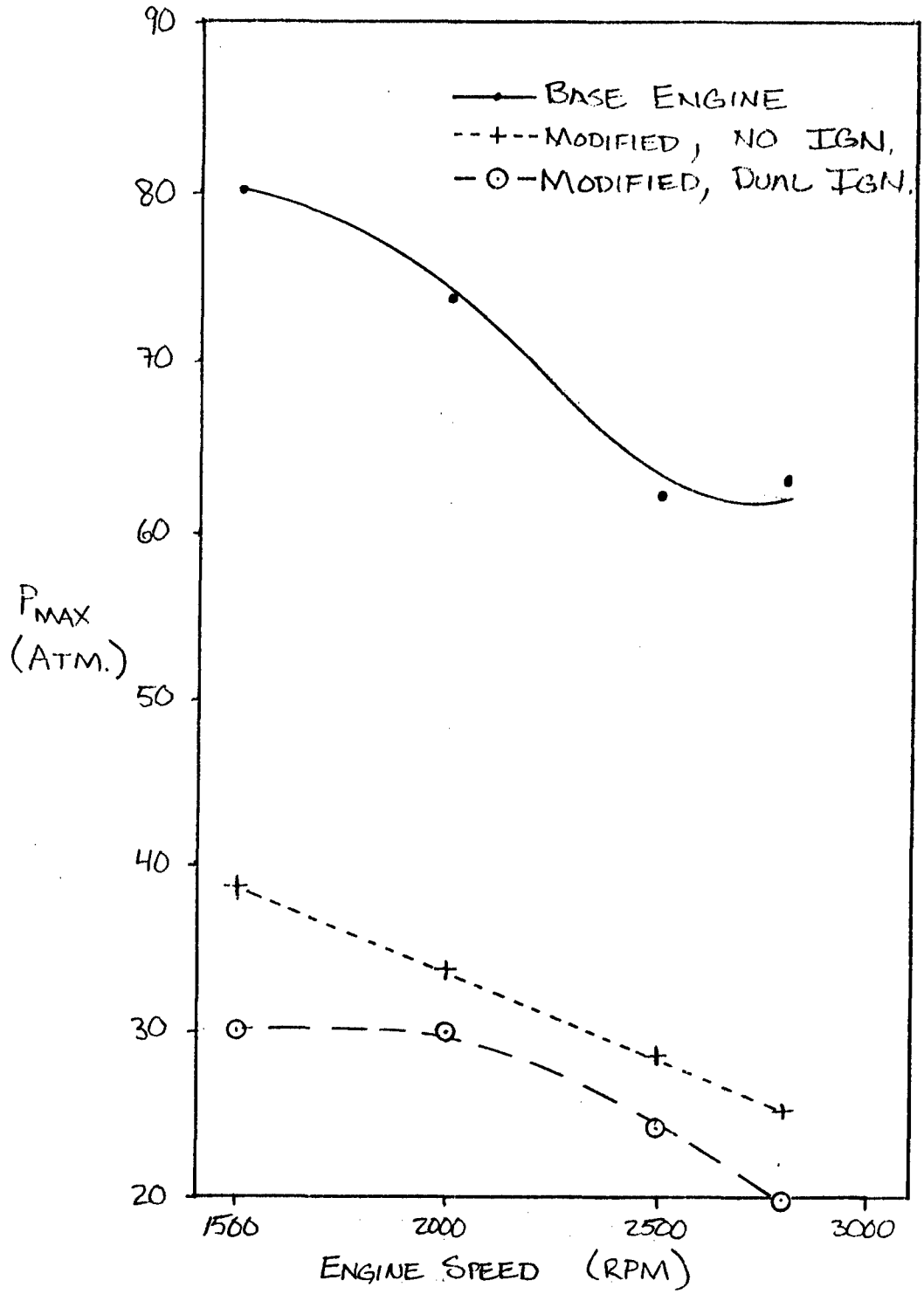


FIGURE 5-10. PEAK PRESSURE VERSUS R.P.M. @ 10 Ft·lbs TORQUE

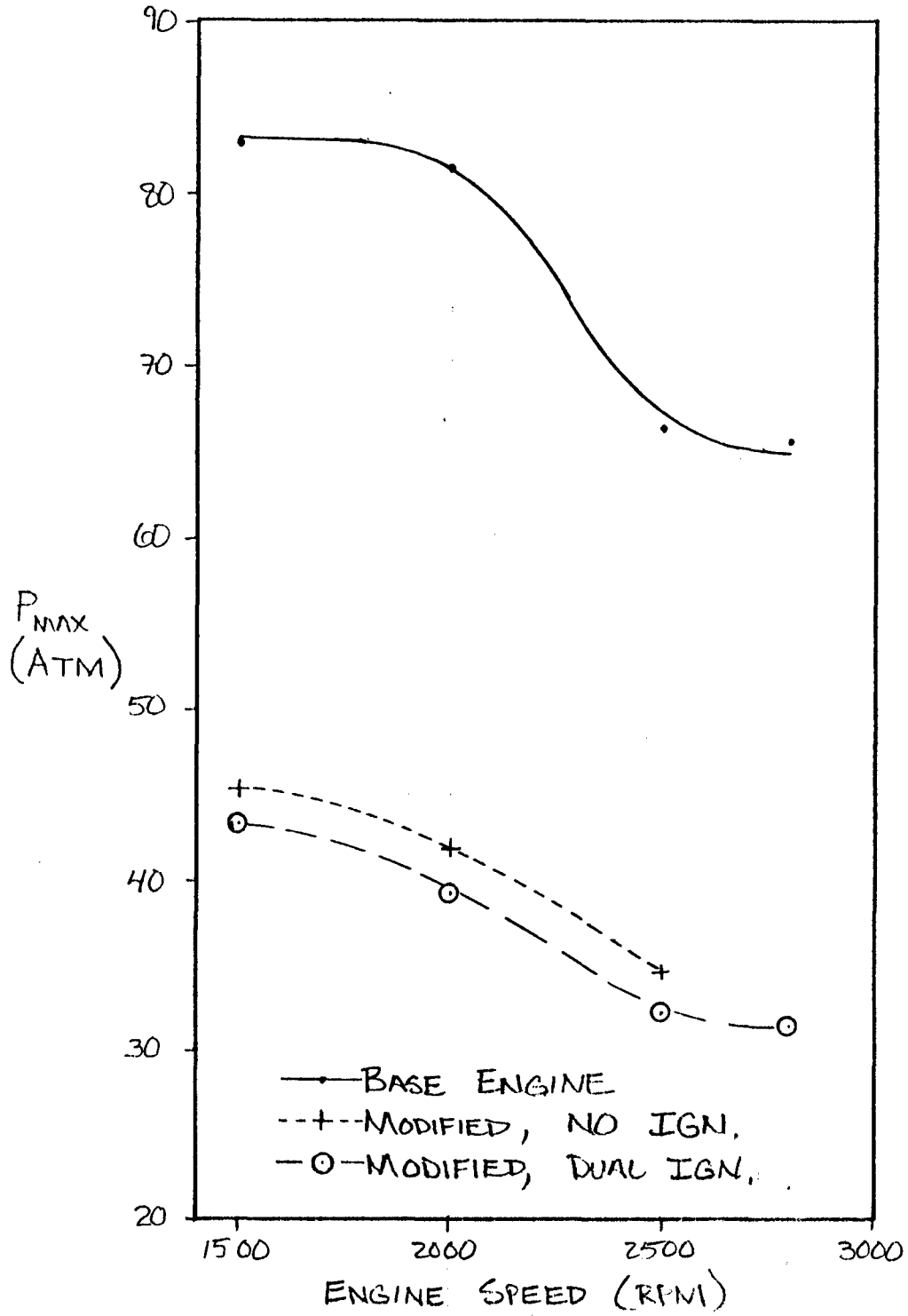


FIGURE 5-11. PEAK PRESSURE VERSUS R.P.M. @ 20 Ft·lbs TORQUE

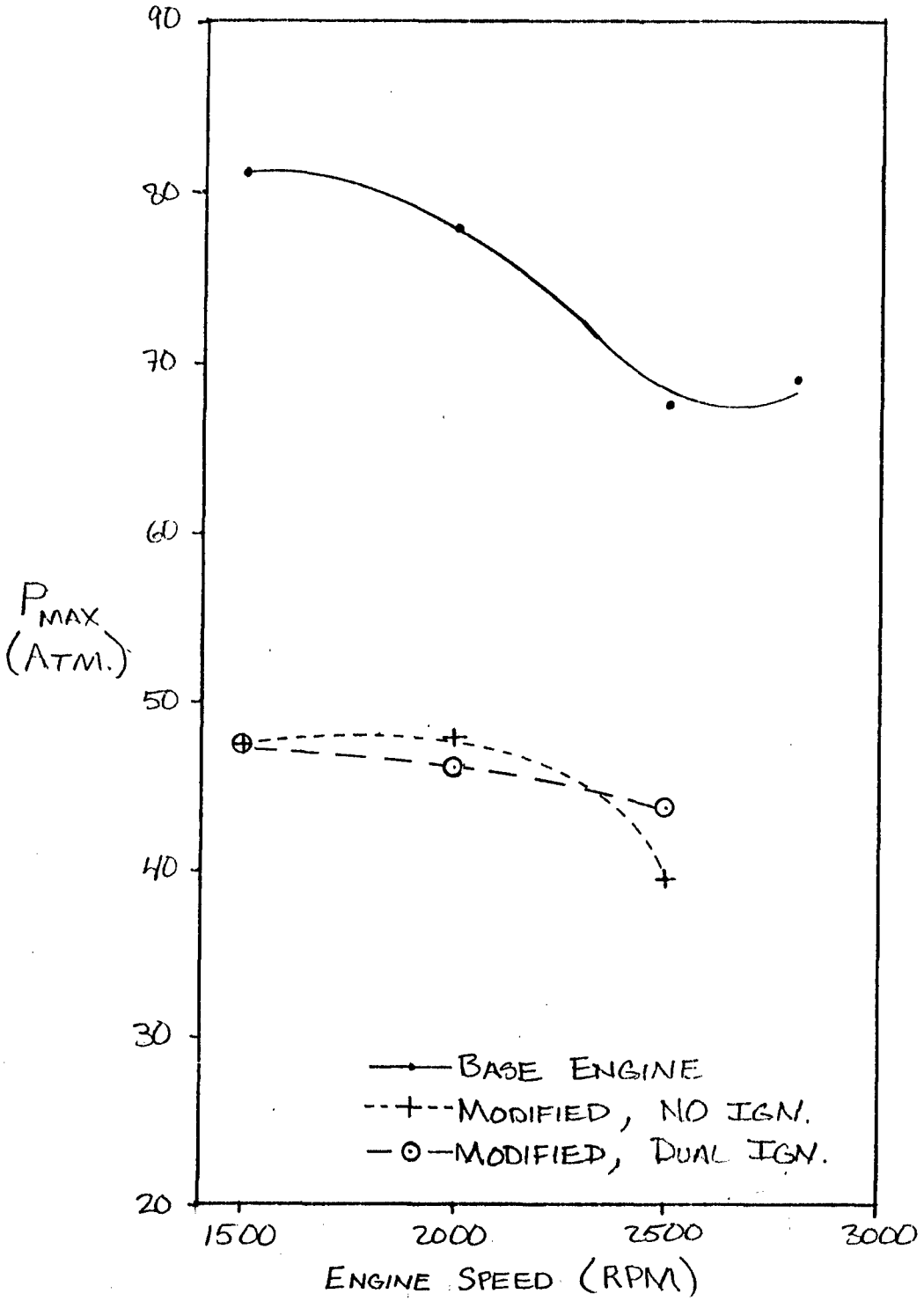


FIGURE 5-12. PEAK PRESSURE VERSUS R.P.M. @ FULL TORQUE

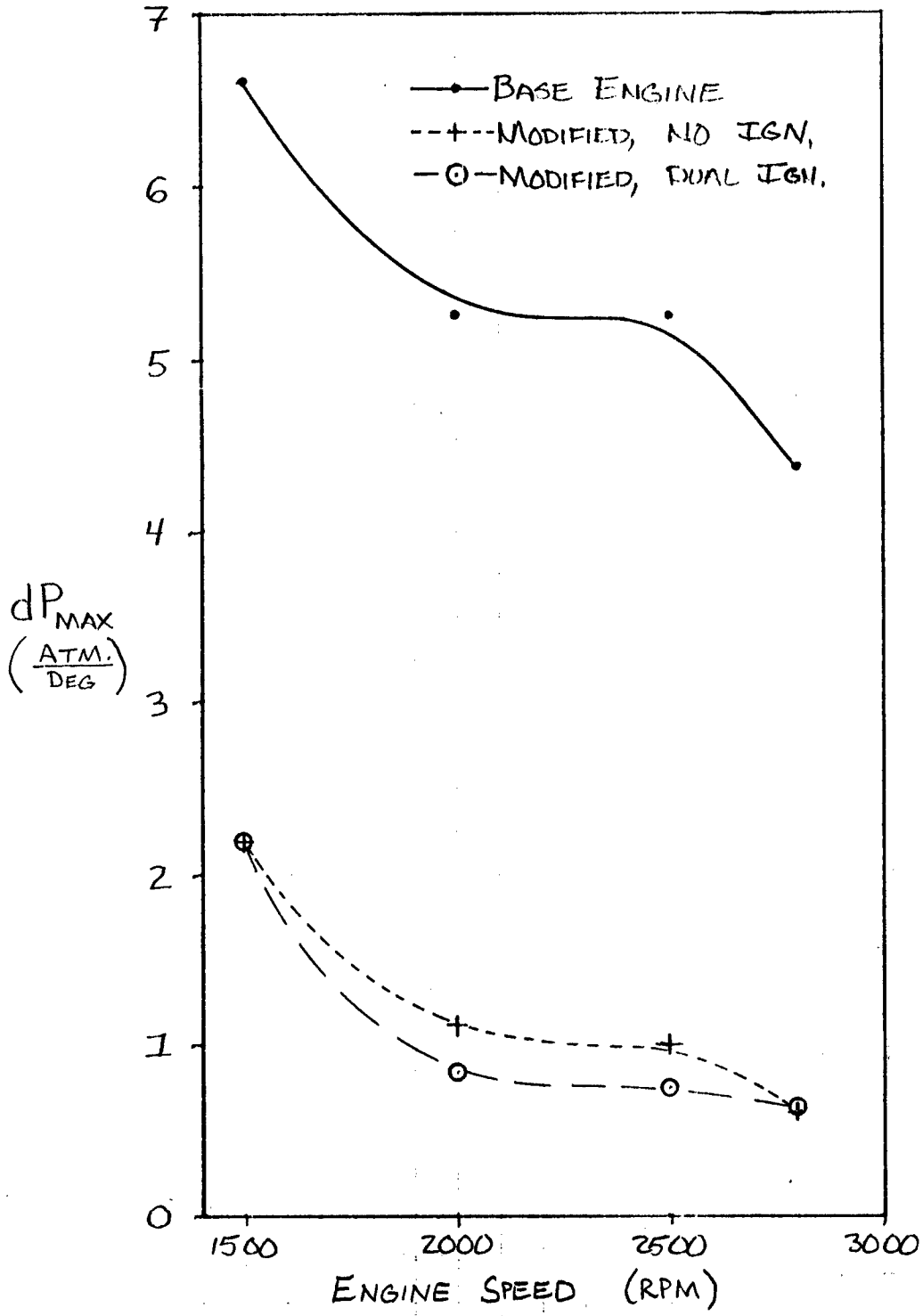


FIGURE 5-13. PEAK RATE OF RISE OF PRESSURE VERSUS R.P.M. @ 10 Ft·lbs TORQUE

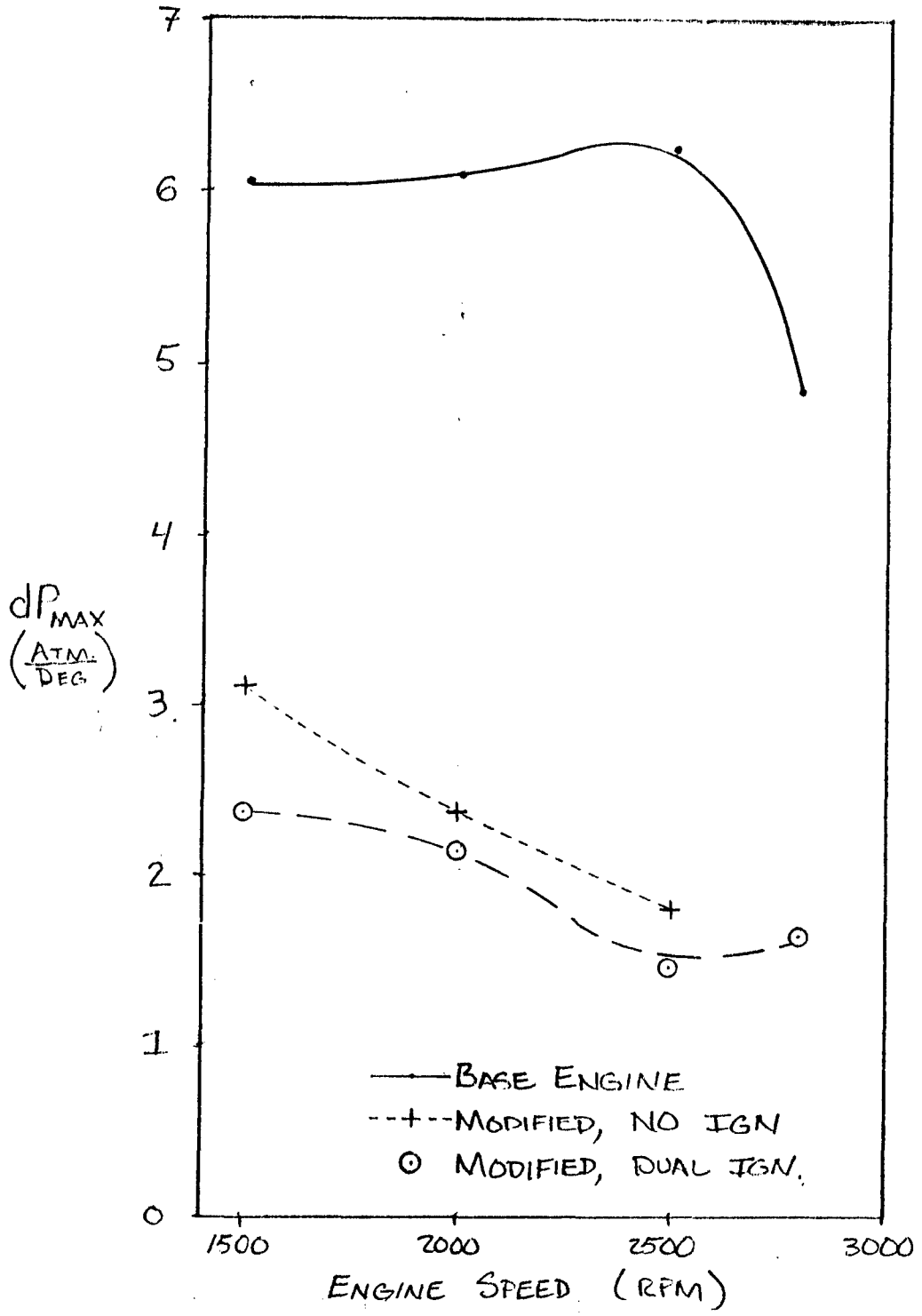


FIGURE 5-14. PEAK RATE OF RISE OF PRESSURE VERSUS R.P.M. @ 20 FT·LBS TORQUE

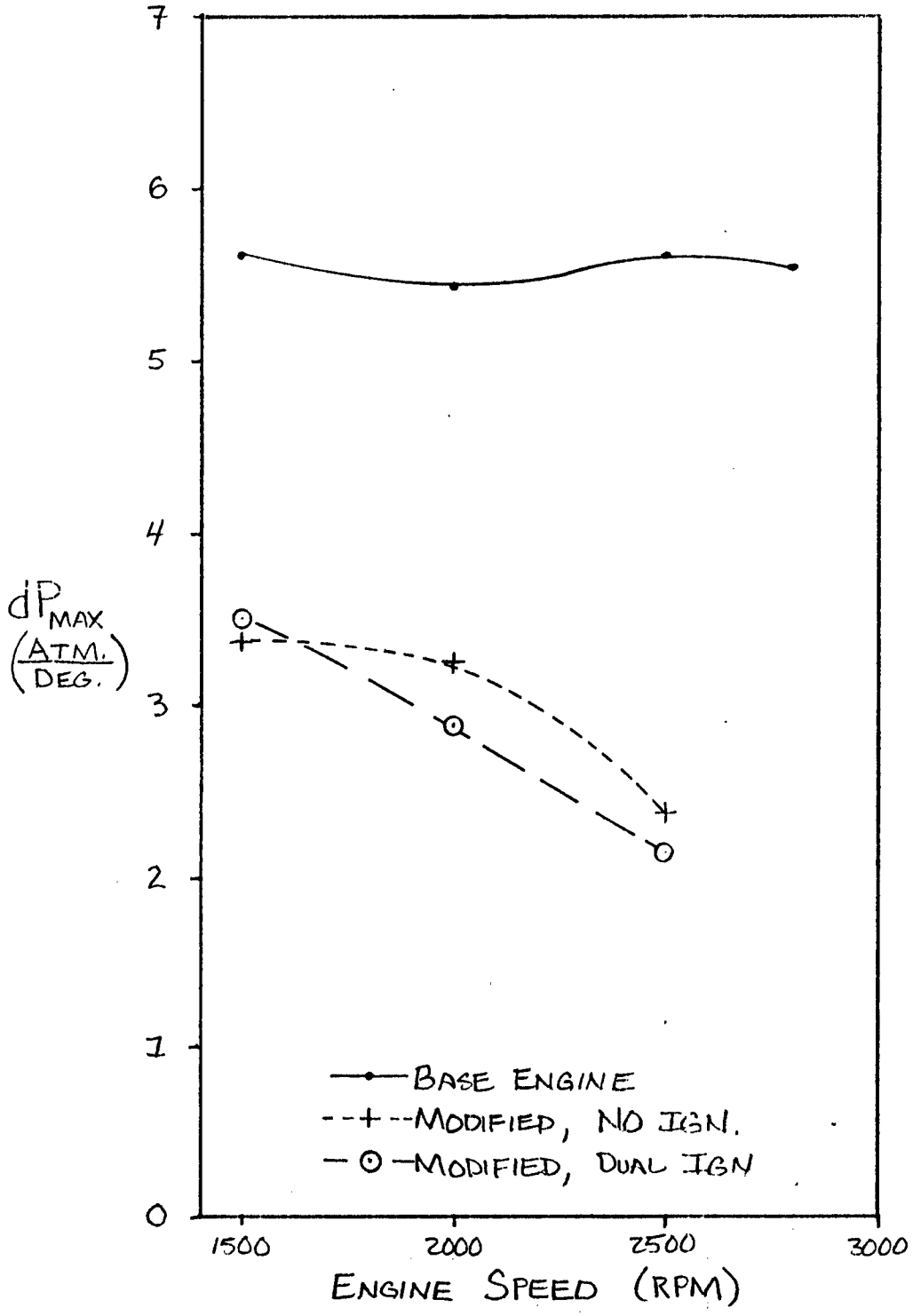


FIGURE 5-15. PEAK RATE OF RISE OF PRESSURE VERSUS R.P.M. @ FULL TORQUE.

5.7. Conclusions and Alternatives

From inspection of the data, one can draw several conclusions relating to the use of ignition in the modified engine relative to the baseline engine. The key conclusions are enumerated below:

1) The modified engine operates at similar efficiency and slightly lower peak output power as the baseline engine through the use of the ignition. This is an important result when one bears in mind that the engine compression ratio was a full 5 compression ratios lower, i.e. approximately 12 to 1 versus 17 to 1 compression ratio. This means that, in principle, one can have a significantly lighter engine (because of the reduced compression ratio), and significantly lower heat transfer to the walls. Furthermore, from an exhaust emission perspective, one would expect somewhat lower NOX emissions because of the lower peak pressures and temperatures at lower compression ratios.

2) This engine was operated without swirl and yet had approximately the same characteristics as the baseline engine. It can therefore be concluded that it would have significantly lower heat transfer losses because of the low swirl. This has a particular benefit of allowing the engine to operate with miminal air cooling, versus continuous forced air-cooling or water cooling, which is undesirable from the military application perspective.

3) At light loads, the efficiency of the modified engine was found to be significantly higher than the baseline engine. The reasons for this are not totally clear, since improved ignition probably should not have such a large effect. The differences may be attributed, in part, to the lighter air-cooling requirements of the engine under light-load conditions in its modified form, versus in the baseline form, where an approximately constant amount of forced air cooling was provided at all load conditions (for given engine speed).

The cooling air-blower, item 39, Figure 5-16, manufacturer's drawing of the engine, was removed and replaced by a small electric fan which was turned on when the engine had reached operating temperature. In addition, cooling was provided by the high temperature synthetic oil which was used in the engine, although no data was taken to evaluate this.

Discussions with a technical manufacturer's representative indicate that the cooling air blower (item 39) would absorb approximately 1/2 horsepower at an engine speed of 1500 RPM, which would account for approximately one half of the difference in efficiency found at the 10 ft lb, 1500 RPM (and 2000 RPM) case shown in Figure 5-6.

4) The modified engine exhibited approximately half the peak pressure and half the rate-of-rise-of-pressure under the conditions tested, excepting for the case of cold start where the modified engine in its spark-ignited form provided a higher peak pressure than without ignition, as is desired.

5) The modified engine provided instant cold start, as desired.

In the "Recommendations" section, Section 4.0, it was stated that should it be desirable to use the current approach of electrically igniting the spray in a diesel engine, then certain precautions should be taken, including taking into account the design recommendations enumerated below to optimize the chances of success. The principle concern, as already stated, is spark plug fouling by the fuel spray and the high pressure the ignition has to operate under.

In Figures 5-17 and 5-18, two approaches are shown which make use of the principles of ignition described in this report for the case of a conventional four-stroke diesel engine (Figure 5-17) and a two-stroke engine (Figure 5-18), which is recommended for this application. In both cases, certain design principles are followed, which are enumerated below:

1. The spark plugs should have extended insulators to reduce the chance of plug fouling due to the insulator becoming coated with fuel and/or carbon.

2. The spark plugs are preferably located near the region of high squish which aids the cleaning of the plug. However, as shown in these figures, the cleaning action would be restricted to principally one side of the plug.

3. The spark plug should be located far away from the fuel injector, approximately 1.5 inches in the cases shown here, for a combustion chamber with a bore size of approximately 4 inches. This has the following desirable characteristics:

a. The spray will have entrained significant air and become relatively homogeneous by the time it traverses the approximate 1.5 inch length to reach the spark plug site.

b. The spray velocity will have approached close to zero near the spark plug site, especially upon encountering the oppositely directed air squish created by the small piston-head near the spark plug.

4. The spark plugs should not have a ground, or "Jay" electrode, and should form the spark to appropriate protrusions on the piston. This permits the use of a larger spark gap under most operating conditions where ignition may occur 20 to 40 degrees BTDC. This is especially helpful at high engine speeds where a stronger ignition is provided through a larger gap provided by the earlier firing of the plug.

5. The sparking protrusions on the piston, which are preferably composed of erosion-resistant material such as tungsten-nickel-iron, will tend to run hotter than the other parts of the combustion chamber and, therefore, further aid in the ignition process by supplementing heat energy to the spark energy.

6. Finally, it should be appreciated that by placing the spark plug tip in a region where the squish fields and fuel spray collide will produce high microscale turbulance, which is helpful in producing strong flame initiation.

With respect to Figure 5-17, it should be understood that what is being proposed here is "a way" of implementing the above recommendations in a four stroke diesel engine design. There are numerous variations to this design, which depend in part on where one wants to locate the combustion chamber and the fuel injector.

Figure 5-18 depicts a cross scavenged two-stroke engine which is particularly well suited for using the design recommendations. The edge of the deflector section of the piston provides an edge suitable for firing the spark to, and for achieving a large spark gap.

English

Constructions Groups: General View

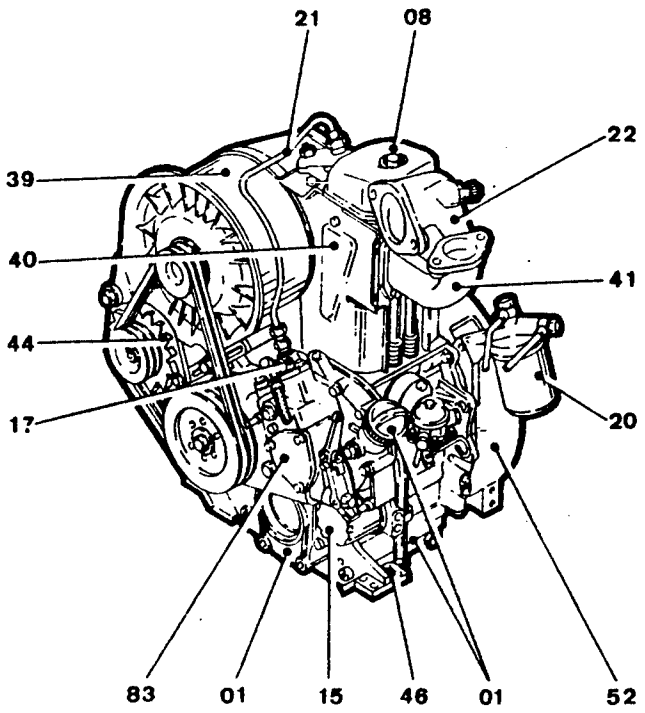


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Figure 5-16. Manufacturer's Drawing of Deutz Test Engine

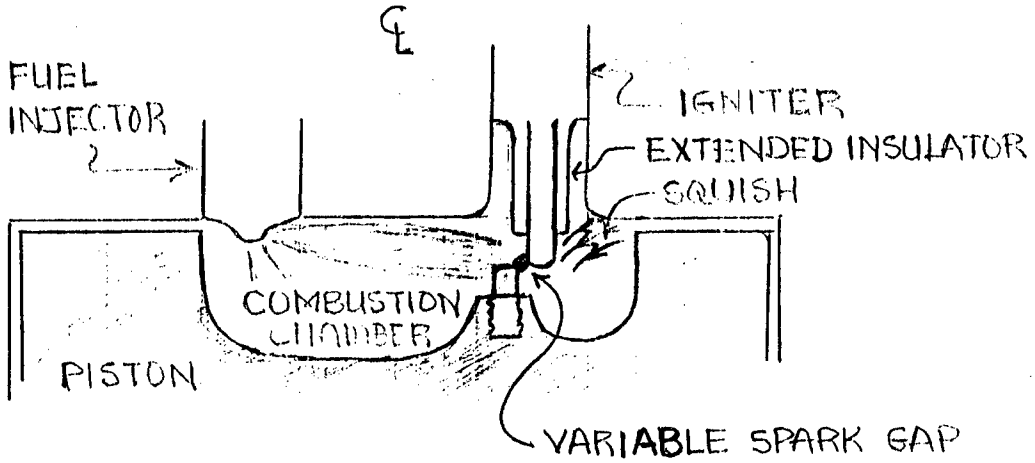

Figure 5-17. Alternative Spark Ignited Diesel

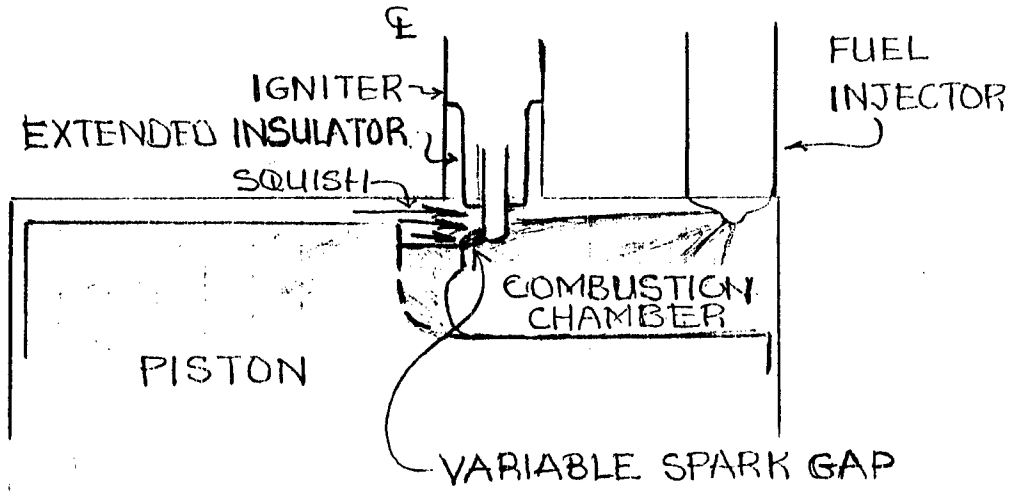

Figure 5-18. Alternative Spark Ignited Diesel
(Two Stroke Engine)

APPENDIX A

FUEL INJECTION NOZZLE CHARACTERISTICS

SUPPORTING DATA

Technical Report No. 5

FUEL INJECTOR DESIGN EFFORT

Summary

The design of the fuel injector for the electrically ignited quiescent open chamber combustion process should meet, as closely as possible, several goals according to our current thinking.

The first goal is to mix the fuel and air using the energy in the fuel spray, since swirl and squish have been minimized to reduce heat transfer losses. To obtain this result it appears that the number of holes in the injector should be maximized since the Abramovitch jet mixing theory (to be briefly discussed later) indicates that there is no practical control of the cone angle of the spray for multi hole nozzles.

The second goal is to avoid liquid fuel impingement on the cylinder wall or ceramic insert since fuel impingment on the wall could lead to loss of fuel into the lubricating system. Thus the traversal time from the injector to the cylinder wall should be large enough for the fuel of the expected droplet size to completely vaporize. The quiescent non swirl combustion chamber design tends to minimize the travel time, since the fuel travels straight to the wall and not in a longer spiral path.

The third goal involves placing a combustible mixture at the ignitors at the proper time for ignition, preferably using the fuel injector cam and pump supplied with the engines. We currently think that not all of the fuel should be injected before ignition to minimize the rapid rate of pressure rise that could occur if a significant fraction of the mixture were to auto ignite (knock). For testing and evaluation purposes we would like to have the flexibility of having some combustible mixture arrive at the ignitor at say 30 degrees BTDC so that the effect of timing advance can be evaluated. Since our current fuel injection system is expected to start injection at 24 degrees BTDC, little time is available for fuel travel and mixing (relative to TDC). More advance may be desirable to provide more time for mixing and evaporation. If the combustion process works like a W.O.T. gasoline engine, less advance will be needed - probably about 15 degrees at 2,000 RPM, which would correspond to an injection timing of about 30 degrees BTDC.

With these initial goals established, we next attempted to learn about the state of the art in injector capabilities and analytical predictive techniques, by questioning local suppliers, manufacturers, two consultants, and reviewing recent SAE literature. We also measured some of the characteristics of the fuel injection system supplied with the single cylinder Deutz engine, such as the cam profile, full rack and partial rack injected volume, and line pressure vs speed and rack setting. With this data and a theoretical model we evaluated several design parameters and developed a "first" injector design.

Determination of Deutz Engine Fuel Injection System Parameters

The first project was to measure the cam follower-plunger lift profile. A gear driven auxiliary drive pulley was accurately marked in five degree increments and the plunger lift position was measured to the nearest .001 inch using a dial indicator. From these measurements we estimate that injection could in principle start as early as approximately 50 degrees BTDC and could end at 10 degrees ATDC. The manual indicates that the injection starts at 24 degrees BTDC. We still need to learn why this time is so retarded from the apparent potential starting point of 50 degrees BTDC and whether we can obtain some advance by modifying the pump.

The next tests were conducted by Boston Fuel Injection Company. They determined the peak line pressure and amount of fuel injected at each of four speeds and four rack settings. The delivery at the maximum rack setting was much less than the swept volume of the plunger minus the retraction volume, which was equal to about ten times the injected volume.

An estimate of the volume of fuel delivered per revolution for the standard engine was made using the rated power of 17.5 Hp and the BSFC of 0.41 lbs/hp-hr. This required a delivery of .040 cc/rev. assuming a fuel specific gravity of 0.9. This corresponded to a volume much closer to the measured volume than the swept volume.

Discussions with Deutz confirmed that the fuel injection system was designed to start injection at 24 degrees BTDC and to inject a maximum of 44 cc/1000 revolutions. This confirmation of engine based fuel delivery estimates leaves us currently without an understanding of how to optimally redesign the fuel system without further knowledge. For example the displacement rate of the injector plunger would deliver the maximum amount of fuel in 10 crankshaft degrees if no compliance existed in the piping and injector. We may set up a simple test fixture to suspend the fuel injector so it will spray an absorbent disc attached to the engine shaft to determine the duration of injection. This will improve our ability to design the nozzle hole size and pick the number of holes.

As a further attempt to understand the fuel injection process, we plotted the pressure vs delivery rate and found that the pressure varied linearly, not quadratically with speed, as would be predicted for normal orifice flow. Also the dynamic pressure computed for our smallest orifice, 12 hole design is only 862 psi for 2000 engine RPM, while line pressures over 4000 psi were measured using the standard, four hole (of unknown diameter) nozzle. Thus we will not attempt to determine the source of the line pressure during our current effort. Nor will we attempt to predict absolute values of injection timing or jet velocities, unless we are able to obtain additional information from Bosch or United Technologies.

Fuel Jet Model Assumptions

Based on the analytical results of the Rife jet velocity prediction equations, we are able to compare fuel injector designs of different hole size and number of holes. The analysis is based on the model that assumes that air is entrained into the jet in a manner which conserves linear momentum. Thus as the distance along the path from the nozzle hole increases, the jet velocity decreases since more mass (entrained air) is included in the jet. The result is that the diameter of the jet becomes a linear function of distance from the so called "pole" position, the position from which the jet appears to diverge (with infinite speed) and minimum (fuel) mass. The entrainment parameter is the sole determinant of the cone angle of the jet for a given fuel to compressed air density ratio! Neither changes in hole size nor fuel velocity have any effect on the predicted cone angle. They do have a small effect on the distance from the fuel injector to the pole position but over the range of interest in this project that distance is predicted to change by only a maximum of 0.1".

Predicted Results

Since we have no means to effect the entrainment factor for quiescent non swirl flow, our only means to improve the fuel distribution process appears to be to increase the number of holes in the fuel injector nozzle. For a given hole diameter, the predicted velocity is inversely proportional to the number of holes. If compressibility effects are important (not considered here) then a lower dependence on the number of holes would be expected.

Although the cone angle of the nozzle sprays is predicted to be invariant, the distance for a given loss of velocity ratio relative to the computed nozzle speed is directly proportional to the jet diameter. Thus smaller diameter jets slow down more rapidly than larger ones. This phenomenon led to an interesting result for the time for the jet to reach the ignitor location one inch from the center of the cylinder. For a design of 12 holes of 0.0035" diameter relative to a design of 6 holes of 0.007" diameter, we found that while the initial speed of the .0035" diameter hole jets was twice that for the larger hole nozzle, (four times the area but half the number of holes), the greater rate of decrease of velocity with distance for the smaller jets led to the predicted results that both jets arrive at the ignitor at practically the same time.

We can summarize results for time to distance predictions for dimensions similar to the cylinder radius by the following rules of thumb.

1. Time to distance is inversely proportional to the product of nozzle flow speed times hole diameter.
2. For a given plunger diameter and cam profile, time to distance is proportional to the number of holes of a given diameter or inversely proportional to diameter for a given number of holes.

Figure 1 shows the computed time vs. distance predictions for several hole sizes and number of holes which bound the range of expected designs. The time vs. distance calculations were made on the basis of the velocity between computed velocity intervals predicted by the Rife Equations being assumed to be the geometric mean of the two end point velocities. This is a reasonable approximation for the present purposes.

Our current research on drilling holes for the nozzle tips indicates that holes of 0.007 inch appear to be readily available. One vendor believes that 0.005 inch holes are possible by diamond drilling unhardened nozzle bodies. We have not yet determined if laser drilling or ultrasonic machining can produce smaller holes. Thus our present first designs are for 10 to 12 holes of 0.005" diameter if available, or 10 holes of .007" diameter. An analysis of the 12 hole, 0.005" hole diameter case is included (Figure 3) along with some other cases.

The travel times to the injector for the first part of the jet on the centerline for these nozzle designs are predicted to be on the order of 15 to 20 crankshaft degrees for the 2000 RPM condition we modelled. Thus the start of injection will need to be earlier than the present 24 degrees if we desire to start the ignition process at 20 to 30 degrees BTDC which is typical of normal spark ignition timing.

The time for other than the centerline of the jet to reach the one inch distance is even larger than the above calculated times. Thus we are considering ways to change the start of injection by about 20 to 25 degrees. We are considering obtaining another cam and mounting it onto the cam shaft at the appropriate timing.

The actual fuel injector we expect to use is one manufactured by United Technologies. It has a larger body than the pencil nozzle made by Stanadyne, but individual nozzle tips are available for it, and we expect to be able to get these tips machined to our specifications locally. We can accomodate the larger 17mm body within our current cylinder head design without significant compromise. Stanadyne was not willing to cooperate with us at this time because of too large a backlog.

SUPPORTING DATA
Tech. Rpt. #5

17 April 1986

Holes, Hole diameter, in

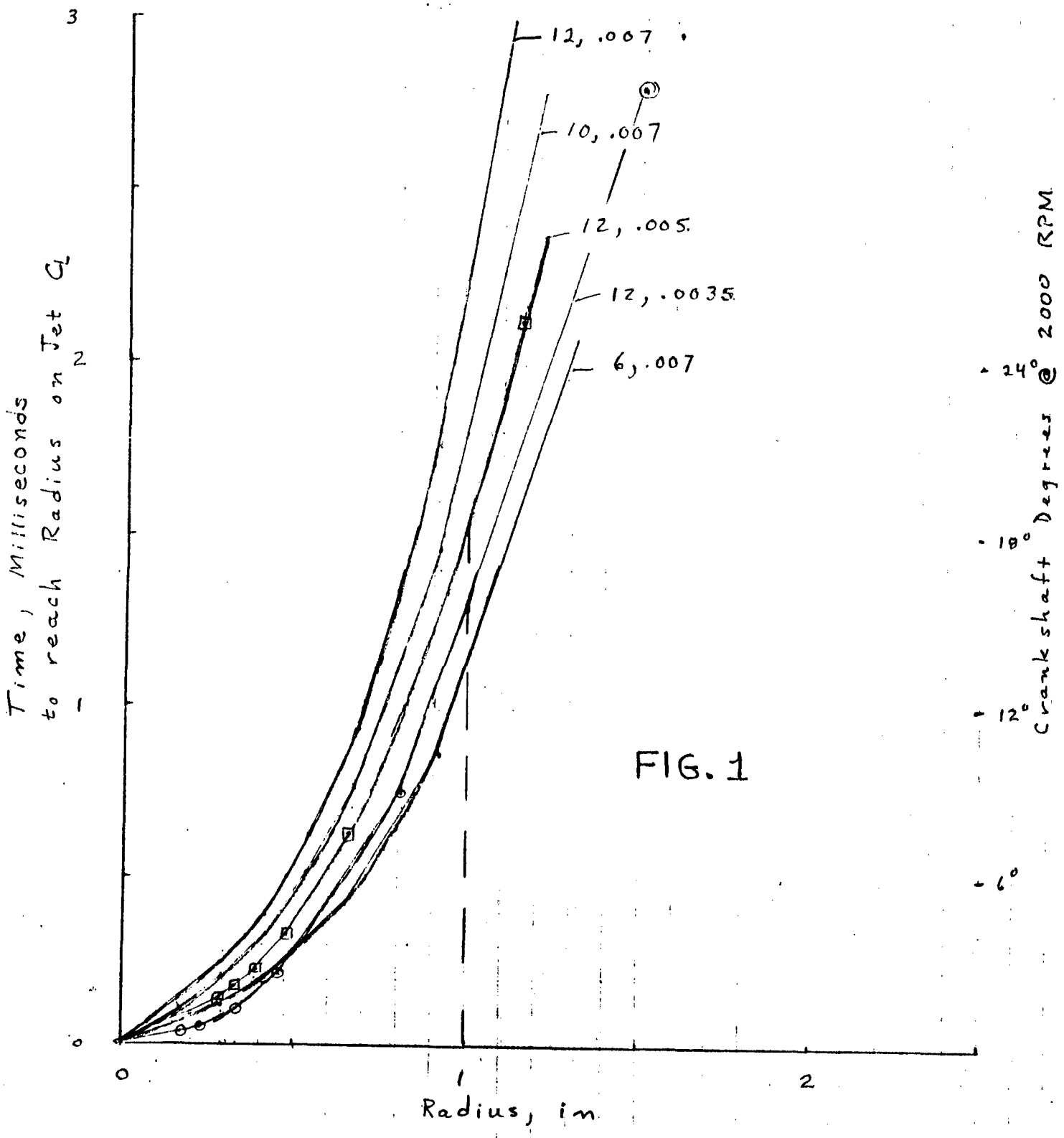

FIG. 1

(1)

NOZZLE SCALING CALCULATIONS
17-Apr-86

Supporting Data, Tech. Rpt. # 5

ENGINE:

Bore: (in)	3.94	Disp. Vol.: (in^3)	50.4
Stroke: (in)	4.13		
Speed: (rpm)	2000		
Comp. Ratio:	11	Clearance:	5.04

PUMP:

Plunger: (mm)	7.5	Vol./Stroke:	274.3	0.913
Stroke: (mm)	7			!sp. gravity
Retract: (mm^3)	35	Inj. Mass: (mg)	250.4	Rohsenow & Choi

NOZZLE:

Hole Size: (in)	0.007	Hole Area:	3.85E-05
Number:	12	Total:	4.62E-04
Coefficient:	0.6		

INJECTION PARAMETERS:
Specified in crankangle degrees (TDC = 0)

Start: (deg.)	-50	Duration:	60
End: (deg.)	10		

Single Hole:		Nozzle:		
Rate: (mg/deg.)	0.35	Rate: (mg/deg.)	4.17	
Rate: (g/sec)	417	Rate: (g/sec)	5004	
Velocity: (m/sec)	30.7			!RCM was 122 m/sec (JMR)

INLET:

Vol. Effic.:	0.95		
Polytropic:	1.3	Air at TDC:	
Inlet Press.:	14.7	TDC Press:	332
Inlet Temp. (F)	90	TDC Temp:	1129
Density:	1.14E-03	Density Ratio:	11
		TDC Density:	1.26E-02

COMBUSTION CHAMBER: Jet Mixing

Density Ratio:	72.7
Jet Vel.:	30.7
Radius:	0.0035
Entrain: (axial)	0.11

FIG. 2

JET CALCULATION

Pole:	0.219								
No Crossflow									
Rel Vel, Vf/Vi:	0.9	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.05
Velocity m/sec:	28	21	18	15	12	9	6	3	2
Mass Ratio:	9	2.33	1.5	1	0.67	0.43	0.25	0.11	0.05
Air/Fuel:	0.111	0.429	0.667	1	1.493	2.326	4	9.091	20
Mean Radius:	2.996	6.672	8.988	12.058	16.511	23.779	38.131	80.889	166.211
Radius, inches:	0.01000	0.02300	0.03100	0.04200	0.05800	0.08300	0.13300	0.28300	0.58200
Mean Distance:	19.13	40.68	53.4	69.65	92.42	128.45	197.62	398.28	792.17
Distance, in.:	0.29000	0.36000	0.41000	0.46000	0.54000	0.67000	0.91000	1.61000	2.99000
Time msec:	0.251236	0.32456	0.38988	0.46717	0.618628	0.93636	1.76592	5.95671	20.2666

NOZZLE SCALING CALCULATIONS
17-Apr-86

Supporting Data, Tech. Rpt. #5

ENGINE:

Bore: (in)	3.94	Disp. Vol.: (in^3)	50.4
Stroke: (in)	4.13		
Speed: (rpm)	2000		
Comp. Ratio:	11	Clearance:	5.04

PUMP:

Plunger: (mm)	7.5	Vol./Stroke:	274.3	0.913
Stroke: (mm)	7			!sp. gravity
Retract: (mm^3)	35	Inj. Mass: (mg)	250.4	Rohsenow & Choi

NOZZLE:

Hole Size: (in)	0.005	Hole Area:	1.96E-05
Number:	12	Total:	2.36E-04
Coefficient:	0.6		

INJECTION PARAMETERS:
Specified in crankangle degrees (TDC = 0)

Start: (deg.)	-50	Duration:	60
End: (deg.)	10		

Single Hole:		Nozzle:		
Rate: (mg/deg.)	0.35	Rate: (mg/deg.)	4.17	
Rate: (g/sec)	417	Rate: (g/sec)	5004	
Velocity: (m/sec)	60.1			!RCM was 122 m/sec (JMR)

INLET:

Vol. Effic.:	0.95		
Polytropic:	1.3	Air at TDC:	
Inlet Press.:	14.7	TDC Press:	332
Inlet Temp. (F)	90	TDC Temp:	1129
Density:	1.14E-03	Density Ratio:	11
		TDC Density:	1.26E-02

COMBUSTION CHAMBER: Jet Mixing

Density Ratio:	72.7
Jet Vel.:	60.1
Radius:	0.0025
Entrain: (axial)	0.11

FIG. 3

JET CALCULATION

Pole: 0.156

No Crossflow

Rel Vel, Vf/Vi:	0.9	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.05
Velocity m/sec:	54	42	36	30	24	18	12	6	3
Mass Ratio:	9	2.33	1.5	1	0.67	0.43	0.25	0.11	0.05
Air/Fuel:	0.111	0.429	0.667	1	1.493	2.326	4	9.091	20
Mean Radius:	2.996	6.672	8.988	12.058	16.511	23.779	38.131	80.889	166.211
Radius, inches:	0.00700	0.01700	0.02200	0.03000	0.04100	0.05900	0.09500	0.20200	0.41600
Mean Distance:	19.13	40.68	53.4	69.65	92.42	128.45	197.62	398.28	792.17
Distance, in.:	0.20000	0.26000	0.29000	0.33000	0.39000	0.48000	0.65000	1.15000	2.14000
Time msec:	0.089172	0.12117	0.14076	0.17168	0.228481	0.33846	0.63226	2.12897	8.05594

(3)

NOZZLE SCALING CALCULATIONS
17-Apr-86

Supporting Data, Tech. Rpt. #5

ENGINE:

Bore: (in)	3.94	Disp. Vol.: (in^3)	50.4	
Stroke: (in)	4.13			
Speed: (rpm)	2000			
Comp. Ratio:	11	Clearance:	5.04	

PUMP:

Plunger: (mm)	7.5	Vol./Stroke:	274.3	0.913
Stroke: (mm)	7			!sp. gravity
Retract: (mm^3)	35	Inj. Mass: (mg)	250.4	Rohsenow & Choi

NOZZLE:

Hole Size: (in)	0.0035	Hole Area:	9.62E-06
Number:	12	Total:	1.15E-04
Coefficient:	0.6		

INJECTION PARAMETERS:
Specified in crankangle degrees (TDC = 0)

Start: (deg.)	-50	Duration:	60
End: (deg.)	10		

Single Hole:		Nozzle:		
Rate: (mg/deg.)	0.35	Rate: (mg/deg.)	4.17	
Rate: (g/sec)	417	Rate: (g/sec)	5004	
Velocity: (m/sec)	122.6			!RCM was 122 m/sec (JMR)

INLET:

Vol. Effic.:	0.95		
Polytropic:	1.3	Air at TDC:	
Inlet Press.:	14.7	TDC Press:	332
Inlet Temp. (F)	90	TDC Temp:	1129
Density:	1.14E-03	Density Ratio:	11
		TDC Density:	1.26E-02

COMBUSTION CHAMBER: Jet Mixing

Density Ratio:	72.7
Jet Vel.:	122.6
Radius:	0.00175
Entrain: (axial)	0.11

FIG. 4

JET CALCULATION

Pole:	0.109								
No Crossflow									
Rel Vel, Vf/Vi:	0.9	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.05
Velocity m/sec:	110	86	74	61	49	37	25	12	6
Mass Ratio:	9	2.33	1.5	1	0.67	0.43	0.25	0.11	0.05
Air/Fuel:	0.111	0.429	0.667	1	1.493	2.326	4	9.091	20
Mean Radius:	2.996	6.672	8.988	12.058	16.511	23.779	38.131	80.889	166.211
Radius, inches:	0.00500	0.01200	0.01600	0.02100	0.02900	0.04200	0.06700	0.14200	0.29100
Mean Distance:	19.13	40.68	53.4	69.65	92.42	128.45	197.62	398.28	792.17
Distance, in.:	0.14000	0.18000	0.20000	0.23000	0.27000	0.33000	0.45000	0.81000	1.50000
Time msec:	0.030621	0.04106	0.04743	0.05877	0.077360	0.11315	0.21336	0.74129	2.80675

(4)

NOZZLE SCALING CALCULATIONS
17-Apr-86

ENGINE:

Bore: (in)	3.94	Disp. Vol.: (in^3)	50.4	
Stroke: (in)	4.13			
Speed: (rpm)	2000			
Comp. Ratio:	11	Clearance:	5.04	

PUMP:

Plunger: (mm)	7.5	Vol./Stroke:	274.3	0.913
Stroke: (mm)	7			!sp. gravity
Retract: (mm^3)	35	Inj. Mass: (mg)	250.4	Rohsenow & Choi

NOZZLE:

Hole Size: (in)	0.0035	Hole Area:	9.62E-06
Number:	6	Total:	5.77E-05
Coefficient:	0.6		

INJECTION PARAMETERS:
Specified in crankangle degrees (TDC = 0)

Start: (deg.)	-50	Duration:	60
End: (deg.)	10		

Single Hole:		Nozzle:		
Rate: (mg/deg.)	0.7	Rate: (mg/deg.)	4.17	
Rate: (g/sec)	835	Rate: (g/sec)	5010	
Velocity: (m/sec)	245.6			!RCM was 122 m/sec (JMR)

INLET:

Vol. Effic.:	0.95		
Polytropic:	1.3	Air at TDC:	
Inlet Press.:	14.7	TDC Press:	332
Inlet Temp. (F)	90	TDC Temp:	1129
Density:	1.14E-03	Density Ratio:	11
		TDC Density:	1.26E-02

COMBUSTION CHAMBER: Jet Mixing

Density Ratio:	72.7
Jet Vel.:	245.6
Radius:	0.00175
Entrain: (axial)	0.11

JET CALCULATION
Pole: 0.109
No Crossflow

Rel Vel, Vf/Vi:	0.9	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.05
Velocity m/sec:	221	172	147	123	98	74	49	25	12
Mass Ratio:	9	2.33	1.5	1	0.67	0.43	0.25	0.11	0.05
Air/Fuel:	0.111	0.429	0.667	1	1.493	2.326	4	9.091	20
Mean Radius:	2.996	6.672	8.988	12.058	16.511	23.779	38.131	80.889	166.211
Radius, inches:	0.00500	0.01200	0.01600	0.02100	0.02900	0.04200	0.06700	0.14200	0.29100
Mean Distance:	19.13	40.68	53.4	69.65	92.42	128.45	197.62	398.28	792.17
Distance, in.:	0.14000	0.18000	0.20000	0.23000	0.27000	0.33000	0.45000	0.81000	1.50000
Time msec:	0.015263	0.02047	0.02366	0.02933	0.038590	0.05648	0.10710	0.36836	1.38022

(5)

NOZZLE SCALING CALCULATIONS
17-Apr-86

ENGINE:

Bore: (in)	3.94	Disp. Vol.: (in^3)	50.4	
Stroke: (in)	4.13			
Speed: (rpm)	2000			
Comp. Ratio:	11	Clearance:	5.04	

PUMP:

Plunger: (mm)	7.5	Vol./Stroke:	274.3	0.913
Stroke: (mm)	7			!sp. gravity
Retract: (mm^3)	35	Inj. Mass: (mg)	250.4	Rohsenow & Choi

NOZZLE:

Hole Size: (in)	0.005	Hole Area:	1.96E-05
Number:	6	Total:	1.18E-04
Coefficient:	0.6		

INJECTION PARAMETERS:
Specified in crankangle degrees (TDC = 0)

Start: (deg.)	-50	Duration:	60
End: (deg.)	10		

Single Hole:		Nozzle:		
Rate: (mg/deg.)	0.7	Rate: (mg/deg.)	4.17	
Rate: (g/sec)	835	Rate: (g/sec)	5010	
Velocity: (m/sec)	120.3			!RCM was 122 m/sec (JMR)

INLET:

Vol. Effic.:	0.95		
Polytropic:	1.3	Air at TDC:	
Inlet Press.:	14.7	TDC Press:	332
Inlet Temp. (F)	90	TDC Temp:	1129
Density:	1.14E-03	Density Ratio:	11
		TDC Density:	1.26E-02

COMBUSTION CHAMBER: Jet Mixing

Density Ratio:	72.7
Jet Vel.:	120.3
Radius:	0.0025
Entrain: (axial)	0.11

JET CALCULATION

Pole:	0.156								
No Crossflow									
Rel Vel, Vf/Vi:	0.9	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.05
Velocity m/sec:	108	84	72	60	48	36	24	12	6
Mass Ratio:	9	2.33	1.5	1	0.67	0.43	0.25	0.11	0.05
Air/Fuel:	0.111	0.429	0.667	1	1.493	2.326	4	9.091	20
Mean Radius:	2.996	6.672	8.988	12.058	16.511	23.779	38.131	80.889	166.211
Radius, inches:	0.00700	0.01700	0.02200	0.03000	0.04100	0.05900	0.09500	0.20200	0.41600
Mean Distance:	19.13	40.68	53.4	69.65	92.42	128.45	197.62	398.28	792.17
Distance, in.:	0.20000	0.26000	0.29000	0.33000	0.39000	0.48000	0.65000	1.15000	2.14000
Time msec:	0.044567	0.06056	0.07036	0.08582	0.114222	0.16921	0.31611	1.06447	4.02795

(6)

NOZZLE SCALING CALCULATIONS
17-Apr-86

Supporting Data, Tech. Rpt. # 5

ENGINE:

Bore: (in)	3.94	Disp. Vol.: (in^3)	50.4
Stroke: (in)	4.13		
Speed: (rpm)	2000		
Comp. Ratio:	11	Clearance:	5.04

PUMP:

Plunger: (mm)	7.5	Vol./Stroke:	274.3	0.913
Stroke: (mm)	7			!sp. gravity
Retract: (mm^3)	35	Inj. Mass: (mg)	250.4	Rohsenow & Choi

NOZZLE:

Hole Size: (in)	0.007	Hole Area:	3.85E-05
Number:	6	Total:	2.31E-04
Coefficient:	0.6		

INJECTION PARAMETERS:
Specified in crankangle degrees (TDC = 0)

Start: (deg.)	-50	Duration:	60
End: (deg.)	10		

Single Hole:		Nozzle:		
Rate: (mg/deg.)	0.7	Rate: (mg/deg.)	4.17	
Rate: (g/sec)	835	Rate: (g/sec)	5010	
Velocity: (m/sec)	61.4			!RCM was 122 m/sec (JMR)

INLET:

Vol. Effic.:	0.95		
Polytropic:	1.3	Air at TDC:	
Inlet Press.:	14.7	TDC Press:	332
Inlet Temp. (F)	90	TDC Temp:	1129
Density:	1.14E-03	Density Ratio:	11
		TDC Density:	1.26E-02

COMBUSTION CHAMBER: Jet Mixing

Density Ratio:	72.7
Jet Vel.:	61.4
Radius:	0.0035
Entrain: (axial)	0.11

FIG. 5

JET CALCULATION
Pole: 0.219
No Crossflow

Rel Vel, Vf/Vi:	0.9	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.05
Velocity m/sec:	55	43	37	31	25	18	12	6	3
Mass Ratio:	9	2.33	1.5	1	0.67	0.43	0.25	0.11	0.05
Air/Fuel:	0.111	0.429	0.667	1	1.493	2.326	4	9.091	20
Mean Radius:	2.996	6.672	8.988	12.058	16.511	23.779	38.131	80.889	166.211
Radius, inches:	0.01000	0.02300	0.03100	0.04200	0.05800	0.08300	0.13300	0.28300	0.58200
Mean Distance:	19.13	40.68	53.4	69.65	92.42	128.45	197.62	398.28	792.17
Distance, in.:	0.29000	0.36000	0.41000	0.46000	0.54000	0.67000	0.91000	1.61000	2.99000
Time msec:	0.126755	0.16331	0.19515	0.23265	0.305646	0.46130	0.87608	2.97147	11.2333

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NOZZLE SCALING CALCULATIONS
17-Apr-86

Supporting Data, Tech. Rpl. #5

ENGINE:

Bore: (in)	3.94	Disp. Vol.: (in^3)	50.4
Stroke: (in)	4.13		
Speed: (rpm)	2000		
Comp. Ratio:	11	Clearance:	5.04

PUMP:

Plunger: (mm)	7.5	Vol./Stroke:	274.3	0.913
Stroke: (mm)	7			!sp. gravity
Retract: (mm^3)	35	Inj. Mass: (mg)	250.4	Rohsenow & Choi

NOZZLE:

Hole Size: (in)	0.007	Hole Area:	3.85E-05
Number:	10	Total:	3.85E-04
Coefficient:	0.6		

INJECTION PARAMETERS:
Specified in crankangle degrees (TDC = 0)

Start: (deg.)	-50	Duration:	60
End: (deg.)	10		

Single Hole:		Nozzle:		
Rate: (mg/deg.)	0.42	Rate: (mg/deg.)	4.17	
Rate: (g/sec)	501	Rate: (g/sec)	5010	
Velocity: (m/sec)	36.8			!RCM was 122 m/sec (JMR)

INLET:

Vol. Effic.:	0.95		
Polytropic:	1.3	Air at TDC:	
Inlet Press.:	14.7	TDC Press:	332
Inlet Temp. (F)	90	TDC Temp:	1129
Density:	1.14E-03	Density Ratio:	11
		TDC Density:	1.26E-02

COMBUSTION CHAMBER: Jet Mixing

Density Ratio:	72.7
Jet Vel.:	36.8
Radius:	0.0035
Entrain: (axial)	0.11

FIG. 6

JET CALCULATION

Pole:	0.219								
No Crossflow									
Rel Vel, Vf/Vi:	0.9	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.05
Velocity m/sec:	33	26	22	18	15	11	7	4	2
Mass Ratio:	9	2.33	1.5	1	0.67	0.43	0.25	0.11	0.05
Air/Fuel:	0.111	0.429	0.667	1	1.493	2.326	4	9.091	20
Mean Radius:	2.996	6.672	8.988	12.058	16.511	23.779	38.131	80.889	166.211
Radius, inches:	0.01000	0.02300	0.03100	0.04200	0.05800	0.08300	0.13300	0.28300	0.58200
Mean Distance:	19.13	40.68	53.4	69.65	92.42	128.45	197.62	398.28	792.17
Distance, in.:	0.29000	0.36000	0.41000	0.46000	0.54000	0.67000	0.91000	1.61000	2.99000
Time msec:	0.211373	0.27207	0.32517	0.38899	0.512658	0.76971	1.46442	4.82452	17.2172

APPENDIX B

BASELINE ENGINE DATA
SUPERFLOW AND APA100 DATA

DATE	TIME, #	NOMINAL RPM	TORQUE (lb-ft)	H.P.	FUEL (lb/HR)	AIR (SCFM)	AIR (lb/HR)	A/F.	B.S.F.C lb/HP·HR	EXHAUST TEMP. °F
12/23	11:01, 31	1500	7.9	2.8	1.67	21.6	98.5	59.0	0.596	360° (12
12/22	15:05, 23	2000	10.0	3.8	2.29	26.6	121.3	53.0	0.603	130°
12/22	15:34, 25	2500	10.3	4.9	2.90	29.2	133.2	45.9	0.592	260°
12/22	15:57, 27	2800	9.9	5.3	3.36	34.0	155.0	46.1	0.634	350°
12/22	14:49, 22	1500	20.4	6.0	2.50	21.9	99.9	40.0	0.417	325°
12/23	10:50, 33	2000	20.2	7.8	3.37	26.3	119.9	35.6	0.432	610°
12/22	15:20, 24	2500	20.1	9.6	4.26	29.1	132.7	31.2	0.444	270°
12/22	15:45, 26	2800	19.7	10.4	5.00	33.7	153.7	30.7	0.481	500°
12/23	9:57, 29	1500	21.3	6.1	2.54	21.5	98.0	38.6	0.416	525°
12/23	10:10, 30	2000	26.5	10.0	4.15	26.1	119.0	28.7	0.415	700°
12/23	10:25, 31	2500	26.3	12.6	5.30	28.9	131.8	24.9	0.421	850
12/23	10:37, 32	2800	26.0	13.9	6.11	33.6	153.2	25.1	0.440	875

COMBUSTION ELECTROMAGNETICS INC.
32 PRENTISS ROAD
Arlington, Massachusetts 02174
PHONE: (617) 641-0520

Test Number: 34
Date (M/D/Y): 12/23/88 Time (H:M:S): 11:01:24 Operator: Pohlhammes
Engine description: Duty F1L511, STOCK
Test description: 2 sec intervals, 1500 RPM, 1/2 rated load, Fuel #2

Test: 2.00 Seconds/Data Point Fuel Spec. Grav.: .832 Air Sensor: 4.0
Vapor Pressure: .37 Barometric Pres.: 29.38 Ratio: 1.00 TO 1
Engine Type: 4-Cycle Diesel Engine displacement: 50.0 Stroke: 4.130

Speed rpm	Trq lb-Ft	Pwr Hp	FA-FB lb/hr	AI scfm	A/F	BSFC lb/Hphr	BSAC	Man-P in Hg	Oil psi	CAT F	Fuel F	Oil Out	Wat Out
1502	9.9	2.8	1.3	21.6	76.3	.46	35.41	-51.39	.0	66	151	195	0
1507	9.6	2.8	1.0	21.6	99.1	.36	35.41	-51.39	.0	66	151	195	0
1502	10.1	2.9	1.3	21.6	76.3	.45	34.19	-51.39	.0	66	151	194	0
1501	9.9	2.8	1.3	21.5	75.9	.46	35.24	-51.39	.0	67	152	194	0
1502	10.0	2.9	1.1	21.5	89.7	.38	34.03	-51.39	.0	67	152	195	0
1501	10.0	2.9	1.2	21.5	82.2	.41	34.03	-51.39	.0	66	152	195	0
1502	9.9	2.8	1.2	21.6	82.6	.43	35.41	-51.39	.0	66	152	194	0
1503	9.8	2.8	1.3	21.6	76.3	.46	35.41	-51.39	.0	66	152	192	0
1509	9.5	2.7	1.1	21.7	90.6	.41	36.89	-51.39	.0	65	152	193	0
1503	10.0	2.9	1.1	21.6	90.1	.38	34.19	-51.39	.0	65	151	194	0
1496	10.3	2.9	1.1	21.6	90.1	.38	34.19	-51.39	.0	65	151	195	0
1498	10.1	2.9	1.1	21.6	90.1	.38	34.19	-51.39	.0	65	151	194	0
1499	10.1	2.9	1.1	21.6	90.1	.38	34.19	-51.39	.0	66	151	194	0
1496	10.3	2.9	1.3	21.5	75.9	.45	34.03	-51.39	.0	66	152	194	0
1497	10.0	2.9	1.1	21.5	89.7	.38	34.03	-51.39	.0	66	151	193	0
1496	9.9	2.8	1.2	21.5	82.2	.43	35.24	-51.39	.0	67	151	193	0
1501	9.8	2.8	1.2	21.5	82.2	.43	35.24	-51.39	.0	67	151	192	0
1503	10.0	2.9	1.3	21.6	76.3	.45	34.19	-51.39	.0	66	151	192	0
1507	9.9	2.8	1.2	21.7	83.0	.43	35.57	-51.39	.0	63	151	192	0
1506	9.9	2.8	1.3	21.6	76.3	.46	35.41	-51.39	.0	65	150	192	0
1502	10.0	2.9	1.3	21.6	76.3	.45	34.19	-51.39	.0	65	151	192	0
1508	9.8	2.8	1.2	21.6	82.6	.43	35.41	-51.39	.0	65	150	193	0
1506	9.9	2.8	1.1	21.7	90.6	.39	35.57	-51.39	.0	64	150	193	0
1502	9.8	2.8	1.4	21.6	70.8	.50	35.41	-51.39	.0	65	151	193	0
1509	9.5	2.7	1.2	21.6	82.6	.44	36.72	-51.39	.0	66	152	193	0
1507	9.8	2.8	1.2	21.6	82.6	.43	35.41	-51.39	.0	66	151	193	0
1503	9.9	2.8	1.3	21.6	76.3	.46	35.41	-51.39	.0	66	151	193	0
1503	9.8	2.8	1.2	21.6	82.6	.43	35.41	-51.39	.0	66	151	194	0
1501	10.0	2.9	1.2	21.6	82.6	.41	34.19	-51.39	.0	67	150	193	0
1497	10.0	2.9	1.2	21.6	82.6	.41	34.19	-51.39	.0	64	150	193	0
1498	10.0	2.9	1.2	21.6	82.6	.41	34.19	-51.39	.0	65	150	193	0
1503	9.5	2.7	1.1	21.6	90.1	.41	36.72	-51.39	.0	65	149	193	0
1507	9.9	2.8	1.2	21.5	82.2	.43	35.24	-51.39	.0	67	150	192	0
1503	9.9	2.8	1.2	21.6	82.6	.43	35.41	-51.39	.0	65	150	191	0
1504	9.8	2.8	1.2	21.7	83.0	.43	35.57	-51.39	.0	64	150	192	0
	9.9	2.8		21.6						66	151	193	

1st 10 gr in 45.45 sec = 1.75
2ND 10 gr in 49.55 sec = 1.60 } 1.67 lbs/HR

DE09JA.010

COMBUSTION ELECTROMAGNETICS, INC.

9-Jan-89
10:47:56

12-JAN-89
15:08:10

Indicated Data vs Crankangle

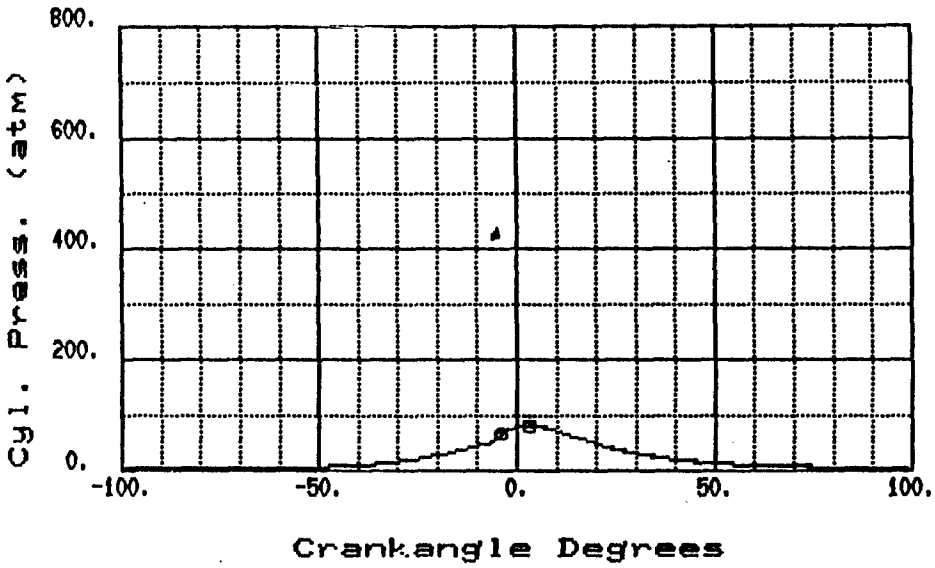
Engine : DEUTZ F1L 511
Cell : Superflow
Project : TACOM Baseline

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	17.00	Intake	=	328.5,-120.5
Ign Timing	=	984.0 Deg	Exhaust	=	108.5, 392.5

Engine Speed = 1512.0 rpm Engine Torque= 13.56 N-m

APA100: U.S. Army Tank Automotive Command

Title : de09ja.010



DATA MARKERS :

Pmax =	79.9824
@	3.00
dPmax=	6.6167
@	-4.00

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS INC.
32 PRENTISS ROAD
Arlington, Massachusetts 02174
PHONE: (617) 641-0520

Test Number: 23
Date (M/D/Y): 12/22/88 Time (H:M:S): 15:05:13 Operator: POHLHAMMER
Engine description: DEUTZ F1L511, STOCK
Test description: 2 sec. intervals, 2000 RPM, 1/3 RATED TORQUE, FUEL #2

Test: 2.00 Seconds/Data Point Fuel Spec. Grav.: .832 Air Sensor: 4.0
Vapor Pressure: .38 Barometric Pres.: 29.38 Ratio: 1.00 TO 1
Engine Type: 4-Cycle Diesel Engine displacement: 50.0 Stroke: 4.130

Speed rpm	Trq lb-Ft	Pwr Hp	FA-FB lb/hr	A1 scfm	A/F	BSFC lb/Hphr	BSAC	Man-P in Hg	Oil psi	CAT F	Fuel F	Oil Out	Wat Out
1981	9.9	3.7	2.0	26.7	61.3	.54	33.12	-51.32	.0	69	159	169	0
1981	9.9	3.7	2.0	26.7	61.3	.54	33.12	-51.32	.0	69	159	169	0
1982	9.9	3.7	1.9	26.7	64.5	.51	33.12	-51.32	.0	69	159	168	0
1980	9.9	3.7	2.0	26.6	61.1	.54	33.00	-51.32	.0	69	158	168	0
1982	9.9	3.7	2.0	26.7	61.3	.54	33.12	-51.32	.0	69	158	168	0
1981	9.9	3.7	1.9	26.7	64.5	.51	33.12	-51.32	.0	69	158	168	0
1982	9.9	3.7	2.0	26.7	61.3	.54	33.12	-51.32	.0	69	157	168	0
1981	10.0	3.8	1.8	26.6	67.8	.47	32.13	-51.32	.0	69	157	169	0
1982	10.0	3.8	2.0	26.7	61.3	.53	32.25	-51.32	.0	69	158	169	0
1984	9.9	3.7	2.1	26.6	58.1	.57	33.00	-51.32	.0	70	158	169	0
1984	9.9	3.7	2.0	26.6	61.1	.54	33.00	-51.32	.0	71	158	169	0
1983	9.9	3.7	2.0	26.6	61.1	.54	33.00	-51.32	.0	70	159	169	0
1984	9.9	3.7	2.0	26.6	61.1	.54	33.00	-51.32	.0	70	159	169	0
1983	10.0	3.8	2.1	26.6	58.1	.55	32.13	-51.32	.0	70	158	169	0
1984	10.1	3.8	2.3	26.6	53.1	.61	32.13	-51.32	.0	70	158	169	0
1984	10.0	3.8	2.2	26.6	55.5	.58	32.13	-51.32	.0	70	157	169	0
1986	10.0	3.8	2.2	26.6	55.5	.58	32.13	-51.32	.0	70	157	169	0
1986	10.0	3.8	2.2	26.6	55.5	.58	32.13	-51.32	.0	69	157	170	0
1986	10.0	3.8	2.1	26.7	58.4	.55	32.25	-51.32	.0	68	157	170	0
1985	10.1	3.8	1.9	26.7	64.5	.50	32.25	-51.32	.0	69	157	171	0
1983	9.9	3.7	2.0	26.7	61.3	.54	33.12	-51.32	.0	68	158	171	0
1982	9.9	3.7	1.8	26.7	68.1	.49	33.12	-51.29	.0	69	158	171	0
1982	9.9	3.7	2.2	26.6	55.5	.59	33.00	-51.32	.0	71	158	170	0
1984	9.9	3.7	2.1	26.6	58.1	.57	33.00	-51.32	.0	70	158	170	0
1984	9.9	3.7	1.9	26.6	64.3	.51	33.00	-51.32	.0	70	158	169	0
1983	10.0	3.8	2.2	26.6	55.5	.58	32.13	-51.32	.0	69	158	169	0
1983	9.9	3.7	1.8	26.6	67.8	.49	33.00	-51.32	.0	69	157	169	0
1982	9.9	3.7	2.0	26.6	61.1	.54	33.00	-51.32	.0	70	157	169	0
1982	10.0	3.8	1.7	26.6	71.8	.45	32.13	-51.32	.0	70	157	169	0
1981	9.9	3.7	1.8	26.6	67.8	.49	33.00	-51.32	.0	69	158	169	0
1982	9.8	3.7	2.0	26.6	61.1	.54	33.00	-51.32	.0	69	158	170	0
1982	10.0	3.8	1.9	26.6	64.3	.50	32.13	-51.32	.0	69	159	171	0
1981	10.0	3.8	2.0	26.6	61.1	.53	32.13	-51.32	.0	69	159	171	0
1982	10.0	3.8	2.1	26.6	58.1	.55	32.13	-51.32	.0	69	159	171	0
1981	10.0	3.8	1.8	26.6	67.8	.47	32.13	-51.32	.0	70	159	171	0
1980	10.1	3.8	1.9	26.6	64.3	.50	32.13	-51.32	.0	70	158	170	0
1980	10.1	3.8	1.8	26.6	67.8	.47	32.13	-51.32	.0	70	158	170	0
	10.0	3.8		26.6									

1st 20g in 71.10 sec = 2.23
2ND 20g in 67.87 sec = 2.34 > 2.29 lbs/HR

COMBUSTION ELECTROMAGNETICS, INC.

9-Jan-89
10:47:56

12-JAN-89
16:10:01

Indicated Data vs Crankangle

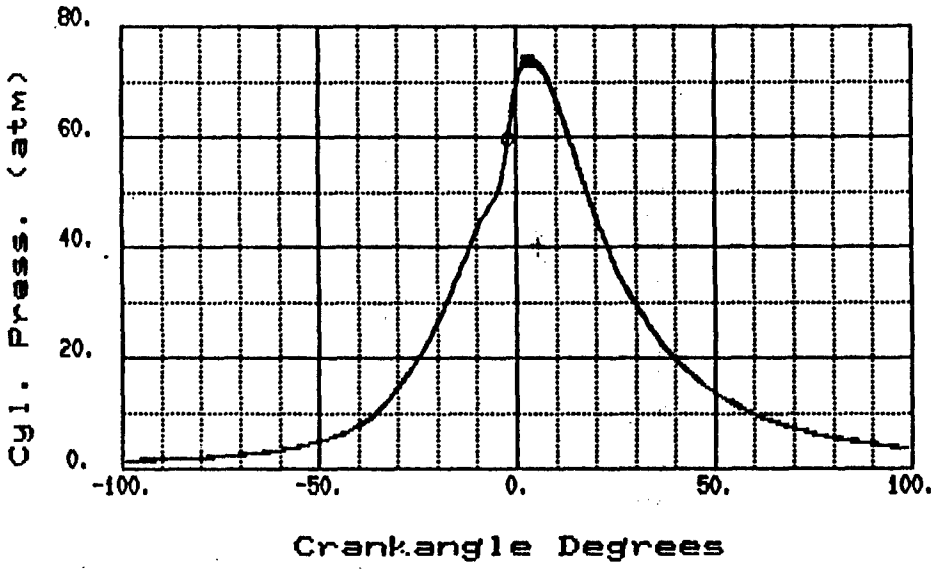
Engine : DEUTZ F1L 511
Cell : Superflow
Project : TACOM Baseline

No. Cylinders	= 1	Bore	= 100.00 mm
		Stroke	= 105.00 mm
Compr. Ratio	= 17.00	Intake	= 328.5,-120.5
Ign Timing	= 984.0 Deg	Exhaust	= 108.5, 392.5

Engine Speed = 2015.0 rpm Engine Torque= 13.97 N-m

APA100: U.S. Army Tank Automotive Command

Title : de09ja.012



DATA MARKERS :

Pmax =	73.6342
@	3.00
dPmax=	5.2802
@	-2.00

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS INC.
32 PRENTISS ROAD
Arlington, Massachusetts 02174
PHONE: (617) 641-0520

Test Number: 25
Date (M/D/Y): 12/22/88 Time (H:M:S): 15:34:58 Operator: PUHLHANMER
Engine description: DEUTZ F1L511, STOCK
Test description: 2 sec. intervals, 2500 RPM, 1/3 RATED TORQUE, FUEL #2

Test: 2.00 Seconds/Data Point Fuel Spec. Grav.: .832 Air Sensor: 4.0
Vapor Pressure: .37 Barometric Pres.: 29.38 Ratio: 1.00 TO 1
Engine Type: 4-Cycle Diesel Engine displacement: 50.0 Stroke: 4.130

Speed rpm	Trq lb-Ft	Pwr Hp	FA-FB lb/hr	A1 scfm	A/F	BSFC lb/Hphr	BSAC	Man-P In Hg	Oil psi	CAT F	Fuel F	Oil Out	Wat Out
2490	10.0	4.7	2.3	29.4	58.7	.49	28.71	-51.24	.0	73	158	198	0
2489	10.5	5.0	2.4	29.4	56.2	.48	26.99	-51.24	.0	73	157	198	0
2491	10.3	4.9	2.5	29.3	53.8	.51	27.45	-51.24	.0	74	158	198	0
2491	10.1	4.8	2.3	29.3	58.5	.48	28.02	-51.24	.0	74	159	199	0
2494	10.3	4.9	2.4	29.3	56.0	.49	27.45	-51.24	.0	74	159	200	0
2492	10.4	4.9	2.4	29.3	56.0	.49	27.45	-51.24	.0	74	159	199	0
2493	10.4	4.9	2.4	29.3	56.0	.49	27.45	-51.24	.0	74	159	199	0
2490	10.5	5.0	2.5	29.2	53.6	.50	26.81	-51.24	.0	75	158	199	0
2491	10.4	4.9	2.4	29.3	56.0	.49	27.45	-51.24	.0	75	158	199	0
2489	10.5	5.0	2.6	29.2	51.6	.52	26.81	-51.22	.0	75	158	200	0
2490	10.3	4.9	2.6	29.2	51.6	.53	27.35	-51.22	.0	75	158	200	0
2488	10.4	4.9	2.5	29.3	53.8	.51	27.45	-51.24	.0	74	158	200	0
2488	10.1	4.8	2.4	29.3	56.0	.50	28.02	-51.24	.0	74	158	199	0
2486	10.1	4.8	2.5	29.3	53.8	.52	28.02	-51.24	.0	74	158	200	0
2488	10.3	4.9	2.3	29.2	58.3	.47	27.35	-51.24	.0	75	158	200	0
2490	10.1	4.8	2.3	29.2	58.3	.48	27.92	-51.24	.0	75	158	199	0
2489	10.3	4.9	2.6	29.2	51.6	.53	27.35	-51.24	.0	75	158	198	0
2490	10.4	4.9	2.8	29.1	47.7	.57	27.26	-51.24	.0	76	159	198	0
2490	10.3	4.9	2.6	29.2	51.6	.53	27.35	-51.22	.0	75	158	198	0
2490	10.3	4.9	2.4	29.2	55.9	.49	27.35	-51.24	.0	75	158	198	0
2493	10.0	4.7	2.4	29.3	56.0	.51	28.61	-51.24	.0	74	158	198	0
2491	10.1	4.8	2.3	29.3	58.5	.48	28.02	-51.24	.0	74	158	199	0
2491	10.1	4.8	2.4	29.2	55.9	.50	27.92	-51.24	.0	75	158	199	0
2490	10.3	4.9	2.4	29.2	55.9	.49	27.35	-51.24	.0	75	158	199	0
2491	10.1	4.8	2.4	29.2	55.9	.50	27.92	-51.24	.0	75	158	199	0
2489	10.3	4.9	2.4	29.2	55.9	.49	27.35	-51.24	.0	75	158	199	0
2491	10.0	4.7	2.3	29.2	58.3	.49	28.52	-51.24	.0	75	158	200	0
2489	10.1	4.8	2.3	29.2	58.3	.48	27.92	-51.24	.0	75	159	199	0
2489	10.1	4.8	2.4	29.2	55.9	.50	27.92	-51.24	.0	75	159	200	0
2487	10.3	4.9	2.3	29.2	58.3	.47	27.35	-51.24	.0	74	156	198	0
2486	10.3	4.9	2.3	29.2	58.3	.47	27.35	-51.24	.0	75	157	199	0
2488	10.1	4.8	2.4	29.2	55.9	.50	27.92	-51.24	.0	74	158	199	0
2488	10.4	4.9	2.4	29.3	56.0	.49	27.45	-51.24	.0	74	158	198	0
2490	10.3	4.9	2.5	29.3	53.8	.51	27.45	-51.24	.0	74	158	199	0
2486	10.3	4.9	2.6	29.3	51.7	.53	27.45	-51.24	.0	74	158	198	0
	10.3	4.9		29.2						74	158	199	

1st 20gr in 54.54 sec = 2.91
2ND 20gr in 54.80 sec = 2.90 } 2.90 lbs/HR

COMBUSTION ELECTROMAGNETICS, INC.

9-Jan-89
10:47:56

10-JAN-89
15:27:34

Indicated Data vs Crankangle

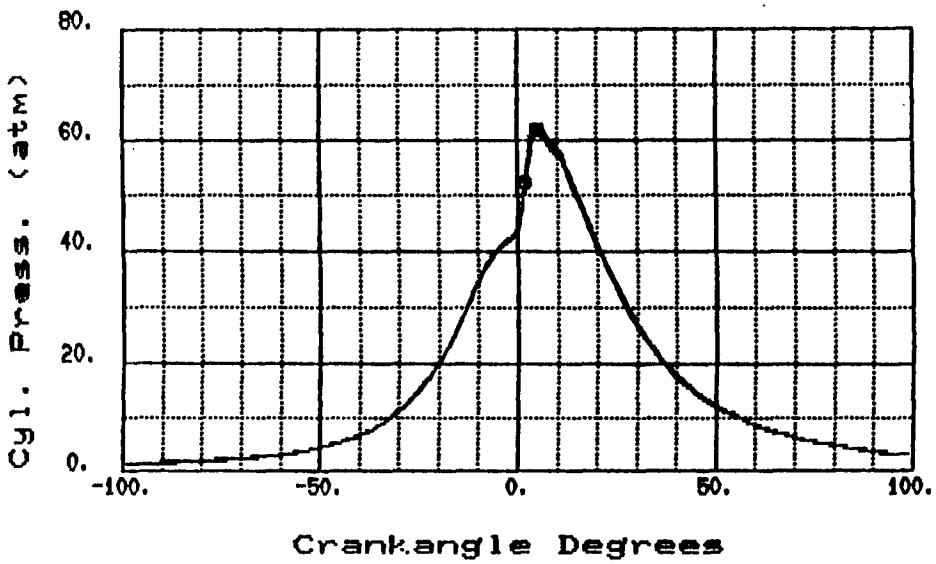
Engine : DEUTZ F1L 511
Cell : Superflow
Project : TACOM Baseline

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	17.00	Intake	=	328.5,-120.5
Ign Timing	=	984.0 Deg	Exhaust	=	108.5, 392.5

Engine Speed = 2480.0 rpm Engine Torque= 13.97 N-m

APA100: U.S. Army Tank Automotive Command

Title : de03ja.007



DATA MARKERS :

Pmax =	62.0278
@	5.00
dPmax=	5.2560
@	2.00

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS INC.
32 PRENTISS ROAD
Arlington, Massachusetts 02174
PHONE: (617) 641-0520

Test Number: 27
Date (M/D/Y): 12/22/88 Time (H:M:S): 15:57:23 Operator: POHLHAMMER
Engine description: DEUTZ F1L511, STOCK
Test description: 2 sec. intervals, 2800 RPM, 1/3 RATED TORQUE, Fuel #2

Test: 2.00 Seconds/Data Point Fuel Spec. Grav.: .832 Air Sensor: 4.0
Vapor Pressure: .37 Barometric Pres.: 29.38 Ratio: 1.00 TO 1
Engine Type: 4-Cycle Diesel Engine displacement: 50.0 Stroke: 4.130

Speed rpm	Trq lb-Ft	Pwr Hp	FA-FB lb/hr	AI scfm	A/F	BSFC lb/Hphr	BSAC	Man-P In Hg	Oil psi	CAT F	Fuel F	Oil Out	Wat Out
2798	9.9	5.3	3.7	33.9	42.1	.70	29.36	-51.32	.0	77	160	210	0
2789	9.8	5.2	3.6	34.0	43.4	.69	30.01	-51.34	.0	76	160	209	0
2798	10.0	5.3	3.5	34.0	44.6	.66	29.45	-51.34	.0	76	159	210	0
2800	9.9	5.3	3.5	34.0	44.6	.66	29.45	-51.34	.0	77	159	211	0
2799	10.0	5.3	3.5	34.0	44.6	.66	29.45	-51.34	.0	77	160	211	0
2797	10.0	5.3	3.7	34.1	42.3	.70	29.53	-51.34	.0	76	160	211	0
2798	9.9	5.3	3.6	34.1	43.5	.68	29.53	-51.34	.0	76	160	210	0
2799	10.0	5.3	3.5	34.2	44.9	.66	29.62	-51.34	.0	74	160	211	0
2801	10.0	5.3	3.6	34.2	43.6	.68	29.62	-51.34	.0	73	160	209	0
2800	9.8	5.2	3.7	34.1	42.3	.71	30.10	-51.32	.0	75	160	210	0
2797	10.0	5.3	3.7	34.0	42.2	.70	29.45	-51.32	.0	76	159	211	0
2796	10.0	5.3	3.5	34.1	44.7	.66	29.53	-51.32	.0	75	160	212	0
2798	10.0	5.3	3.3	34.1	47.4	.62	29.53	-51.32	.0	75	160	210	0
2800	9.9	5.3	3.4	34.0	45.9	.64	29.45	-51.32	.0	76	160	210	0
2799	9.9	5.3	3.3	34.0	47.3	.62	29.45	-51.32	.0	76	159	210	0
2797	9.9	5.3	3.2	34.0	48.8	.60	29.45	-51.32	.0	77	159	211	0
2796	9.9	5.3	3.5	34.0	44.6	.66	29.45	-51.34	.0	77	159	211	0
2797	10.0	5.3	3.3	33.9	47.2	.62	29.36	-51.34	.0	77	159	211	0
2799	10.0	5.3	3.6	33.9	43.2	.68	29.36	-51.32	.0	76	160	210	0
2799	9.8	5.2	3.5	33.9	44.5	.67	29.92	-51.32	.0	76	159	210	0
2796	9.9	5.3	3.3	33.9	47.2	.62	29.36	-51.32	.0	76	160	212	0
2795	9.9	5.3	3.4	33.9	45.8	.64	29.36	-51.32	.0	76	159	212	0
2797	9.8	5.2	3.4	34.0	45.9	.65	30.01	-51.34	.0	76	159	213	0
2799	9.9	5.3	3.3	33.9	47.2	.62	29.36	-51.32	.0	77	160	213	0
2800	9.9	5.3	3.5	33.9	44.5	.66	29.36	-51.34	.0	76	160	212	0
2798	10.0	5.3	3.7	33.9	42.1	.70	29.36	-51.34	.0	76	160	212	0
2796	10.0	5.3	3.8	33.9	41.0	.72	29.36	-51.34	.0	76	160	211	0
2796	9.9	5.3	3.6	33.9	43.2	.68	29.36	-51.32	.0	76	159	211	0
2799	9.9	5.3	3.4	33.9	45.8	.64	29.36	-51.32	.0	77	159	211	0
2800	10.0	5.3	3.4	34.0	45.9	.64	29.45	-51.32	.0	76	159	211	0
2797	10.0	5.3	3.5	33.9	44.5	.66	29.36	-51.32	.0	77	159	212	0
2795	9.8	5.2	3.3	34.0	47.3	.63	30.01	-51.32	.0	77	160	212	0
2796	9.9	5.3	3.4	34.0	45.9	.64	29.45	-51.32	.0	77	160	212	0
2798	9.8	5.2	3.7	33.9	42.1	.71	29.92	-51.32	.0	77	160	213	0
2798	10.0	5.3	3.4	33.9	45.8	.64	29.36	-51.32	.0	78	160	213	0
	9.9	5.3		34.0						76	160	211	

1st 20gr in 47.62 sec = 3.33
2ND 20gr in 46.87 sec = 3.39 > 3.36 lbs/HR

COMBUSTION ELECTROMAGNETICS, INC.

9-Jan-89
10:47:56

11-JAN-89
10:31:18

Indicated Data vs Crankangle

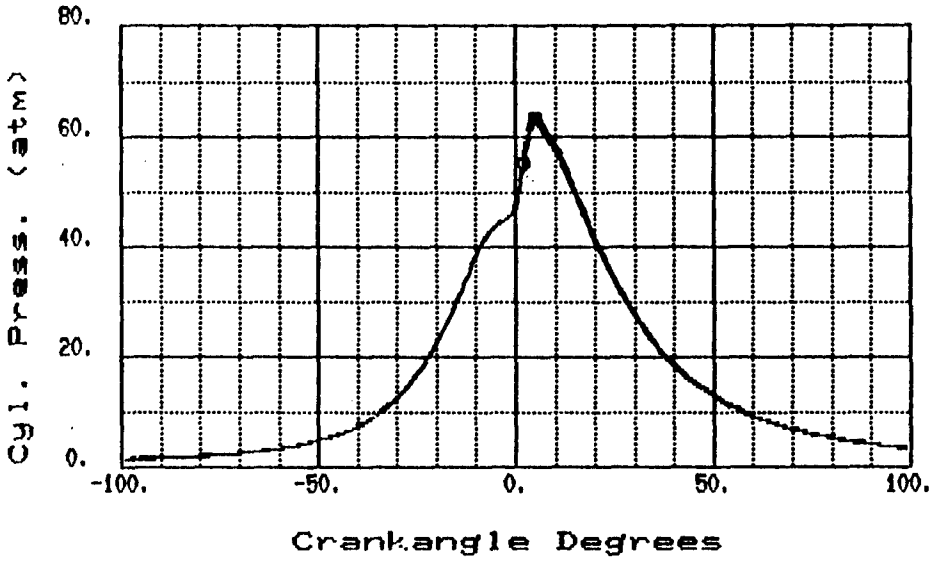
Engine : DEUTZ F1L 511
Cell : Superflow
Project : TACOM Baseline

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	17.00	Intake	=	328.5,-120.5
Ign Timing	=	984.0 Deg	Exhaust	=	108.5, 392.5

Engine Speed = 2795.0 rpm Engine Torque= 13.70 N-m

APA100: U.S. Army Tank Automotive Command

Title : de03ja.008



DATA MARKERS :

Pmax =	63.0768
@	5.00
dPmax=	4.3756
@	2.00

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS INC.
38 PRENTISS ROAD
Arlington, Massachusetts 02174
PHONE: (617) 641-0520

Test Number: 22
Date (M/D/Y): 12/22/88 Time (H:M:S): 14:49:30 Operator: POHLHAMMER
Engine description: DEUTZ F1L511, STOCK
Test description: 2 sec. intervals, 1500 RPM, 2/3 RATED TORQUE, Fuel #2

Test: 2.00 Seconds/Data Point Fuel Spec. Grav.: .832 Air Sensor: 4.0
Vapor Pressure: .38 Barometric Pres.: 29.38 Ratio: 1.00 TO 1
Engine Type: 4-Cycle Diesel Engine displacement: 50.0 Stroke: 4.130

Speed rpm	Trq lb-ft	Pwr Hp	FA-FB lb/hr	A1 scfm	A/F	BSFC lb/Hphr	BSAC	Man-P in Hg	Oil psi	EXT F	Fuel F	Oil Out	Wat Out
1540	20.3	6.0	1.8	21.9	55.9	.30	16.75	-51.37	.0	66	159	149	0
1539	20.3	5.9	2.0	21.9	50.3	.34	17.04	-51.37	.0	66	159	149	0
1538	20.4	6.0	2.0	21.8	50.0	.33	16.68	-51.37	.0	67	160	148	0
1542	20.3	6.0	2.1	21.8	47.7	.35	16.68	-51.37	.0	68	160	149	0
1545	20.3	6.0	1.9	21.8	52.7	.32	16.68	-51.37	.0	68	159	149	0
1544	20.4	6.0	1.9	21.9	52.9	.32	16.75	-51.37	.0	67	158	149	0
1544	20.5	6.0	1.9	21.9	52.9	.32	16.75	-51.37	.0	67	159	150	0
1540	20.8	6.1	1.7	21.9	59.1	.28	16.48	-51.37	.0	67	159	150	0
1543	20.6	6.1	1.9	21.9	52.9	.31	16.48	-51.37	.0	67	160	151	0
1543	20.5	6.0	1.8	21.9	55.9	.30	16.75	-51.37	.0	67	159	150	0
1546	20.1	5.9	1.7	21.9	59.1	.29	17.04	-51.37	.0	67	160	149	0
1544	20.5	6.0	1.7	21.9	59.1	.28	16.75	-51.37	.0	67	160	149	0
1549	20.0	5.9	1.9	21.9	52.9	.32	17.04	-51.37	.0	66	159	148	0
1548	20.3	6.0	1.9	21.9	52.9	.32	16.75	-51.37	.0	66	159	149	0
1548	20.3	6.0	2.0	21.9	50.3	.33	16.75	-51.37	.0	67	159	149	0
1544	20.4	6.0	2.0	21.8	50.0	.33	16.68	-51.37	.0	68	158	149	0
1541	20.8	6.1	1.9	21.8	52.7	.31	16.40	-51.37	.0	67	159	149	0
1544	20.1	5.9	2.1	21.9	47.9	.36	17.04	-51.37	.0	66	159	150	0
1542	20.5	6.0	2.0	21.9	50.3	.33	16.75	-51.37	.0	67	159	151	0
1542	20.0	5.9	1.9	21.9	52.9	.32	17.04	-51.37	.0	66	159	151	0
1540	20.0	5.9	2.0	21.9	50.3	.34	17.04	-51.37	.0	67	160	151	0
1538	20.3	5.9	2.2	21.9	45.7	.37	17.04	-51.37	.0	66	160	152	0
1545	20.1	5.9	2.0	21.9	50.3	.34	17.04	-51.37	.0	67	159	151	0
1544	20.4	6.0	2.0	21.9	50.3	.33	16.75	-51.37	.0	66	158	151	0
1545	20.3	6.0	1.9	21.9	52.9	.32	16.75	-51.37	.0	67	158	151	0
1544	20.6	6.1	2.1	21.9	47.9	.34	16.48	-51.37	.0	67	158	151	0
1545	20.6	6.1	2.1	21.9	47.9	.34	16.48	-51.37	.0	66	159	150	0
1549	20.4	6.0	1.9	21.9	52.9	.32	16.75	-51.37	.0	66	159	151	0
1549	20.4	6.0	1.9	21.9	52.9	.32	16.75	-51.37	.0	66	159	151	0
1547	20.1	5.9	2.0	21.9	50.3	.34	17.04	-51.37	.0	66	159	150	0
1544	20.3	6.0	2.0	22.0	50.5	.33	16.83	-51.34	.0	65	159	151	0
1545	20.3	6.0	1.8	21.9	55.9	.30	16.75	-51.37	.0	66	159	152	0
1544	20.5	6.0	1.9	21.9	52.9	.32	16.75	-51.37	.0	67	160	151	0
1543	20.6	6.1	1.8	21.9	55.9	.30	16.48	-51.37	.0	66	159	149	0
1544	20.1	5.9	2.3	21.9	43.7	.39	17.04	-51.37	.0	67	160	149	0
	20.4	6.0		21.9						67	159	150	

1st 20g in 63.22 sec = 2.51
2nd 20g in 64.00 sec = 2.48 > 2.50 lbs/HR

COMBUSTION ELECTROMAGNETICS, INC.

9-Jan-89
10:47:56

11-JAN-89
11:25:31

Indicated Data vs Crankangle

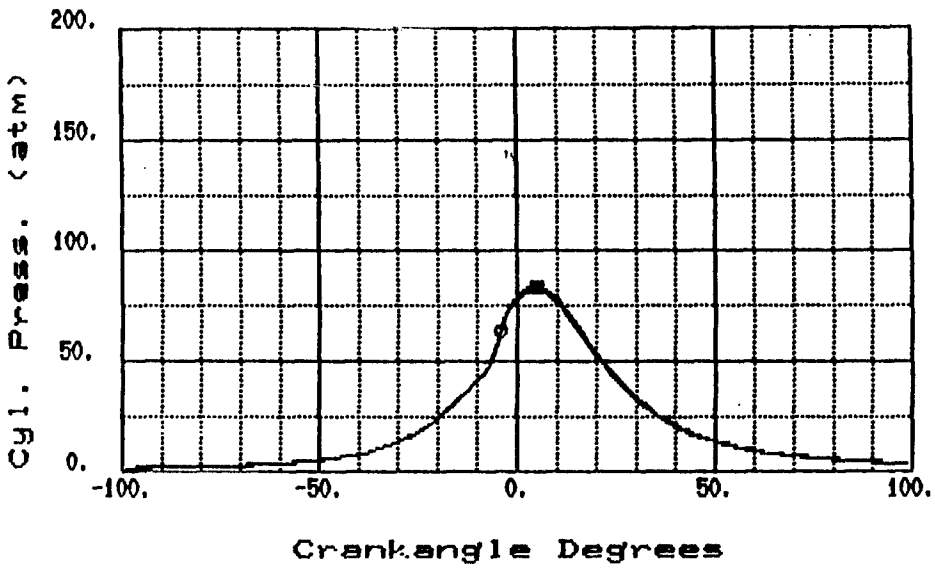
Engine : DEUTZ F1L 511
Cell : Superflow
Project : TACOM Baseline

No. Cylinders	= 1	Bore	= 100.00 mm
		Stroke	= 105.00 mm
Compr. Ratio	= 17.00	Intake	= 328.5,-120.5
Ign Timing	= 984.0 Deg	Exhaust	= 108.5, 392.5

Engine Speed = 1550.0 rpm Engine Torque= 27.25 N-m

APA100: U.S. Army Tank Automotive Command

Title : de03ja.009



DATA MARKERS :

Pmax =	82.7084
@	5.00
dPmax=	6.0615
@	-4.00

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS INC.
32 PRENTISS ROAD
Arlington, Massachusetts 02174
PHONE: (617) 641-0520

Test Number: 33
Date (M/D/Y): 12/23/88 Time (H:M:S): 10:50:03 Operator: POHLHAMMER
Engine description: DEUTZ F1L511, STOCK
Test description: 2 sec. intervals, 2000 RPM, 2/3 LOAD, FUEL #2

Test: 2.00 Seconds/Data Point Fuel Spec. Grav.: .832 Air Sensor: 4.0
Vapor Pressure: .37 Barometric Pres.: 29.38 Ratio: 1.00 TO 1
Engine Type: 4-Cycle Diesel Engine displacement: 50.0 Stroke: 4.130

Speed rpm	Trq lb-ft	Pwr Hp	FA-FB lb/hr	Al scfm	A/F	BSFC lb/Hphr	BSAC	Man-P in Hg	Oil psi	CAT F	Fuel F	Oil Out	Wat Out
2023	20.3	7.8	3.4	26.3	35.5	.44	15.48	-51.37	.0	69	157	[illegible]	0
2017	20.4	7.8	3.5	26.3	34.5	.45	15.48	-51.37	.0	69	157	210	0
2020	20.3	7.8	3.4	26.3	35.5	.44	15.48	-51.37	.0	69	157	209	0
2025	20.1	7.7	3.4	26.3	35.5	.44	15.68	-51.37	.0	68	157	209	0
2024	20.3	7.8	3.5	26.3	34.5	.45	15.48	-51.37	.0	70	157	209	0
2027	20.3	7.8	3.6	26.3	33.5	.46	15.48	-51.37	.0	70	157	209	0
2025	20.3	7.8	3.7	26.3	32.6	.47	15.48	-51.37	.0	70	157	209	0
2023	20.4	7.9	3.5	26.2	34.4	.44	15.22	-51.37	.0	70	157	208	0
2023	20.4	7.9	3.5	26.3	34.5	.44	15.28	-51.37	.0	69	156	207	0
2027	20.4	7.9	3.5	26.4	34.6	.44	15.34	-51.37	.0	68	157	208	0
2027	20.3	7.8	3.5	26.4	34.6	.45	15.54	-51.37	.0	68	157	209	0
2026	20.1	7.8	3.6	26.3	33.5	.46	15.48	-51.37	.0	68	157	209	0
2025	20.1	7.7	3.8	26.4	31.9	.49	15.74	-51.37	.0	68	157	209	0
2028	20.3	7.8	3.6	26.4	33.7	.46	15.54	-51.37	.0	68	157	208	0
2028	20.3	7.8	3.7	26.3	32.6	.47	15.48	-51.34	.0	70	157	208	0
2029	20.1	7.8	3.8	26.3	31.8	.49	15.48	-51.37	.0	70	157	209	0
2028	20.0	7.7	3.6	26.3	33.5	.47	15.68	-51.37	.0	70	157	210	0
2028	20.1	7.8	3.4	26.3	35.5	.44	15.48	-51.37	.0	69	157	210	0
2026	20.3	7.8	3.4	26.3	35.5	.44	15.48	-51.37	.0	68	157	208	0
2023	20.5	7.9	3.4	26.3	35.5	.43	15.28	-51.37	.0	68	158	208	0
2021	20.4	7.9	3.2	26.3	37.7	.41	15.28	-51.37	.0	69	157	208	0
2025	20.1	7.7	3.6	26.3	33.5	.47	15.68	-51.37	.0	70	157	208	0
2029	20.0	7.7	3.7	26.3	32.6	.48	15.68	-51.37	.0	70	157	208	0
2026	20.5	7.9	3.8	26.3	31.8	.48	15.28	-51.39	.0	69	156	208	0
2025	20.4	7.9	3.5	26.4	34.6	.44	15.34	-51.37	.0	68	155	209	0
2026	20.3	7.8	3.7	26.3	32.6	.47	15.48	-51.37	.0	68	156	208	0
2024	20.4	7.9	3.7	26.3	32.6	.47	15.28	-51.37	.0	70	157	207	0
2028	20.3	7.8	3.6	26.3	33.5	.46	15.40	-51.37	.0	69	157	208	0
2027	20.0	7.7	3.6	26.3	33.5	.47	15.68	-51.37	.0	70	157	207	0
2027	20.1	7.8	3.6	26.3	33.5	.46	15.40	-51.37	.0	69	157	207	0
2027	20.0	7.7	3.5	26.3	34.5	.45	15.68	-51.37	.0	69	157	207	0
2029	20.0	7.7	3.6	26.4	33.7	.47	15.74	-51.37	.0	69	157	207	0
2025	20.3	7.8	3.5	26.4	34.6	.45	15.54	-51.37	.0	68	157	207	0
2024	20.1	7.7	3.7	26.4	32.8	.48	15.74	-51.37	.0	68	157	207	0
2024	20.4	7.9	3.7	26.4	32.8	.47	15.34	-51.37	.0	67	157	207	0
	20.2	7.8		26.3						69	157	208	

1st 20gr in 46.52 sec = 3.41
2ND 70gr in 47.66 sec = 3.33 } 3.37 lbs/HR

COMBUSTION ELECTROMAGNETICS, INC.

9-Jan-89
10:47:56

13-JAN-89
09:09:16

Indicated Data vs Crankangle

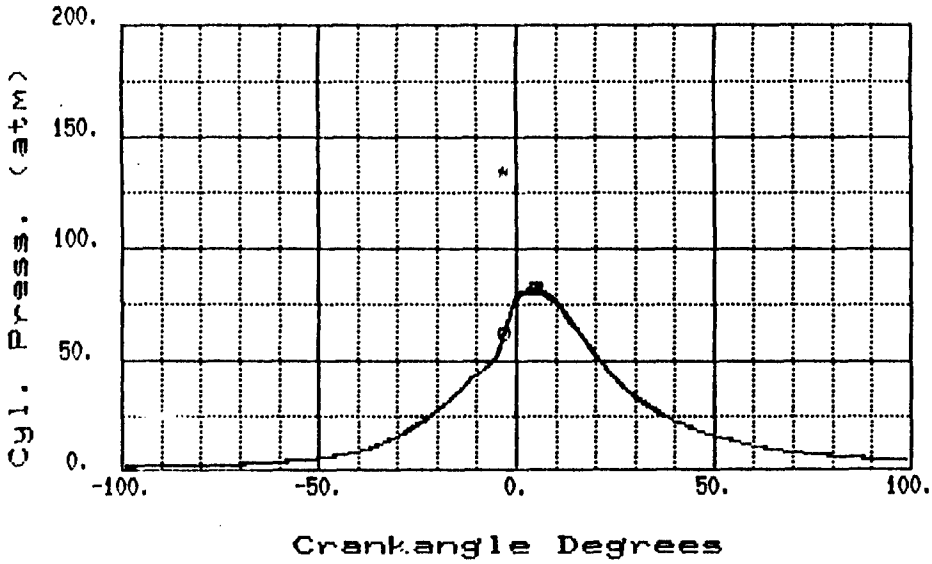
Engine : DEUTZ F1L 511
Cell : Superflow
Project : TACOM Baseline

No. Cylinders	= 1	Bore	= 100.00 mm
		Stroke	= 105.00 mm
Compr. Ratio	= 17.00	Intake	= 328.5,-120.5
Ign Timing	= 984.0 Deg	Exhaust	= 108.5, 392.5

Engine Speed = 2025.0 rpm Engine Torque= 27.52 N-m

APA100: U.S. Army Tank Automotive Command

Title : de09ja.015



DATA MARKERS :

Pmax =	81.4000
@	5.00
dPmax=	6.0999
@	-3.00

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS INC.
32 PRENTISS ROAD
Arlington, Massachusetts 02174
PHONE: (617) 641-0520

Test Number: 84
Date (M/D/Y): 12/22/88 Time (H:M:S): 15:19:48 Operator: POHLHAMMER
Engine description: DEUTZ F1L511, STOCK
Test description: 2 sec. intervals, 2500 RPM, 2/3 RATED TORQUE, Fuel #2

Test: 2.00 Seconds/Data Point Fuel Spec. Grav.: .832 Air Sensor: 4.0
Vapor Pressure: .37 Barometric Pres.: 29.38 Ratio: 1.00 TO 1
Engine Type: 4-Cycle Diesel Engine displacement: 50.0 Stroke: 4.130

Speed rpm	Trq lb-Ft	Pwr Hp	FA-FB lb/hr	A1 scfm	A/F	BSFC lb/Hphr	BSAC	Man-P in Hg	Oil psi	CAT F	Fuel F	Oil Out	Wat Out
2502	20.1	9.6	3.9	29.1	34.3	.41	13.91	-51.27	.0	72	160	196	0
2504	19.9	9.5	4.2	29.1	31.8	.44	14.06	-51.27	.0	73	160	196	0
2503	20.0	9.5	3.9	29.1	34.3	.41	14.06	-51.27	.0	74	159	197	0
2504	20.1	9.6	3.7	29.1	36.1	.39	13.91	-51.27	.0	73	159	198	0
2509	19.8	9.5	3.7	29.2	36.2	.39	14.11	-51.24	.0	72	159	197	0
2508	20.1	9.6	3.9	29.2	34.4	.41	13.96	-51.24	.0	73	159	196	0
2506	20.0	9.5	3.8	29.2	35.3	.40	14.11	-51.24	.0	72	159	197	0
2510	20.0	9.6	3.8	29.2	35.3	.40	13.96	-51.27	.0	72	159	198	0
2508	19.9	9.5	3.9	29.1	34.3	.41	14.06	-51.24	.0	73	160	196	0
2509	20.0	9.6	3.7	29.2	36.2	.39	13.96	-51.27	.0	72	161	196	0
2506	20.1	9.6	3.7	29.1	36.1	.39	13.91	-51.27	.0	73	160	196	0
2506	20.3	9.7	3.8	29.1	35.2	.39	13.77	-51.27	.0	72	160	197	0
2507	20.0	9.5	3.8	29.2	35.3	.40	14.11	-51.27	.0	71	160	196	0
2507	20.0	9.5	3.8	29.1	35.2	.40	14.06	-51.27	.0	73	160	196	0
2509	19.9	9.5	3.7	29.1	36.1	.39	14.06	-51.27	.0	73	159	196	0
2510	20.1	9.6	4.2	29.2	31.9	.44	13.96	-51.27	.0	73	159	197	0
2507	20.0	9.5	4.3	29.2	31.2	.45	14.11	-51.27	.0	72	159	198	0
2505	20.1	9.6	3.9	29.2	34.4	.41	13.96	-51.27	.0	71	160	199	0
2506	20.3	9.7	3.8	29.2	35.3	.39	13.82	-51.24	.0	72	161	197	0
2506	20.3	9.7	3.7	29.1	36.1	.38	13.77	-51.24	.0	73	161	195	0
2505	20.3	9.7	3.8	29.1	35.2	.39	13.77	-51.24	.0	74	160	196	0
2509	20.3	9.7	3.8	29.2	35.3	.39	13.82	-51.27	.0	73	160	197	0
2510	19.9	9.5	3.9	29.2	34.4	.41	14.11	-51.27	.0	74	161	197	0
2507	20.1	9.6	3.7	29.2	36.2	.39	13.96	-51.27	.0	73	160	197	0
2505	20.1	9.6	4.0	29.3	33.6	.42	14.01	-51.27	.0	71	160	197	0
2498	20.1	9.6	3.8	29.2	35.3	.40	13.96	-51.27	.0	72	160	198	0
2501	19.9	9.5	3.8	29.1	35.2	.40	14.06	-51.27	.0	73	160	198	0
2503	19.9	9.5	3.8	29.1	35.2	.40	14.06	-51.27	.0	73	160	198	0
2501	20.0	9.5	3.7	29.1	36.1	.39	14.06	-51.24	.0	74	159	198	0
2497	20.4	9.7	3.8	29.1	35.2	.39	13.77	-51.24	.0	74	159	199	0
2501	20.1	9.6	3.7	29.1	36.1	.39	13.91	-51.24	.0	74	160	197	0
2505	19.9	9.5	3.8	29.1	35.2	.40	14.06	-51.27	.0	73	160	197	0
2507	20.0	9.5	3.7	29.2	36.2	.39	14.11	-51.24	.0	73	160	197	0
2503	19.9	9.5	3.6	29.1	37.1	.38	14.06	-51.24	.0	74	159	198	0
2504	19.9	9.5	3.6	29.1	37.1	.38	14.06	-51.24	.0	74	159	198	0
	20.1	9.6		29.1						73	160	197	

WEIGHED FUEL FLOW
1st 70g in 37.40 sec = 4.25
2ND 70g in 37.10 sec = 4.28 > 4.26 lbs/HR

COMBUSTION ELECTROMAGNETICS, INC.

9-Jan-89
10:47:56

12-JAN-89
08:27:23

Indicated Data vs Crankangle

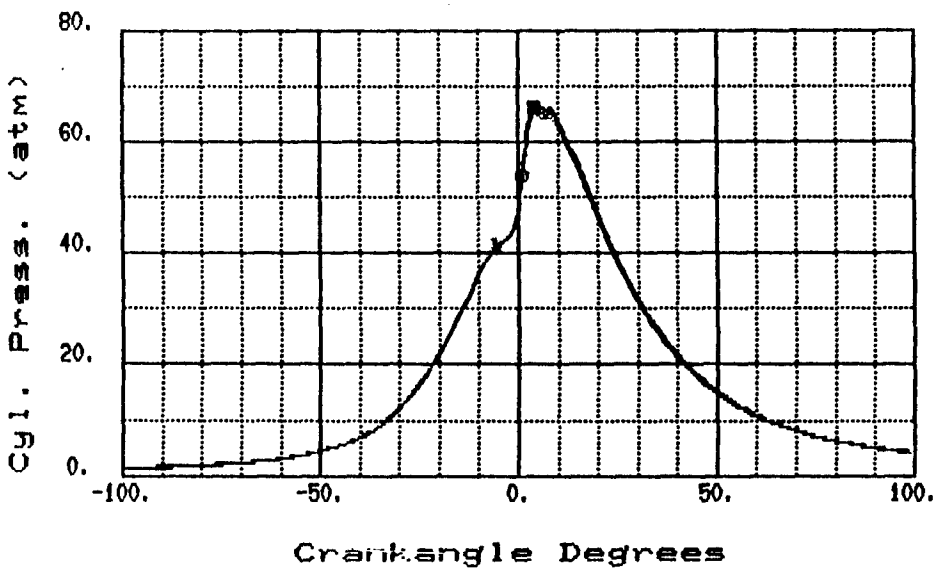
Engine : DEUTZ F1L 511
Cell : Superflow
Project : TACOM Baseline

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	17.00	Intake	=	328.5,-120.5
Ign Timing	=	984.0 Deg	Exhaust	=	108.5, 392.5

Engine Speed = 2490.0 rpm Engine Torque= 26.98 N-m

APA100: U.S. Army Tank Automotive Command

Title : de03ja.011



DATA MARKERS :

Pmax =	65.8773
@	4.00
dPmax=	6.2426
@	1.00

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS INC.
32 PRENTISS ROAD
Arlington, Massachusetts 02174
PHONE: (617) 641-0520

218

Test Number: 26
Date (M/D/Y): 12/22/88 Time (H:M:S): 15:45:14 Operator: POHLHAMMER
Engine description: DEUTZ F1L511, STOCK
Test description: 2 sec. intervals, 2800 RPM, 2/3 RATED TORQUE, Fuel #2

Test: 2.00 Seconds/Data Point Fuel Spec. Grav.: .832 Air Sensor: 4.0
Vapor Pressure: .37 Barometric Pres.: 29.38 Ratio: 1.00 TO 1
Engine Type: 4-Cycle Diesel Engine displacement: 30.0 Stroke: 4.130

Speed rpm	Trq lb-Ft	Pwr Hp	FA-FB lb/hr	A1 scfm	A/F	BSFC lb/Hphr	BSAC	Man-P in Hg	Oil psi	CAT F	Fuel F	Oil Out	Wat Out
2810	20.1	10.8	4.8	33.7	32.2	.44	14.32	-51.32	.0	75	161	209	0
2800	20.4	10.9	4.8	33.7	32.2	.44	14.19	-51.34	.0	75	160	209	0
2810	19.9	10.6	4.9	33.7	31.6	.46	14.59	-51.34	.0	75	160	209	0
2810	20.0	10.7	4.8	33.8	32.3	.45	14.50	-51.34	.0	74	160	209	0
2812	20.0	10.7	4.7	33.8	33.0	.44	14.50	-51.34	.0	74	160	209	0
2814	19.5	10.4	4.9	33.8	31.7	.47	14.92	-51.34	.0	74	161	208	0
2813	19.8	10.6	5.0	33.8	31.0	.47	14.64	-51.32	.0	74	160	209	0
2815	19.0	10.2	5.0	33.7	30.9	.49	15.17	-51.32	.0	75	161	210	0
2812	19.7	10.5	4.6	33.7	33.6	.44	14.73	-51.32	.0	76	161	210	0
2812	20.0	10.7	4.8	33.7	32.2	.45	14.46	-51.34	.0	75	160	210	0
2818	18.7	10.0	4.7	33.7	32.9	.47	15.47	-51.34	.0	76	160	211	0
2818	19.2	10.3	4.7	33.7	32.9	.46	15.08	-51.34	.0	76	159	210	0
2822	18.2	9.8	4.6	33.7	33.6	.47	15.78	-51.34	.0	76	159	210	0
2824	17.6	9.5	4.5	33.8	34.5	.47	16.33	-51.34	.0	75	159	209	0
2817	19.0	10.2	4.5	33.8	34.5	.44	15.21	-51.34	.0	75	160	209	0
2813	20.1	10.8	4.7	33.7	32.9	.44	14.32	-51.34	.0	75	160	210	0
2814	20.0	10.7	4.8	33.7	32.2	.45	14.46	-51.34	.0	76	160	211	0
2814	20.0	10.7	4.8	33.8	32.3	.45	14.50	-51.32	.0	75	161	209	0
2813	20.0	10.7	4.7	33.7	32.9	.44	14.46	-51.34	.0	76	161	208	0
2813	19.8	10.6	4.5	33.7	34.4	.42	14.59	-51.32	.0	76	160	209	0
2811	20.3	10.9	4.7	33.7	32.9	.43	14.19	-51.34	.0	76	160	210	0
2811	20.0	10.7	4.7	33.6	32.8	.44	14.41	-51.32	.0	77	160	210	0
2812	19.8	10.6	4.8	33.6	32.1	.45	14.55	-51.32	.0	77	159	209	0
2813	19.7	10.6	4.8	33.7	32.2	.45	14.59	-51.32	.0	76	159	208	0
2808	20.3	10.9	4.9	33.8	31.7	.45	14.23	-51.32	.0	75	160	208	0
2808	20.4	10.9	5.0	33.8	31.0	.46	14.23	-51.32	.0	74	160	209	0
2809	20.3	10.9	5.1	33.8	30.4	.47	14.23	-51.34	.0	74	160	211	0
2809	20.0	10.7	5.0	33.8	31.0	.47	14.50	-51.32	.0	74	159	211	0
2810	19.9	10.6	5.0	33.7	30.9	.47	14.59	-51.34	.0	75	160	210	0
2814	18.9	10.1	4.8	33.7	32.2	.48	15.32	-51.34	.0	75	160	208	0
2809	19.5	10.4	4.7	33.8	33.0	.45	14.92	-51.32	.0	74	160	208	0
2809	19.8	10.6	4.6	33.7	33.6	.43	14.59	-51.32	.0	75	161	208	0
2807	20.3	10.8	4.4	33.6	35.1	.41	14.28	-51.34	.0	76	161	209	0
2808	20.3	10.9	4.8	33.6	32.1	.44	14.15	-51.34	.0	77	161	208	0
2809	20.4	10.9	4.8	33.7	32.2	.44	14.19	-51.32	.0	75	160	208	0
	19.7	10.4	—	33.7	—	—	—	—		75	160	210	

WEIGHED FUEL FLOW
1st 30gm in 48.29 sec = 4.93
2ND 30gm in 46.96 sec = 5.07 > 5.00 lbs/HR

COMBUSTION ELECTROMAGNETICS, INC.

9-Jan-89
10:47:56

12-JAN-89
09:32:25

Indicated Data vs Crankangle

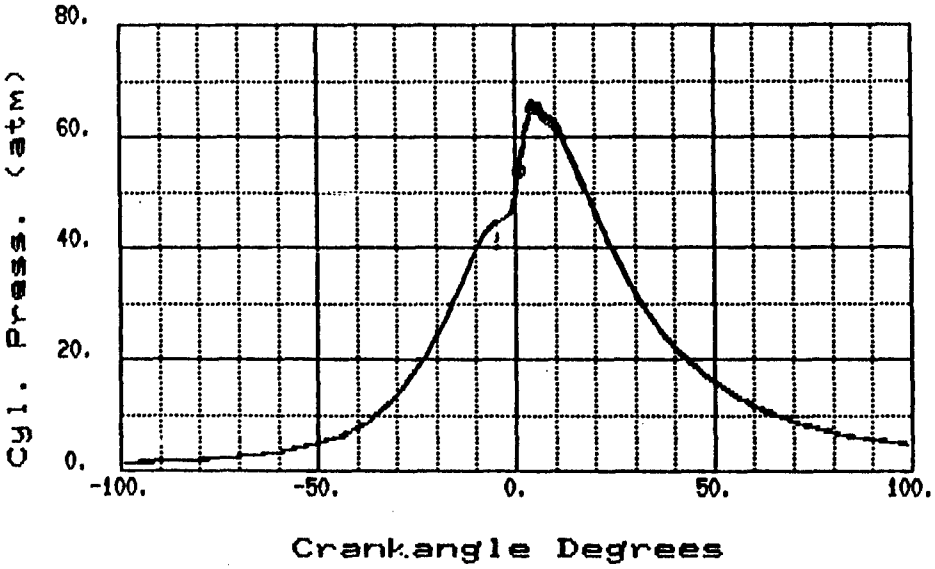
Engine : DEUTZ F1L 511
Cell : Superflow
Project : TACOM Baseline

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	17.00	Intake	=	328.5,-120.5
Ign Timing	=	984.0 Deg	Exhaust	=	108.5, 392.5

Engine Speed = 2820.0 rpm Engine Torque= 26.44 N-m

APA100: U.S. Army Tank Automotive Command

Title : de03ja.012



DATA MARKERS :

Pmax =	65.3684
@	5.00
dPmax=	4.8220
@	1.00

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS INC.
32 PRENTISS ROAD
Arlington, Massachusetts 02174
PHONE: (617) 641-0520

Test Number: 29
Date (M/D/Y): 12/23/88 Time (H:M:S): 09:57:38 Operator: Pollhammer
Engine description: Deutz F1L511 STOCK
Test description: 1500 RPM, MAX LOAD, Fuel #2

Test: 2.00 Seconds/Data Point Fuel Spec. Grav.: .832 Air Sensor: 4.0
Vapor Pressure: .37 Barometric Pres.: 29.38 Ratio: 1.00 TO 1
Engine Type: 4-Cycle Diesel Engine displacement: 50.0 Stroke: 4.130

Speed rpm	Trq lb-ft	Pwr Hp	FA-FB lb/hr	A1 scfm	A/F	BSFC lb/Hphr	BSAC	Man-P in Hg	Oil psi	CAT F	Fuel F	Oil Out	Wat Out
1497	21.4	6.1	2.3	21.4	42.7	.38	16.10	-51.47	.0	65	159	155	0
1505	21.1	6.0	2.2	21.5	44.9	.37	16.45	-51.47	.0	65	159	155	0
1498	21.4	6.1	2.2	21.5	44.9	.36	16.18	-51.47	.0	64	159	155	0
1495	21.7	6.2	2.3	21.5	42.9	.37	15.92	-51.47	.0	63	159	155	0
1494	21.6	6.1	2.3	21.5	42.9	.38	16.18	-51.47	.0	63	159	154	0
1498	21.4	6.1	2.4	21.5	41.1	.39	16.18	-51.47	.0	64	158	154	0
1498	21.2	6.0	2.4	21.5	41.1	.40	16.45	-51.47	.0	64	158	154	0
1496	21.4	6.1	2.7	21.5	36.6	.44	16.18	-51.47	.0	65	159	154	0
1498	21.4	6.1	2.4	21.5	41.1	.39	16.18	-51.47	.0	64	158	155	0
1501	21.0	6.0	2.3	21.5	42.9	.38	16.45	-51.47	.0	64	159	155	0
1501	21.1	6.0	2.4	21.5	41.1	.40	16.45	-51.47	.0	64	159	155	0
1493	21.6	6.1	2.2	21.5	44.9	.36	16.18	-51.47	.0	64	160	156	0
1497	21.5	6.1	2.1	21.5	47.0	.34	16.18	-51.47	.0	63	159	155	0
1491	21.6	6.1	2.3	21.5	42.9	.38	16.18	-51.47	.0	63	159	155	0
1496	21.6	6.2	2.3	21.5	42.9	.37	15.92	-51.47	.0	62	158	155	0
1501	21.0	6.0	2.4	21.5	41.1	.40	16.45	-51.47	.0	62	158	154	0
1500	21.1	6.0	2.2	21.6	45.1	.37	16.52	-51.47	.0	62	158	153	0
1497	21.5	6.1	2.4	21.6	41.3	.39	16.25	-51.47	.0	62	158	154	0
1497	21.4	6.1	2.5	21.5	39.5	.41	16.18	-51.47	.0	62	158	155	0
1496	21.4	6.1	2.6	21.5	38.0	.43	16.18	-51.47	.0	63	158	156	0
1497	21.1	6.0	2.7	21.5	36.6	.45	16.45	-51.47	.0	63	159	156	0
1499	20.9	6.0	2.5	21.5	39.5	.42	16.45	-51.47	.0	64	159	156	0
1500	21.0	6.0	2.4	21.5	41.1	.40	16.45	-51.47	.0	63	158	156	0
1502	21.0	6.0	2.3	21.5	42.9	.38	16.45	-51.47	.0	63	159	155	0
1498	21.2	6.0	2.3	21.5	42.9	.38	16.45	-51.47	.0	64	159	155	0
1502	21.0	6.0	2.4	21.5	41.1	.40	16.45	-51.47	.0	64	158	154	0
1496	21.5	6.1	2.4	21.5	41.1	.39	16.18	-51.47	.0	62	158	154	0
1494	21.2	6.0	2.3	21.5	42.9	.38	16.45	-51.47	.0	62	158	154	0
1499	21.1	6.0	2.3	21.5	42.9	.38	16.45	-51.47	.0	62	159	154	0
1497	21.4	6.1	2.2	21.5	44.9	.36	16.18	-51.47	.0	63	158	155	0
1493	21.2	6.0	2.4	21.5	41.1	.40	16.45	-51.47	.0	63	158	156	0
1497	21.2	6.0	2.3	21.5	42.9	.38	16.45	-51.47	.0	63	159	155	0
1499	21.4	6.1	2.4	21.5	41.1	.39	16.18	-51.47	.0	63	160	156	0
1501	21.6	6.2	2.4	21.5	41.1	.39	15.92	-51.47	.0	64	159	156	0
1495	21.7	6.2	2.5	21.4	39.3	.40	15.84	-51.47	.0	65	158	156	0
	21.3	6.1		21.5						64	159	156	

1st 20gr in 63.00 sec = 2.52
2ND 20gr in 61.93 sec = 2.56 > 2.54 = 16g/HR

COMBUSTION ELECTROMAGNETICS, INC.

9-Jan-89
10:47:56

12-JAN-89
13:48:11

Indicated Data vs Crankangle

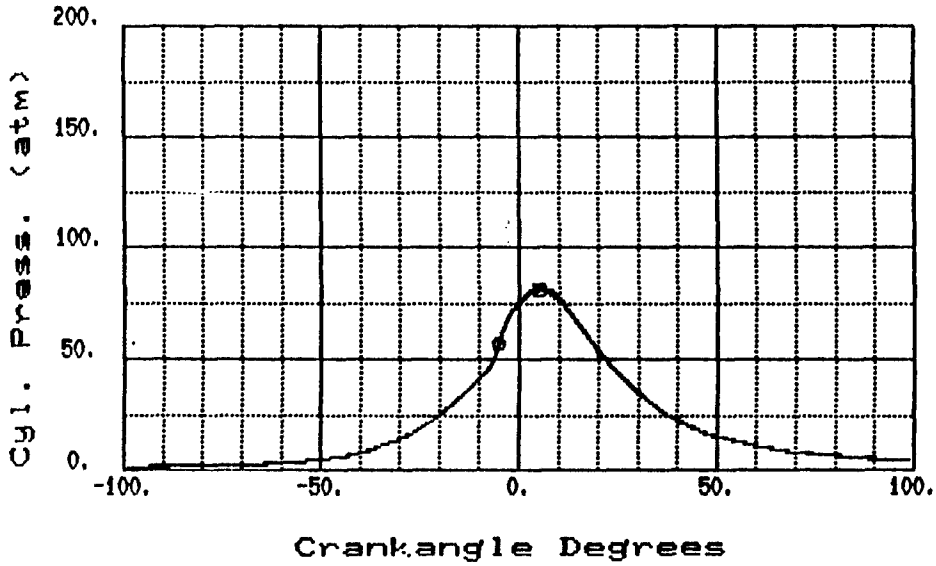
Engine : DEUTZ F1L 511
Cell : Superflow
Project : TACOM Baseline

No. Cylinders =	1	Bore =	100.00 mm
		Stroke =	105.00 mm
Compr. Ratio =	17.00	Intake =	328.5,-120.5
Ign Timing =	984.0 Deg	Exhaust =	108.5, 392.5

Engine Speed = 1535.0 rpm Engine Torque= 28.48 N-m

APA100: U.S. Army Tank Automotive Command

Title : "de03ja.016"



DATA MARKERS :

Pmax =	80.9975
@	5.00
dPmax=	5.6322
@	-5.00

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS INC.
32 PRENTISS ROAD
Arlington, Massachusetts 02174
PHONE: (617) 641-0520

Test Number: 30
Date (M/D/Y): 12/23/88 Time (H:M:S): 10:10:22 Operator: Pohlhammer
Engine description: Detroit F7L511, STOCK
Test description: 2000 RPM, MAX LOAD, Fuel #2

Test: 2.00 Seconds/Data Point Fuel Spec. Grav.: .832 Air Sensor: 4.0
Vapor Pressure: .37 Barometric Pres.: 29.38 Ratio: 1.00 TO 1
Engine Type: 4-Cycle Diesel Engine displacement: 50.0 Stroke: 4.130

Speed rpm	Trq lb-Ft	Pwr Hp	FA-FB lb/hr	A1 scfm	A/F	BSFC lb/Hphr	BSAC	Man-P In Hg	Oil psi	CAT F	Fuel F	Oil Out	Wat Out
1981	26.6	10.0	3.9	26.1	30.7	.39	11.98	-51.44	.0	66	160	173	0
1983	26.6	10.0	3.9	26.1	30.7	.39	11.98	-51.44	.0	66	160	173	0
1982	26.6	10.0	4.1	26.0	29.1	.41	11.93	-51.44	.0	67	159	172	0
1970	26.6	10.0	3.9	26.1	30.7	.39	11.98	-51.44	.0	66	159	173	0
1986	26.4	10.0	3.8	26.1	31.5	.38	11.98	-51.44	.0	66	159	171	0
1979	26.7	10.1	4.1	26.2	29.3	.41	11.91	-51.44	.0	64	158	172	0
1978	26.1	9.8	4.0	26.1	30.0	.41	12.22	-51.44	.0	65	159	172	0
1983	26.4	10.0	4.2	26.2	28.6	.42	12.03	-51.44	.0	65	159	173	0
1983	26.5	10.0	4.3	26.1	27.9	.43	11.98	-51.44	.0	66	158	172	0
1979	26.5	10.0	4.2	26.1	28.5	.42	11.98	-51.44	.0	65	159	173	0
1983	26.4	10.0	4.1	26.0	29.1	.41	11.93	-51.44	.0	66	159	173	0
1992	26.4	10.0	4.1	26.1	29.2	.41	11.98	-51.44	.0	66	159	173	0
1994	26.5	10.1	4.2	26.1	28.5	.42	11.86	-51.44	.0	66	160	173	0
1991	26.4	10.0	4.2	26.2	28.6	.42	12.03	-51.44	.0	66	159	173	0
1996	26.4	10.0	4.0	26.2	30.1	.40	12.03	-51.44	.0	66	159	173	0
1995	26.4	10.0	4.2	26.2	28.6	.42	12.03	-51.44	.0	65	159	172	0
1993	26.5	10.1	4.1	26.2	29.3	.41	11.91	-51.44	.0	65	159	172	0
1983	26.5	10.0	4.1	26.1	29.2	.41	11.98	-51.44	.0	65	159	171	0
1981	26.3	9.9	4.1	26.2	29.3	.41	12.15	-51.44	.0	63	160	173	0
1979	26.4	9.9	4.0	26.1	30.0	.40	12.10	-51.44	.0	64	160	173	0
1988	26.3	10.0	4.2	26.1	28.5	.42	11.98	-51.44	.0	65	160	173	0
1980	26.4	10.0	4.2	26.0	28.4	.42	11.93	-51.44	.0	67	160	172	0
1986	26.4	10.0	4.2	26.1	28.5	.42	11.98	-51.44	.0	67	159	173	0
1995	26.3	10.0	4.2	26.1	28.5	.42	11.98	-51.44	.0	67	159	174	0
2000	26.5	10.1	4.2	26.2	28.6	.42	11.91	-51.42	.0	66	160	172	0
1993	26.5	10.1	4.2	26.2	28.6	.42	11.91	-51.44	.0	64	159	172	0
1987	26.6	10.1	4.2	26.2	28.6	.42	11.91	-51.44	.0	64	159	173	0
1982	26.3	9.9	4.2	26.1	28.5	.42	12.10	-51.44	.0	65	160	173	0
1976	26.5	10.0	4.3	26.0	27.8	.43	11.93	-51.44	.0	66	159	173	0
1975	26.6	10.0	4.2	26.0	28.4	.42	11.93	-51.44	.0	66	159	174	0
1976	26.4	9.9	4.2	26.0	28.4	.42	12.05	-51.44	.0	65	159	174	0
1976	26.5	10.0	4.3	26.1	27.9	.43	11.98	-51.44	.0	66	159	173	0
1981	26.5	10.0	4.4	26.1	27.2	.44	11.98	-51.44	.0	66	159	173	0
1983	26.3	9.9	4.2	26.0	28.4	.42	12.05	-51.44	.0	67	160	173	0
1978	26.5	10.0	4.4	26.1	27.2	.44	11.98	-51.44	.0	66	159	174	0
	26.5	10.0		26.1						66	160	173	

1st 20gr in 38.78 sec = 4.09
2ND 20gr in 37.79 sec = 4.20 > 4.15 lbs/HR

COMBUSTION ELECTROMAGNETICS, INC.

9-Jan-89
10:47:56

12-JAN-89
12:51:22

Indicated Data vs Crankangle

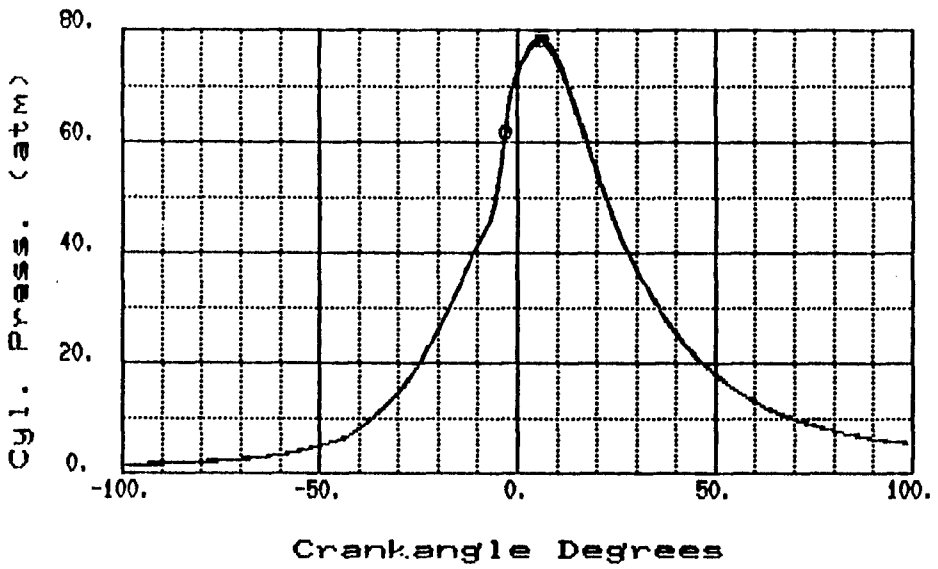
Engine : DEUTZ F1L 511
Cell : Superflow
Project : TACOM Baseline

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	17.00	Intake	=	328.5,-120.5
Ign Timing	=	984.0 Deg	Exhaust	=	108.5, 392.5

Engine Speed = 2015.0 rpm Engine Torque= 34.44 N-m

APA100: U.S. Army Tank Automotive Command

Title : deo3ja.015



DATA MARKERS :

Pmax	=	77.8286
	@	6.00
dPmax	=	5.4527
	@	-3.00

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS, INC.

9-Jan-89
10:47:56

12-JAN-89
11:55:23

Indicated Data vs Crankangle

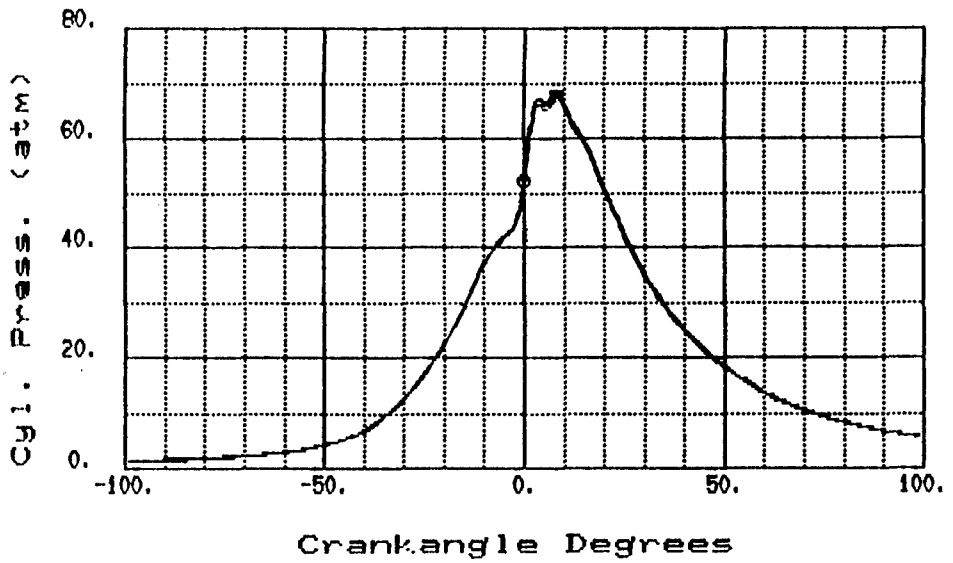
Engine : DEUTZ F1L 511
Cell : Superflow
Project : TACOM Baseline

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	17.00	Intake	=	328.5,-120.5
Ign Timing	=	984.0 Deg	Exhaust	=	108.5, 392.5

Engine Speed = 2580.0 rpm Engine Torque= 34.58 N-m

APA100: U.S. Army Tank Automotive Command

Title : de03ja.014



DATA MARKERS :

Pmax	=	67.4321
	@	8.00
dPmax	=	5.6135
	@	0.00

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS INC.
32 PRENTISS ROAD
Arlington, Massachusetts 02174
PHONE: (617) 641-0520

Test Number: 31
Date (M/D/Y): 12/23/88 Time (H:M:S): 10:25:04 Operator: Pohlhammer
Engine description: DEUTZ F7L511, STOCK
Test description: 2 sec intervals, 2500 RPM, MAX LOAD, Fuel #2

Test: 2.00 Seconds/Data Point Fuel Spec. Grav.: .832 Air Sensor: 4.0
Vapor Pressure: .37 Barometric Pres.: 29.38 Ratio: 1.00 TO 1
Engine Type: 4-Cycle Diesel Engine displacement: 50.0 Stroke: 4.130

Speed rpm	Trq lb-Ft	Pwr Hp	FA-FB lb/hr	A1 scfm	A/F	BSFC lb/Hphr	BSAC	Man-P In Hg	Oil psi	CAT F	Fuel F	Oil Out	Wat Out
2525	26.6	12.3	5.5	29.1	24.3	.45	10.86	-51.39	.0	69	157	208	0
2516	26.4	12.6	5.7	29.1	23.4	.45	10.60	-51.39	.0	68	158	208	0
2500	26.6	12.7	5.6	28.8	23.6	.44	10.41	-51.39	.0	68	157	209	0
2489	26.3	12.5	5.6	28.6	23.4	.45	10.50	-51.39	.0	69	157	210	0
2480	26.7	12.6	5.7	28.5	23.0	.45	10.38	-51.37	.0	69	158	210	0
2483	26.0	12.3	5.6	28.4	23.3	.46	10.60	-51.37	.0	69	158	210	0
2498	26.3	12.5	5.4	28.6	24.3	.43	10.50	-51.39	.0	69	158	209	0
2507	26.4	12.6	5.8	28.8	22.8	.46	10.49	-51.39	.0	69	158	209	0
2500	26.3	12.5	5.6	28.7	23.5	.45	10.54	-51.39	.0	69	158	208	0
2516	26.1	12.5	5.4	28.8	24.5	.43	10.58	-51.39	.0	69	158	208	0
2525	25.9	12.5	5.5	29.0	24.2	.44	10.65	-51.42	.0	70	158	208	0
2523	26.0	12.5	5.9	29.1	22.6	.47	10.69	-51.39	.0	69	157	208	0
2524	26.0	12.5	5.7	29.2	23.5	.46	10.72	-51.39	.0	68	157	208	0
2525	26.0	12.5	5.9	29.3	22.8	.47	10.76	-51.39	.0	67	158	208	0
2526	26.1	12.6	5.5	29.2	24.4	.44	10.64	-51.39	.0	68	158	209	0
2525	26.1	12.5	5.8	29.1	23.0	.46	10.69	-51.42	.0	69	159	209	0
2523	26.3	12.6	5.8	29.1	23.0	.46	10.60	-51.42	.0	69	159	209	0
2514	26.6	12.7	5.5	29.1	24.3	.43	10.52	-51.42	.0	67	159	209	0
2518	26.5	12.7	6.1	29.0	21.8	.48	10.48	-51.39	.0	68	159	209	0
2522	26.1	12.5	6.0	29.0	22.2	.48	10.65	-51.39	.0	69	159	209	0
2522	26.4	12.7	5.8	29.1	23.0	.46	10.52	-51.39	.0	69	158	209	0
2527	26.3	12.7	5.8	29.1	23.0	.46	10.52	-51.42	.0	68	158	209	0
2523	26.5	12.7	5.9	29.1	22.6	.46	10.52	-51.39	.0	68	159	208	0
2522	26.4	12.7	5.7	29.0	23.4	.45	10.48	-51.39	.0	68	158	209	0
2526	25.9	12.5	5.6	29.0	23.8	.45	10.65	-51.39	.0	69	158	209	0
2521	25.6	12.3	5.4	29.1	24.7	.44	10.86	-51.42	.0	69	157	209	0
2529	25.9	12.5	5.5	29.2	24.4	.44	10.72	-51.42	.0	69	157	209	0
2513	26.6	12.7	5.5	29.0	24.2	.43	10.48	-51.39	.0	70	158	209	0
2503	26.4	12.6	5.4	28.8	24.5	.43	10.49	-51.39	.0	69	159	210	0
2511	26.1	12.5	5.4	28.9	24.6	.43	10.61	-51.39	.0	69	158	209	0
2515	26.1	12.5	5.6	28.9	23.7	.45	10.61	-51.39	.0	69	158	210	0
2505	26.5	12.6	5.6	28.9	23.7	.44	10.53	-51.39	.0	68	158	211	0
2504	26.4	12.6	5.6	28.8	23.6	.44	10.49	-51.39	.0	69	157	211	0
2504	26.3	12.5	5.5	28.8	24.0	.44	10.58	-51.39	.0	68	157	209	0
2509	26.1	12.5	5.6	28.8	23.6	.45	10.58	-51.39	.0	69	158	210	0
	26.3	12.6		28.9						69	158	210	

1st 20gr in 29.81 sec = 5.33
2ND 20gr in 31.00 sec = 5.12
3RD 20gr in 29.08 sec = 5.46
} 5.30 LB/HR

COMBUSTION ELECTROMAGNETICS INC.
32 PRENTISS ROAD
Arlington, Massachusetts 02174
PHONE: (617) 641-0520

Test Number: 32
Date (M/D/Y): 12/23/88 Time (H:M:S): 10:37:40 Operator: Pohlhammer
Engine description: Deutz F1L511, STOCK
Test description: 2 sec Intervals, 2800 RPM, MAX LOAD, FUEL #2

Test: 2.00 Seconds/Data Point Fuel Spec. Grav.: .832 Air Sensor: 4.0
Vapor Pressure: .37 Barometric Pres.: 29.38 Ratio: 1.00 TO 1
Engine Type: 4-Cycle Diesel Engine displacement: 50.0 Stroke: 4.130

Speed rpm	Trq lb-Ft	Pwr Hp	FA-FB lb/hr	Ai scfm	A/F	BSFC lb/Hphr	BSAC	Man-P In Hg	Oil psi	CAT F	Fuel F	Oil Out	Wat Out
2844	25.8	14.0	5.8	33.8	26.8	.41	11.08	-51.47	.0	69	157	219	0
2832	26.0	14.0	5.8	33.8	26.8	.41	11.08	-51.49	.0	69	156	219	0
2830	26.0	14.0	5.8	33.7	26.7	.41	11.05	-51.49	.0	70	157	219	0
2820	26.1	14.0	5.8	33.5	26.5	.41	10.98	-51.47	.0	71	157	219	0
2808	26.1	14.0	5.8	33.5	26.5	.41	10.98	-51.49	.0	70	157	219	0
2805	26.1	13.9	5.8	33.5	26.5	.42	11.06	-51.47	.0	70	156	220	0
2811	26.0	13.9	5.8	33.5	26.5	.42	11.06	-51.47	.0	70	156	220	0
2809	26.1	14.0	5.9	33.5	26.1	.42	10.98	-51.49	.0	70	157	220	0
2808	25.9	13.8	6.3	33.5	24.4	.46	11.14	-51.47	.0	70	158	220	0
2814	25.9	13.9	5.9	33.5	26.1	.42	11.06	-51.47	.0	70	158	219	0
2813	26.1	14.0	5.8	33.5	26.5	.41	10.98	-51.47	.0	70	157	219	0
2815	25.9	13.9	5.8	33.5	26.5	.42	11.06	-51.47	.0	70	158	220	0
2810	26.1	14.0	5.7	33.5	27.0	.41	10.98	-51.49	.0	70	157	220	0
2807	26.0	13.9	5.9	33.5	26.1	.42	11.06	-51.47	.0	70	157	220	0
2800	26.3	14.0	5.8	33.5	26.5	.41	10.98	-51.47	.0	70	157	220	0
2792	26.0	13.8	6.3	33.4	24.3	.46	11.11	-51.47	.0	70	156	218	0
2799	26.1	13.9	6.3	33.5	24.4	.45	11.06	-51.47	.0	70	157	219	0
2801	26.1	13.9	6.0	33.5	25.6	.43	11.06	-51.47	.0	70	157	219	0
2800	26.3	14.0	5.9	33.4	26.0	.42	10.95	-51.47	.0	71	158	219	0
2804	26.1	13.9	6.1	33.4	25.1	.44	11.03	-51.47	.0	71	158	220	0
2810	26.0	13.9	5.8	33.5	26.5	.42	11.06	-51.47	.0	70	159	220	0
2803	26.4	14.1	6.0	33.5	25.6	.43	10.91	-51.47	.0	69	157	220	0
2793	26.1	13.9	5.8	33.4	26.4	.42	11.03	-51.47	.0	70	157	220	0
2795	26.0	13.8	5.8	33.4	26.4	.42	11.11	-51.47	.0	70	157	217	0
2807	25.9	13.8	5.8	33.5	26.5	.42	11.14	-51.47	.0	70	157	218	0
2814	25.8	13.8	5.9	33.5	26.1	.43	11.14	-51.47	.0	70	157	219	0
2826	25.8	13.9	5.8	33.6	26.6	.42	11.10	-51.47	.0	70	157	219	0
2841	25.9	14.0	5.9	33.6	26.1	.42	11.02	-51.47	.0	71	158	220	0
2840	25.8	14.0	5.7	33.7	27.1	.41	11.05	-51.49	.0	71	157	220	0
2845	25.6	13.9	5.7	33.8	27.2	.41	11.16	-51.49	.0	70	158	220	0
2840	25.8	14.0	5.7	33.7	27.1	.41	11.05	-51.47	.0	71	159	220	0
2843	25.8	14.0	5.7	33.8	27.2	.41	11.08	-51.47	.0	70	159	221	0
2846	25.6	13.9	5.8	33.8	26.8	.42	11.16	-51.49	.0	71	158	220	0
2840	26.0	14.1	5.6	33.7	27.6	.40	10.97	-51.49	.0	71	157	220	0
2839	26.0	14.1	5.7	33.6	27.1	.40	10.94	-51.47	.0	71	157	220	0
	26.0	13.9		33.6						70	158	220	

1st 30 gr in 39.31 = 6.06
2ND 30 gr in 38.62 = 6.17 > 6.11 lbs/HR

COMBUSTION ELECTROMAGNETICS, INC.

9-Jan-89
10:47:56

12-JAN-89
10:56:44

Indicated Data vs Crankangle

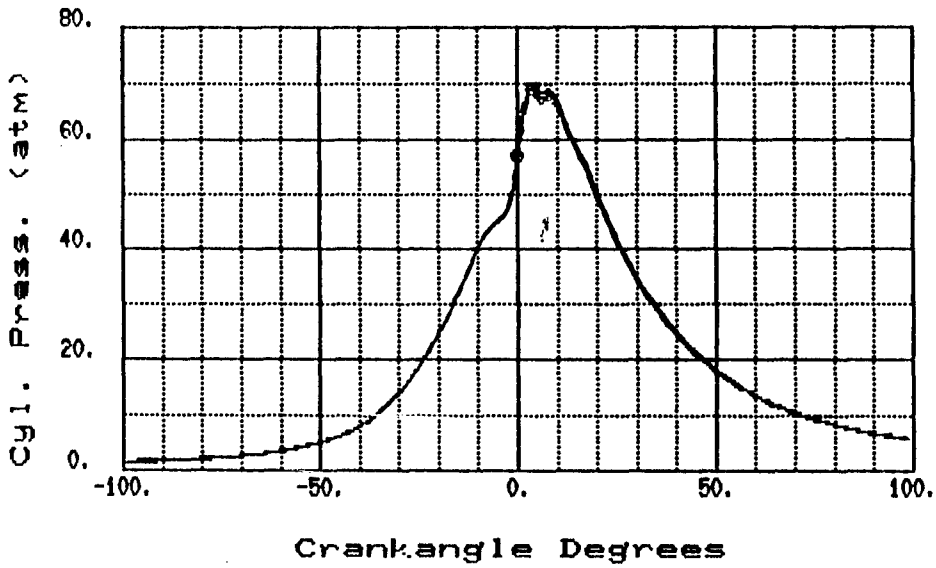
Engine : DEUTZ F1L 511
Cell : Superflow
Project : TACOM Baseline

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	17.00	Intake	=	328.5,-120.5
Ign Timing	=	984.0 Deg	Exhaust	=	108.5, 392.5

Engine Speed = 2818.0 rpm Engine Torque= 35.26 N-m

APA100: U.S. Army Tank Automotive Command

Title : de03ja.013



DATA MARKERS :

Pmax =	69.0961
@	4.00
dPmax=	5.5308
@	0.00

Double-triangle is valve timing.

APPENDIX C

PEAK PRESSURE VERSUS ELAPSED TIME DATA

COMBUSTION ELECTROMAGNETICS INC.
32 PRENTISS ROAD
Arlington, Massachusetts 02174
PHONE: (617) 641-0520

DE19JA

Test Number: ~~3~~
Date (M/D/Y): 1/19/90 Time (H:M:S): 12:13:17 Operator: cmp,cp,mw
Engine description: DEUTZ F1L511, CEI HEAD,CYLINDER, PISTON #2.2
Test description: CEI, SINGLE DOUBLE PLUG, 26deg Inj. 24° ADV

Test: Data Recorded Manually Fuel Spec. Grav.: .831 Air Sensor: 4.0
Vapor Pressure: .35 Barometric Pres.: 30.43 Ratio: 1.00 TO 1
Engine Type: 4-Cycle Diesel Engine displacement: 50.0 Stroke: 4.130

	Speed rpm	Trq lb-Ft	Pwr Hp	FA lb/hr	A1 scfm	A/F	BSFC BSAC lb/Hphr	Man-P In Hg	Oil psi	CAT F	Fuel F	Oil Out	Wat Out
	1368	.4	.1	.0	17.5	.0	.00147.89	.32	.0	62	51	67	0
	1367	.4	.1	.0	17.5	.0	.00147.89	.32	.0	62	51	67	0
11	1370	.5	.1	.0	17.5	.0	.00147.89	.32	.0	62	51	67	0
	1373	1.2	.3	.0	17.5	.0	.00267.75	.32	.0	62	51	67	0
	1432	1.1	.3	.0	18.1	.0	.00276.93	.32	.0	62	49	67	0
	1430	.4	.1	.0	18.0	.0	.00170.84	.32	.0	62	50	67	0
12	1430 IGN	1.1	.3	.0	18.0	.0	.00275.40	.30	.0	62	50	67	0
	1432	1.6	.4	.0	18.0	.0	.00206.55	.30	.0	62	49	67	0
	1390	.0	.0	.0	17.6	.0	.00 .00	.32	.0	62	51	68	0
	1391	.8	.2	.0	17.6	.0	.00251.44	.32	.0	62	51	68	0
13	1387	.6	.2	.0	17.6	.0	.00251.44	.32	.0	62	51	68	0
	1389	.1	.0	.0	17.6	.0	.00 .00	.32	.0	62	51	68	0
	1431	1.3	.4	.0	17.9	.0	.00205.40	.32	.0	63	48	70	0
14	1431 IGN	1.8	.5	.0	17.9	.0	.00164.32	.32	.0	63	50	70	0
	1432	1.9	.5	.0	17.9	.0	.00164.32	.32	.0	63	50	70	0
	1430	2.1	.6	.0	17.9	.0	.00136.94	.32	.0	63	51	70	0
	1409	.9	.2	.0	17.7	.0	.00249.14	.32	.0	62	52	71	0
	1409	.3	.1	.0	17.7	.0	.00157.07	.32	.0	62	52	71	0
15	1410	.3	.1	.0	17.7	.0	.00157.07	.32	.0	62	52	71	0
	1408	.3	.1	.0	17.7	.0	.00157.07	.32	.0	62	52	71	0
	1432	.6	.2	.0	17.8	.0	.00246.85	.32	.0	63	49	74	0
	1432	1.2	.3	.0	17.8	.0	.00272.34	.32	.0	63	49	74	0
16	1430 IGN	1.7	.5	.0	17.8	.0	.00163.40	.32	.0	63	49	74	0
	1432	.2	.1	.0	17.8	.0	.00161.66	.32	.0	63	50	74	0
	1420	2.0	.5	.0	17.8	.0	.00163.40	.32	.0	62	52	75	0
	1420	.3	.1	.0	17.8	.0	.00161.66	.32	.0	62	52	75	0
17	1418	1.1	.3	.0	17.8	.0	.00272.34	.35	.0	62	52	75	0
	1420	.7	.2	.0	17.8	.0	.00246.85	.32	.0	62	52	75	0
	1433	1.0	.3	.0	17.8	.0	.00272.34	.32	.0	63	50	79	0
	1436	1.6	.4	.0	17.8	.0	.00204.26	.32	.0	63	50	79	0
18	1435 IGN	1.9	.5	.0	17.8	.0	.00163.40	.32	.0	63	49	79	0
	1434	2.1	.6	.0	17.8	.0	.00136.17	.32	.0	63	50	79	0
	1423	2.1	.6	.0	17.7	.0	.00135.41	.32	.0	62	52	80	0
	1422	.9	.2	.0	17.7	.0	.00249.14	.32	.0	62	53	80	0
19	1422	1.3	.4	.0	17.7	.0	.00203.11	.32	.0	62	52	80	0
	1420	1.7	.5	.0	17.7	.0	.00162.49	.32	.0	62	52	80	0

TACOM Engine Testing: With + Without Ignition 1/19/90
Cold Start/Oil temp effect

Average Engine speed: 1500 RPM
Average Torque: 10 ft.lbs
Dual CEI Ignition (15 pulses)
Timing: 24° BTDC

WARM CRANKING CURVE DEI9TA.001

Ignition Condition	Time	RPM Start	RPM end	Torque start	Torque end	Oil T.	Time, 10 gms	File #
ON	1:00	1420	1400	[illegible]	[illegible]			10
OFF	1:30	[illegible]	1370	9.3				11
ON	2:00	1424	1427	9.5				12
OFF	2:30	1384	1430 ON	[illegible]				13
ON	4:00	1433	1430					14
OFF	4:30	1410	1410 1430					15
ON	6:00	1430	1432					16
OFF	6:30	1420	141[illegible] 1431		28 ft lbs	77°F		17
ON	8:00	1435	1433					18
OFF	8:30	1424	1424			81°		19
ON	12:00	1508	1509	10.0				20
OFF	12:30	1508	1505	9.9	9.8	92°	21	21
ON	16:00	1504	1500	10.1	10.1	102°F	52.73	22

COMBUSTION ELECTROMAGNETICS, INC.

19-Jan-90
12:15:47

19-JAN-90
13:52:01

Indicated Data vs Crankangle

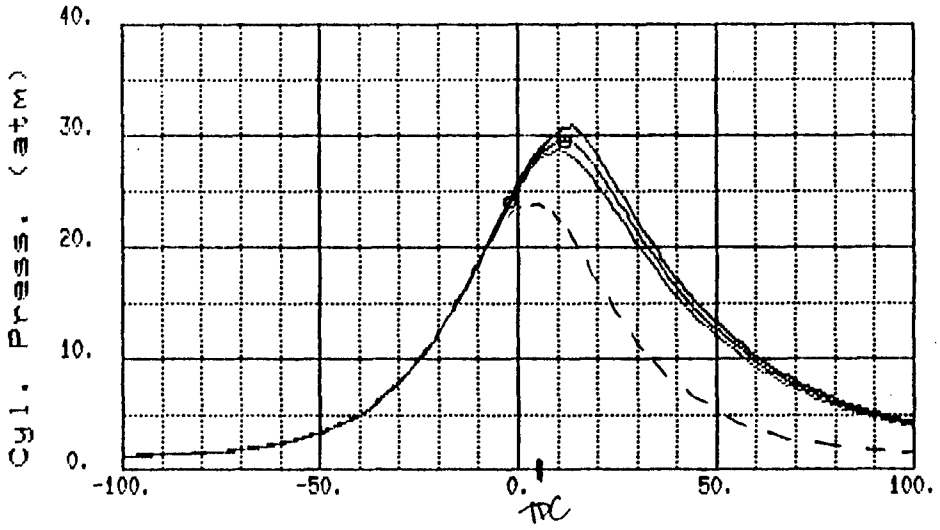
Engine : DEUTZ F1L-511, CEI Ver 2.2
Cell : Superflow
Project : TACOM

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	12.00	Intake	=	328.5,-120.5
Ign Timing	=	~~984.0 Deg~~	Exhaust	=	108.5, 392.5

Engine Speed = ~~1500.0~~ rpm Engine Torque= 0.00 N-m

APA100: U.S. Army Tank Automotive Command

Title : DE19JA.010



IGN.
1:00
≈ 1420 RPM ??

≈ -5° offset

DATA MARKERS :

Pmax =	29.5854		
@	~~12.00~~	+7°	
dPmax=	0.7234		
@	~~2.00~~	-7°	

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS, INC.

19-Jan-90
13:55:43

19-JAN-90
14:37:24

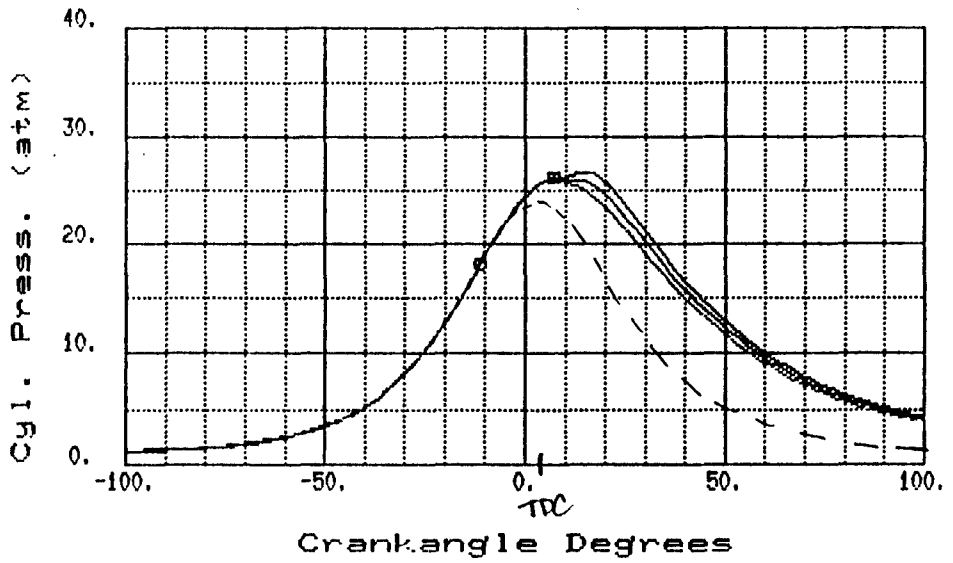
Indicated Data vs Crankangle

Engine : DEUTZ F1L-511, CEI Ver 2.2
Cell : Superflow
Project : TACOM

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	12.00	Intake	=	328.5,-120.5
Ign Timing	=	~~984.0 Deg~~	Exhaust	=	108.5, 392.5
Engine Speed	=	~~1500.0 rpm~~	Engine Torque	=	0.00 N-m

APA100: U.S. Army Tank Automotive Command

Title : DE19JA.011



NO. IGN.
1:30
1370 RPM

≈ -4° effect

DATA MARKERS :

Pmax =	26.0778		
@	~~7.00~~	+3°	
dPmax=	0.6609		
@	~~-11.00~~	-15°	

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS, INC.

19-Jan-90
12:17:13

19-JAN-90
14:50:18

Indicated Data vs Crankangle

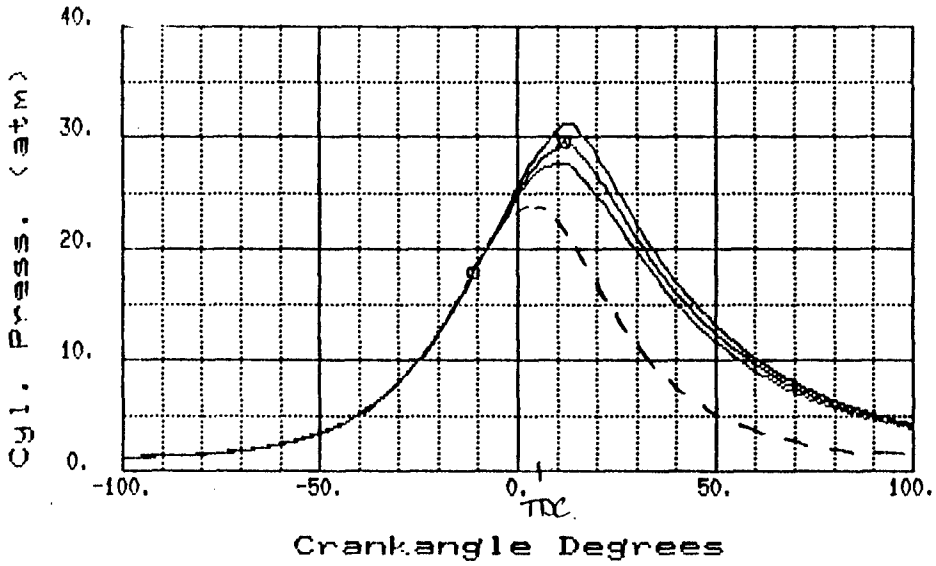
Engine : DEUTZ F1L-511, CEI Ver 2.2
Cell : Superflow
Project : TACOM

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	12.00	Intake	=	328.5,-120.5
Ign Timing	=	~~994.0 Deg~~	Exhaust	=	108.5, 392.5

Engine Speed = ~~1500.0 rpm~~ Engine Torque= 0.00 N-m

APA100: U.S. Army Tank Automotive Command

Title : **DE19JA.012**



IGN
2:00
1431 RPM.

x -5° offset

DATA MARKERS :

Pmax = 29.3668
@ ~~12.00~~ +7°
dPmax= 0.7494
@ -11.00 -16°

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS, INC.

19-Jan-90
12:17:50

19-JAN-90
14:57:42

Indicated Data vs Crankangle

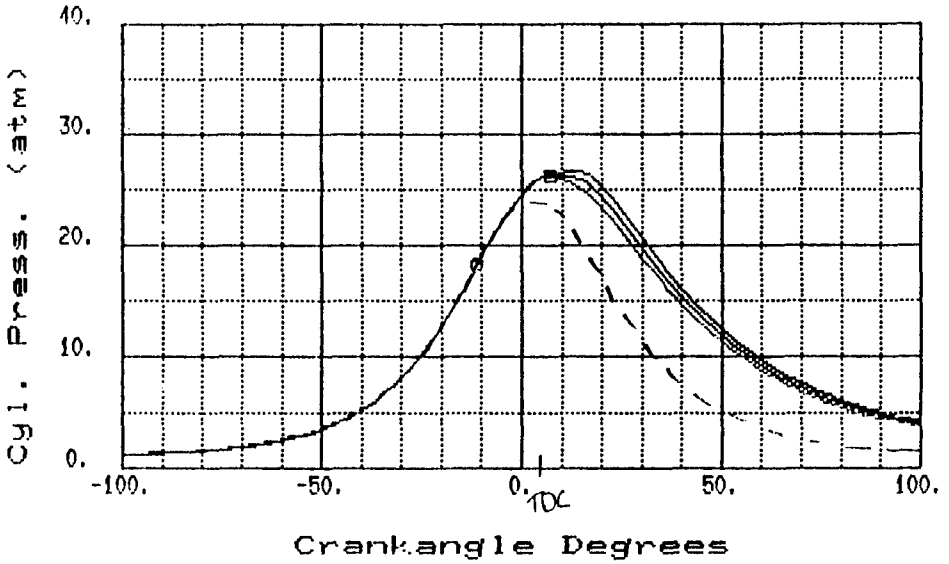
Engine : DEUTZ F1L-511, CEI Ver 2.2
Cell : Superflow
Project : TACOM

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	12.00	Intake	=	328.5,-120.5
Ign Timing	=	~~984.0 Deg~~	Exhaust	=	108.5, 392.5

Engine Speed = ~~1500.0 rpm~~ Engine Torque= 0.00 N-m

APA100: U.S. Army Tank Automotive Command

Title : DE19JA.013 1



NO IGN
2:30
1389 RPM

≈ -5° offset

DATA MARKERS :

Pmax =	26.2547	
@	~~7.00~~	+2°
dPmax=	0.6609	
@	~~-11.00~~	-16°

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS, INC.

19-Jan-90
12:18:30

19-JAN-90
15:04:12

Indicated Data vs Crankangle

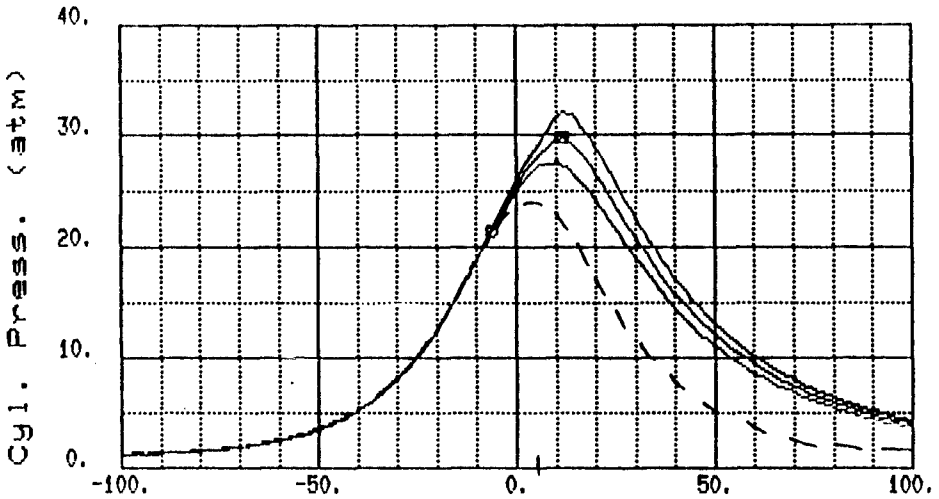
Engine : DEUTZ F1L-511, CEI Ver 2.2
Cell : Superflow
Project : TACOM

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	12.00	Intake	=	328.5,-120.5
Ign Timing	=	~~984.0 Deg~~	Exhaust	=	108.5, 392.5

Engine Speed = ~~1500.0 rpm~~ Engine Torque= 0.00 N-m

APA100: U.S. Army Tank Automotive Command

Title : DE19JA.014



IGN
4:00
1431 RPM

≈ -5° offset

DATA MARKERS :

Pmax =	29.6166	
@	~~-12.00~~	+7°
dPmax=	0.7182	
@	~~-6.00~~	-11°

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS, INC.

19-Jan-90
12:19:35

19-JAN-90
15:23:06

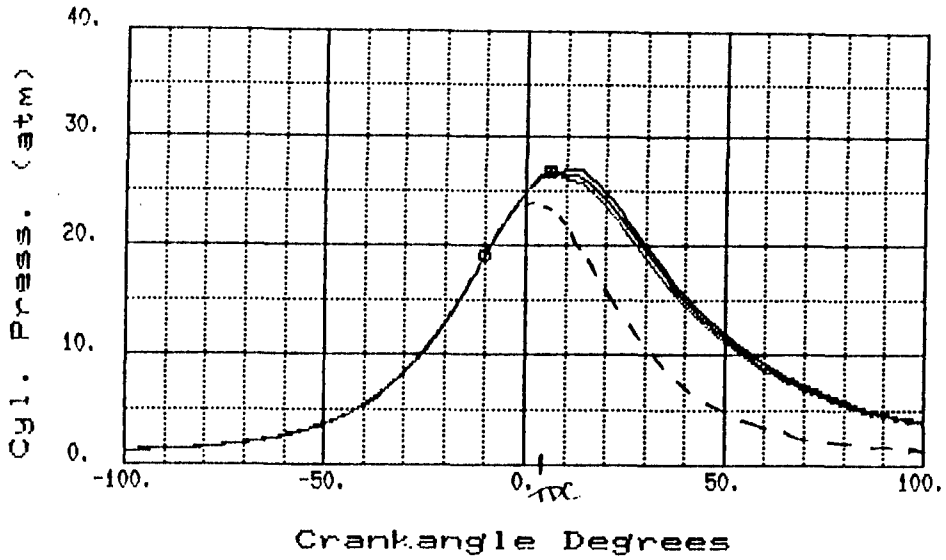
Indicated Data vs Crankangle

Engine : DEUTZ F1L-511, CEI Ver 2.2
Cell : Superflow
Project : TACOM

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	12.00	Intake	=	328.5,-120.5
Ign Timing	=	~~984.0 Deg~~	Exhaust	=	108.5, 392.5
Engine Speed	=	~~1500.0 rpm~~	Engine Torque	=	0.00 N-m

APA100: U.S. Army Tank Automotive Command

Title : DE19JA.015



NO IGN
4:30
1409 RPM

DATA MARKERS : ≈ -4° offset

Pmax = 26.5566
@ ~~6.00~~ +2°
dPmax= 0.6661
@ ~~-10.00~~ -14°

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS, INC.

19-Jan-90
12:20:58

19-JAN-90
15:30:30

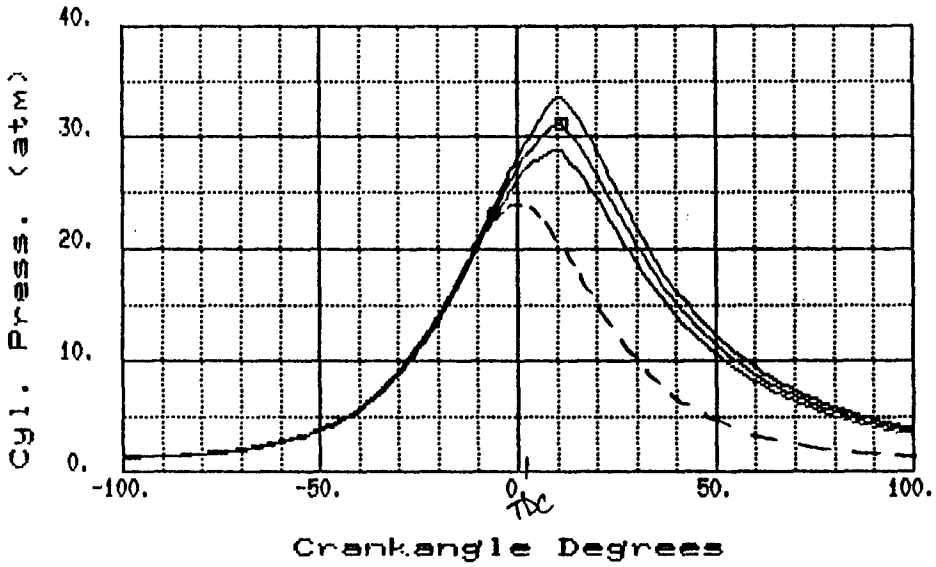
Indicated Data vs Crankangle

Engine : DEUTZ F1L-511, CEI Ver 2.2
Cell : Superflow
Project : TACOM

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	12.00	Intake	=	328.5,-120.5
Ign Timing	=	~~984.0 Deg~~	Exhaust	=	108.5, 392.5
Engine Speed	=	~~1500.0 rpm~~	Engine Torque	=	0.00 N-m

APA100: U.S. Army Tank Automotive Command

Title : DE19JA.016



IGN
6:00
1431 RPM

≈ -2° offset

DATA MARKERS :

Pmax =	31.0988	
@	~~11.00~~	+9°
dPmax=	0.7182	
@	~~-6.00~~	-8°

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS, INC.

19-Jan-90
12:21:49

19-JAN-90
15:40:39

Indicated Data vs Crankangle

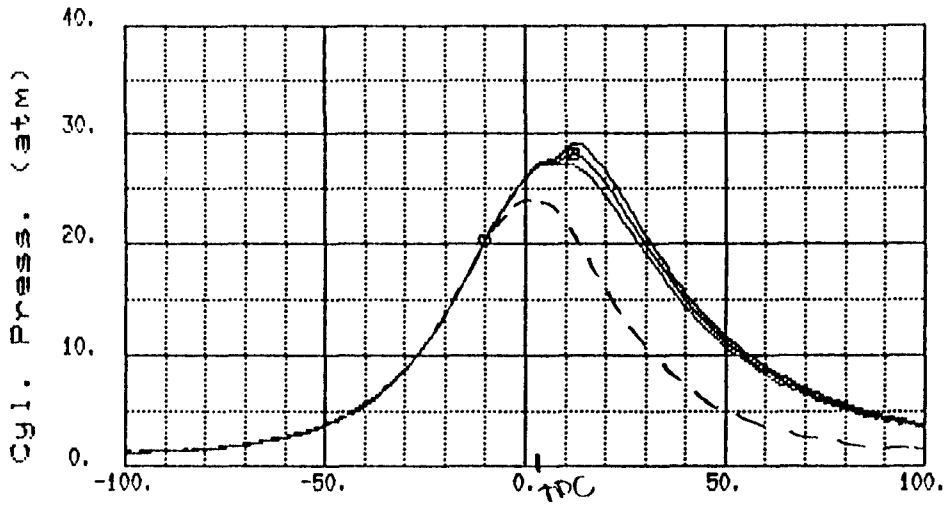
Engine : DEUTZ F1L-511, CEI Ver 2.2
Cell : Superflow
Project : TACOM

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	12.00	Intake	=	328.5,-120.5
Ign Timing	=	~~984.0 Deg~~	Exhaust	=	108.5, 392.5

Engine Speed = ~~1500.0 rpm~~ Engine Torque= 0.00 N-m

APA100: U.S. Army Tank Automotive Command

Title : **DE19JA.017**



NO IGN
6:30
1419 RPM

≈ -3° off set

DATA MARKERS :

Pmax =	27.9888		
@	~~12.00~~	+9°	
dPmax=	0.6870		
@	~~-10.00~~	-13°	

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS, INC.

19-Jan-90
12:23: 9

19-JAN-90
15:47:52

Indicated Data vs Crankangle

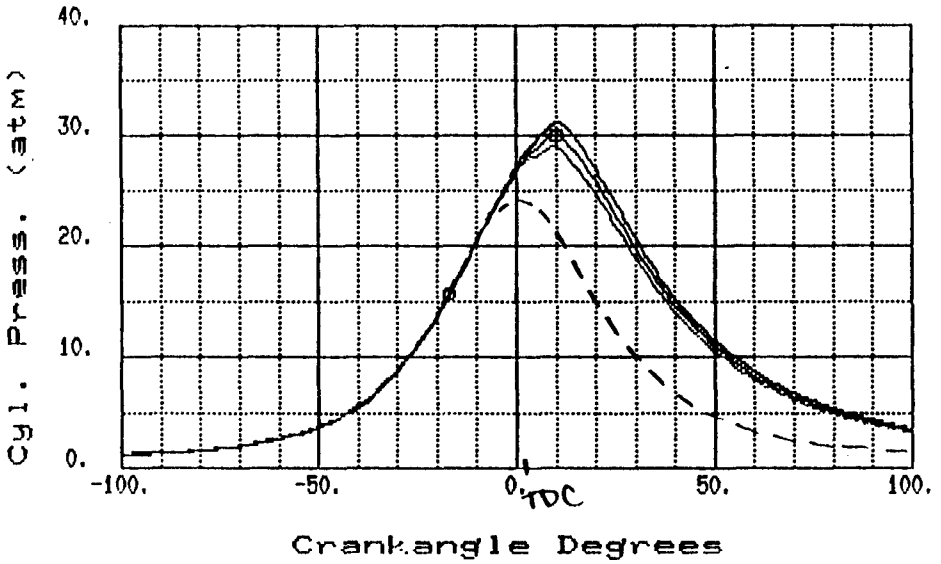
Engine : DEUTZ F1L-511, CEI Ver 2.2
Cell : Superflow
Project : TACOM

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	12.00	Intake	=	328.5,-120.5
Ign Timing	=	~~984.0 Deg~~	Exhaust	=	108.5, 392.5

Engine Speed = ~~1500.0 rpm~~ Engine Torque= 0.00 N-m

APA100: U.S. Army Tank Automotive Command

Title : DE19JA.018



IGN
8:00
1434 RPM

≈ -2° offset

DATA MARKERS :

Pmax = 30.0496
@ ~~-10.00~~ +8°
dPmax= 0.7307
@ ~~-17.00~~ −19°

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS, INC.

19-Jan-90
12:23:57

19-JAN-90
15:54:07

Indicated Data vs Crankangle

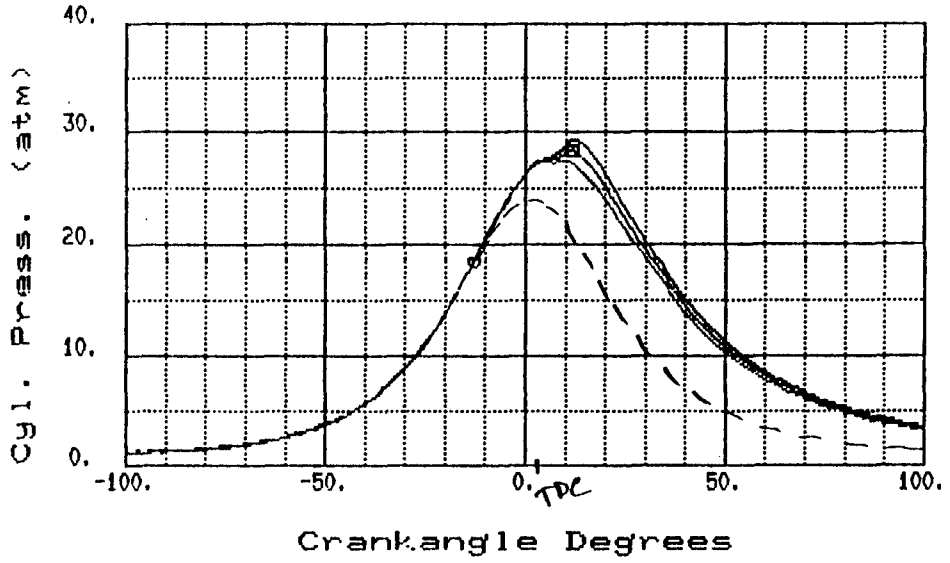
Engine : DEUTZ F1L-511, CEI Ver 2.2
Cell : Superflow
Project : TACOM

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	12.00	Intake	=	328.5,-120.5
Ign Timing	=	~~584.0 Deg~~	Exhaust	=	108.5, 392.5

Engine Speed = ~~1500.0 rpm~~ Engine Torque= 0.00 N-m

APA100: U.S. Army Tank Automotive Command

Title : DE19JA.019



NO IGN
8:30
1422 RPM

≈ -3 offset

DATA MARKERS :

Pmax =	28.2136	
@	~~12.00~~	+9°
dPmax=	0.7244	
@	~~-18.00~~	-16°

Double-triangle is valve timing.

APPENDIX D

MODIFIED ENGINE DATA
SUPERFLOW AND APA-100 DATA

COMBUSTION ELECTROMAGNETICS INC.
32 PRENTISS ROAD
Arlington, Massachusetts 02174
PHONE: (617) 641-0520

123 File: [redacted]
Date: 1/17/90
Engine: Deutz F1L-511, CEI head, cylinder, piston [redacted]
Test: [redacted] Double Plugs, 20 deg adv, 26 deg inj
[redacted] 10 ft-lbs

Test DE17JA

#	10	04	06	08
RPM	1504	1998	2492	2807
TRQ ,ft-lb	10.3	9.8	10.0	9.8
COV	1.46%	0.84%	1.01%	0.60%
HP	3.0	3.7	4.7	5.2
Fuel ,lb/hr	1.33	1.97	2.80	3.95
Air ,scfm	17.2	24.8	27.4	27.4
A/F	59.0	57.3	44.7	31.6
BSFC	0.451	0.526	0.590	0.756
ManP				
CAT (F)	66	62	64	66
FuelT (F)	53	49	53	54
OilT (F)	212	151	173	203
Ex T (F)	392	330	477	643
SAE TRQ	9.8	9.2	9.2	9.0
SAE HP	2.8	3.5	4.3	4.8
VolEff	0.79	0.86	0.76	0.67
Adv., deg	20	20	20	20
Ignition	ON	ON	ON	ON
APA-100 data				
Pmax (atm)	38.0	29.8	23.9	19.5
@ (deg)	1	7	13	-4
dPmax (atm)	2.18	0.82	0.77	0.65
@ (deg)	-5	-16	-16	-26

COMBUSTION ELECTROMAGNETICS INC.
32 PRENTISS ROAD
Arlington, Massachusetts 02174
PHONE: (617) 641-0520

123 File: DE17JA5.WK1
Date: 1/17/90
Engine: Deutz F1L-511, CEI head, cylinder, piston #2.2
Test: CEI Double Plugs, 20 deg adv, 26 deg inj
Medium Load, 20 ft-lbs

Test #	DE17JA 11	05	07	14
RPM	1498	1997	2505	2797
TRQ ,ft-lb	20.1	20.1	19.9	20.4
COV	1.75%	1.84%	0.91%	1.34%
HP	5.7	7.6	9.5	10.9
Fuel ,lb/hr	2.33	3.16	4.15	4.94
Air ,scfm	16.9	24.2	26.4	19.7
A/F	33.0	34.9	29.0	18.2
BSFC	0.406	0.415	0.438	0.453
ManP				
CAT (F)	64	63	65	65
FuelT (F)	52	53	54	55
OilT (F)	209	165	188	239
Ex T (F)	489	489	626	817
SAE TRQ	19.1	18.8	18.8	19.2
SAE HP	5.5	7.2	8.9	10.2
VolEff	0.78	0.84	0.73	0.49
Adv., deg	20	20	20	20
Ignition	ON	ON	ON	ON
APA-100 data				
Pmax (atm)	43.3	39.3	32.3	31.4
@ (deg)	3	6	7	5
dPmax (atm)	2.86	2.15	1.46	1.66
@ (deg)	-5	0	2	-2

COMBUSTION ELECTROMAGNETICS INC.
32 PRENTISS ROAD
Arlington, Massachusetts 02174
PHONE: (617) 641-0520

123 File: DE17JA6.WK1
Date: 1/17/90
Engine: Deutz F1L-511, CEI head, cylinder, piston #2.2
Test: CEI Double Plugs, 20 deg adv, 26 deg inj
Maximum Stable Load

Test #	DE17JA 12	13	DE29JA.015
RPM	1509	2015	2524
TRQ ,ft-lb	25.1	26.8	26.0
COV	1.66%	1.30%	0.62%
HP	7.2	10.3	12.5
Fuel ,lb/hr	2.91	4.19	5.53
Air ,scfm	16.5	21.5	—
A/F	25.8	23.3	—
BSFC	0.403	0.408	0.442
ManP			0.43
CAT (F)	63	64	62
FuelT (F)	53	55	54
OilT (F)	211	218	207
Ex T (F)	606	737	890
SAE TRQ	23.8	25.5	24.6
SAE HP	6.8	9.8	11.8
VolEff	0.75	0.74	—
Adv., deg	20	20	24
Ignition	ON	ON	ON
APA-100 data			
Pmax (atm)	47.4	46.1	43.7
@ (deg)	0	2	9
dPmax (atm)	3.47	2.88	2.15
@ (deg)	-7	-6	1

COMBUSTION ELECTROMAGNETICS, INC.

17-Jan-90
16: 6:23

18-JAN-90
10:52:33

Indicated Data vs Crankangle

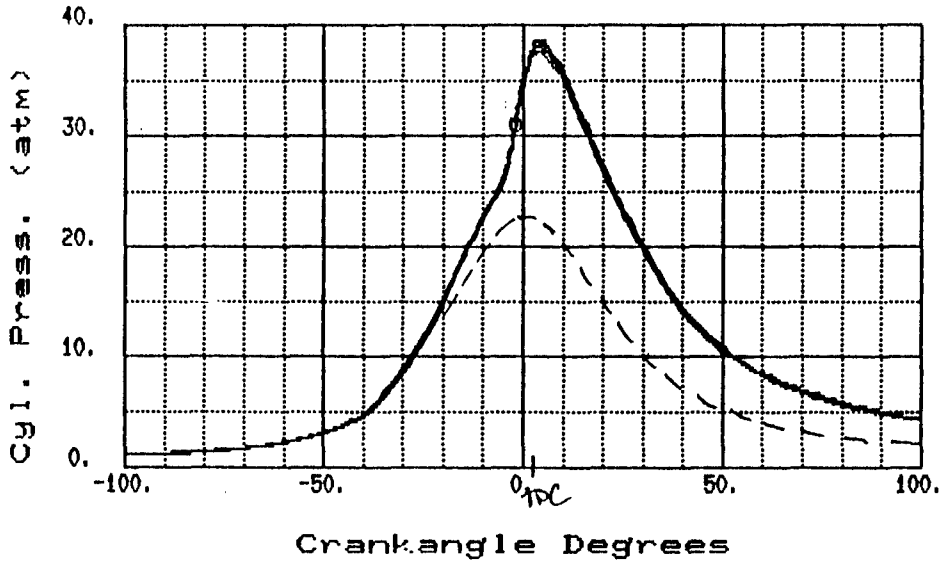
Engine : DEUTZ F1L-511, CEI Ver 2.2
Cell : Superflow
Project : TACOM

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	12.00	Intake	=	328.5,-120.5
Ign Timing	=	984.0 Deg	Exhaust	=	108.5, 392.5

Engine Speed = 2800.0 rpm Engine Torque= 0.00 N-m

APA100: U.S. Army Tank Automotive Command

Title : DE17JA.010



1504 RPM
10.3 ft.lbs
.451 BSFC
2 PLUGS.

DATA MARKERS : ≈ -3° offset

Pmax = 38.0059
@ ~~4.00~~ 1°
dPmax= 2.1806
@ ~~2.00~~ -5°

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS, INC.

17-Jan-90
16: 6:23

18-JAN-90
09:24:41

Indicated Data vs Crankangle

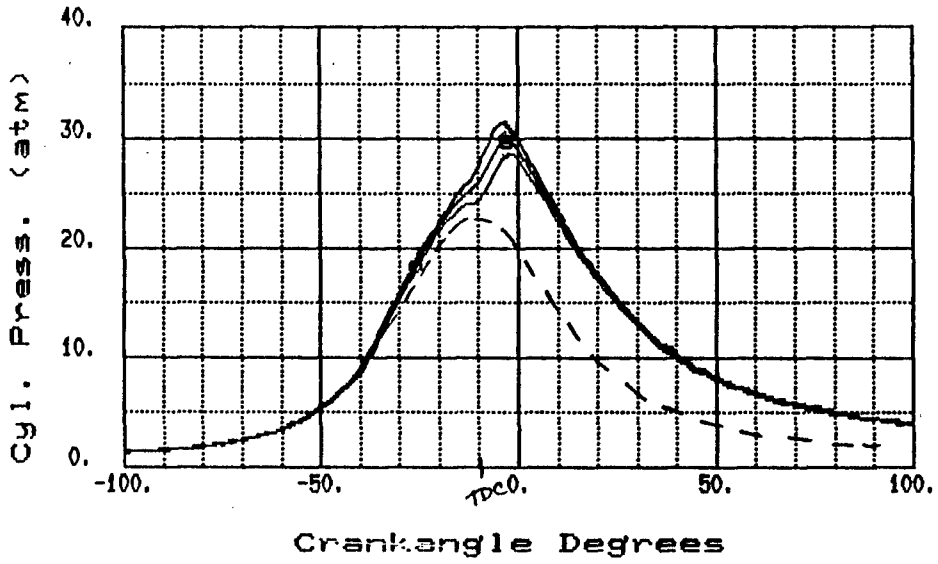
Engine : DEUTZ F1L-511, CEI Ver 2.2
Cell : Superflow
Project : TACOM

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	12.00	Intake	=	328.5,-120.5
Ign Timing	=	984.0 Deg	Exhaust	=	108.5, 392.5

Engine Speed = 2000.0 rpm Engine Torque= 0.00 N-m

APA100: U.S. Army Tank Automotive Command

Title : DE17JA.004



1998 RPM
9.8 ft.lbs
.526 BSFC
DOUBLE PLUG

DATA MARKERS : x +10° offset

Pmax = 29.7624
@ ~~-3.00~~ +7°
dPmax= 0.8171
@ ~~-26.00~~ -16°

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS, INC.

17-Jan-90
16: 6:23

18-JAN-90
10:11:48

Indicated Data vs Crankangle

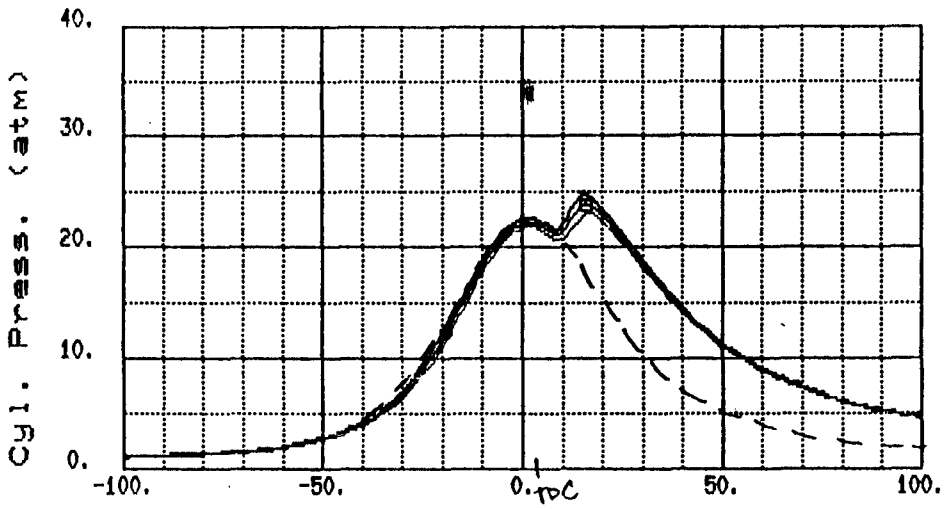
Engine : DEUTZ F1L-511, CEI Ver 2.2
Cell : Superflow
Project : TACOM

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	12.00	Intake	=	328.5,-120.5
Ign Timing	=	984.0 Deg	Exhaust	=	108.5, 392.5

Engine Speed = 2000.0 rpm Engine Torque= 0.00 N-m

APA100: U.S. Army Tank Automotive Command

Title : DE17JA.006



2492 RPM
10 ft lbs
.590 BSFC
& 2 PLUGS

DATA MARKERS : ≈ -3° offset

Pmax = 23.8607
@ ~~16.00~~ +13°
dPmax= 0.7650
@ ~~19.00~~ -16°

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS, INC.

17-Jan-90
16: 6:23

18-JAN-90
10:38:12

Indicated Data vs Crankangle

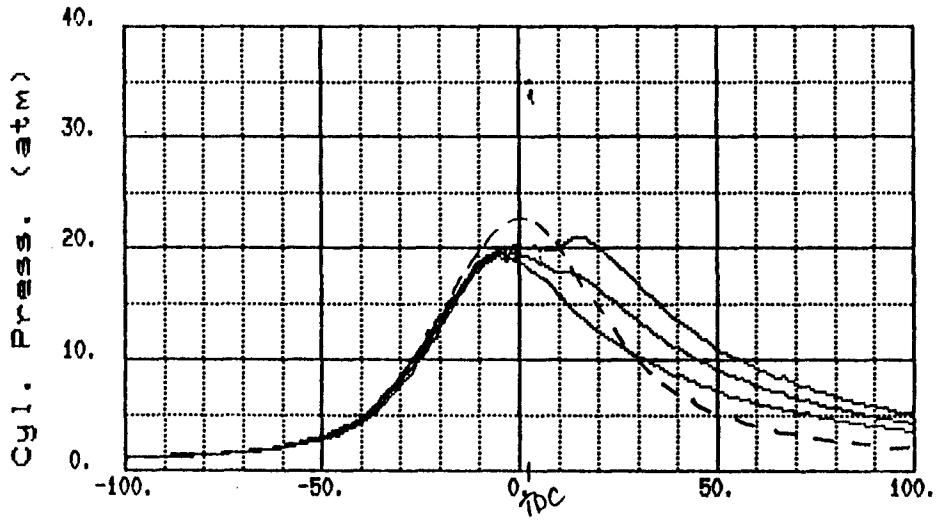
Engine : DEUTZ F1L-511, CEI Ver 2.2
Cell : Superflow
Project : TACOM

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	12.00	Intake	=	328.5,-120.5
Ign Timing	=	984.0 Deg	Exhaust	=	108.5, 392.5

Engine Speed = 2800.0 rpm Engine Torque= 0.00 N-m

APA100: U.S. Army Tank Automotive Command

Title : DE17JA.00~~0~~8



2807 RPM
9.8 ft.lbs
.756 BSFC
2 PLUGS

≈ -2° offset

DATA MARKERS :

Pmax =	19.5204	
@	~~-2.00~~	-4°
dPmax=	0.6453	
@	~~-22.00~~	-26°

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS, INC.

17-Jan-90
16: 6:23

18-JAN-90
11:04:50

Indicated Data vs Crankangle

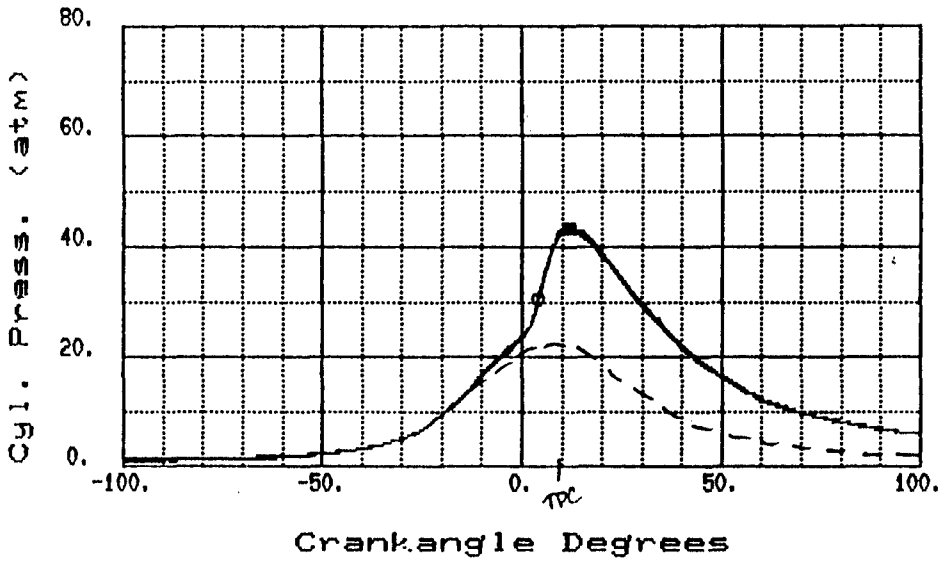
Engine : DEUTZ F1L-511, CEI Ver 2.2
Cell : Superflow
Project : TACOM

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	12.00	Intake	=	328.5,-120.5
Ign Timing	=	984.0 Deg	Exhaust	=	108.5, 392.5

Engine Speed = ~~2000.0 rpm~~ Engine Torque= 0.00 N-m

APA100: U.S. Army Tank Automotive Command

Title : DE17JA.011



1498 RPM
20.1 ft·lbs
.406 BSFC
2 PLUGS.

≈-9° offset

DATA MARKERS :

Pmax = 43.2622
@ ~~12.00~~ 3°
dPmax= 2.8623
@ ~~4.00~~ -5°

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS, INC.

17-Jan-90
16: 6:23

18-JAN-90
09:51:57

Indicated Data vs Crankangle

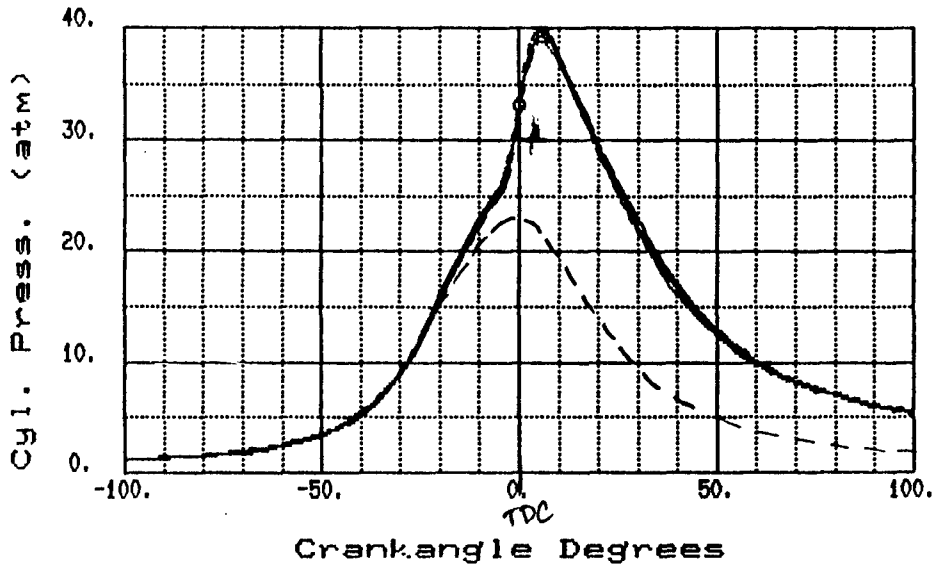
Engine : DEUTZ F1L-511, CEI Ver 2.2
Cell : Superflow
Project : TACOM

No. Cylinders =	1	Bore =	100.00 mm
		Stroke =	105.00 mm
Compr. Ratio =	12.00	Intake =	328.5,-120.5
Ign Timing =	984.0 Deg	Exhaust =	108.5, 392.5

Engine Speed = 2000.0 rpm Engine Torque= 0.00 N-m

APA100: U.S. Army Tank Automotive Command

Title DE17JA.005



1997 RPM
20.1 ft.lbs
.415 BSFC
Double Plug

DATA MARKERS : 0° offset

Pmax =	39.2653
@	6.00
dPmax=	2.1546
@	0.00

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS, INC.

17-Jan-90
16: 6:23

18-JAN-90
10:24:35

Indicated Data vs Crankangle

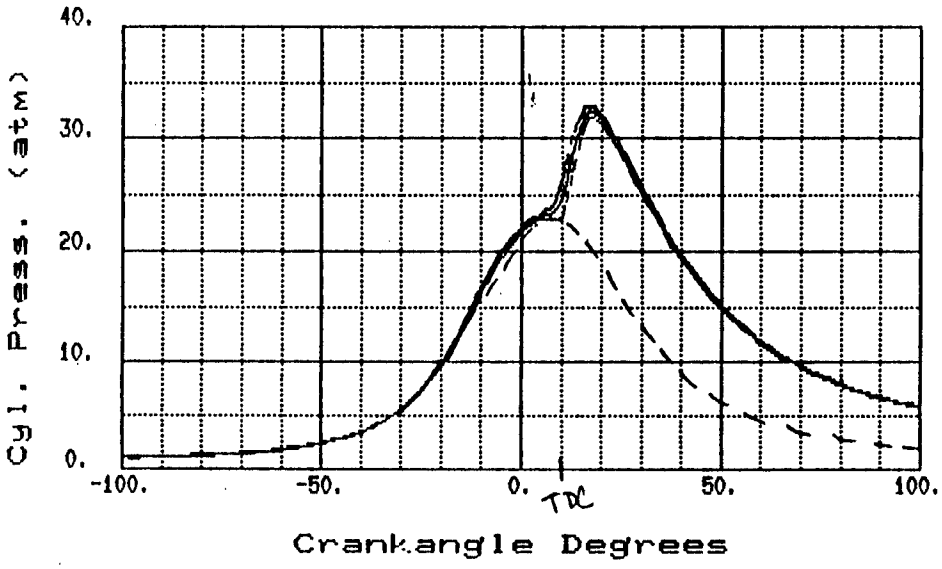
Engine : DEUTZ F1L-511, CEI Ver 2.2
Cell : Superflow
Project : TACOM

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	12.00	Intake	=	328.5,-120.5
Ign Timing	=	984.0 Deg	Exhaust	=	108.5, 392.5

Engine Speed = 2500.0 rpm Engine Torque= 0.00 N-m

APA100: U.S. Army Tank Automotive Command

Title : DE17JA.007



2505 RPM
19.9 SC.lbs
.438 BSFC
2 PLUGS

DATA MARKERS : ≈ -10° offset

Pmax = 32.3333
@ ~~17.00~~ 7°
dPmax= 1.4572
@ ~~12.00~~ 2°

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS, INC.

17-Jan-90
16: 6:23

18-JAN-90
12:04:00

Indicated Data vs Crankangle

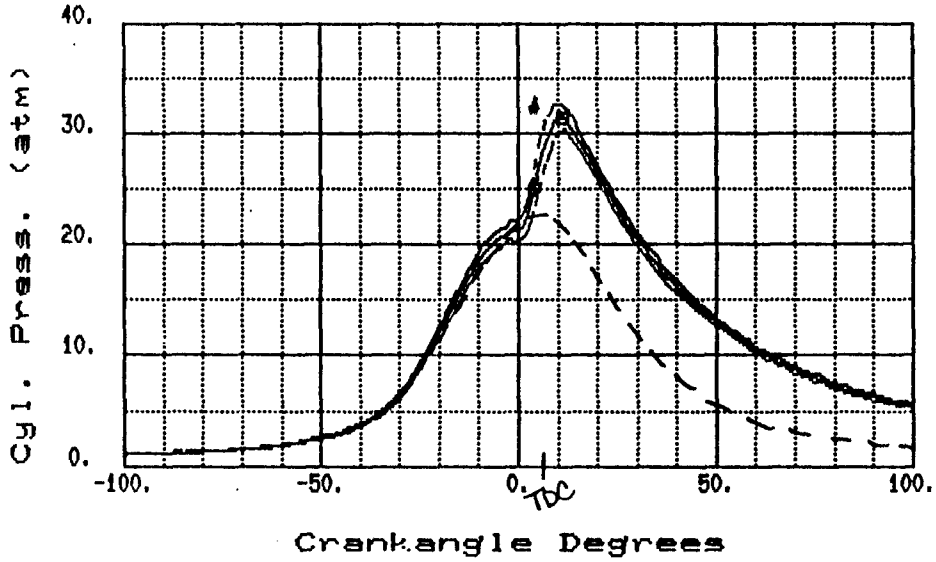
Engine : DEUTZ F1L-511, CEI Ver 2.2
Cell : Superflow
Project : TACOM

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	12.00	Intake	=	328.5,-120.5
Ign Timing	=	984.0 Deg	Exhaust	=	108.5, 392.5

Engine Speed = 2800.0 rpm Engine Torque= 0.00 N-m

APA100: U.S. Army Tank Automotive Command

Title : DE17JA.014



2797 RPM
20.4 ft.lbs
.453 BSFC

1 PLUG
(ONE CUT OUT)

DATA MARKERS : ≈ -6° offset

Pmax = 31.3757
@ ~~11.00~~ 5°
dPmax= 1.6602
@ ~~4.00~~ -2°

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS, INC.

17-Jan-90
16: 6:23

18-JAN-90
11:32:55

Indicated Data vs Crankangle

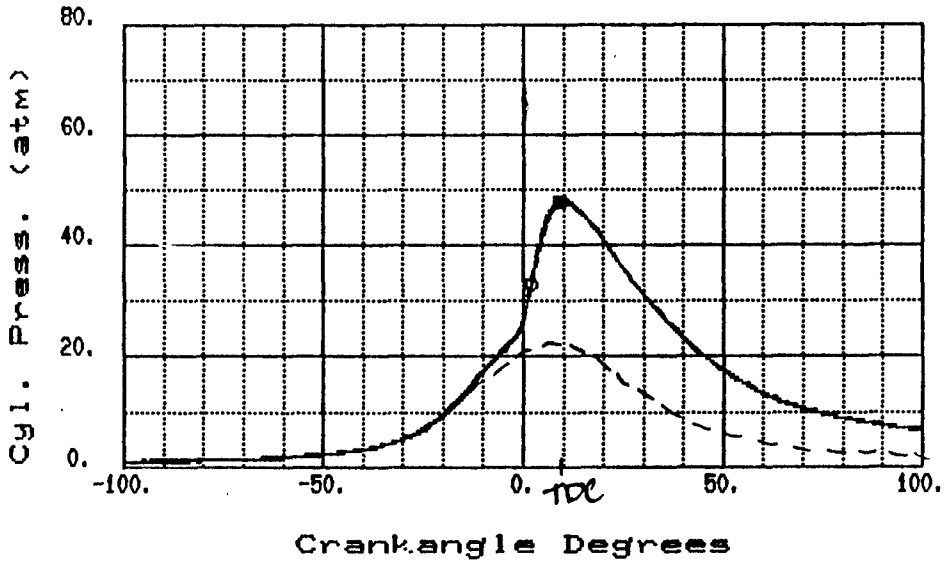
Engine : DEUTZ F1L-511, CEI Ver 2.2
Cell : Superflow
Project : TACOM

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	12.00	Intake	=	328.5,-120.5
Ign Timing	=	984.0 Deg	Exhaust	=	108.5, 392.5

Engine Speed = 1500.0 rpm Engine Torque= 0.00 N-m

APA100: U.S. Army Tank Automotive Command

Title : DE17JA.012



1509 RPM
MAX LOAD = 25.1 ft·lb
.403 BSFC
2 PLUGS.

DATA MARKERS : -9 TDC offset

Pmax = 47.4464
@ ~~9.00~~ 0°
dPmax= 3.4660
@ ~~2.00~~ -7°

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS, INC.

17-Jan-90
16: 6:23

18-JAN-90
11:45:14

Indicated Data vs Crankangle

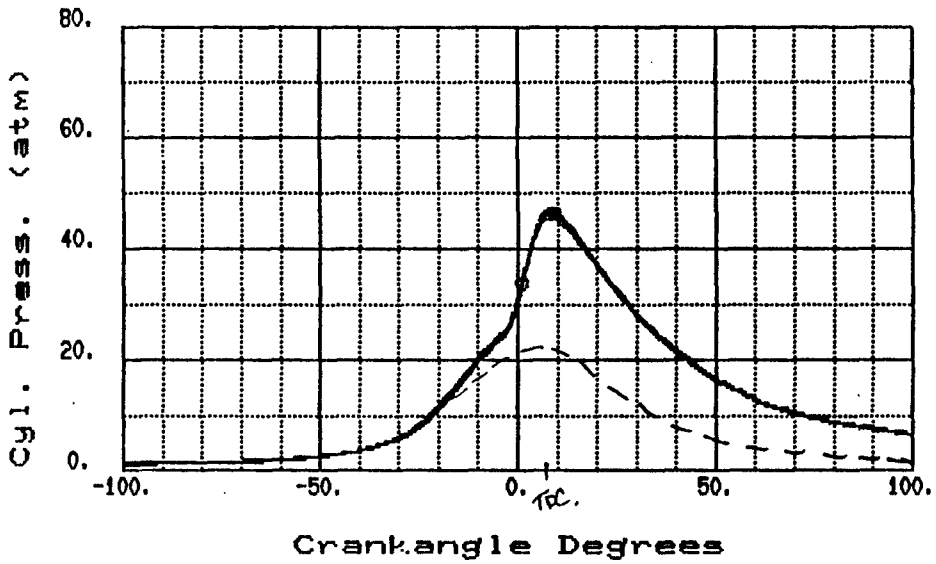
Engine : DEUTZ F1L-511, CEI Ver 2.2
Cell : Superflow
Project : TACOM

No. Cylinders	=	1	Bore	=	100.00 mm
			Stroke	=	105.00 mm
Compr. Ratio	=	12.00	Intake	=	328.5,-120.5
Ign Timing	=	984.0 Deg	Exhaust	=	108.5, 392.5

Engine Speed = 2000.0 rpm Engine Torque= 0.00 N-m

APA100: U.S. Army Tank Automotive Command

Title 1 DE17JA1013



2015 RPM
26.8 ft.lbs
MAX LOAD
.408 BSFC
2 PLUGS

≈ -7° offset

DATA MARKERS :

Pmax = 46.1141
@ ~~9.00~~ 2°
dPmax= 2.8832
@ ~~1.00~~ -6°

Double-triangle is valve timing.

COMBUSTION ELECTROMAGNETICS, INC.

29-Jan-90
11:14:14

29-JAN-90
12:09:06

Indicated Data vs Crankangle

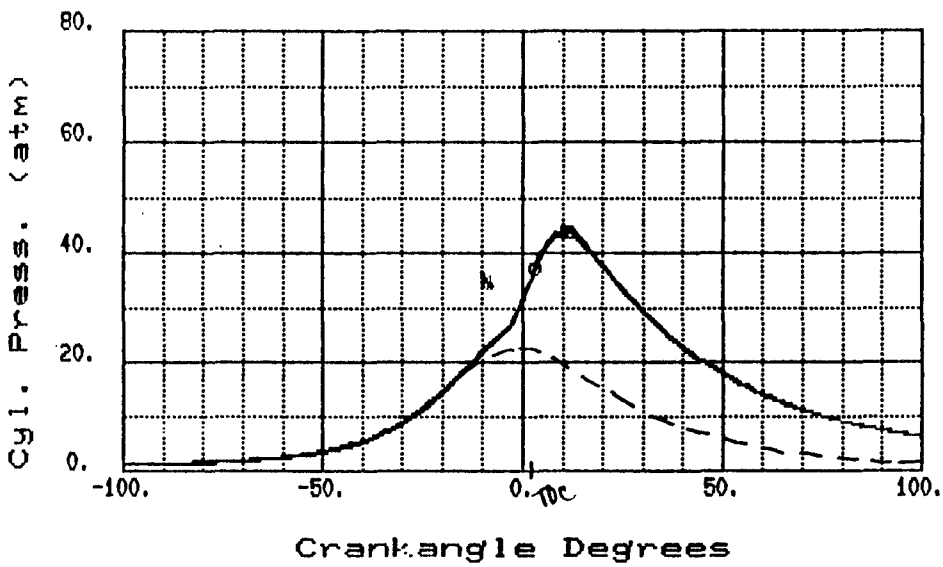
Engine : DEUTZ F1L-511, CEI Ver 2.2
Cell : Superflow
Project : TACOM

No. Cylinders =	1	Bore =	100.00 mm
		Stroke =	105.00 mm
Compr. Ratio =	12.00	Intake =	328.5,-120.5
Ign Timing =	984.0 Deg	Exhaust =	108.5, 392.5
Engine Speed =	2500.0 rpm	Engine Torque=	0.00 N-m

APA100: U.S. Army Tank Automotive Command

BDC = -9°

Title : DE29JA.015



DUAL IGN
2524 RPM
26.0 ft.lbs(max)
T_{OIL} = 207 °F
.442 BSFC

Azet = -2°

DATA MARKERS :

Pmax =	43.6515	
@	~~11.00~~	+9°
dPmax=	2.1483	
@	~~3.00~~	+1°

Double-triangle is valve timing.

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